PEMBROKE

Olive Downs Coking Coal Project

Draft Environmental Impact Statement

Appendix E

Surface Water Assessment

Pembroke Olive Downs Pty Ltd
Olive Downs Coking Coal Project
H354065

Engineering Report
Civil Engineering
Olive Downs Coking Coal Project EIS

Report

Olive Downs Coking Coal Project EIS – Surface Water Assessment

H354065-0000-228-230-0005

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DATE	**REV.**	**STATUS**	**PREPARED BY WRM**	**CHECKED BY WRM**	**APPROVED BY**	**APPROVED BY**
				Discipline Lead	**Functional Manager**	**Client**

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1. Introduction

1.1 Background

Pembroke Olive Downs Pty Ltd (Pembroke) proposes to develop the Olive Downs Coking Coal Project (the Project), a metallurgical coal mine and associated infrastructure within the Bowen Basin, located approximately 40 kilometres south east of Moranbah, Queensland (see Figure 1-1).

The Project provides an opportunity to develop an open cut metallurgical coal resource within the Bowen Basin mining precinct that can deliver up to 20 million tonnes per annum (Mtpa) run-of-mine (ROM) coal. The Olive Downs Coking Coal Project is hereafter referred to in this report as the Project.

Hatch was commissioned by Pembroke to undertake a surface water impact assessed for the Project. The surface water impact assessment will form part of an Environmental Impact Statement (EIS) for the Project under Sections 70 and 71 of the *Environment Protection Act 1994* (QLD).

This report presents the following:

- An overview of the regulatory framework which applies to the Project (including aspects which do not directly relate to the surface water assessment);
- A description of the existing surface water environment surrounding the Project, and the associated environmental values;
- A detailed description of the proposed water management strategy to manage water in and around the Project and details of the expected performance of the proposed water management system;
- A discussion of the potential impacts of the Project and the proposed mitigation and management measures to mitigate these potential impacts. This include a cumulative impact assessment of the Project considering potential compounding interactions with similar impacts from other projects within an appropriate region of influence.

Details of the Project relating to flooding, the proposed Ripstone Creek diversion and flood protection levees are not covered in this report. This information is provided in a separate Flood Assessment report (Hatch, 2018).

1.2 Project Description

The Project comprises the Olive Downs South and Willunga domains and associated linear infrastructure corridors, including a rail spur connecting to the Norwich Park Branch Railway, a water pipeline connecting to the Eungella pipeline network, an electricity transmission line (ETL) and access roads (Figure 1-2).

The proposed Olive Downs South domain open cut pits are generally aligned from north to south and are located on the western side of the Isaac River (Figure 1-3). At peak development of the Olive Downs South domain, production of ROM coal is expected to approximately 12 Mtpa.

The proposed Willunga domain open cut pits are located on the eastern side of the Isaac River (Figure 1-4). The Willunga domain is expected to produce approximately 8 Mtpa ROM coal at peak operation.

The main surface water-related activities associated with the development of the Project include:

- up to 20 Mtpa of ROM coal production (15 Mtpa product) for an operational mine life of approximately 79 years, including mining operations using conventional mining equipment (e.g. excavators, dozers, front end loaders and trucks) and strip mining, associated with:
    - development of the Olive Downs South domain open cut pits and out-of-pit waste rock emplacements within Mining Lease Application (MLA) 700032, MLA 700033, MLA 700035 and MLA 700036 (within Mineral Development Licenses [MDL] 3012 and MDL 3013); and
    - development of the Willunga domain open cut pits and out-of-pit waste rock emplacements within MLA 700034 (within MDL 3014).
- progressive placement of waste rock in emplacements adjacent to and nearby the open pit extents;
- progressive backfilling of the mine voids with waste rock behind the advancing open cut mining operations;
- progressive development of new haul roads and internal roads, including an Isaac River road crossing to provide access between the Olive Downs South and Willunga domains;
- installation and operation of on-site ROM coal handling and crushing facilities at the Willunga domain;
- transfer of crushed ROM coal from the Willunga domain to the CHPP at the Olive Downs South domain, via either haul road or conveyor with an Isaac River crossing;
- storage and disposal of CHPP rejects (coarse and fine rejects) during the initial years (until in-pit containment facilities become available) in initial rejects storage facilities including tailings cells;

- disposal of CHPP rejects (coarse and fine rejects) on-site within appropriate in-pit containment facilities, including mine voids behind the advancing open cut mining operations, and where circumstances allow, disposal in other out-of-pit containment facilities;
- progressive development of sediment dams and water storage dams and installation of pumps, pipelines and other water management equipment and structures (including up-catchment diversions and levees);
- wastewater and sewage treatment by package sewage treatment plants;
- advance dewatering of Olive Downs South and Willunga domain open cut pits and construction and use of a groundwater supply borefield subject to the prevalence of suitable hydrogeological conditions;
- installation of a raw water supply pipeline from the existing Eungella pipeline network;
- discharge of excess water off-site in accordance with relevant principles and conditions of the Model Water Conditions for Coal Mines in the Fitzroy Basin (DEHP, 2013);
- construction of a new rail loop and rail spur from the Norwich Park Branch Railway, and rail loadout facility including product coal stockpiles at the Olive Downs South domain for rail transport of coking and PCI coal products and by-products (i.e. thermal coal) for the export market via the DBCT (subject to availability of rail and port allocation); and
- other associated minor infrastructure, plant, equipment and activities.

Existing local and regional infrastructure would be used to transport product coal to the port for export including the Norwich Park Branch Railway and the Dalrymple Bay Coal Terminal (DBCT).

Indicative general arrangements for Years 2027, 2043, 2066 and 2085 of the Project are shown on Figure 1-5 to Figure 1-11. These indicative general arrangements are based on planned maximum production and mine progression. The mining layout and sequence may vary to take account of localised geological features, coal market volume and quality requirements, mining economics and Project detailed engineering design.

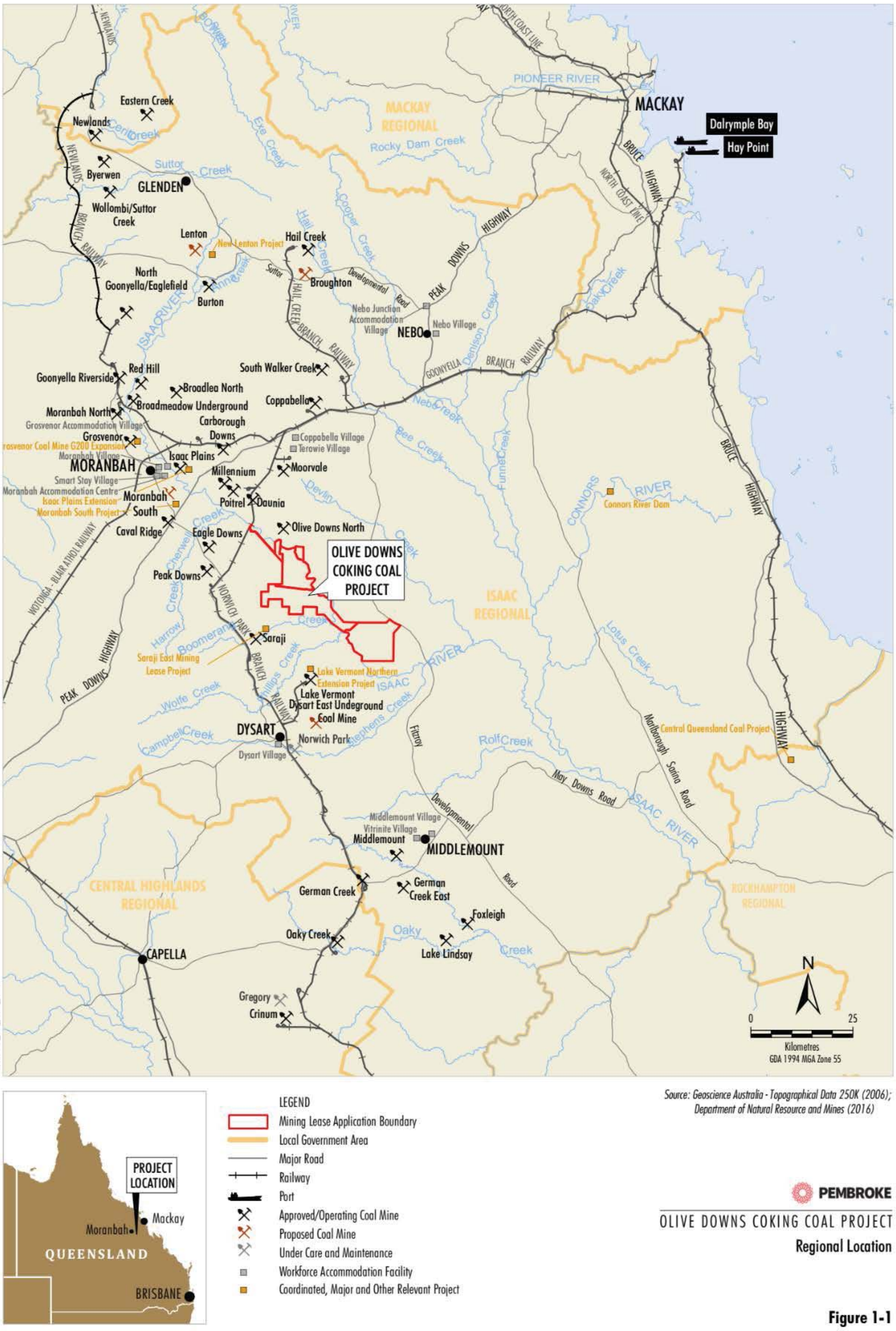

Figure 1-1: Olive Downs Coking Coal Project – Regional Location

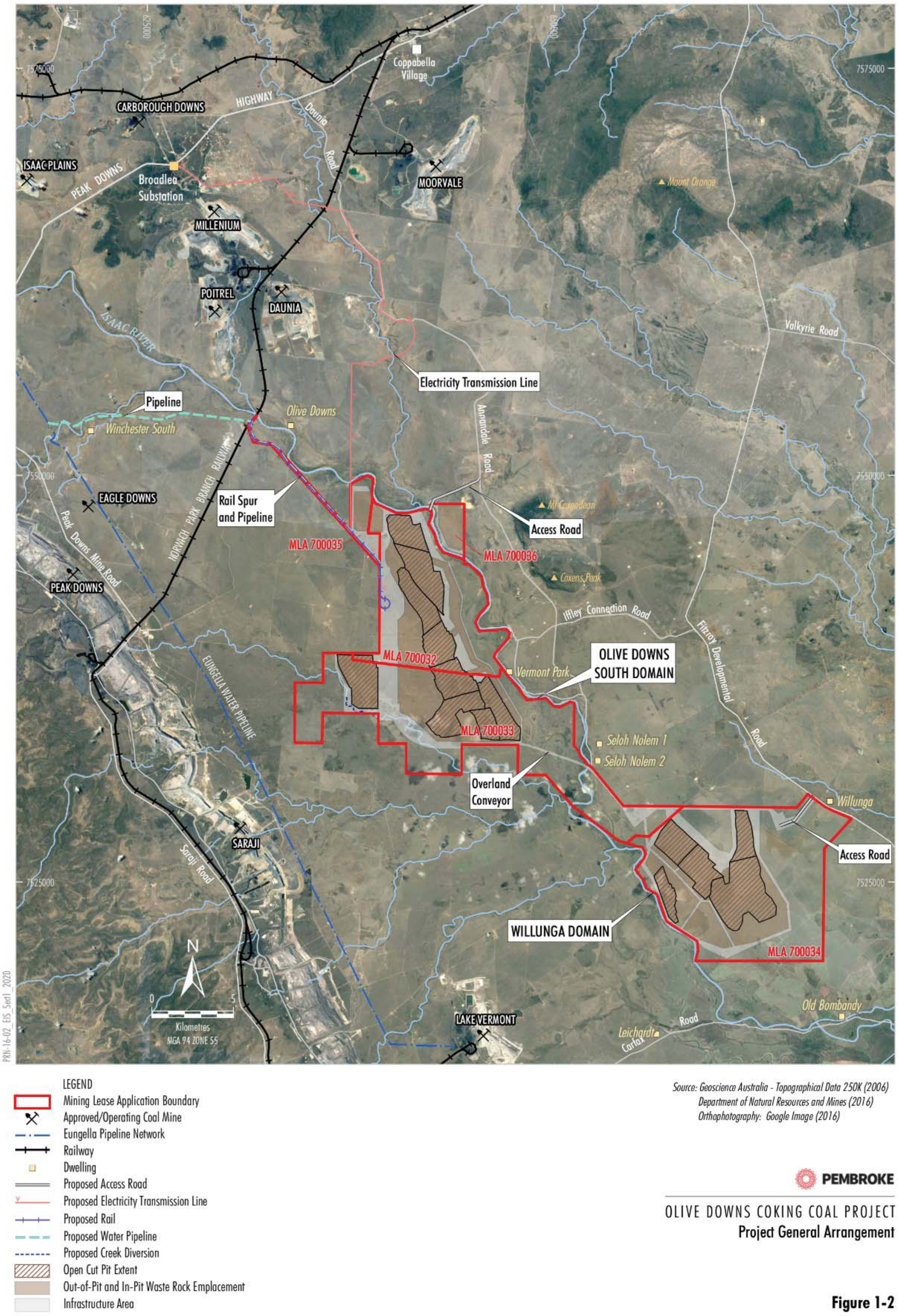

Figure 1-2: Olive Downs Coking Coal Project – Project General Arrangement

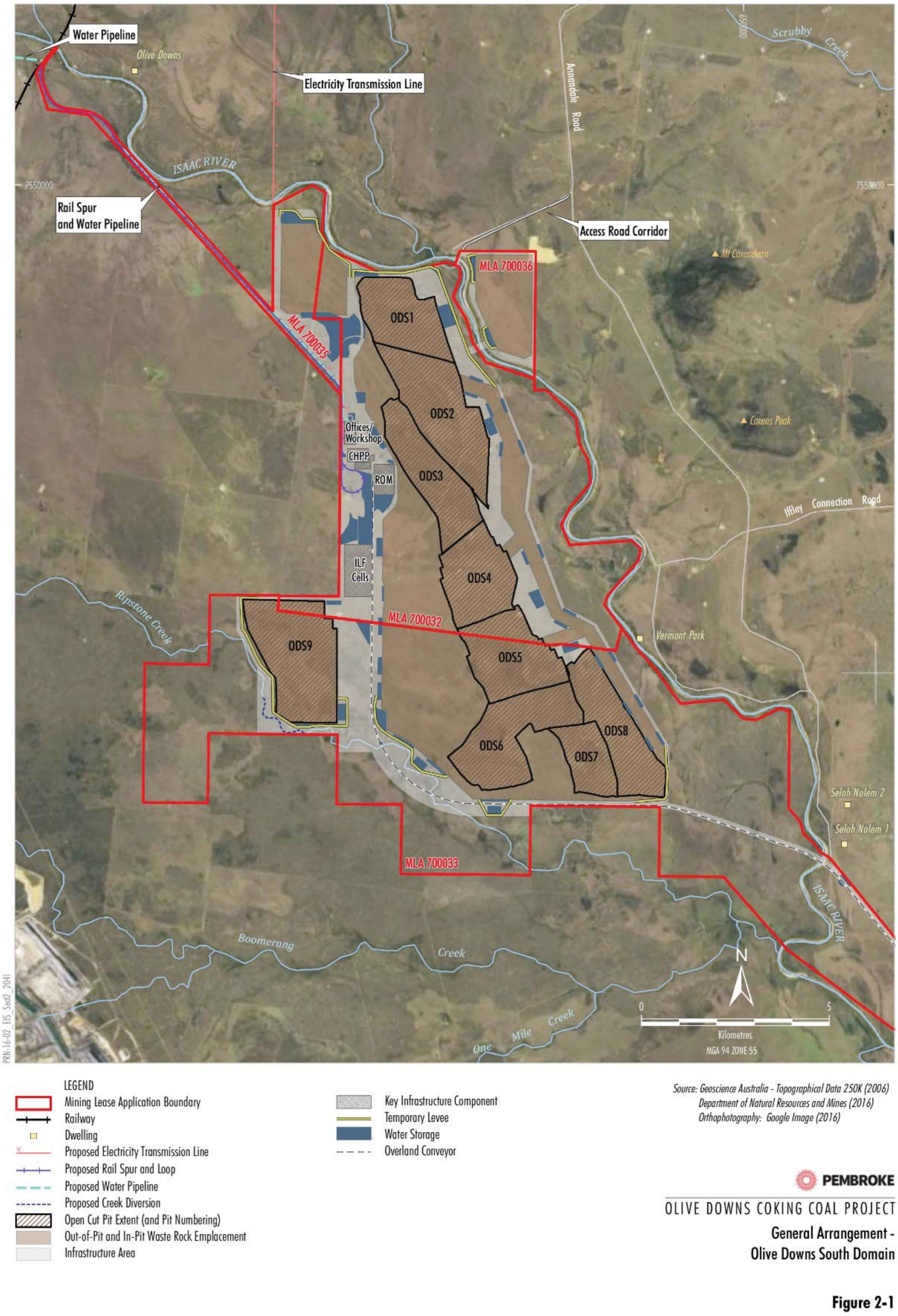

Figure 1-3: General Arrangement – Olive Downs South Domain

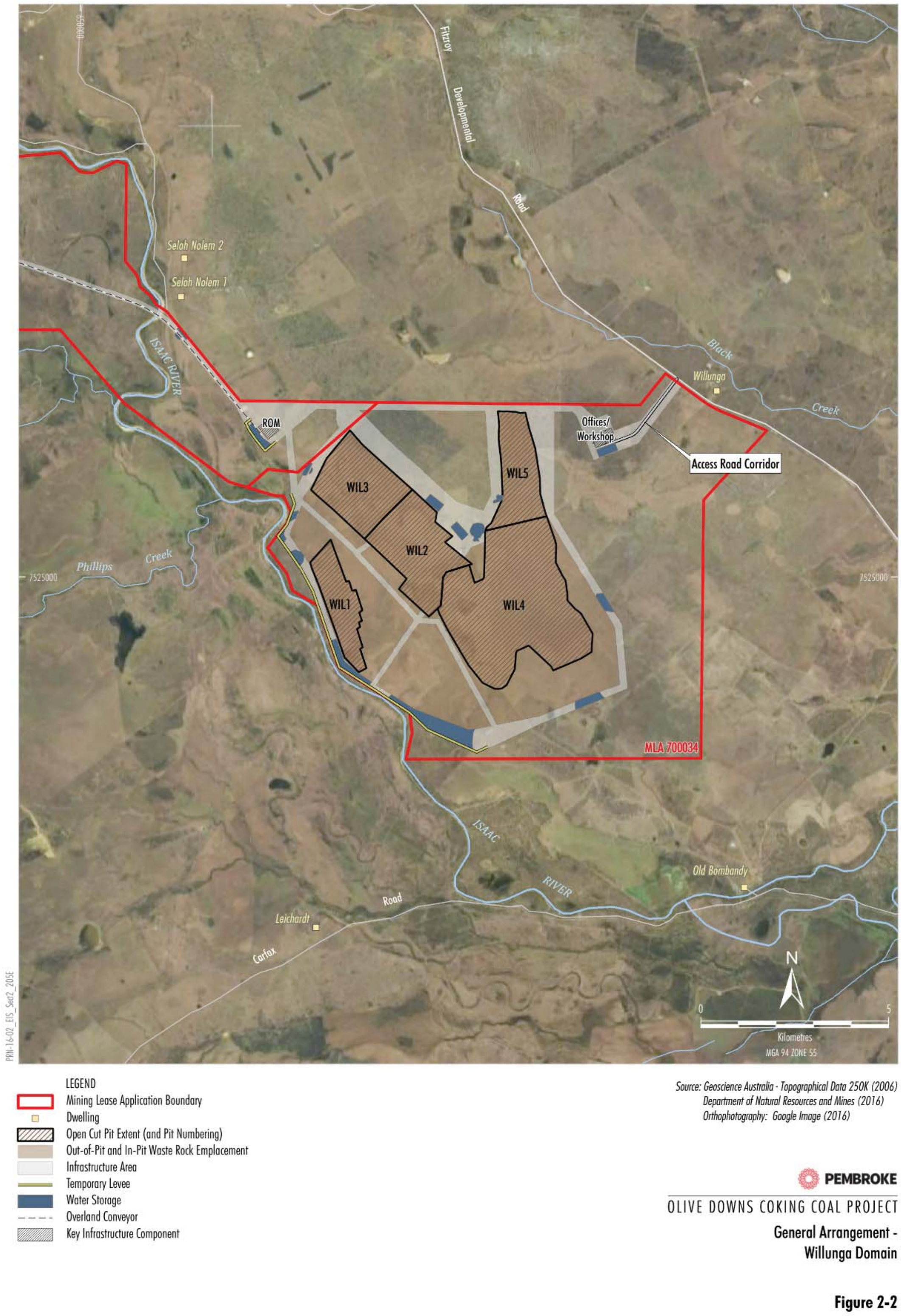

Figure 1-4: General Arrangement - Willunga Domain

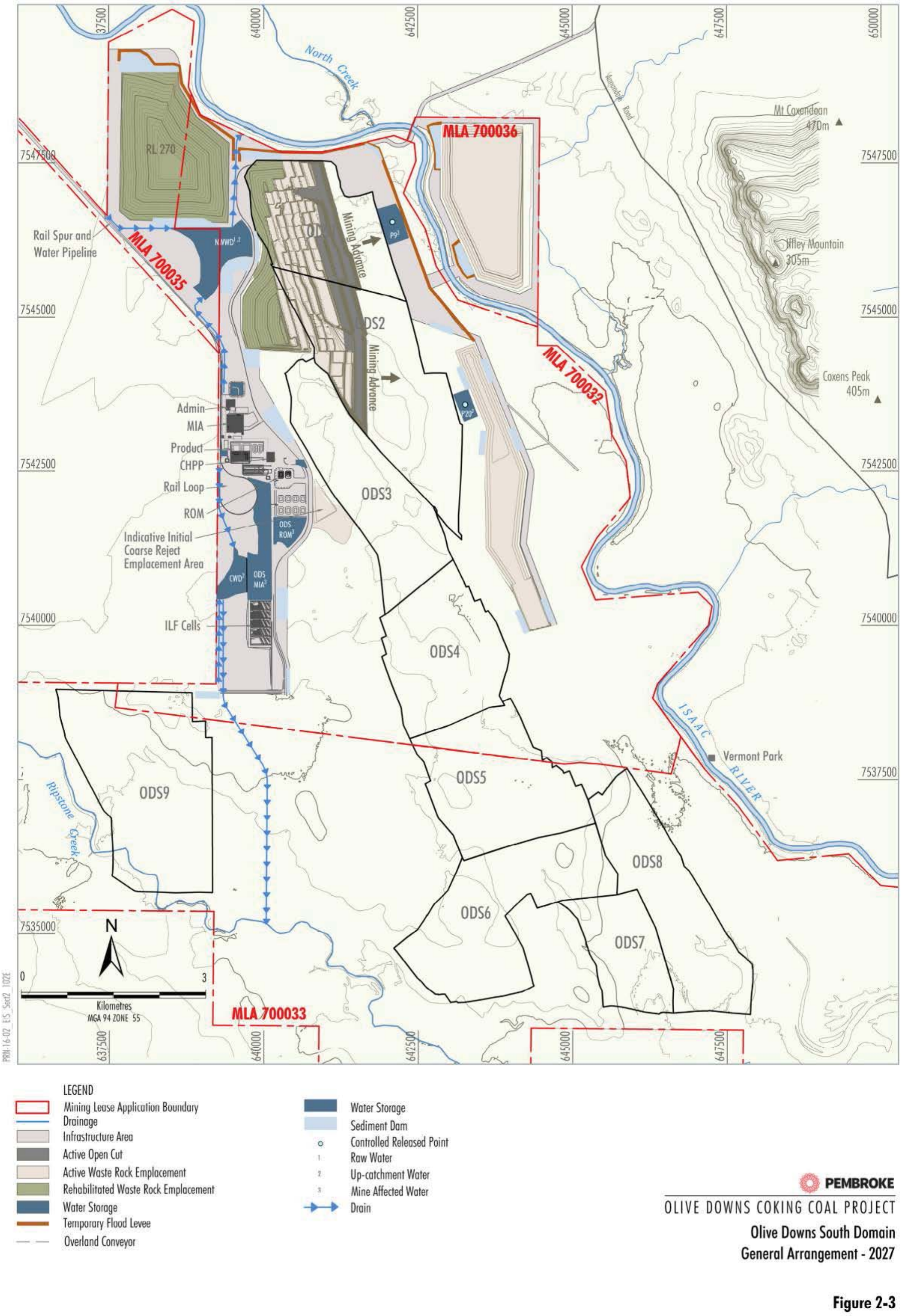

Figure 1-5: Olive Downs South General Arrangement - 2027

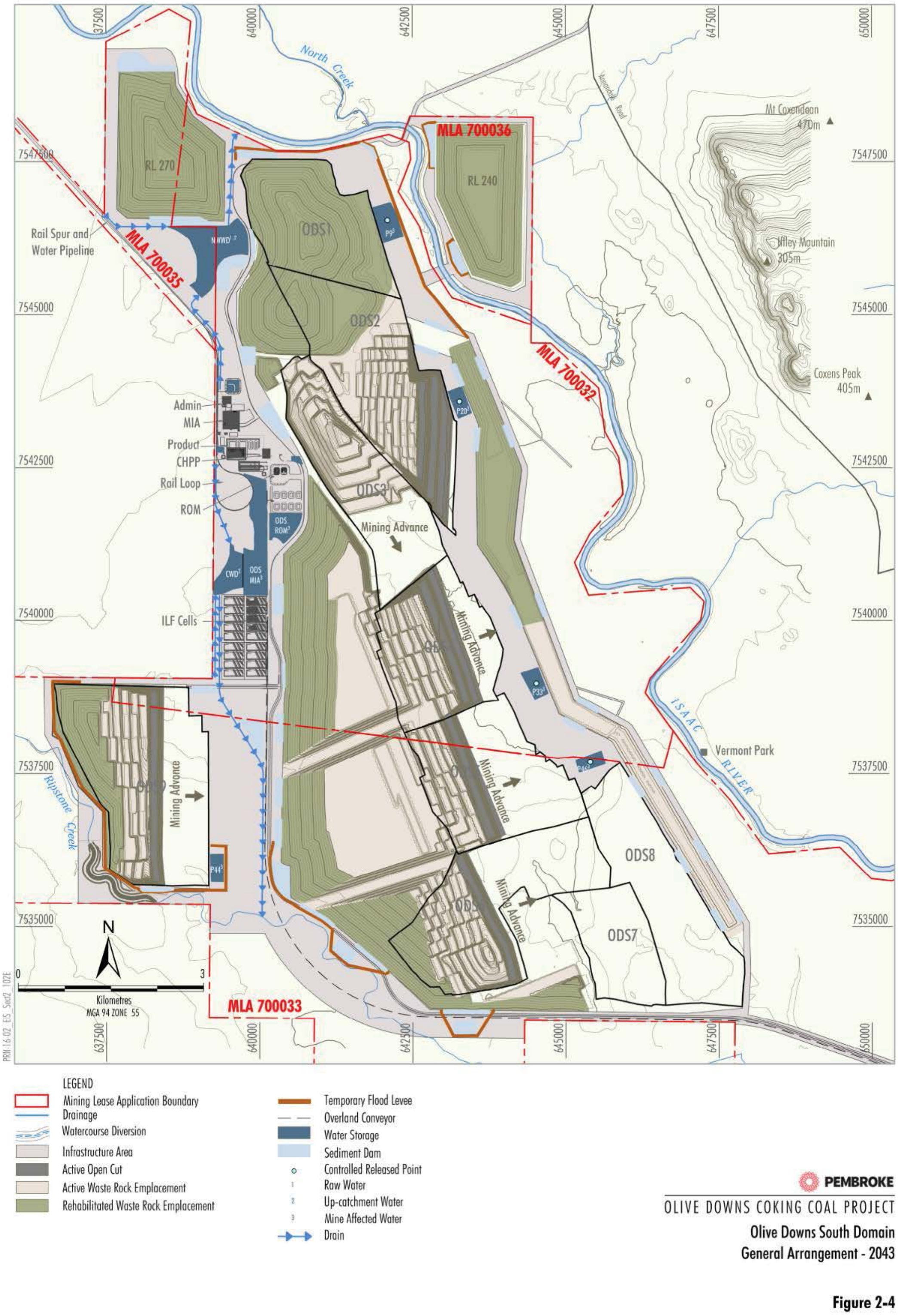

Figure 1-6: Olive Downs South General Arrangement - 2043

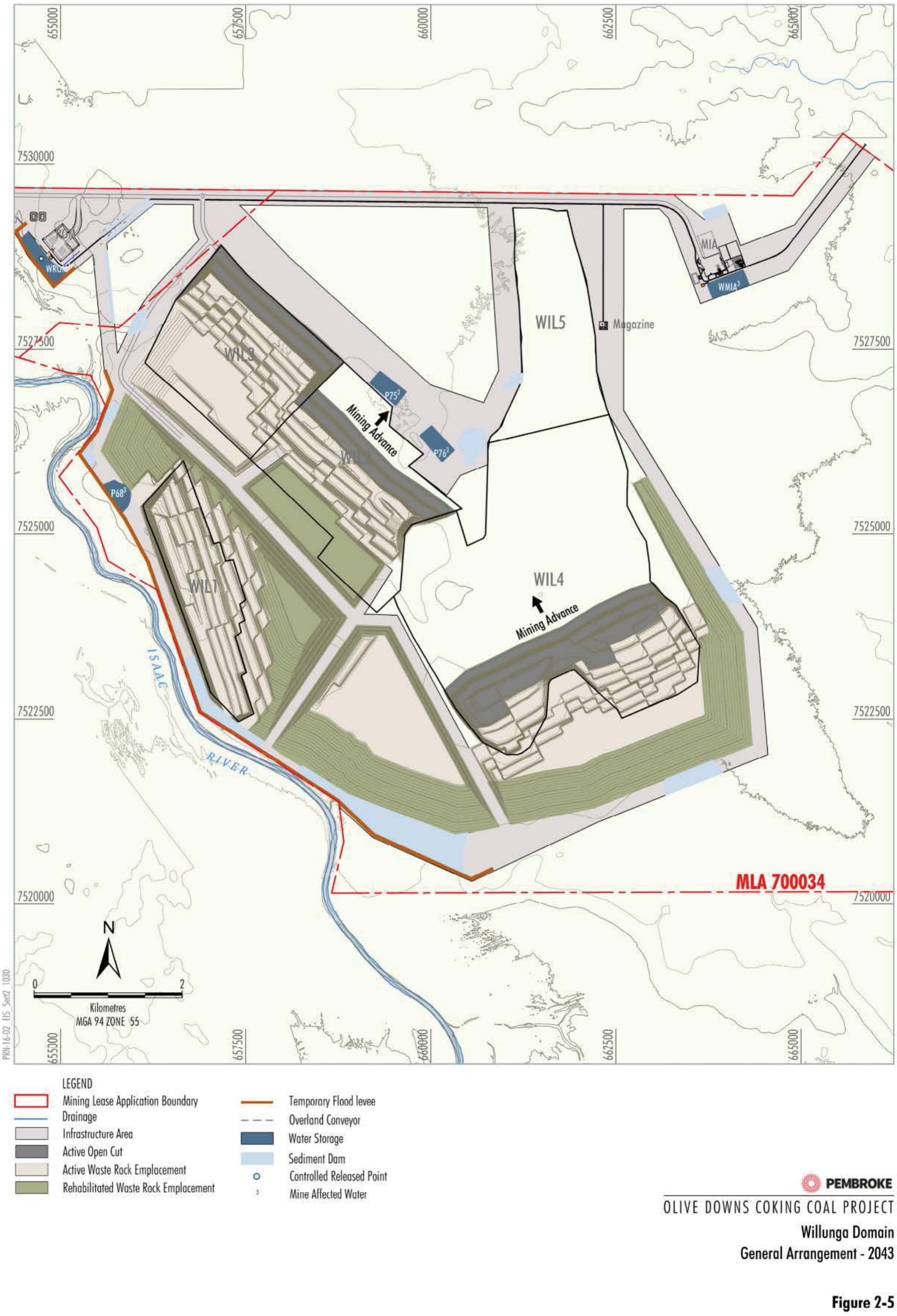

Figure 1-7: Willunga General Arrangement - 2043

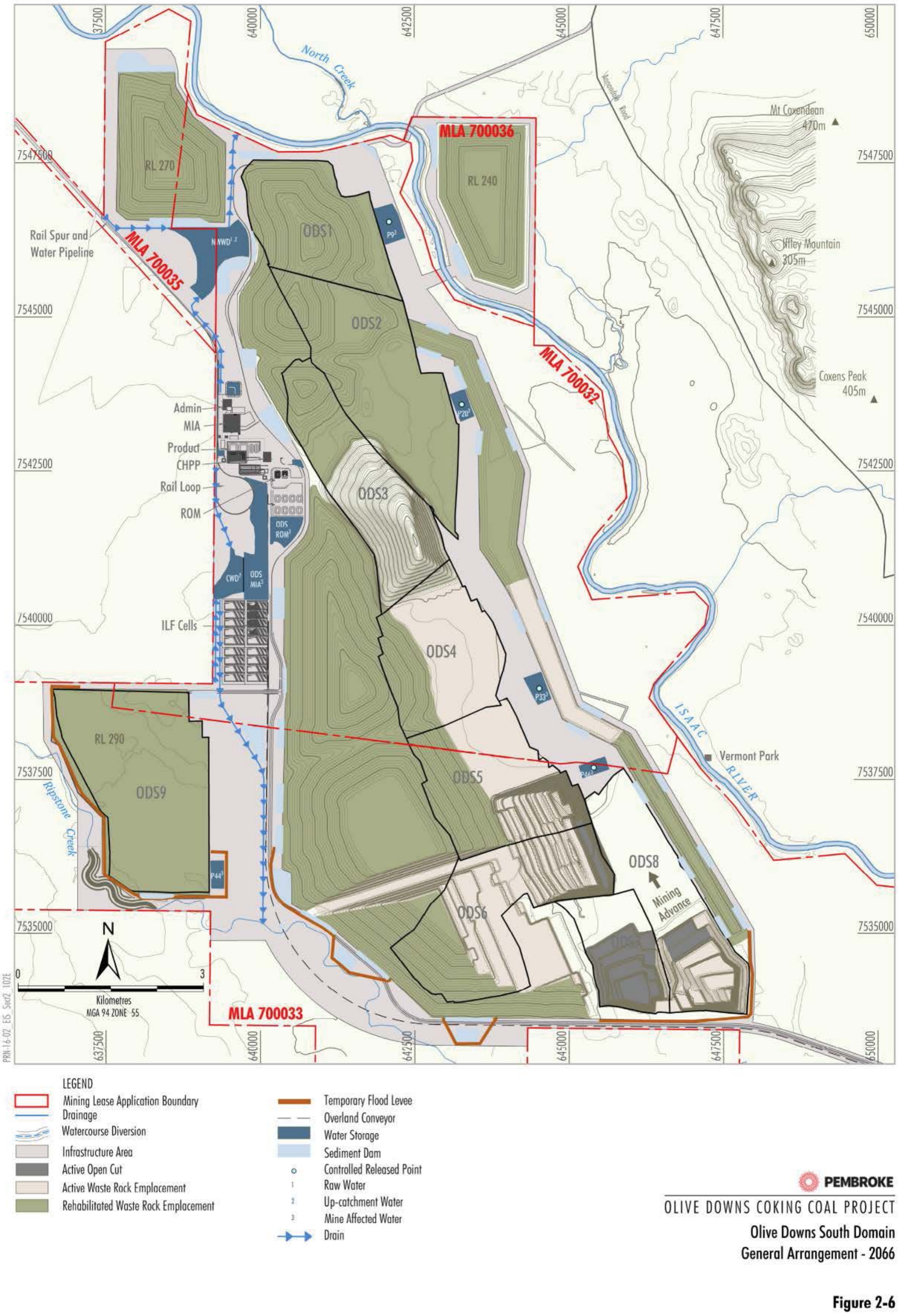

Figure 1-8: Olive Downs South General Arrangement - 2066

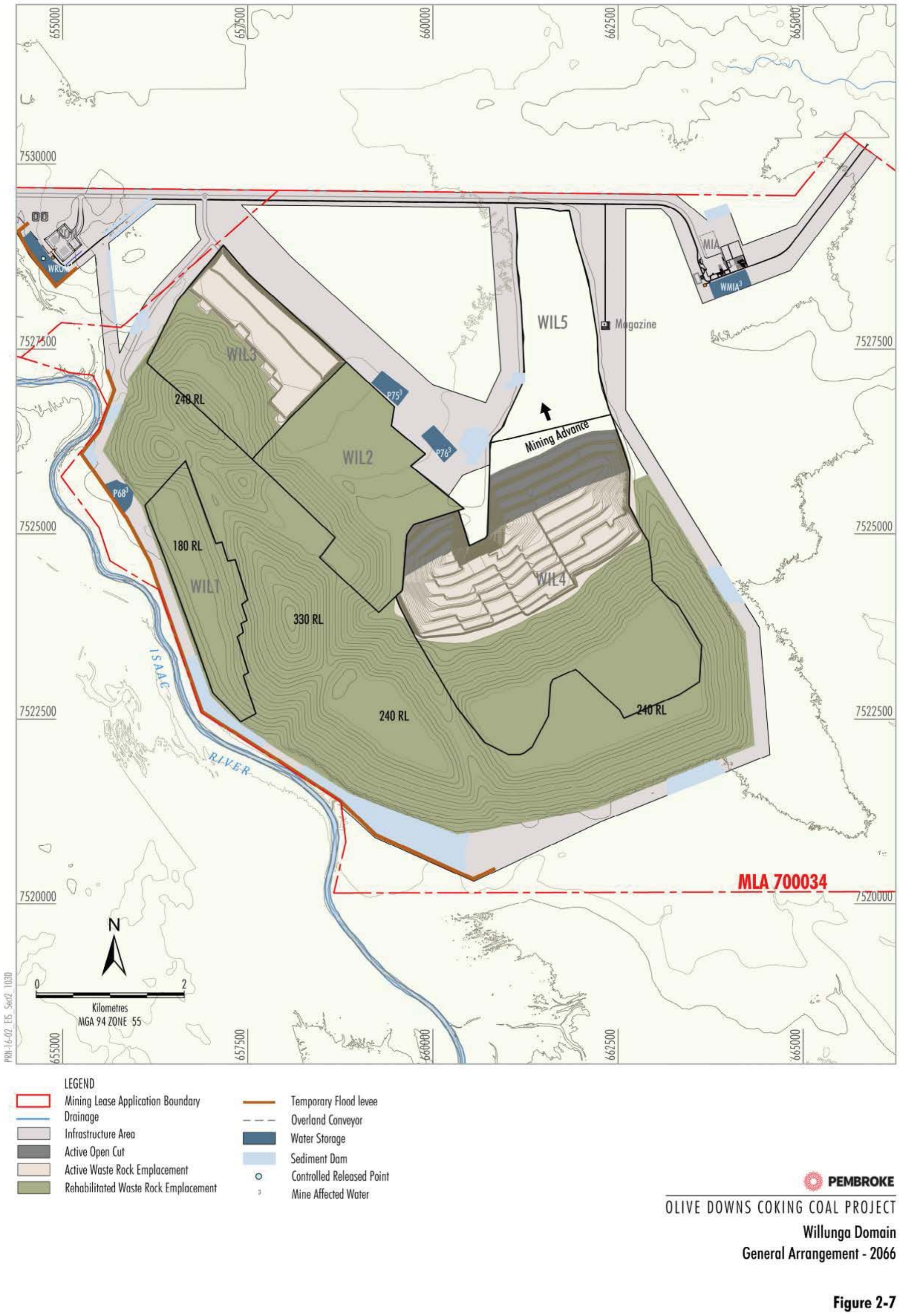

Figure 1-9: Willunga General Arrangement - 2066

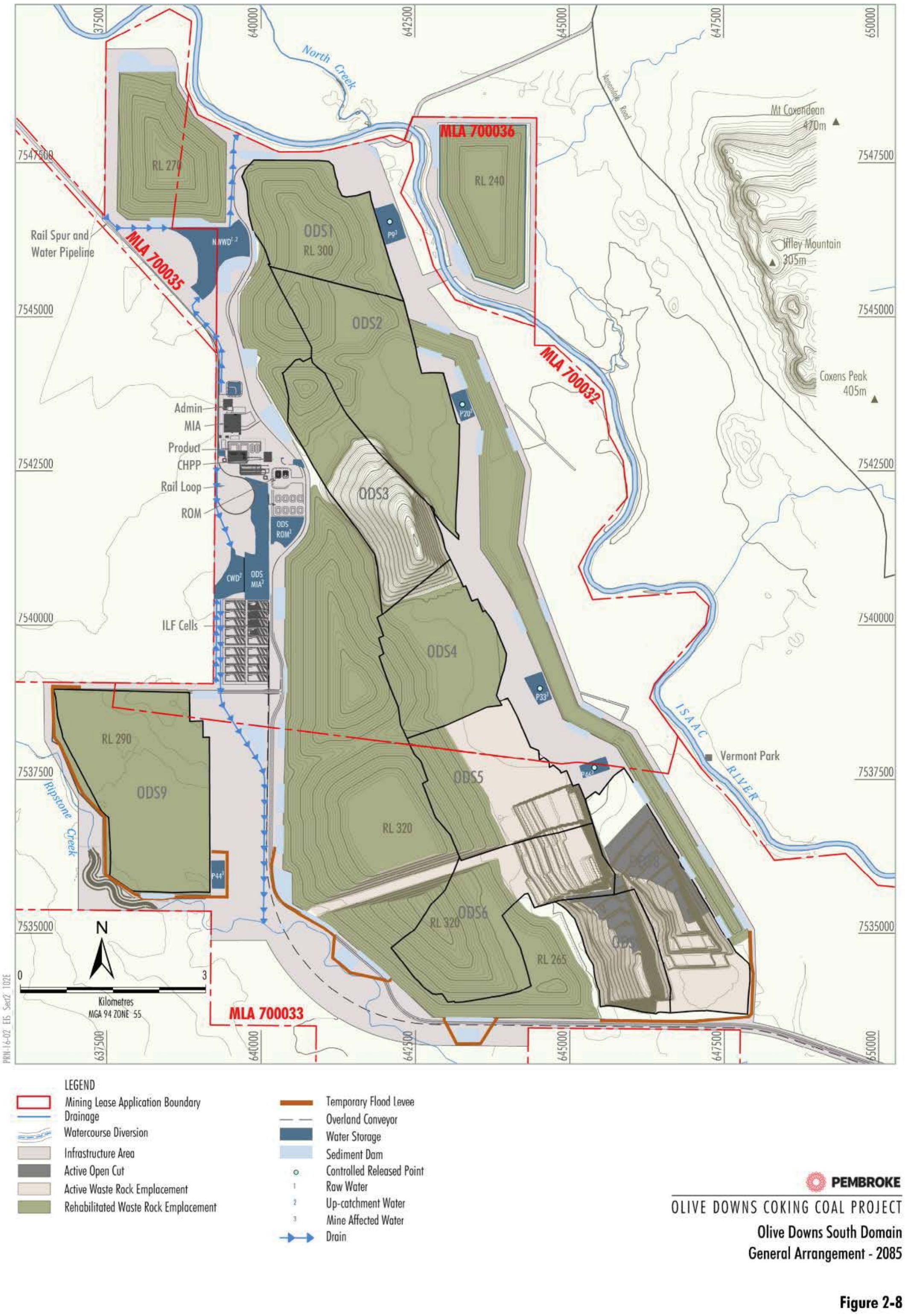

Figure 1-10: Olive Downs South General Arrangement - 2085

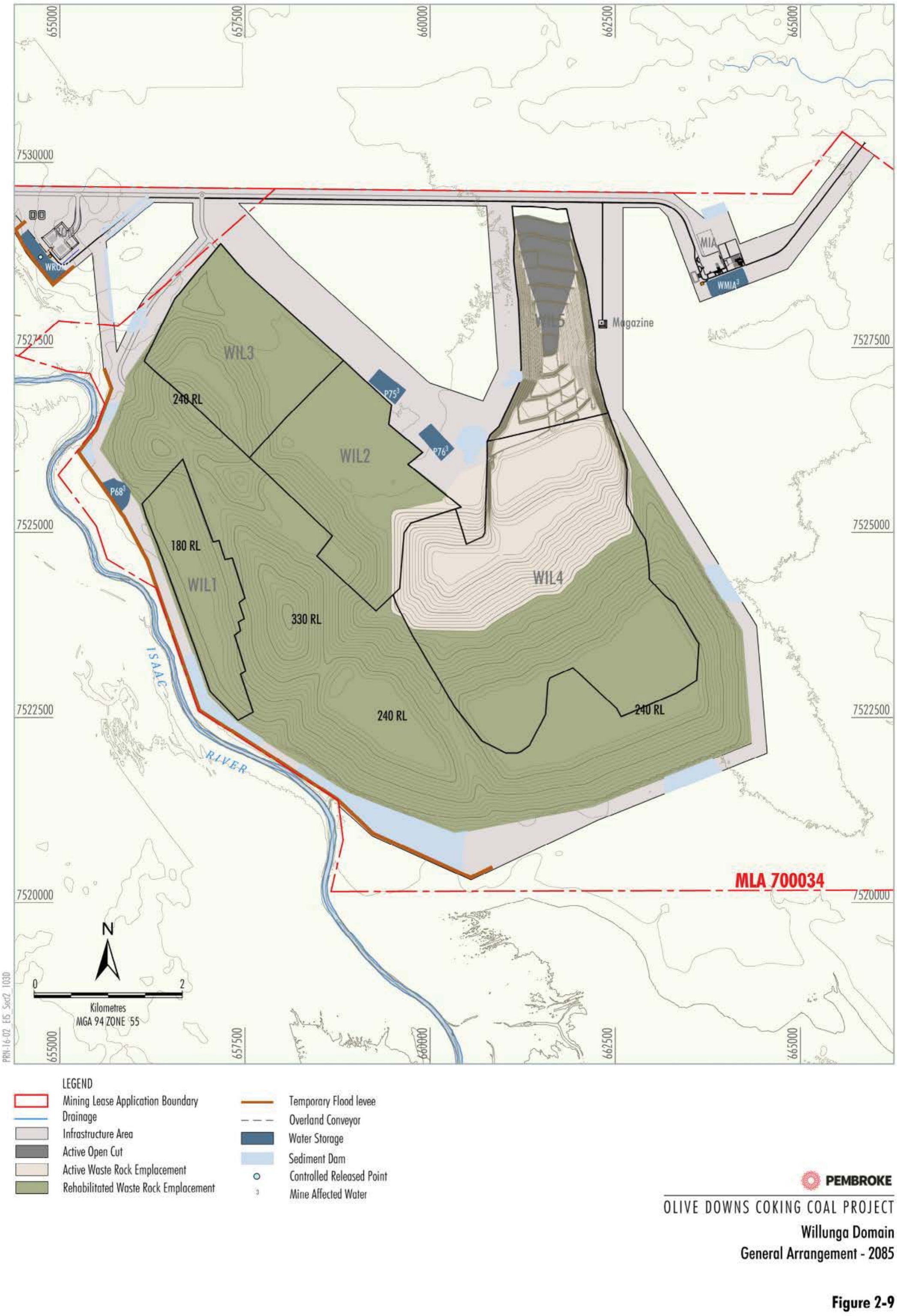

Figure 1-11: Willunga General Arrangement - 2085

2. Terms of Reference for EIS – Surface Water

The site-specific Terms of Reference (TOR) seek information corresponding to the project assessment requirements of the EP Act. The EIS process applies to site-specific environmental authority (EA) applications for undertaking resource projects that meet any of the Department of Environment and Heritage Protection's (DEHP) EIS triggers in the guideline "*Environmental impact statement – Triggers for environmental impact statements under the Environmental Protection Act 1994 for mining, petroleum and gas activities*".

This assessment, which forms part of the EIS, addresses the TOR concerning surface water. Table 2-1 lists the elements of the TOR relevant to this assessment and the sections of this report where those TORs are addressed.

Table 2-1: Final Terms of Reference for the Project – Surface Water Resources

Key Issue	Requirement	Report Section
10. Project description		
• 10.10 Climate	Describe the site's climate patterns that are relevant to the environmental assessment, with particular regard to discharges to water and air and the propagation of noise. Climate information should be presented in a statistical form including long-term averages and extreme values, as necessary.	Section 5.2
11. Assessment of project specific matters		
Matters of national environmental significance - Assessment requirements		
• 11.12	The EIS should include an assessment of the cumulative impacts, with respect to each controlling provision for each proposed action and all identified consequential actions related to each proposed action and all known developments (of which the proponent should reasonably be aware) that have been, or are being, taken or that have been approved in the region affected by each proposed action.	Section 10.6
• 11.13	With respect to each controlling provision for each proposed action, describe any avoidance measures proposed to reduce the impact on MNES and the anticipated result of proposed avoidance measures. Supporting evidence should be provided to demonstrate the appropriateness of avoidance measures proposed. Where the likely success of avoidance measures cannot be supported by evidence, identify contingencies in the event the avoidance is not successful.	Section 10
• 11.14	With respect to each controlling provision for each proposed action, describe any mitigation measures proposed to reduce the impact on MNES and the anticipated result of proposed mitigation measures. Supporting evidence should be provided to demonstrate the appropriateness of mitigation measures proposed. Where the likely success of mitigation measures cannot be supported by evidence, identify contingencies in the event the mitigation is not successful.	Section 10
• 11.15	With respect to each controlling provision for each proposed action, describe the residual significant impacts of each proposed action after all proposed avoidance and mitigation measures are taken into account and any compensatory measures proposed.	Section 10
A water resource, in relation to coal seam gas development and large coal mining development		

Key Issue	Requirement	Report Section
• 11.24	In relation to the proposed mine site and access road (EPBC 2017/7867), the EIS must provide details on the current state of groundwater and surface water in the region as well as any use of these resources.	Section 5
• 11.25	The EIS must describe and assess the impacts to water resources giving consideration to the Significant Impact Guidelines 1.3: Coal seam gas and large coal mining developments – impacts on water resources.	Sections 10.1, 10.3, 10.4, 10.5 & 10.6
• 11.26	The EIS must address the information requirements contained in the Information Guidelines for the Independent Expert Scientific Committee advice on coal seam gas and large coal mining development proposals and provide a cross-reference table to identify where each component of the guidelines has been addressed.	Section 3.1.2
Water quality – information requirements		
• 11.62	Detail the chemical and physical characteristics of surface waters and groundwater within the area that may be affected by the project in accordance with Department of Environment and Heritage Protection's TOR guideline – Water.	Section 5.4
• 11.64	Identify the quantity, quality and location of all potential discharges of water and waste water by the project, whether as point sources (such as controlled discharges from regulated dams) or diffuse sources (such as seepage from waste rock dumps or irrigation to land of treated sewage effluent). Assess the potential impacts of any discharges on the quality and quantity of receiving waters taking into consideration the assimilative capacity of the receiving environment and the practices and procedures that would be used to avoid or minimise impacts.	Sections, 7.10, 8.3.5, 8.3.6, 8.3.7 & 10.5
• 11.65	Demonstrate how the implementation of mitigation strategies would mitigate significant impacts of water discharges on the receiving environment. Information should be supported with references to relevant legislation, policies, guidelines and modelling	Section 10
• 11.66	Describe how the achievement of the objectives would be monitored and audited, and how corrective actions would be managed.	Section 10.7
Water resources – information requirements		
• 11.68	Provide details of any proposed impoundment, extraction (i.e. volume and rate), discharge, injection, use or loss of surface water or groundwater. Identify any approval or allocation that would be needed under the Water Act 2000.	Sections 7.8, 7.9 & 8.3
• 11.69	Detail any significant diversion or interception of overland flow including an assessment of impacts in accordance with the DNRME Guideline on Watercourse Diversions and include the consideration of alternatives. Include maps of suitable scale showing the location of diversions and other water-related infrastructure in relation to mining infrastructure.	Refer to Flood Assessment Report
• 11.70	Describe the options for supplying water to the project, and assess any potential consequential impacts in relation to the objectives of the Water Plan (Fitzroy Basin) 2011 and any resource operations plan that may apply	Sections 7.8, 8.3.4 & 10.3
• 11.72	Develop hydrological models as necessary to describe the inputs, movements, exchanges and outputs of all significant quantities and resources of surface water and groundwater that may be affected by the project.	Section 6.5

Key Issue	Requirement	Report Section
	The models should address the range of climatic conditions that may be experienced at the site, and adequately assess the potential impacts of the project on water resources including to the post-decommissioning phase. The models should also include a site water balance. This should enable a description of the project's impacts at the local scale and in a regional context including proposed: (a) changes in flow regimes from diversions, water take and discharges (b) alterations to riparian vegetation and bank and channel morphology (c) direct and indirect impacts arising from the development	
• 11.74	Provide details of the management strategies for mine-affected water for the life of the project to demonstrate minimisation of any impacts to land and waters, in particular off-site.	Section 6
Flooding and regulated dams – information requirements		
• 11.108	Describe current flood risk for a range of a range of annual exceedance probabilities up to the probable maximum flood for potentially affected waterways and assess (through flood modelling) how the project may potentially change flooding characteristics and be affected by floods. Flood modelling should consider all infrastructure and disturbance areas associated with the project including levees, roads and linear infrastructure and all proposed measures to avoid or minimize impacts.	Refer to Flood Assessment Report
• 11.109	List and describe all dams and levees proposed or existing on the project site and undertake an assessment to determine the consequence category of each dam or levee assessed (low, significant, or high), consistent with the criteria in the EHP Manual for Assessing Consequence Categories and Hydraulic Performance of Structures. Illustrate how any regulated structure on site would be managed during periods of high incidental rainfall and/or flooding on site so that any potential impacts to land or water are minimised.	Section 7.13

3. Regulatory Framework

This section describes the regulatory framework (legislation, policies and standards) at Commonwealth and State level that would apply to surface water management for the Project.

3.1 Commonwealth

3.1.1 EPBC Act

The Environmental Protection and Biodiversity Conservation Act 1999 (EPBC Act) outlines the requirements relating to the management and protection of matters of national environmental significance (MNES). The following Project actions have been deemed to be controlled actions under the EPBC Act:

- Olive Downs Coking Coal Project Mine Site and Access Road, 40 km south-east of Moranbah, Queensland (EPBC 2017-7867);
- Olive Downs Coking Coal Project Water Pipeline, 40 km south-east of Moranbah, Queensland (EPBC 2017-7868);
- Olive Downs Coking Coal Project Electricity Transmission Line, 20 km east of Moranbah, Queensland (EPBC 2017-7869); and
- Olive Downs Coking Coal Project Rail Spur, 30 km south-east of Moranbah, Queensland (EPBC 2017-7870).

Note that only the Olive Downs Coking Coal Project Mine Site and Access Road controlled action includes ‘a water resource, in relation to coal seam gas development and large coal mining development (sections 24D & 24E)’ as the relevant controlling provision, which is of relevance to the Surface Water Assessment.

3.1.2 Independent Expert Scientific Committee

The Independent Expert Scientific Committee (IESC) on Coal Seam Gas and Large Coal Mining Developments provides scientific advice to decision makers on the impact that coal seam gas and large coal mining development may have on Australia’s water resources.

The IESC provides independent, expert scientific advice on coal seam gas and large coal mining proposals as requested by the federal and state government regulators. The IESC assess the proposals against the Information Guidelines for Independent Expert Scientific Committee advice (IESC, 2018) on coal seam gas and large coal mining development proposals where there is a significant impact on water resources. The core purpose of the guideline is to determine whether a coal seam gas (CSG) or large coal mining development has or is likely to have a significant impact on a water resource.

As described in Section 2.1.1, on 3rd March 2017, the Olive Downs Coking Coal Project Mine Site and Access Road was deemed a controlled action under the EPBC Act, with one of the controlling provisions being ‘a water resource, in relation to coal seam gas development and large coal mining development (sections 24D & 24E)’ and therefore requires approval from the Australian Government Environment Minister (the Minister).

The report sections where the IESC information requirements for individual proposals have been addressed are outlined in Table 3-1.

Table 3-1: IESC Information Requirements

Project information	Report Section
Description of the proposal	
Provide a regional overview of the proposed project area including a description of the geological basin; coal resource; surface water catchments; groundwater systems; water-dependent assets; and past, current and reasonably foreseeable coal mining and CSG developments.	Section 1.2
Describe the proposal's location, purpose, scale, duration, disturbance area, and the means by which it is likely to have a significant impact on water resources and water-dependent assets.	Section 1 & Section 6
Describe the statutory context, including information on the proposal's status within the regulatory assessment process and any applicable water management policies.	Section 2
Describe how impacted water resources are currently being regulated under state or Commonwealth law, including whether there are any applicable standard conditions.	Section 2
Surface water – context and conceptualisation	
Describe the hydrological regime of all watercourses, standing waters and springs across the site including: • Geomorphology, including drainage patterns, sediment regime, and floodplain features; • Spatial, temporal and seasonal trends in streamflow and/or standing water levels; • Spatial, temporal and seasonal trends in water quality data (such as turbidity, acidity, salinity, relevant organic chemicals, metals, metalloids and radionuclides); and • Current stressors on watercourses, including impacts from any currently approved projects.	Section 5
Describe the existing flood regime, including flood volume, depth, duration, extent and velocity for a range of annual exceedance probabilities. Provide flood hydrographs and maps identifying peak flood extent, depth and velocity. This assessment should be informed by topographic data that has been acquired using lidar or other reliable survey methods with accuracy stated.	Refer to Flood Assessment Report
Provide an assessment of the frequency, volume, seasonal variability and direction of interactions between water resources, including surface water/groundwater connectivity and connectivity with sea water.	Refer to Groundwater Assessment Report
Surface water – analytical and numerical modelling	
Provide conceptual models at an appropriate scale, including water quality, stores, flows and use of water by ecosystems.	Section 6.5
Use methods in accordance with the most recent publication of *Australian Rainfall and Runoff* (Ball et al. 2016).	Refer to Flood Assessment Report
Develop and describe a program for review and update of the models as more data and information becomes available.	Section 8.5
Describe and justify model assumptions and limitations and calibrate with appropriate surface water monitoring data.	Section 6.5
Provide an assessment of the risks and uncertainty inherent in the data used in the modelling, particularly with respect to predicted scenarios.	Section 8.5
Provide a detailed description of any methods and evidence (e.g. expert opinion, analogue sites) employed in addition to modelling.	Section 8.5

Project information	Report Section
Surface water – impacts to water resources and water-dependent assets Describe all potential impacts of the proposed project on surface waters. Include a clear description of the impact to the resource, the resultant impact to any assets dependent on the resource (including water-dependent ecosystems such as riparian zones and floodplains), and the consequence or significance of the impact. Consider: • Impacts on streamflow under the full range of flow conditions. • Impacts associated with surface water diversions. • Impacts to water quality, including consideration of mixing zones. • The quality, quantity and ecotoxicological effects of operational discharges of water (including saline water), including potential emergency discharges, and the likely impacts on water resources and water-dependent assets. • Landscape modifications such as subsidence, voids, post rehabilitation landform collapses, onsite earthworks (including disturbance of acid-forming or sodic soils, roadway and pipeline networks) and how these could affect surface water flow, surface water quality, erosion, sedimentation and habitat fragmentation of water-dependent species and communities.	Section 10.1
Discuss existing water quality guidelines, environmental flow objectives and requirements for the surface water catchment(s) within which the development proposal is based.	Section 4 & Section 5.4
Identify processes to determine surface water guidelines and quantity thresholds which incorporate seasonal variation but provide early indication of potential impacts to assets.	Section 8
Propose mitigation actions for each identified significant impact.	Table 7-5
Describe the adequacy of proposed measures to prevent or minimise impacts on water resources and water-dependent assets.	Section 8, Section 9 & Section 10
Describe the cumulative impact of the proposal on surface water resources and water-dependent assets when all developments (past, present and/or reasonably foreseeable) are considered in combination.	Section 10.6
Provide an assessment of the risks of flooding (including channel form and stability, water level, depth, extent, velocity, shear stress and stream power), and impacts to ecosystems, project infrastructure and the final project landform.	Refer to Flood Assessment Report
Surface water – data and monitoring Identify monitoring sites representative of the diversity of potentially affected water-dependent assets and the nature and scale of potential impacts, and match with suitable replicated control and reference sites (BACI design) to enable detection and monitoring of potential impacts.	Section 10.7
Ensure water quality monitoring complies with relevant National Water Quality Management Strategy (NWQMS) guidelines (ANZECC/ARMCANZ 2000) and relevant legislated state protocols (e.g. QLD Government 2013).	Section 10.7
Identify data sources, including streamflow data, proximity to rainfall stations, data record duration and a describe of data methods, including whether missing data has been patched.	Section 5.2.2
Develop and describe a surface water monitoring programme that will collect sufficient data to detect and identify the cause of any changes from established baseline conditions and assess the effectiveness of mitigation and management measures. The program will: • Include baseline monitoring data for physico-chemical parameters, as well as contaminants (e.g. metals). • Comparison of physico-chemical data to national/regional guidelines or to site- specific guidelines derived from reference condition monitoring if available. • identify baseline contaminant concentrations and compare these to national guidelines, allowing for local background correction if required.	Section 10.7

Project information	Report Section
Describe the rationale for selected monitoring parameters, duration, frequency and methods, including the use of satellite or aerial imagery to identify and monitor large-scale impacts.	Refer to Geomorphology Report
Develop and describe a plan for ongoing ecotoxicological monitoring, including direct toxicity assessment of discharges to surface waters where appropriate.	
Identify dedicated sites to monitor hydrology, water quality, and channel and floodplain geomorphology throughout the life of the proposed project and beyond.	
Water-dependent assets – context and conceptualisation Identify water-dependent assets, including: • Water-dependent fauna and flora and provide surveys of habitat, flora and fauna (including stygofauna) (see Doody et al. [in press]). • Public health, recreation, amenity, Indigenous, tourism or agricultural values for each water resource.	Refer to Aquatic Ecology Report
Identify GDEs in accordance with the method outlined by Eamus et al. (2006). Information from the GDE Toolbox15 (Richardson et al. 2011) and GDE Atlas (CoA 2017a) may assist in identification of GDEs (see Doody et al. [in press]).	Refer to Groundwater Assessment Report
Describe the conceptualisation and rationale for likely water-dependence, impact pathways, tolerance and resilience of water-dependent assets. Examples of ecological conceptual models can be found in Commonwealth of Australia (2015).	
Estimate the ecological water requirements of identified GDEs and other water-dependent assets (see Doody et al. [in press]).	
Identify the hydrogeological units on which any identified GDEs are dependent (see Doody et al. [in press]).	
Provide an outline of the water-dependent assets and associated environmental objectives and the modelling approach to assess impacts to the assets.	Section 4.1
Describe the process employed to determine water quality and quantity triggers and impact thresholds for water-dependent assets (e.g. threshold at which a significant impact on an asset may occur).	Section 5.4
Water-dependent assets – impacts, risk assessment and management of risks Provide an assessment of direct and indirect impacts on water-dependent assets, including ecological assets such as flora and fauna dependent on surface water and groundwater, springs and other GDEs (see Doody et al. [in press]).	Section 10
Describe the potential range of drawdown at each affected bore, and clearly articulate the scale of impacts to other water users.	Refer to Groundwater Assessment Report
Indicate the vulnerability to contamination (e.g. from salt production and salinity) and the likely impacts of contamination on the identified water-dependent assets and ecological processes.	Refer to Aquatic Ecology Report
Identify and consider landscape modifications (e.g. voids, on-site earthworks, and roadway and pipeline networks) and their potential effects on surface water flow, erosion and habitat fragmentation of water-dependent species and communities.	Section 9
Provide estimates of the volume, beneficial uses and impact of operational discharges of water (particularly saline water), including potential emergency discharges due to unusual events, on water-dependent assets and ecological processes.	Section 8 and Section 10.5
Assess the overall level of risk to water-dependent assets through combining probability of occurrence with severity of impact.	Section 10
Identify the proposed acceptable level of impact for each water-dependent asset based on leading-practice science and site-specific data, and ideally developed in conjunction with stakeholders.	Section 3.2.1
Propose mitigation actions for each identified impact, including a description of the adequacy of the proposed measures and how these will be assessed.	Section 10

Project information	Report Section
Water-dependent assets – data and monitoring Identify an appropriate sampling frequency and spatial coverage of monitoring sites to establish pre-development (baseline) conditions, and test potential responses to impacts of the proposal (see Doody et al. [in press]).	Section 10.7
Consider concurrent baseline monitoring from unimpacted control and reference sites to distinguish impacts from background variation in the region (e.g. BACI design, see Doody et al. [in press]).	
Develop and describe a monitoring program that identifies impacts, evaluates the effectiveness of impact prevention or mitigation strategies, measures trends in ecological responses and detects whether ecological responses are within identified thresholds of acceptable change (see Doody et al. [in press]).	
Describe the process for regular reporting, review and revisions to the monitoring program.	
Ensure ecological monitoring complies with relevant state or national monitoring guidelines (e.g. the DSITI guideline for sampling stygofauna (QLD Government 2015)).	Refer to Aquatic Ecology Report
Water and salt balance and water management strategy Provide a quantitative site water balance model describing the total water supply and demand under a range of rainfall conditions and allocation of water for mining activities (e.g. dust suppression, coal washing etc.), including all sources and uses.	8
Describe the water requirements and on-site water management infrastructure, including modelling to demonstrate adequacy under a range of potential climatic conditions.	Section 7.8 and Section 8.3
Provide estimates of the quality and quantity of operational discharges under dry, median and wet conditions, potential emergency discharges due to unusual events and the likely impacts on water-dependent assets.	Section 8
Provide salt balance modelling that includes stores and the movement of salt between stores and takes into account seasonal and long-term variation.	Section 8.3.8 and Section 10.5.3
Cumulative impacts – context and conceptualisation Provide cumulative impact analysis with sufficient geographic and temporal boundaries to include all potentially significant water-related impacts.	Section 10.6
Consider all past, present, and reasonably foreseeable actions, including development proposals, programs and policies that are likely to impact on the water resources of concern in the cumulative impact analysis. Where a proposed project is located within the area of a bioregional assessment consider the results of the bioregional assessment.	Section 10.6
Cumulative impacts – impacts Provide an assessment of the condition of affected water resources which includes: • Identification of all water resources likely to be cumulatively impacted by the proposed development. • A description of the current condition and quality of water resources and information on condition trends. • Identification of ecological characteristics, processes, conditions, trends and values of water resources. • Adequate water and salt balances. • Identification of potential thresholds for each water resource and its likely response to change and capacity to withstand adverse impacts (e.g. altered water quality, drawdown).	Section 5
Assess the cumulative impacts to water resources considering: • The full extent of potential impacts from the proposed project, (including whether there are alternative options for infrastructure and mine configurations which could reduce impacts), and encompassing all linkages, including both direct and indirect links, operating upstream, downstream, vertically and laterally. • All stages of the development, including exploration, operations and post closure/decommissioning. • Appropriately robust, repeatable and transparent methods.	Section 10.6

Project information	Report Section
• The likely spatial magnitude and timeframe over which impacts will occur, and significance of cumulative impacts. • Opportunities to work with other water users to avoid, minimise or mitigate potential cumulative impacts.	
Cumulative Impacts – Mitigation, monitoring and management Identify modifications or alternatives to avoid, minimise or mitigate potential cumulative impacts. Evidence of the likely success of these measures (e.g. case studies) should be provided.	Section 10.6
Identify measures to detect and monitor cumulative impacts, pre and post development, and assess the success of mitigation strategies.	Section 10.7
Identify cumulative impact environmental objectives.	Section 10.6
Describe appropriate reporting mechanisms.	Section 10.7
Propose adaptive management measures and management responses.	Section 8.5
Final landform and voids – coal mines Identify and consider landscape modifications (e.g. voids, on-site earthworks, and roadway and pipeline networks) and their potential effects on surface water flow, erosion, sedimentation and habitat fragmentation of water-dependent species and communities.	Section 9
Assess the adequacy of modelling, including surface water and groundwater quantity and quality, lake behaviour, timeframes and calibration.	Section 9
Provide an assessment of the long-term impacts to water resources and water-dependent assets posed by various options for the final landform design, including complete or partial backfilling of mining voids. Assessment of the final landform for which approval is being sought should considers: • Groundwater behaviour – sink or lateral flow from void. • Water level recovery – rate, depth, and stabilisation point (e.g. timeframe and level in relation to existing groundwater level, surface elevation). • Seepage – geochemistry and potential impacts. • Long-term water quality, including salinity, pH, metals and toxicity. • Measures to prevent migration of void water off-site. For other final landform options considered sufficient detail of potential impacts should be provided to clearly justify the proposed option.	Section 9
Assess the probability of overtopping of final voids with variable climate extremes, and management mitigations.	
Acid-forming materials and other contaminants of concern Identify the presence and potential exposure of acid-sulphate soils (including oxidation from groundwater drawdown).	Refer to Geochemical Report
Identify the presence and volume of potentially acid-forming waste rock, fine-grained amorphous sulphide minerals and coal reject/tailings material and exposure pathways.	
Identify other sources of contaminants, such as high metal concentrations in groundwater, leachate generation potential and seepage paths.	
Describe handling and storage plans for acid-forming material (co-disposal, tailings dam, encapsulation).	
Assess the potential impact to water-dependent assets, taking into account dilution factors, and including solute transport modelling where relevant, representative and statistically valid sampling, and appropriate analytical techniques.	
Describe proposed measures to prevent/minimise impacts on water resources, water users and water-dependent ecosystems and species.	

3.2 Queensland

3.2.1 EP Act 1994

Resource activities are defined as environmentally relevant activities (ERAs) under the Queensland Environmental Protection Act 1994 (EP Act) and as such, the development and operation of the Project are governed by the EP Act. The object of the EP Act is to:

Protect Queensland's environment while allowing for development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends (ecologically sustainable development).

3.2.1.1 Environmental Authority

An environmental authority (EA) is granted in accordance with the EP Act and details the prescribed conditions that govern the ERA. In the context of surface water management, the EA sets out conditions that will be relevant to the Project, including:

- Management of contained water including release;
- Water management plan requirements;
- Regulation of water structures including dams and levees;
- Saline drainage management;
- Acid rock drainage management; and
- Storm water and sediment laden runoff management.

3.2.1.1.1 Model Mining Conditions

New mining project applications should apply the model mining conditions as outlined in *Model mining conditions* (DEHP, 2017). The purpose of the model mining conditions is to provide a set of model conditions to form the general environmental protection commitments given for EA's for mining activities administered under the EP Act. The model conditions may be used as a basis for proposing environmental protection commitments in application documents (such as an EIS).

Model conditions can be modified to suit the specific circumstances of a mining project, subject to the assessment criteria outlined in the EP Act. It is unlikely that the administering authority will accept less rigorous environmental protection commitments or EA conditions without clear evidence that the risk of the environmental harm is addressed by environmental management practices, technologies or the nature of the EVs impacted by the project.

Schedule F – Water (Fitzroy model conditions) form the basis of the requirements for the Project Water Management System design.

3.2.1.2 Environmental Protection (Water) Policy 2009

The *Environmental Protection (Water) Policy 2009* (EPP Water) is the primary instrument for surface water management under the EP Act. The EPP Water governs discharge to land, surface water and groundwater, aims to protect environmental values (EVs) and sets water quality guidelines and objectives.

The processes to identify Environmental Values (EVs) and to determine Water Quality Guidelines (WQGs) and Water Quality Objectives (WQOs) in Queensland waters based on the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC/ARMCANZ guidelines).

3.2.1.3 Isaac River Sub-basin Environmental Values and Water Quality Objectives 2011

The relevant document, pursuant to the EPP Water, for the Project is the *Isaac River Sub-basin Environmental Values and Water Quality Objectives Basin No. 130 (part)*, including all waters of the Isaac River Sub-basin (including Connors River, September 2011 (DEHP, 2011). The document is made pursuant to the provisions of the EPP Water. It contains Environmental Values (EVs) and Water Quality Objectives (WQOs) for waters in the Isaac River Sub-basin, and they are listed under Schedule 1 of EPP Water. Refer to Section 4 for further details.

3.2.1.4 Manual for Assessing Consequence Categories and Hydraulic Performance of Structures

The *Manual for Assessing Consequence Categories and Hydraulic Performance of Structures* (the Manual) defines the methodology and assessment criteria to determine if a structure associated with an ERA should be regulated under the EP Act. The manual details the hydraulic design requirements for regulated structures and this document has been used as a reference in the preliminary design of the water management system and preliminary sizing of dams associated with the Project.

3.2.1.5 Guideline – Application Requirements for Activities with Impacts to Water

This guideline focuses on the types of impacts that environmentally relevant activities (ERAs) can have on water and outlines the information to be provided to the department as part of the ERA application process.

Section 4 of the guideline requires the applicant to provides details on a number of surface water-related issues, including:

- Discharges and releases;
- Unplanned and uncontrolled releases;
- Water infrastructure;
- Wetlands;
- Hydrology of receiving waters; and
- Mixing zones.

Table 3-2 lists the elements of the guideline relevant to this assessment and the sections of this report where those elements are addressed.

The guideline also refers to the department’s technical guideline “Wastewater releases to Queensland waters”, which is discussed in Section 3.2.1.5.1.

Table 3-2: Application Requirements for Activities with Impact to Water - Guideline

Item	Report Section
Discharges and releases	
• Identify the location, depth and configuration of all potential discharge points	Section 6.4
• Details of the water to be released	Sections 6.4, 7.11 & 8.3.5
Unplanned and uncontrolled releases	
• Identify activities that could lead to indirect impacts and unplanned/uncontrolled release of contaminants to water, such as, spills and leaks or stream bed and/or bank disturbance and describe the magnitude of the disturbance	Sections 6.1, 6.4, 6.5
• Identify the location, depth and configuration (if relevant) of the areas where the unplanned/uncontrolled release could be discharge to waters	Sections 6.4
• Identify infrastructure (including containment devices) with the potential to release unplanned/uncontrolled contaminants to waters.	Sections 6.4, 8.3.6, 8.3.7
• Identify the potential contaminant type and quantities that could be released on infrastructure	Section 7.12
Water infrastructure	
• Provide details on the location and storage capacity of water infrastructure on the site which may include regulated structures, tailings dams, waste rock dams, water storage dams, levees, heap leach pads and any other water management infrastructure.	Sections 6, 7.2.1, 7.4 & 7.5
Wetlands	
• Applicants must describe how the existing environmental values of any wetlands on, or adjacent to, the site will be maintained, or enhanced.	Section 10.5.4
Hydrology of Receiving Waters	
• Describe, preferably through the use of water quality monitoring or modelling, how the proposed ERA will impact on hydrology of receiving waters.	Section 10
Mixing Zones	
• For planned/controlled release to water, describe the impact to any initial mixing zone(s)	Section 6.4.1

3.2.1.5.1 Technical Guideline – Wastewater Release to Queensland Waters

This guideline is provided to support a risk-based assessment approach to licensing releases of wastewater to surface water and applies the philosophy of the ANZECC & ARMCANZ (2000) Water Quality Guidelines and the intent of the Environmental Protection (Water) Policy 2009.

The information requirements identified in this guideline are as follows:

- Describe the proposed activity.
- Describe the receiving environment.
- Predict outcomes or impacts of the proposed wastewater release.
- Set circumstances, limits and monitoring conditions.

Table 3-3 lists the elements of the guideline relevant to this assessment and the sections of this report where those elements are addressed.

Table 3-3: Wastewater Release to QLD Waters – Technical Guideline

Item	Report Section
Step 1 – Describe the proposed activity	
• Define the industry type and size	Section 1.2
• Identify the potential contaminants of concern in the proposed release	Section 7.12
• Assess the characteristics of the proposed release	Sections 7.11, 8.3.5, 8.3.6 & 8.3.7
• Check the location and configuration of the proposed release	Section 6.4
Step 2 – Describe the receiving environment	
• Identify water bodies potentially affected by the proposed release	Sections 5.1 & 5.3.3
• Provide all relevant information on the receiving environment	Section 5
• Consideration of temporary streams	Section 5
• Identify all relevant EV and WQO's	Section 4
• Ensure all government planning requirements applying to the water bodies have been considered	Section 3
• Check the location and configuration of the proposed release	Section 6.4
Step 3 – Predict outcomes of the proposed wastewater release	
• Assess whether contaminants are potentially toxic	Section 7.12
• Consideration of an initial mixing zone	Section 6.4.1
• Predict the assimilative capacity and sustainable load	Sections 7.11, 8.3.5, 10.5.3 & 10.6.3
• Consider other potential impacts	Section 10
Step 4 – Set circumstances, limits and monitoring conditions	
• Specify any circumstances related to the approved wastewater release	Section 7.11
• Derive end-of-pipe limit from approved release loads and characteristics	Section 7.11
• Include a receiving environment monitoring program (REMP) requirement	Section 10.7
• Include reporting requirements for approved activity	Section 10.7.5

3.2.2 *Water Act 2000*

In Queensland, the Water Act 2000 (Water Act) is the primary statutory document that establishes a framework for the planning, allocation and use of non-tidal water. The Water Act is primarily administered by the Department of Natural Resources, Mines and Energy (DNRME) and the Department of Energy and Water Supply (DEWS).

The main purpose of the Water Act is to provide a framework for the following:

- The sustainable management of Queensland's water resources and quarry material by establishing a system for:
  - The planning, allocation and use of water; and
  - The allocation of quarry material and riverine protection.
- The sustainable and secure water supply for the south-east Queensland region and other designated regions;

- The management of impacts on underground water caused by the exercise of underground water rights by the resource sector; and
- The effective operation of water authorities.

A watercourse is defined by the Water Act as a river, creek or stream in which water flows permanently or intermittently and includes the bed and banks and any other element of a river, creek or stream confining or containing water. The DNRME have published a watercourse identification map of the state that shows: watercourses (other than their lateral limits); the downstream limit of watercourses; drainage features; lakes; and springs. This watercourse map is discussed in Section 5.3.3.

3.2.2.1 Water Plan (Fitzroy Basin) 2011

The Water Plan (Fitzroy Basin) 2011, which replaces the Water Resource (Fitzroy Basin) Plan 2011, is subordinate legislation to the Water Act. The plan is developed and administered by DNRME. The purpose of the plan is:

- To define the availability of water in the Fitzroy Basin;
- To provide a framework for sustainably managing water and the taking of water;
- To identify priorities and mechanisms for dealing with future water requirements;
- To provide a framework for establishing water allocations;
- To provide a framework for reversing, where practicable, degradation in natural ecosystems;
- To regulate the taking of overland flow water; and
- To regulate the taking of groundwater.

3.2.2.2 Water Regulation 2016

Water Regulation 2016 is subordinate legislation to the Water Act and provides details, protocol and instruction for the following:

- Water rights and planning;
- Statutory authorisations to take or interfere with water;
- Matters relating to water licenses;
- Water allocations;
- Water supply and demand management;
- Declarations about watercourses.

3.2.3 Water Supply (Safety & Reliability) Act 2008

The Water Supply (Safety and Reliability) Act 2008 provides for the safety and reliability of water supply in Queensland. The purpose is achieved primarily by:

- Providing a regulatory framework for providing water and sewerage services in the State;
- Providing a regulatory framework for providing recycled water and drinking water quality, primarily for protecting public health;
- The regulation of referable dams; and
- Stating flood mitigation responsibilities.

4. Environmental Values

The Olive Downs South Domain is located within the Isaac western upland tributaries developed areas (refer Section 3.2.1.3) of the Isaac River sub-basin and the Willunga domain is located on the border of Isaac northern tributaries-developed areas and Isaac and lower Connors River main channel-developed areas, shown in Figure 4-1. The following EVs have been nominated broadly to the mapped areas for protection of zone:

- Aquatic ecosystems
- Irrigation
- Farm supply/use
- Stock Water
- Aquaculture (Isaac western upland tributaries only)
- Human consumption
- Primary recreation
- Secondary recreation
- Visual recreation
- Drinking water
- Industrial use
- Cultural and spiritual values

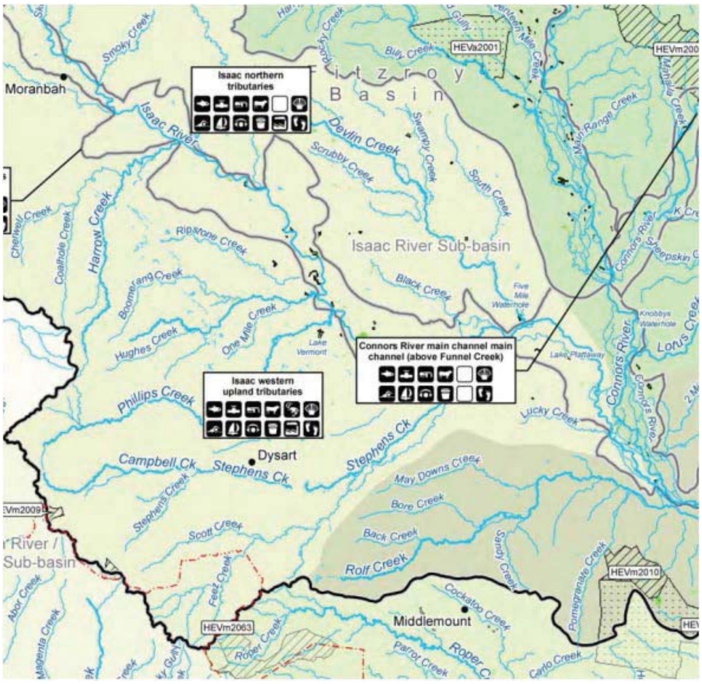

Figure 4-1: Isaac River Sub-Basin EVs

The following WQOs for the above EVs are provided in Table 4-1. Where different EVs have different WQOs the lowest value has been adopted. WQOs are displayed for physio-chemical parameters only.

Table 4-1: Water Quality Objectives for the Upper Isaac River catchments waters

Parameter	WQO	Relevant EV
Ammonia N	< 20 µg/L	Aquatic ecosystem[a]
Oxidised N	< 60 µg/L	Aquatic ecosystem[a]
Organic N	< 420 µg/L	Aquatic ecosystem[a]
Total nitrogen	< 500 µg/L	Aquatic ecosystem[a]
Filterable Reactive Phosphorus (FRP)	< 20 µg/L	Aquatic ecosystem[a]
Total Phosphorus	< 50 µg/L	Aquatic ecosystem[a]
Chlorophyll a	< 5 µg/L	Aquatic ecosystem[a]
Dissolved oxygen	85-110% saturation > 4 mg/L at surface	Aquatic ecosystem[a] Drinking water[b]
Turbidity	< 50 NTU	Aquatic ecosystem[a]
Suspended solids	< 55 mg/L	Aquatic ecosystem[a]
pH	pH 6.5-8.5	Aquatic ecosystem[a]
Conductivity (EC) baseflow	720 µS/cm	Aquatic ecosystem[a]
Conductivity (EC) high flow	250 µS/cm	Aquatic ecosystem[a]
Sulphate	25 mg/L	Aquatic ecosystem[a]
Total Dissolved Solids	< 2000 mg/L	Stock watering[c]
Colour	50 Hazen Units	Drinking water[b]
Total Hardness	150 mg/L as CaCO3	Drinking water[b]
Sodium	< 30 mg/L	Drinking water[b]
Aluminium	< 5 mg/L < 0.055 mg/L	Stock watering[c] Aquatic ecosystem[d]
Arsenic	2.0 mg/L 0.5 mg/L up to 5 mg/L < 0.024 mg/L	Irrigation[b, e] Stock watering[f] Aquatic ecosystem[d]
Beryllium	< 0.5 mg/L	Irrigation[g]
Boron	< 5 mg/L < 0.37 mg/L	Stock watering[f,e] Aquatic ecosystem[d]
Cadmium	< 0.01 mg/L < 0.0002 mg/L	Stock watering[f,e] Aquatic ecosystem[d]
Chromium	< 1 mg/L < 0.001 mg/L	Stock watering[f,e] Aquatic ecosystem[d]
Cobalt	< 0.1 mg/L	Irrigation[g]
Copper	< 1 mg/L < 0.0014 mg/L	Stock watering (cattle)[f,e] Aquatic ecosystem[d]
Fluoride	< 2 mg/L	Irrigation[g]
Iron	< 10 mg/L	Irrigation[g]

Parameter	WQO	Relevant EV
Lead	< 0.1 mg/L < 0.0034 mg/L	Stock watering[f,e] Aquatic ecosystem[d]
Lithium	< 2.5 mg/L	Irrigation[g]
Manganese	< 10 mg/L < 1.9 mg/L	Irrigation[g] Aquatic ecosystem[d]
Mercury	< 0.002 mg/L < 0.00006 mg/L	Irrigation[g] Aquatic ecosystem[d]
Molybdenum	< 0.05 mg/L	Irrigation[g]
Nickel	< 1 mg/L < 0.011 mg/L	Stock watering[f, e] Aquatic ecosystem[d]
Selenium	< 0.02 mg/L < 0.005 mg/L	Stock watering[f,e] Aquatic ecosystem[d]
Uranium	< 0.1 mg/L	Irrigation[g]
Vanadium	< 0.5 mg/L	Irrigation[g]
Zinc	< 5 mg/L < 0.008 mg/L	Irrigation[g] Aquatic ecosystem[d]

a/ Table 2 of Isaac River Sub-basin Environmental Values and Water Quality Objectives: Aquatic ecosystem - moderately disturbed
b/ Table 4 of Isaac River Sub-basin Environmental Values and Water Quality Objectives: Drinking water EV
c/ Table 10 of Isaac River Sub-basin Environmental Values and Water Quality Objectives: Stock watering EV: salinity
d/ Table 3.4.1 of Australian and New Zealand Guidelines for Fresh and Marine Water Quality: trigger values for slightly-moderately disturbed systems (95% level of protection)
e/ short-term trigger value
f/ Table 11 of Isaac River Sub-basin Environmental Values and Water Quality Objectives: Stock watering EV: heavy metals and metalloids
g/ Table 9 of Isaac River Sub-basin Environmental Values and Water Quality Objectives: Irrigation EV: heavy metals and metalloids

4.1 Aquatic Ecosystem Environmental Values

DPM EnviroScience's Pty Ltd (DPM) have undertaken baseline aquatic ecology surveys for the Project. This work identified the following wetlands and Matters of State Environmental Significance (MSES).

4.1.1 Wetlands

DPM identified a total of 60 palustrine wetlands mapped as occurring within the Project area and wider surrounds, including 11 wetlands of High Ecological Significance (HES) and 49 wetlands of General Ecological Significance (GES). A further 16 previously unmapped GES wetlands were also identified during the aquatic ecology surveys. The HES wetlands include a paleochannel lake, ox-bow lakes and flood channel wetlands on the Isaac River floodplain, as well as vegetated swamps in depressions on and beyond the floodplain. The GES wetlands include riverine wetlands of the Isaac River, as well as numerous floodplain and non-floodplain palustrine wetlands. Seven lacustrine wetlands are mapped as occurring within the Project area, comprising dams ranging in size from approximately 1 to 12 ha. These dams provide a water source for an array of aquatic and terrestrial fauna, domestic livestock, as well as foraging and breeding habitat for water birds, wader birds, frogs, reptiles, water rats and other mammals.

4.1.2 *Matters of State Environmental Significance (MSES)*

DPM identified Matters of State Environmental Significance (MSES) within the Project area to include regulated vegetation (terrestrial Regional Ecosystems), state significant drainage lines (waterways that intersect regulated vegetation) and HES wetlands. These MSES provide habitat and connectivity important for both aquatic and terrestrial flora and fauna. This includes areas of State biodiversity significance, including the Isaac River corridor. MSES aquatic fauna species that are likely to occur within the broader area include the critically endangered southern snapping turtle and vulnerable Fitzroy River turtle, each listed under the Queensland Nature Conservation Act 1992. However, neither species is likely to occur within the Project area due to lack of their preferred habitat. No MSES aquatic flora species are likely to occur within the Project area.

4.1.3 *Aquatic Ecosystem Environmental Values Summary*

DPM identified that the aquatic flora and fauna within the Project area are "generally well adapted to environmental extremes, including the wetting and drying cycles expected in these seasonal and ephemeral systems. This is expected to include tolerance of a wide range of water quality conditions, such as elevated conductivity and fluctuating dissolved oxygen in senescing pools between flow events."

4.1.4 *Fitzroy Basin Aquatic Ecosystem Health*

The Fitzroy Partnership for River Health is a collaboration between Government, industry, research organisations and community to facilitate improved water quality monitoring, collate and assess data, and publicly report on waterway health and sustainable use.

In 2015-16 the Fitzroy Basin (including the Upper Isaac and Lower Isaac areas covering the Project area) received a B grade for aquatic ecosystem health:

- Physical-chemical results were generally good and comparable to the long-term average. Salinity and sulfate results were stable. Turbidity results improved in the Upper Isaac and pH results were generally excellent or good across all catchments.
- Copper and aluminium continue to stand out as the toxicants of interest across the Basin and further investigation is being considered.

4.2 Matters of National Environmental Significance (MNES)

DPM identified that aquatic fauna species that are Matters of Environmental Significant (MNES) have been recorded in the broader area surrounding the Project area. This includes the critically endangered southern snapping turtle (Elseya albagula) and vulnerable Fitzroy River turtle (Rheodytes leukops), each listed under the EPBA Act. DPM state that although the Project area falls within the potential distributional range of these species, it is unlikely that either species occur within the waterways or wetlands of the Project area as either resident or transient occurrences due to the lack of their preferred habitat. Habitat for these species was not encountered within the Project area during the early wet aquatic surveys in December 2016.

No MNES aquatic flora species are likely to occur within the Project area, nor are any aquatic Threatened Ecological Communities expected to occur.

5. Existing Surface Water Environment

5.1 Location and Catchment Context

The Project is located within the headwaters of the Isaac sub-catchment of the greater Fitzroy Basin. The Isaac River is the main watercourse which bisects the Project area and flows in a north-west to south-east direction, passing the township of Moranbah and the Millennium, Poitrel and Daunia coal mines upstream of the Project area. The Isaac River flows to the north/east of the Olive Downs South domain and then further downstream to the south of the Willunga domain before continuing in a south-easterly direction.

The Connors River, which has a catchment area similar to the upstream Isaac River, flows into the Isaac River approximately 85 kilometres (km) downstream of the Project area. The Isaac River finally converges with the Mackenzie River a further approximate 50 km downstream.

Ultimately, the Mackenzie River joins the Fitzroy River, which flows initially north and then east towards the east coast of Queensland and discharges into the Coral Sea southeast of Rockhampton near Port Alma.

At a regional scale, the greater Isaac-Connors sub-catchment area (at the confluence with the Mackenzie River) is approximately 22,364 square kilometres (km^2) of the total Fitzroy River catchment of 142,665 km^2, or if represented as a percentage, it accounts for 15 percent of the overall Fitzroy River catchment area.

The Project mining lease application area is approximately 250 km^2 and represents one percent and 0.2 percent of the overall Isaac-Connors and Fitzroy river catchment areas, respectively.

Figure 5-1 presents the location of the Olive Down Project area and Isaac River catchment upstream of confluence with Connors River. Figure 5-2 is a photo of the Isaac River, upstream of the Project area and Figure 5-3 is a photo of the Isaac River, downstream of the Project area.

The Isaac River is a seasonally flowing watercourse, typically with surface flows in the wetter months from November to April, reducing to shallow subsurface flows from about May to October. All other waterways of the Project area are expected to be ephemeral and experience flow only after sustained or intense rainfall in the catchment. Stream flows are highly variable, with most channels drying out during winter to early spring when rainfall and runoff is historically low, although with some pools expected to hold water for extended periods. Therefore, physical attributes, water quality, and the composition of aquatic flora and fauna communities are also expected to be highly variable over time.

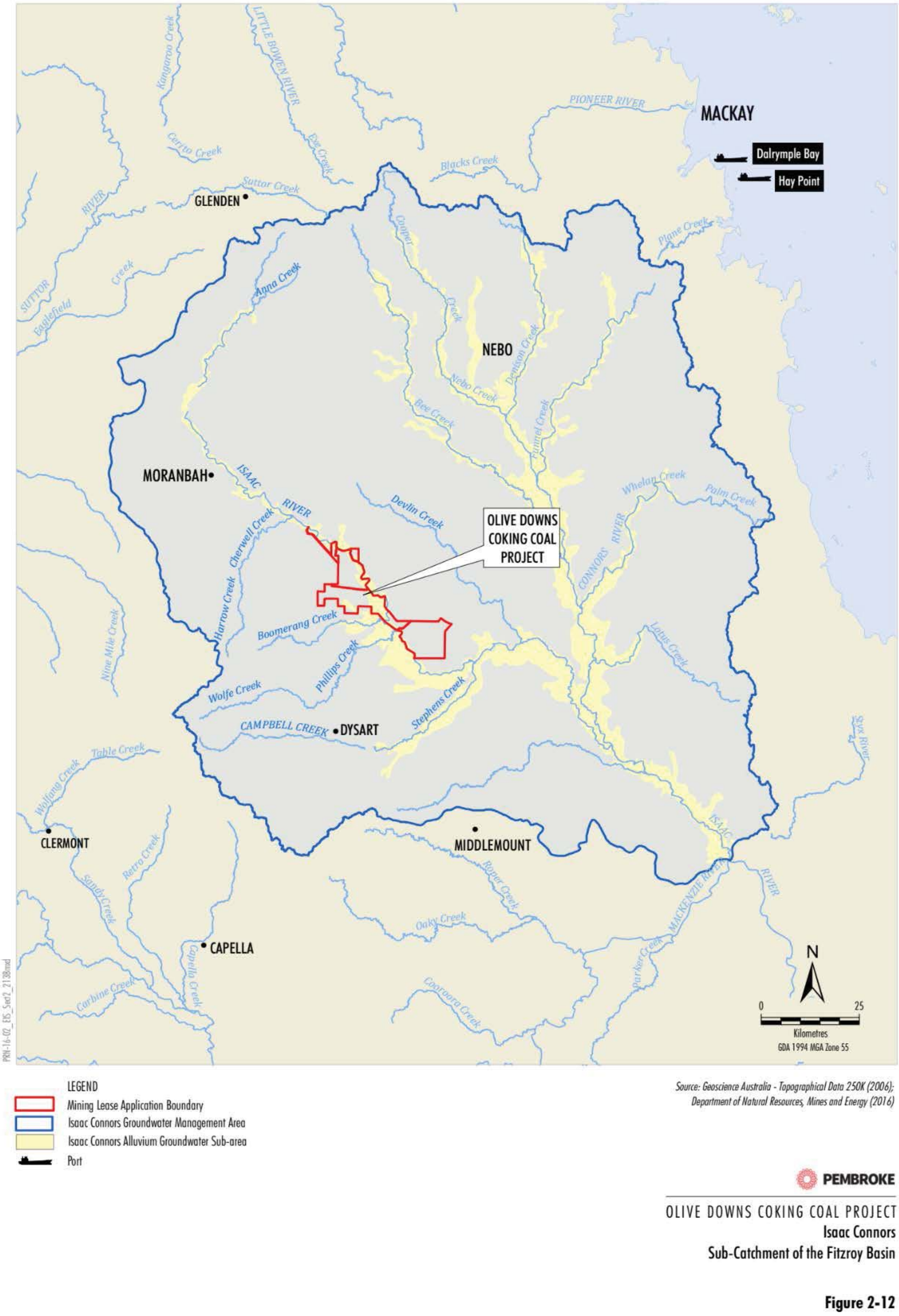

Figure 5-1: Isaac River Catchment and Project Area

Figure 5-2: Isaac River Upstream of the Project

Figure 5-3: Isaac River Downstream of the Project

5.1.1 Local Drainage

Tributaries of the Isaac River in the vicinity of the Project area include (from upstream to downstream) (see Figure 5-13 for locations):

- North Creek;
- Ripstone Creek;
- Boomerang Creek; and
- Phillips Creek.

North Creek enters the Isaac River immediately to the north of the Project area. The North Creek catchment area upstream of its confluence with the Isaac River is approximately 342 km^2 with predominant land use within the catchment being stock grazing and mines. The existing Moorvale Mine has approval to release to North Creek and the approved Olive Downs North Mine may be constructed and operated within the North Creek catchment. A photograph of North Creek is shown in Figure 5-4.

Ripstone Creek runs west to east, south of the Olive Downs South pits, while intersecting the satellite pit to the south west of the main Olive Downs South pits. The Ripstone Creek catchment area is approximately 286 km^2 with predominant land use within the catchment being stock grazing and open cut mining. The existing Peak Downs Mine has approval to release to Ripstone Creek). A photograph of Ripstone Creek is shown in Figure 5-5. Note that Figure 5-5 is showing a farm dam, rather than a permanent water body or billabong.

Boomerang Creek runs west to east, south of the Olive Downs South domain and joins the Isaac River between the Olive Downs South domain and Willunga domain. The Boomerang Creek catchment area is approximately 156 km^2 with predominant land use within the catchment being stock grazing and the Saraji Coal Mine. The Saraji Coal Mine has an existing diversion of Boomerang Creek and has approval to release to Boomerang Creek.

Phillips Creek runs west to east into the Isaac River adjacent to the Willunga domain. It has a catchment area of approximately 487 km^2 to the confluence with the Isaac River. Land uses within the Phillips Creek catchment include low intensity cattle grazing and open cut mining. The existing Saraji Mine and Lake Vermont Mine both have existing diversions/levees on Phillips Creek and approval to discharge to Phillips Creek. A photograph of Phillips Creek is shown in Figure 5-6.

Figure 5-4: North Creek Upstream of the Project

Figure 5-5: Ripstone Creek Upstream of the Project

Figure 5-6: Phillips Creek Upstream of the Project

5.2 Rainfall and Evaporation

5.2.1 Local Climate Data

Table 5-1 shows summary details of Bureau of Meteorology (BOM) and DNRME rainfall and evaporation recording stations with a significant period of record near the Project. These stations are shown in Figure 5-10.

Table 5-1: BOM & DNRME Rainfall & Evaporation Stations in Project Vicinity

Station No.	Station Name	Data Obtained	Elevation (mAHD)	Distance from Project	Opened	Closed
130414	Isaac River at Goonyella	Rainfall	245	50 km	1983	2011
534003	Isaac River at Deverill	Rainfall	-	adjacent to Project	1968	-
034035	Moranbah Airport	Rainfall, Min. & Max. Temp.	232	29 km	2012	-
034038	Moranbah Water Treatment Plant	Rainfall, Evaporation, Min. & Max. Temp.	260	36 km	1972	2012

The data from the Moranbah Water Treatment Plant station is presented within this section as this station has the longest concurrent rainfall and evaporation dataset within the region.

Table 5-2 shows the long term monthly rainfall and evaporation averages for the period of record at the Moranbah Water Treatment Plant (WTP). Table 5-3 shows the variability in monthly rainfall at the Moranbah WTP.

Figure 5-7 shows the annual distribution of monthly rainfall and evaporation at the Moranbah WTP. Both rainfall and evaporation are higher in the warmer months, with evaporation substantially exceeding rainfall in all months.

Table 5-2: Mean Monthly Rainfall and Pan Evaporation

Month	Rainfall	Pan Evaporation
	Moranbah WTP (Apr 1972 – Mar 2012)	Moranbah WTP (Apr 1972 – Mar 2012)
January	98.7	240.2
February	95.8	207.5
March	51.4	208.5
April	34.6	160.6
May	33.7	119.5
June	21.6	91.2
July	17.1	108.5
August	24.4	142.7
September	8.4	183.8
October	33.9	234.6
November	65.9	239.6
December	98.9	243.1
TOTAL	**584.4**	**2,180**

Table 5-3: Monthly Rainfall Statistics for Moranbah WTP (mm/month)

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	99	96	51	35	34	22	17	24	8.4	34	66	99	584
Maximum	315	347	268	271	197	170	104	247	61	147	220	350	1,109
90th %ile	214	214	185	81	75	48	63	72	21	104	154	200	877
Median	89	86	33	24	19	10	5.8	9.8	3.6	15	53	82	543
10th %ile	17	6.0	1.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	4.0	18	327
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	101

Rainfall across the Project area is expected to be greatest during the summer months, with the lowest rainfalls occurring mid-winter, as inferred from the 40 years of data collected at the Moranbah Water Treatment Plant.

Evaporation across the Project area is also expected to be greatest during the summer months, with the lowest evaporation rates generally occurring mid-winter, as inferred from the 26 years of data collected at the Moranbah WTP.

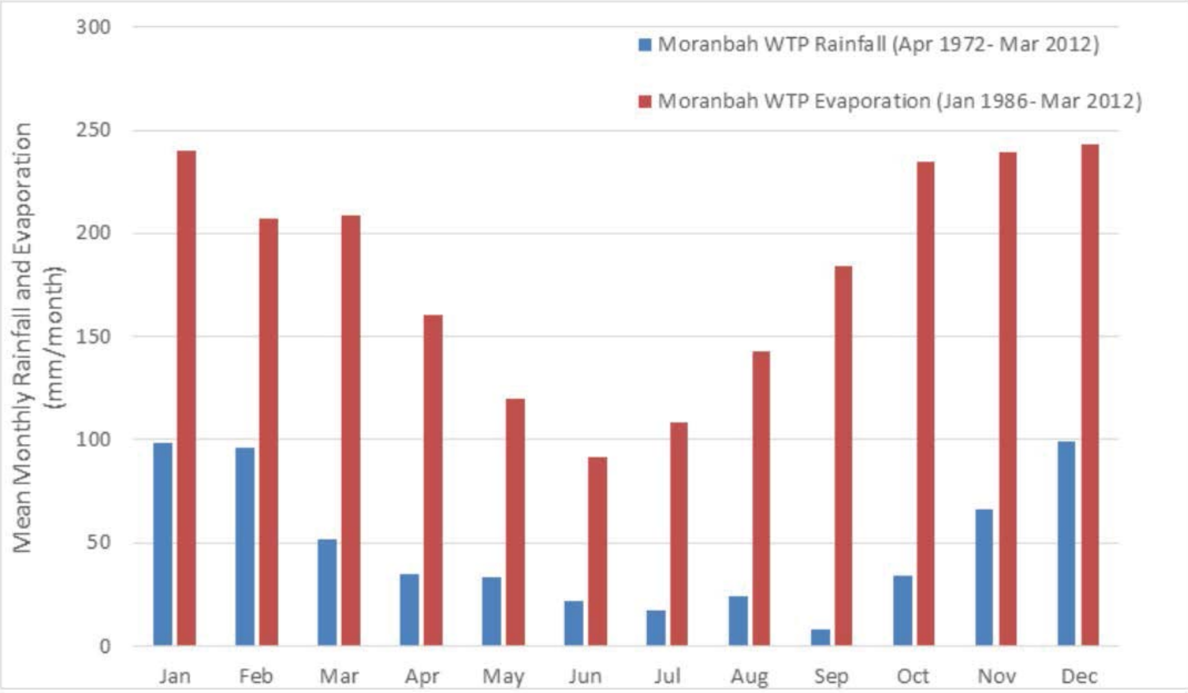

Figure 5-7: Distribution of Monthly Rainfall and Pan Evaporation – Moranbah WTP

5.2.2 DataDrill Climate Data

5.2.2.1 Rainfall

As described in Section 5.2.1, there is around 46 years of recorded rainfall data available for the Moranbah WTP and Moranbah Airport gauges. In order to extend the dataset, long term daily rainfall data for the Project area from 1 January 1889 to 31 December 2017 (129 years) was obtained from the DSITIA Data Drill service. This data set is corrected for accumulated daily rainfall totals and missing data.

Given the long mine life (79 years), a stochastic rainfall data set based on the DataDrill rainfall data using the Stochastic Climate Library (SCL) software which forms part of the eWater CRC catchment modelling toolkit has been generated. The SCL User Guide (SCL, 2004) explains stochastic climate data as follows:

"In short, stochastic climatic data are random numbers that are modified so that they have the same characteristics (in terms of mean, variance, skew, long-term persistency, etc…) as the historical data from which they are based. Each stochastic replicate (sequence) is different and has different characteristics compared to the historical data, but the average of each characteristic from all stochastic replicates is the same as the historical data.

Using historical climate data as inputs into hydrological models provides results that are based on only one realization of the past climate. Stochastic climate data provide alternative realizations that are equally likely to occur and can therefore be used as inputs into hydrological and ecological models to quantify uncertainty in environmental system associated with climate variability."

Using the SCL, 100 replicates of a 79-year rainfall sequence have been generated for use in the water balance model. The model generates 100 sets of results (or realisations) that reflect the variation in the historical rainfall data (1939 to 2017).

The annual rainfall totals for each year of the DataDrill rainfall dataset have been ranked and compared against the 100 replicates generated by the SCL program and is presented in Figure 5-8.

Review of Figure 5-8 shows that the stochastically generated annual rainfall totals appears to consistently represent (with variation) the historical rainfall dataset, with a few outliers at the low end of the probability curve.

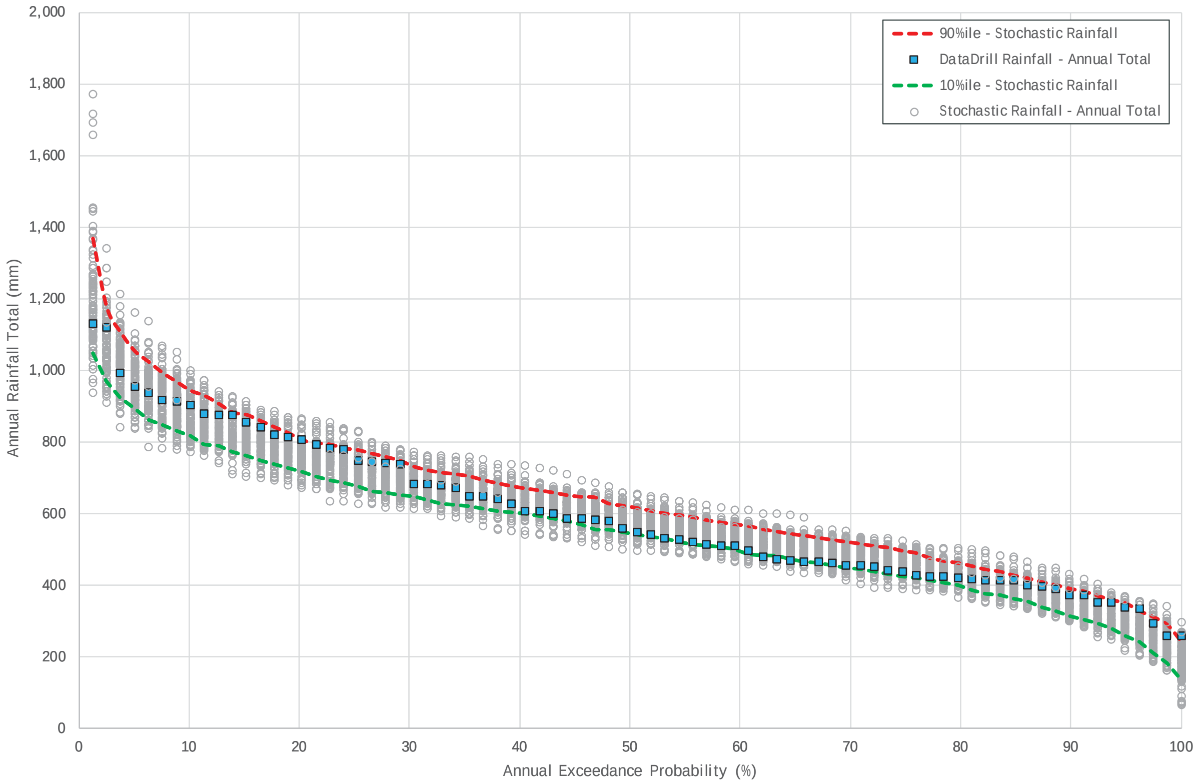

Figure 5-8: Comparison of DataDrill vs Stochastic Rainfall Data

5.2.2.2 *Evaporation*

Morton's equation for Lake evaporation has been used to estimate evaporation losses from storages. Table 5-4 shows the long-term monthly averages for Morton's Lake evaporation and DataDrill rainfall.

Figure 5-9 shows the annual distribution of monthly rainfall and Morton's Lake evaporation. Average annual lake evaporation is more than three times the average annual rainfall.

Table 5-4: Long-term Average Rainfall and Evaporation – DataDrill (1889-2017)

Month	SILO DataDrill Rainfall (mm)	Morton's Lake Evaporation (mm)
January	111.2	201.2
February	96.6	169.9
March	66.2	170.0
April	30.9	134.6
May	27.6	104.1
June	30.7	83.0
July	21.4	93.3
August	19.7	120.3
September	17.2	153.2
October	31.6	190.0
November	52.0	200.7
December	85.8	212.2
TOTAL	**591**	**1,833**

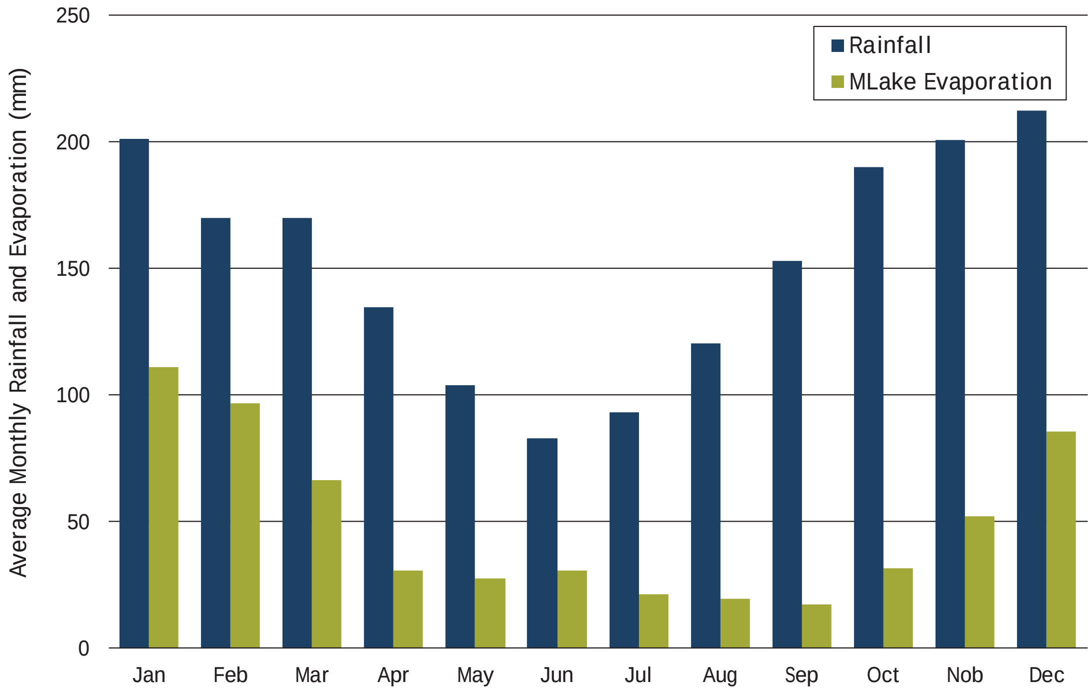

Figure 5-9: Distribution of Monthly Rainfall and Evaporation – DataDrill (1889-2017)

Estimates of soil moisture evapotranspiration and open pit evaporation have been derived through the application of the following factors:

- AWBM Evapotranspiration Factor: 0.97
- Open Pit Evaporation Factor: 0.70

5.3 Streamflows

5.3.1 DNRME Streamflow Gauges

There are five DRNME streamflow gauges located upstream of the Project receiving waters. Of these, three are located on the Isaac River itself (at Burton Gorge, Goonyella and Deverill). The gauge at Burton Gorge is not operational.

The other two are located on Phillips Creek and Scotts Creek, however these gauges are no longer operational. The details and locations of these gauges are provided in Table 5-5 and Figure 5-10.

The nearest downstream gauge on the Isaac River is located at Yatton. The details of this gauge are provided in Table 5-5.

Table 5-5: DNRME Stream Gauges Along the Isaac River

Gauge No.	Gauge Name	Stream	AMTD (km)	Catchment Area (km^2)	Distance from Project (km)	Start	End
130402A	Burton Gorge	Isaac R	208.3	551	63	01/05/1964	30/09/1988
130414A	Goonyella	Isaac R	242.8	1,214	50	24/05/1983	-
130410A	Deverill	Isaac R	174.7	4,092	adjacent to Project	20/05/1968	-
130401A	Yatton	Isaac R	43.0	19,720	60	01/10/1962	-
130409A	Tayglen	Phillips Ck	34.3	344	24	18/05/1968	27/10/1988
130415A	Norwich Park	Scotts Ck	25.0	388	37	20/10/1972	28/02/1988

Historical flow and river height monitoring data (1968-2018) for the Isaac River at Deverill (DNRME monitoring station 130410A), located to the north-west of the Project area, provides an indication of the local flow regime (refer Figure 5-11). Surveyed cross section data for this gauging station in September 2014 (DNRME, 2017a) indicates that sediment covers the bottom one metre of the gauge range. The mean river height data shown in Figure 5-11 suggests that surface flow above the sand is more likely to occur only in the wetter months from November to April, reducing to shallow subsurface flows from about May to October in an average year.

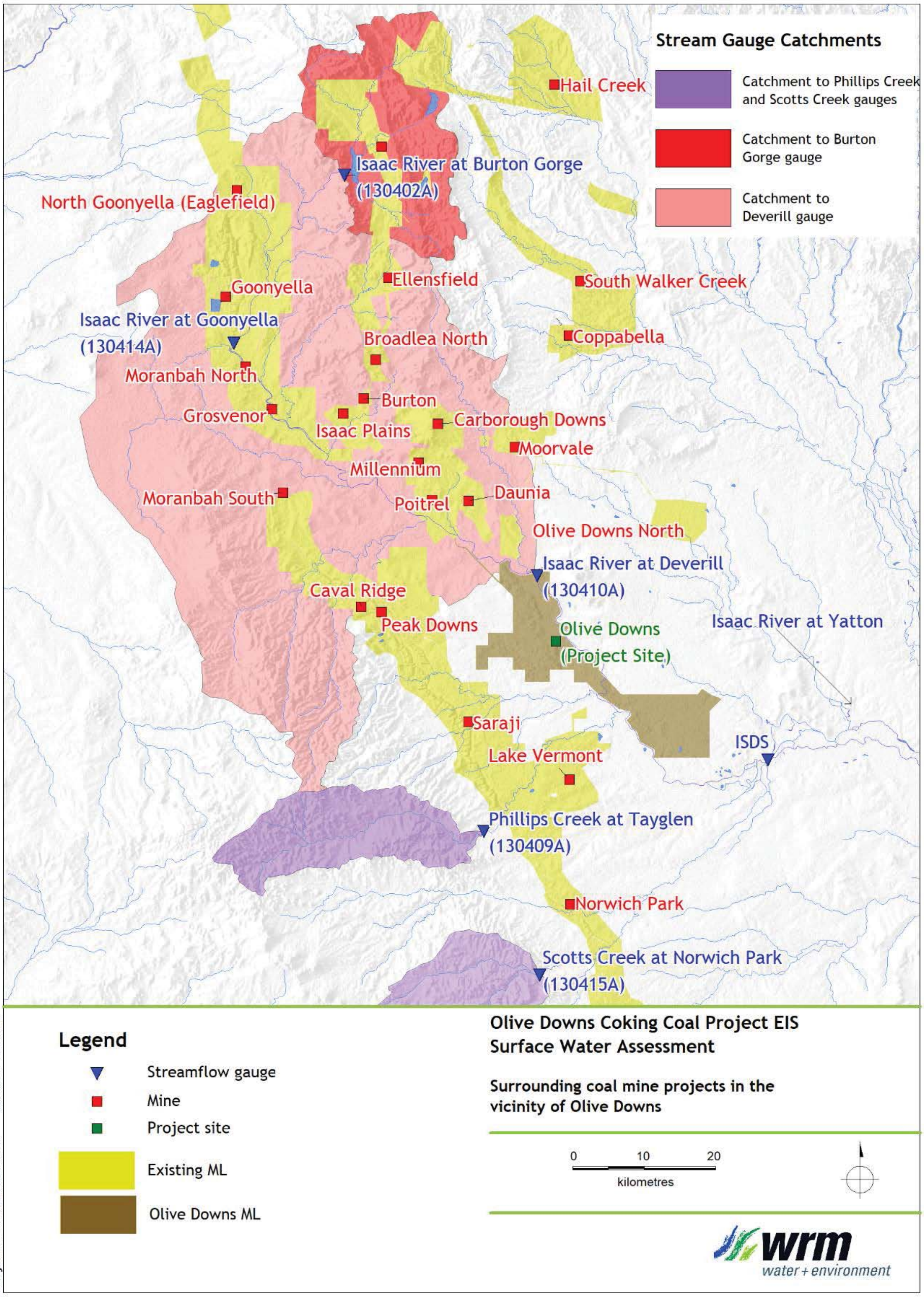

Figure 5-10: DNRME streamflow gauges and other coal mine projects in the vicinity of the Project

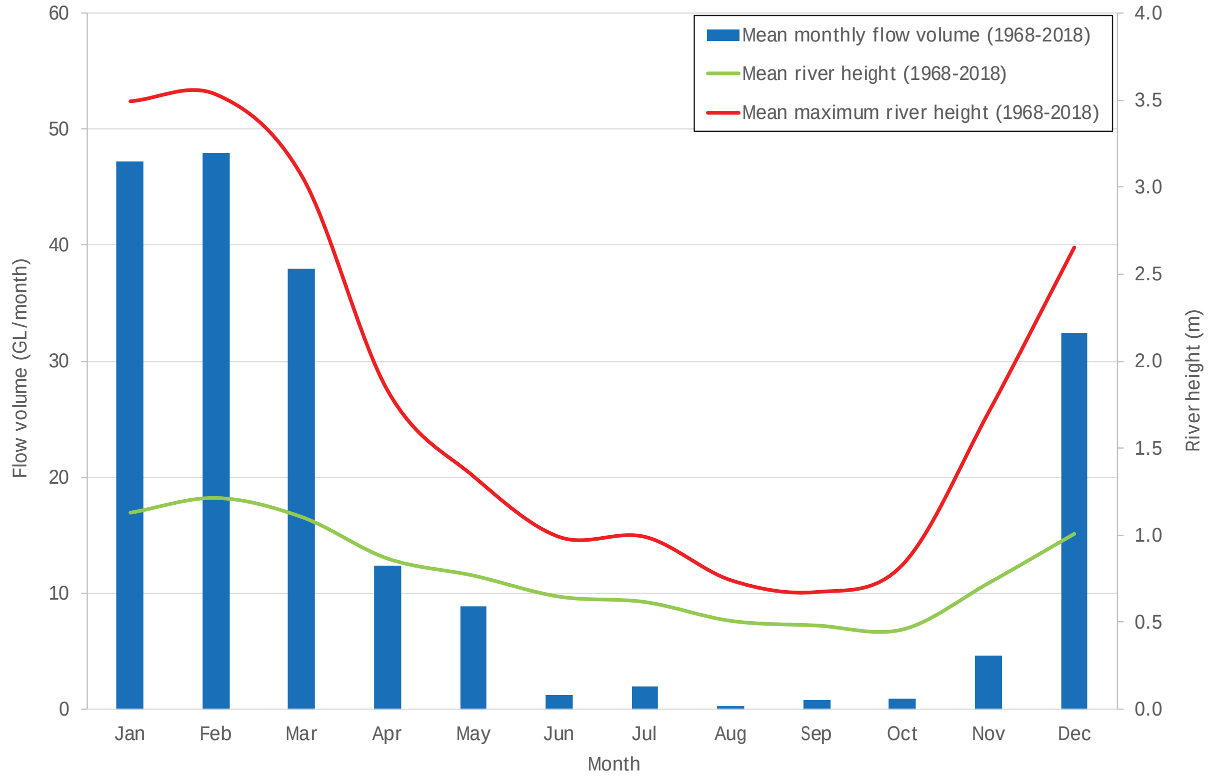

Figure 5-11: Flow Volume and River Height in the Isaac River at Deverill (DNRME station 130410A, located to the northwest of the Project area)

5.3.2 *ISDS Data*

Pembroke installed a monitoring station on the Isaac River, downstream of the Project area, named "ISDS", to collect baseline water quality and flow information. The monitoring station, shown in Figure 5-10 and Figure 5-14, is located to the west of the Fitzroy Development Road Bridge and was commissioned in December 2016.

The monitoring station was installed in compliance with the relevant manuals, standards and guidelines. It continuously records water level, pH, EC and water temperature, and converts water level to discharge using a rating curve developed by Hatch. The station is included in the bi-monthly maintenance and calibration schedule along with all other Project surface water monitoring stations.

Sub-daily monitoring data has been recorded from 22 December 2016 and most recently downloaded on 29 June 2018. The recorded Isaac River flow data is displayed in Figure 5-12.

Figure 5-12 shows that there have been 5 flow events recorded (with a peak flow greater than 1 m^3/s) since installation, with the highest recorded discharge of 804 m^3/sec occurring in March 2017. Data has been omitted from the 29th of March at 4:20pm to the 1st of April at 1:00pm due to an error in the monitoring station. The flow increased instantaneously from a value of 804 m^3/s to 7,999 m^3/s which has been deemed an error in the gauge. This error has been attributed to the effects of Cyclone Debby which occurred late March 2017.

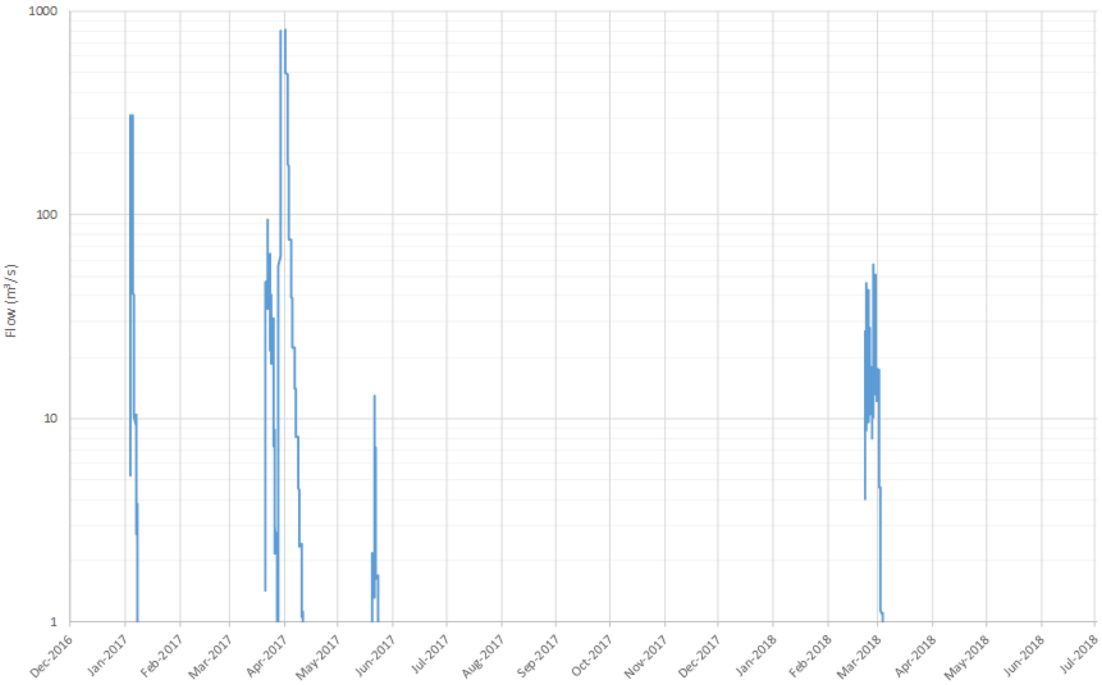

Figure 5-12: ISDS Gauge Recorded Flow Rate

5.3.3 Watercourse Classification

The Queensland Wetlands Map 2009 (DSITI 2015) identifies riverine systems, watercourses, waterways or drainage lines (here referred to collectively as waterways) for the Project area.

There are 21 waterways mapped for the Study area, including:

- 16 waterways of (Strahler) stream order one;
- three waterways of stream order two;
- one waterway of stream order three (Ripstone Creek); and
- one waterway of stream order six (the Isaac River).

The DNRME (2017) watercourse identification map identifies the Isaac River and Ripstone Creek as waterways that exhibit the characteristics of a watercourse as defined by the Water Act 2000 (refer Section 3.2.2), as well as several smaller waterways corresponding with the Queensland Wetland Map 2009 (DSITI, 2015).

The nearby waterways of Phillips Creek and Boomerang Creek have also been identified as watercourses. The other waterways are classified as drainage features that facilitate overland flow.

5.3.3.1 *Drainage Line 1 Determination*

Drainage Line 1 is located within MLA700036, at the north-eastern extent of the ODS Domain on the eastern side of the Isaac River. Pembroke recently sought a watercourse determination from the DNRME for this drainage line. In a letter dated 21 June 2018, the DNRME confirmed that Drainage Line 1 is not a watercourse, rather it is a drainage feature as defined under the Water Act 2000 that facilitates overland flow (DNRME, 2018).

5.3.4 Geomorphology

A geomorphological characterisation of the Project study area has been undertaken by Fluvial Systems (Fluvial Systems, 2018). A summary of the assessment is as follows:

- Repeatable field and desktop methods were used to characterise geomorphological attributes of the Project study area. Most of the stream reaches were in a stable, close to natural geomorphic condition. Some streams were potentially impacted by factors that reduced their condition, in particular high loads of sand in the bed, but without historical data concerning condition prior to the land cover and drainage being modified for agricultural and mining use, this remains uncertain. No knickpoints or zones of major geomorphic instability were observed.
- The risk of erosion of the Isaac River channel and floodplain was assessed using the method of maximum permissible bed shear stress and velocity assessment, with the hydraulic variables modelled as part of the flood study. This assessment of the most critical areas found that while there could be isolated areas subject to somewhat higher risk of scour compared to the existing situation, the overall risk of rapid and significant geomorphic change in the Isaac River due to the proposed mining activity was low.
- Geomorphic monitoring should include topographic survey of Isaac River channel and floodplain, repeated every year for 3 years, and then either every five years, or after every flood event exceeding the 5 year ARI (20% AEP) event. This should be done using LiDAR technology, flown when the flow is very low. A Before-After, Control-Intervention monitoring design should be used, with tolerable limits of change in the intervention reaches set by the observed degree of change in control reaches.
- Mitigation measures would be triggered by unexpectedly large change in channel morphology identified through monitoring. The most appropriate response would need to be assessed at the time.

Refer to Attachment A for the full geomorphological assessment report.

5.4 Water Quality

Water quality monitoring results for the area surrounding the Project area are available from a number gauging stations, in addition to the baseline monitoring that has been undertaken by Pembroke. Details on the various gauges are displayed in Table 5-6 and their locations are shown in Figure 5-13 and Figure 5-14.

Table 5-6: Water Quality Data Monitoring Locations

Site Name	Watercourse	Location		Data Source	Duration of Record	No. of Samples	Analytes
		Lat. (decimal degrees)	Long. (decimal degrees)				
Deverill	Isaac River (US of Project Area)	-22.17	148.35	DNRME	6 Jul 1964 – 24 Nov 2016	50	Range[1]
Red Hill Mine Lower Isaac	Isaac River (US of Project Area)	-21.87	147.97	BMA (Red Hill Mining Lease EIS)	14 Nov 2010 – 4 Apr 2011	51	Range[2]
Red Hill Mine Upper Isaac	Isaac River (US of Project Area)	-21.80	147.99	BMA (Red Hill Mining Lease EIS)	18 Nov 2010 – 4 Apr 2011	45	
Riverine 1 (R1)	Unnamed tributary of the Isaac River	-22.42	148.60	DPM Aquatic Ecology Data	12 Dec 2016	1	Temp, EC, pH, DO, Turbidity
Riverine 2 (R2)	Isaac River	-22.40	148.53	Pembroke (EDM Aquatic Ecology Report)	14 Dec 2016	1	
Riverine 3 (R3)	Unnamed tributary of Ripstone Creek	-22.31	148.44	Pembroke (EDM Aquatic Ecology Report)	17 Dec 2016 – 8 Jul 2017	2	
Riverine 4 (R4)	Unmapped riverine wetland	-22.28	148.44	DPM Aquatic Ecology Data	7 Jul 2017	1	
Riverine 5 (R5)	Ripstone Creek	-22.28	148.37	DPM Aquatic Ecology Data	6 Jul 2017	1	
Riverine 6 (R6)	Isaac River	-22.27	148.46	Pembroke (EDM Aquatic Ecology Report)	14 Dec 2016 – 9 Jul 2017	2	
Riverine 7 (R7)	Unnamed tributary of the Isaac River	-22.18	148.37	DPM Aquatic Ecology Data	4 Jul 2017	1	
Riverine 8 (R8)	Isaac River	-22.32	148.47	Pembroke (EDM Aquatic Ecology Report)	16 Dec 2016 – 10 Jul 2017	2	
Lake Vermont (AQ3)	Phillips Creek	-22.46	148.36	Lake Vermont Resources Pty Ltd (ARC)	13 - 16 May 2013	1	Range[3]
Lake Vermont (AQ4)	Phillips Creek	-22.39	148.42	Lake Vermont Resources Pty Ltd (ARC)	13 - 16 May 2013	1	Range[3]
Lake Vermont (MP3)	Isaac River (DS of Project Area)	-22.39	148.42	Lake Vermont Resources Pty Ltd (ARC)	13 - 16 May 2013	1	Range[3]
Olive Downs ISDS	Isaac River (DS of Project Area)	-22.42	148.70	Pembroke (Gauge)	22 Dec 2016 – 15 Nov 2017	Continuous monitoring station	pH, EC and Temp
SW1 (original)	Isaac River	-22.15	148.34	Pembroke (Gauge)	15 Aug 2017 – 14 Sep 2017	6	Range[4]
SW1 (new)		-22.16	148.35				
SW2	Isaac River	-22.16	148.37	Pembroke (Gauge)	19 Jul 207 – 14 Sep 2017	8	Range[4]
SW3	Isaac River	-22.17	148.38	Pembroke (Gauge)	15 Aug – 14 Sep 2017	10	Range[4]

Site Name	Watercourse	Location		Data Source	Duration of Record	No. of Samples	Analytes
		Lat. (decimal degrees)	Long. (decimal degrees)				
SW4 (original)	Ripstone Creek	-22.26	148.32	Pembroke (Gauge)	20 Jul 2017	1	Range[4]
SW4 (new)		-22.26	148.33				
SW6	Ripstone Creek	-22.31	148.40	Pembroke (Gauge)	20 Jul 2017	1	Range[4]
SW8	Isaac River (DS of Boomerang Creek)	-22.33	148.46	Pembroke (Gauge)	20 Jul 2017	1	Range[4]
SW11 (original)	Isaac River	-22.42	148.54	Pembroke (Gauge)	13 Sep 2017	5	Range[4]
SW11 (new)		-22.45	148.56				
SW12	Isaac River	-22.42	148.70	Pembroke (Gauge)	13 Sep 2017	7	Range[4]

Range 1: Conductivity @ 25C , Turbidity, Colour True, pH, Total Alkalinity as CaCO3, Hydroxide as OH, Carbonate as CO3, Bicarbonate as HCO3, Hardness as CaCO3, Hydrogen as H, Total Dissolved Solids, Total Dissolved Ions, Total Suspended Solids, Calcium as Ca soluble, Chloride as Cl, Magnesium as Mg soluble, Nitrate as NO3, Total Nitrogen, Organic Nitrogen, Nitrate + nitrite as N soluble, Ammonia as N – soluble, Oxygen (Dissolved), Total Phosphorus as P, Total React P, Potassium as K, Sodium as Na, Sulphate as SO4, Aluminium as Al soluble, Boron as B, Copper as Cu soluble, Fluoride as F, Iron as Fe soluble, Manganese as Mn soluble, Silica as SiO2 soluble, Zinc as Zn soluble.

Range 2: Total Aluminium, Total Ammonia, Total Antimony, Total Arsenic, Total Barium, Total Beryllium, Total Boron, Total Cadmium, Total Calcium, Total Chloride, Total Chromium, Total Copper, Total Cyanide, Total Fluoride, Total Iron, Total Lead, Total Magnesium, Total Manganese, Total Mercury, Total Molybdenum, Total Nickel, Total Nitrate, Total Nitrite, Total Oxygen, pH, Total Potassium, Total Selenium, Total Sodium, Total Sulphate, Total Zinc, Total Ammonium, Chlorophyll a, Filterable Reactive Phosphorous, Electrical Conductivity, Total Nitrogen, Total Phosphorus, Total Dissolved Solids, Total Suspended Solids, Turbidity, Cobalt, Dissolved Aluminium, Dissolved Antimony, Dissolved Arsenic, Dissolved Beryllium, Dissolved Boron, Dissolved Cadmium, Dissolved Calcium, Dissolved Chromium, Dissolved Copper, Dissolved Iron, Dissolved Lead, Dissolved Magnesium, Dissolved Manganese, Dissolved Mercury, Dissolved Molybdenum, Dissolved Nickel, Dissolved Potassium, Dissolved Selenium, Dissolved Zinc, Oil and Grease, MBAS, Chemical Oxygen Demand, Bicarbonate Alkalinity, Total Alkalinity, C6-C9, C10-C14, C15-C28, C29-C36, BOD, C10-C36 Fraction, NO2+NO3, Orthophosphate as P, Dissolved Cobalt, Total Silver, Dissolved Silver, Dissolved Uranium, Total Uranium, Dissolved Vanadium, Total Vanadium.

Range 3: pH, EC, DO, Total Alkalinity, Turbidity, Sulphate (SO42-), Suspended Solids, Sodium, Total Chloride, Ammonia, Total Nitrogen, Total Phosphorus, Oxidised N, Aluminium, Arsenic, Boron, Cadmium, Cobalt, Chromium, Copper, Manganese, Nickel, Lead, Vanadium, Zinc, Molybdenum, Selenium, Silver, Iron, Uranium, Mercury, Total Aluminium, Total Arsenic, Total Boron, Total Cadmium, Total Cobalt, Total Chromium, Total Copper, Total Manganese, Total Nickel, Total Lead, Total Vanadium, Total Zinc, Total Molybdenum, Total Selenium, Total Silver, Total Iron, Total Uranium, Total Mercury.

Range 4: 1.2-Dichloroethane-D4 %, 4-Bromofluorobenzene %, >C10 - C16 Fraction, >C10 - C16 Fraction minus Naphthalene (F2), >C10 - C40 Fraction (sum), >C16 - C34 Fraction, >C34 - C40 Fraction, Dissolved Aluminium, Total Aluminium, Ammonia as N, Dissolved Arsenic, Total Arsenic, Benzene, Dissolved Boron, Total Boron, C10 - C14 Fraction, C10 - C36 Fraction (sum), C15 - C28 Fraction, C29 - C36 Fraction, C6 - C10 Fraction, C6 - C10 Fraction minus BTEX (F1), C6 - C9 Fraction, Dissolved Cadmium, Total Cadmium, Dissolved Chromium, Total Chromium, Dissolved Cobalt, Total Cobalt, Dissolved Copper, Total Copper, Dissolved Oxygen % saturation, Dissolved Oxygen, Electrical Conductivity (Temperature Compensated), Electrical Conductivity (Non Compensated), Ethylbenzene, Fluoride, Dissolved Iron, Total Iron, Dissolved Lead, Total Lead, Dissolved Manganese, Total Manganese, Dissolved Mercury, Total Mercury, meta- & para-Xylene, Dissolved Molybdenum, Total Molybdenum, Naphthalene, Dissolved Nickel, Total Nickel, Nitrate as N, Nitrite + Nitrate as N, Nitrite as N, ortho-Xylene, pH, Reactive Phosphorus as P, Dissolved Selenium, Total Selenium, Dissolved Silver, Total Silver, Dissolved Sodium, Sulfate as SO4 - Turbidimetric, Sum of BTEX, Suspended Solids (SS), Temperature, Toluene, Toluene-D8 %, Total Hardness as CaCO3, Total Kjeldahl Nitrogen as N, Total Nitrogen as N, Total Phosphorus as P, Total Xylenes, Turbidity, Dissolved Uranium, Total Uranium, Dissolved Vanadium, Total Vanadium, Dissolved Zinc, Total Zinc.

Range 5: pH, Conductivity, Total Suspended Solids, Total Iron, Total Sodium, Total Potassium, Total Calcium, Total Magnesium, Total Chloride, Total Sulphate, Total Fluoride, Total Manganese, Total Aluminium, Total Boron, Total Cadmium, Total Copper, Total Lead, Total Zinc.

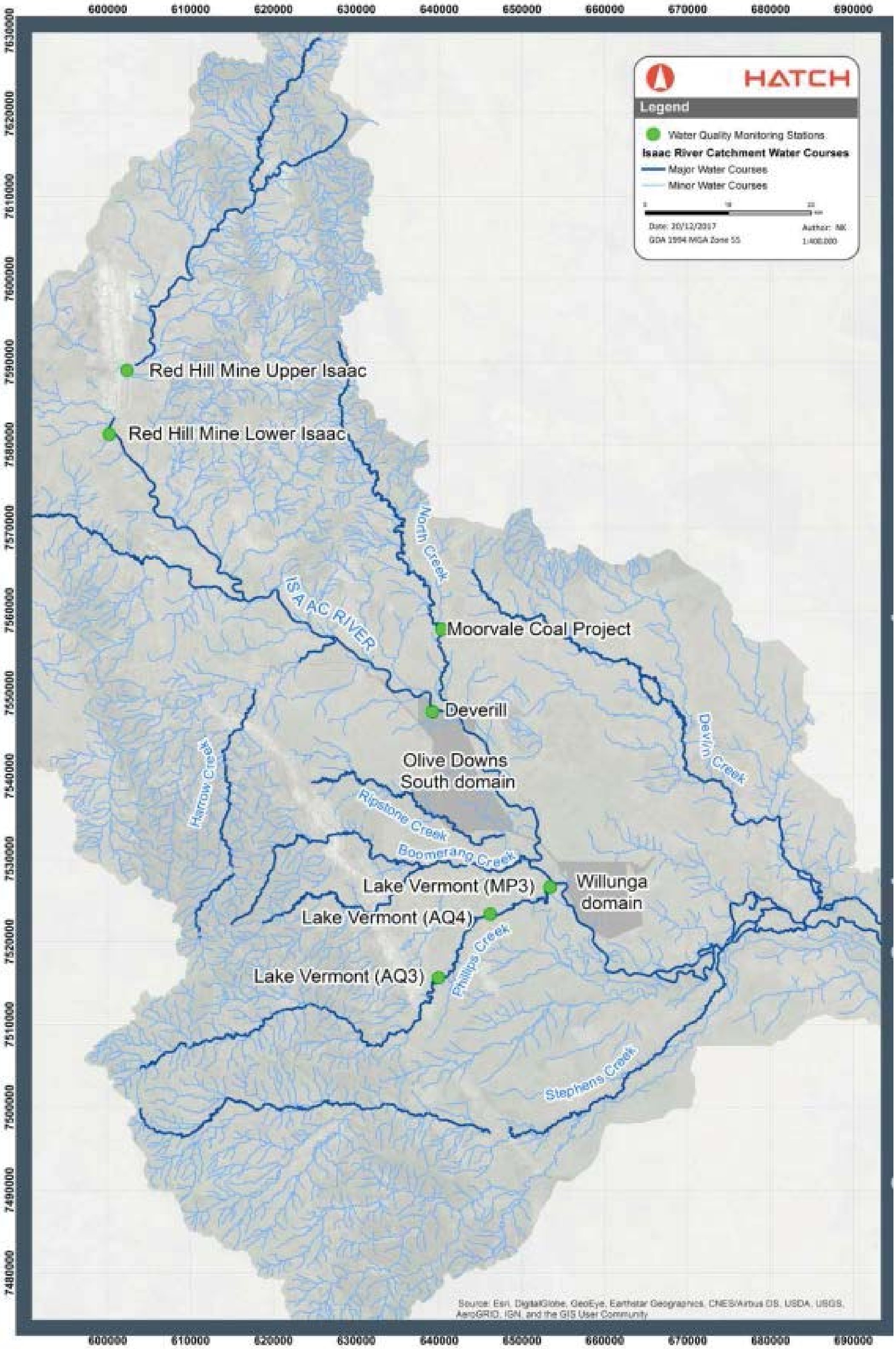

Figure 5-13: Regional Water Quality Monitoring Locations

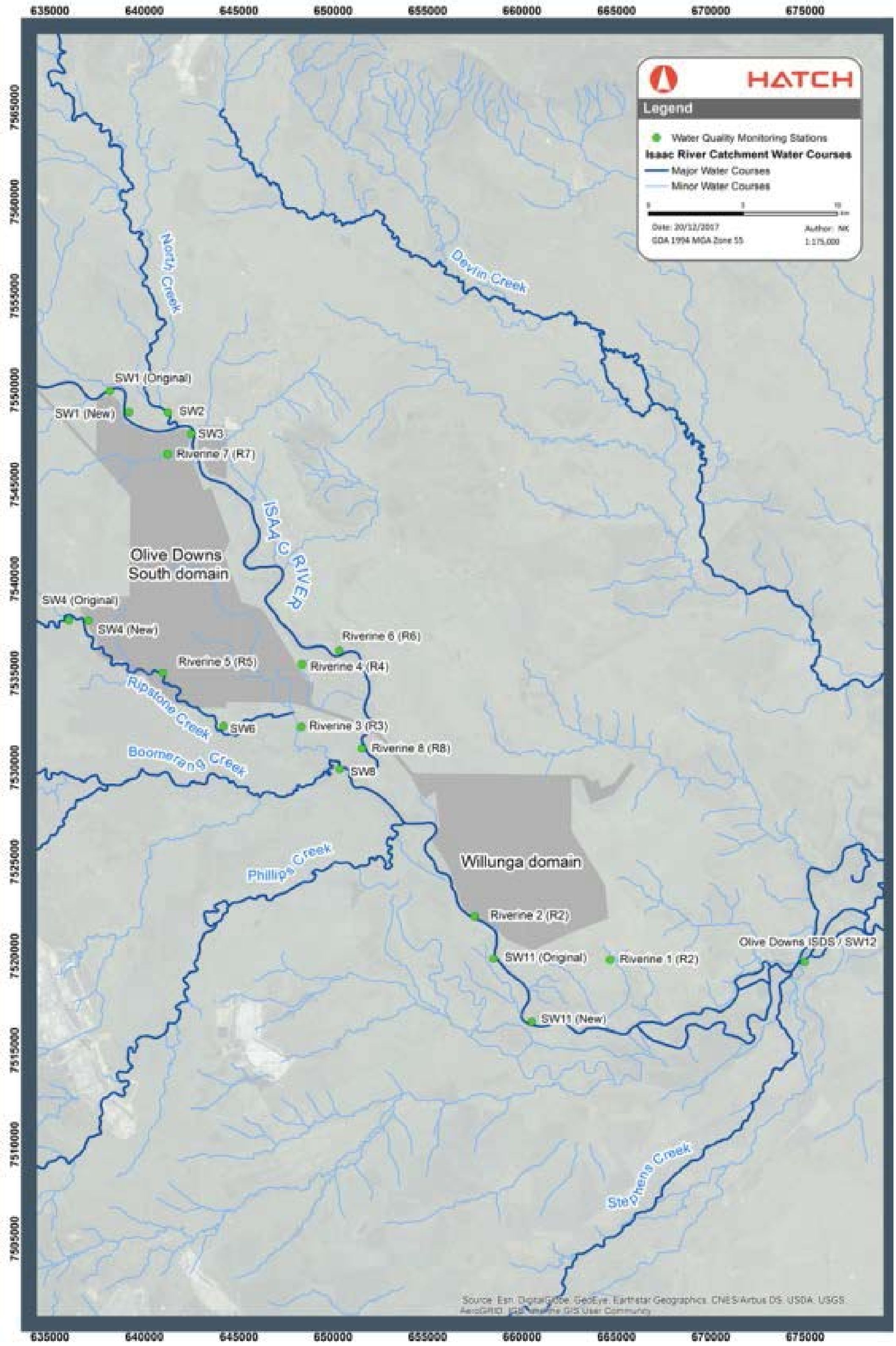

Figure 5-14: Local Water Quality Monitoring Locations

5.4.1 *Regional Water Quality*

Publicly available regional water quality data for the Isaac River at the Deverill Gauging Station and at Red Hill Mining Lease (Lower and Upper Isaac River locations) have been analysed and a comparison of median water quality at these sites are displayed in Table 5-7. These sites were selected as complete datasets (i.e. individual sample analysis results) are publicly available as opposed to only summary data being publicly available.

The Red Hill stations are located downstream of the Goonyella, North Goonyella, Broadlea and Burton mines and therefore includes mine release water quality. It is also about 80 km upstream of the Project. However, it provides an indication of water quality and in particular metal toxicants in the Isaac River at this location.

Review of Table 5-7 shows that some readings at the Red Hill Mining Lease are at or above the regional WQO. These include the following:

- Total aluminium (1.7 times higher than the WQO for stock watering)
- Dissolved aluminium (13 times higher than the WQO for aquatic ecosystems)
- Total cobalt (70 times higher than the WQO for irrigation)
- Total iron (1.1 times higher than the WQO for irrigation)
- Total suspended solids (7 times higher than the WQO for aquatic ecosystems)
- Turbidity (12 times higher than the WQO for aquatic ecosystems).

Based on the limited data set available at Deverill, there was an exceedance of dissolved zinc (1.3 times higher than the WQO for aquatic ecosystems), as well as exceedances of total suspended solids and turbidity.

Table 5-7: Regional Water Quality Monitoring Data Summary

Parameter	Unit	Isaac River at Deverill	Red Hill Mining Lease Lower Isaac	Red Hill Mining Lease Upper Isaac	WQO (refer Table 4-1)
Aluminium - Total	mg/L	-	8.5	8.5	< 5 (stock)
Aluminium - Dissolved	mg/L	0.05	0.42	0.405	< 0.055 (aquatic)
Ammonia - Total	µg/L	-	0.01	0.02	< 20 (aquatic)
Arsenic - Total	mg/L	-	0.0025	0.0025	<2.0 (irrigation) < 0.5 (stock)
Arsenic - Dissolved	mg/L	-	0.0005	0.0005	< 0.024 (aquatic)
Beryllium - Total	mg/L	-	0.0025	ND	< 0.5 (irrigation)
Beryllium - Dissolved	mg/L	-	0.0025	ND	-
Boron - Total	mg/L	0.06	0.05	0.05	< 5 (stock)
Boron - Dissolved	mg/L	-	0.04	0.04	< 0.37 (aquatic)
Cadmium - Total	mg/L	-	0.00025	0.00025	< 0.01 (stock)
Cadmium - Dissolved	mg/L	-	0.00005	0.00005	<0.0002 (aquatic)
Cobalt - Total	mg/L	-	7	6	< 0.1 (irrigation)
Cobalt - Dissolved	mg/L	-	0.0005	0.0005	-
Calcium - Dissolved	mg/L	16	ND	ND	-
BOD	mg/L	-	0.001	0.001	-

Parameter	Unit	Isaac River at Deverill	Red Hill Mining Lease Lower Isaac	Red Hill Mining Lease Upper Isaac	WQO (refer Table 4-1)
C6-C9	mg/L	-	0.025	0.025	-
C10-C14	mg/L	-	0.025	0.025	-
C15-C28	mg/L	-	0.1	0.1	-
C29-C36	mg/L	-	0.025	0.025	-
C10-C36 Fraction	mg/L	-	0.1	0.1	-
Chemical Oxygen Demand	mg/L	-	33	31.5	-
Chloride - Total	mg/L	32	Non-Detect (ND)	ND	-
Chlorophyll a	µg/L	-	ND	ND	< 5 (aquatic)
Chromium - Total	mg/L	-	0.016	0.015	< 1 (stock)
Chromium – Dissolved	mg/L	-	0.0005	0.0005	< 0.001 (aquatic)
Copper - Total	mg/L	-	0.011	0.011	<1 (stock)
Copper - Dissolved	mg/L	0.03	0.003	0.002	< 0.0014 (aquatic)
EC	µS/cm	261	220	170	< 720 (baseflow) < 250 (high flow)
Filterable Reactive Phosphorus	µg/L	0.35	0.43	0.294	< 20 (aquatic)
Fluoride - Total	mg/L	0.14	0.1	0.1	< 2 (irrigation)
Iron - Total	mg/L	-	11	11	< 10 (irrigation)
Iron - Dissolved	mg/L	0.06	0.24	0.26	-
Lead – Total	mg/L	-	0.005	0.006	< 0.1 (stock)
Lead - Dissolved	mg/L	-	0.0005	0.0005	< 0.0034 (aquatic)
Magnesium - Total	mg/L	-	0.273	ND	-
Manganese - Dissolved	mg/L	0.01	0.002	0.0025	< 1.9 (aquatic)
Manganese - Total	mg/L	-	0.251	0.261	< 10 (irrigation)
Mercury - Total	mg/L	-	0.00005	0.00005	< 0.002 (irrigation)
Mercury - Dissolved	mg/L	-	0.00005	0.00005	< 0.00006 (aquatic)
Molybdenum - Total	mg/L	-	0.0025	0.0025	< 0.05 (irrigation)
Molybdenum - Dissolved	mg/L	-	0.001	0.0005	-
Nickel - Total	mg/L	-	0.019	0.015	< 1 (stock)
Nickel - Dissolved	mg/L	-	0.002	0.002	< 0.005 (aquatic)
Nitrate - Total	mg/L	1.4	0.05	0.02	-
Nitrogen – Total	µg/L	0.76	ND	ND	< 500 (aquatic)
NO2+NO3	mg/L	-	0.14	0.085	-
pH	-	7.6	7.8	7.8	6.5–8.5 (aquatic)
Phosphorus - Total	µg/L	0.35	ND	ND	< 50 (aquatic)
Potassium - Total	mg/L	4.55	ND	ND	-
Selenium - Total	mg/L	-	0.0025	0.0025	< 0.02 (stock)
Selenium - Dissolved	mg/L	-	0.0025	0.0025	< 0.005 (aquatic)
Silver - Total	mg/L	-	0.00025	0.00025	-
Silver - Dissolved	mg/L		0.00005	0.00005	-
Sodium - Total	mg/L	22	ND	ND	< 30 (drinking water)
Sulphate - Total	mg/L	10.9	0.0048	0.002	< 25 (aquatic)
Total Alkalinity	mg/L	78	ND	ND	-

Parameter	Unit	Isaac River at Deverill	Red Hill Mining Lease Lower Isaac	Red Hill Mining Lease Upper Isaac	WQO (refer Table 4-1)
Total Dissolved Solids	mg/L	155	254	200	< 2,000 (stock)
Total Suspended Solids	mg/L	135	380	340	< 55 (aquatic)
Turbidity	NTU	247	597	450	< 50 (aquatic)
Uranium - Total	mg/L	-	0.0005	0.0005	<0.1 (irrigation)
Uranium - Dissolved	mg/L	-	0.0002	0.0002	-
Vanadium - Total	mg/L	-	0.029	0.0265	<0.5 (irrigation)
Vanadium - Dissolved	mg/L	-	0.0025	0.0025	-
Zinc - Total	mg/L	-	0.03	0.024	< 5 (irrigation)
Zinc - Dissolved	mg/L	0.01	0.0025	0.0025	< 0.008 (aquatic)

The Department of Natural Resources Mines and Energy (DNRME) has collected daily electrical conductivity data at the Isaac River at the Deverill and Yatton gauges. Electrical conductivity, which is a measure of the salt concentration with the flows, has been used to define the potential water quality impacts of the Project. The Deverill gauge is located near the upstream boundary of the Project and would be representative of water quality that drains past the site. The Yatton gauge is located downstream of the Connors River confluence but includes mining releases from all mines within the Isaac River catchment.

Figure 5-15 presents a time history of recorded instantaneous EC and stream flow for the Isaac River at Deverill gauging station. Figure 5-16 details the relationship between instantaneous flow and EC at the Isaac River at Deverill gauging station. The data collected by DNRME at the Deverill gauging station spans the period from 2011 to 2018 and indicates:

- The EC for high flows greater than 200 m^3/s are generally below the high flow WQO EC of 250 μs/cm.
- The EC of instantaneous flows below 100 m^3/s vary significantly from 50 μS/cm to 1,870 μS/cm with many recorded values exceeding the low flow WQO EC of 720 μS/cm.
- The mean daily EC has exceeded the low flow WQO on a total of 23 days over this period and all of these days experienced some flow (not stagnant flow).
- The stream flows are highly ephemeral with baseflows ceasing within a few days or weeks of a runoff event, or at least flowing below the top of the sandy bed.

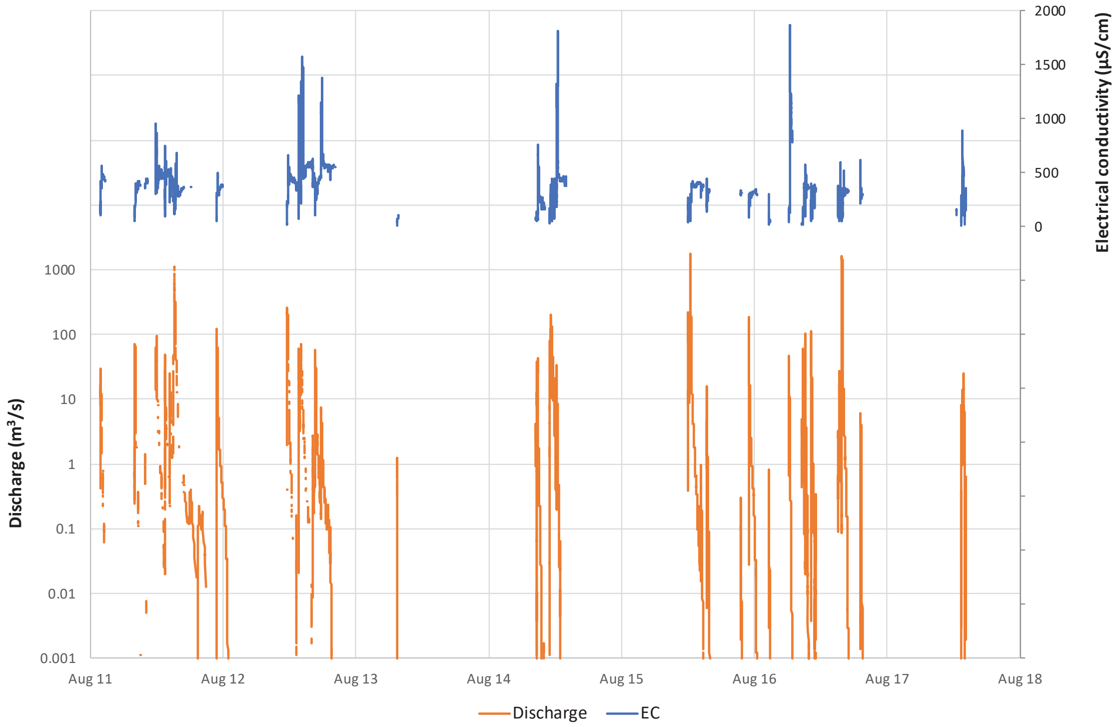

Figure 5-15: Electrical Conductivity and Flow (Isaac River at Deverill Gauge)

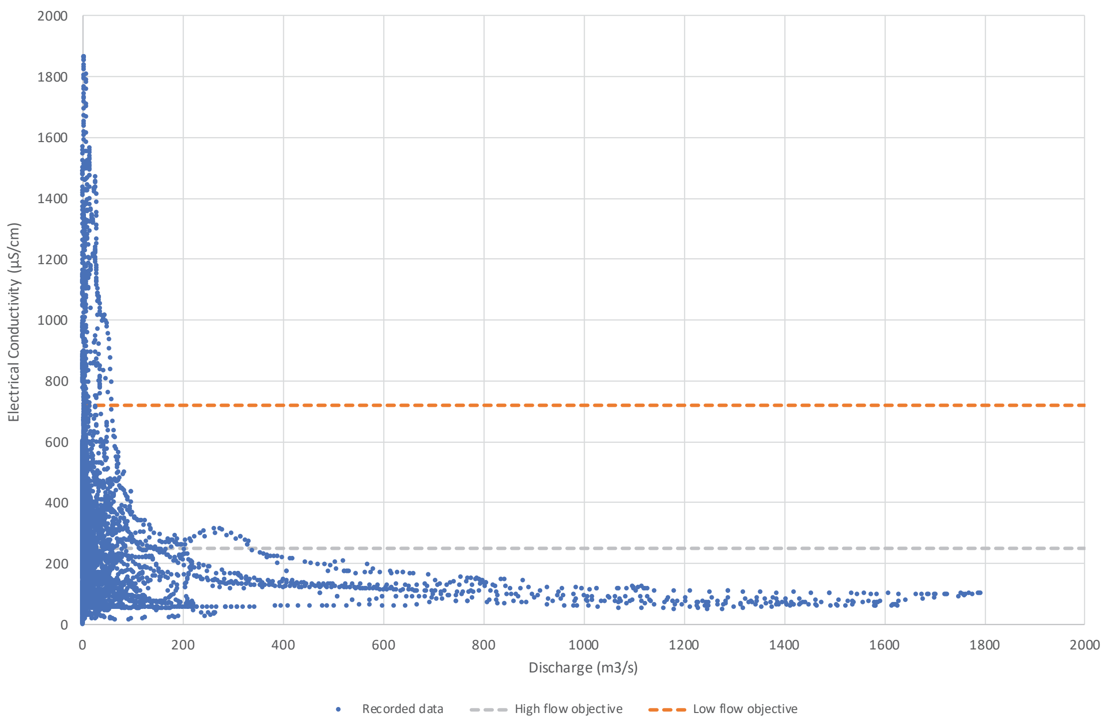

Figure 5-16: Flow vs Electrical Conductivity (Isaac River at Deverill Gauge)

Figure 5-17 presents a time history of recorded instantaneous EC and stream flow for the Isaac River at Yatton gauging station. Figure 5-18 details the relationship between instantaneous flow and EC at the Isaac River at Yatton gauging station recorded from 1995 to 2011 as well as from 2011 to 2018. The latter data period has been shown to provide a direct comparison with the period of record common with the Isaac River at Deverill gauge. The figures indicate:

- The EC for high flows greater than 200 m^3/s vary much more than at Deverill but are generally below 400 μs/cm.
- The high flow EC since 2011 has generally been below the high flow WQO.
- The low flow EC has frequently been above the low flow WQO of 410 μS/cm. Figure 5-17 shows that EC rises during extended baseflow periods, which would be associated with either the Connors River or an increase in baseflow in the reach between Deverill and Yatton gauges.
- The recorded low flow EC is generally less than at Deverill.

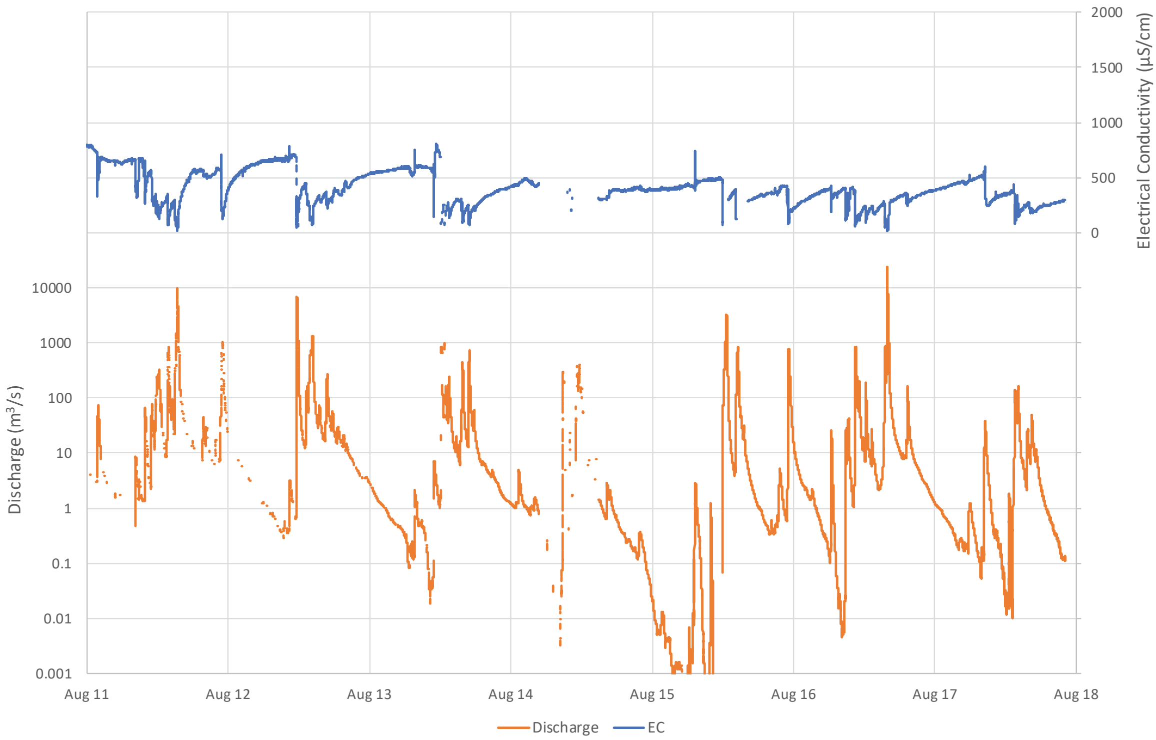

Figure 5-17: Electrical Conductivity and Flow (Isaac River at Yatton Gauge)

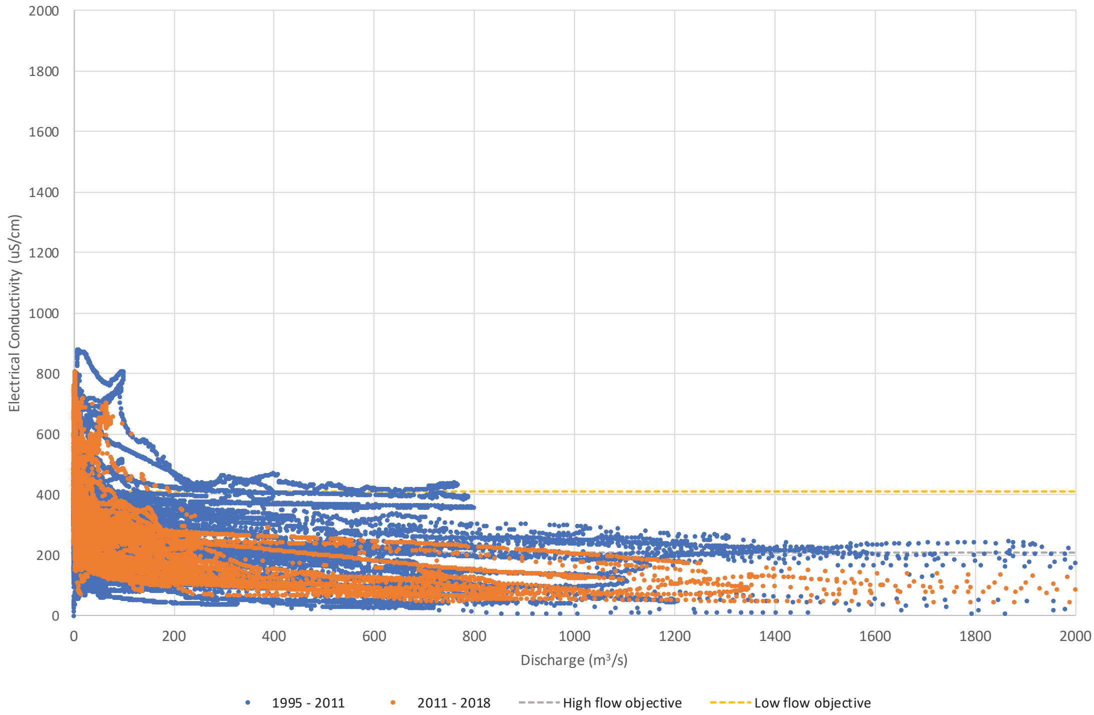

Figure 5-18: Flow vs Electrical Conductivity (Isaac River at Yatton Gauge)

5.4.2 ISDS Data

As mentioned in Section 5.3.2 Pembroke installed a monitoring station on the Isaac River, downstream of the Project area, named “ISDS”, to collect baseline water quality and flow information. Sub-daily monitoring data has been recorded from 22 December 2016 and most recently downloaded on 29 June 2018. The Isaac River flow discharge and its relationship with electrical conductivity and pH are displayed in Figure 5-19 and Figure 5-20 respectively.

Review of Figure 5-19 shows an increase in EC (above typical background levels) at the ISDS gauge starting from around 1 April 2017, continuing until 12 April. The recorded EC was within the Isaac River WQO’s (i.e. less than 720 µs/cm) for most of the event, however there was a period of elevated EC included a spike of around 3,100 µs/cm on 6 April 2017. This spike occurred for about 12 hours and was not recorded at the Deverill gauge.

The cause of this spike in EC is not known but may due to the release of water from an operating mine between the Deverill and ISDS gauges. According to the DEHP website (https://www.ehp.qld.gov.au/land/mining/water-releases), ten coal mines upstream of the ISDS gauge released to the Isaac River catchment during this period.

There was a second short period of elevated EC in May 2017 that exceed the Isaac River WQO’s. However, there were no recorded releases upstream of the gauge during this period.

This information shows that the water quality in the Isaac River during and after significant flow events has exceeded the Isaac River WQO's in the past for short periods of time. However, for the most part, the water quality in the Isaac River is within the WQO's.

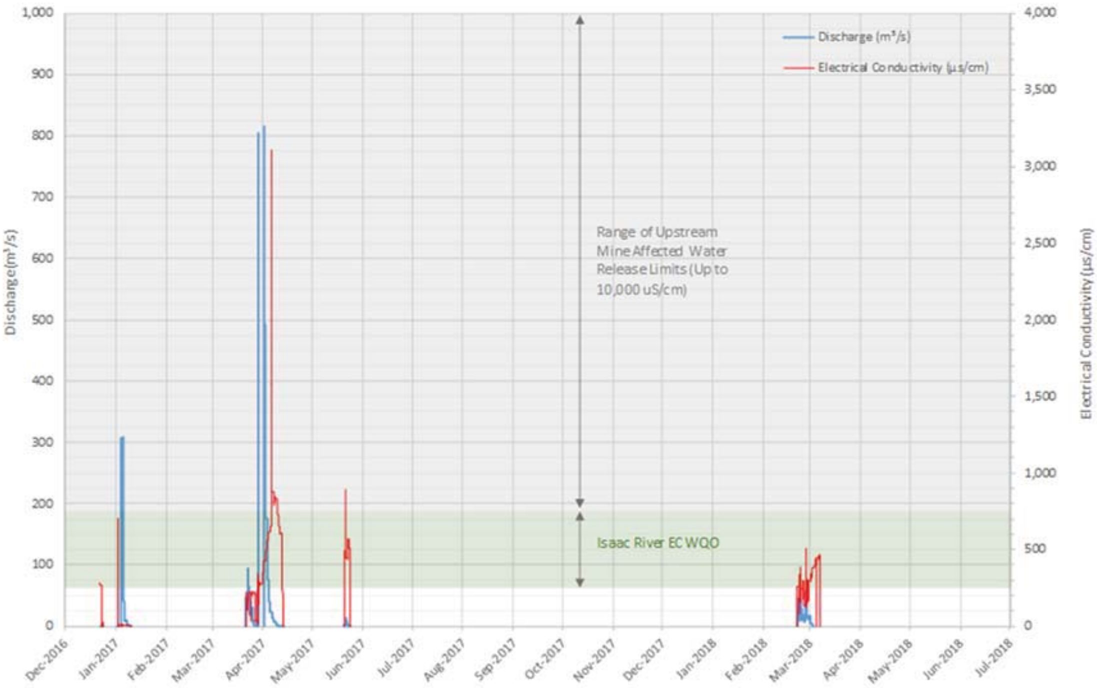

Figure 5-19: ISDS Flow and Electrical Conductivity

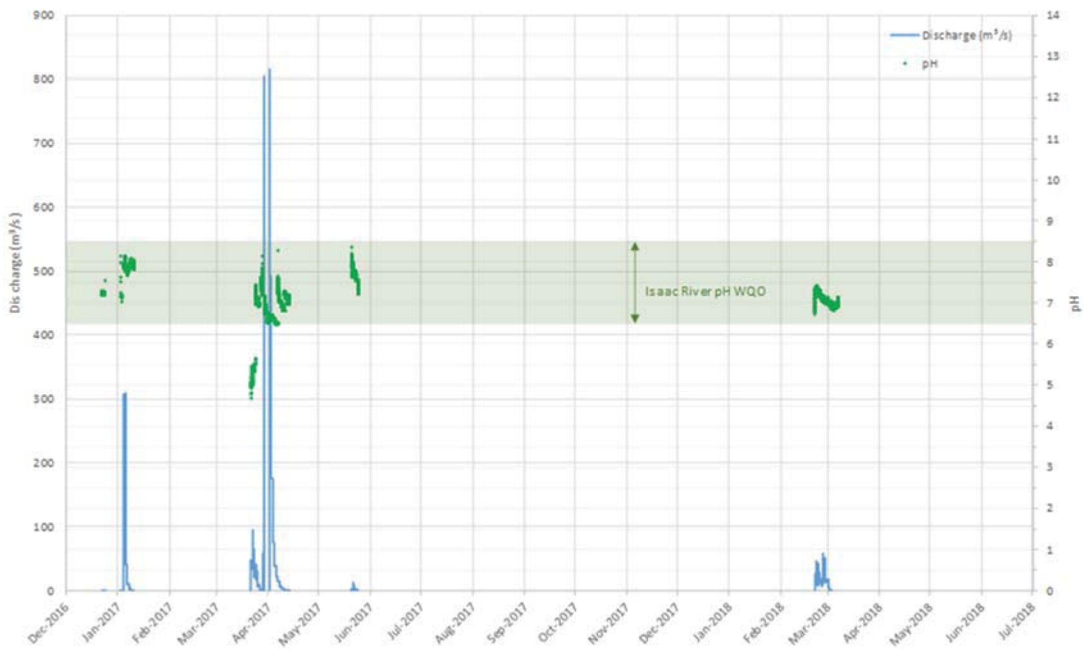

Figure 5-20: ISDS Flow and pH

5.4.2.1 *Olive Downs South Water Quality Data*

Water quality sampling was undertaken as a component of the baseline surface water quality sampling in between July 2017 and July 2018 for the Project. Analyses for a range of physio-chemical parameters were completed at sites SW1, SW2, SW3, SW4, SW6, SW8, SW11 and SW12. Note that the some of these samples are taken from pooled water as no flow was present at the time of sampling.

Review of Table 5-8, Table 5-9 and Table 5-10 shows that certain baseline water quality values surrounding the Project do not meet the WQOs for the region. These include:

- Dissolved aluminium;
- Dissolved copper;
- Dissolved zinc;
- Ammonia as N;
- Dissolved oxygen (% Saturation);
- Electrical conductivity;
- pH;
- Sulfate as SO_4
- Suspended solids;
- Total hardness as $CaCO_3$;
- Total Nitrogen as N;
- Total Phosphorus as P; and
- Turbidity.

Table 5-8: Physio-chemical Water Quality Parameters, July 2017 to May 2018 (SW1 & SW2)

Parameter	Unit	SW1						SW2								WQO (refer Table 4-1)
		15/08/17	14/09/17	12/10/17	16/11/17	14/12/17	25/01/18	19/07/17	15/08/17	14/09/17	12/10/17	15/2/18	14/03/18	13/04/18	23/05/18	
No. of samples	-	6						8								-
1.2-Dichloroethane-D4	%	102	98.5	98.2	109	117	103	100	98.9	99.5	102	109	97.2	103	97.5	-
4-Bromofluorobenzene	%	97.9	91.8	104	95.5	93.2	96.2	96.4	98.5	91.7	98.9	93.4	97.4	101	101	-
>C10 - C16 Fraction	µg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	-
>C10 - C16 Fraction minus Naphthalene (F2)	µg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	-
>C10 - C40 Fraction (sum)	µg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	120	160	<100	170	160	-
>C16 - C34 Fraction	µg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	120	160	<100	170	160	-
>C34 - C40 Fraction	µg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	-
Aluminium - Total	mg/L	0.28	0.30	0.27	0.21	0.36	1.10	0.80	0.74	1.30	1.01	1.11	3.76	0.58	0.58	< 5 (stock)
Aluminium – Dissolved	mg/L	0.02	0.08	0.11	0.15	0.05	0.05	0.04	0.07	0.07	0.13	0.61	0.36	0.05	0.05	< 0.055 (aquatic)
Ammonia as N	mg/L	0.04	0.10	0.05	0.03	0.12	0.21	<0.01	<0.01	0.04	0.04	0.16	0.08	0.12	0.05	< 0.02 (aquatic)
Arsenic - Total	mg/L	<0.001	0.001	0.001	0.002	0.001	0.002	<0.001	<0.001	0.001	0.002	0.002	0.002	0.002	0.001	< 0.5 (stock)
Arsenic – Dissolved	mg/L	<0.001	0.001	0.001	0.002	0.001	0.001	<0.001	<0.001	<0.001	0.002	0.001	0.001	0.001	<0.001	< 0.024 (aquatic)
Benzene	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	-
Boron - Total	mg/L	<0.05	0.05	0.05	0.06	0.05	0.07	0.06	<0.05	0.07	0.08	<0.05	<0.05	0.06	0.06	< 5 (stock)
Boron – Dissolved	mg/L	<0.05	<0.05	<0.05	0.06	0.06	<0.05	<0.05	0.05	0.05	0.08	<0.05	<0.05	0.06	0.10	< 0.37 (aquatic)
C10 - C14 Fraction	µg/L	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	-
C10 - C36 Fraction (sum)	µg/L	<50	<50	<50	<50	<50	<50	<50	<50	<50	50	140	<50	150	140	-
C15 - C28 Fraction	µg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	140	<100	150	140	-
C29 - C36 Fraction	µg/L	<50	<50	<50	<50	<50	<50	<50	<50	<50	50	<50	<50	<50	<50	-
C6 - C10 Fraction	µg/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	-
C6 - C10 Fraction minus BTEX (F1)	µg/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	-
C6 - C9 Fraction	µg/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	-
Cadmium - Total	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.01 (stock)
Cadmium – Dissolved	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.00002 (aquatic)
Chromium - Total	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	0.001	0.001	0.001	0.003	<0.001	<0.001	< 1 (stock)
Chromium – Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.001 (aquatic)
Cobalt - Total	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	0.002	0.002	<0.001	0.002	<0.001	<0.001	< 0.1 (irrigation)
Cobalt – Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	-
Copper - Total	mg/L	<0.001	<0.001	0.001	<0.001	<0.001	0.002	<0.001	0.003	0.004	0.003	0.004	0.004	0.001	0.001	< 1 (stock)
Copper – Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.002	0.002	0.002	0.002	0.001	<0.001	0.002	< 0.0014 (aquatic)
Dissolved Oxygen % Saturation	%	59.3	52.4	56.5	60.8	42.0	44.5	73.1	39.8	33.1	94.9	24.8	3.1	16.1	4.0	85-110 (aquatic)
EC (Non-Compensated)	µS/cm	389	398	467	475	464	449	399	479	493	516	124	203	319	261	< 720 (baseflow) < 250 (high flow)
Ethylbenzene	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	-
Fluoride	mg/L	0.2	0.2	0.2	0.2	<0.1	0.2	0.2	0.2	0.3	0.3	<0.1	0.2	0.2	0.3	< 2 (irrigation)
Iron - Total	mg/L	0.28	0.42	0.40	0.44	0.81	2.71	0.73	0.65	1.54	1.55	1.20	3.95	1.12	1.12	< 10 (irrigation)
Iron – Dissolved	mg/L	0.08	0.14	0.09	0.18	0.12	0.07	<0.05	<0.05	<0.05	0.16	0.52	0.30	0.06	0.09	-
Lead - Total	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.001	<0.001	0.002	<0.001	<0.001	<0.001	< 0.1 (stock)

Parameter	Unit	SW1						SW2								WQO (refer Table 4-1)
		15/08/17	14/09/17	12/10/17	16/11/17	14/12/17	25/01/18	19/07/17	15/08/17	14/09/17	12/10/17	15/2/18	14/03/18	13/04/18	23/05/18	
Lead – Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.0034 (aquatic)
Manganese - Total	mg/L	0.350	0.344	0.157	0.2697	0.469	0.781	0.136	0.157	0.980	1.430	0.094	0.408	0.309	0.098	< 10 (irrigation)
Manganese - Dissolved	mg/L	0.280	0.278	0.073	0.294	0.370	0.562	0.007	0.002	<0.001	0.922	0.016	0.005	0.028	0.056	< 1.9 (aquatic)
Mercury – Total	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.002 (irrigation)
Mercury - Dissolved	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.00006 (aquatic)
meta- & para-Xylene	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	-
Molybdenum – Total	mg/L	<0.001	0.001	0.001	0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.05 (irrigation)
Molybdenum - Dissolved	mg/L	0.001	0.001	<0.001	<0.001	0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Naphthalene	µg/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	-
Nickel – Total	mg/L	<0.001	0.001	0.002	0.002	0.002	0.003	0.002	<0.001	0.003	0.004	0.004	0.005	0.002	0.002	< 1 (stock)
Nickel - Dissolved	mg/L	<0.001	<0.001	0.001	0.002	0.002	0.001	<0.001	0.001	<0.001	0.002	0.003	0.002	0.002	0.002	< 0.011 (aquatic)
Nitrate as N	mg/L	<0.01	<0.01	<0.01	<0.01	0.02	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	-
Nitrite + Nitrate as N	mg/L	<0.01	<0.01	<0.01	<0.01	0.02	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	-
Nitrite as N	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-
ortho-Xylene	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	-
pH	-	8.29	8.21	8.32	8.36	8.24	7.87	8.32	8.24	8.07	7.74	6.37	7.07	6.67	7.43	6.5 - 8.5 (aquatic)
Reactive Phosphorus as P	mg/L	<0.01	<0.01	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	<0.01	<0.01	-
Selenium – Total	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.02 (stock)
Selenium - Dissolved	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.005 (aquatic)
Silver – Total	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001	-
Silver – Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001	-
Sodium - Dissolved	mg/L	33	38	57	53	41	37	30	33	38	50	4	15	17	28	-
Sulfate as SO4 - Turbidimetric	mg/L	6	4	8	3	3	4	2	1	1	<1	<1	<1	<1	<1	< 25 (aquatic)
Sum of BTEX	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	-
Suspended Solids (SS)	mg/L	11	11	16	13	12	66	24	28	58	51	14	24	17	25	< 55 (aquatic)
Temperature	°C	21.94	28.44	28.21	28.82	29.41	23.54	22.51	18.92	23.36	23.88	23.46	17.55	17.50	16.70	-
Toluene	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	-
Toluene-D8	%	101	99.9	98.7	99.0	108	99.7	104	104	100	99.7	102	97.7	103	100	-
Total Hardness as CaCO3	mg/L	98	109	132	160	186	-	130	137	162	190	32	74	106	124	< 150 (drinking)
Total Kjeldahl Nitrogen as N	mg/L	0.3	0.5	0.4	0.5	0.3	1.3	0.5	0.6	1.1	1.4	0.8	0.7	0.6	0.8	-
Total Nitrogen as N	mg/L	0.3	0.5	0.4	0.5	0.3	1.3	0.5	0.6	1.1	1.4	0.8	0.7	0.6	0.8	< 0.5 (aquatic)
Total Phosphorus as P	mg/L	0.02	0.02	0.03	0.04	0.02	0.10	0.05	0.04	0.09	0.14	0.25	0.09	0.04	0.05	< 0.05 (aquatic)
Total Xylenes	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	-
Turbidity	NTU	7.4	8.3	15.2	62.3	30	123	55.3	56.2	132	82.0	30.2	109	51.7	-	< 50 (aquatic)
Uranium – Total	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.002	-	<0.001	<0.001	<0.001	< 0.1 (irrigation)
Uranium - Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.002	-	<0.001	<0.001	<0.001	-
Vanadium – Total	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.5 (irrigation)
Vanadium - Dissolved	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-
Zinc – Total	mg/L	<0.005	<0.005	0.025	<0.005	0.01	<0.005	<0.005	0.011	0.006	<0.005	<0.005	0.012	<0.005	<0.005	< 5 (irrigation)
Zinc - Dissolved	mg/L	<0.005	<0.005	<0.005	<0.005	0.01	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	< 0.008 (aquatic)

Table 5-9: Physio-chemical Water Quality Parameters, July 2017 to May 2018 (SW3, SW4, SW6 & SW8)

Parameter	Unit	SW3										SW4	SW6	SW8	WQO (refer Table 4-1)
		15/08/17	14/09/17	12/10/17	16/11/17	14/12/17	25/01/18	15/02/18	14/03/18	13/04/18	23/05/18	20/07/17	20/07/17	20/17/17	
No. of samples	-	10										1	1	1	-
1.2-Dichloroethane-D4	%	100	103	96.4	107	114	108	103	98.7	104	95.3	94.0	95.4	95.2	-
4-Bromofluorobenzene	%	101	95.8	103	113	96.8	98.1	89.6	97.6	106	101	97.4	97.9	97.8	-
>C10 - C16 Fraction	µg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	-
>C10 - C16 Fraction minus Naphthalene (F2)	µg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	-
>C10 - C40 Fraction (sum)	µg/L	<100	<100	<100	<100	<100	130	<100	<100	<100	<100	<100	<100	<100	-
>C16 - C34 Fraction	µg/L	<100	<100	<100	<100	<100	130	<100	<100	<100	<100	<100	<100	<100	-
>C34 - C40 Fraction	µg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	-
Aluminium - Total	mg/L	0.11	0.27	0.15	0.12	0.04	0.07	10.5	0.39	0.22	0.26	0.11	1.15	0.43	< 5 (stock)
Aluminium – Dissolved	mg/L	0.09	0.07	0.05	0.05	0.02	0.02	0.52	0.12	0.04	0.04	0.05	0.08	0.11	< 0.055 (aquatic)
Ammonia as N	mg/L	0.04	0.03	0.05	0.04	0.2	<0.01	0.17	0.06	0.06	0.15	<0.01	<0.01	0.02	< 0.02 (aquatic)
Arsenic – Total	mg/L	<0.001	<0.001	0.002	0.002	<0.001	0.002	0.004	<0.001	0.001	0.001	<0.001	<0.001	<0.001	< 0.5 (stock)
Arsenic – Dissolved	mg/L	<0.001	<0.001	0.001	0.001	0.001	0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	< 0.024 (aquatic)
Benzene	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	-
Boron – Total	mg/L	<0.05	0.05	<0.05	<0.05	<0.05	0.05	<0.05	<0.05	0.05	0.05	0.09	0.11	0.08	< 5 (stock)
Boron – Dissolved	mg/L	<0.05	<0.05	<0.05	<0.05	0.06	<0.05	<0.05	<0.05	0.06	0.07	0.10	0.11	0.08	< 0.37 (aquatic)
C10 - C14 Fraction	µg/L	<50	<50	<50	<50	<50	50	<50	<50	<50	<50	<50	<50	<50	-
C10 - C36 Fraction (sum)	µg/L	<50	<50	<50	<50	<50	210	<50	<50	<50	<50	<50	<50	<50	-
C15 - C28 Fraction	µg/L	<100	<100	<100	<100	<100	110	<100	<100	<100	<100	<100	<100	<100	-
C29 - C36 Fraction	µg/L	<50	<50	<50	<50	<50	50	<50	<50	<50	<50	<50	<50	<50	-
C6 - C10 Fraction	µg/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	-
C6 - C10 Fraction minus BTEX (F1)	µg/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	-
C6 - C9 Fraction	µg/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	-
Cadmium – Total	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.01 (stock)
Cadmium – Dissolved	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.00002 (aquatic)
Chromium – Total	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.011	0.001	<0.001	<0.001	0.011	<0.001	<0.001	< 1 (stock)
Chromium – Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.001 (aquatic)
Cobalt – Total	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	<0.001	0.001	<0.001	<0.001	0.001	<0.001	< 0.1 (irrigation)
Cobalt – Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	-
Copper – Total	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.011	<0.001	<0.001	<0.001	<0.001	0.003	0.002	< 1 (stock)
Copper – Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.002	0.002	0.002	< 0.0014 (aquatic)
Dissolved Oxygen % Saturation	%	41.5	30.7	23.8	33.6	42.2	57.2	27.1	29.8	17.3	5.1	78.0	62.2	59.5	85-110 (aquatic)
EC (Non-Compensated)	µS/cm	330	311	317	313	322	358	218	225	297	295	781	1230	2020	< 720 (baseflow) < 250 (high flow)
Ethylbenzene	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	-
Fluoride	mg/L	0.2	0.1	0.2	0.1	<0.1	0.1	0.2	0.1	0.2	0.2	0.3	0.4	0.3	< 2 (irrigation)
Iron – Total	mg/L	0.15	0.35	0.65	0.91	0.80	1.41	12.6	0.44	0.57	1.28	0.20	1.04	0.31	< 10 (irrigation)
Iron – Dissolved	mg/L	0.06	0.09	0.39	0.63	0.61	0.47	0.31	0.1	0.2	0.3	<0.05	<0.05	0.07	-
Lead – Total	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.009	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.1 (stock)

Parameter	Unit	SW3										SW4	SW6	SW8	WQO (refer Table 4-1)
		15/08/17	14/09/17	12/10/17	16/11/17	14/12/17	25/01/18	15/02/18	14/03/18	13/04/18	23/05/18	20/07/17	20/07/17	20/17/17	
Lead – Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.0034 (aquatic)
Manganese - Total	mg/L	0.083	0.217	0.978	1.1	0.407	0.679	0.288	0.075	0.962	0.530	0.019	0.201	0.024	< 10 (irrigation)
Manganese - Dissolved	mg/L	0.045	0.144	0.9	1.05	0.418	0.576	0.011	0.070	0.916	0.504	0.005	0.106	0.006	< 1.9 (aquatic)
Mercury - Total	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.002 (irrigation)
Mercury - Dissolved	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.00006 (aquatic)
meta- & para-Xylene	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	-
Molybdenum - Total	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.003	0.002	< 0.05 (irrigation)
Molybdenum - Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.003	0.002	-
Naphthalene	µg/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	-
Nickel - Total	mg/L	<0.001	0.002	0.001	0.001	<0.001	0.002	0.015	0.002	0.002	0.002	0.002	0.004	0.003	< 1 (stock)
Nickel - Dissolved	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.002	0.001	0.002	0.001	0.002	0.003	0.002	< 0.011 (aquatic)
Nitrate as N	mg/L	<0.01	<0.01	<0.01	0.25	<0.01	<0.01	0.02	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	-
Nitrite + Nitrate as N	mg/L	<0.01	<0.01	<0.01	0.25	<0.01	<0.01	0.02	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	-
Nitrite as N	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-
ortho-Xylene	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	-
pH	-	8.04	7.17	7.51	7.67	8.18	8.08	6.40	7.44	7.00	7.45	8.38	8.33	8.47	6.5 - 8.5 (aquatic)
Reactive Phosphorus as P	mg/L	<0.01	<0.01	<0.01	-	<0.01	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-
Selenium - Total	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.02 (stock)
Selenium - Dissolved	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.005 (aquatic)
Silver - Total	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Silver – Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Sodium - Dissolved	mg/L	34	32	39	38	36	39	19	23	30	34	105	197	300	-
Sulfate as SO4 - Turbidimetric	mg/L	8	6	5	4	5	5	9	6	5	5	57	156	410	< 25 (aquatic)
Sum of BTEX	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	-
Suspended Solids (SS)	mg/L	11	10	<5	<5	<5	6	38	<5	<5	13	5	28	<5	< 55 (aquatic)
Temperature	°C	18.81	22.75	25.44	26.26	26.62	25.15	23.31	16.65	18.05	18.60	13.9	14.3	19.1	-
Toluene	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	-
Toluene-D8	%	99.7	101	97.6	98.4	113	101	99.8	96.9	103	100	103	104	103	-
Total Hardness as CaCO3	mg/L	65	72	79	86	105		48	57	82	96	147	149	300	< 150 (drinking)
Total Kjeldahl Nitrogen as N	mg/L	0.3	0.2	0.2	0.4	0.4	0.6	1.1	0.1	0.5	0.5	0.6	0.9	0.8	-
Total Nitrogen as N	mg/L	0.3	0.2	0.2	0.6	0.4	0.6	1.1	0.1	0.5	0.5	0.6	0.9	0.8	< 0.5 (aquatic)
Total Phosphorus as P	mg/L	0.01	0.02	0.02	0.03	0.02	0.04	0.28	0.07	0.03	0.02	0.02	0.07	0.05	< 0.05 (aquatic)
Total Xylenes	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	-
Turbidity	NTU	7.7	1.7	0.5	35.7	4.4	12.4	498	10.4	15.2	-	4.9	95.4	14.5	< 50 (aquatic)
Uranium - Total	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001	<0.001	0.001	0.001	< 0.1 (irrigation)
Uranium - Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001	<0.001	0.001	0.001	-
Vanadium - Total	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.5 (irrigation)
Vanadium - Dissolved	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-
Zinc - Total	mg/L	<0.005	<0.005	0.017	<0.005	<0.005	0.008	0.026	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	< 5 (irrigation)
Zinc - Dissolved	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	< 0.008 (aquatic)

Table 5-10: Physio-chemical Water Quality Parameters, July 2017 to May 2018 (SW11 & SW12)

Parameter	Unit	SW11					SW12							WQO (refer Table 4-1)
		13/09/17	12/10/17	16/11/17	14/12/17	14/03/18	13/09/17	12/10/17	16/11/17	14/1 2/17	25/01/18	14/03/18	23/05/18	
No. of samples	-			5						7				-
1.2-Dichloroethane-D4	%	101	95.7	109	115	98.6	99.2	100	112	120	104	98.4	97.6	-
4-Bromofluorobenzene	%	92.9	99.3	97.6	96.5	96.7	91.8	99.0	97.9	89.5	94.2	96.0	101	-
>C10 - C16 Fraction	µg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	-
>C10 - C16 Fraction minus Naphthalene (F2)	µg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	-
>C10 - C40 Fraction (sum)	µg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	260	<100	100	-
>C16 - C34 Fraction	µg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	260	<100	100	-
>C34 - C40 Fraction	µg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	-
Aluminium - Total	mg/L	0.84	0.43	0.59	0.62	2.70	0.55	0.21	0.63	0.56	1.27	2.83	0.87	< 5 (stock)
Aluminium – Dissolved	mg/L	0.28	0.20	0.14	0.16	0.27	0.12	0.11	0.11	0.12	0.05	0.23	0.04	< 0.055 (aquatic)
Ammonia as N	mg/L	0.05	0.14	0.03	0.10	0.10	0.04	0.07	0.03	0.06	0.02	0.10	0.02	< 0.02 (aquatic)
Arsenic – Total	mg/L	<0.001	0.002	0.002	0.003	0.001	<0.001	0.003	0.002	0.002	0.003	0.001	0.001	< 0.5 (stock)
Arsenic – Dissolved	mg/L	<0.001	0.001	0.002	0.002	<0.001	<0.001	0.003	0.001	0.002	0.002	<0.001	<0.001	< 0.024 (aquatic)
Benzene	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	-
Boron – Total	mg/L	0.06	<0.05	0.06	<0.05	<0.05	0.07	0.07	<0.05	0.09	0.10	<0.05	0.06	< 5 (stock)
Boron – Dissolved	mg/L	0.05	<0.05	0.05	0.07	<0.05	0.05	0.06	<0.05	0.09	0.08	<0.05	0.06	< 0.37 (aquatic)
C10 - C14 Fraction	µg/L	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	-
C10 - C36 Fraction (sum)	µg/L	<50	<50	<50	<50	<50	<50	<50	<50	<50	300	<50	<50	-
C15 - C28 Fraction	µg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	180	<100	<100	-
C29 - C36 Fraction	µg/L	<50	<50	<50	<50	<50	<50	<50	<50	<50	120	<50	<50	-
C6 - C10 Fraction	µg/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	-
C6 - C10 Fraction minus BTEX (F1)	µg/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	-
C6 - C9 Fraction	µg/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	-
Cadmium – Total	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.01 (stock)
Cadmium – Dissolved	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.00002 (aquatic)
Chromium – Total	mg/L	0.001	<0.001	<0.001	0.001	0.005	<0.001	<0.001	0.001	<0.001	0.003	0.005	0.001	< 1 (stock)
Chromium – Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.001 (aquatic)
Cobalt – Total	mg/L	<0.001	<0.001	0.001	0.001	0.001	<0.001	0.001	0.001	<0.001	0.002	0.002	0.001	< 0.1 (irrigation)
Cobalt – Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Copper – Total	mg/L	0.002	0.001	0.008	<0.001	0.004	0.002	<0.001	0.002	<0.001	0.002	0.004	<0.001	< 1 (stock)
Copper – Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	< 0.0014 (aquatic)
Dissolved Oxygen % Saturation	%	57.9	25.5	29.5	7.0	34.6	44.8	79.3	22.8	11.8	31.0	12.7	3.2	85-110 (aquatic)
EC (Non-Compensated)	µS/cm	595	590	515	515	262	612	631	571	556	784	237	414	< 720 (baseflow) < 250 (high flow)
Ethylbenzene	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	-
Fluoride	mg/L	0.2	0.2	0.2	<0.1	0.1	0.2	0.2	0.2	<0.1	0.3	0.1	0.2	< 2 (irrigation)
Iron – Total	mg/L	0.94	0.85	0.92	1.50	3.20	0.67	1.29	1.41	1.60	2.55	3.70	1.80	< 10 (irrigation)
Iron – Dissolved	mg/L	0.15	0.34	0.19	0.38	0.17	0.1	0.87	0.18	0.25	0.07	0.2	0.1	-
Lead – Total	mg/L	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	< 0.1 (stock)
Lead – Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.0034 (aquatic)

Parameter	Unit	SW11					SW12							WQO (refer Table 4-1)
		13/09/17	12/10/17	16/11/17	14/12/17	14/03/18	13/09/17	12/10/17	16/11/17	14/1 2/17	25/01/18	14/03/18	23/05/18	
Manganese – Total	mg/L	0.024	0.129	0.784	1.30	0.064	0.196	1.06	0.817	0.861	0.866	0.221	0.242	< 10
Manganese - Dissolved	mg/L	0.006	0.091	0.709	1.43	0.002	0.116	1.000	0.591	0.794	0.726	0.097	0.206	< 1.9 (aquatic)
Mercury – Total	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.002 (irrigation)
Mercury - Dissolved	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.00006 (aquatic)
meta- & para-Xylene	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	-
Molybdenum – Total	mg/L	<0.001	0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	< 0.05 (irrigation)
Molybdenum - Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	-
Naphthalene	µg/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	-
Nickel – Total	mg/L	0.003	0.002	0.003	0.002	0.005	0.002	0.002	0.003	0.004	0.005	0.005	0.003	< 1 (stock)
Nickel - Dissolved	mg/L	<0.001	0.002	0.002	0.003	0.001	0.002	0.002	0.002	0.002	0.003	0.002	0.002	< 0.011 (aquatic)
Nitrate as N	mg/L	<0.01	<0.01	0.13	<0.01	0.19	<0.01	<0.01	0.18	<0.01	<0.01	0.05	<0.01	-
Nitrite + Nitrate as N	mg/L	<0.01	<0.01	0.13	<0.01	0.19	<0.01	<0.01	0.18	<0.01	<0.01	0.05	<0.01	-
Nitrite as N	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-
ortho-Xylene	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	-
pH	-	8.32	7.21	7.22	7.26	7.10	7.73	7.44	7.73	7.90	8.10	7.03	7.44	6.5 - 8.5 (aquatic)
Reactive Phosphorus as P	mg/L	<0.01	<0.01		<0.01	<0.01	<0.01	0.02		<0.01	<0.01	<0.01	<0.01	-
Selenium – Total	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.02 (stock)
Selenium - Dissolved	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.005 (aquatic)
Silver – Total	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Silver – Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Sodium - Dissolved	mg/L	78	83	65	63	23	64	85	67	75	85	21	30	-
Sulfate as SO4 - Turbidimetric	mg/L	47	39	36	27	13	36	14	15	6	8	12	9	< 25 (aquatic)
Sum of BTEX	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	-
Suspended Solids (SS)	mg/L	16	<5	17	15	16	11	<5	16	10	51	28	27	< 55 (aquatic)
Temperature	°C	28.92	22.3	24.48	23.18	17.73	29.8	23.81	25.22	25.95	23.00	17.20	13.50	-
Toluene	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	-
Toluene-D8	%	101	95.9	96.8	109	98.2	99.0	99.7	96.6	105	99.8	98.5	101	-
Total Hardness as CaCO3	mg/L	110	142	125	146	61	119	166	132	157		64	104	< 150 (drinking)
Total Kjeldahl Nitrogen as N	mg/L	0.5	0.4	0.4	0.4	0.4	0.5	0.7	0.9	0.5	1.3	0.8	0.6	-
Total Nitrogen as N	mg/L	0.5	0.4	0.5	0.4	0.6	0.5	0.7	1.1	0.5	1.3	0.8	0.6	< 0.5 (aquatic)
Total Phosphorus as P	mg/L	0.03	0.03	0.04	0.03	0.12	0.04	0.11	0.07	0.04	0.14	0.11	0.06	< 0.05 (aquatic)
Total Xylenes	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	-
Turbidity	NTU	26.4	8.8	84.3	35.2	101	12.5	1.7	77.6	40.6	104	125	-	< 50 (aquatic)
Uranium – Total	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.1 (irrigation)
Uranium - Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Vanadium – Total	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.5 (irrigation)
Vanadium - Dissolved	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-
Zinc - Total	mg/L	<0.005	<0.005	0.012	0.009	0.013	<0.005	<0.005	<0.005	<0.005	0.006	0.010	<0.005	< 5 (irrigation)
Zinc – Dissolved	mg/L	<0.005	<0.005	<0.005	0.006	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	< 0.008 (aquatic)

5.4.2.2 REMP Outcomes at Nearby Mine Sites

We have undertaken a review of various The Receiving Environment Management Plan (REMP) and Annual Return documents which were provided by DES for nearby operating coal mines. These include:

- Lake Vermont Mine:
  - 2016 Receiving Environment Monitoring Program (November 2016)
  - Receiving Environment Monitoring Program Progress Report (July 2017)
- Peak Downs Mine:
  - Receiving Environment Monitoring Program – Annual Report – end June 2013 (July 2014)
  - Receiving Environment Monitoring Program – Annual Report – end June 2017 (December 2017)
- Saraji Mine:
  - Receiving Environment Monitoring Program – Annual Report – 2015/16 (April 2017)
  - Receiving Environment Monitoring Program – Annual Report – end June 2017 (December 2017)

A summary of the key outcomes from the various documents are summarized in Table 5-11.

Table 5-11: Summary of Key Outcomes from REMP's at nearby mine sites

Site	Document	Key Outcome
Lake Vermont Mine	2016 REMP	• There were some occasions in the past few years where certain in-situ water quality parameters were outside EA limits. • These were observed at upstream reference sites and downstream impacted sites. • Based on spatial trends and timing in relation to release events, these occurrences do not appear to correlate with mine releases. • Exceedances during periods of no mine releases were observed for Al, Cu, Fe, MN, Zn, Pb, Hg and B. • The current release limits are largely sufficient to protect the receiving waters. • There is no evidence of mine-affected water release impacts on the receiving environment watercourses downstream of mine operations or releases or any impacts on the ecological community and aquatic habitat.
Lake Vermont Mine	2017 REMP	• Variation in reference and impact sites from 2013-2017 for physio-chemical parameters, total metals, dissolved metals and petroleum hydrocarbons was minimal, indicating that mining activities are unlikely to impact water quality. • Few exceedances of specific WQOs related to the EVs relevant to the Project were recorded indicating that EVs are not at risk from mining activity throughout the Project.
Peak Downs Mine	2013 REMP	• The median EC downstream Ripstone Creek (2,084μS/cm) was greater than the upstream average 80th percentile.

Site	Document	Key Outcome
		• The average upstream 80th percentile (293µS/cm) and the Isaac River upstream 80th percentile (590µS/cm) were well below the current EA trigger for downstream Isaac River (2,000µS/cm) and the Queensland guideline for the Fitzroy North region (720µS/cm). • The current EA trigger of 2,000µS/cm accommodates the natural, variation in each stream and aligns with recent ecotoxicology studies (Prasad, et al., 2012) using ANZECC & ARMCANZ (2000) methodology which found salinity levels up to 2,000µS/cm-2,500µS/cm provide 95% protection (acceptable for SMD systems) for aquatic species in the Fitzroy Basin
Peak Downs Mine	2017 REMP	• Electrical conductivity was at times above the ANZECC & ARMCANZ (2000) aquatic ecosystem (720 µS/cm) and ADWG (2011) drinking water (400 µg/L) guideline at downstream Isaac River Seloh Nolem (MP18), however remained well below the EA trigger and other ANZECC & ARMCANZ (2000) guidelines. • Dissolved aluminium and copper were above the ANZECC & ARMCANZ (2000) ecosystem guideline at upstream and downstream sites, however downstream concentrations of these analytes remained below their respective EA triggers. • Total aluminium, iron and manganese were above ANZECC & ARMCANZ (2000) recreational, irrigation and livestock guidelines at upstream and downstream sites. Downstream concentrations of these analytes were generally below or within the range of values recorded upstream, and well within historical ranges, indicating a natural enrichment in the area. • In conclusion, the results indicate values above guidelines generally occurred both upstream and downstream of mining and are likely a function of background and associated land use influences outside of mining. Downstream median concentrations for these metals during the overall REMP study remained within the upstream 80th percentile considered acceptable for slightly-to-moderately disturbed systems (QWQG, 2009).
Saraji Mine	2015/16 REMP	• Electrical Conductivity was above drinking water (400 µg/L) and ecosystem (720 µg/L) guidelines at Hughes Creek DS and Phillips Creek DS recording 843 µg/L and 1,920 µg/L respectively during flows in February. However, these recordings were below the EA trigger value (2,000 µg/L) and historical ranges. High EC levels were also detected at upstream and downstream sites during nil flow periods, with most sites staying within the EA trigger value and historical ranges. Only Phillips Creek US exceeded the EA trigger, recording 2,411 µg/L during May 2016. Samples taken during nil-flow periods commonly exhibit elevated salt concentrations. • Dissolved zinc concentrations in Hughes Creek US and Phillips Creek DS (50 and 60 µg/L respectively) were detected above the ecosystem guideline and EA trigger (8 µg/L) in February 2016. These readings are likely the result of a laboratory error as total zinc concentrations (7 and 18 µg/L) were well below dissolved concentrations at the same sites on the same day • Total aluminium, iron and manganese exceeded recreational and irrigation guidelines during flow and nil-flow sampling both upstream and downstream, however these metals are naturally enriched in the area • In conclusion, the results indicate that exceedances of guideline values occurred both upstream and downstream of mining and are likely a function of background and associated land use influences outside of mining. Where analytes were recorded downstream in high concentrations, the amount was either below the EA trigger value, or within the range of historical data recorded at upstream sites or remained within the upstream 80th percentile considered acceptable for slightly to moderately disturbed systems (QWQG, 2009).

Site	Document	Key Outcome
Saraji Mine	2017 REMP	• Water quality results for 2016/2017 were mostly within the Queensland and Australian guidelines for livestock watering, irrigation, general use, and raw water for drinking. Where exceptions occurred, they were mainly both upstream and downstream of mining. Where concentrations were higher downstream, the level was either below the EA trigger value, or within the range of historical data recorded at upstream sites, or the downstream median remained within the upstream 80th percentile considered acceptable for slightly-to-moderately disturbed systems (QWQG, 2009). • Downstream medians from between 2010 and 2017, mostly remained below the upstream 80 percentile, defined as acceptable by the Queensland Water Quality Guidelines (2009) for slightly-to moderately disturbed ecosystems, with some exceptions. • The downstream medians for these analytes were however below available guidelines pertinent for the area and/or the EA trigger value, indicating the increase presents a low risk to environmental values. • Statistical analysis of data captured during the REMP study (since 2010) found a new EA trigger value should be considered for aluminium. • **Recommendation**: A new trigger value of 534 µg/L is proposed for aluminium, based on the average upstream 80th percentile, because the current EA trigger of 416 µg/L is more than one standard error (96 µg/L) below background conditions.

5.4.2.3 *Aquatic Ecology Data*

DPM undertook baseline aquatic ecology surveys in December 2016 and July 2017 for the Project. Part of the baseline surveys included collection of physiochemical water quality parameters at riverine sites R2, R3, R6 and R8, refer Table 5-12. Note that riverine sites R1 and R5 were unable to be sampled during the December 2016 surveys due to dry conditions and sites R4 and R7 were unable to be sampled due to restricted access. Riverine sites R1 and R7 were unable to be sampled in July due to restricted access.

Review of Table 5-12 show that water samples at a range of sites exceeded the regional WQOs for dissolved oxygen and turbidity. It is noted that the flow conditions (e.g. flowing or ponded water) at the time of sampling is expected to have influenced the parameters sampled.

5.5 Upstream and Downstream Users

Detailed information regarding individual licences for Isaac River surface water users was obtained through analysis of water licences data provided by DNRME. Some limitations in the dataset include the absence of names of water users, and in some cases, allocated volumes for water licenses due to privacy restrictions. Details regarding the volume, source and purpose of the licences is included in Table 5-13.

Table 5-12: Physio-chemical Water Quality Parameters, December 2016 and July 2017

Parameter	Units	Riverine Sites									WQO (refer Table 3-1)
		R2	R3		R4	R5	R6		R8		
		14/12/16	17/12/16	08/07/17	07/07/17	06/07/17	14/02/17	09/17/17	16/12/16	10/07/17	
Temperature	ºC	26.7	32.6	18.6	19.5	20.4	31.5	20.0	31.0	20.9	-
EC	µS/cm	151	221	220	182	680	193	293	244	287	< 720 (base flow) < 250 (high flow)
pH	-	7.73	7.59	6.9	7.3	7.60	7.24	7.5	7.86	7.4	6.5-8.5
Dissolved Oxygen (DO)	%	82.5	97.0	77.2	59.4	81.0	88.6	81	88.3	86.3	85-110
	mg/L	6.61	6.94	7.1	5.30	7.40	6.50	7.4	6.56	7.7	> 4
Turbidity	NTU	459	11.7	27.7	23.4	12.8	274	51	168	26.1	< 50

Table 5-13: List of Isaac River Surface Water Licences

Study Sub-catchment	Watercourse	Authorisation Reference	Authorisation Type	Authorisation Status	Authorisation Expiry Date	Purpose	Allocation	Location Land List	Location
Fitzroy Basin	Isaac River	0548416L	Licence to take water	Issued	30/06/2111	Mining	100 ML	ML 70108	Isaac River U/S of Project Area
Fitzroy Basin	Isaac River	174800	Licence to interfere by diversion channel	Issued	30/06/2111	Divert the course of flow	NULL	ML 70109	Isaac River U/S of Project Area
Fitzroy Basin	Isaac River	405577	Licence to take water	Issued	30/06/2111	Irrigation; Stock Intensive	60 ML	14/ROP89	Isaac River D/S of Project Area
Fitzroy Basin	Isaac River	405578	Licence to take water	Issued	30/06/2111	Irrigation	150 ha	14/ROP89	Isaac River D/S of Project Area
Fitzroy Basin	Isaac River	43173WL	Licence to take water	Issued	30/06/2111	Water harvesting	NULL	18/SP1133 22	Isaac River U/S of Project Area
Fitzroy Basin	Isaac River	43174L	Licence to take water	Issued	30/06/2111	Water harvesting	NULL	18/SP1133 22	Isaac River U/S of Project Area
Fitzroy Basin	Isaac River	45202U	Licence to take water	Issued	30/06/2111	Stock	NULL	A ON ROP185	Isaac River D/S of Project Area
Fitzroy Basin	Isaac River	45321U	Licence to take water	Issued	30/06/2111	Irrigation	40 ha	14/ROP89	-
Fitzroy Basin	Isaac River	55557L	Licence to interfere	Issued	30/06/2111	Impound water	NULL	11/RP8524 66	Isaac River U/S of Project Area
Fitzroy Basin	Isaac River	55661L	Licence to take water	Issued	30/06/2111	Domestic supply; Mining; Stock	1,700 ML	11/RP8524 66	-
Fitzroy Basin	Isaac River	54781U	Licence to take water	Issued	30/06/2111	Irrigation	40 ha	6/ RP86005 1	Isaac River D/S of Project Area
Fitzroy Basin	Isaac River	617184	Licence to take water	Issued	15/03/219	Construction	5 ML	11/KL135; 9/CNS98	Isaac River at Project Area

6. Proposed Surface Water Management Strategy and Infrastructure

6.1 Types of Water Generated on Site

Land disturbance associated with mining has the potential to adversely affect the quality of surface runoff in downstream receiving waters through increased sediment loads. In addition, runoff from active mining areas (including coal stockpiles, etc.) may have increased concentrations of salts and other pollutants when compared to natural runoff. The proposed strategy for the management of surface water at the Project is based on the separation of water from different sources based on anticipated water quality.

Definitions of the types of water generated within the Project are shown in Table 6-1.

Table 6-1: Types of Water

Water type	Definition
Mine affected water	In accordance with the DEHP Guideline Model Mining Conditions, mine affected water means the following types of water: i) pit water, tailings dam water, processing plant water ii) water contaminated by a mining activity which would have been an environmentally relevant activity under Schedule 2 of the Environmental Protection Regulation 2008 if it had not formed part of the mining activity iii) rainfall runoff which has been in contact with any areas disturbed by mining activities which have not yet been rehabilitated, excluding rainfall runoff discharging through release points associated with erosion and sediment control structures that have been installed in accordance with the standards and requirements of an Erosion and Sediment Control Plan to manage such runoff, provided that this water has not been mixed with pit ware, tailings dam water, processing plant water or workshop water iv) groundwater which has been in contact with any areas disturbed by mining activities which have not yet been rehabilitated v) groundwater from the mine dewatering activities vi) a mix of mine affected water (under any of paragraphs i to v) and other water
Sediment water	Surface water runoff from areas that are disturbed by mining operations (including out-of-pit waste rock emplacements). This runoff does not come into contact with coal or other carbonaceous material and may contain high sediment loads but does not contain elevated level of other water quality parameters (e.g. electrical conductivity, pH, metals, metalloids, non-metals). This runoff must be managed to ensure adequate sediment removal prior to release to receiving waters.
Clean catchment water	Surface runoff from areas unaffected by mining operations. Clean catchment water includes runoff from undisturbed areas and fully rehabilitated areas.
Raw water	Untreated water, generally from an external water supply, that has not been contaminated by mining activities.
Potable water	Treated water suitable for human consumption.

6.2 Water Management Strategy Overview

The water management system for the Project aims to protect the identified downstream EV's and comprises the following key objectives:

- clean/mine affected water separation to ensure that up-catchment water and mine affected water remain separate wherever practicable;
- capture of mine affected runoff (e.g. mine industrial area, haul road/overland conveyor runoff, storage and priority reuse as mine water supply;
- diversion of up-catchment water runoff from upstream catchments around the active mining area;
- minimise external catchment runoff draining into pits;
- use of erosion and sediment control (ESC) measures to manage sediment from disturbed catchment areas (e.g. out-of-pit waste rock emplacements, cleared/pre-strip areas) prior to release offsite;
- preferential reuse of onsite water (e.g. mine affected water) to support mine operational water demands (and therefore reduce release of mine affected water under normal operating conditions); and
- management of any mine affected water releases to the receiving environment to meet environmental release conditions.

The Project water management system will include up-catchment diversions, a watercourse diversion (Ripstone Creek Diversion), mine water drainage, mine water storages, ESC, pit water storages and flood protection works (i.e. levees). Further details of the mine site water management strategy are provided in Section 6.5.

6.3 Proposed Water Management Infrastructure

Figure 6-1 to Figure 6-12 show indicative locations of the key features of the mine, including infrastructure related to the management of water on the Project site for seven different phases of mining (Stage 1 to Stage 7). The main components of water-related infrastructure include:

- sediment dams to collect and treat runoff from out-of-pit waste rock emplacement areas;
- drains to divert sediment-laden runoff from out-of-pit waste rock emplacement areas to sediment dams;
- up-catchment water drains to divert runoff from undisturbed catchments around areas disturbed by mining; and
- a mine-affected water system to store water pumped out of the open cut mining areas and to collect runoff from the CHPP and coal stockpile area.

Details of proposed water storages, including indicative storage sizes and pumping rules are provided in Section 6.5.

6.4 Release of Waters to the Receiving Environment

There are three key mechanisms through which water from the Project can enter the receiving environment:

- Controlled release through authorised release points;
- Overflows from sediment dams; and
- Runoff from rehabilitated catchments.

Both controlled releases and overflows from sediment dams are point sources. Model predictions of volumes and salt loads from these sources are provided in Section 8.3.5 and 8.3.6.

Runoff from rehabilitated catchments is likely to be both a point and diffuse source of water to the receiving environment. When a sediment dam catchment is completely rehabilitated, and water quality monitoring of the runoff has established that it is consistent with natural background conditions, the sediment dam and associated drainage infrastructure will be decommissioned. Surface runoff and seepage from the rehabilitated catchment will be allowed to shed directly to the receiving environment.

6.4.1 Controlled Release Mixing zones

Controlled release of water from the water management system will occur directly t the Isaac River from a number of mine affected water dams directly to the Isaac River through a gravity discharge arrangement. The maximum distance between the controlled release point and the Isaac River is around 1.6 km, where it will mix directly with flow in the Isaac River.

Controlled releases will only occur in accordance with the proposed controlled release strategy discussed in Section 7.11. This proposed strategy has been developed to ensure that the release rate does not exceed 12.5% of the Isaac River discharge (as measured at Deverill gauge).

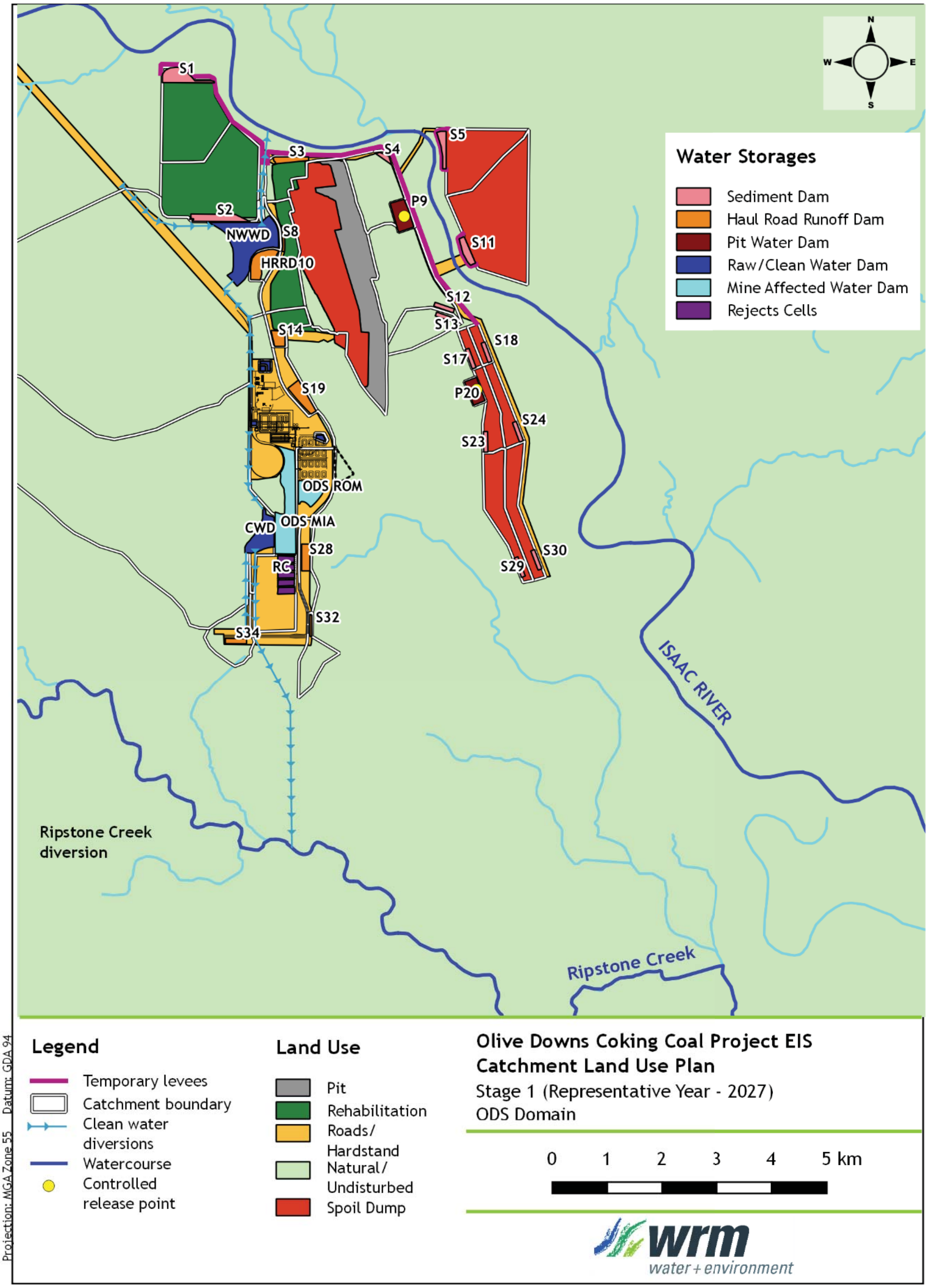

Figure 6-1: Olive Downs South domain – Stage 1 (Year 2027) Mine Plans

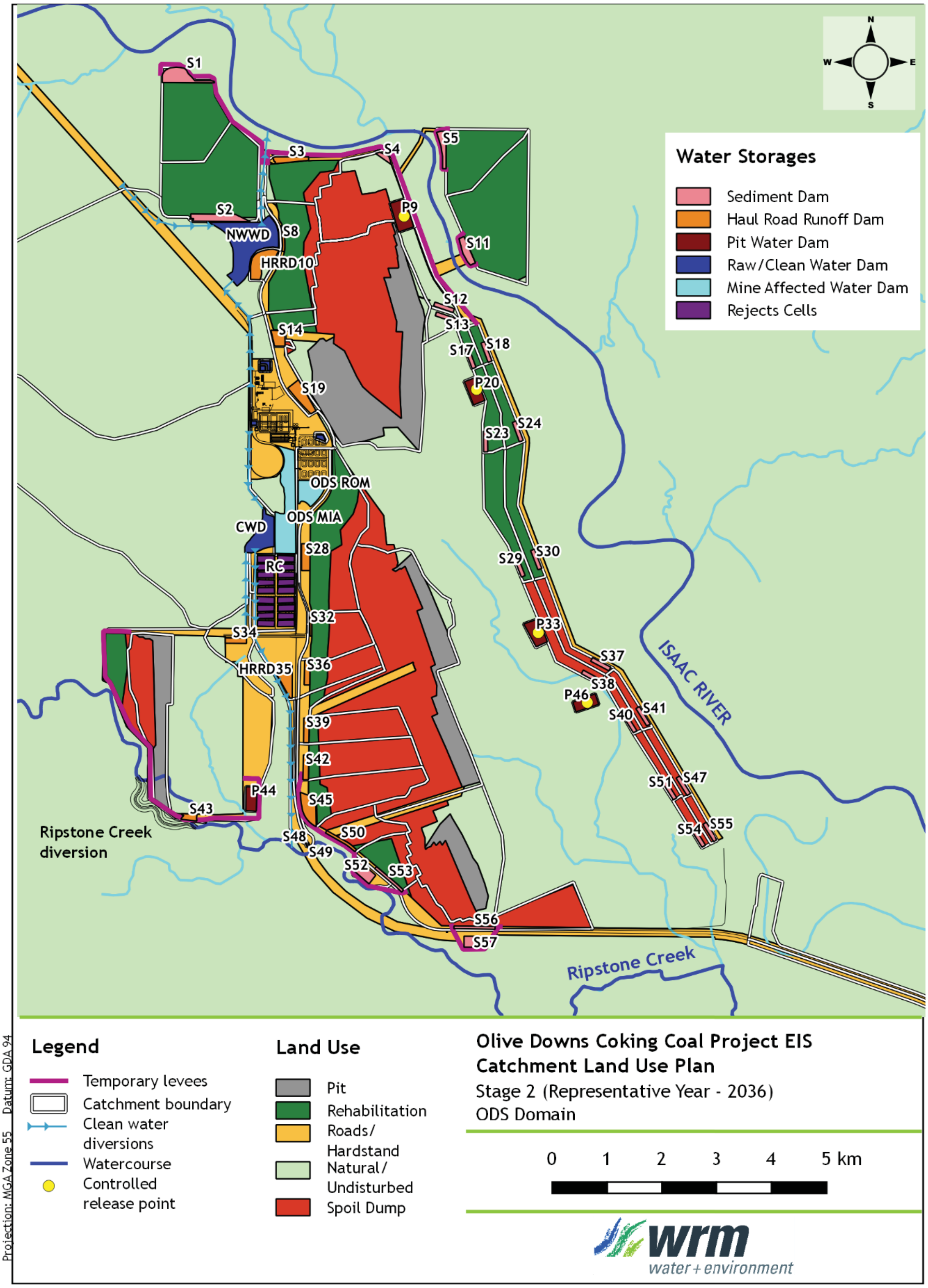

Figure 6-2: Olive Downs South domain – Stage 2 (Year 2036) Mine Plans

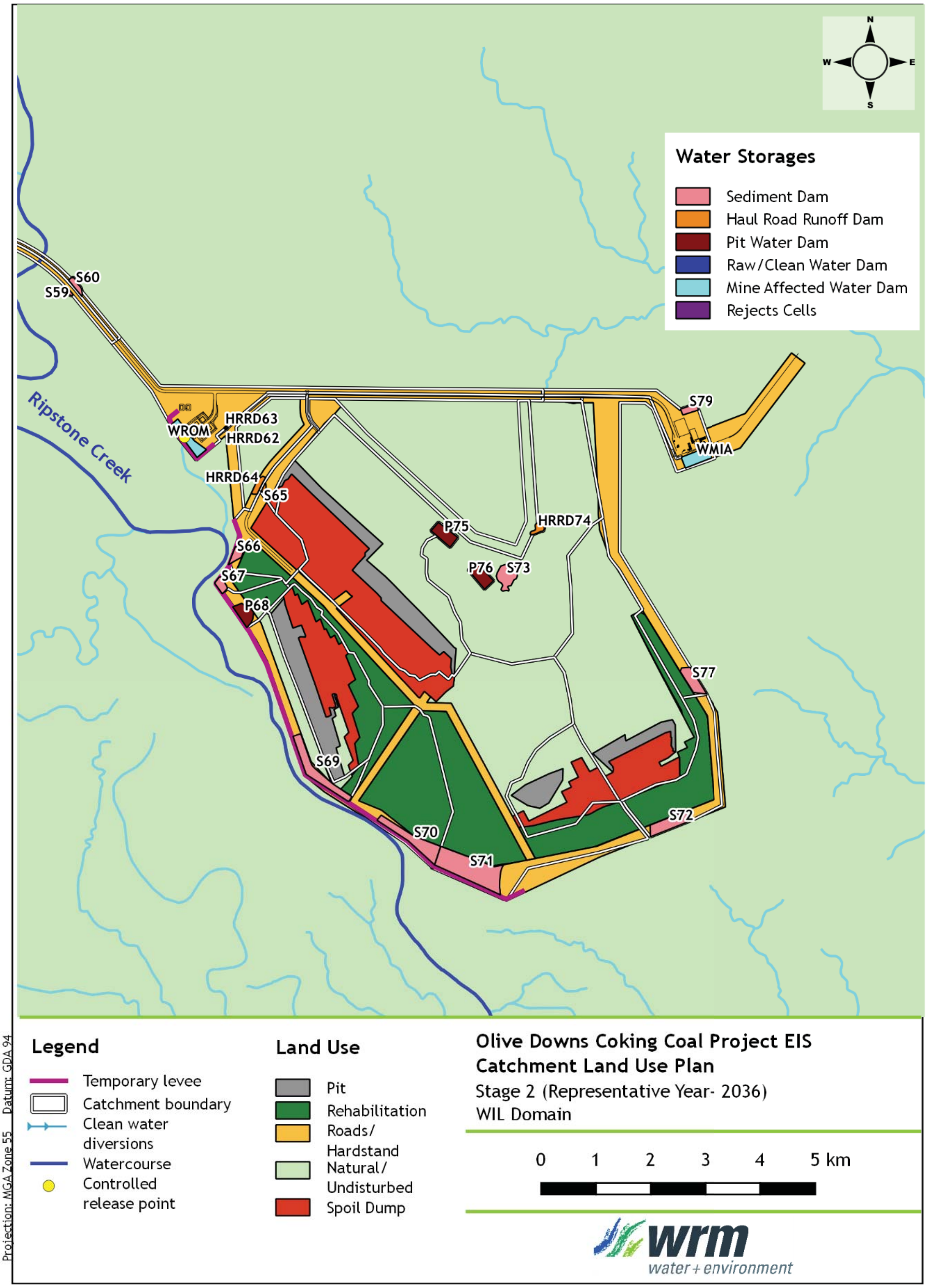

Figure 6-3: Willunga domain – Stage 2 (Year 2036) Mine Plans

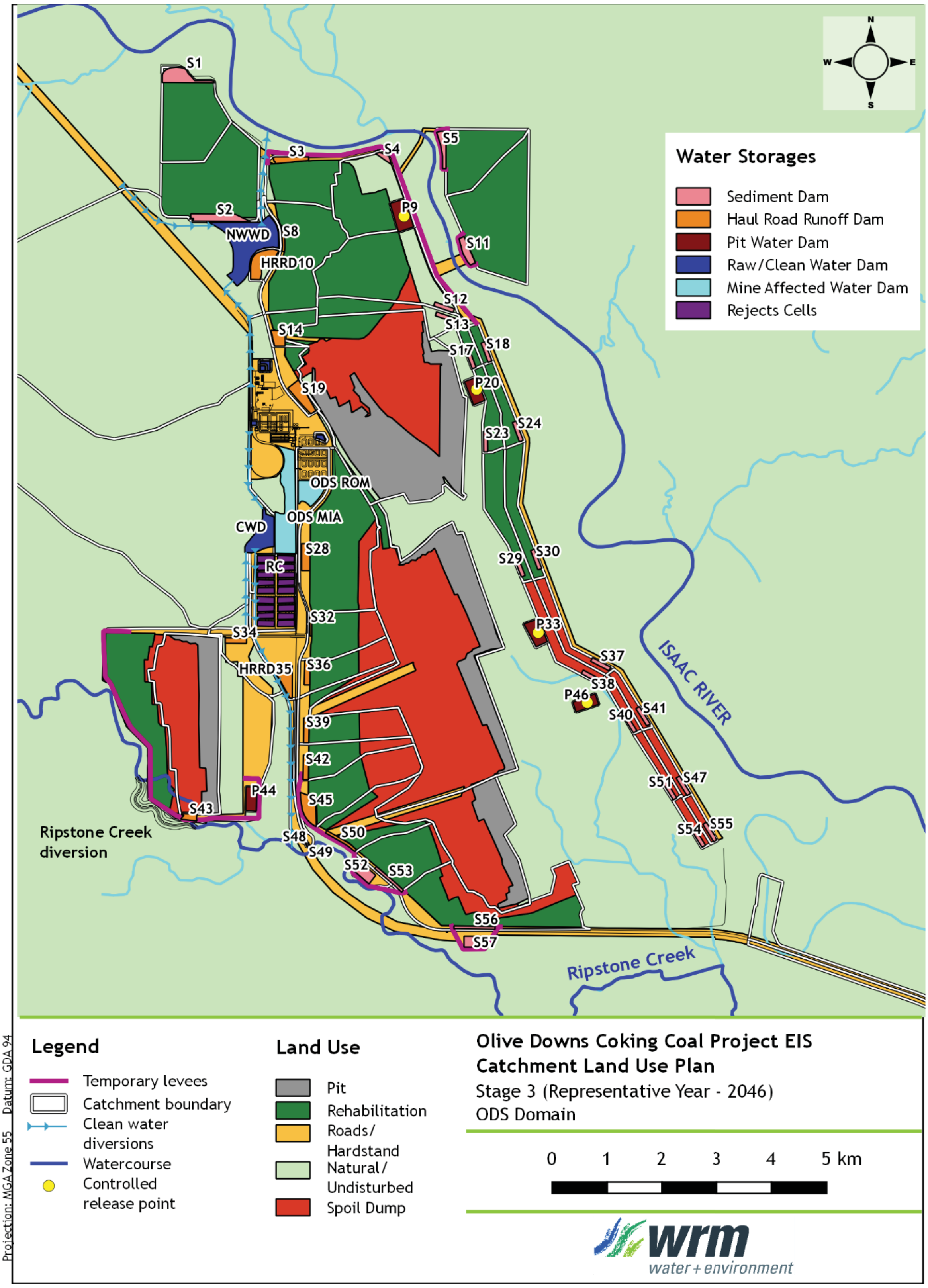

Figure 6-4: Olive Downs South domain – Stage 3 (Year 2046) Mine Plans

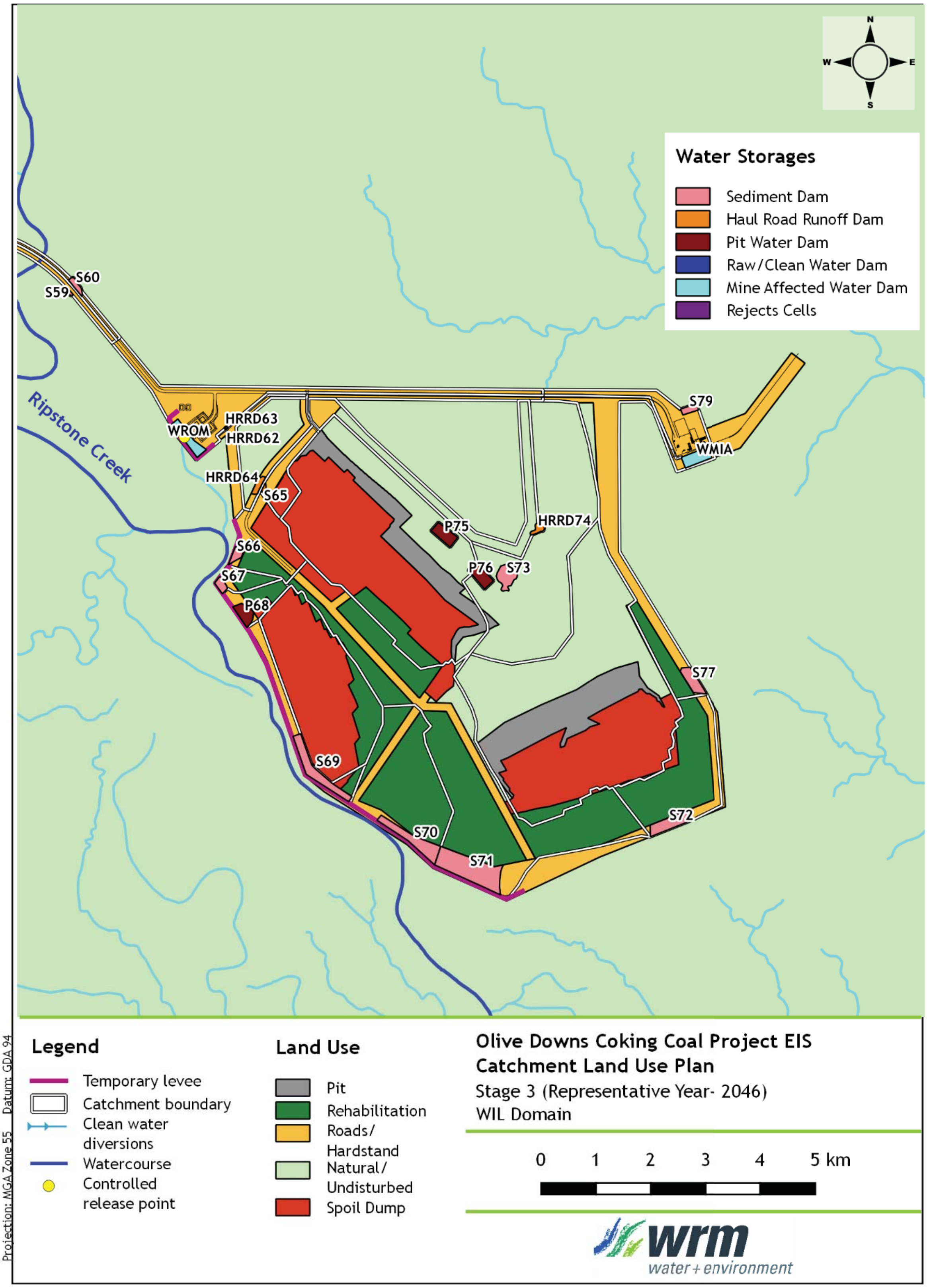

Figure 6-5: Willunga domain – Stage 3 (Year 2046) Mine Plans

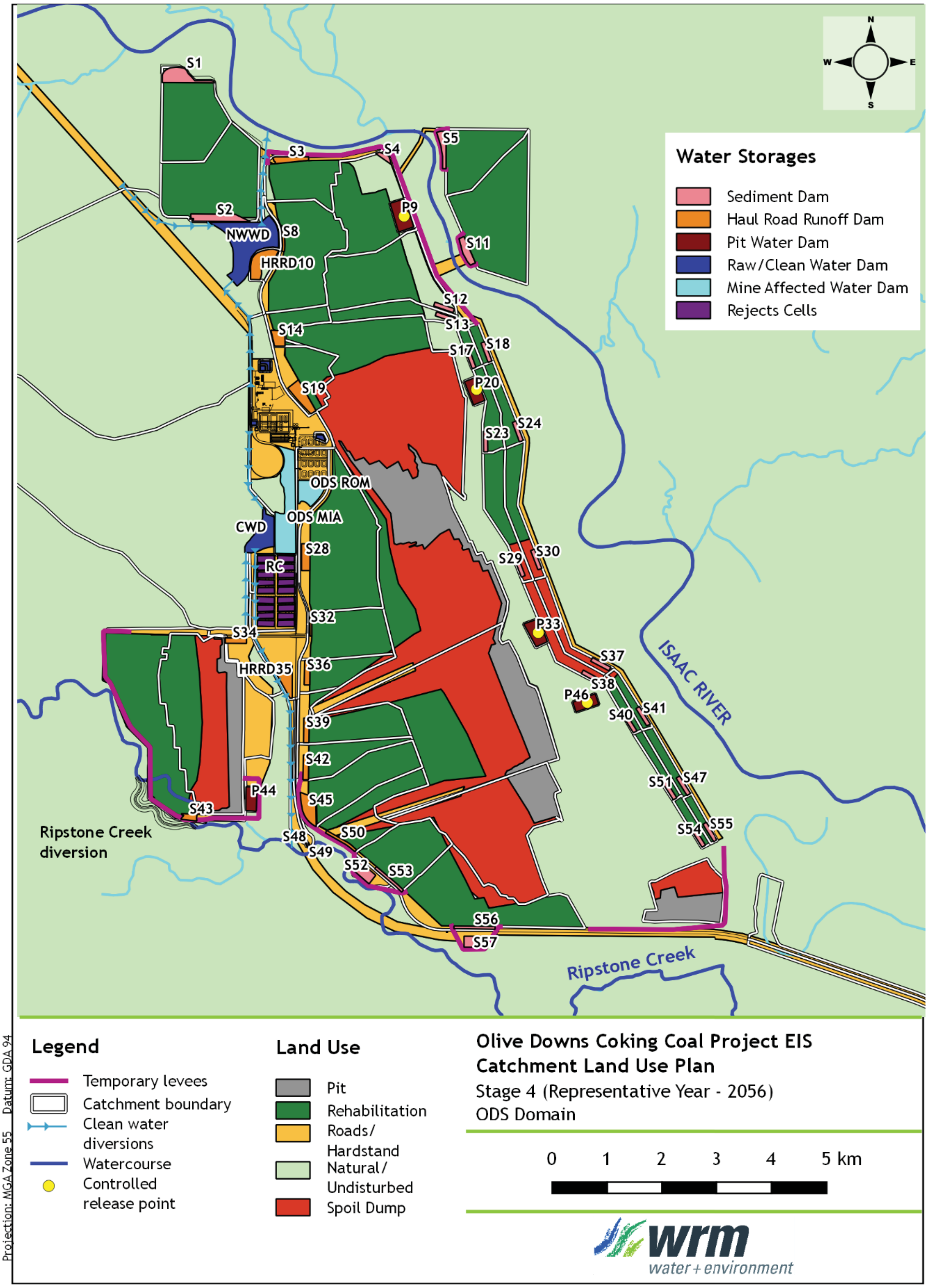

Figure 6-6: Olive Downs South domain – Stage 4 (Year 2056) Mine Plans

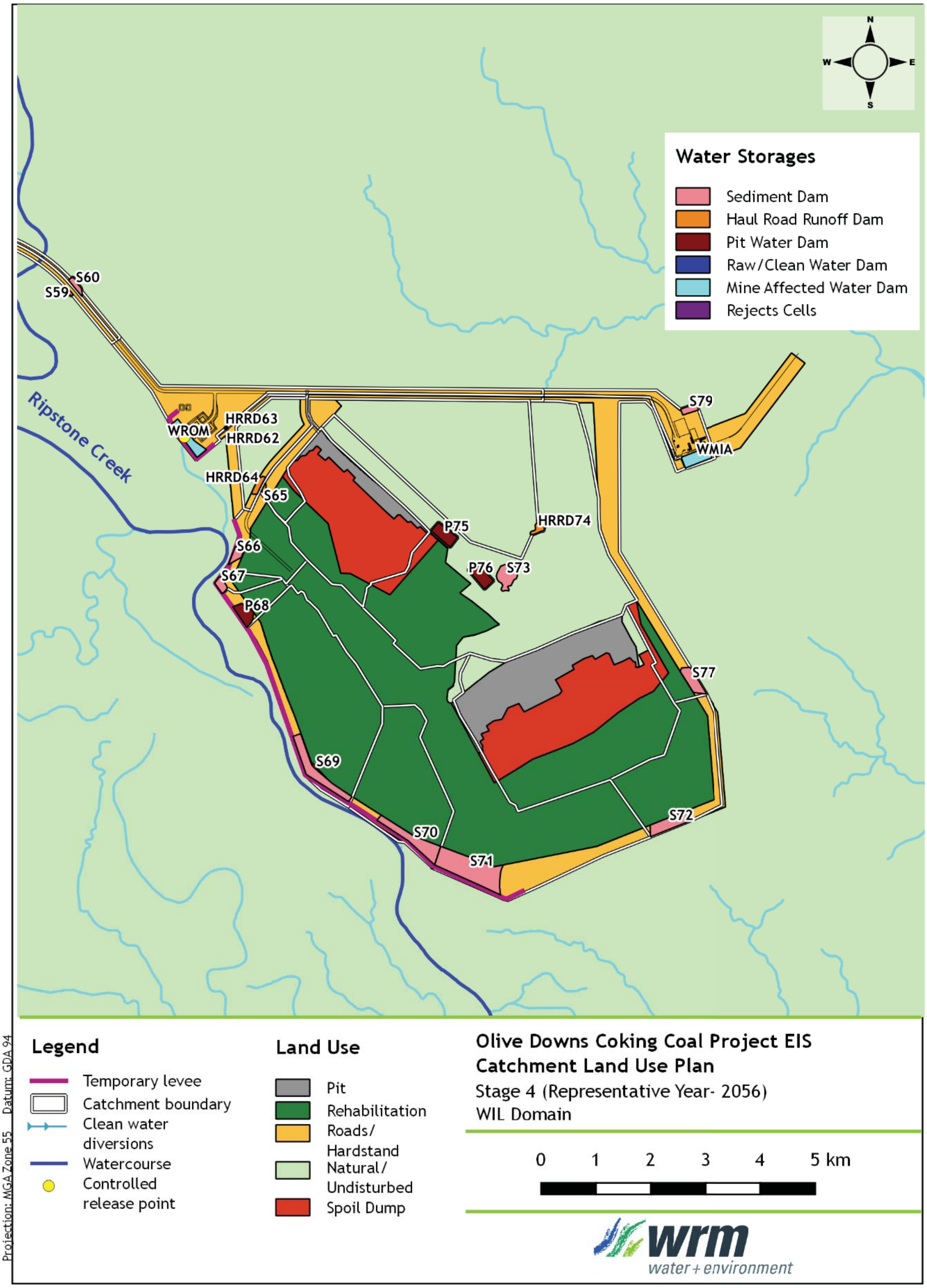

Figure 6-7: Willunga domain – Stage 4 (Year 2056) Mine Plans

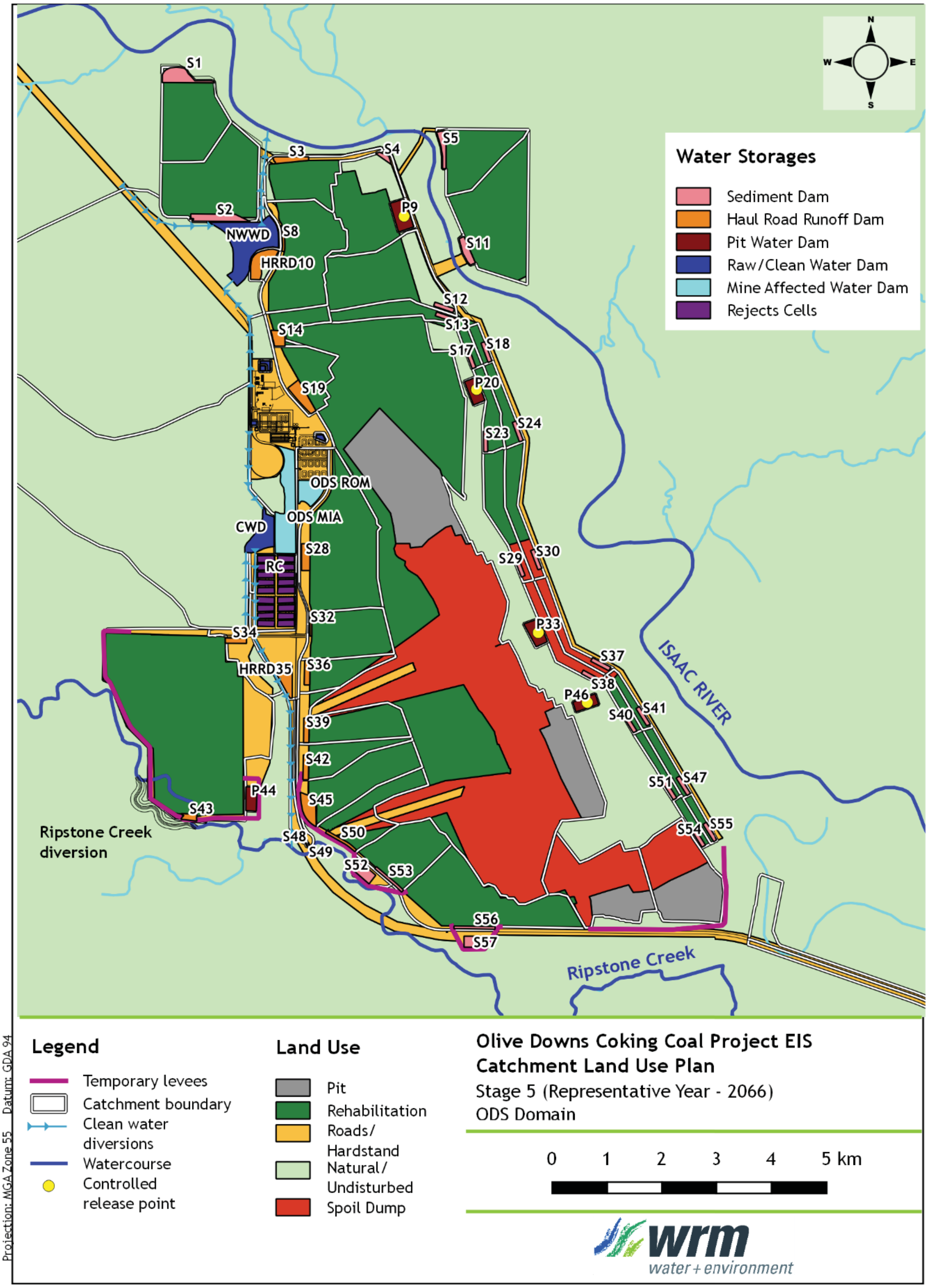

Figure 6-8: Olive Downs South domain – Stage 5 (Year 2066) Mine Plans

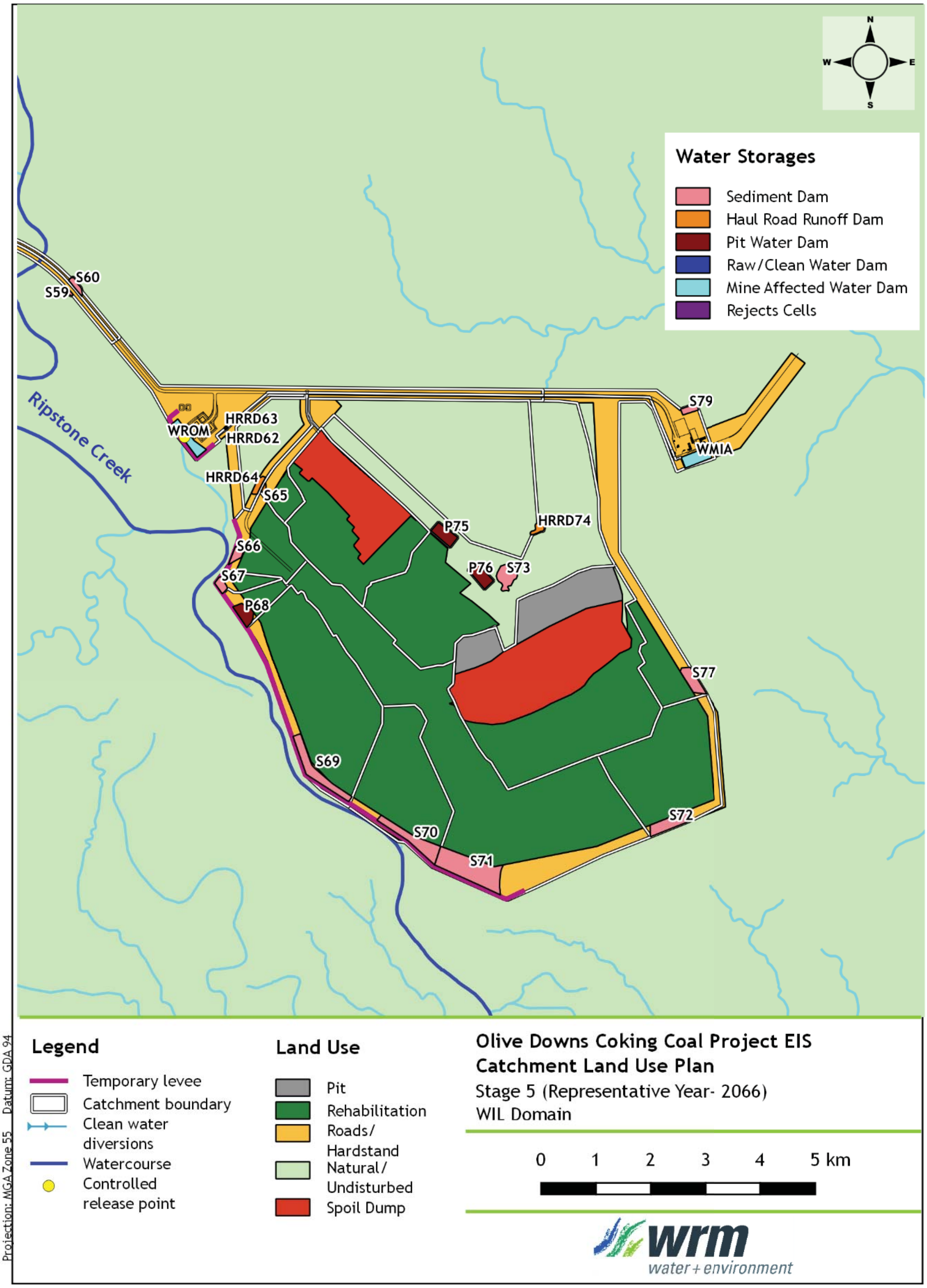

Figure 6-9: Willunga domain – Stage 5 (Year 2066) Mine Plans

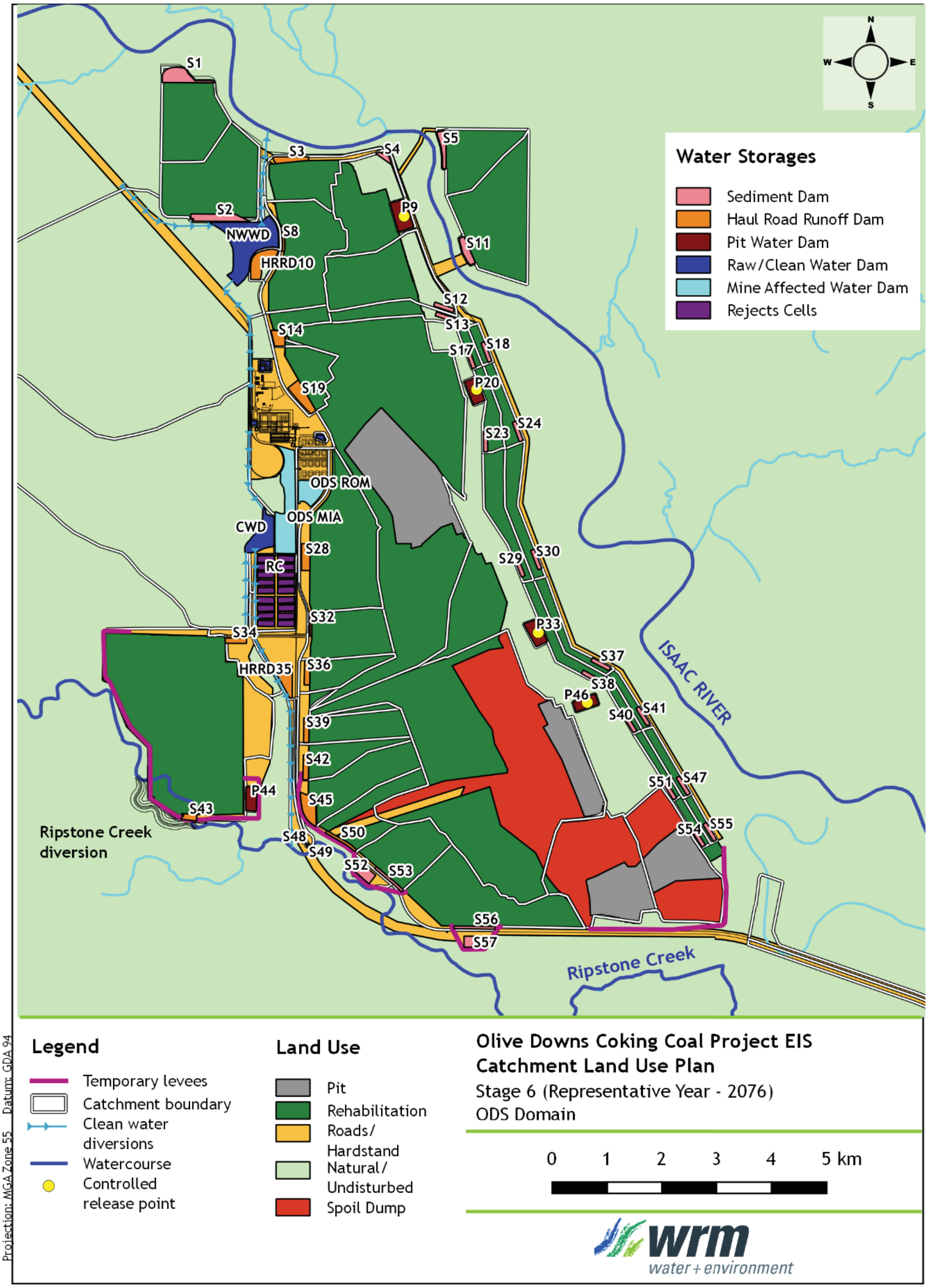

Figure 6-10: Olive Downs South domain – Stage 6 (Year 2076) Mine Plans

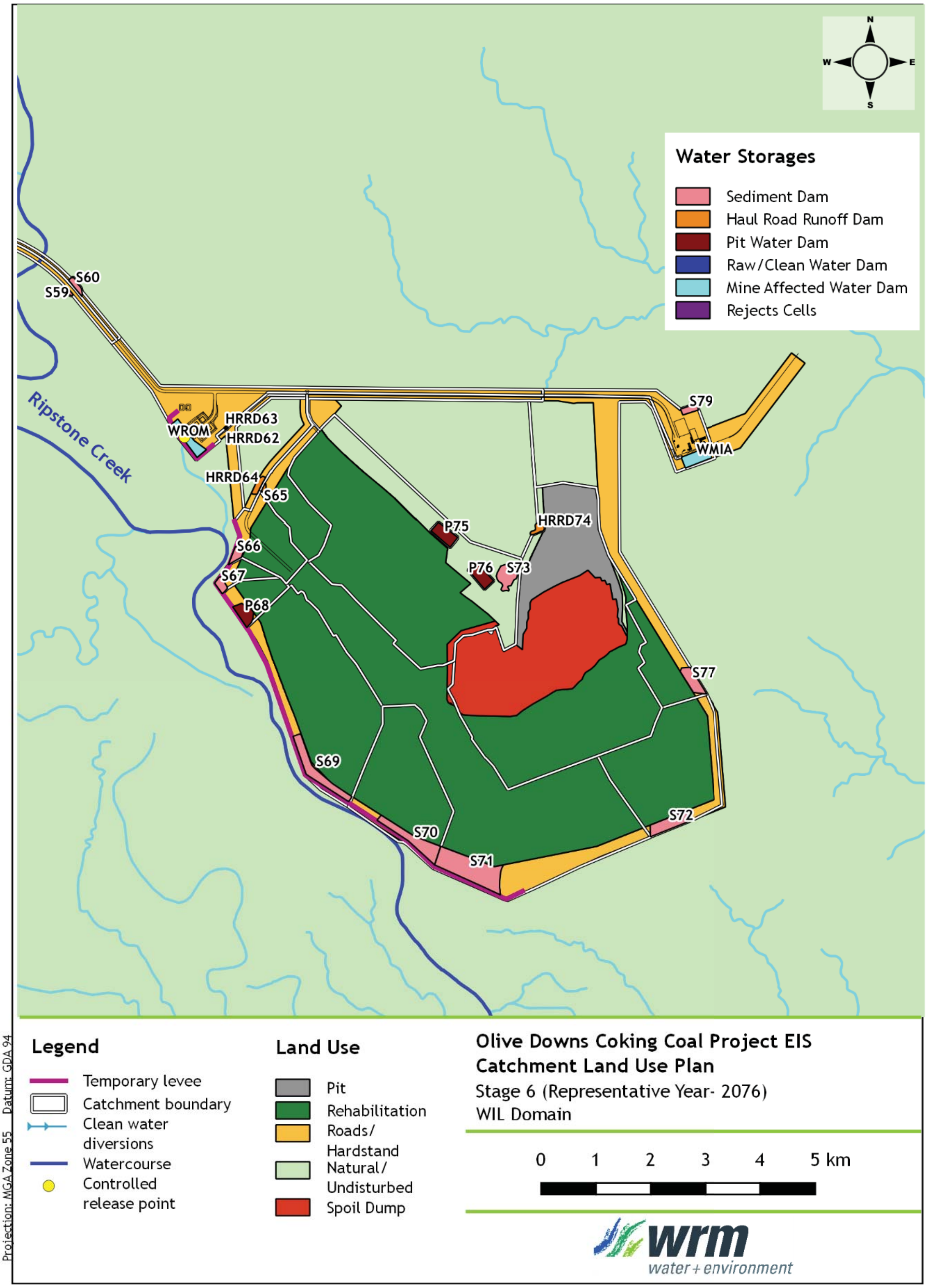

Figure 6-11: Willunga domain – Stage 6 (Year 2076) Mine Plans

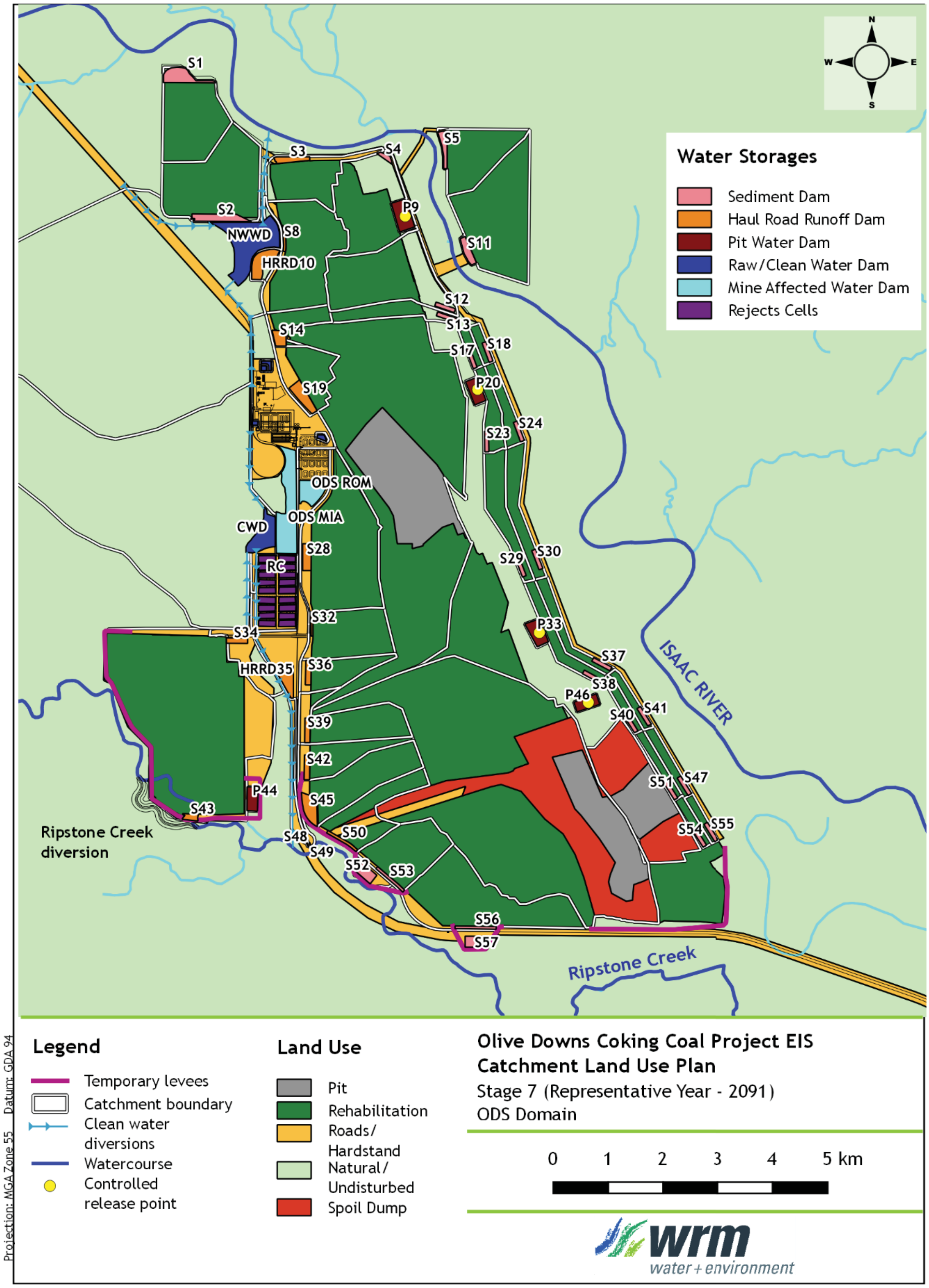

Figure 6-12: Olive Downs South domain – Stage 7 (Year 2091) Mine Plans

6.5 Sewage and Effluent Disposal

Containerised sewage treatment plants and effluent disposal systems will be constructed to service the mine infrastructure areas at the ODS and Willunga domains. Until the sewage treatment plants are operational, sewage from temporary ablution blocks (to be used during the construction phase) will be pumped by a licensed contractor and transported to a local council sewage treatment plant.

Waste sludge will be pumped to storage tanks before being pumped out and transported off-site by a licensed contractor to a licensed disposal facility.

The effluent disposal systems will discharge through an irrigation system. Based on the design capacity of 50 kL per day per plant, a minimum effluent irrigation area of 2.5 ha will be required at the ODS and Willunga domains. The irrigation areas will be located within Project mining tenements and have been designed with prescribed setback distances, but strategically positioned beyond the extent of the 1:1000 AEP flood event to reduce the potential for dispersion off site.

The location of the irrigation areas also considered the proximity to existing groundwater users to reduce potential of effluent seepage to groundwater sources.

Effluent will not be irrigated immediately prior to expected rainfall or if pooling of water was evident at the site, to reduce the potential for runoff contamination. During these periods, effluent will be stored within wet weather storage tanks until such time as irrigation could recommence.

As part of the detailed design phase, modelling will be conducted to confirm the design of the effluent irrigation system and wet weather storage tank capacities, using the Model for Effluent Disposal Using Land Irrigation (MEDLI) software.

The sewage treatment plants will be designed and installed in accordance with the Queensland Government guidelines and relevant Australian Standards

7. Water Balance Model Configuration

7.1 Overview

A computer-based operational simulation model (OPSIM) was used to assess the dynamics of the mine water balance under conditions of varying rainfall and catchment conditions throughout the development of the Project. The OPSIM model dynamically simulates the operation of the water management system and keeps complete account of all site water volumes and representative water quality on a daily time step.

The model has been configured to simulate the operations of all major components of the water management system. The simulated inflows and outflows included in the model are given in Table 7-1.

Table 7-1: Simulated Inflows and Outflows to the Water Management System

Inflows	Outflows
Direct rainfall on water surface of storages	Evaporation from water surface of storages
Catchment runoff	CHPP demand
Groundwater inflows to the open cut pit	Haul road dust suppression demand
Raw water supply	Coal crushing/conveyor dust suppression demand
	Miscellaneous raw water demands
	Mine infrastructure demands
	Potable WTP demands
	Dam overflows
	Controlled releases

7.2 Simulation Methodology

7.2.1 Modelled Staging of Mine Plans

The Project water management system will change over the 79-year mine life, including changes in catchment areas, production profile and site water demands. To represent the evolution of the mine layout over time, the Project was modelled in six discrete stages. Seven representative years have been selected to reflect the average conditions over the mine stage.

The modelled mining phases stages are summarised in Table 7-2. Construction activities are proposed during Years 2018 and 2019, and these two years have not been included in the water balance modelling assessment.

Table 7-2: Application of Representative Mine Stages to Full Mine Life

Representative Mine Stage	Representative Year	Applied Range of Mine Life	Stage Duration
Stage 1	2027	Year 2020 – 2030	11 years
Stage 2	2036	Year 2031 – 2040	10 years
Stage 3	2046	Year 2041 – 2050	10 years
Stage 4	2056	Year 2051 – 2060	10 years
Stage 5	2066	Year 2061 – 2072	12 years

Representative Mine Stage	Representative Year	Applied Range of Mine Life	Stage Duration
Stage 6	2076	Year 2073 – 2085	13 years
Stage 7	2091	Year 2086 – 2098	13 years

7.3 Catchment Yield Parameters

The OPSIM model uses the Australian Water Balance Model (AWBM) (Boughton, 2003) to estimate runoff from rainfall. The AWBM is a saturated overland flow model which allows for variable source areas of surface runoff. The AWBM uses a group of connected conceptual storages (three surface water storages and one ground water storage) to represent a catchment. Water in the conceptual storages is replenished by rainfall and is reduced by evaporation (surface stores only). Simulated surface runoff occurs when the conceptual storages fill and overflow.

The model uses daily rainfalls and estimates of catchment evapotranspiration to calculate daily values of runoff using a daily water balance of soil moisture. The model has a baseflow component which simulates the recharge and discharge of a shallow subsurface store. Runoff depth calculated by the AWBM model is converted into runoff volume by multiplying the contributing catchment area.

The model parameters define the storage depths (C1, C2 and C3), the proportion of the catchment draining to each of the storages (A1, A2 and A3), and the rate of flux between them (K_{base}, K_{surf} and BFI). Catchments across the site have been characterised into the following land use types:

- Natural/undisturbed, representing areas in their natural state;
- Roads and hardstand areas;
- Open cut mining pit floor;
- Spoil dump, representing uncompacted dumped overburden material; and
- Rehabilitated, representing established rehabilitated spoil areas.

The adopted AWBM parameters are shown in Table 7-3. These parameters have been based on parameters typical for coal mines in this part of the Bowen Basin.

Table 7-3: Adopted AWBM parameters

Parameter	Natural/ undisturbed	Roads/ hardstand	Mining pit	Spoil dump	Rehab
A1	0.134	0.1	0.134	0.07	0.134
A2	0.433	0.9	0.433	0.10	0.433
A3	0.433	-	0.433	0.83	0.433
C1	5.7	4	2.6	5	5.1
C2	57.8	16	26.7	10	52.0
C3	115.7	-	53.3	200	104.1
C_{avg}	75.9	14.8	35.0	167	68.3
BFI	0	0	0	0.5	0.5

Parameter	Natural/ undisturbed	Roads/ hardstand	Mining pit	Spoil dump	Rehab
k_{base}	0	0	0	0.9	0.9
k_{surf}	0.1	0	0	0.1	0.1
C_{v*}	15.7%	37.2%	25.8%	10.1%	16.9%

* Long term volumetric runoff coefficient

7.4 Conceptual Water Management System Configuration and Schematic

A conceptual water management system layout for the Project has been developed based on the water management principles described in Section 6 and is presented in Figure 6-1 to Figure 6-12. A schematized plan for the modelled Project's water management system configuration is shown in Figure 7-1.

The proposed Project water management system has been split up into two separate domains; the Olive Downs South (ODS) domain and the Willunga domain. A summary of the mine affected water and clean water storages within the proposed water management system are provided in Table 7-4. Refer to Section 7.14 for details regarding the proposed sediment dams.

A description of summary of the modelled water management system configuration is outlined in Table 7-5.

Table 7-4: Olives Downs Project – Proposed Storage Details

Storage Name	Storage Type	Overflows To
Olive Downs South domain		
ODS MIA	Mine affected water dam	Mining pit
ODS ROM	Mine affected water dam	Mining pit
P9	Pit water dam	Mining pit
P20	Pit water dam	Mining pit
P33	Pit water dam	Mining pit
P44	Pit water dam	Ripstone Creek
P46	Pit water dam	Mining pit
NWWD	Clean water dam	Isaac River
CWD	Clean water dam	Ripstone Creek
Willunga domain		
WROM	Mine affected water dam	Isaac River
WMIA	Mine affected water dam	Isaac River
P68	Pit water dam	Mining pit
P75	Pit water dam	Mining pit
P76	Pit water dam	Mining pit

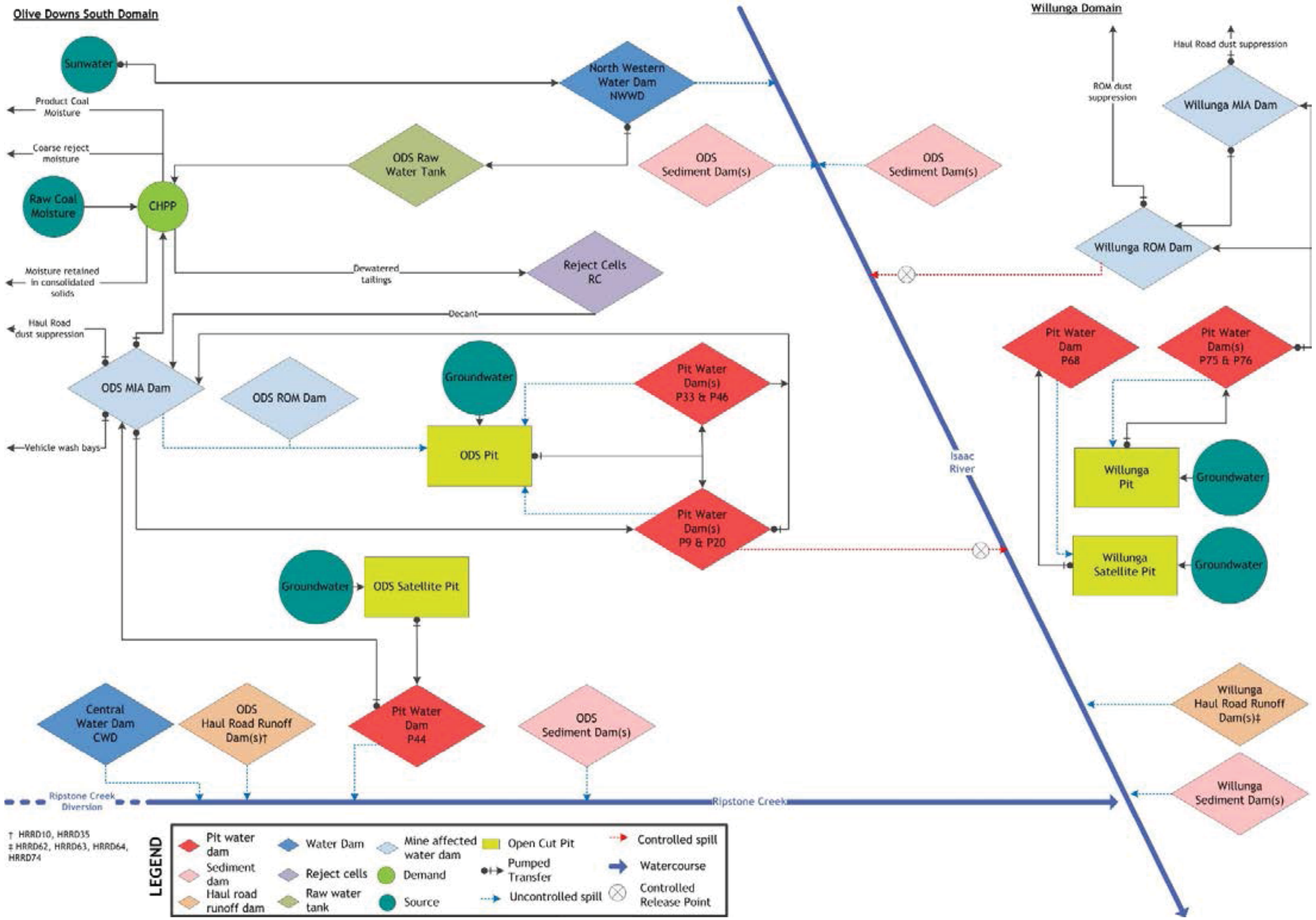

Figure 7-1: Water Management System Schematic

Table 7-5: ODS and Willunga Domains – Modelled Water Management System Configuration

Item		
1.0	**External water supply**	
1.1	Sunwater via Eungella pipeline network	• Supplementary supply to the CHPP (via NWWD and ODS Raw Water Tank) • Supplementary supply to mine infrastructure and raw water demands
2.0	***Supply to demands***	
2.1	CHPP	• Demand supplied from ODS MIA Dam (1st priority) and ODS Raw Water Tank (2nd priority) • Transfers water to the Rejects Cells within the tailings waste stream
2.2	Haul road dust suppression	• Demand supplied from ODS MIA Dam and WMIA Dam
2.3	Coal crushing / conveyor dust suppression	• Demand supplied from ODS MIA Dam
2.4	Miscellaneous raw water demands	• Demand supplied from ODS Raw Water Tank
2.5	Mine infrastructure demands	• Demand supplied from ODS MIA Dam
2.6	Potable water treatment plant (PWTP)	• Demand supplied from ODS Raw Water Tank
3.0	***Transfer of pit water***	
3.1	ODS Pits	• Includes Pit 1, Pit 2, Pit 3, Pit 4, Pit 6, Pit7 and Pit 8 • Pit dewatering directed to ODS MIA Dam via the following storages: o P9 o P20 o P33 (Stage 2 onwards) o P46 (Stage 2 onwards)
3.2	ODS Satellite Pit	• Includes Pit 9 • Pit dewatering directed to ODS MIA Dam via P44 (Stage 2 onwards)
3.3	Willunga Pits	• Includes Pit 2, Pit 3, Pit 4 and Pit 5 • Pit dewatering directed to WROM/WMIA Dam via the following storages: o P75 o P76
3.4	Willunga Satellite Pit	• Pit dewatering directed to WROM/WMIA Dam via the following storages: o P68
4.0	***Operation of mine affected water dams***	
4.1	ODS MIA	• Supplies water to the coal crushing and conveyor, haul road dust suppression, CHPP and other mine industrial demands • Receives decant water from the reject cells • Receives pumped inflows from P9, P20, P33, P44, P46 and ODS ROM

Item		
		• Pumped transfer to P9 and P20 (for controlled release) • Overflows to the mining pit
4.2	ODS ROM	• Pumped transfer to ODS MIA Dam • Overflows to mining pit
4.3	P9	• Pumped transfer to ODS MIA Dam • Controlled discharge to the Isaac River via a controlled release point • Overflows to mining pit
4.4	P20	• Pumped transfer to ODS MIA Dam • Controlled discharge to the Isaac River via a controlled release point • Overflows to mining pit
4.5	P33	• Pumped transfer to ODS MIA Dam • Overflows to mining pit
4.6	P44	• Pumped transfer to ODS MIA Dam • Overflows to Ripstone Creek
4.7	P46	• Pumped transfer to ODS MIA Dam • Overflows to mining pit
4.8	P68	• Pumped transfer to WROM Dam • Overflows to mining pit
4.9	P75	• Pumped transfer to WROM Dam • Overflows to mining pit
4.10	P76	• Pumped transfer to WROM Dam • Overflows to mining pit
4.11	WROM	• Supplies water to ROM dust suppression • Receives pit dewatering from Willunga Pits and Willunga Satellite Pit • Controlled discharge to the Isaac River via a controlled release point • Overflows to the Isaac River
4.12	WMIA	• Transfers water to haul road dust suppression • Receives pit dewatering from Willunga Pits and Willunga Satellite Pit • Pumped transfer to WROM dam • Overflows to Isaac River
4.13	Reject cells	• Receives water within the tailings waste stream • Decant water pumped to ODS MIA Dam • Overflows to ODS MIA Dam
4.14	Haul road runoff dams	• Up to 6 haul road runoff dams active over the life of the project • Receive catchment runoff from haul road catchments • Overflow to receiving environment
5.0	***Operations of clean water dams***	
5.2	NWWD	• Receives local catchment inflows and raw water supply from the Eungella pipeline

Item		
		• Overflows to the Isaac River
5.3	CWD	• Overflows to Ripstone Creek
6.0	***Operations of sediment dams***	
6.1	Sediment dams	• Up to 53 sediment dams active over the life of the project • Assumed to be emptied within 5 days (not modelled) • Overflow to receiving environment
7.0	**Miscellaneous**	• All storages and pits receive local catchment runoff and lose water through evaporation

7.5 Mine Affected Water Dam Capacities

Table 7-6 shows the capacities of the proposed mine affected water dams at the ODS and Willunga domains. These proposed dam capacities are preliminary only and will be confirmed as part of the detailed design process.

Table 7-6: Proposed Mine Affected Water Dam Capacities

Storage	Full Supply Volume (ML)	Target Operating Volume (ML)	Full Supply Surface Area (ha)
ODS domain			
ODS MIA	1,380	1,118	54.2
ODS ROM	552	456	18.4
P9	412	358	21.7
P20	359	312	18.9
P33	236	174	12.4
P44	165	122	8.7
P46	171	126	9.0
Willunga domain			
WMIA	159	104	11.0
WROM	207	153	11.8
P68	956	707	9.0
P75	188	139	9.9
P76	186	138	9.8

7.6 CHPP Water Circuit

The CHPP at the ODS domain will operate 24 hours, seven days a week. Crushed ROM coal from the ODS and Willunga domains will be stockpiled adjacent to the CHPP for direct reclaim and feed.

There are two waste products generated by the CHPP; coarse rejects and fine rejects. Coarse rejects will be transferred to the rejects bin for reclaim by truck and placement to in-pit waste rock emplacement within the final pit footprint, or a separate emplacement area until such time as in-pit disposal areas become available.

Fine rejects from the fine coal circuit will be thickened for transfer (via pipeline) to the Reject Cells, where flocculants will be added and water recovered and recycled in the CHPP. Dewatered and dried fine rejects will be excavated and trucked for disposal with the in-pit disposal area (below existing ground level) and later buried by spoils (generally within three months of placement).

Water is supplied to the CHPP for materials processing from ODS MIA Dam (as a first priority) and ODS Raw Water Tank (as a second priority). The CHPP will use mine affected water as a first priority, and only use raw water when mine affected reserves are depleted.

The moisture contained with the coarse rejects stream (nominally 15% w/w moisture content) is lost from the system during the emplacement process. The moisture contained within the fine rejects stream (nominally 65% w/w moisture content) is partially recovered from the Rejects Cells and recycled back to the CHPP water circuit via ODS MIA Dam. The remaining moisture is either entrained within the dried fine rejects (which is disposed of in-pit) or evaporated from the surface of the Rejects Cells.

Mine affected water generated by the CHPP is contained within the CHPP/Rejects Cells/ODS MIA Dam water circuit, as does not interact with the rest of the water management system. Further details on the CHPP circuit water balance is provided in Section 7.8.1.

7.7 Clean Water Storages and Diversions

7.7.1 Up catchment (Clean) Water Management System

There are two proposed up-catchment (i.e. clean) water storages which form part of the proposed water management system, namely:

- <u>*North Western Water Dam (NWWD)*</u>: an existing farm dam that will continue to collect up-catchment runoff from a catchment of around 2,015 ha, with a modelled capacity of 438 ML. NWWD also operates as a buffer storage for raw water direct from the Eungella pipeline. Overflows from NWWD will discharge north to the Isaac River via a clean water drain.
- <u>*Central Water Dam (CWD)*</u>: a partitioned water storage to segregate up-catchment runoff from the mine affected water management system (i.e. ODS MIA). CWD collects runoff from a catchment of around 1,425 ha, with a modelled capacity of 311 ML. Overflows from CWD will discharge south to Ripstone Creek via a clean water drain. There will be no harvesting of water (or water take) from CWD.

The configuration of the proposed NWWD and CWD storages, as well as the associated up-catchment diversions, is presented in Figure 7-2.

An assessment of the expected annual average water take from NWWD to the Project is provided in Section 8.3.4.1.

7.7.2 Highwall Clean Water Management

During the Project development, there is a large clean water catchment located between the pit highwall and the temporary flood levees and permanent highwall emplacement (which acts as a levee).

Between Stage 1 and Stage 3 of the Project, this catchment will be managed by directing the runoff south via a series of clean water drains. This runoff will ultimately drain to Ripstone Creek via an unnamed drainage feature.

By Stage 4 (when Pit ODS8 begins development), the south-eastern section of the proposed Ripstone Creek levee will be constructed, cutting off the unnamed drainage feature. From Stage 4 onwards, the highwall catchment (which reduces in area over the life of the Project) will be captured within a system of clean water drains and dams, which will be pumped directly to either Ripstone Creek or the Isaac River following rainfall.

Design of the highwall clean water management system will be undertaken during the detailed design process.

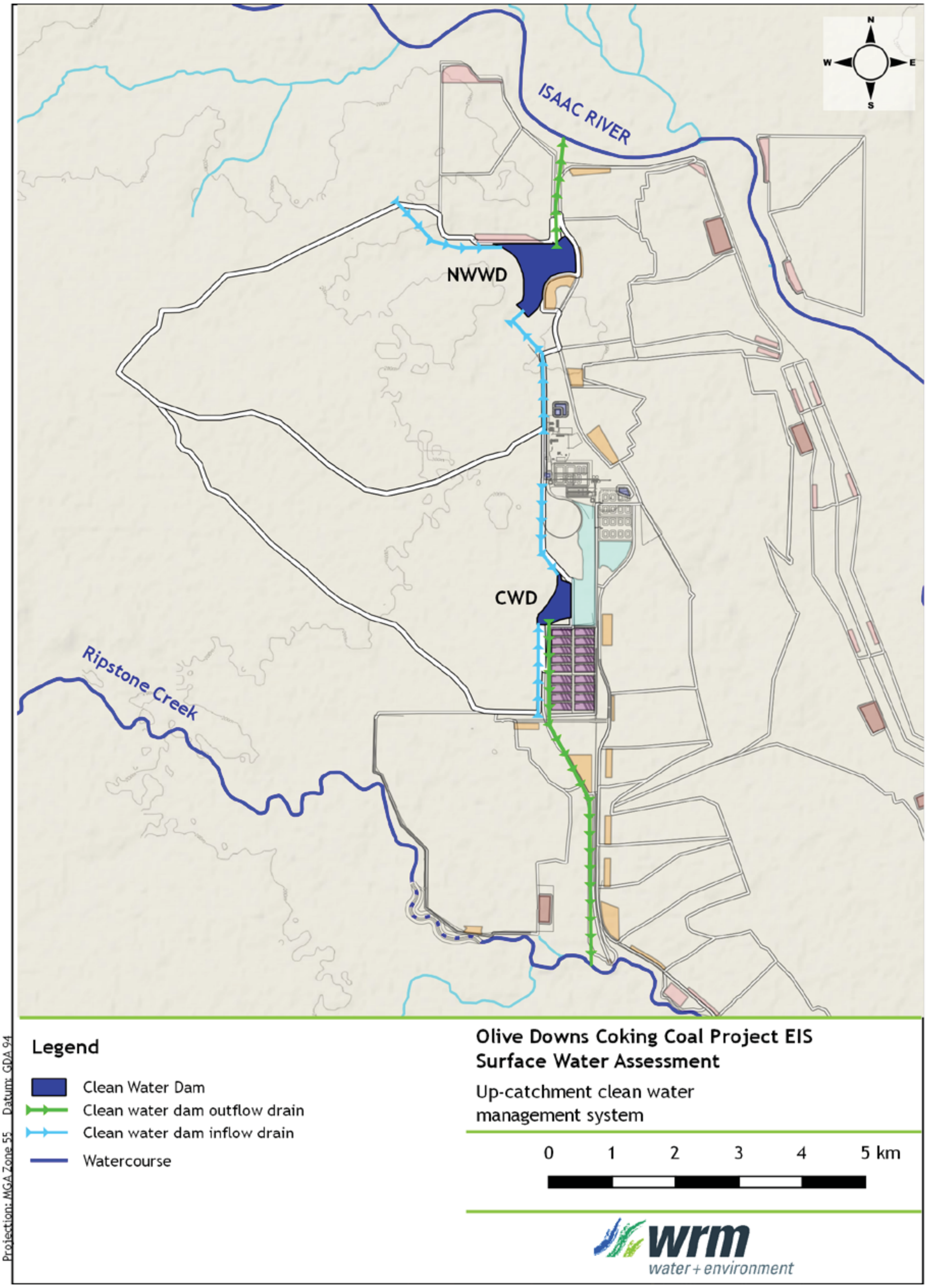

Figure 7-2: Configuration of Proposed Up-catchment Storage and Diversions

7.8 Site Water Demands

7.8.1 Coal Handling and Preparation Plant (CHPP)

The projected annual coal production schedule for the Project, broken down by domain, is summarized in Table 7-7. The key parameters for the CHPP water balance are shown in Table 7-8.

The adopted decant return rate (provided by Phronis) from the Rejects Cells to the CHPP (via ODA MIA Dam) is 70%. This decant return rate is considered appropriate for the proposed configuration of the fine rejects circuit. This decant rate significantly reduces the net CHPP makeup water requirement.

The estimated gross and net annual CHPP water makeup requirement for each year is provided in Table 7-9 and presented in Figure 7-3.

Table 7-7: Forecast Annual Production Data

Stage	Year	ROM (Mtpa) (wet)			Product (Mtpa) (wet)		
		ODS	Willunga	Total	ODS	Willunga	Total
1	2020	1.00	0.00	1.00	0.76	0.00	0.76
	2021	3.00	0.00	3.00	2.19	0.00	2.19
	2022	5.70	0.00	5.70	4.15	0.00	4.15
	2023	6.00	0.00	6.00	4.32	0.00	4.32
	2024	6.00	0.00	6.00	4.44	0.00	4.44
	2025	5.93	0.00	5.93	4.38	0.00	4.38
	2026	6.00	0.00	6.00	4.44	0.00	4.44
	2027	6.00	0.00	6.00	4.42	0.00	4.42
	2028	5.91	0.00	5.91	4.41	0.00	4.41
	2029	5.40	0.00	5.40	4.06	0.00	4.06
	2030	5.64	0.12	5.76	4.22	0.08	4.29
2	2031	6.00	5.00	11.00	4.53	3.28	7.81
	2032	9.00	4.83	13.83	6.81	3.12	9.93
	2033	12.00	6.00	18.00	9.15	3.95	13.09
	2034	12.00	8.00	20.00	9.15	5.43	14.58
	2035	11.82	8.00	19.82	8.98	5.58	14.56
	2036	12.00	8.00	20.00	9.11	5.74	14.85
	2037	12.00	8.00	20.00	9.24	5.80	15.05
	2038	12.00	8.00	20.00	8.98	5.81	14.79
	2039	12.00	8.00	20.00	9.20	5.80	15.00
	2040	12.00	8.00	20.00	9.15	5.79	14.94
3	2041	11.56	8.00	19.56	8.72	5.91	14.63
	2042	10.60	8.00	18.60	7.96	5.79	13.76
	2043	11.14	8.00	19.14	8.39	5.69	14.08
	2044	12.00	8.00	20.00	9.07	5.93	15.00
	2045	11.75	7.13	18.87	8.84	5.27	14.12
	2046	12.00	6.86	18.86	9.12	5.25	14.37
	2047	9.49	6.74	16.23	7.12	5.11	12.24

Stage	Year	ROM (Mtpa) (wet)			Product (Mtpa) (wet)		
		ODS	Willunga	Total	ODS	Willunga	Total
	2048	7.70	6.04	13.74	5.61	4.63	10.24
	2049	7.57	7.63	15.20	5.55	5.86	11.41
	2050	9.75	4.92	14.66	7.05	3.89	10.93
4	2051	6.34	4.50	10.83	4.92	3.47	8.39
	2052	2.97	3.89	6.86	2.31	3.04	5.35
	2053	4.98	4.69	9.67	3.89	3.67	7.56
	2054	5.09	3.98	9.07	3.96	2.99	6.95
	2055	5.95	4.12	10.06	4.62	3.27	7.89
	2056	6.64	3.51	10.15	5.18	2.72	7.90
	2057	3.08	4.78	7.86	2.40	3.69	6.08
	2058	3.77	3.51	7.29	2.90	2.68	5.58
	2059	2.85	3.55	6.39	2.21	2.74	4.95
	2060	3.00	4.66	7.67	2.28	3.60	5.88
5	2061	2.93	3.64	6.56	2.29	2.80	5.08
	2062	2.24	4.50	6.75	1.69	3.49	5.18
	2063	1.05	4.13	5.19	0.80	3.20	4.00
	2064	2.22	3.11	5.32	1.68	2.34	4.02
	2065	1.20	4.06	5.26	0.87	3.09	3.96
	2066	2.62	4.31	6.93	2.00	3.26	5.26
	2067	2.59	4.18	6.78	1.98	3.13	5.11
	2068	0.84	4.81	5.65	0.63	3.64	4.28
	2069	0.98	4.77	5.75	0.75	3.63	4.38
	2070	1.34	3.46	4.79	1.03	2.51	3.54
	2071	0.71	0.18	0.89	0.56	0.15	0.71
	2072	1.36	0.61	1.98	1.04	0.52	1.55
6	2073	0.75	0.80	1.56	0.58	0.66	1.24
	2074	1.05	1.92	2.98	0.82	1.52	2.35
	2075	0.71	1.35	2.06	0.54	1.02	1.57
	2076	0.92	2.41	3.33	0.72	1.86	2.58
	2077	1.07	1.82	2.89	0.79	1.35	2.13
	2078	0.97	2.14	3.12	0.73	1.65	2.38
	2079	1.37	1.32	2.69	1.03	1.04	2.07
	2080	0.85	1.71	2.56	0.64	1.32	1.96
	2081	1.29	1.64	2.94	0.96	1.27	2.23
	2082	1.27	1.31	2.58	0.94	1.00	1.94
	2083	1.08	1.54	2.62	0.83	1.15	1.98
	2084	1.26	1.75	3.02	0.96	1.31	2.27
	2085	1.39	1.69	3.08	1.06	1.25	2.32
7	2086	1.47	0.00	1.47	1.12	0.00	1.12
	2087	1.78	0.00	1.78	1.35	0.00	1.35
	2088	1.71	0.00	1.71	1.31	0.00	1.31
	2089	1.84	0.00	1.84	1.44	0.00	1.44
	2090	0.40	0.00	0.40	0.31	0.00	0.31

Stage	Year	ROM (Mtpa) (wet)			Product (Mtpa) (wet)		
		ODS	Willunga	Total	ODS	Willunga	Total
	2091	0.62	0.00	0.62	0.48	0.00	0.48
	2092	0.56	0.00	0.56	0.43	0.00	0.43
	2093	0.38	0.00	0.38	0.29	0.00	0.29
	2094	0.58	0.00	0.58	0.45	0.00	0.45
	2095	0.81	0.00	0.81	0.63	0.00	0.63
	2096	1.13	0.00	1.13	0.88	0.00	0.88
	2097	1.43	0.00	1.43	1.13	0.00	1.13
	2098	1.42	0.00	1.42	1.09	0.00	1.09

Table 7-8: Key CHPP Water Balance Parameters

Item	Moisture Content (% w/w)
Moisture contents	
ROM coal	7.0
Product coal	10.0
Coarse rejects	15.0
Fine rejects	65.0
Coarse reject split	77%
Fine reject split	23%

Table 7-9: Estimated Annual CHPP Makeup Requirements

Stage	Year	Gross CHPP Makeup Requirement	Decant Return Volume	Net CHPP Makeup Requirement
		(ML/a)	(ML/a)	(ML/a)
1	2020	145.5	74.2	71.3
	2021	468.8	244.0	224.8
	2022	900.7	470.1	430.6
	2023	963.8	505.3	458.4
	2024	914.7	472.8	441.8
	2025	907.4	469.6	437.7
	2026	916.7	474.2	442.5
	2027	922.0	477.7	444.3
	2028	887.1	456.6	430.5
	2029	800.0	410.1	389.8
	2030	868.5	447.5	421.0
2	2031	1810.4	955.3	855.1
	2032	2234.6	1173.5	1061.1
	2033	2840.3	1482.2	1358.0
	2034	3143.2	1638.6	1504.7
	2035	3072.2	1595.4	1476.8

Stage	Year	Gross CHPP Makeup Requirement	Decant Return Volume	Net CHPP Makeup Requirement
		(ML/a)	(ML/a)	(ML/a)
	2036	3031.3	1564.5	1466.8
	2037	2952.6	1512.4	1440.2
	2038	3055.1	1580.3	1474.8
	2039	2973.1	1526.0	1447.1
	2040	2994.8	1540.3	1454.4
3	2041	2919.4	1500.3	1419.2
	2042	2843.7	1471.2	1372.5
	2043	2955.3	1533.2	1422.1
	2044	2971.0	1524.6	1446.4
	2045	2819.0	1448.9	1370.1
	2046	2707.6	1375.6	1332.1
	2047	2386.8	1221.2	1165.6
	2048	2067.3	1064.8	1002.5
	2049	2255.2	1156.9	1098.3
	2050	2204.1	1135.0	1069.2
4	2051	1500.7	754.0	746.7
	2052	935.3	467.6	467.7
	2053	1312.4	655.0	657.3
	2054	1289.0	652.7	636.3
	2055	1356.1	675.3	680.8
	2056	1392.9	697.6	695.3
	2057	1092.5	549.4	543.1
	2058	1037.8	525.9	511.9
	2059	887.4	446.1	441.3
	2060	1087.3	550.3	537.0
5	2061	910.8	457.9	453.0
	2062	953.1	481.8	471.3
	2063	725.4	365.5	359.8
	2064	779.8	398.5	381.3
	2065	774.8	396.6	378.1
	2066	1007.0	513.4	493.7
	2067	993.7	508.0	485.7
	2068	825.1	421.3	403.9
	2069	827.3	420.6	406.7
	2070	732.8	379.2	353.7
	2071	113.4	55.4	57.9
	2072	263.8	131.0	132.8
6	2073	200.3	98.2	102.1
	2074	395.6	196.1	199.5
	2075	296.8	151.0	145.8
	2076	462.3	232.3	229.9

Stage	Year	Gross CHPP Makeup Requirement	Decant Return Volume	Net CHPP Makeup Requirement
		(ML/a)	(ML/a)	(ML/a)
	2077	444.2	230.1	214.1
	2078	447.1	227.0	220.0
	2079	380.4	192.4	188.1
	2080	364.3	184.5	179.8
	2081	424.8	216.3	208.5
	2082	380.8	195.0	185.7
	2083	380.2	193.8	186.3
	2084	444.5	227.6	216.9
	2085	455.5	233.4	222.1
7	2086	210.9	107.2	103.7
	2087	259.2	132.2	127.0
	2088	242.1	122.6	119.5
	2089	247.9	123.5	124.5
	2090	53.8	26.8	27.0
	2091	83.1	41.4	41.7
	2092	77.3	38.9	38.4
	2093	51.6	25.9	25.8
	2094	77.2	38.4	38.8
	2095	112.4	56.4	55.9
	2096	154.8	77.5	77.3
	2097	190.4	94.4	96.1
	2098	203.3	103.1	100.2

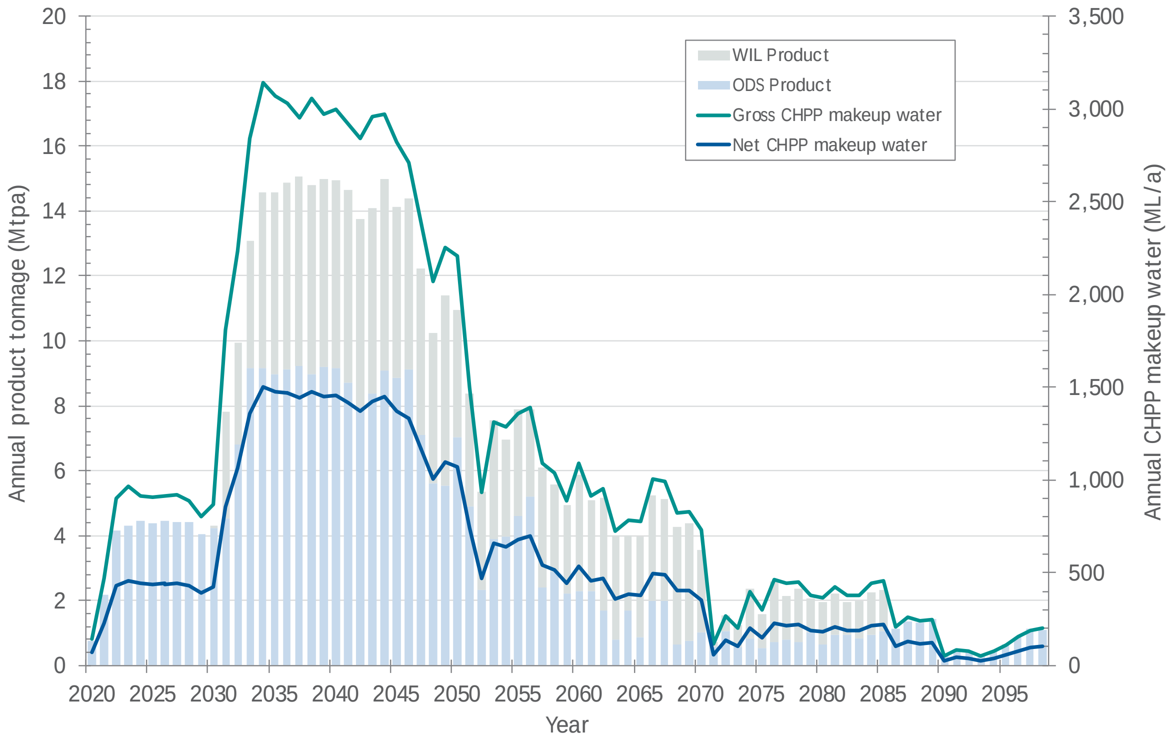

Figure 7-3: Estimated Gross and Net Annual CHPP Makeup Water Requirements

7.8.2 *Haul Road Dust Suppression*

Water for haul road dust suppression is sourced from the ODS and Willunga MIA dams. Haul road dust suppression watering rates have been applied to the haul road areas that vary as mining progresses. Haul road length were measured from the provided mine plans and are summarised as follows:

- Stage 1 – approximately 9.5 km of haul road
- Stages 2 to 6 – approximately 39.0 km of haul road

The following rules were used to determine the applied dust suppression rate on any given day of the historical rainfall record:

- The assessment used daily pan evaporation rates sourced from the SILO Datadrill evaporation dataset.
- For a dry day (zero rainfall), the haul road watering rate is equal to the daily evaporation rate.
- For a rain day when rainfall is less than the daily evaporation rate, the watering rate is reduced and is only required to make up the remaining depth to the daily evaporation rate.
- For a rain day when rainfall exceeds the daily evaporation rate, no haul road watering is required.
- It was assumed that 27.5 metres of the haul road width would be watered.

The estimated consumption rates for each phase are summarised in Table 7-10.

Table 7-10: Forecast Haul Road Dust Suppression Usage

Stage	Haul Road Length (km)	Avg. Daily Application Rate (mm/d)	Max. Daily Application Rate (mm/d)	Avg. Annual Usage (ML/a)	Avg. Daily Usage (ML/d)
1	9.5	5.0	14.2	473	1.3
2 to 7	39.0	5.0	14.2	1,948	5.3

7.8.3 *Coal Crushing / Conveyor Dust Suppression*

Water for coal crushing and conveyor dust suppression will be supplied from the mine affected water system at an estimated annual rate of 400 ML/a.

7.8.4 *Miscellaneous Raw Water Demands*

Miscellaneous raw water demands will be supplied from the Raw Water Tank at an estimated annual rate of 80 ML/a.

7.8.5 *Mine Infrastructure Demands*

Mine infrastructure demands will be supplied from the mine affected water system at an estimated annual rate of 40 ML/a.

7.8.6 *Potable Water Treatment Plant Demands*

The proposed Potable Water Treatment Plant (PWTP) will be supplied by the Raw Water Tank at an estimated annual rate of 50 ML/a.

7.8.7 *Construction Water Supply Demands*

The estimated the use of water during construction would be approximately 570 ML/a (i.e. approximately 1.6 ML/day). The construction phase of the Project has not been modelled.

7.9 Water Sources

7.9.1 *Groundwater Inflows*

The adopted groundwater inflows to the open cut pits are based on estimates provided by SLR Consulting and have been provided annually between 2020 and 2055 and as 5-year averages between 2055 and 2098. A summary of the predicted groundwater inflows (grouped by main pit area) are provided in Table 7-11 and Figure 7-4.

Table 7-11: Estimated Annual Groundwater Inflows

Stage	Year	ODS Main Pits	ODS Satellite Pit	Willunga Main Pits	Willunga Satellite Pit	TOTAL
		(ML/a)	(ML/a)	(ML/a)	(ML/a)	(ML/a)
1	2020	0	0	0	0	0
	2021	31	0	0	0	31
	2022	150	0	0	0	150
	2023	261	0	0	0	261
	2024	373	0	0	0	373

Stage	Year	ODS Main Pits (ML/a)	ODS Satellite Pit (ML/a)	Willunga Main Pits (ML/a)	Willunga Satellite Pit (ML/a)	TOTAL (ML/a)
	2025	364	0	0	0	364
	2026	367	0	0	0	367
	2027	353	0	0	0	353
	2028	397	0	0	0	397
	2029	401	0	0	0	401
	2030	336	0	88	0	423
2	2031	560	0	317	0	877
	2032	729	6	213	0	947
	2033	757	45	153	0	955
	2034	720	134	124	0	978
	2035	684	109	98	410	1,302
	2036	622	115	95	588	1,420
	2037	598	108	126	748	1,581
	2038	532	93	127	716	1,458
	2039	496	53	124	674	1,347
	2040	530	44	121	563	1,257
3	2041	543	45	127	474	1,190
	2042	577	41	139	772	1,530
	2043	582	40	135	640	1,397
	2044	724	54	165	504	1,448
	2045	485	38	113	0	636
	2046	366	41	107	0	514
	2047	277	41	78	0	396
	2048	138	41	26	0	205
	2049	144	41	45	0	230
	2050	219	40	53	0	312
4	2051	213	40	37	0	290
	2052	676	32	34	0	742
	2053	696	38	37	0	771
	2054	517	40	38	0	594
	2055	448	17	34	0	498
	2056	205	0	17	0	222
	2057	204	0	17	0	222
	2058	204	0	17	0	222
	2059	204	0	17	0	222
	2060	205	0	17	0	222

Stage	Year	ODS Main Pits	ODS Satellite Pit	Willunga Main Pits	Willunga Satellite Pit	TOTAL
		(ML/a)	(ML/a)	(ML/a)	(ML/a)	(ML/a)
5	2061	151	0	26	0	177
	2062	151	0	26	0	177
	2063	151	0	26	0	177
	2064	152	0	26	0	177
	2065	151	0	26	0	177
	2066	110	0	30	0	140
	2067	110	0	30	0	140
	2068	110	0	30	0	140
	2069	110	0	30	0	140
	2070	110	0	30	0	140
	2071	79	0	18	0	97
	2072	79	0	18	0	97
6	2073	79	0	18	0	97
	2074	79	0	18	0	97
	2075	79	0	18	0	97
	2076	60	0	43	0	103
	2077	59	0	43	0	102
	2078	59	0	43	0	102
	2079	59	0	43	0	102
	2080	60	0	43	0	103
	2081	51	0	100	0	151
	2082	51	0	100	0	151
	2083	51	0	100	0	151
	2084	51	0	100	0	151
	2085	51	0	100	0	151
7	2086	67	0	28	0	95
	2087	67	0	28	0	95
	2088	68	0	28	0	96
	2089	67	0	28	0	95
	2090	67	0	28	0	95
	2091	71	0	5	0	76
	2092	72	0	5	0	76
	2093	71	0	5	0	76
	2094	71	0	5	0	76
	2095	71	0	5	0	76
	2096	71	0	5	0	76

Stage	Year	ODS Main Pits	ODS Satellite Pit	Willunga Main Pits	Willunga Satellite Pit	TOTAL
		(ML/a)	(ML/a)	(ML/a)	(ML/a)	(ML/a)
	2097	71	0	5	0	76
	2098	71	0	5	0	76

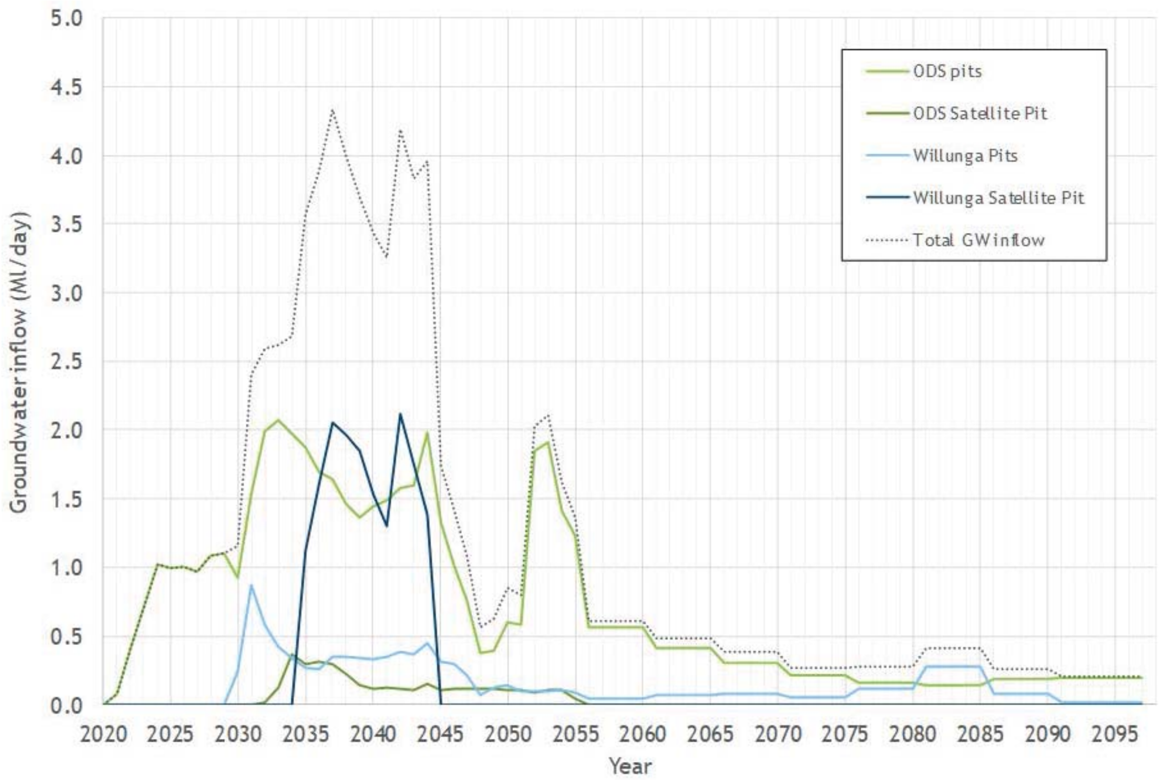

Figure 7-4: Estimated Annual Groundwater Inflows

7.10 Isaac River Flow Modelling

Flows in the Isaac River are simulated using a calibrated AWBM parameter set, as summarised in Table 7-12. This AWBM parameter set was calibrated against recorded stream flows at the Goonyella Gauge (130414A) between June 1998 and July 2000. This period was chosen as it is a known period where there were no discharges from Burton Gorge Dam. The outcomes from the calibration are presented in Figure 7-5.

Table 7-12: Adopted AWBM parameters for Isaac River

Parameter	Isaac River
A1	0.134
A2	0.433
A3	0.433
C1	15.4
C2	91.2
C3	181.0

Parameter	Isaac River
C_{avg}	119.9
BFI	0.35
k_{base}	0.6
k_{surf}	0.1

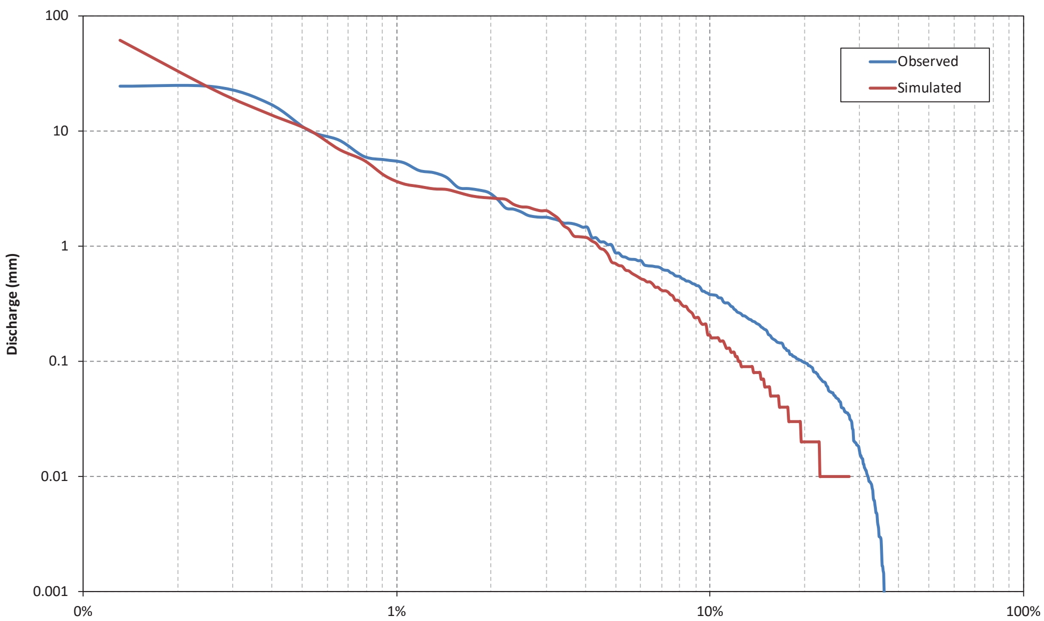

Figure 7-5: Isaac River Catchment AWBM Parameter Calibration, Flow Duration Relationship – Simulated vs Observed

7.11 Controlled Releases

Water release conditions have been developed for releases to the Isaac based on the *DEHP Guideline Model Mining Conditions*. The water balance model has been configured to simulate these release conditions, using salt measured as electrical conductivity as the target contaminant. A summary of the proposed release conditions is provided in Table 7-13 and presented in Figure 7-6.

The proposed controlled releases strategy comprises a number of mine affected water dams which will have the ability to discharge water to the Isaac River through a gravity pipe system. There are four proposed controlled release points (RP's) at the ODS domain and one at the Willunga domain. However, due to the progressive mining activities from north to south at the ODS domain, it is likely that only two of the four dams would operate simultaneously.

The release point dams are proposed to be above ground turkey's nest type dams around 5 m deep. They will be constructed above the natural surface to provide sufficient driving head for gravity discharge. The gravity discharge solution is preferred because it allows for an efficient discharge mechanism and can provide significant discharge capacity during the relatively short discharge opportunities for the Isaac River flow regime.

Potential pump solutions to supplement to gravity release system will be considered during the detailed design process.

Table 7-13: Proposed Mine Affected Water Release Limits (During Flow Events)

Receiving waters	Release Point (RP)	Gauging Station	Receiving Water Flow Criteria for Discharge	Maximum Release Rate (for all combined RP flows)*2	Electrical Conductivity Release Limits
Isaac River	P9 P20 P33 P46 WROM P44*1 WMIA*1	130410A Isaac River @ Deverill	**Medium Flow**		
			4 m^3/s	0.5 m^3/s	1,000 µs/cm
			10 m^3/s	1.0 m^3/s	1,200 µs/cm
			High Flow		
			50 m^3/s	2.0 m^3/s	4,000 µs/cm
			100 m^3/s	3.0 m^3/s	6,000 µs/cm
			Very High Flow		
			300 m^3/s	5.0 m^3/s	10,000 µs/cm

Note: *1 Although P44 and WMIA are designated release points, they are not part of the overall controlled release strategy.
*2 The specified Maximum Release Rate represents the combined discharge rate from all active release points. This will likely include only two or three controlled release points at any stage of the Project.

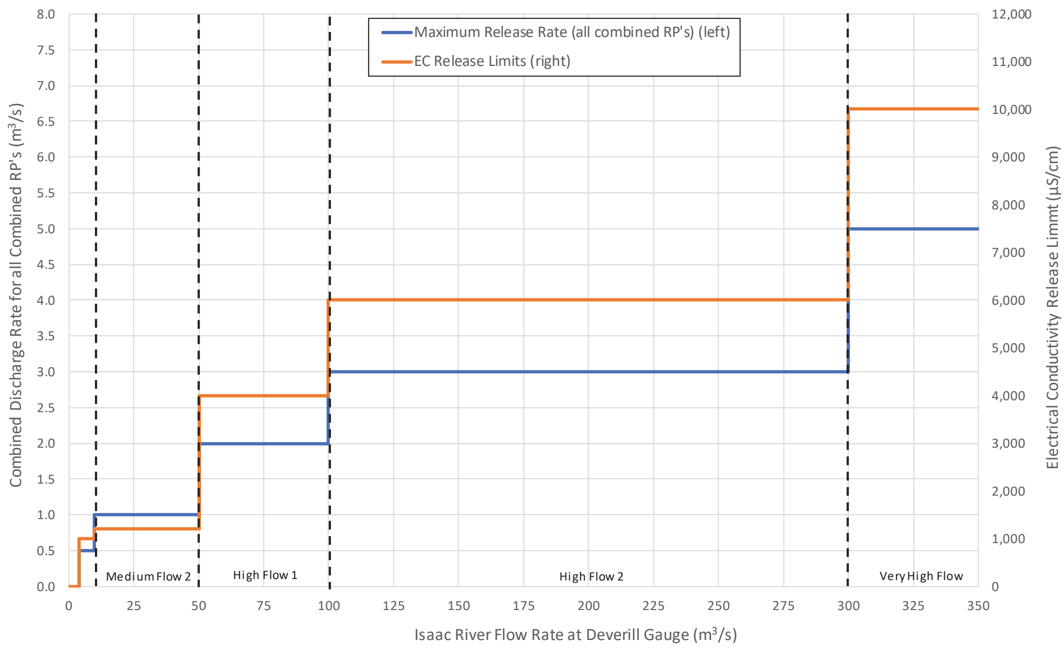

Figure 7-6: Proposed Controlled Release Strategy

7.12 Water Quality Modelling

7.12.1 Overview

The Project water balance model is configured to use salinity as an indicator of water quality. This has been achieved by assigning representative electrical conductivity (EC) values to runoff from catchments and other sources of water.

The geochemical characterisation of the potential spoil (Terrenus, 2018) provided the following commentary regarding other contaminants:

- The total sulfur concentration of potential spoil is low. Almost all spoil samples are classified as Non Acid Forming (NAF) and most (93% of) NAF samples are further classified as 'barren' with respect to sulfur concentrations.
- Total metal and metalloid concentrations in potential spoil samples are very low compared to average element abundance in soil in the earth's crust.
- Soluble multi-element results indicate that leachate from bulk spoil has the potential to contain slightly elevated soluble aluminium, arsenic and/or selenium concentrations compared to applied ANZECC (2000) aquatic ecosystem protection water quality guideline concentrations. Slightly elevated concentrations for some metals/metalloids for spoil and coal reject materials are common at coal mines in the Bowen Basin and generally do not result in any significant water quality issues.
- It is important to note that the results represent an 'assumed worst case' scenario as the samples are pulverised (to minus 75 micrometres) prior to testing. Therefore, samples have a very high surface area compared to materials in the field. Materials would also be well mixed at storage locations. Hence, it is expected that the concentration of metal/metalloids in surface run-off and seepage from spoil (and coal reject) materials in the field would be significantly less than the laboratory results from these 'pulped' samples.

Given the outcomes from the geochemical characterisation report, modelling of other contaminants has not been undertaken as part of this surface water assessment. If, when operations commence, monitoring indicates that there are other contaminants of concern, then the water balance model can be updated to include additional water quality parameters.

7.12.2 *Adopted Salinity Parameters*

The proposed EC values are shown in Table 7-14, with discussion relating to the source of the proposed values.

Table 7-14: Adopted Salinity Concentrations

Water Source/ Land Use	EC (µs/cm)	Comment
Isaac River flows	80-800 (dependent on flow)	Flow vs EC relationship developed based on recorded EC at Deverill Gauging Station between 2011 and 2017. Refer to Section 7.12.3 for further details
Natural/undisturbed	300	Based on typical values of water quality samples taken at various Riverine sites between Dec-16 and Jul-17
Roads/hardstand	900	Value adopted for Lake Vermont Northern Extension SWA
Mining pit	4,500	Value adopted for Lake Vermont Northern Extension SWA
Spoil	350	Based on median value from the Terrenus geochemical assessment (Terrenus, 2018)
Rehab	300	Assumed to be similar to natural/undisturbed
Pit groundwater inflows	8,910	Based on Fitzroy Plan WQO – shallow groundwater (80th percentile)
Raw water (pipeline)	200	Based on recorded data at a nearby operations
ROM Coal moisture	10,000	Salinity of ROM Coal unknown, conservatively high value adopted

Salt is lost from the system through the product coal, coarse rejects and fine rejects streams. The amount of salt lost varies depending on the EC of the feed water supply to the CHPP water circuit. Salt is also lost through haul road dust suppression.

7.12.3 *Isaac River salinity*

As described in Section 5.4.1, EC has been continuously monitored and recorded at the Deverill gauging station since August 2011. This monitoring data has been analysed and a relationship between EC and discharge (expressed as runoff depth) has been developed, as shown in Figure 7-7. This relationship flow-EC relationship for the Isaac River has been incorporated into the water balance model.

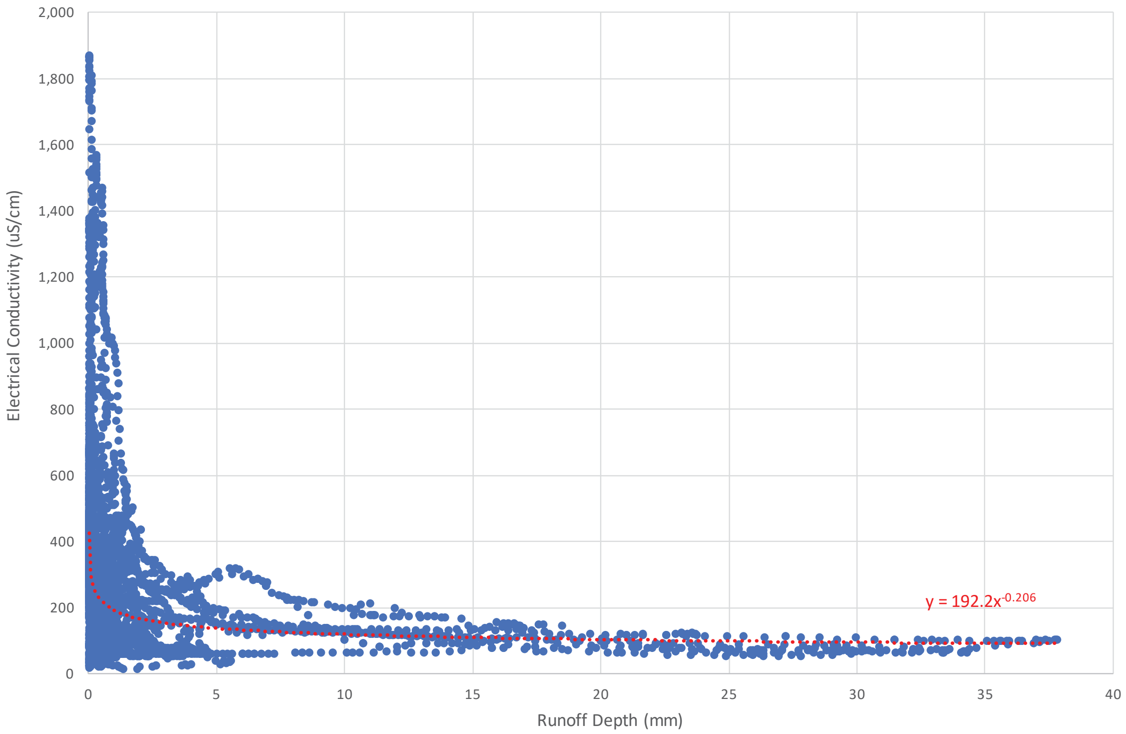

Figure 7-7: Relationship between EC and Excess Rainfall Depth at Deverill Gauge

7.13 Preliminary Consequence Category Assessment

All proposed mine affected water dams which overflow internally (i.e. do not discharge to the receiving environment) have been assigned a preliminary category of low consequence due to the low risk of significant consequence in the event of a failure to contain or dam break.

There are only three mine affected water dams that can discharge to the receiving environment:

- P44 (ODS domain)
- WROM (Willunga domain); and
- WMIA (Willunga domain).

These dams have been assessed against Table 1 of the Manual and have been assigned a low consequence category for the failure to contain criteria based on the predicted water quality results from the water balance model. Refer to Section 8 for the water balance model results.

7.14 Sediment Dams

7.14.1 Conceptual Sizing

Catchment runoff from both active and newly rehabilitated overburden dumps at the ODS and Willunga domains will be managed in accordance with an ESCP. The sediment dams have been sized in accordance with the IECA method (IECA, 2008), and have been based on the following design standards and methodology:

- "Type F" sediment basins;
- total sediment basin volume = settling zone + sediment storage volume. The sediment storage volume is the portion of the basin storage volume that progressively fills with sediment until the basin is de-silted. The settling zone is the minimum required free storage capacity that must be restored within 5 days after a runoff event;
- sediment basin settling volume based on 85th percentile 5-day duration rainfall with an adopted volumetric event runoff coefficient for disturbed catchments of 0.45 (Group C soils – loamy clay); and
- solids storage volume = 50% of settling zone volume.

The adopted design standard does not provide 100% containment for runoff from disturbed areas. Hence, it is possible that overflows will occur from sediment dams if rainfall exceeds the design standard.

A summary of the conceptual sediment dam capacities and the surface areas (based on average 5 m depth) is provided in Table 7-15.

Table 7-15: Conceptual Sediment Dam Capacities and Surface Areas

Sediment Dam	Max. Catchment Area (ha)	Total Volume Required (ML)	Dam Surface Area (ha)
S1	235.0	51.5	1.37
S2	248.0	54.3	1.45
S3	122.1	26.8	0.71
S4	254.2	55.7	1.49
S5	144.9	31.8	0.85
S8	202.2	44.3	1.18
S11	320.6	70.3	1.87
S12	304.4	66.7	1.78
S13	66.1	14.5	0.39
S14	43.1	9.4	0.25
S17	72.2	15.8	0.42
S18	22.1	4.8	0.13
S19	97.7	21.4	0.57
S23	29.8	6.5	0.17
S24	31.6	6.9	0.18
S28	313.4	68.7	1.83

Sediment Dam	Max. Catchment Area (ha)	Total Volume Required (ML)	Dam Surface Area (ha)
S29	60.5	13.3	0.35
S30	72.6	15.9	0.42
S32	130.3	28.5	0.76
S34	85.0	18.6	0.50
S36	97.8	21.4	0.57
S37	60.0	13.2	0.00
S38	48.6	10.6	0.28
S39	133.2	29.2	0.78
S40	23.4	5.1	0.42
S41	30.3	6.6	0.00
S42	133.9	29.3	0.78
S43	614.8	134.7	3.59
S45	153.4	33.6	0.90
S47	22.9	5.0	0.00
S48	25.8	5.7	0.15
S49	17.0	3.7	0.64
S50	109.5	24.0	0.14
S51	31.1	6.8	0.28
S52	18.1	4.0	0.14
S53	126.4	27.7	0.18
S54	34.4	7.5	0.11
S55	34.5	7.6	0.00
S56	277.1	60.7	0.74
S57	21.5	4.7	0.20
S58	24.3	5.3	1.62
S59	62.4	13.7	0.13
S60	93.5	20.5	0.14
S65	162.9	35.7	0.95
S66	139.3	30.5	0.37
S67	33.6	7.4	0.81
S69	512.5	112.3	0.20
S70	353.3	77.4	2.99
S71	1026.0	224.8	2.06
S72	357.6	78.4	5.99
S73	1180.9	258.8	2.09
S77	468.9	102.8	6.90

8. Water Management System Assessment

8.1 Overview

The Project OPSIM model was used to assess the performance of the Project water management system, using the following key performance indicators:

- overall water balance – the average inflows and outflows of the water management system based on all model realisations (Section 8.3.1);
- mine water inventory – the risk of accumulation (or reduction) of the overall mine water inventory (Section 8.3.2);
- in-pit storage – the risk of accumulation of water in the mining pits, and the associated water volumes (Section 8.3.3);
- external water demand – the risk and associated volumes of requiring imported external water (via the SunWater pipeline) to supplement site mine water supplies (Section 8.3.4);
- controlled water releases – the risk and associated volumes (and salt loads) of controlled water releases to the receiving environment (Section 8.3.5);
- uncontrolled spillway discharges – the risk and associated volumes (and salt loads) of uncontrolled discharge from the mine affected water storages and sediment dams to the receiving environment (Section 8.3.6);
- rehabilitated catchment discharges – the risk and associated volumes (and salt loads) of runoff from rehabilitated catchments to the receiving environment (Section 8.3.7);
- overall salt balance – the average salt loads in and out of the water management system based on all model realisations (Section 8.3.8)

The use of a large number of climate sequences reflecting the full range of historical climatic conditions provides an indication of the system performance under very wet, very dry and average climatic conditions. It is important to note that the results of the water balance modelling are dependent on the accuracy of input assumptions. There is inherent uncertainty with respect to some key site characteristics (e.g. catchment yield/runoff, groundwater inflows etc.).

8.2 Interpretation of Model Results

In interpreting the results of the water balance assessment, it should be noted that the results provide a statistical analysis of the water management system's performance over the 79 years of mine life, based on 100 stochastically generated climatic rainfall sequences and historical average monthly evaporation.

The model results are presented as a probability of exceedance. For example, the 10th percentile represents 10% probability of exceedance and the 90th percentile results represent 90% probability of exceedance. There is an 80% chance that the result will lie between the 10th and 90th percentile traces.

Whether a percentile trace corresponds to wet or dry conditions depends upon the parameter being considered. For site water storage, where the risk is that available storage capacity will be exceeded, the lower percentiles correspond to wet conditions. For example, there is only a small chance that the 1 percentile storage volume will be exceeded, which would correspond to very wet climatic conditions. For off-site site water supply volumes (for example), where the risk is that insufficient water will be available, there is only a small chance that more than the 1 percentile water supply volume would be required. This would correspond to very dry climatic conditions.

It is important to note that a percentile trace shows the likelihood of a particular value on each day and does not represent continuous results from a single model realisation. For example, the 50th percentile trace does not represent the model time series for median climatic conditions.

8.3 Water Balance Model Results

8.3.1 Overall Water Balance

Water balance results for all of the 100 model realisations are presented in Table 8-1, averaged over each model phase. The results presented in Table 8-1 are the average of all realisations and will include wet and dry periods distributed throughout the mine life. Rainfall yield for each stage is affected by the variation in climatic conditions within the adopted climate sequence.

Table 8-1 provides an indication of the long-term average annual inflows and outflows. Key outcomes from the overall water balance are as follows:

- Average annual inflows from rainfall runoff are largely consistent between Stage 2 and Stage 7.
- External water requirements are highest in Stage 1, and consistently reduce between Stage 2 and Stage 7.
- The change in stored volume per stage is small in comparison to the inflow and outflow volumes and therefore the water management system is generally in balance.

Table 8-1: Average Annual Water Balance – All Realisations

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7
INFLOWS (ML/a)							
Rainfall/runoff	6,170	17,531	18,016	18,619	19,147	18,498	18,940
Groundwater inflows	258	1,214	787	398	147	116	80
External water	1,129	775	700	522	465	378	371
ROM coal moisture	361	1,279	1,224	601	361	190	76
TOTAL INFLOWS	**7,918**	**20,799**	**20,727**	**20,141**	**20,119**	**19,183**	**19,468**
OUTFLOW (ML/a)							
Evaporation from storages	2,323	4,416	4,658	3,747	3,491	3,453	3,786
Dam overflows (offsite)							
Mine affected water	0	0	0	0	0	0	0
Sediment water	999	5,235	5,057	3,851	2,384	3,102	4,291
Rehab/up-catchment water	2,335	5,265	5,637	8,533	10,482	9,265	8,099
Controlled releases	404	650	547	800	906	760	665
CHPP							
Product moisture	381	1,346	1,308	666	392	207	84
Coarse rejects moisture	193	688	634	282	178	93	36
Fine rejects - entrained	216	609	565	288	206	137	91
Haul road dust suppression	475	1,551	1,688	1,709	1,600	1,524	977
Coal crushing/conveyor dust suppression	400	400	400	400	400	400	400
Miscellaneous raw water demands	80	80	80	80	80	80	80
Mine infrastructure demands	40	40	40	40	40	40	40
Potable WTP demands	50	50	50	50	50	50	50
TOTAL OUTFLOWS	**7,896**	**20,331**	**20,666**	**20,446**	**20,209**	**19,112**	**18,600**
CHANGE IN VOLUME (ML/a)							
Change in stored volume	22	468	61	-305	-90	71	866

8.3.2 Mine Affected Water Inventory

Figure 8-1 shows the combined forecast inventory for the key out-of-pit mine affected water storages over the 79-year forecast. To prevent uncontrolled discharges from the mine water storages, target operating volumes (TOVs) have been set for the out-of-pit mine affected water storages. The TOV is the volume at which pumping from the open cut pits to the mine affected water storages ceases. This was included as an operating rule in the OPSIM model. Also shown is the combined Full Supply Volume (FSV), which is the combined capacity of these dams.

The model results show the following:

- For the 10th percentile results (wet climatic conditions), the peak inventory in the out-of-pit storages reaches a volume of around 2,450 ML.

- For the 50th percentile results (median climatic conditions), the peak inventory in the out-of-pit storages reaches a volume of around 1,280 ML.
- The combined out-of-pit mine affected water inventory is maintained well below the combined capacity of all the mine affected water dams. This is primarily due to the ODS MIA Dam (the largest mine affected water dam) being operated at a low level to provide adequate buffer for large storm events, given its large surface area and catchments.

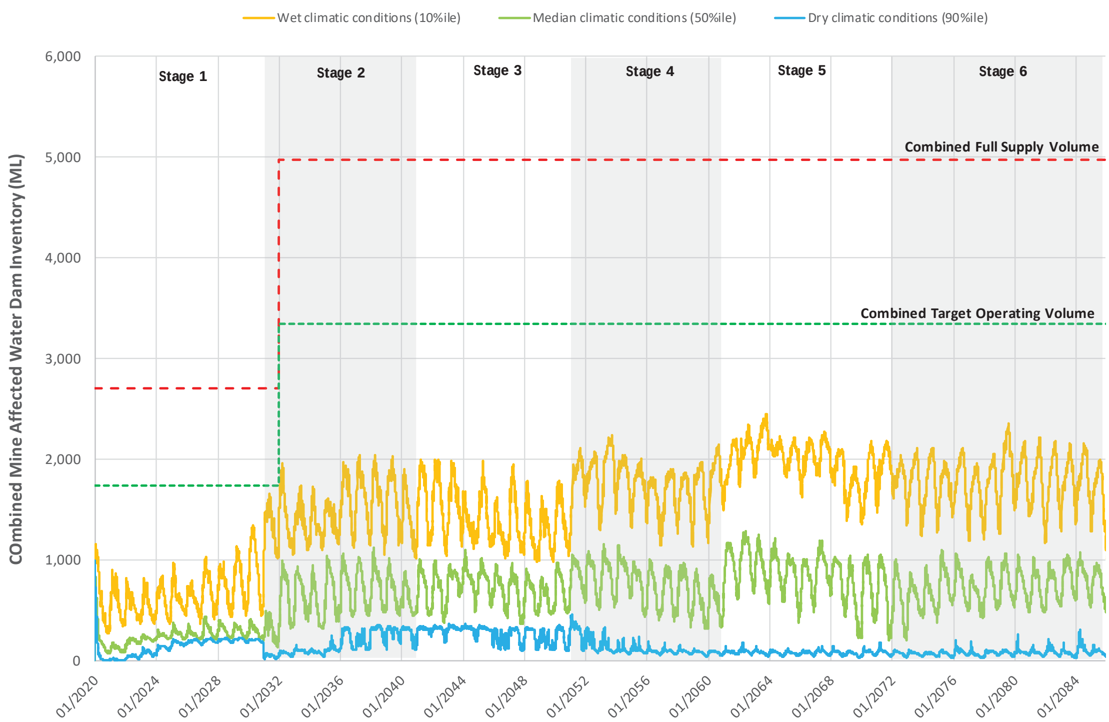

Figure 8-1: Forecast Mine Affected Water Inventory

8.3.3 *In-pit Storage*

Figure 8-2, Figure 8-3 and Figure 8-4 shows the forecast inventory for the ODS, Willunga and combined mining pits, respectively, over the 79-year simulation. A build-up of water in the mining pit generally occurs when the out-of-pit mine affected water storages are too full to accept additional pit water or the pumping infrastructure is unable to dewater the pits quickly enough. In other words, it is used to determine whether additional out-of-pit storage is required.

The forecast modelling results for the mining pit inventory are summarised as follows:

- ODS pits (Figure 8-2):
  - For the 10th percentile results (wet climatic conditions), water begins to accumulate at the beginning of Stage 2 and reaches a peak inventory of around 9,100 ML by the end of the Project.

    - For the 50th percentile results (median climatic conditions), water begins to accumulate at the beginning of Stage 5 and reaches a peak inventory of around 2,000 ML by the end of the Project.

- Willunga pits (Figure 8-3):
    - For the 10th percentile results (wet climatic conditions), water begins to accumulate at the beginning of Stage 2 and reaches a peak inventory of around 9,900 ML during Stage 2, before reducing by Stage 6.
    - For the 50th percentile results (median climatic conditions), water accumulates during Stage 2 and 3, but generally empties from Stage 4 onwards.
- Combined pits (Figure 8-4):
    - For the 10th percentile results (wet climatic conditions), water begins to accumulate at the beginning of Stage 2 and reaches a peak inventory of around 12,580 ML during Stage 3 of the Project.
    - For the 50th percentile results (median climatic conditions), water accumulates during Stage 2 and 3, then reduces to an inventory of around 2,000 ML by the end of the Project.
- By the end of Stage 3, a substantial amount of additional storage capacity (around 550 GL) will be available within the Pit 1/2/3 void as mining has been completed by this time. These voids would be used to storage excess water as required, depending on the prevailing climatic conditions.

Overall, the results suggest that sufficient out-of-pit storage has been provided. Should wet conditions prevail, Pembroke shall:

- Store excess water temporarily in an active pit until there is sufficient out-of-pit storage available; or
- Construct additional pit water dams ahead of mining in the ODS domain to temporarily store any excess mine affected water until there is sufficient out-of-pit storage available.

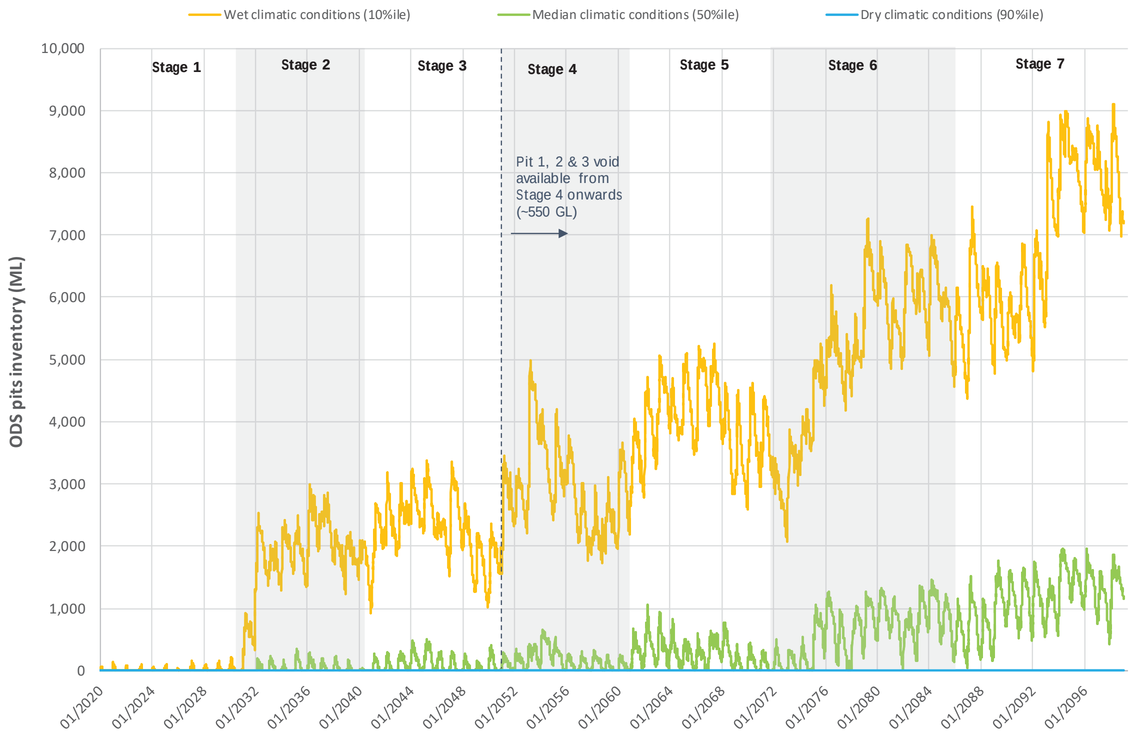

Figure 8-2: Forecast Pit Inventory - ODS

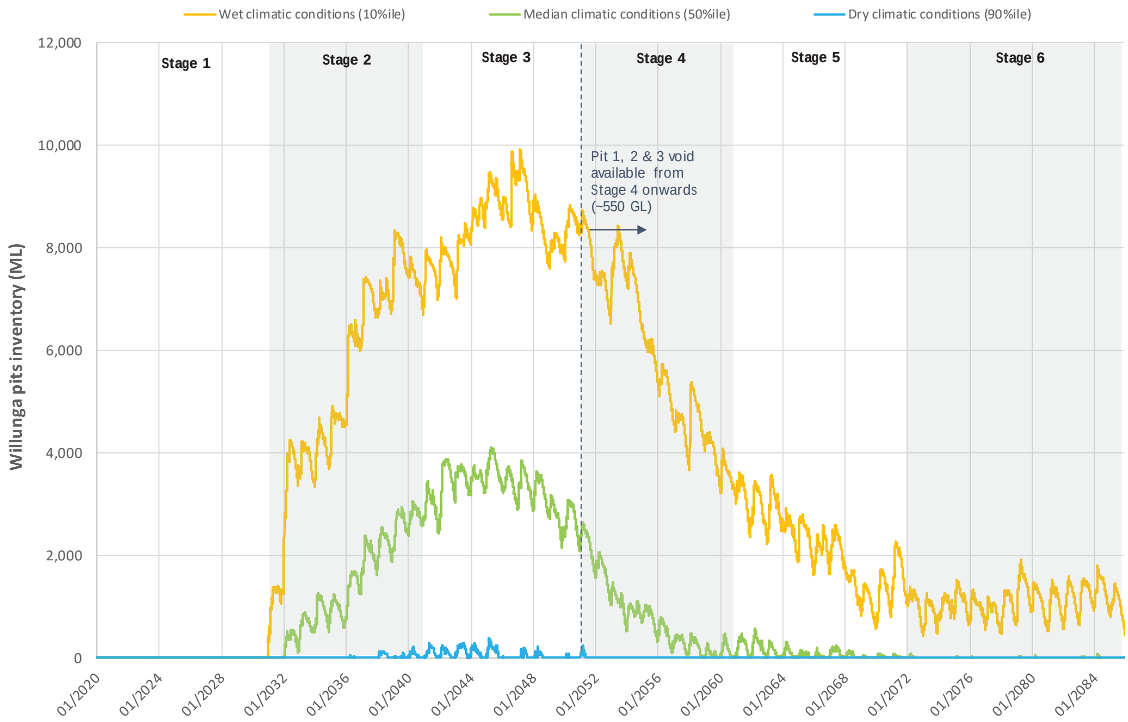

Figure 8-3: Forecast Pit Inventory - Willunga

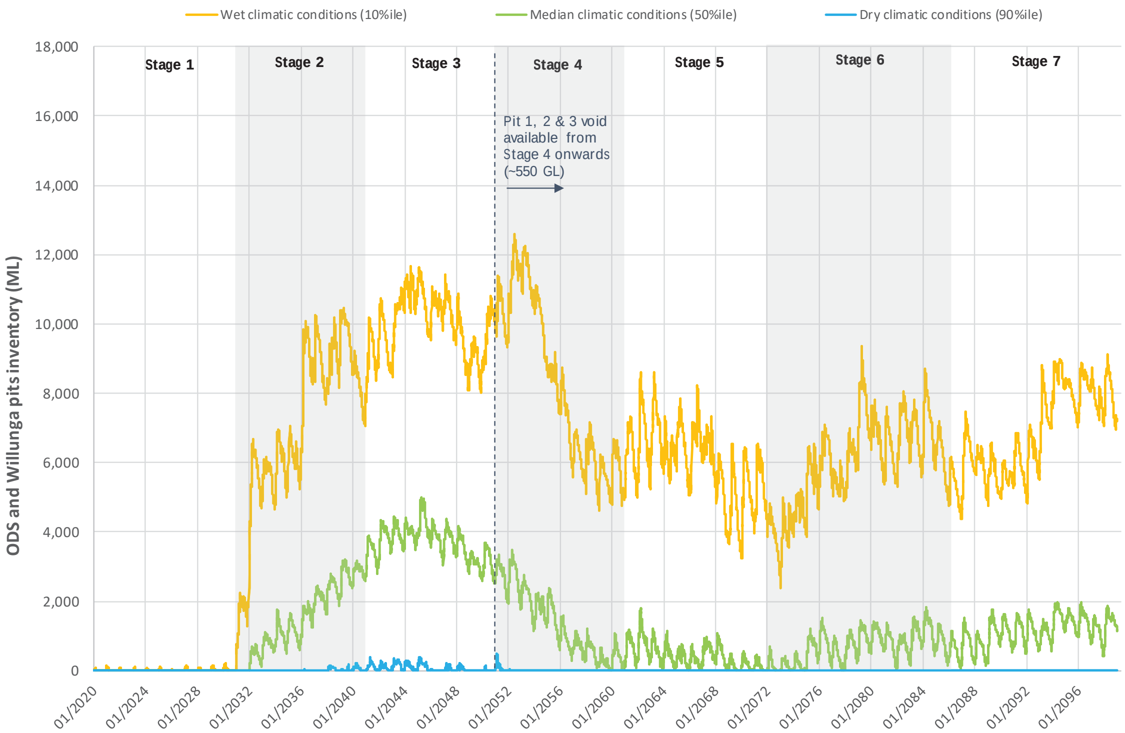

Figure 8-4: Forecast Pit Inventory - Combined

8.3.4 *External Makeup Requirements*

Water from external sources is required to meet operational water demands, primarily during extended dry climatic periods and periods of low groundwater inflows. In addition to the water captured within the water management system from surface runoff within the operational areas and groundwater inflows, water will also need to be sourced from external sources (e.g. the SunWater pipeline supply).

A key objective of the mine site water management system is to maximise the reuse of captured surface water runoff and groundwater inflows. Recycling mine water will minimise the volume of water from external sources that is required to satisfy site demands. However, the volume of water captured on site is highly variable dependent upon climatic conditions and groundwater inflows. Hence, the required makeup water volume from the external sources is likely to vary significantly from year to year.

Figure 8-5 shows the total annual modelled demand for water from external sources over the 79-year simulation.

The modelling results show the following:

- During Stage 1, the requirement for external supply is highest. There is a:
  - 10% risk of requiring 2,120 ML/a (or more) from the pipeline.
  - 50% risk of requiring 1,450 ML/a (or more) from the pipeline.

- During Stage 2, the requirement for external supply increases during dry climatic conditions but reduces during median and wet climatic conditions. There is a:
  - 10% risk of requiring 2,250 ML/a (or more) from the pipeline.
  - 50% risk of requiring 860 ML/a (or more) from the pipeline.
- The external supply requirement reduces over the remainder of the Project. By Stage 5, there is little to no external water required under median climatic conditions.
- During Stage 6 and Stage 7, there is a 10% risk of requiring around 1,710 ML/a (or more) from the pipeline.

The modelling results show that external water requirements generally reduce over the life of the Project. This is primarily due to the continual increase in mine disturbance area over time (and subsequent capture of rainfall runoff), as well as the reduction in predicted CHPP water consumption from Stage 3 onwards as the production throughput decreases.

Pembroke has an agreement with SunWater to provide a water supply via the Project pipeline from the Eungella network for the life of the Project, up to an annual volume of 2,250 ML/a. To supplement the SunWater supply, Pembroke has applied to DNRME for licences for take of unallocated general reserve water from the Isaac River under the Water Act.

In the unlikely event additional external water is required, additional water allocation from the Eungella or Burdekin networks operated by Sunwater could be sought by Pembroke over the life of the Project to meet raw water demands. It is also noted that Pembroke has applied for two licences for the take of 65 ML of unallocated general reserve water from the Isaac River. Any additional requirement for extraction from the Isaac River would be subject to separate licences to be applied for at a later date (in accordance with the *Water Plan (Fitzroy Basin) 2011*), to ensure no adverse impacts on water availability for other licenced water users.

Subject to availability of flows and obtaining relevant licences, direct pumping of water from the Isaac River may be undertaken opportunistically to minimise the external water supply requirements as required. The pump and associated infrastructure would be located at the ODS access road. Pumping of water from the Isaac River would be undertaken in a manner as to avoid and minimise potential impacts on aquatic ecology, including:

- starting the pump slowly and then gradually ramping up velocity;
- installing a suitable self-cleaning screen; and
- regularly inspecting the pump and screen.

There are also potential water harvesting opportunities from the site up-catchment water dams and sediment dams, as well as water saving measures such as dust suppressants.

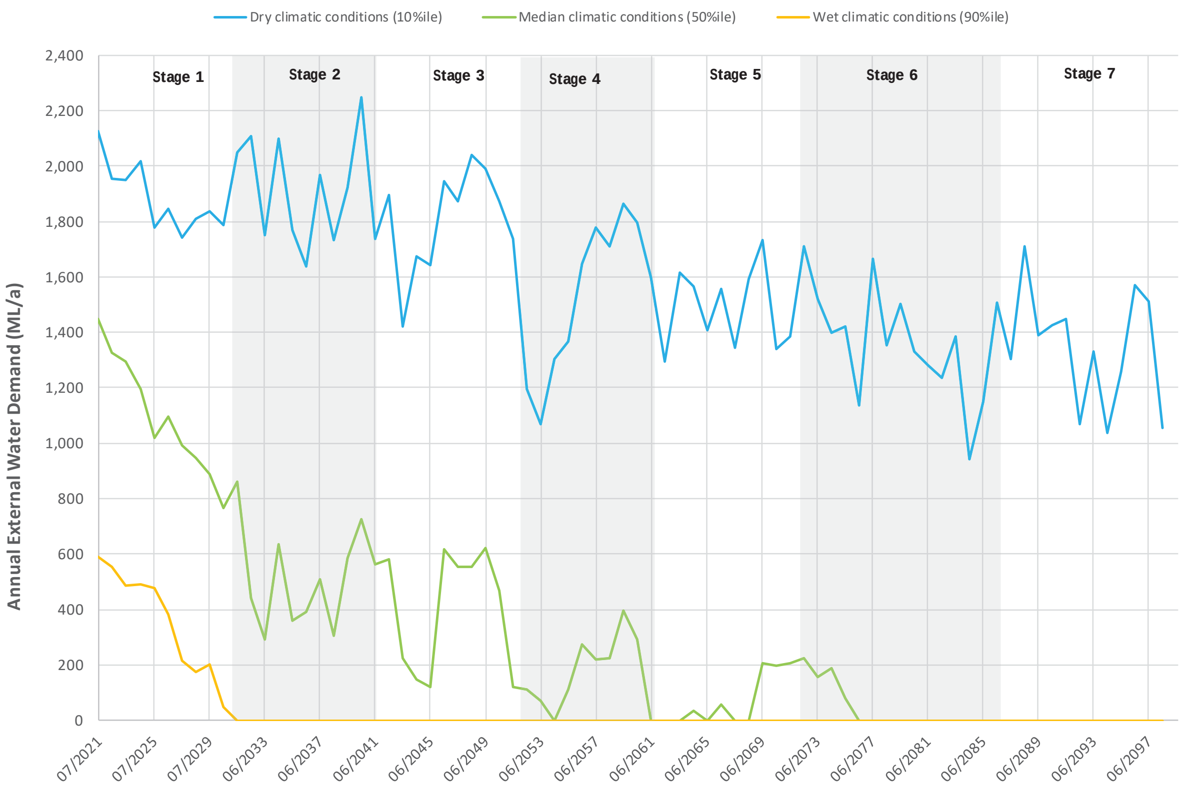

Figure 8-5: Forecast Annual External Water Requirements

8.3.4.1 *Overland flow capture*

As described in Section 7.7, NWWD is used to store water from the Eungella pipeline prior to its use within the Project. As it has as contributing catchment of 1,425 ha, this storage will capture some up-catchment runoff.

An assessment has been undertaken to estimate the average annual volume of up-catchment runoff that is used within the Project using the water balance model. The outcomes from this assessment (broken up by Phase) are provided in Table 8-2.

Review of Table 8-2 shows the estimated average annual “water take” from NWWD is between 417 ML/a (in Phase 1), reducing down to 151 ML/a by the end of the Project.

There is no modelled water take from the CWD.

Table 8-2: Estimated Annual Average Water Take from NWWD

Process	Average Annual Volume (per Phase)							Comment
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Phase 7	
Pipeline Supply	1,129	775	700	522	465	378	371	Water supplied to NWWD via pipeline
Supply to Demand	1,546	1,020	932	727	652	539	521	Water supplied to site demands from NWWD
Est. Water Take	**417**	**246**	**232**	**205**	**187**	**161**	**151**	**Balance is contribution from NWWD catchment runoff or "water take"**

8.3.5 Controlled Water Releases

The water balance model is configured to release water in accordance with the rules outlined in Section 7.10. The predicted annual controlled release volumes from the mine affected water dams are provided in Figure 8-6. The results show that:

- For wet climatic conditions (10%ile), predicted annual controlled releases range between 500 and 2,140 ML/a, with the highest releases occurring during Stage 2 to Stage 5.
- For median climatic conditions (50%ile), predicted annual controlled releases range between 90 and 890 ML/a.
- For dry climatic conditions (90%ile), predicted annual controlled releases range between 15 and 370 ML/a.

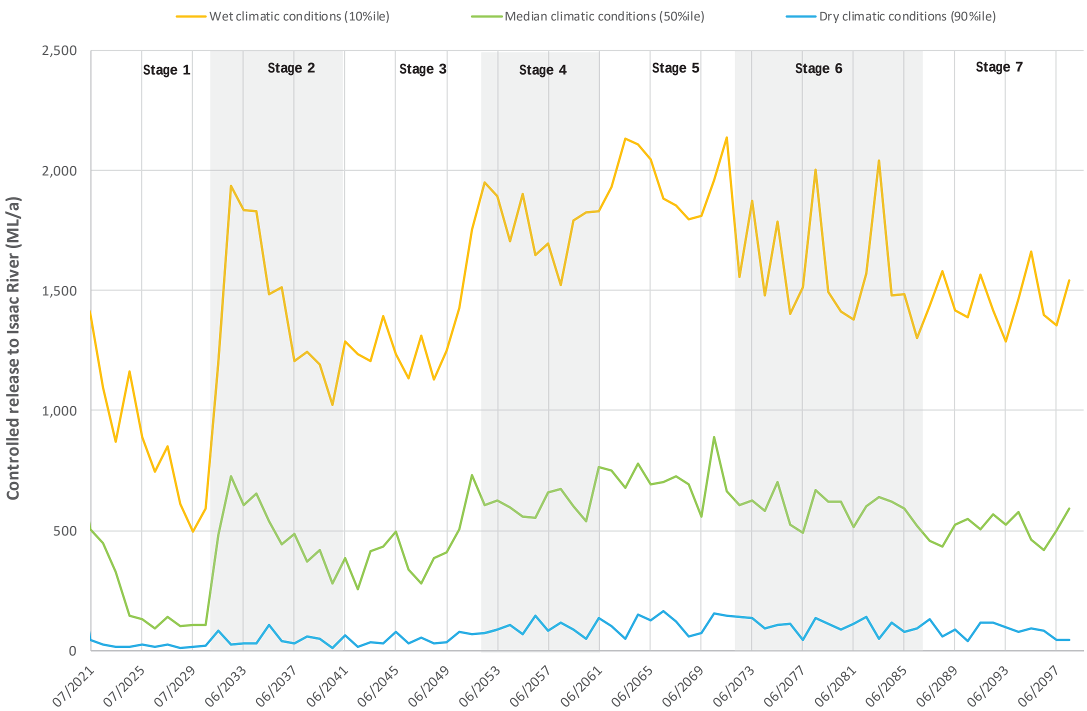

Figure 8-6: Forecast Annual Controlled Release Volumes

An assessment of the predicted annual salt load discharged through the controlled release system to the receiving environment has been undertaken for a representative "median" climatic sequence over the 79-year Project life. The annual salt loads have been ranked and presented as an AEP in Figure 8-7, which shows that under median climatic conditions:

- The annual salt load in rehabilitated and clean catchment discharges is around 35 tonnes/year (or more) for 90% of years.
- The annual salt load is rehabilitated and clean catchment discharges is around 630 tonnes/year (or more) for 50% of years.
- The annual salt load is rehabilitated and clean catchment discharges is around 2,500 tonnes/year (or more) for 10% of years.

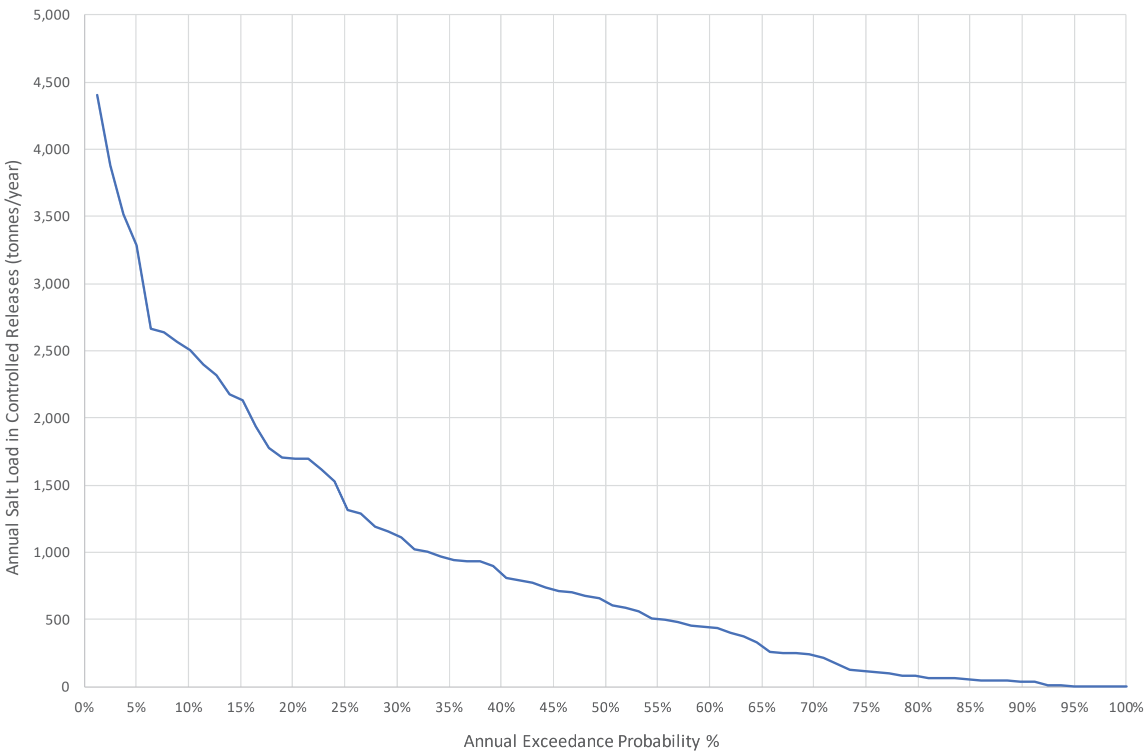

Figure 8-7: Controlled Release System Discharges – Annual Salt Load

8.3.5.1 *Dilution Ratio of Controlled Releases to Isaac River Flows*

An assessment of the dilution ratio of controlled releases to Isaac River flow has been undertaken, where the dilution ratio is the daily volume of the Isaac River flow divided by the daily volume of controlled releases to the Isaac River. Figure 8-8 shows a ranked plot of the minimum modelled daily dilution ratio on release days within each release category, for a represent median climatic cycle (Cycle 50). The results show that:

- The minimum modelled dilution ratio that occurred from all release categories throughout the median realisation is 22;

- The minimum modelled dilution ratio that occurred within each category was not less than the target dilution ratio under the controlled release rules; and
- 50% of release days exceed a minimum dilution ratio of:
  - 241:1 for Medium Flow 1 regime.
  - 229:1 for Medium Flow 2 regime.
  - 243:1 for High Flow 1 regime.
  - 444:1 for High Flow 2 regime.
  - 1,350:1 for Flood Flow regime.

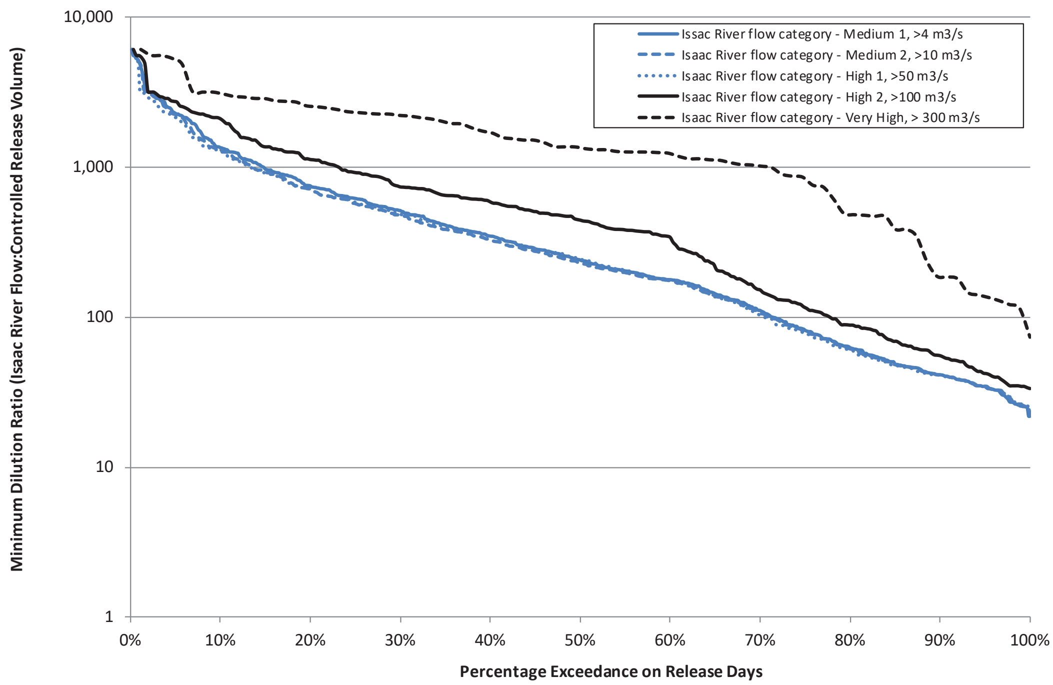

Figure 8-8: Ranked Plot of Minimum Dilution Ratios on Release Days

8.3.5.2 Release Scenarios

The water balance model results were analyzed in further detail to assess the modelled controlled releases from the Project. The release scenarios that were investigated include:

- Scenario 1 – The highest concentration of EC released from the Project; and
- Scenario 2 – The highest flow rate released from the Project.

The release events were compared to the proposed flow criteria detailed in Table 7-13. The release scenarios were assessed against the following four conditions:

- Flow criteria – The flow criteria is based on the flow rate within the receiving waters. The flow criteria specify the maximum release rate and EC release limit for all release points;
- Maximum release rate – The maximum combined release rate from all release points for a given flow criteria;
- EC release limit – The maximum EC for releases from mine water dams for a given flow criteria; and

For a release scenario to be in compliance, the maximum release rate and EC release limit must be below the specified corresponding flow criteria in Table 7-13.

8.3.5.2.1 Scenario 1 – Highest concentration of EC released

The highest modelled release EC for the Project is 9,600 µs/cm. Figure 8-9 and Figure 8-10 show the release rate and EC from the Project compared to the flow rate in the Isaac River. The proposed receiving water flow criteria and release conditions listed in Table 7-13 are also shown.

There are three different flow criteria and corresponding maximum release rates during this release:

- The Very High flow criteria of greater than 300 m^3/s at the start of the release. This flow criteria allows a maximum release rate of 5.0 m^3/s with a maximum EC of 10,000 µS/cm;
- When the receiving waters flow rate declines below 300 m3/s, the High Flow 2 flow criteria “steps down” to 100 m^3/s. This flow criteria allows a maximum release rate of 3.0 m^3/s with a maximum EC of 6,000 µS/cm;
- When the receiving waters flow rate declines below 100 m3/s, the High Flow 1 flow criteria “steps down” to 50 m^3/s. This flow criteria allows a maximum release rate of 2.0 m^3/s with a maximum EC of 4,000 µS/cm;

The OPSIM model predicts that during Scenario 1 release, the controlled release from the Project would be compliant in terms of release rates and EC using the proposed flow criteria in the receiving waters (Table 7-13).

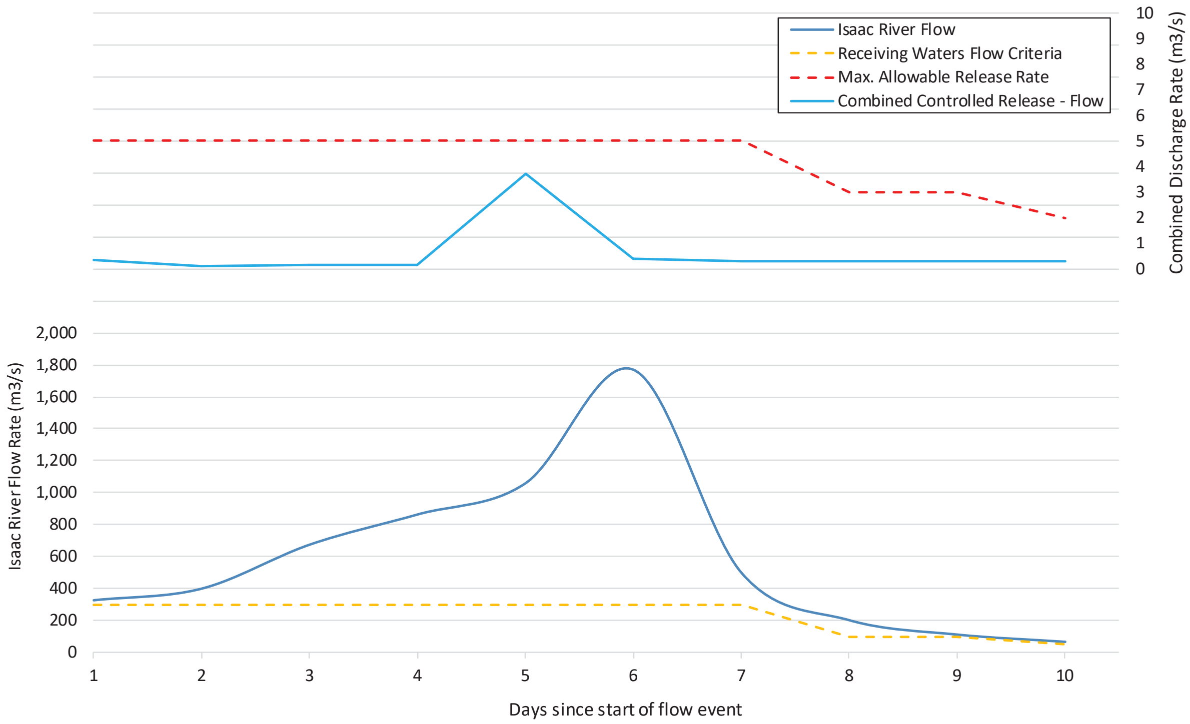

Figure 8-9: Release Rate Compared to Flow Rate in Isaac River and Corresponding Flow Criteria and Maximum Release Rate – Scenario 1

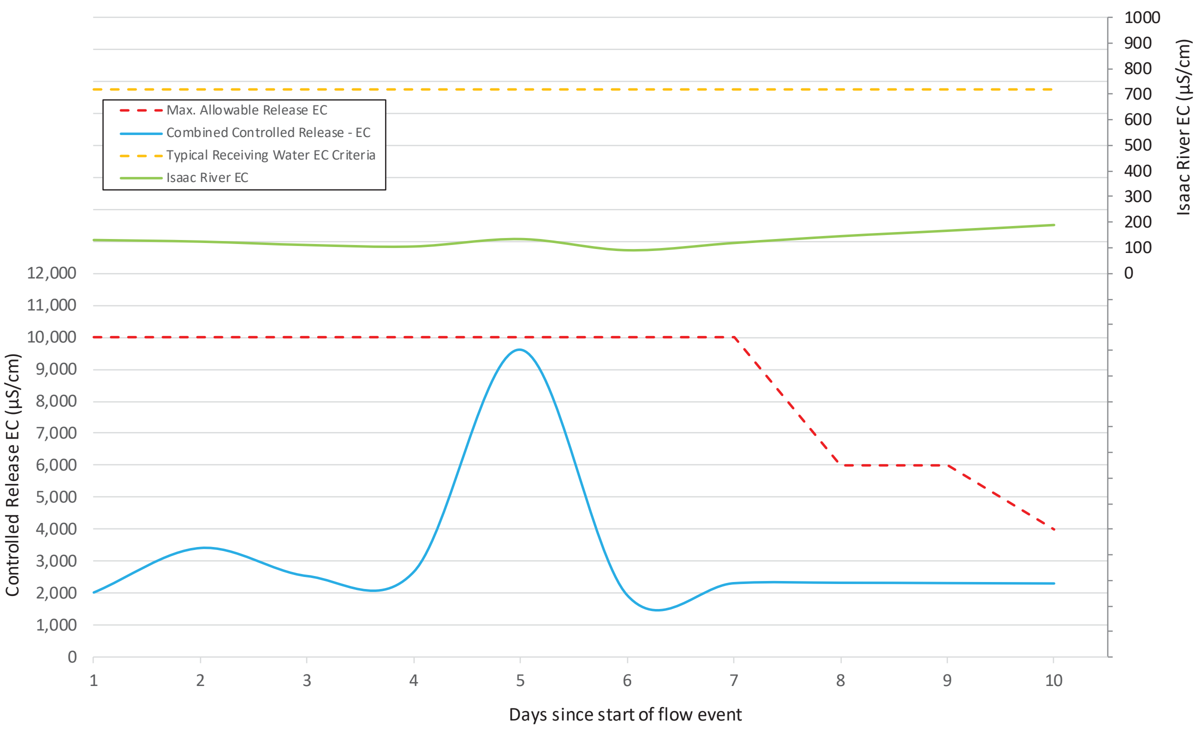

Figure 8-10: Release Water EC Compared to EC in Isaac River and Corresponding Flow Criteria and Maximum Release Rate – Scenario 1

8.3.5.2.2 Scenario 2 – Highest release flow rate

The highest modelled release rate for the Project is 5.0 m^3/s (daily averaged), which is the maximum allowable discharge rate under the proposed release strategy. Figure 8-11 and Figure 8-12 show the release rate and EC from the Project compared to the flow rate in the Isaac River. The proposed receiving water flow criteria and release conditions listed in Table 7-13 are also shown.

There are five different flow criteria and corresponding maximum release rates during this release:

- The Very High flow criteria of greater than 300 m^3/s at the start of the release. This flow criteria allows a maximum release rate of 5.0 m^3/s with a maximum EC of 10,000 µS/cm;
- When the receiving waters flow rate declines below 300 m3/s, the High Flow 2 flow criteria "steps down" to 100 m^3/s. This flow criteria allows a maximum release rate of 3.0 m^3/s with a maximum EC of 6,000 µS/cm;
- When the receiving waters flow rate declines below 100 m3/s, the High Flow 1 flow criteria "steps down" to 50 m^3/s. This flow criteria allows a maximum release rate of 2.0 m^3/s with a maximum EC of 4,000 µS/cm;
- When the receiving waters flow rate declines below 50 m3/s, the Medium Flow 2 flow criteria "steps down" to 10 m^3/s. This flow criteria allows a maximum release rate of 1.0 m^3/s with a maximum EC of 1,200 µS/cm;
- When the receiving waters flow rate declines below 10 m3/s, the Medium Flow 1 flow criteria "steps down" to 4 m^3/s. This flow criteria allows a maximum release rate of 0.5 m^3/s with a maximum EC of 1,000 µS/cm;

The OPSIM model predicts that during Scenario 2 release, the controlled release from the Project would be compliant in terms of release rates and EC using the proposed flow criteria in the receiving waters (Table 7-13).

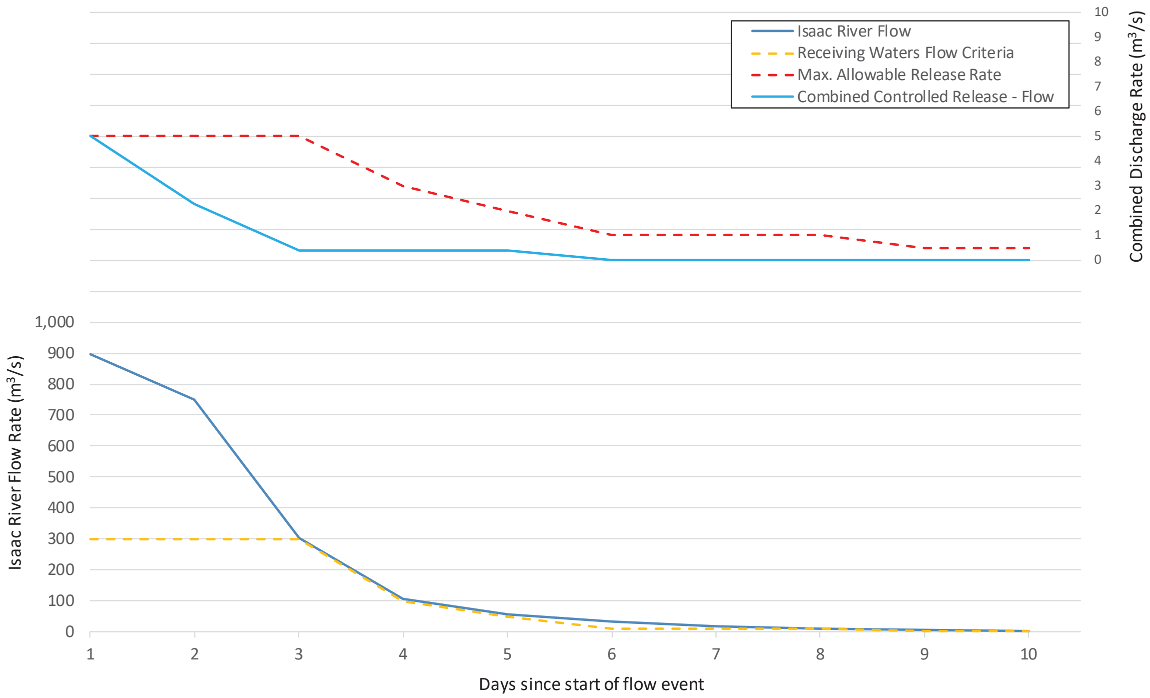

Figure 8-11: Release Rate Compared to Flow Rate in Isaac River and Corresponding Flow Criteria and Maximum Release Rate – Scenario 2

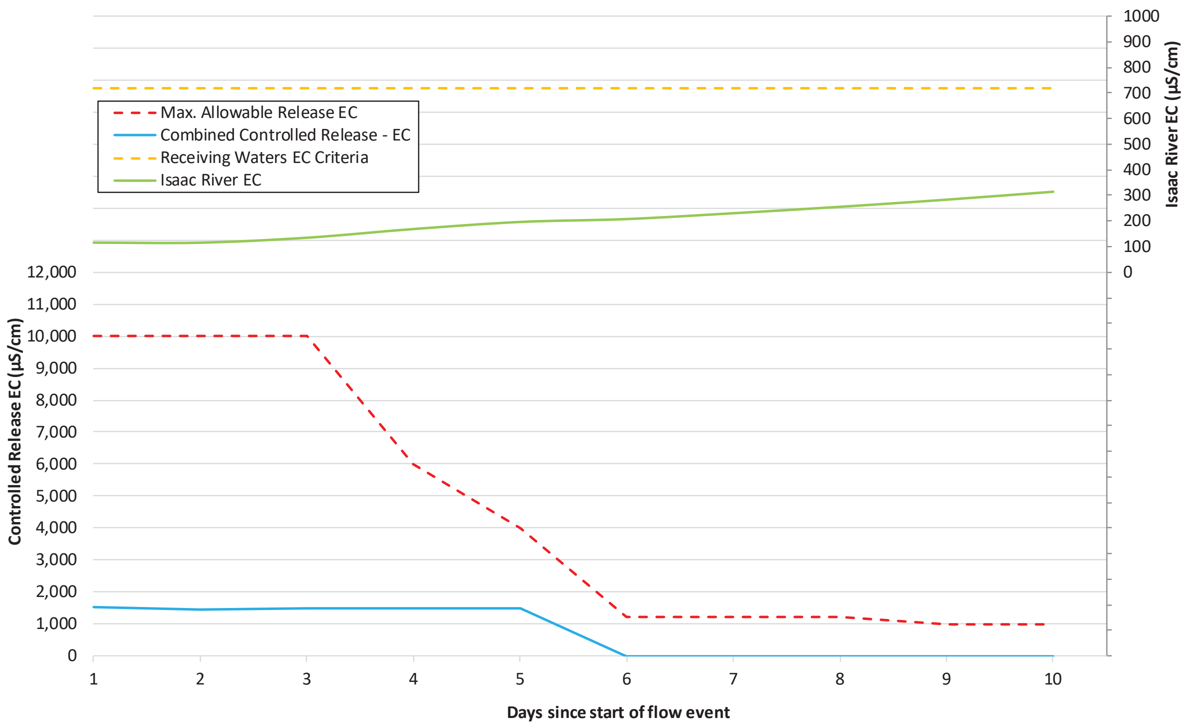

Figure 8-12: Release Water EC Compared to EC in Isaac River and Corresponding Flow Criteria and Maximum Release Rate – Scenario 2

8.3.6 Uncontrolled Spillway Discharges

8.3.6.1 Mine Affected Water Dams

The Project water balance model was used to assess the risk of uncontrolled offsite spills from the mine affected water management system. The mine water dams that could potentially overflow directly to the receiving environment if rainfall exceeded the storage design criteria include:

- P44 (to Ripstone Creek);
- WROM (to the Isaac River); and
- WMIA (to the Isaac River).

There were no modelled overflows from P44, WROM and WMIA to the Isaac River during any of the model realisations over the life of the Project.

8.3.6.2 Sediment Dams

The adopted design standard for sediment dams does not provide 100% containment for captured runoff. Hence overflows will occur from sediment dams when rainfall exceeds the design standard.

The potential for overflows from the proposed sediment dams has been assessed using a forecast assessment simulation. For simplicity, sediment dams have been modelled using a passive overflow rather than active release (to regain storage capacity within 5 days).

The predicted annual combined sediment dam overflows under this scenario are provided in Figure 8-13. Note that Figure 8-13 only include active sediment dams with catchments that are not fully rehabilitated. The results show that:

- During wet climatic conditions (10%ile) where rainfall events often exceed the dam design standard, modelled sediment dam overflows are between 1,730 ML/year and 12,960 ML/year.
- During median climatic conditions (50%ile) where rainfall events sometimes exceed the dam design standard, modelled sediment dam overflows are between 250 ML/year and 5,400 ML/year.
- During dry climatic conditions (90%ile) where few rainfall events exceed the dam design standard, modelled sediment dam overflows are between 0 ML/year and 1,340 ML/year.

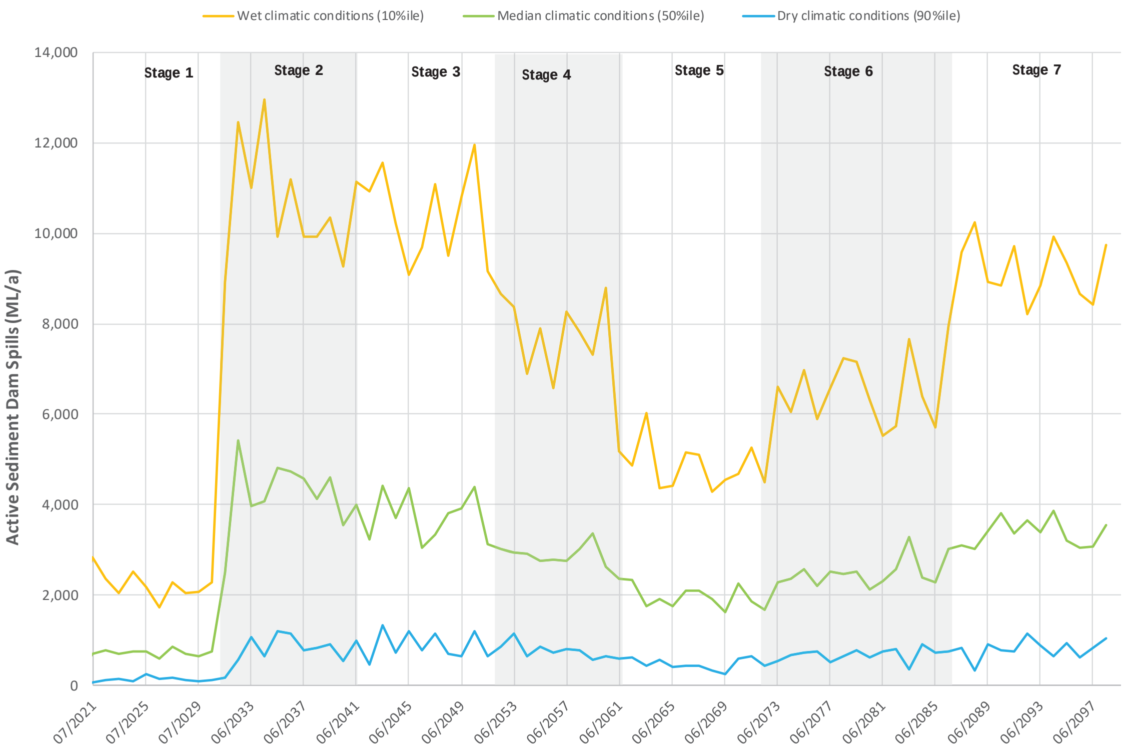

Figure 8-13: Forecast Annual Sediment Dam Overflows to Receiving Waters

An assessment of the predicted annual salt load discharged from the sediment dams to the receiving environment has been undertaken for a representative "median" climatic sequence over the 79-year Project life. The annual salt loads have been ranked and presented as an AEP in Figure 8-14, which shows that under median climatic conditions:

- The annual salt load in sediment dam overflows is around 1,40 tonnes/year (or more) for 90% of years.
- The annual salt load in sediment dam overflows is around 1,200 tonnes/year (or more) for 50% of years.
- The annual salt load in sediment dam overflows is around 4,600 tonnes/year (or more) for 10% of years.

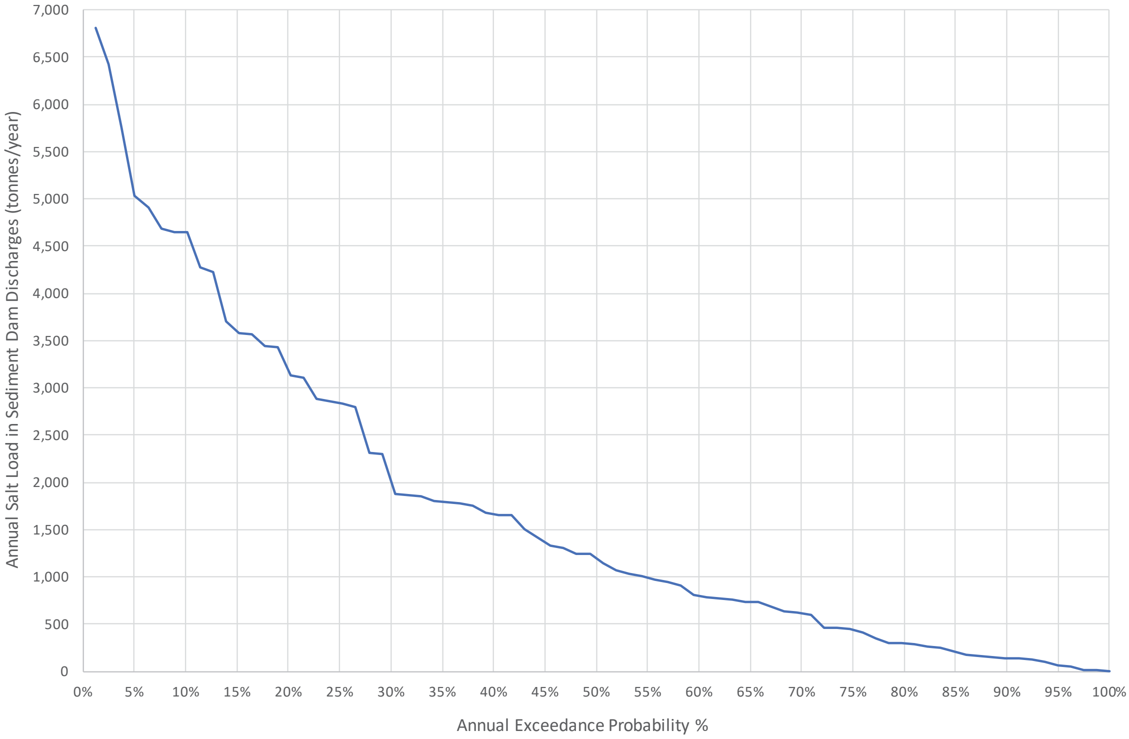

Figure 8-14: Sediment Dam Overflows – Annual Salt Load

8.3.7 Rehabilitated Catchment Discharges

As described in Section 6.4, when a sediment dam catchment is completely rehabilitated, and water quality monitoring of the runoff has established that it is consistent with natural background conditions, the sediment dam and associated drainage infrastructure will be decommissioned. Surface runoff and seepage from the rehabilitated catchment will be allowed to shed directly to the receiving environment.

The predicted annual combined rehabilitated catchment discharges are presented in Figure 8-15. Note that Figure 8-15 also includes runoff from diverted clean water catchments. The results show that:

- During wet climatic conditions (10%ile) modelled rehabilitated and clean catchment discharges are between 4,330 ML/year and 29,610 ML/year.
- During median climatic conditions (50%ile) modelled rehabilitated and clean catchment discharges are between 1,110 ML/year and 9,760 ML/year.
- During dry climatic conditions (90%ile) modelled rehabilitated and clean catchment discharges are between 40 ML/year and 2,490 ML/year.

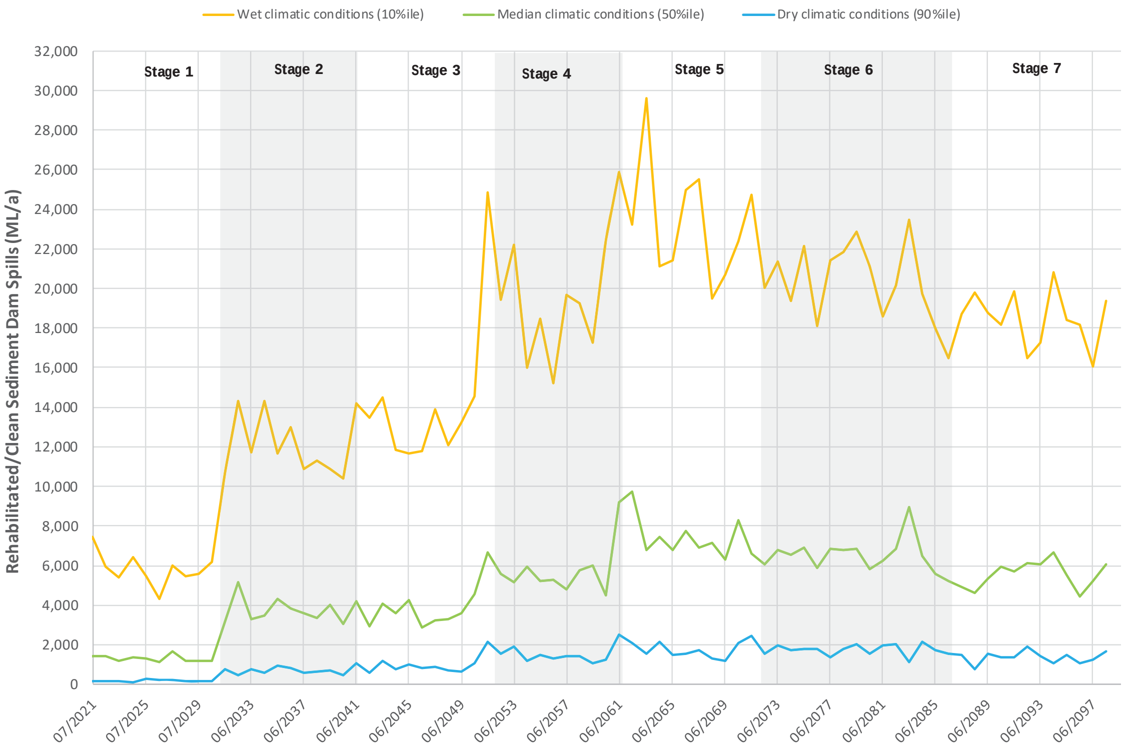

Figure 8-15: Forecast Annual Rehabilitated Catchment Discharges

An assessment of the predicted annual salt load discharged from the rehabilitated and clean catchments to the receiving environment has been undertaken for a representative “median” climatic sequence over the 79-year Project life. The annual salt loads have been ranked and presented as an AEP in Figure 8-16, which shows that under median climatic conditions:

- The annual salt load in rehabilitated and clean catchment discharges is around 190 tonnes/year (or more) for 90% of years.
- The annual salt load is rehabilitated and clean catchment discharges is around 1,560 tonnes/year (or more) for 50% of years.
- The annual salt load is rehabilitated and clean catchment discharges is around 5,130 tonnes/year (or more) for 10% of years.

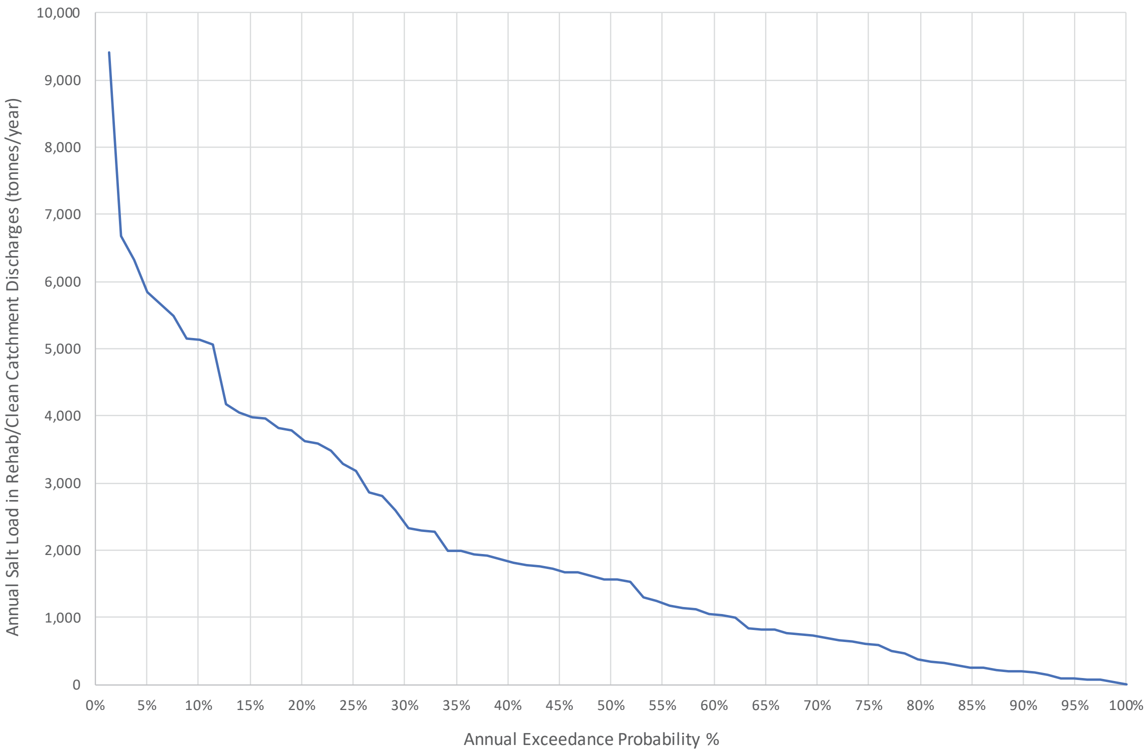

Figure 8-16: Rehabilitated/Clean Catchment Discharges – Annual Salt Load

8.3.8 *Overall Salt Balance*

Figure 8-17 shows a schematic of the salt inputs and outputs from the Project. Salt inputs to the Project include salts in the groundwater inflows, catchment runoff, direct rainfall, and external water. Salt outputs from the Project include salts which are lost through the CHPP in the rejects and product coal, site demands (including dust suppression and industrial usage), discharges through the controlled release strategy and offsite (spillway) discharges from the water management system.

The CHPP is a net user of water, as during the washing and sizing process the moisture content of the coarse and fine rejects and product materials is increased. This process traps water (and salt) in the coarse and fine rejects material. The material is then disposed of in dedicated zones within the open cut mining areas.

Table 8-3 shows the average annual salt balance for the Project, for each stage. The results indicate the following:

- The largest contributor to the Project salt load is through rainfall runoff from the various surfaces on the site. Significant salt loads are also imported via groundwater inflows and within the ROM coal moisture;
- The largest losses of salt from the Project are generally within the CHPP processing circuit (product coal and coarse rejects). Relatively large salt loads are also exported through dust suppression and sediment dam overflows; and
- The change in stored salt load is generally low in comparison to the total inputs and outputs, which suggests salt will not accumulative on site.

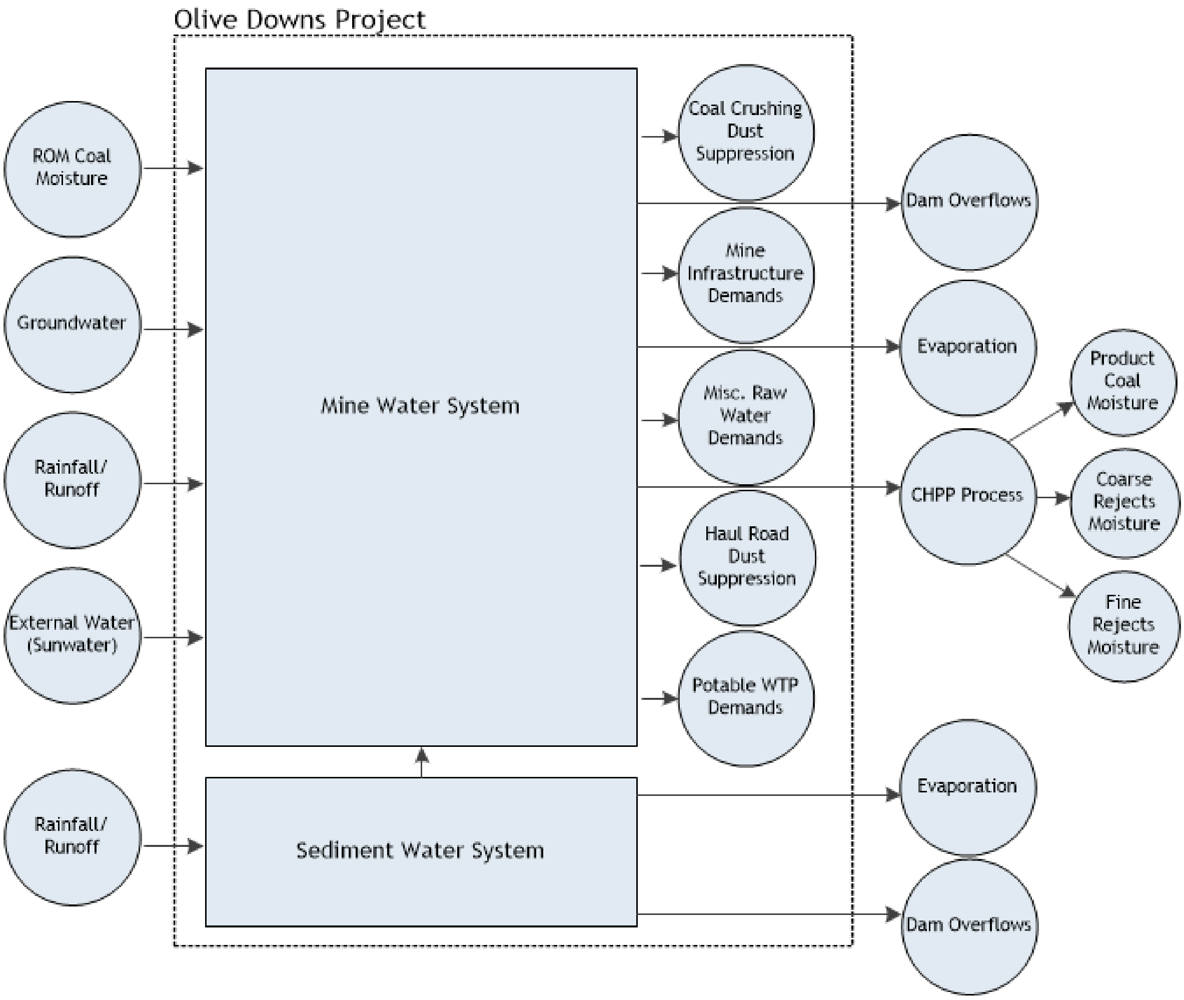

Figure 8-17: Simplified Surface Water Salt Balance Schematic

Table 8-3: Average Annual Salt Balance

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7
SALT INPUTS (tonnes/year)							
Rainfall/runoff	2,404	9,357	9,935	9,166	8,775	8,689	9,111
Groundwater inflows	1,659	7,572	4,909	2,485	915	724	499
External water	158	102	98	73	53	53	52
ROM coal moisture	2,528	8,952	8,570	4,209	2,524	1,333	534
TOTAL INPUTS	**6,749**	**25,990**	**23,512**	**15,933**	**12,278**	**10,798**	**10,196**
SALT OUTPUTS (tonnes/year)							
Evaporation from storages	0	0	0	0	0	0	0
Dam overflows (offsite)							
Mine affected water	0	0	0	0	0	0	0
Sediment water	331	2,558	2,430	1,898	1,167	1,436	2,303
Rehab/up-catchment water	590	1,547	1,626	2,420	3,201	2,766	2,476
Controlled releases	784	1,395	1,157	1,209	1,100	965	815
CHPP							
Product moisture	1,040	5,543	4,979	2,429	1,195	618	244
Coarse rejects moisture	1,354	4,816	4,440	1,975	1,247	654	252
Fine rejects - entrained	457	2,277	1,946	854	469	259	122
Haul road dust suppression	806	4,956	4,377	3,791	2,748	2,777	1,674
Coal crushing/conveyor dust suppression	696	1,718	2,171	1,397	1,003	933	686
Miscellaneous raw water demands	139	276	241	213	159	151	137
Mine infrastructure demands	70	138	121	107	79	75	69
Potable WTP demands	10	12	12	13	13	13	13
TOTAL OUTPUTS	**6,275**	**25,235**	**23,500**	**16,306**	**12,380**	**10,649**	**8,792**
CHANGE IN SALT LOAD (tonnes/year)							
Change in stored salt load	474	755	12	-373	-102	149	1,404

8.4 Model Sensitivity Assessment

A suite of sensitivity analyses have been undertaken to assess the potential impact of variations in key parameters to the performance of the proposed water management system. These sensitivity scenarios that have been assessed are as follows:

- Scenario 1: Rejects cells decant return rate increased by 5%
- Scenario 2: Rejects cells decant return rate decreased by 5%
- Scenario 3: Global increase in AWBM soil capacity by 20%
- Scenario 4: Global decrease in AWBM soil capacity by 20%
- Scenario 5: Global increase in source salinity by 25%

The results from these sensitivity analyses are provided in Appendix A.

8.5 Adaptive Management of the Water Management System

The model results presented above represent the application of the proposed water management system rules over the mine life, regardless of climatic conditions. In reality, there are numerous options for adaptive management of the mine water system to respond to climatic conditions and the current site water inventory in a way that will reduce the risks of impacts to surface water resources.

A site water balance model will be developed once the mine is operational and will be updated regularly (annually or biennially) using site monitoring data.

8.6 Climate Change Assessment

8.6.1 Methodology

8.6.1.1 Approach

The climate change impact assessment for the Project was undertaken adopting the projections and methodologies given in the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Commonwealth Bureau of Meteorology (BoM) report entitled “*Climate Change in Australia Technical Report*” (CSIRO, 2015). This report provides guidance on the possible projections of future climate for the East Coast based on a current understanding of the climate system, historical trends and model simulations of the climate response to changing greenhouse gas and decreasing aerosol emissions.

Projections are given for a number of climatic variables including (but not limited to) temperature, rainfall, solar radiation, wind speed, cyclones, potential evapotranspiration and sea levels for both short-term (2030) and long-term (2090) climate projections.

CSIRO (2015) presents a number of possible approaches to quantify risks associated with climate change impacts. The Project has adopted the ‘sensitivity analysis’ approach for the assessment of climate change impacts. Sensitivity analysis approach involves running a climate impact model with an observed climate dataset to establish a baseline level of risk, and then rerunning the model with the same input data, modified to represent ‘best’, ‘worst’ and ‘maximum consensus’ climate change scenarios to determine how sensitive the Project is to the scenario assessed.

For this assessment, the Representative Concentration Pathway 4.5 (RCP4.5) emissions scenario has been adopted.

8.6.1.2 Sensitivity Parameters

The climate variable inputs (rainfall and evaporation) to the Project water balance model (see Section 5.2.2) were adjusted to undertake the climate change impact assessment. Table 8-4 shows the adopted long-term (2090) climate projections for the ‘best case’ and ‘worst case’ RCP4.5 climate change scenarios. The ‘maximum consensus’ scenario has not been run as it falls between ‘best case’ and ‘worst case’ scenarios. These ranges were obtained using the projection builder tool provided in the Climate Change Australia website.

Table 8-4: Adopted Climate Change Impact Projections

Case	Change in Annual Rainfall	Change in Annual Evapotranspiration	Comments
Best Case	-19.8%	+6.9%	Representative model: GFDL-ESM2M Consensus: Low
Worst Case	+4.4%	+5.5%	Representative model: NorESM1-M Consensus: Low

Note: changes in annual rainfall and evapotranspiration are relative to the climate dataset (which was based on the 1889 to 2017 SILO dataset)

8.6.2 Potential Climate Change Impacts

8.6.2.1 Overview

Climate change impacts to the water balance were assessed for the operational period of the Project (2020-2098). The water balance model developed for the Project was used to simulate the 'best' case and 'worst' case climate scenarios. The water balance model climate inputs (rainfall and evaporation) were factored by the values given in Table 8-4.

8.6.2.2 In-pit Storage

Figure 8-18 and Figure 8-19 show the forecast inventory for the combined ODS and Willunga mining pits for the 'best' and 'worst' case climate scenarios in comparison to the base case results.

The model results are summarised as follows:

- 'Best' case climate scenario (Figure 8-18):
  - For the 10th percentile results (wet climatic conditions), the 'best' case modelled in-pit inventories are, on average, around 700 ML lower than the base case results.
  - For the 50th percentile results (median climatic conditions), the 'best' case modelled inventories are, on average, around 300 ML lower than the base case results.
- 'Worst' case climate scenario (Figure 8-19):
  - For the 10th percentile results (wet climatic conditions), the 'worst' case modelled in-pit inventories are, on average, around 1,200 ML lower than the base case results.
  - For the 50th percentile results (median climatic conditions), the 'worst' case modelled inventories are, on average, around 420 ML lower than the base case results.

Both climate cases result in a significant reduction in pit inventory during wet climatic conditions. This is likely due the increased evaporation for both climate cases.

Interestingly, the results for the 'best' case (or low rainfall case) show higher pit inventories worse than the 'worst' (or high rainfall case). This is due to the significant reduction in controlled release opportunities under the 'best' case due to less Isaac River flows. Refer to Section 8.6.2.4 for further details of the controlled release volumes for both climate scenarios.

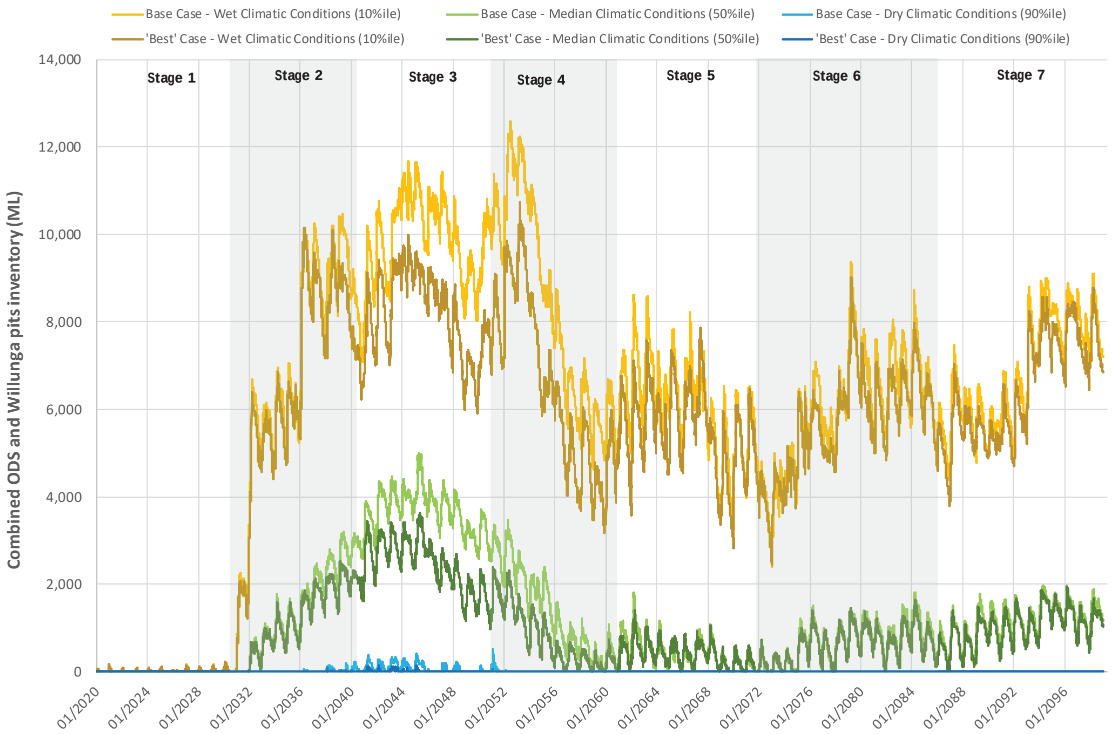

Figure 8-18: Forecast Pit Inventory – Combined - 'Best' Case Climate Change Sensitivity Assessment

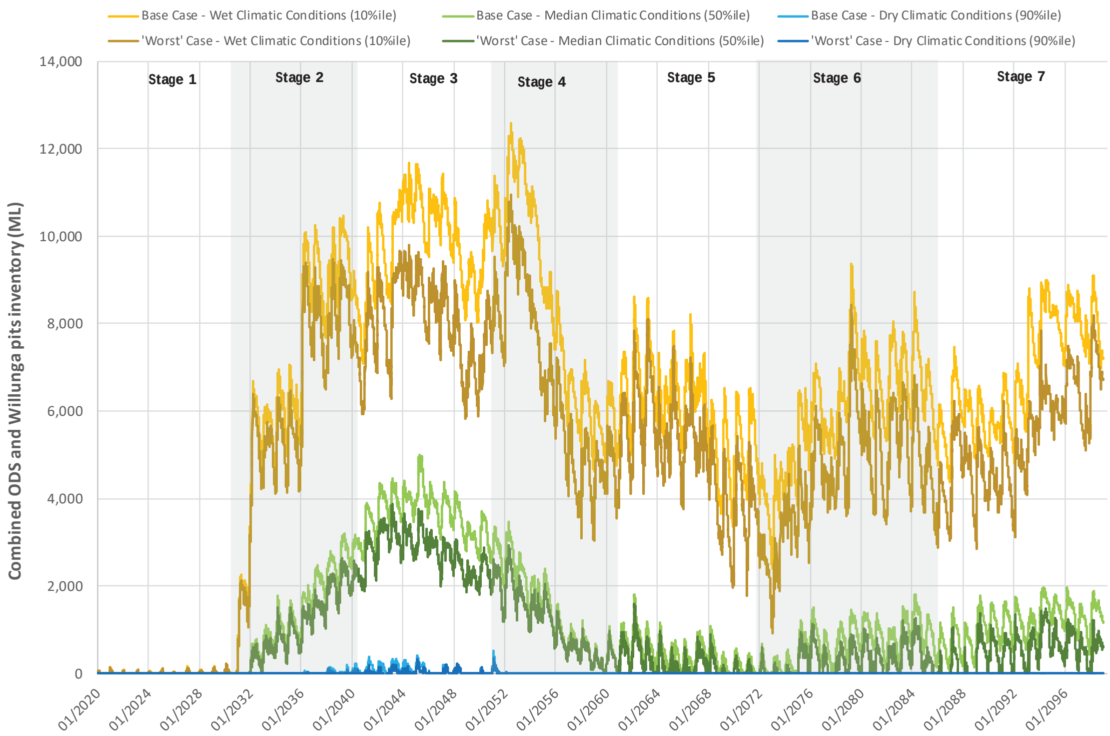

Figure 8-19: Forecast Pit Inventory – Combined - 'Worst' Case Climate Change Sensitivity Assessment

8.6.2.3 *External Makeup Requirements*

Figure 8-20 and Figure 8-21 show the forecast annual modelled demand for water from external sources for the 'best' and 'worst' case climate scenarios in comparison to the base case results.

The model results are summarised as follows:

- 'Best' case climate scenario (Figure 8-20):
  - For the 10th percentile results (dry climatic conditions), the 'best' case modelled annual external water demands are, on average, around 70 ML/a higher than the base case results.
  - For the 50th percentile results (median climatic conditions), the 'best' case modelled annual external water demands are, on average, around 10 ML/a higher than the base case results.
- 'Worst' case climate scenario (Figure 8-21):
  - For the 10th percentile results (dry climatic conditions), the 'worst' case modelled annual external water demands are, on average, around 200 ML/a higher than the base case results.
  - For the 50th percentile results (median climatic conditions), the 'worst' case modelled annual external water demands are, on average, around up to 100 ML/a higher than the base case results.

There is an increase in external water demand requirements under both the ‘best’ and ‘worst’ climate scenarios, when compared with the base case results. This is due to the increase in evaporation under both scenarios, which is enough to offset the increase in rainfall under the ‘worst’ case conditions.

Pembroke have sufficient allocation to meet site water demands under most climatic condition, for both climate change scenarios.

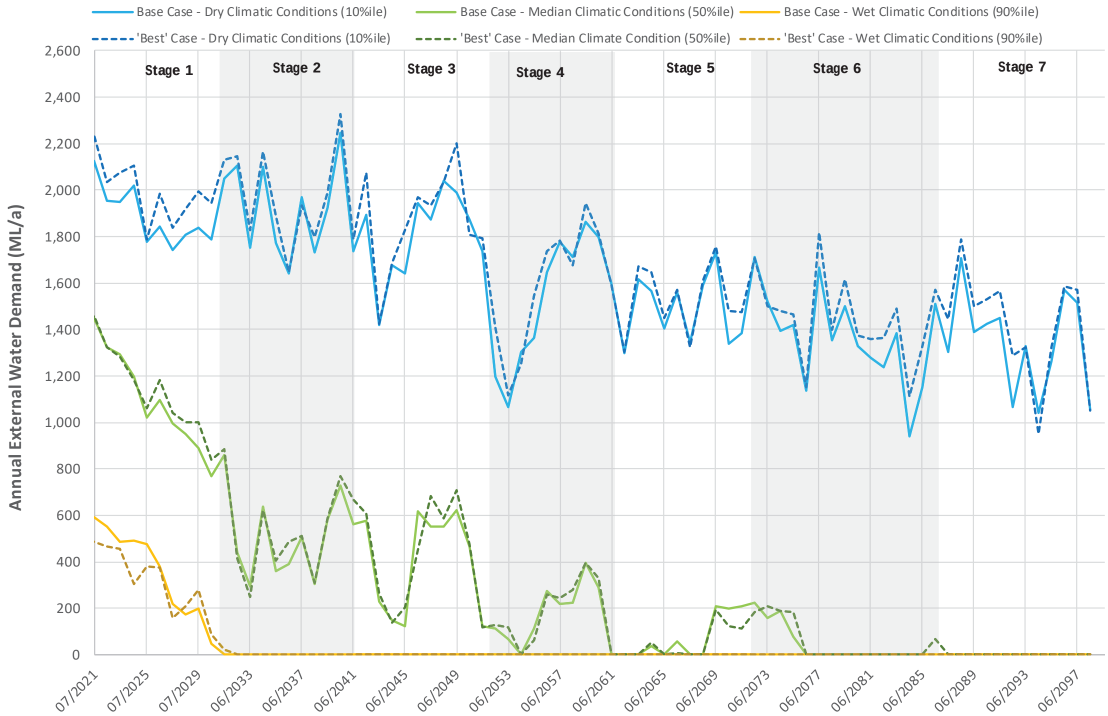

Figure 8-20: Forecast Annual External Water Requirements – ‘Best’ Case Climate Change Sensitivity Assessment

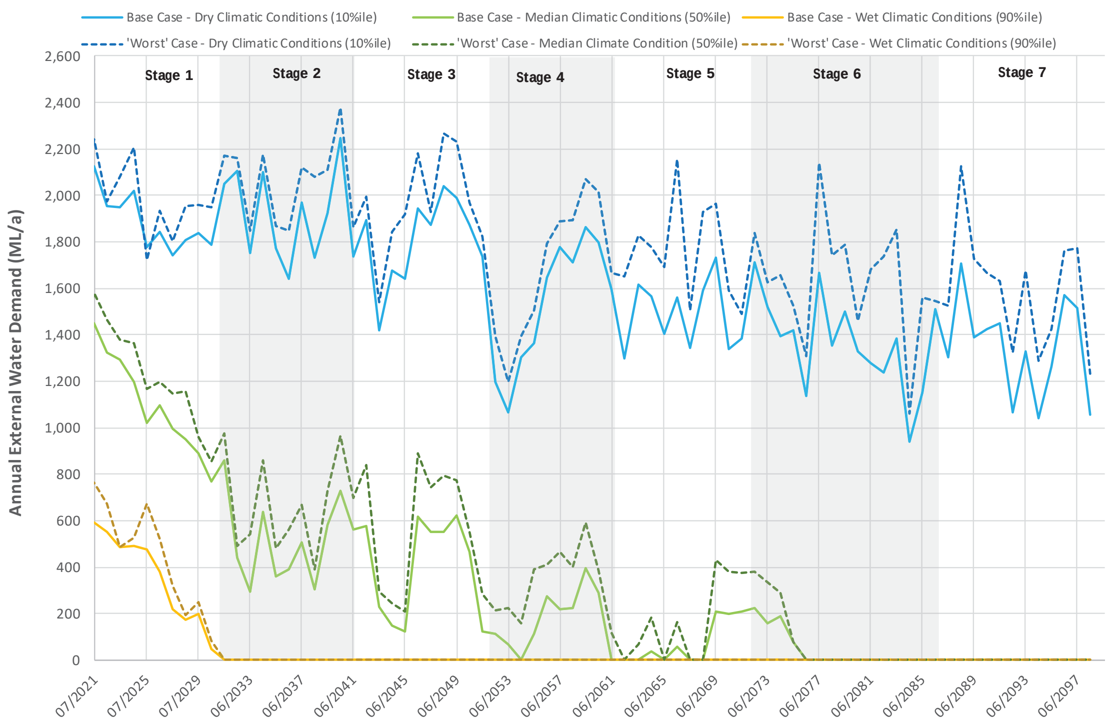

Figure 8-21: Forecast Annual External Water Requirements – 'Worst' Case Climate Change Sensitivity Assessment

8.6.2.4 *Controlled Water Releases*

Figure 8-22 and Figure 8-23 show the forecast annual controlled release volumes from the mine water storages for the 'best' and 'worst' case climate scenarios in comparison to the base case results.

The model results are summarised as follows:

- 'Best' case climate scenario (Figure 8-22):
    - For the 10th percentile results (wet climatic conditions), the 'best' case modelled annual controlled releases volumes are up to 920 ML/a lower than the base case results.
    - For the 50th percentile results (median climatic conditions), the 'best' case modelled annual controlled releases volumes are up to 430 ML/a lower than the base case results.
- 'Worst' case climate scenario (Figure 8-23):
    - For the 10th percentile results (wet climatic conditions), the 'best' case modelled annual controlled releases volumes are up to 330 ML/a lower than the base case results.
    - For the 50th percentile results (median climatic conditions), the 'best' case modelled annual controlled releases volumes are up to 190 ML/a lower than the base case results.

There is an overall decrease in annual controlled release volumes under both the 'best' and 'worst' climate scenarios, when compared with the base case results. The decrease is far more significant under the 'best' case climate scenario. This is primarily due to the reduction in average rainfall resulting in a significant lower number of release opportunities in the Isaac River.

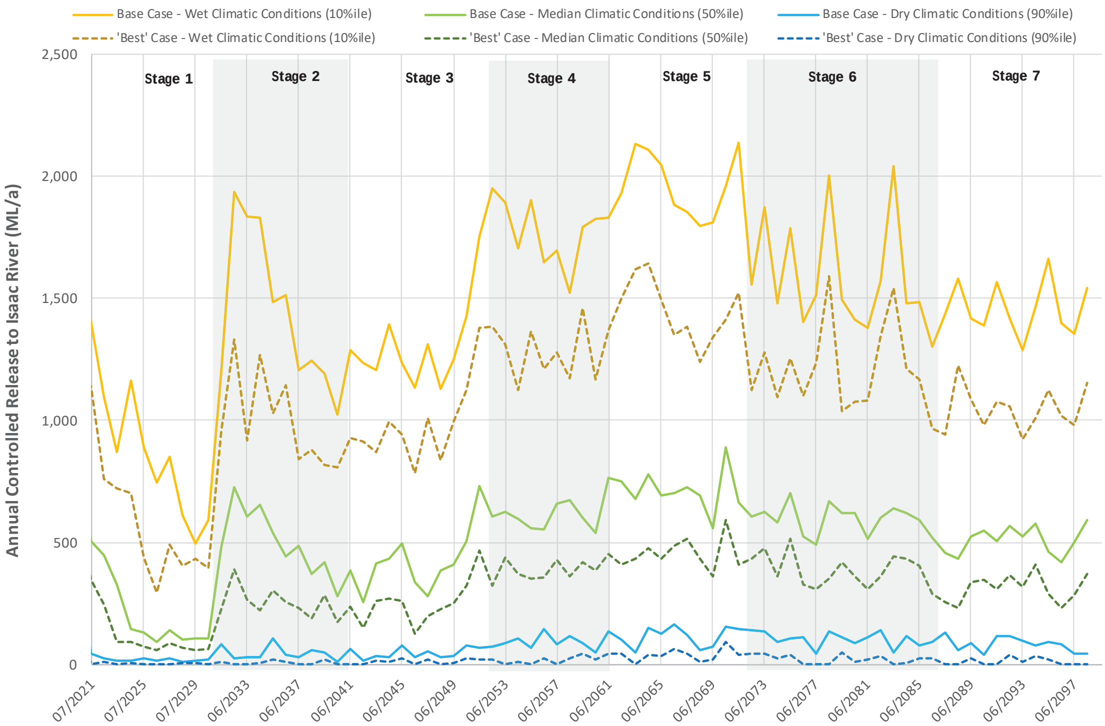

Figure 8-22: Forecast Annual Controlled Release Volumes – 'Best' Case Climate Change Sensitivity Assessment

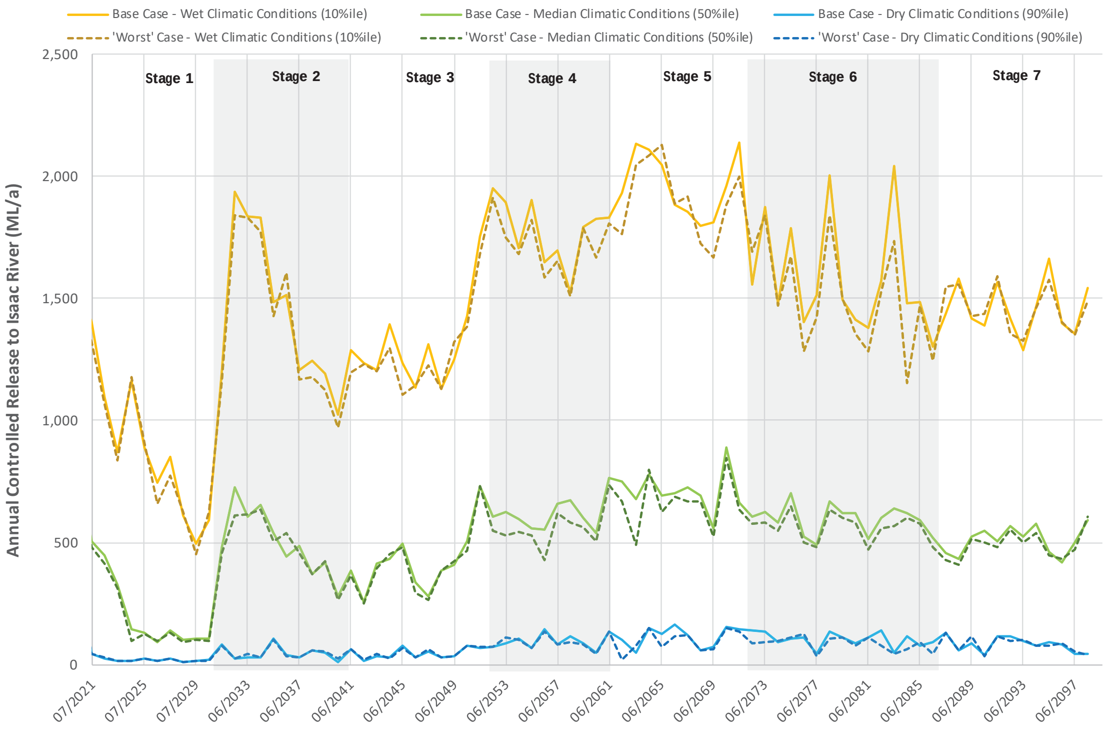

Figure 8-23: Forecast Annual Controlled Release Volumes – 'Worst' Case Climate Change Sensitivity Assessment

9. Final Void Behaviour

9.1 Overview

Water levels in the final voids will vary over time, depending on the prevailing climatic conditions, and the balance between evaporation losses and inflows from rainfall, surface runoff, and groundwater. A GOLDSIM model (separate to the OPSIM model used for the operational modelling) was used to assess the likely long-term water level behaviour of the final voids. The historical rainfall and evaporation sequences (128 years) were repeated 5 times to create a long-term climate record.

A linearly varying depth-dependent storage evaporation factor has been applied to each void to simulate the change in evaporation as void water levels increase. The storage evaporation factors are as follows:

- Bottom of void – 0.5
- 10m from top of void – 0.95
- Top of void – 1.0

The volume of water in the voids is calculated at each time step as the sum of direct rainfall to the void surface, catchment runoff, and groundwater inflows, less evaporation losses.

9.2 Final Void Configuration

The final void configuration and contributing catchment areas are shown in Figure 9-1 and Figure 9-2 and summarised in Table 9-1. The final catchment draining to the voids will be minimised using up-catchment diversions. The proposed up-catchment diversion drains for the final voids will be designed to the following design criteria:

- Slope of drains to match slope of existing natural gully lines in the vicinity, which is in the order of 0.3% to 0.4%. The slopes will be designed to minimize scouring during major flood events.
- Side slopes of drain batters to be in the order of 1 vertical to 6 horizontal.
- Where drains are constructed in spoil areas, the spoil zone under drains shall be compacted to a depth of 500mm.
- Any fill embankments required for the drains shall be compacted in layers not exceeding 200mm.
- Drains will be designed to convey a 0.1% AEP flow with a minimum freeboard of 1.0 m.
- Drains to be vegetated to match vegetation in existing natural gully lines in the vicinity.
- Erosion and sediment control measures shall be implemented until vegetation in the drains is established.
- Drains to meander to create “natural” looking flow paths.

- Drains to be designed and constructed to be self-sustaining and to avoid ongoing maintenance.

Table 9-1: Contributing Catchment to Final Voids

Final Void	Contributing Catchment (ha)
Pit 3	1,191
Pit 7/8	1,208
Willunga	2,506

9.3 Stage-storage Characteristics

The stage-storage curve for Pit 3, Pit 7/8 and Willunga voids Void have been estimated from the final landform terrain model provided by Pembroke. The geometries of the final voids are summarised in Table 9-2.

Table 9-2: Modelled Final Void Geometry

Final Void	Depth (m)	Pit Void Overflow Level/Volume	Overflow Level/Volume to Receiving Environment
Pit 3	275	172 mAHD/ 339,200 ML	194 mAHD/ 477,000 ML
Pit 7/8	289	163 mAHD/ 619,400 ML	178 mAHD/ 749,300 ML
Willunga	227	157 mAHD/ 648,600 ML	161 mAHD/ 689,000 ML

9.4 Final Void Runoff Salinity

The adopted salinity concentrations for the final void catchment are as follows:

- Mining pit floor: 4,500 µs/cm
- Rehabilitated landform: 300 µs/cm

The adopted runoff salinity for the final void assessment is applied at a fixed concentration and does not include any allowance for decay in runoff salinity over time.

The adopted salinity for groundwater inflows to the final void is the same as that adopted for operational groundwater inflows (8,910 µs/cm).

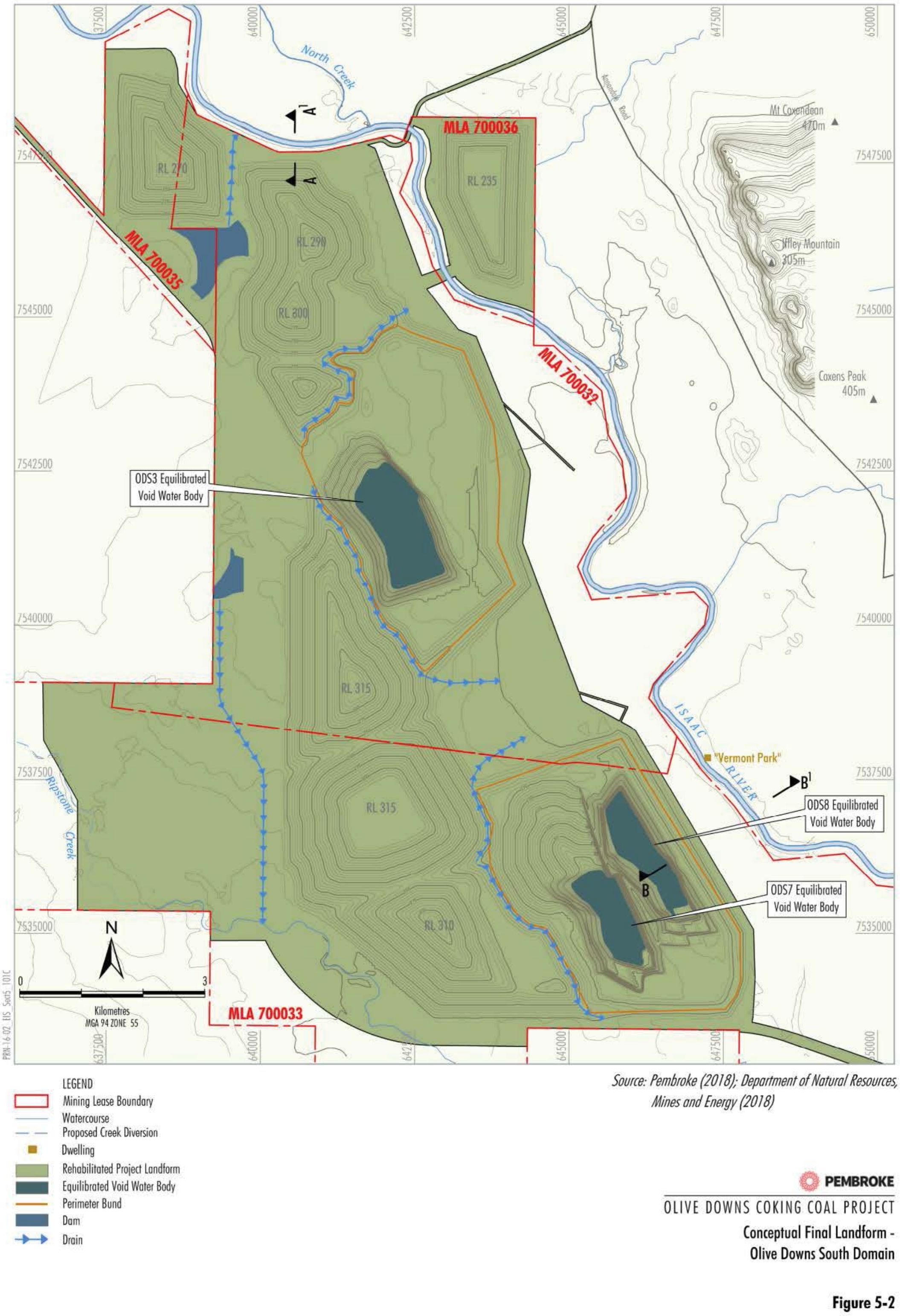

Figure 9-1: Final Void Configuration – ODS Domain

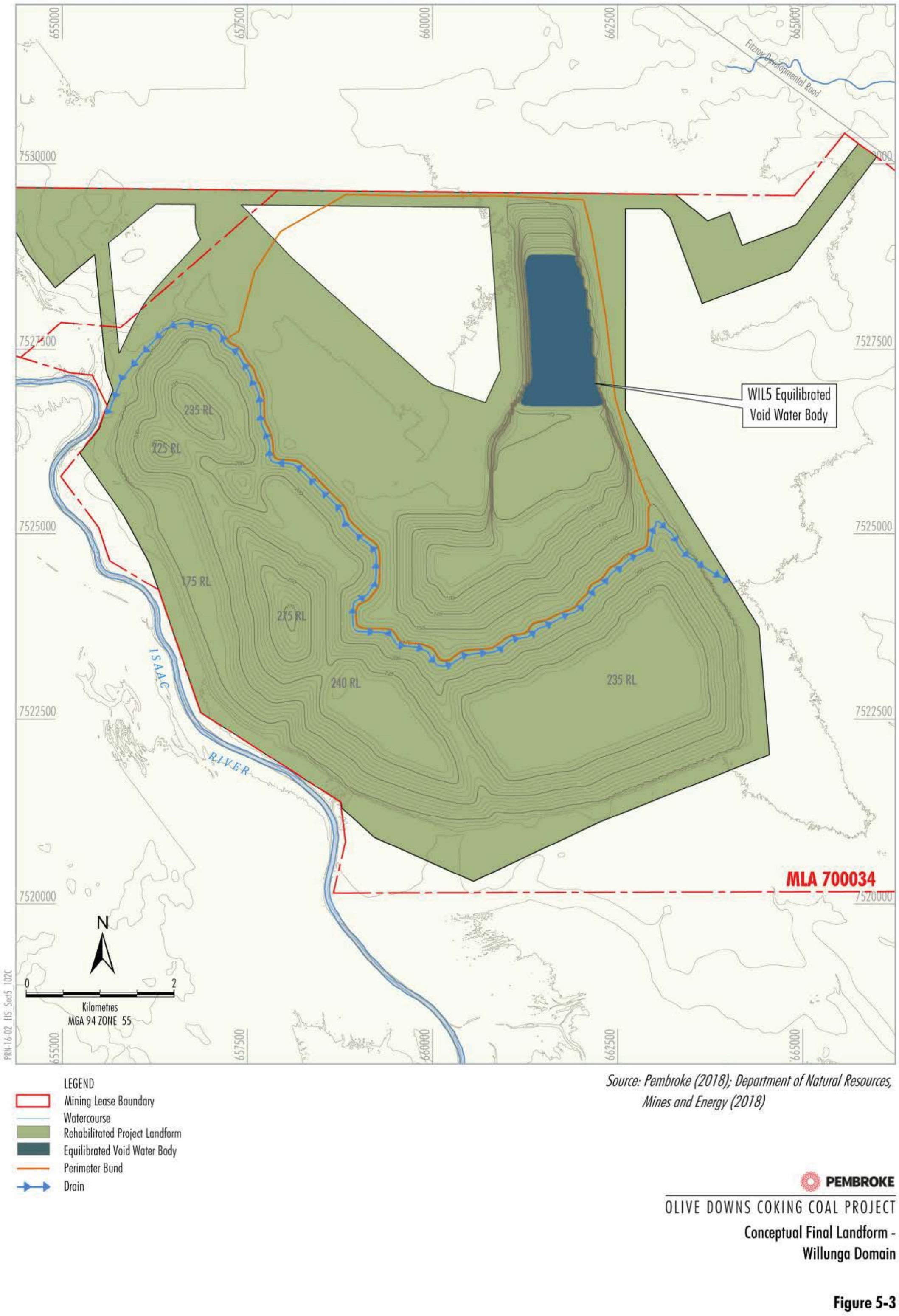

Figure 9-2: Final Void Configuration – Willunga Domain

9.5 Groundwater Inflows

Groundwater inflows to the final voids were provided by SLR. Figure 9-3, Figure 9-4 and Figure 9-5 shows the pit water level versus groundwater inflow rates for the Pit 3, Pit 7/8 and Willunga final voids.

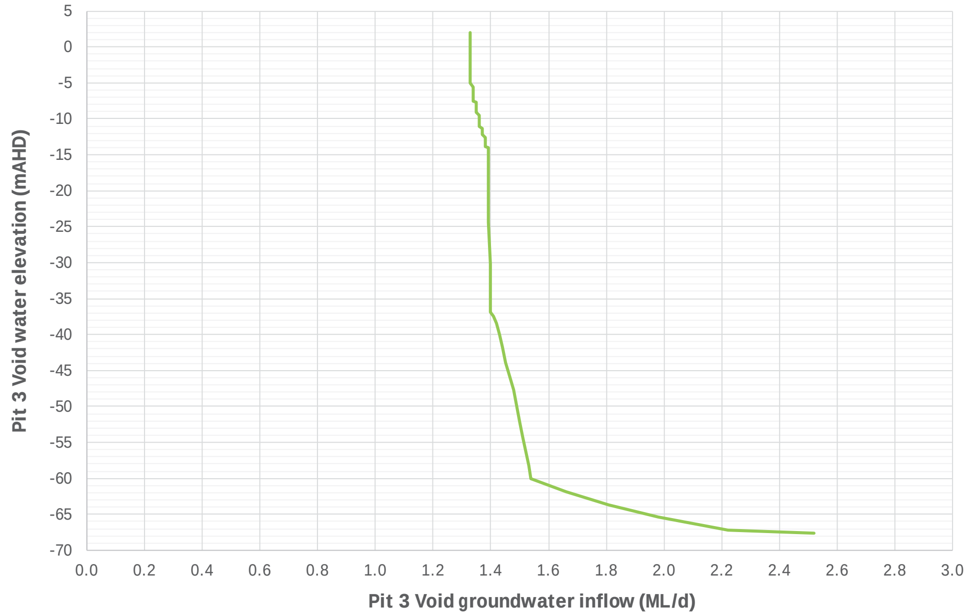

Figure 9-3: Water Level vs Groundwater Inflow Relationship – Pit 3 Final Void

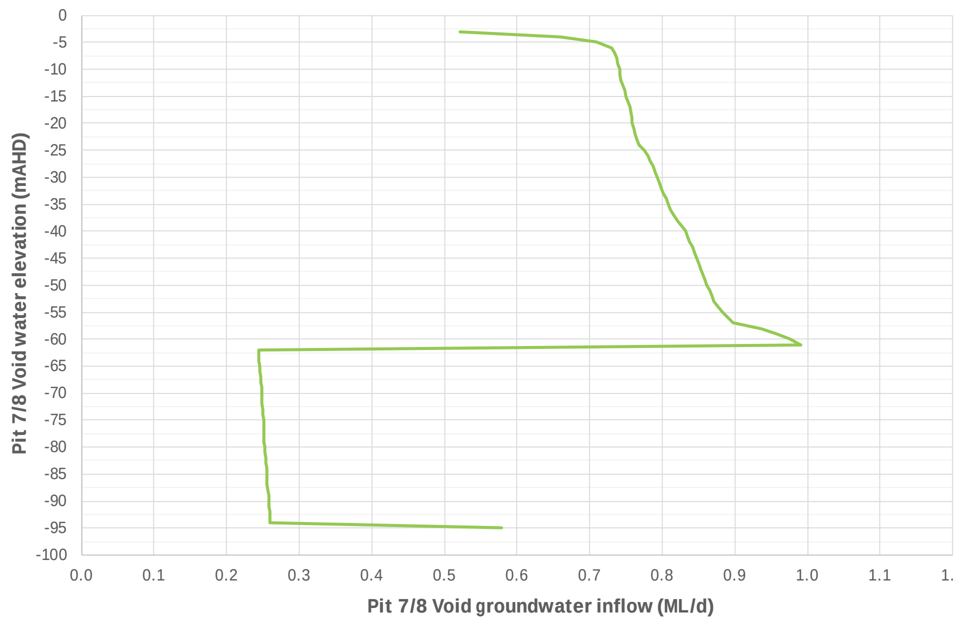

Figure 9-4: Water Level vs Groundwater Inflow Relationship – Pit 7/8 Final Void

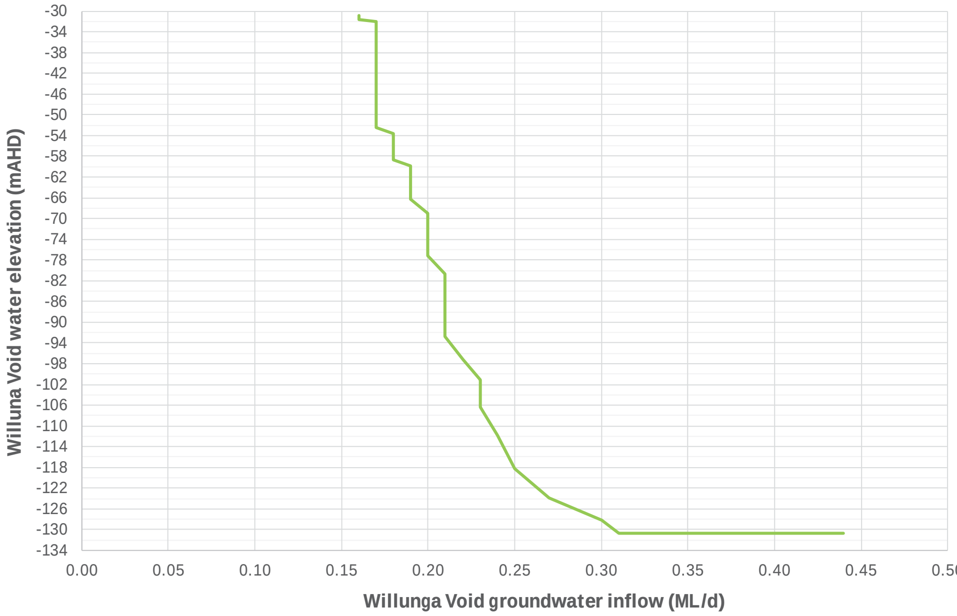

Figure 9-5: Water Level vs Groundwater Inflow Relationship – Willunga Final Void

9.6 Model Results

Figure 9-6, Figure 9-7 and Figure 9-8 show the simulated long-term water levels in the final voids. The model results show the following:

- Pit 3 void
  - The water level reaches equilibrium between 80 mAHD and 90 mAHD after 200 years and generally remains at these levels throughout the remainder of the simulation.
  - The maximum modelled water level is around 82 m below the Pit 3 void overflow level, and around 100 m below the level at which overflows would reach the receiving environment.
  - Salt accumulates within the Pit 3 void at an average rate of around 5,000 tonnes per year. The void becomes hyper-saline (>35,000 mg/L) after around 550 years of simulation.
- Pit 7/8 void
  - The water level reaches equilibrium between 20 mAHD and 30 mAHD after 150 years and generally remains at these levels throughout the remainder of the simulation.
  - The maximum modelled water level is around 130 m below the Pit 7/8 void overflow level, and around 145 m below the level at which overflows would reach the receiving environment.

- Salt accumulates within the Pit 7/8 void at an average rate of around 3,800 tonnes per year. The void becomes hyper-saline (>35,000 mg/L) after around 550 years of simulation.

- Willunga void
  - The water level reaches equilibrium between 55 mAHD and 70 mAHD after 100 years and generally remains at these levels throughout remainder of the simulation.
  - The maximum modelled water level is around 85 m below the Willunga void overflow level, around 90 m below the level at which overflows would reach the receiving environment.
  - Salt accumulates within the Willunga void at an average rate of around 3,000 tonnes per year. The void approaches hyper-salinity (>35,000 mg/L) towards the end of the 600 year simulation.

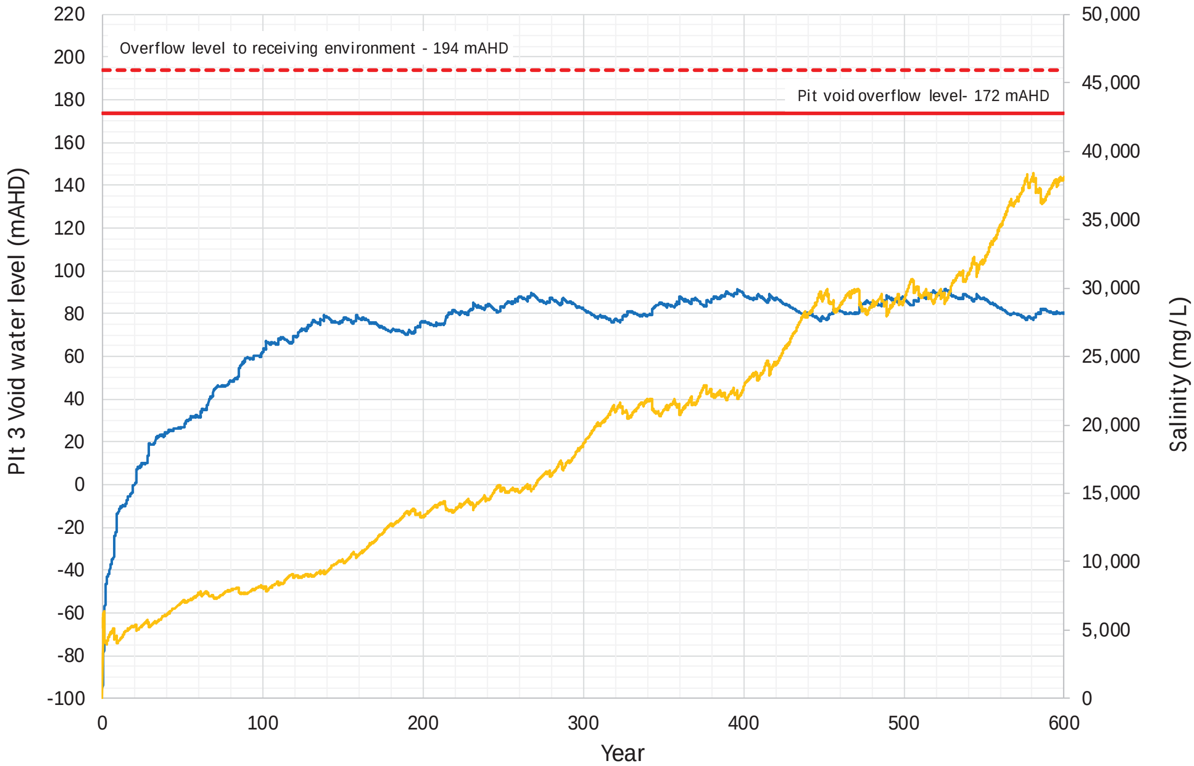

Figure 9-6: Final Void Water Levels and Salt Load – Pit 3 Void

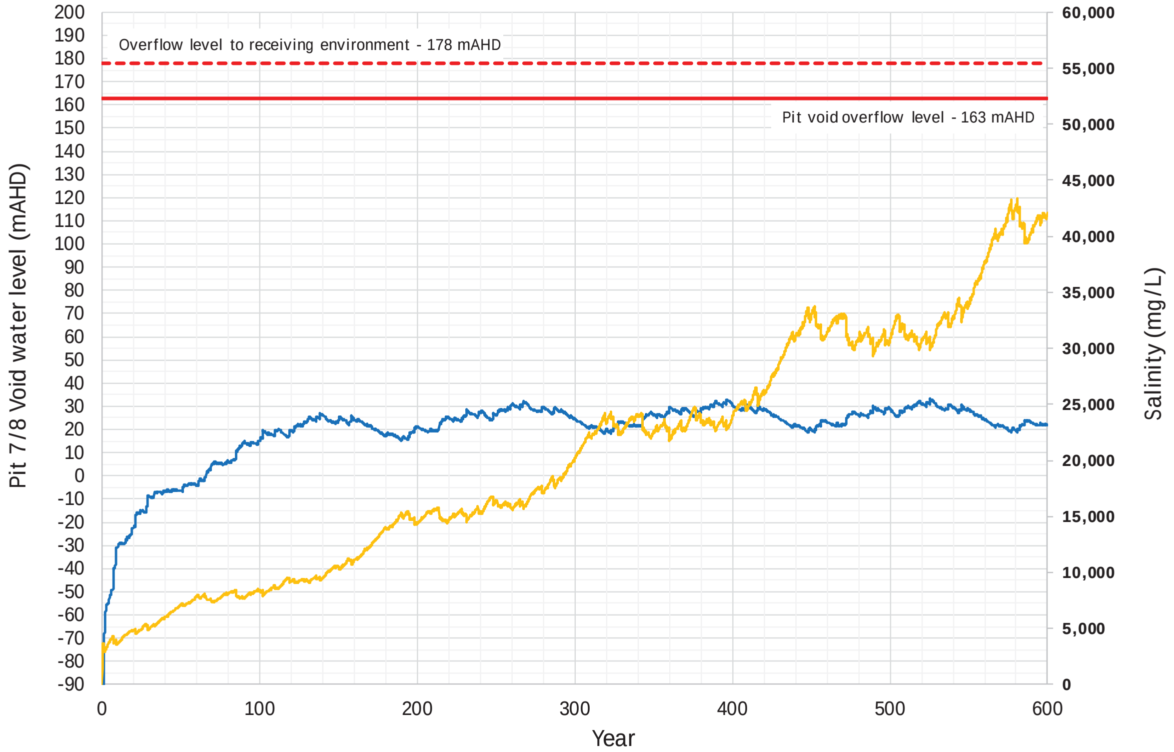

Figure 9-7: Final Void Water Levels and Salt Load – Pit 7/8 Void

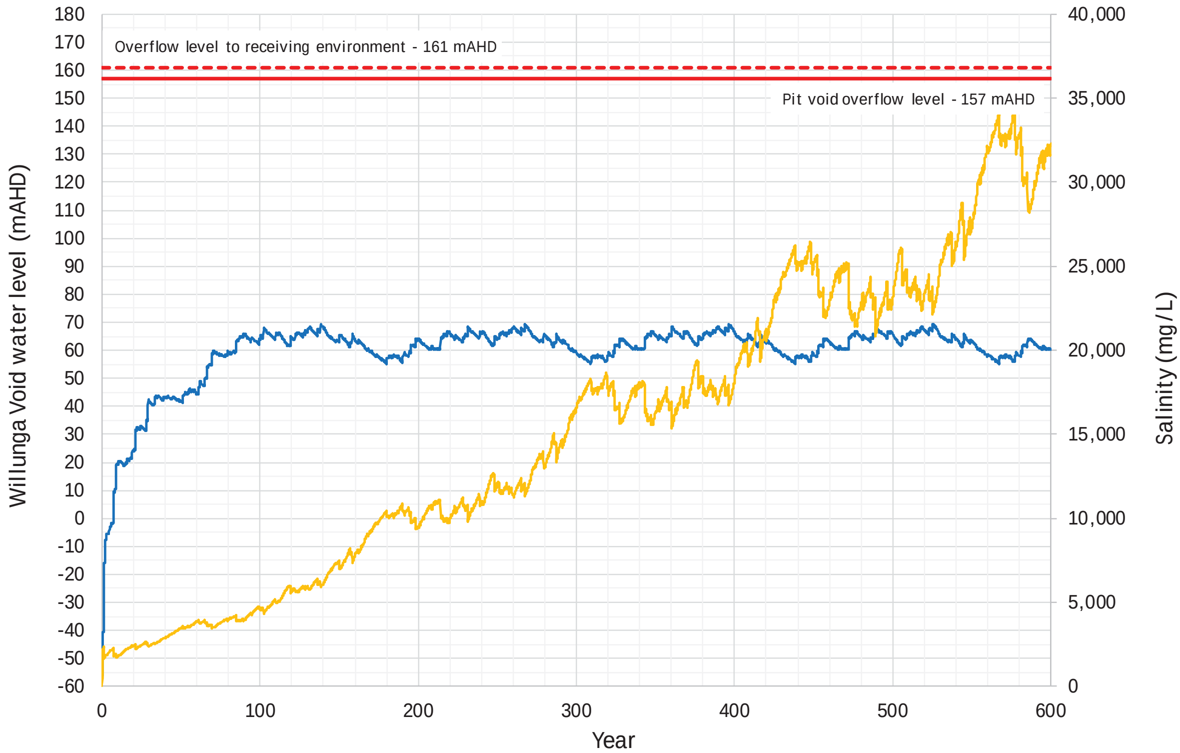

Figure 9-8: Final Void Water Levels and Salt Load – Willunga Void

The final void modelling indicates that the expected water levels are below the full supply levels for each void, and the voids will remain as long-term groundwater sinks (Hydrosimulations, 2018). As there is no mechanism to lose salt within the closed void system, the voids continually accumulate salt over time and become hypersaline or approach hypersaline conditions over the 600-year simulation.

9.7 Sensitivity Analysis

A sensitivity analysis has been undertaken to assess the potential impact of the adopted evaporation factors on the equilibrium level within the final voids.

As described in Section 9.1, a linearly varying depth-dependent storage evaporation factor has been applied to each void to simulate the change in evaporation as void water levels increase. The storage evaporation factors adopted for the base case model are as follows:

- Bottom of void – 0.5
- 10m from top of void – 0.95
- Top of void – 1.0

There is currently very little information available within the mining industry regarding void evaporation factors, and this introduces some uncertainty into the modelling outcomes. To address this uncertainty, a sensitivity assessment using increase and decreased evaporation factors has been undertaken. The proposed modified factors are as follows:

- Reduced evaporation factors:
  - Bottom of void – 0.3
  - Top of void – 0.7
- Increased evaporation factors:
  - Bottom of void – 0.8
  - Top of void – 1.0

The results from these sensitivity analyses are provided in the following section.

9.7.1 Impact of Evaporation Factors on Final Void Water Levels

The impact of variation in evaporation factors for the Pit 3, Pit 7/8 and Willunga final void water levels is presented in Figure 9-9, Figure 9-10 and Figure 9-11. The results show the following (in comparison to the base case results):

- Pit 3 Void (Figure 9-9):
  - With reduced evaporation factors, the equilibrium level takes around 100 years longer to be reached and is around 40 m higher.
  - With increased evaporation factors, the equilibrium level is reached in a similar timeframe and is around 20 m lower.

- Pit 7/8 Void (Figure 9-10):
  - With reduced evaporation factors, the equilibrium level takes around 100 years longer to be reached and is around 30 m higher.
  - With increased evaporation factors, the equilibrium level is reached in a similar timeframe and is around 20 m lower.
- Willunga Void (Figure 9-11):
  - With reduced evaporation factors, the equilibrium level is reached in a similar timeframe and is around 20 m higher.
  - With increased evaporation factors, the equilibrium level is reached in a similar timeframe and is around 5-10 m lower.

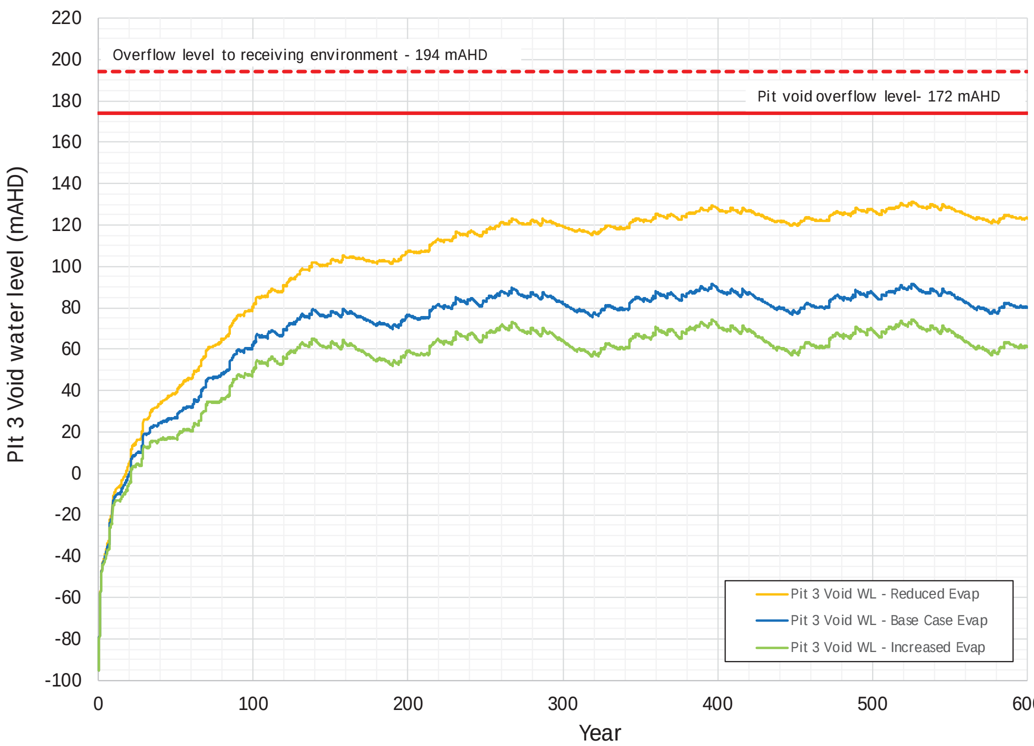

Figure 9-9: Evaporation Factor Sensitivity Analysis - Final Void Water Level – Pit 3 Void

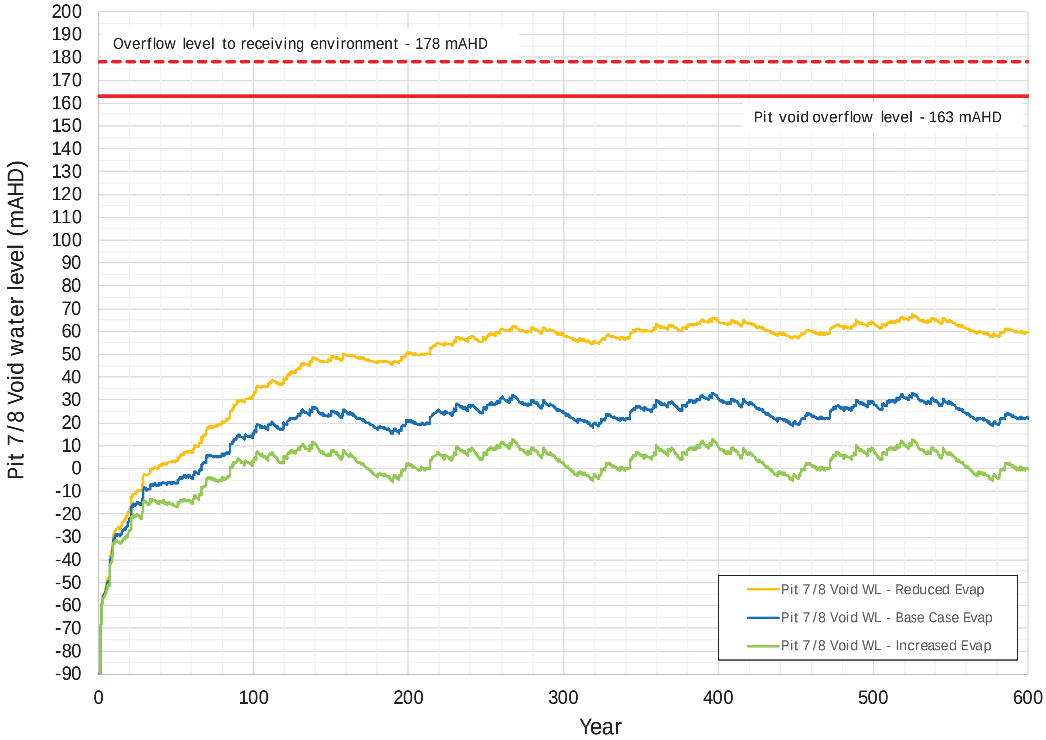

Figure 9-10: Evaporation Factor Sensitivity Analysis - Final Void Water Levels - Pit 7/8 Void

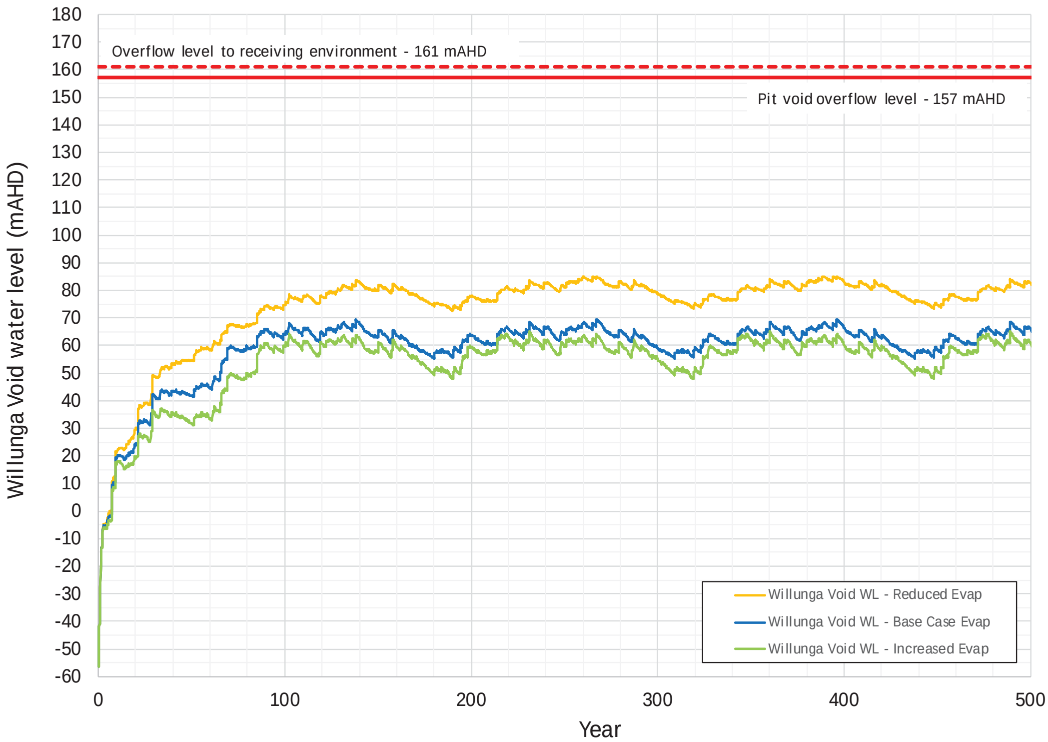

Figure 9-11: S Evaporation Factor Sensitivity Analysis - Final Void Water Levels – Willunga Void

9.7.2 *Impact of Evaporation Factors on Final Void Salinity*

The impact of variation in evaporation factors for the Pit 3, Pit 7/8 and Willunga final void salinity is presented in Figure 9-12, Figure 9-13 and Figure 9-14. The results show the following (in comparison to the base case results):

- Pit 3 Void (Figure 9-12):
  - With reduced evaporation factors, the void salinity following the 600 year simulation is around 40% lower.
  - With increased evaporation factors, the void salinity concentration following the 600 year simulation is around 30% higher.
- Pit 7/8 Void (Figure 9-13):
  - With reduced evaporation factors, the void salinity following the 600 year simulation is around 50% lower.
  - With increased evaporation factors, the void salinity following the 600 year simulation is around 70% higher.
- Willunga Void (Figure 9-14):
  - With reduced evaporation factors, the void salinity following the 600 year simulation is around 35% lower.
  - With increased evaporation factors, the void salinity following the 600 year simulation is around 10% higher.

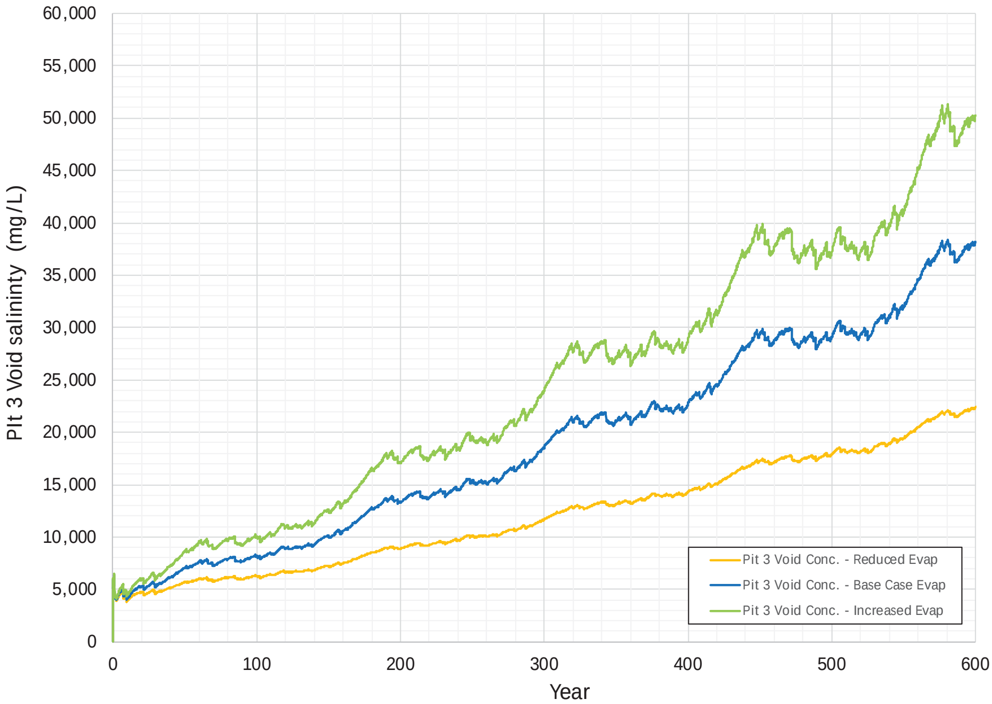

Figure 9-12: Evaporation Factor Sensitivity Analysis - Final Void Water Level – Pit 3 Void

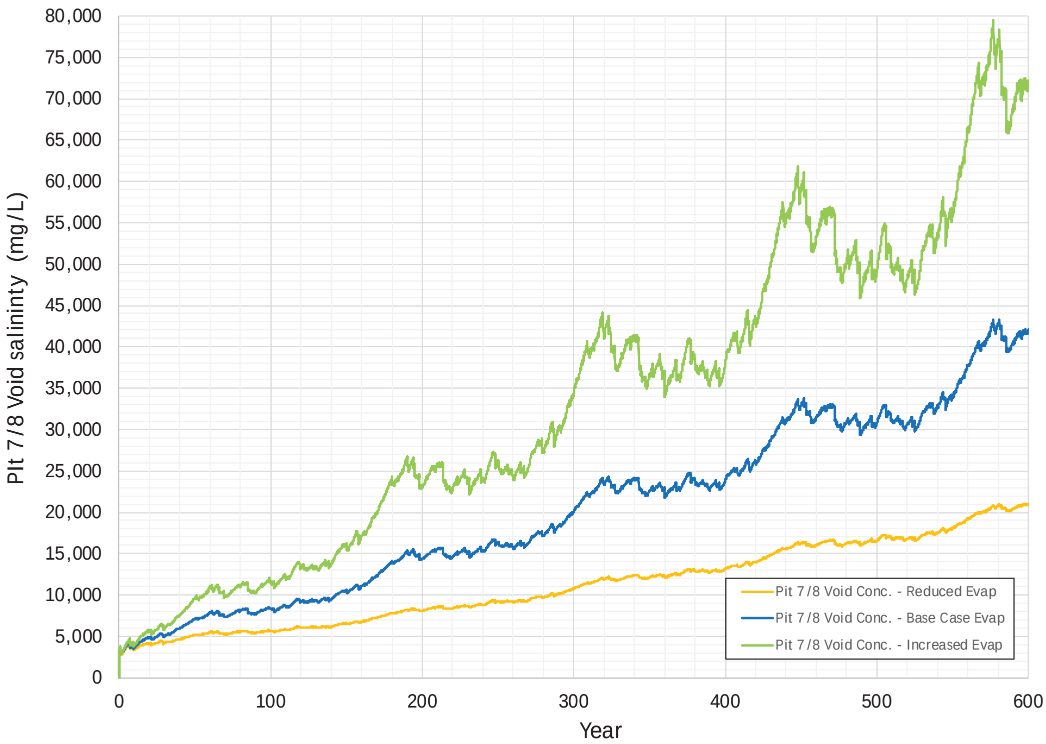

Figure 9-13: Evaporation Factor Sensitivity Analysis - Final Void Water Levels - Pit 7/8 Void

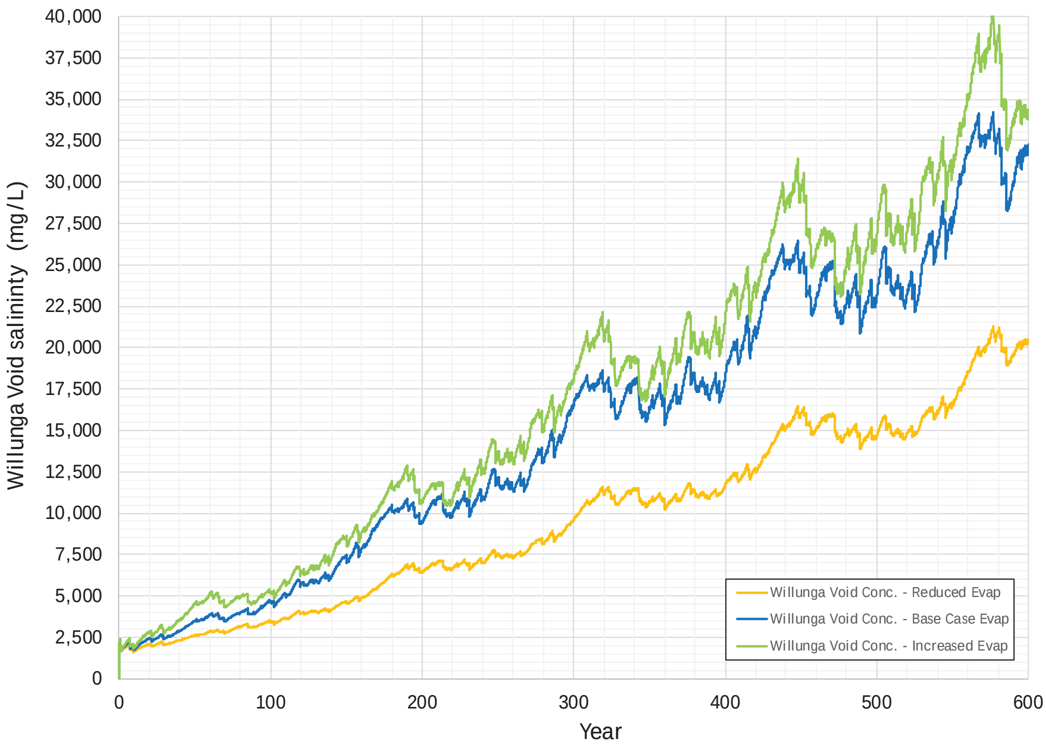

Figure 9-14: S Evaporation Factor Sensitivity Analysis - Final Void Water Levels – Willunga Void

10. Mitigation and Management Measures

10.1 Potential Impacts

The potential impacts of the Project on surface water resources include:

- impacts on flows and the flooding regime in Ripstone Creek and the Isaac River;
- impacts on regional water availability due to the potential need to obtain water from external sources to meet operational water requirements of mining operations;
- impacts on stream flows due to loss of catchment area draining to local drainage paths due to capture of runoff within onsite storages and the open cut pit;
- adverse impacts on the quality of surface runoff draining from the disturbance areas to the various receiving waters surrounding the Project, during both construction and operation of the Project;
- adverse impacts on environmental values in the Isaac River associated with controlled releases from the mine water management system;
- impact of water management system on adjacent wetlands; and
- cumulative impacts of all projects in the region on the environmental values of the receiving waters.

An assessment of each of these potential impacts of the Project is provided in the following sections.

The assessment of surface water impacts has been undertaken based on commonly applied methodologies for the simulation of hydrologic and hydraulic processes using currently available data. The adopted approach is considered suitable for quantifying impacts to a level of accuracy consistent with current industry practice. Certain aspects of the project, such as changes to landforms due to construction of out-of-pit waste rock emplacements or mine subsidence, will create impacts that are irreversible, although this does not mean that any such impacts are necessarily detrimental to the environmental values of receiving waters.

10.2 Flooding

Potential impacts of the Project on flood levels and flood velocities in Ripstone Creek and the Isaac River are addressed in a separate report (Hatch, 2018). Refer to this report for further details regarding the flood-related impact assessment.

10.3 Regional Water Availability Impacts

A significant proportion of mine site water requirements will be sourced from water collected on the site, including rainfall runoff and groundwater inflows to the open cut pit which will be stored in the mine affected water dams for recycling and reuse.

The results of the water balance modelling (see Section 8.3.4) show that there is less than a 10% probability that the proposed water licence allocation of 2,250 ML will require supplementing in any one year.

If, during operations, there was a risk that the allocation could be exceeded, the site water demands could be adjusted (e.g. dust suppressants) or alternative water harvesting measures could be implemented.

10.4 Stream Flow Impacts

10.4.1 During Active Mining Operations

During active mining operations, the Project water management system will capture runoff from areas that would have previously flowed to the receiving waters of Ripstone Creek and the Isaac River. The loss of catchment affects an 8 km reach of Ripstone Creek. The captured catchment area will change as the mine develops, and out-of-pit waste rock emplacement are progressively rehabilitated. A breakdown of the catchment areas reporting to the Project water management system is provided in Table 10-1 and excludes areas managed under the ESCP strategy and areas that are fully rehabilitated. Areas managed under the ESCP will drain from the site following treatment.

Table 10-1 and Figure 10-1 shows the maximum catchment area captured within the Project water management system during active mining operations (excluding ESC managed or fully rehabilitated areas). The maximum captured catchment areas represent:

- Less than 13% of the Ripstone Creek catchment to its confluence with the Isaac River; and
- Less than 1% of the Isaac River at a location downstream of the Project (the ISDS stream gauge).

Given that the runoff volumes from the ESCP areas will be higher than under natural conditions, the loss of stream flows will likely be less than the loss of catchment area. The loss of catchment to Ripstone Creek only affects an 8 km reach the creek.

Table 10-1: Catchment Area Captured Within the Project Water Management System

Catchment	Total Catchment Area (km^2)	Captured Catchment Area (km^2)						
		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7
Ripstone Creek (to the confluence with Isaac River)	286	6	21	26	31	36	35	35
Isaac River (to the ISDS stream gauge)	7,782	10	48	50	48	49	51	38

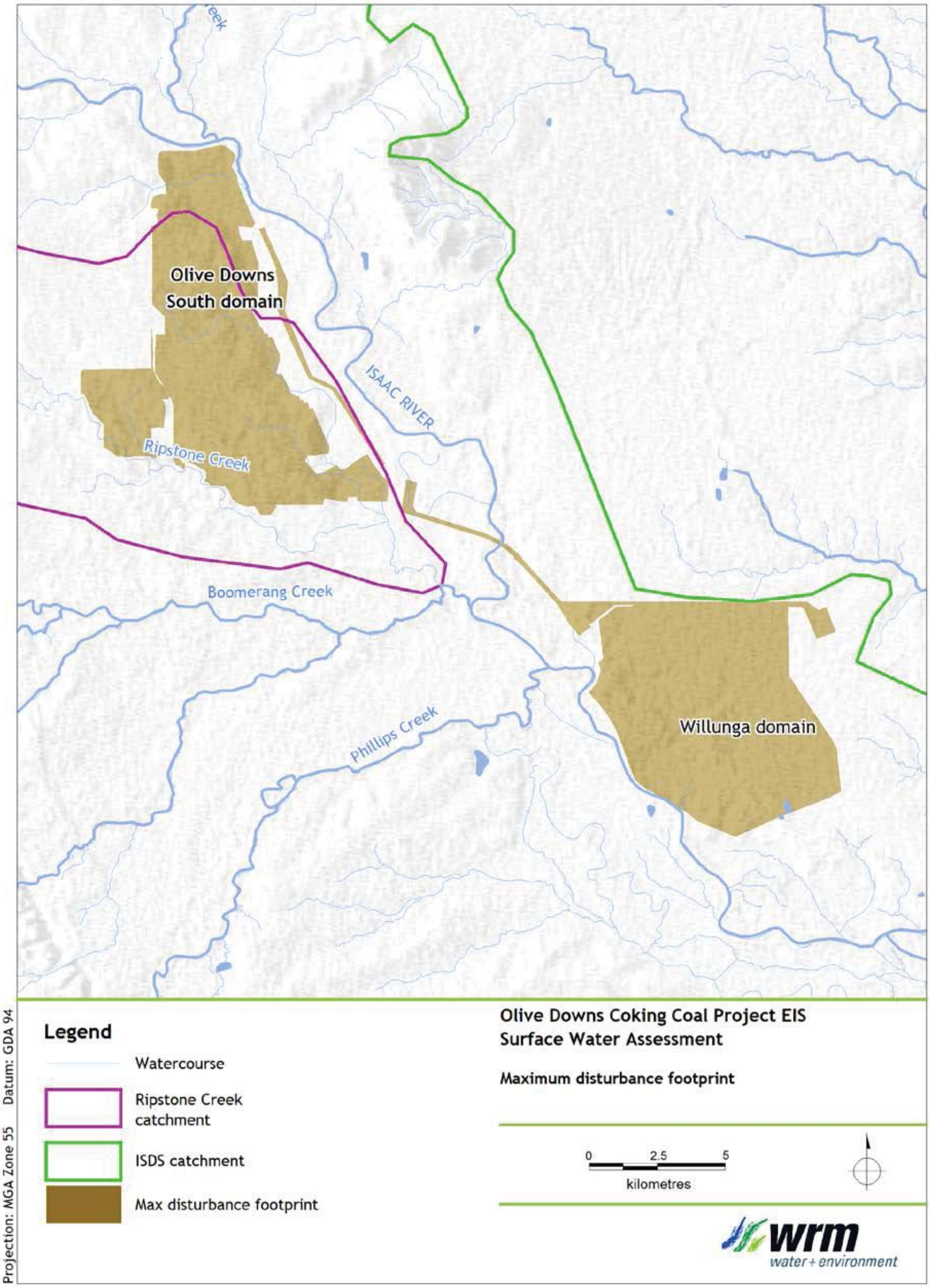

Figure 10-1: Maximum Captured Catchment During Operations

10.4.2 *Post-mining Final Landform*

At the completion of mining, permanent drainage of out-of-pit waste rock emplacement areas will be installed to minimise capture of surface runoff in the final void in general accordance with the configurations shown in Figure 9-1 and Figure 9-2. An area of approximately 49 km^2 will continue to drain to the final voids.

The net change in catchment area draining from the site is summarised in Table 10-2. The changed topography as a result of the Project final landform will have the following impacts on catchment areas:

- The catchment draining to Ripstone Creek will reduce by around 19 km^2 (compared to pre-mining conditions), a decrease of less than 7%.
- The catchment draining to the Isaac River will reduce by around 49 km^2 (compared to pre-mining conditions), a decrease of less than 1%.

Table 10-2: Final Landform – Captured Catchment Areas

Receiving Watercourse	Pre-mining Catchment Area (km^2)	Post-mining Catchment Area (km^2)	Post-mining Captured Catchment Area (km^2)
Ripstone Creek (to the confluence with Isaac River)	286	267	19
Isaac River (to the ISDS stream gauge)	7,782	7,733	49

10.5 Regional Water Quality and Environmental Values

10.5.1 *Overview*

Land disturbance associated with mining has the potential to adversely affect the quality of surface runoff by increasing sediment loads from spoil areas and releasing mine affected water with high salt loads. Section 6.2 outlines the proposed water management strategy to manage these risks.

10.5.2 *Performance of the Proposed Water Management System*

10.5.2.1 *Mine Affected Water*

An assessment of the mine affected water management system is given in Section 8.3. The results of the water balance modelling indicate that, under the current model assumptions and configuration, there is nil risk of uncontrolled spills of mine affected water from the Project to the receiving environment.

An overflow would only occur during an extreme rainfall event which would also generate significant volumes of runoff from the surrounding undisturbed catchment, as well as in the receiving waterways. Hence it is unlikely that mine affected dam overflows will have a measurable impact on receiving water quality and therefore the environmental values.

10.5.2.2 Sediment Water

In the operational phase, progressive rehabilitation of the out-of-pit rock emplacements will minimise the potential generation of sediment. An Erosion and Sediment Control Plan will be developed and implemented throughout construction and operations. A 'best practice' approach will be adopted which is consistent with the International Erosion Control Association (IECA) recommendations. The following broad principles will apply:

- Minimise the area of disturbance;
- Where possible, apply local temporary erosion control measures;
- Intercept run-off from undisturbed areas and divert around disturbed areas; and
- Where temporary measures are likely to be ineffective, divert run-off from disturbed areas to sedimentation basins prior to release from the site.

If implemented effectively, environmental risks from disturbed area runoff are expected to be low. In rainfall events below the design standard, runoff from disturbed areas will be intercepted and treated by sediment dams. In larger events that exceed the design standards, these dams will overflow following a period of settlement.

Available geochemical information indicates that the runoff draining to the sediment dams should have low salinity. Overflows would only occur during significant rainfall events which will also generate runoff from surrounding undisturbed catchments. Hence it is unlikely that sediment dam overflows will have a measurable impact on receiving water quality or environmental values.

Water quality in these dams will be monitored regularly to confirm the geochemical information. Water may be pumped into the mine water management system if required to manage this risk.

10.5.3 Controlled Releases

Figure 10-2 shows a plot of modelled EC in the Isaac River (notionally downstream of the Deverill gauge, but upstream of ISDS) on days when there is a controlled release opportunity (i.e. the Isaac River flow exceeds the minimum flow criteria). The plot shows the modelled EC in the Isaac River both with and without controlled releases from the Project. That is, it shows the potential impact of controlled releases on the Isaac River.

Figure 10-2 shows the following:

- The minimum EC in the Isaac River on a release day is around 75 µs/cm during the largest flood events;
- There is a 50% chance that the downstream Isaac River EC will be greater than 180 µs/cm during a controlled release;
- There is a 10% chance that the downstream Isaac River EC will be greater than 250 µs/cm during a controlled release;
- The EC in the Isaac River is below the receiving water contaminant trigger level of 700 µs/cm on all release days.

- The proposed strategy potentially increases the EC in the Isaac River (in the vicinity of the Project) by up to 50 µS/cm, however it is well below the typical receiving water contaminant trigger level of 700 µS/cm.

The outcomes from the water balance modelling indicates that the proposed controlled release strategy will generally achieve the regional WQO's for the Isaac River and therefore not impact on its environmental values.

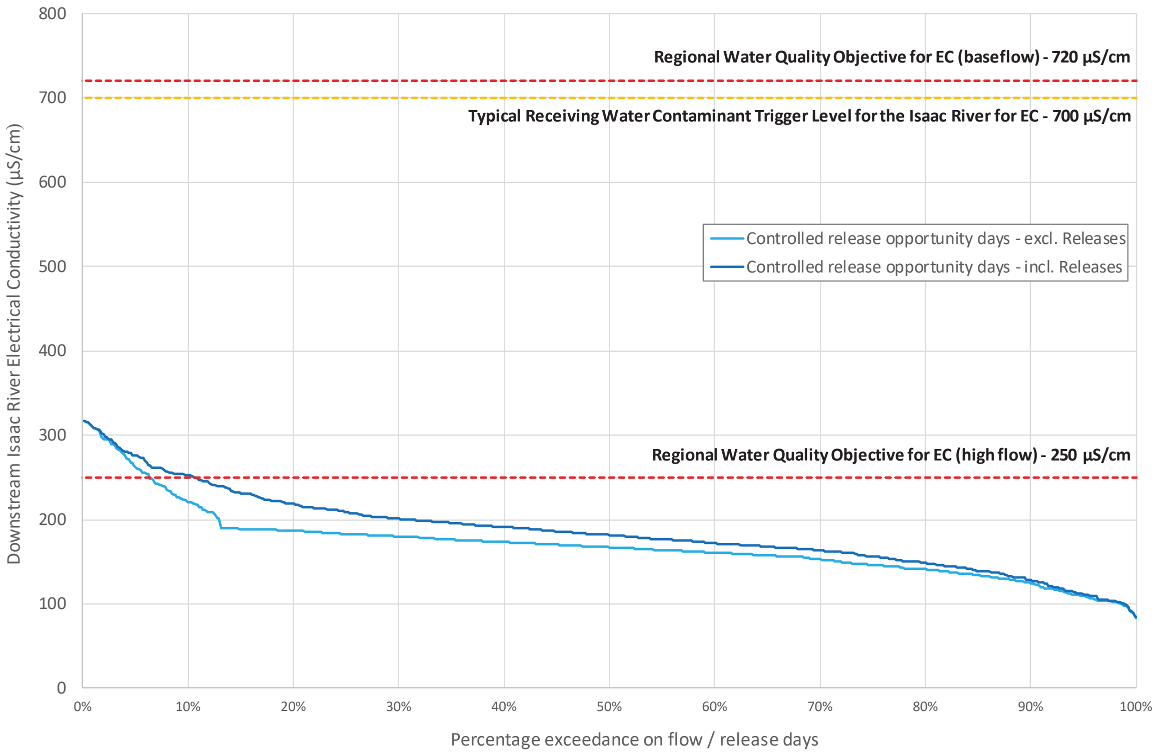

Figure 10-2: Modelled Isaac River Receiving Water Quality – Median Model Realisation (Cycle 50)

10.5.4 *Impact of Water Management System on Adjacent Wetlands*

There are a number of Wetland Protection Areas located within and adjacent to the Project area. Further details of these wetlands are provided in the Aquatic Ecology report (Appendix C of the EIS).

The proposed water management system (including the controlled release system) has been designed to have no interaction with the wetland areas. Therefore, the proposed water management system will have no impact of the wetland areas.

The potential impact of the proposed flood protection levees on the wetland areas is discussed in the Flood Assessment (Appendix F of the EIS).

10.6 Cumulative Impacts – Surface Water

10.6.1 Overview

The objective of this assessment is to identify the potential for impacts from the Project to have compounding interactions with similar impacts from other projects, including activities proposed, under development or already in operation within a suitable region of influence of the Project.

There are three levels at which cumulative impacts may be relevant:

- *Localised cumulative impacts* – These are the impacts that may result from multiple existing or proposed mining operations in the immediate vicinity of the project. Localised cumulative impacts include the effect from concurrent operations that are close enough to potentially cause additive effect on the receiving environment. For the purposes of this assessment, we have included all existing and proposed projects located within the Isaac River catchment.
- *Regional cumulative impacts* – These include the project's contribution to impacts that are caused by mining operations throughout the Bowen Basin region or at a catchment level. Each coal mining operations in itself may not represent a substantial impact at a regional level; however, the cumulative effect on the receiving environment may warrant consideration.
- *Global cumulative impacts* – These includes impacts that the project might contribute to at a global scale. The only potential global scale impact for the project is greenhouse gas (GHG) emissions, and as such has not been addressed in this assessment.

We understand that the Commonwealth Department of Environment and Energy (DoEE) has recently approved the Lake Vermont Coal Mine Northern Extension Project, which is located upstream of the Project adjacent to Phillips Creek. The cumulative impact assessment provided in the following sections has considered the impact of this approval.

10.6.2 Relevant Projects

10.6.2.1 Existing Projects

Projects which are currently operating within the Isaac River catchment upstream of the ISDS streamflow gauge and have been included in the cumulative impacts assessment for the Project are listed in Table 10-3.

Table 10-3: Existing Projects Considered in the Cumulative Impact Assessment

Project	Proponent	Description	Operational Status	Relationship to the Project Area	
				Timing	Location
Burton Mine	Peabody Energy Australia	Open cut coal mine	Ceased production indefinitely	May have overlapping operational phases with the construction and operations of the project, although unlikely given the current operational status.	30 km to the north-northwest of the project area. Located within Isaac River catchment (upstream).
Moorvale Mine	Peabody Energy Australia	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	18 km to the north of the project area. Located within Isaac River catchment (upstream).
Eaglefield Mine	Peabody Energy Australia	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	60 km to the north-northwest of the project area. Located within Isaac River catchment (upstream).
North Goonyella Mine	Peabody Energy Australia	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	60 km to the north-northwest of the project area. Located within Isaac River catchment (upstream).
Millennium Mine	Peabody Energy Australia	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	15 km to the north-northwest of the project area. Located within Isaac River catchment (upstream).
Goonyella Riverside Mine	BMA	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	45 km to the northwest of the project area. Located within Isaac River catchment (upstream).
Moranbah North Mine	Anglo American	Underground coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	40 km to the northwest of the project area. Located within Isaac River catchment (upstream).
Grosvenor Mine	Anglo American	Underground coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	25 km to the northwest of the project area. Located within Isaac River catchment (upstream).
Carborough Downs Mine	Fitzroy Queensland Resources	Underground coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	20 km to the north-northwest of the project area. Located within Isaac River catchment (upstream).
Isaac Plain Mine	Stanmore Coal	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	25 km to the north northwest of the project area. Located within Isaac River catchment (upstream).

Project	Proponent	Description	Operational Status	Relationship to the Project Area	
				Timing	Location
Poitrel Mine	BMA	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	10 km to the north-northwest of the project area. Located within Isaac River catchment (upstream).
Daunia Mine	BMA	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	5 km to the north-northwest of the project area. Located within Isaac River catchment (upstream).
Caval Ridge Coal Mine	BMA	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	25 km to the west of the project area. Located within Isaac River catchment (upstream).
Peak Downs Mine	BMA	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	15 km to the west of the project area. Located within Isaac River catchment (upstream).
Saraji Mine	BMA	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	10 km to the southwest of the project area. Located within Isaac River catchment (upstream/downstream).
Norwich Park Mine	BMA	Open cut coal mine	Ceased production indefinitely	May have overlapping operational phases with the construction and operations of the project.	25 km to the southwest of the project area. Located within Isaac River catchment (downstream).
Lake Vermont Mine	Jellinbah Group	Open cut coal mine	Operating NE Extension Project approved	May have overlapping operational phases with the construction and operations of the project.	20 km to the south of the project area. Located within Isaac River catchment (adjacent), and upstream of the Project on Phillips Creek.

10.6.2.2 New or Developing Projects

Relevant projects that have been considered include:

- Projects within the predicted sphere of influence of the project, as listed on the Department of State Development, Infrastructure and Planning (DSDIP) website that are undergoing assessment under the State Development and Public Works Organisation Act 1971 (SDPWO Act) for which an Initial Advice Statement (IAS) or an EIS are available; and
- Projects within the predicted sphere of influence of the project, which are listed on the website of the Department of Environment and Science (DES) that are undergoing assessment under the Environmental Protection Act 1994 (EP Act) for which an IAS or an EIS are available.
- Projects within the predicted sphere of influence of the project, which are listed on the website of the Department of Infrastructure, Local Government and Planning (DILGP) that are undergoing assessment under the Regional Planning Interests Act 2014 (RPI Act) for which an Assessment Application is available.

Projects currently undergoing assessment or having recently completed assessment under these processes and included in the cumulative impact assessment for the project are listed in Table 10-4.

10.6.3 Cumulative Impacts – Surface Water Resources

10.6.3.1 Water Quality

The project is located in the Isaac River catchment, which is a major tributary within the Fitzroy basin. The Fitzroy basin is the largest catchment in Queensland draining into the Pacific Ocean and also the largest catchment that drains to the Great Barrier Reef, although it does not contribute significant freshwater flows to the coastal environment when compared to river systems further north.

In 2008, the Queensland Government undertook an investigation into the cumulative effects of coal mining in the Fitzroy River basin on water quality (EPA, 2009). The investigation found that:

- There were inconsistencies in discharge quality limits and operating requirements for coal mine water discharges as imposed through environmental authorities.
- In some cases, discharge limits and operating conditions of coal mines were not adequately protecting downstream environmental values.

Table 10-4: New or Developing Projects Considered in the Cumulative Impact Assessment

Project	Proponent	Description	Status	Relationship to the Project Area	
				Timing	Location
Eagle Downs Mine	Bowen Central Coal Joint Venture	Underground coal mine	Construction on hold – site on care and maintenance	May have overlapping operational phases with the construction and operations of the project.	24 km to the northwest of the project area. Located within Isaac River catchment.
Red Hill Mining Lease Project	BMA	Underground coal mine	EIS active	May have overlapping operational phases with the construction and operations of the project.	66 km to the north-northwest of the project area. Located within Isaac River catchment.
Olive Downs North Project	Peabody Energy Australia	Open cut coal mine	Approved project	May have overlapping operational phases with the construction and operations of the project.	4 km to the north of the project area.
New Lenton Coal Project	New Hope Corporation	Open cut coal mine	EIS active	May have overlapping operational phases with the construction and operations of the project.	90 km to the north-northwest of the project area. Located within Isaac River catchment.
Saraji East Mining Lease Project	BMA	Underground coal mine	EIS active	May have overlapping operational phases with the construction and operations of the project.	15 km to the southwest of the project area. Located within Isaac River catchment.
Dysart East Coal Mine	Bengal Coal	Underground coal mine	Application made	May have overlapping operational phases with the construction and operations of the project.	35 km to the south of the project area. Located within Isaac River catchment.
Bowen Gas Project	Arrow Energy	CSG field & production facilities	Approved project	May have overlapping operational phases with the construction and operations of the project.	The Project lies within the Bowen EIS Study Area.

These conclusions led to a number of inter-related actions by Queensland Government and other stakeholders:

- Water quality objectives were developed for the Fitzroy Basin and added to Schedule 1 of the Environmental Protection (Water) Policy 2009 (EPP (Water)) in October 2011.
- Model water conditions were developed for coal mines in the Fitzroy basin (DERM February 2012). These model water conditions are designed to manage water discharges to meet the water quality objectives set out in the EPP (Water) and to provide consistency between mining operations in the Fitzroy basin.
- Environmental authorities for a number of mining operations were amended to introduce conditions consistent with the model water conditions.
- A number of mining operations entered into Transitional Environmental Programs (TEP) under the EP Act. These TEPs were focussed on actions that would allow mines to achieve compliance with new environmental authority conditions and upgrade operating conditions.

With these measures in place, a strong strategic and policy framework is now in place for management of cumulative water quality impacts from mining activities. This framework allows for management of individual mining activities in such a way that overarching water quality objectives can be achieved.

Mine affected water from the proposed Project will be managed through a mine water management system which is designed to operate in accordance with typical EA conditions and the model water conditions. That is, it will have discharge conditions and in-stream trigger levels aligned with the water quality objectives in the EPP (Water).

An extensive review of the release conditions at other coal mines in the vicinity of the Project has been undertaken. A summary of these release conditions is provided in Table 10-5 and the locations of the release points at nearby mines is shown in Figure 10-3. The development of proposed release conditions for the Project (as described in Section 7.10) have taken into consideration the conditions at the nearby mines.

Review of Table 10-5 shows the following:

- The receiving water contaminant trigger levels for:
  - EC range between 864 and 2,000 µs/cm
  - pH ranges vary between 6.5 to 8.0 and 6.5 to 9.0
  - suspended solids range between 300 and 1,000 mg/L (with many to be determined)
- The mine affected water release during flow events varies significantly. The mines closest to the Project (Peak Downs Mine, Saraji Mine and Lake Vermont Mine) have maximum EC release limits of up to 10,000 µs/cm.

Table 10-5: EA Release Conditions at Mines in the Vicinity of the Project

Mine	EA	Location	Receiving Water Contaminant Trigger Levels	Mine Affected Water Quality Limits	Conditions Relating to Receiving Water
Isaac Plains Coal Mine	EPML00932713	Isaac River U/S of the Project Area	• EC: 1000 µS/cm • pH: 6.5 – 8.0 • Suspended Solids: TBD • Sulphate: 1000 mg/L	• EC: 720-8000 µS/cm (dependant on flow) • pH: 6.5 – 9.0 • Turbidity: No Limit • Suspended Solids: No Limit • Sulphate: 250-400 mg/L (dependant on flow)	Release rates vary (2-3 m^3/s) depending on receiving water flows
Millennium Coal Mine	EPML00813213	Isaac River U/S of The Project Area	• EC: 1000 µS/cm • pH: 6.5 – 8.0 • Suspended Solids: TBD • Sulphate: 1000 mg/L	• EC: 1,400 µS/cm • pH: 6.5 – 9.0 • Turbidity: N/A • Suspended Solids: N/A • Sulphate: 1000 mg/L	Release rates calculated as percentage of flow in receiving waters (1% in Isaac and 20% in New Chum Creek)
Poitrel Coal Mine	EPML00963013	Isaac River U/S of The Project Area	• EC: 1000 µS/cm • pH: 6.5 – 8.0 • Turbidity: 750 NTU • Suspended Solids: TBD • Sulphate: 250 mg/L • Sodium: TBD	• EC: 720-7000 µS/cm • pH: 6.5 – 9.0 • Turbidity: 500 NTU • Suspended Solids: N/A • Sulphate: 250-1000 mg/L	Release rates vary (14-290 m^3/s) depending on receiving water flows
Daunia Coal Mine	EPML00561913	Isaac River U/S of The Project Area	• EC: 864 µS/cm – Cease Release • pH: 6.5 – 8.5 • Sulphate: 1000 mg/L	• EC: 5000 µS/cm • pH: 6.5 – 9.0 • Sulphate: 1000 mg/L	Release allowed when minimum flow in the receiving water (Isaac River via New Chum Creek) is greater or equal to $3m^3/s$
Caval Ridge Coal Mine	EPML00562013	Isaac River U/S of The Project Area	• EC: 2000 µS/cm • pH: 6.5 – 8.5 • Sulphate: 1000 mg/L	• EC: 10000 µS/cm • pH: 6.5 – 9.0 • Sulphate: N/A	Release allowed when minimum flow in the receiving water ($3m^3/s$ in Isaac River and $0.5m^3/s$ in Cherwell Creek)

Mine	EA	Location	Receiving Water Contaminant Trigger Levels	Mine Affected Water Quality Limits	Conditions Relating to Receiving Water
Eagle Downs Coal Mine	EPML00586713	Isaac River U/S of The Project Area	• EC: 1000 µS/cm • pH: 6.5 – 8.0 • Turbidity: N/A • Suspended Solids: TBD • Sulphate: 100 mg/L	• EC: 1000 µS/cm • pH: 6.5 – 9.0 • Turbidity: N/A • Suspended Solids: 80th percentile of upstream background sites • Sulphate: 1000 mg/L	
Moorvale Coal Mine	EPML00802813	Isaac River U/S of The Project Area	• EC: 2000 µS/cm • pH: 6.5 – 8.0 • Turbidity: 4000 NTU	• EC: 2500 µS/cm • pH: 6.5 – 9.0 • Turbidity: 4000 NTU • Suspended Solids: N/A • Sulphate: 1000 mg/L	Release allowed when minimum flow when the minimum flow in the receiving water (0.02m^3/s in North Creek)
Lake Vermont Mine	EPML00659513	Isaac River adjacent to The Project Area	• EC: 1000 µS/cm • pH: 6.5 – 8.0 • Suspended Solids: 1,500 mg/L • Sulphate: 300 mg/L • Sodium: 180 mg/L	*Isaac River RP's* • EC: 1,500 µS/cm (• Sulphate: 30 mg/L *Phillips Creek RP's* • EC: 720-5,500 µS/cm (dependant on flow) • Sulphate: 300-1,400 µS/cm (dependant on flow)	Release allowed when minimum flow in the receiving water (7.5m^3/s in Isaac River)
Peak Downs Coal Mine	EPML00318213	Isaac River U/S of The Project Area	• EC: 2000 µS/cm • pH: 6.5 – 9.0	• EC: 10000 µS/cm • pH: 6.5 – 9.5 • Sulphate: N/A (correlated with EC)	Release allowed when minimum flow in the receiving water (3m^3/s in Isaac River and 0.1m^3/s in Boomerang Creek)
Saraji Coal Mine	EPML00862313	Isaac River U/S of The Project Area	• EC: 2000 µS/cm • pH: 6.5 – 9.0	• EC: 10000 µS/cm • pH: 6.5 – 9.5	Release allowed when minimum flow in the receiving water (3m^3/s in Isaac River, 0.1m^3/s in Hughes Creek/One Mile Creek/Spring Creek/Phillips Creek)

Mine	EA	Location	Receiving Water Contaminant Trigger Levels	Mine Affected Water Quality Limits	Conditions Relating to Receiving Water
				• Sulphate: N/A (correlated with EC)	
Norwich Park Coal Mine	EPML00865013	Isaac River D/S of The Project Area	• EC: 2000 µS/cm • pH: 6.5 – 9.0 • Sulphate: 1000 mg/L	• EC: 10000 µS/cm • pH: 6.5 – 9.0 • Sulphate: N/A (correlated with EC)	Release allowed when minimum flow in the receiving water (Scott Creek/Stephens Creek/Rolf Creek) is greater or equal to 1m^3/s
Middlemount Coal Mine	EPML00716913	Isaac River D/S of The Project Area	• EC: 2000 µS/cm • pH: 6.5 – 8.5 • Suspended Solids: 562-1062 mg/L (dependant on flow) • Sulphate: 250 mg/L • Sodium: TBD	• EC: 700-6000 µS/cm (dependent on flow) • pH: 6.5 – 9.5 • Turbidity: N/A • Suspended Solids: 562-1062 mg/L (dependent on flow) • Sulphate: 250-500 mg/L (dependent on flow)	Release rates vary (0.4-5.6m^3/s) depending on receiving water flows (Roper Creek)
German Creek Coal Mine	EPML00732613	Isaac River D/S of The Project Area	• pH: 6.5 – 8.5 • Turbidity: Mine waters released must not exceed background level • Sulphate: 250 mg/L • Sodium: TBD	• EC: <10000 µS/cm • pH: 6.5 – 9.0 • Turbidity: Turbidity limit for discharge is defines as being equal to or less than the upstream turbidity value for the receiving waters • Suspended Solids: 80th percentile of upstream background sites • Sulphate: <3000 mg/L	Release allowed when minimum flow in the receiving water (0.6m3/s in German Creek, 0.5m^3/s in Cattle Creek, 0.143m^3/s in Parrot Creek and 1.0m^3/s in Roper Creek) Maximum combined release rate of 2.0m^3/s Release ceased when flow in receiving waters is reduced to 0.5 m^3/s.
Foxleigh Coal Mine	EPML00744813	Isaac River D/S of The Project Area	• pH: 6.5 – 8.5 • Suspended Solids: 650 mg/L	• EC: <10000 µS/cm • pH: 6.5 – 9.0	Release allowed when minimum flow in the receiving water (0.66m^3/s in Cockatoo Creek and 0.95m^3/s in Roper Creek) Maximum combined release rate of 2.0m^3/s

Mine	EA	Location	Receiving Water Contaminant Trigger Levels	Mine Affected Water Quality Limits	Conditions Relating to Receiving Water
			• Sulphate: <250 mg/L • Sodium: TBD	• Turbidity: Derived from suspended solids limit and demonstrated correlation between turbidity to suspended solids historical monitoring for dam water • Suspended Solids: 650 mg/L • Sulphate: <3000 mg/L	Release ceased when flow in receiving waters is reduced to 0.5 m^3/s

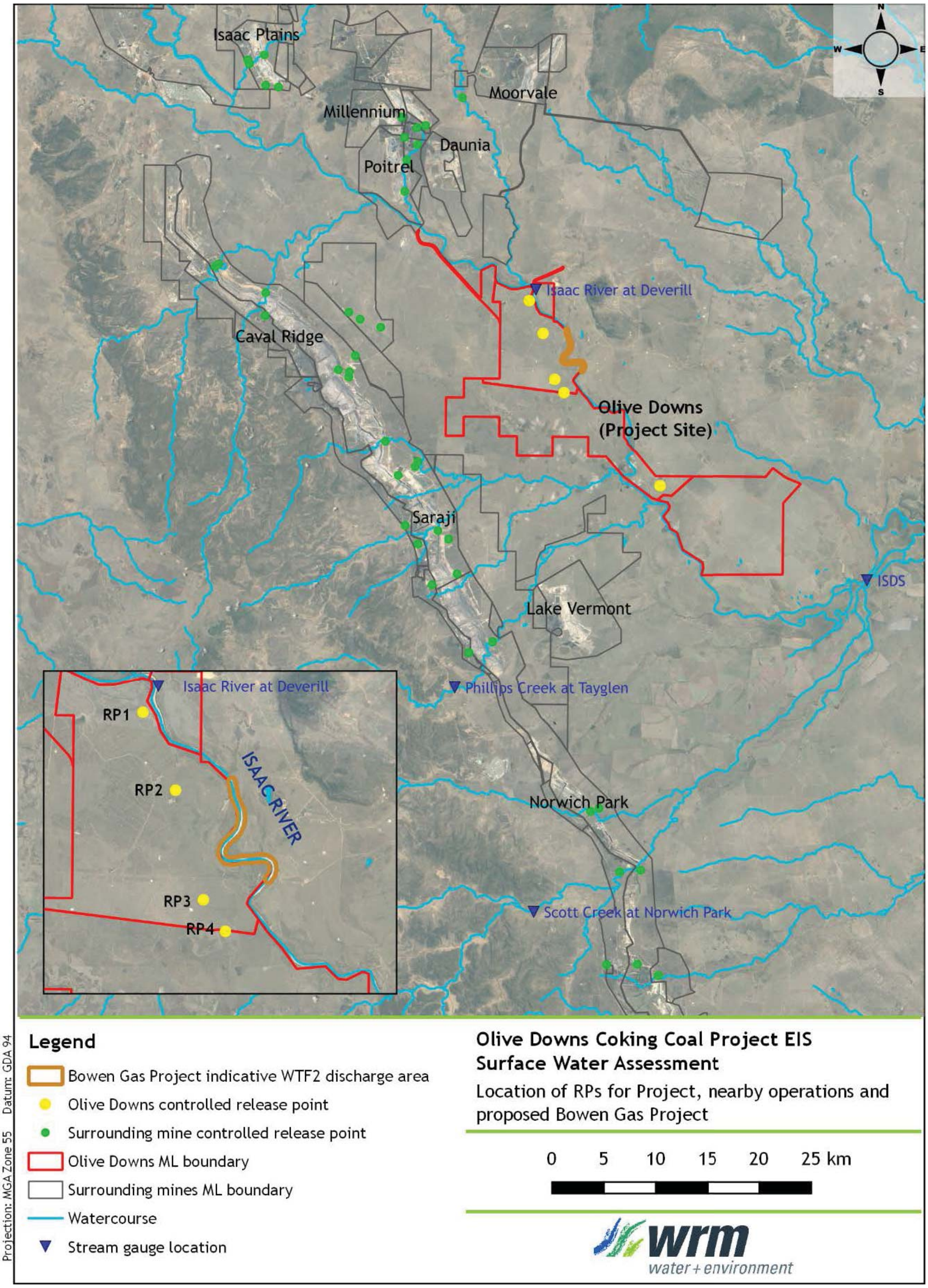

Figure 10-3: Cumulative Impact Assessment – Location of Nearby Release Points

Using the Project water balance model, an analysis has been undertaken on the ability of the proposed water management system to demonstrate compliance with the proposed EA conditions. The outcomes from this assessment is provided in Section 10.5.3.

The Queensland Government commissioned an assessment of mine affected water releases in the Fitzroy River basin during the 2012–2013 wet season (known as the Pilot Scheme). The report, prepared by consultants Gilbert and Sutherland (G&S, 2016), concluded that the Fitzroy as a whole is not currently ‘at capacity’ in terms of salt load at a catchment or sub-catchment scale.

The operational policy of the Pilot Scheme aims to manage the cumulative impact of mine affected water releases across the Fitzroy Basin. To achieve this, trigger values have been derived for six monitoring locations across the basin. If in-stream electrical conductivity (EC) triggers are exceeded during times when mine affected water releases are being undertaken upstream, the regulator has the ability to issue a “cease release” notification to all coal mines in the Fitzroy Basin with conditions that authorise the release of mine affected water.

Given that the proposed Project mine affected water releases are being managed within an overarching strategic framework for management of cumulative impacts of mining activities, the proposed management approach for mine water from the project is expected to have negligible cumulative impact on surface water quality and associated environmental values.

While the EPA cumulative impact assessment of mining in the Fitzroy Basin focused on salinity as the key water quality issue related to mining activities, surface disturbance associated with mining activities can result in erosion and increased sediment levels in surface waters. The Great Barrier Reef outlook report also identified that the Fitzroy Basin contributed one of the highest sediment loads to the reef, largely attributing sediment loads to use of land for agricultural activities (GBRMPA 2009). Water quality data presented in Section 5.4 indicates that suspended solids and turbidity in the upper Isaac River and local tributaries are in excess of water quality objectives and hence, cumulative assessments must consider additional sediment inputs.

The water quality assessment undertaken for the project has identified that sediment inputs can be controlled through drainage, erosion and sediment control measures. On this basis, the proposed project is not expected to make any significant contribution to cumulative sediment loads in the Fitzroy River Basin.

10.6.3.1.1 ACARP Project C18033 Extension

A study was undertaken in 2012 with the aim of gathering information on the tolerances of freshwater macroinvertebrates from the Fitzroy Catchment to saline mine water, that could potentially be utilized for developing guidelines for mine water discharge. Part of this study involved developing ecosystem protection toxicant trigger values calculated from species sensitivity distribution derived from commercial tests. A 95% ecosystem protection trigger value of 2,000 µs/cm and a 99% ecosystem protection trigger value of 900 µs/cm were developed.

These trigger levels are significant higher than the WQO's for the Upper Isaac River catchments water, particularly for 95% ecosystem protection. These trigger values were consistent with the lower range of previously published toxicological and other effects data on relevant aquatic species. These toxicant trigger values derived from the study could be used to inform the regulation of mine water releases were aquatic ecosystem toxicity from salinity is the primary issue of concern.

10.6.3.1.2 Bowen Gas Project EIS

The Project lies within the study area of the Bowen Gas Project (BGP), and there are two water treatment facilities (WTF's) proposed as part of the BGP development. The indicative locations of the WTF discharge points are as follows:

- A section of the upper Isaac River, located downstream of Burton Mine; and
- A section of the Isaac River adjacent to the ODS domain.

The impact assessments for the EIS and SREIS for the BGP indicated that surface water resources within the BGP Project area had been impacted by different historic and current land uses such as agriculture, mining and urban development. The EIS determined that through the implementation of appropriate mitigation measures, the potential impacts on surface water quality could be minimized. In addition, the set of principles for CSG water discharges developed in the SREIS study would allow for CSG water to be discharged without having any significant impact to the receiving environment. It was noted that in the context of the large volumes of mine affected water that are discharged into the Isaac River by coal mines operating in the region, any CSG water that may be released into the Isaac River by the BGP Project would have an insignificant effect on the receiving environment.

Given that the proposed WTF's for the BGP have a design capacity of up to 20 ML/d and water would only be discharged the prescribed limit of an environmental authority, the impact of BGP discharges on the receiving environment are expected to be insignificant from a cumulative impact perspective.

10.6.3.2 Loss of Catchment and Stream Flows in the Isaac River

As detailed in Section 10.4, the Project will result in a loss of catchment to the Isaac River during operations and post-mining. The surface runoff volume lost from the catchment will generally be in proportion to the loss of catchment area. The Project area is less than 2% of the catchment area of the Isaac River to the downstream boundary of the Project (at the ISDS stream gauge). Of this, around 63% of this area is managed through the ESCP and then released to the downstream environment following treatment.

There are approximately 15 existing coal mines upstream of the Project that also capture runoff from the Isaac River catchment, as shown in Figure 10-4. The total estimated captured area of all these projects (including the Project) combined represents around of 9% of the Isaac River catchment to the ISDS stream gauge. If the same percentage of ESCP for the Project is applied to the other mines, then the estimated captured catchment areas reduce to around 37% of the total area (around 2.6% of the Isaac River catchment to the ISDS gauge).

In addition, these mines have discharge licences which return captured surface water, as well as groundwater collected in underground workings, to the Isaac River catchment. Site discharges would reduce the impact on surface water volumes. Unfortunately, there is limited information available on actual discharge volumes from the 15 upstream mines to the Isaac River.

A comparison of the captured catchment areas of the existing mining projects considered in the cumulative impact assessment with the Isaac River catchment to the ISDS gauge is provided in Table 10-6, which indicates the following:

- The combined total catchment area of the existing mines (including the Project) represents around 9% of the total catchment area of the Isaac River to the ISDS gauge.
- The combined mine affected catchment area (estimated) represents less than 3.5% of the total Isaac River catchment area to the ISDS gauge.

When taking into account potential discharges from the operating mines in accordance with their current release rules, the overall loss of catchment area and associated stream flow is relatively small.

Table 10-6: Catchment Areas of Existing Project Considered in the Cumulative Impact Assessment

Catchment	Total Catchment Area (km^2)	Estimated Mine Affected Catchment Area (km^2)
The Project	136	51
Other Mines	550 (est.)	206 (est.)
Combined	686 (est.)	257 (est.)
Isaac River (to the ISDS stream gauge)	7,782	

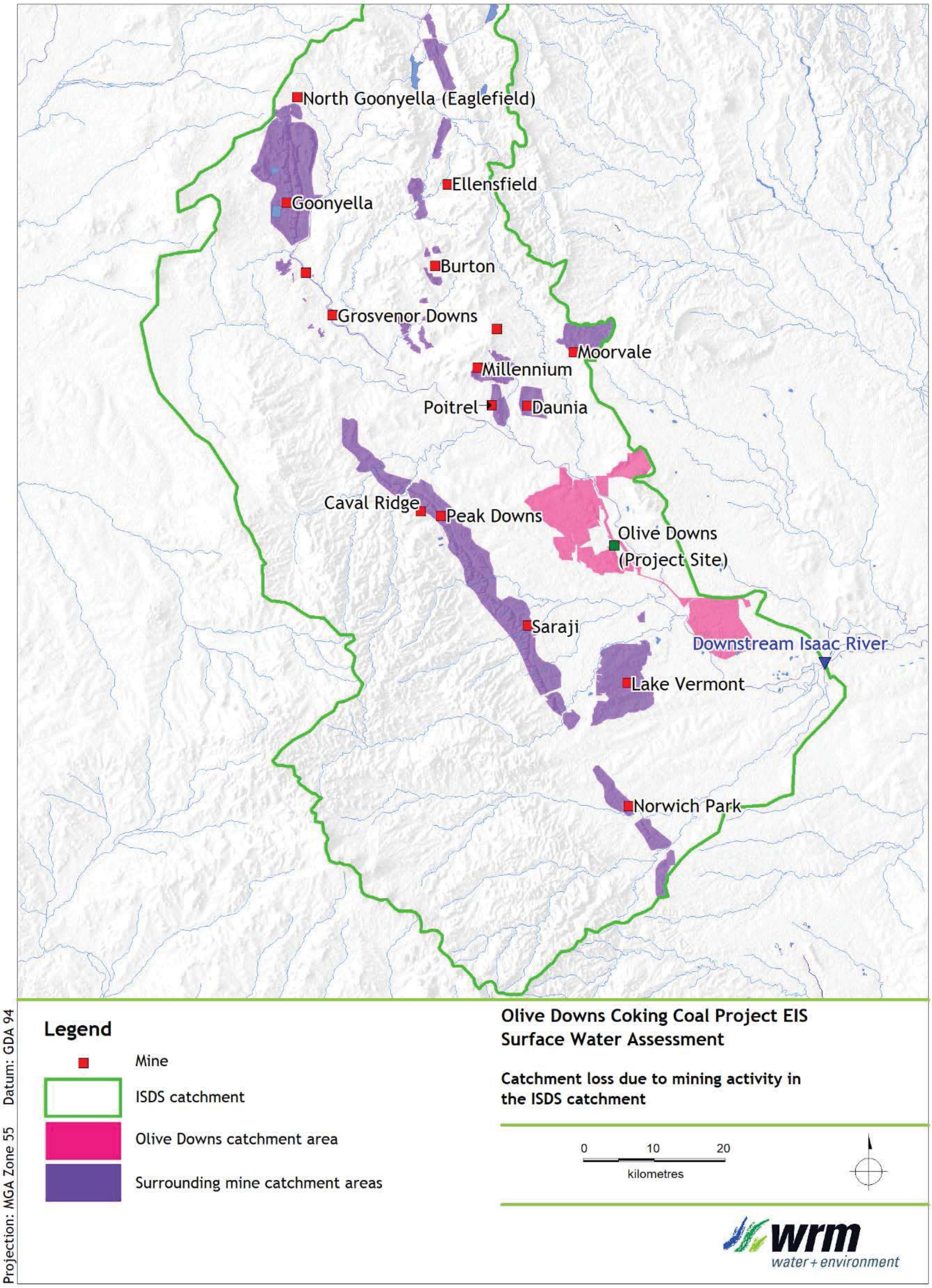

Figure 10-4: Cumulative Impact Assessment – Location of Existing Mines Upstream of the ISDS Gauge

10.7 Surface Water Monitoring Program

10.7.1 Overview

Monitoring of surface water quality both within and external to the mine site will form a key component of the surface water management system. Monitoring of upstream, onsite and downstream water quality will assist in demonstrating that the site water management system is effective in meeting its objective of minimal impact on receiving water quality and will allow for early detection of any impacts and appropriate corrective action.

The surface water monitoring protocols will:

- ensure compliance with the Project Environmental Authority;
- provide valuable information on the performance of the water management system; and
- facilitate adaptive management of water resources on the site.

10.7.2 Water Quality Monitoring Locations

The Proponent has previously monitored a number of surface water locations in the Project vicinity (as detailed in Section 5.4). The Surface Water Monitoring Program will include the continued monitoring of a number of these sites to monitor surface water flows and quality upstream and downstream of the mine.

The water quality monitoring program will also include dam monitoring, including all dams which contain mine affected water and discharge to the receiving environment. This includes the following dams:

- P44;
- WROM; and
- WMIA.

Locations of the proposed surface water monitoring locations are shown in Figure 10-5 and summarised in Table 10-7.

Table 10-7: Proposed Surface Water Monitoring Program

Site Name	Waterway	Location	
		Easting (decimal degrees)	Longitude (decimal degrees)
SW1	Isaac River (upstream of Project)	-22.15	148.35
SW2	Isaac River (upstream of North Creek confluence)	-22.16	148.37
SW3	Isaac River (downstream of North Creek confluence)	-22.17	148.38
SW4	Ripstone Creek (upstream of Project)	-22.26	148.33
SW6	Ripstone Creek (upstream of Isaac River confluence)	-22.31	148.40

Site Name	Waterway	Location	
		Easting (decimal degrees)	Longitude (decimal degrees)
SW8	Isaac River (downstream of Boomerang Creek confluence)	-22.33	148.46
SW11	Isaac River (downstream of Phillips Creek confluence)	-22.45	148.56
SW12/ ISDS	Isaac River (downstream of Project	-22.42	148.70
RP1	Dam P9	-22.18	148.38
RP2	Dam P20	-22.21	148.39
RP3	Dam P33	-22.25	148.40
RP4	Dam P46	-22.27	148.42
RP5	Dam WROM	-22.34	148.50
RP6	Dam P44	-22.28	148.35
RP7	Dam WMIA	-22.34	148.59

10.7.3 Water Quality Monitoring Schedule

Table 10-8 defines the proposed frequency and parameters to be sampled at each location during the discharge of mine affected water. Table 10-9 defines the proposed frequency and parameters to be sample across the dams which can discharge to the receiving environment. The proposed water quality monitoring program provides regular monitoring of key mine site storages.

Table 10-8: Release Event Water Quality Monitoring Schedule

Location	Parameter*	Monitoring Frequency
SW1, SW2, SW3, SW4, SW6, SW8, SW11 & SW12/ISDS	pH, EC, Suspended Solids, Sulphate and Sodium	Daily during release

Note: * Water quality monitoring parameters to be confirmed as part of the Environmental Authority application process.

Table 10-9: Dam Monitoring Schedule

Location	Parameter*	Monitoring Frequency
RP1, RP2, RP3, RP4, RP5, RP6 & RP7	pH, EC, Sulphate, Fluoride, Aluminium, Arsenic, Cadmium, Cobalt, Copper, Lead, Nickel and Zinc	Monthly

Note: * Water quality monitoring parameters to be confirmed as part of the Environmental Authority application process.

The event-based sampling will enable quantification of pollutant loads from the site and their corresponding impact on the water quality of receiving waters. On-site monthly sampling from the water storages allows for any potential problem areas with respect to pollutant generation on-site to be identified in advance ensuring appropriate remedial action can be taken.

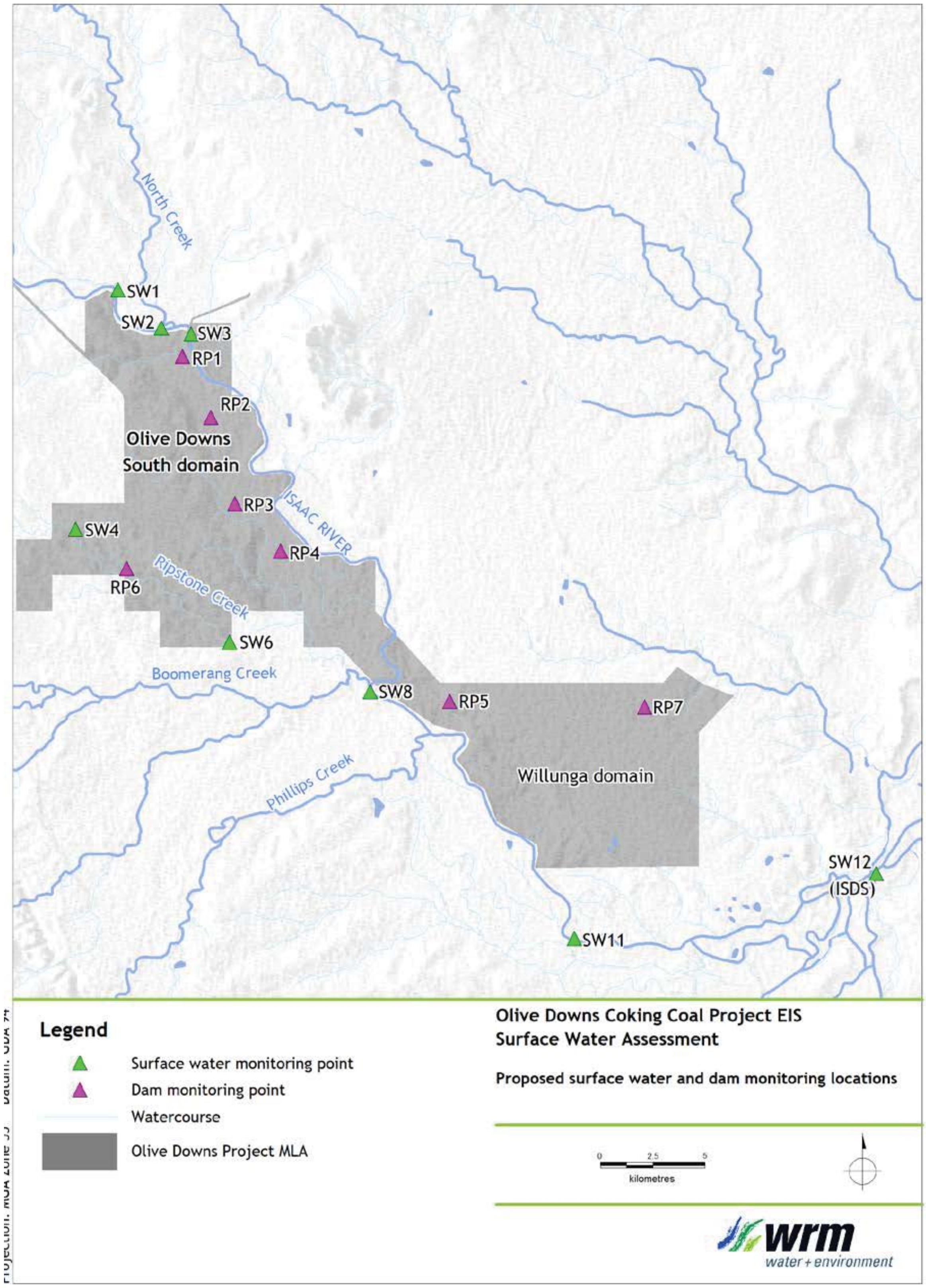

Figure 10-5: Proposed Surface Water Monitoring Locations

10.7.4 *Sediment Dam Monitoring*

Surface runoff and seepage from spoil piles, including any rehabilitated areas, would be monitored for 'standard' water quality parameters including, but not limited to pH, EC, major anions (sulfate, chloride and alkalinity), major cations (sodium, calcium, magnesium and potassium), TDS and a broad suite of soluble metals/metalloids.

The sediment dam monitoring would be used to validate the anticipated quality of water runoff reporting to sediment dams and haul road runoff dams. Initially, the sediment dam monitoring would occur on a regular (e.g. monthly) basis to demonstrate the water quality of stored waters is consistent with the relevant operating parameters to allow releases from sediment dams to occur when required. Subject to demonstrating the water quality objectives can be met, the frequency of monitoring and suite of parameters for the sediment dam monitoring would be reviewed and updated accordingly (e.g. to occur only when releases occur).

10.7.5 *Receiving Environment Monitoring Program (REMP)*

A REMP document will be developed that specifies the proposed monitoring program for the local receiving waters. The REMP will incorporate the historical and proposed monitoring as described in Section 5.4, Section 10.7.2 and Section 10.7.3

The main objective of the REMP will be to report against WQOs for local waterways potentially affected by discharge from the Project and will assist in assessing general aquatic ecosystem health.

11. Summary of Findings

11.1 Overview

The potential impacts of the Project on surface water resources will be mitigated through the implementation of a mine site water management system to control the flow and storage of water of different qualities across the site. A surface water monitoring program will be implemented to continually assess environmental impacts and ensure that the site water management system is meeting its objectives.

11.2 Water Management System Performance

The performance of the mine water management system has been investigated using a detailed site water balance model. The model simulated water inflows and outflows through the various stages of mine development for 100 stochastically generated rainfall sequences which are based on the DataDrill climate dataset.

Water collected on the site will be used as first priority to satisfy site demands, such as coal processing and dust suppression. Water will be drawn from off-site sources only when required to make up a shortfall in water available on the site.

Pembroke is proposing to acquire a 2,250 ML annual water licence allocation from the Sunwater Pipeline. The water balance model results show that there is a greater than 90% probability that the proposed annual water licence allocation of 2,250 ML would be sufficient to meet all site demands, in any one year across the Project life.

If additional external water is required, additional water licences would be sought and purchased by Pembroke over the life of the Project to meet raw water demands. Alternatively, production will be reduced until sufficient supplies are available. Water required from external sources will be obtained under appropriate Water Access Licences to ensure no adverse impacts on water availability for other licensed water users.

Overall, the results suggest that sufficient out-of-pit storage has been provided to prevent uncontrolled spills to the downstream environment and to ensure the pit can be dewatered. The results of the water balance modelling indicate that there is a small probability (around 10% AEP) of large volumes of mine affected water accumulating within the water management system. From the end of Stage 3, there will be a number of inactive voids available to temporarily store mine affected water. Should wet conditions prevail prior to these voids being available for storage, Pembroke shall:

- Store excess water temporarily in an active pit until there is sufficient out-of-pit storage available; or
- Construct additional pit water dams ahead of mining in the ODS domain to temporarily store any excess mine affected water until there is sufficient out-of-pit storage available.

The model results show that is only a very small risk (less than 1% AEP) of uncontrolled spills of mine affected water to the receiving environment, which is consistent with the proposed operating strategy for the mine water management system.

11.3 Impacts of Downstream Water Quality

Controlled releases from the water management system will occur when water quality and river flows meet the proposed release trigger levels. The water balance modelling results (shown in Section 10.5.3) indicate that the proposed controlled release strategy will achieve the WQO's for the Isaac River sub-basin.

11.4 Reduction in Downstream Flows During Operations

The Project will reduce the catchment area draining to receiving watercourses due to capture of runoff from disturbed catchment areas within the water management system. The maximum mine affected catchment areas represent:

- Approximately 13% of the Ripstone Creek catchment.
- Less than 1% of the Isaac River catchment to the downstream ISDS gauge, which is not significant.

The loss of catchment to Ripstone Creek only affects the furthest downstream reach (approximately 8 km) of the creek adjacent to the Project and within the tenement areas.

11.5 Long Term Reduction in Catchment Runoff

At the completion of mining, surface runoff from rehabilitated out-pf-pit waste rock emplacement areas will be released from the site. An area of approximately 49 km^2 will continue to drain to the mine final voids. The changed topography following completion of the Project will have the following impacts on catchment areas:

- the catchment draining to Ripstone Creek will reduce by around 19 km^2 (compared to pre-mining conditions), a decrease of less than 7%.
- the catchment draining to the Isaac River will reduce by around 49 km^2 (compared to pre-mining conditions), a decrease of less than 1%.

11.6 Final Voids

Water balance simulation of the final voids shows that the water surface is expected to reach an equilibrium water level well below the void overflow level and regional water table and will remain a groundwater sink. The pit void lakes will generally take around 100 to 200 years to reach an equilibrium level.

11.7 Cumulative Impacts

The development of the proposed release strategy to the Isaac River has based on the existing release conditions for nearby operating coal mines. The release conditions have developed by the regulators within an overarching strategic framework for the management of the cumulative impacts of water releases mining activities and are therefore expected to have negligible cumulative impact on surface water quality and associated environmental values. In any case, the site water management system has been designed such that the risk of off-site release of mine affected water is very low.

12. References

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Appendix A

Model Sensitivity Assessment Results

A.1 Scenario 1: Rejects Cells Decant Return Rate Increased by 5%

For the Scenario 1 sensitivity analysis, the decant return rate from the rejects cells was increased from 70% to 75%. This impact of this change on the performance of the water management system is presented in the following sections.

A.1.1 In-pit Storage

Figure A1 shows the forecast inventory for the combined mining pits, respectively, over the 79-year simulation for the Scenario 1 sensitivity assessment. The forecast modelling results for the mining pit inventory are summarised as follows:

- For the 10th percentile results (wet climatic conditions), water begins to accumulate at the beginning of Stage 2 and reaches a peak inventory of around 12,600 ML during Stage 3 of the Project.
- For the 50th percentile results (median climatic conditions), water accumulates during Stage 2 and 3, then reduces to an inventory of around 2,000 ML by the end of the Project.
- By the end of Stage 3, a substantial amount of additional storage capacity (around 550 GL) will be available within the Pit 1/2/3 void as mining has been completed by this time. These voids would be used to storage excess water as required, depending on the prevailing climatic conditions.

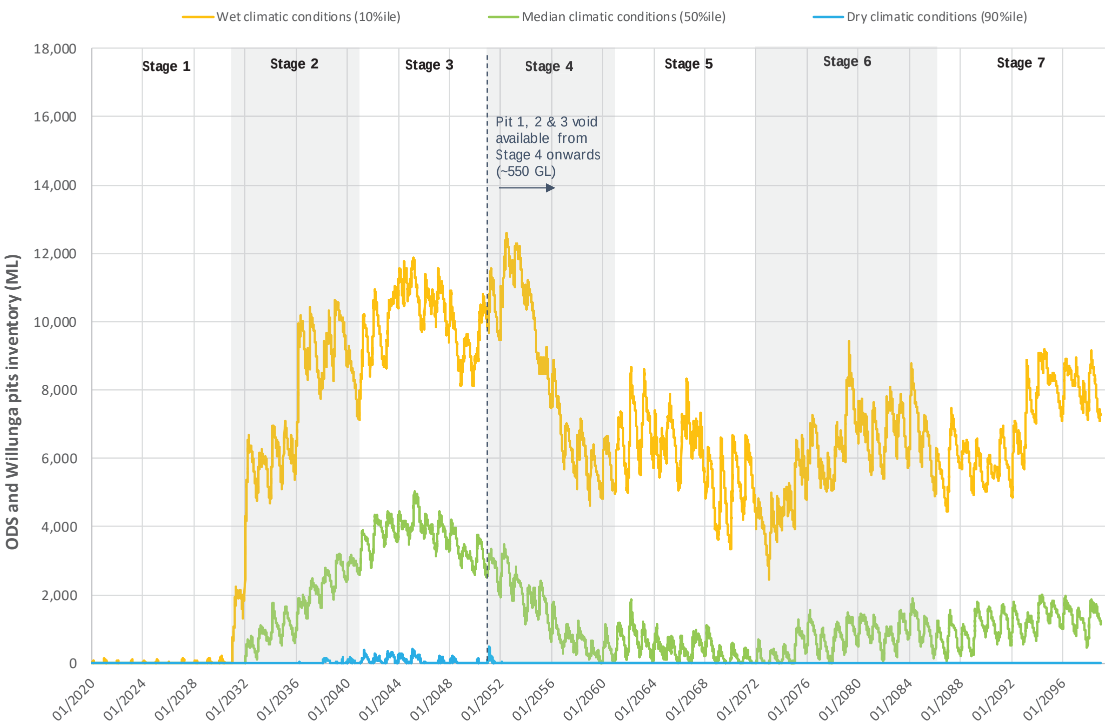

Figure A1: Forecast Combined Pit Inventory – Sensitivity Scenario 1

A.1.2 External Makeup Requirements

Figure A2 shows the total annual modelled demand for water from external sources over the 79-year simulation for Scenario 1. The modelling results show the following:

- During Stage 1, the requirement for external supply is highest. There is a:
  - 10% risk of requiring 2,090 ML/a (or more) from the pipeline.
  - 50% risk of requiring 1,410 ML/a (or more) from the pipeline.
- During Stage 2, the requirement for external supply increases during dry climatic conditions but reduces during median and wet climatic conditions. There is a:
  - 10% risk of requiring 2,210 ML/a (or more) from the pipeline.
  - 50% risk of requiring 820 ML/a (or more) from the pipeline.
- The external supply requirement reduces over the remainder of the Project. By Stage 5, there is little to no external water required under median climatic conditions.
- During Stage 6 and Stage 7, there is a 10% risk of requiring around 1,700 ML/a (or more) from the pipeline.

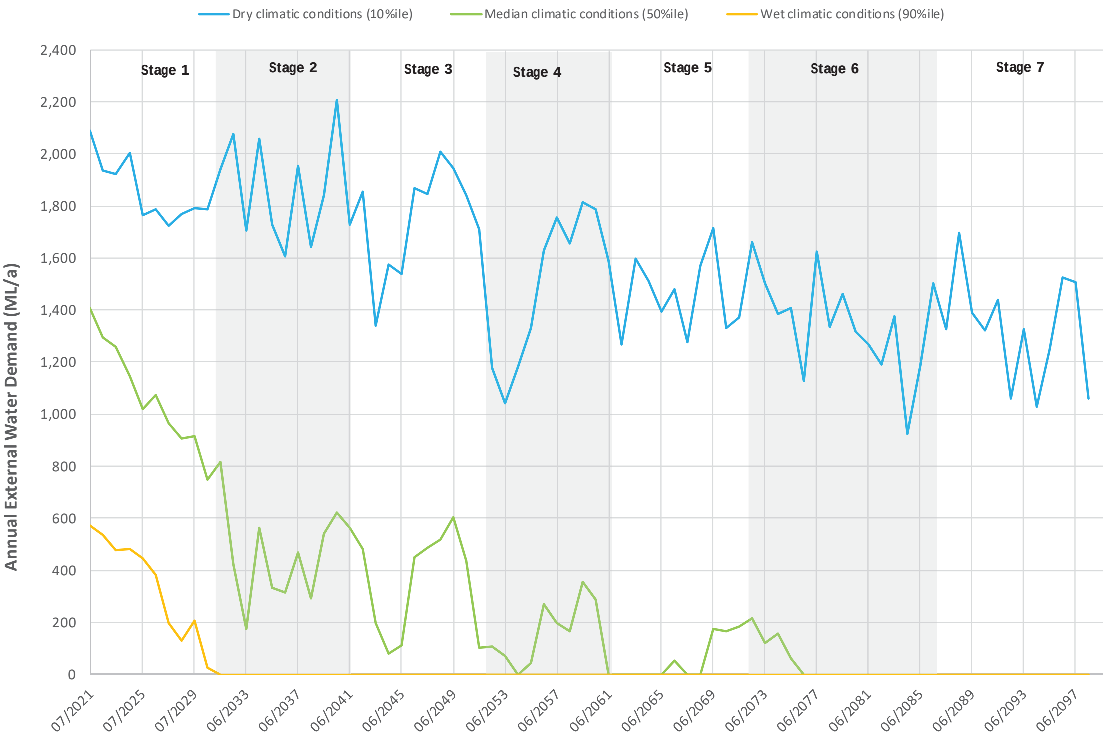

Figure A2: Forecast Annual External Water Requirements – Sensitivity Scenario 1

A.1.3 Controlled Releases

The predicted annual controlled release volumes from the mine affected water dams for Scenario 1 are provided in Figure A3. The results show that:

- For wet climatic conditions (10%ile), predicted annual controlled releases range between 500 and 2,140 ML/a, with the highest releases occurring during Stage 2 to Stage 5.
- For median climatic conditions (50%ile), predicted annual controlled releases range between 90 and 900 ML/a.
- For dry climatic conditions (90%ile), predicted annual controlled releases range between 15 and 390 ML/a.

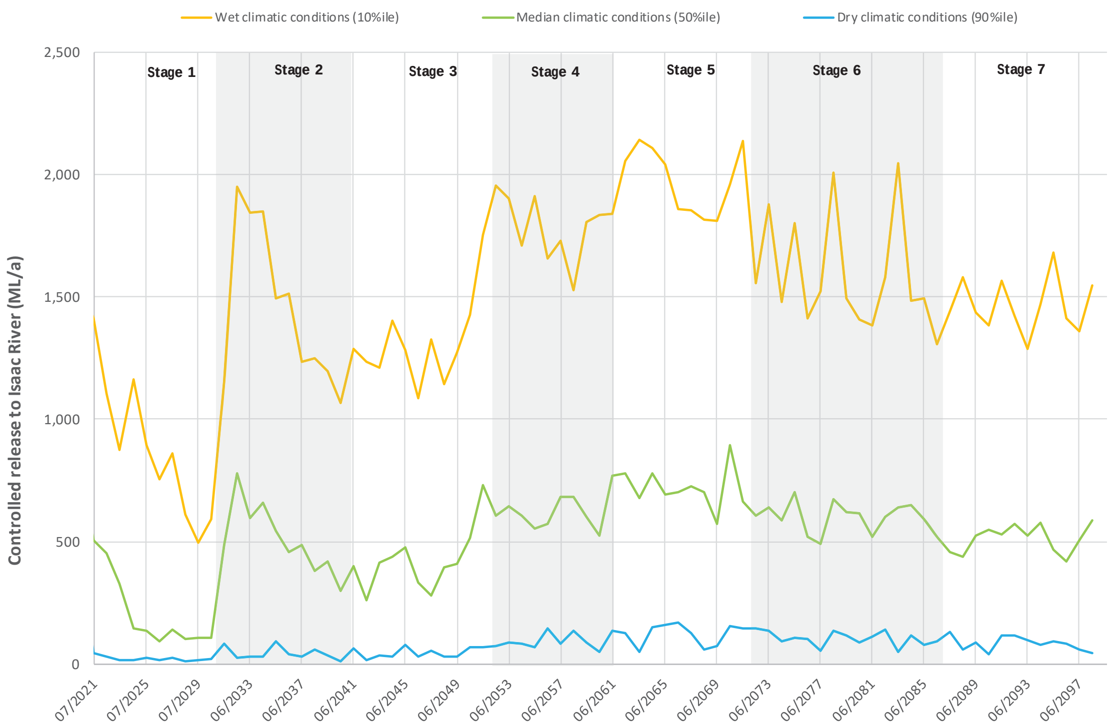

Figure A3: Forecast Annual Controlled Release Volumes – Sensitivity Scenario 1

A.2 Scenario 2: Rejects Cells Decant Return Rate Decreased by 5%

For the Scenario 2 sensitivity analysis, the decant return rate from the rejects cells was decreased from 70% to 65%. This impact of this change on the performance of the water management system is presented in the following sections.

A.2.1 In-pit Storage

Figure A4 shows the forecast inventory for the combined mining pits, respectively, over the 79-year simulation for the Scenario 2 sensitivity assessment. The forecast modelling results for the mining pit inventory are summarised as follows:

- For the 10th percentile results (wet climatic conditions), water begins to accumulate at the beginning of Stage 2 and reaches a peak inventory of around 12,550 ML during Stage 3 of the Project.
- For the 50th percentile results (median climatic conditions), water accumulates during Stage 2 and 3, then reduces to an inventory of around 2,000 ML by the end of the Project.
- By the end of Stage 3, a substantial amount of additional storage capacity (around 550 GL) will be available within the Pit 1/2/3 void as mining has been completed by this time. These voids would be used to storage excess water as required, depending on the prevailing climatic conditions.

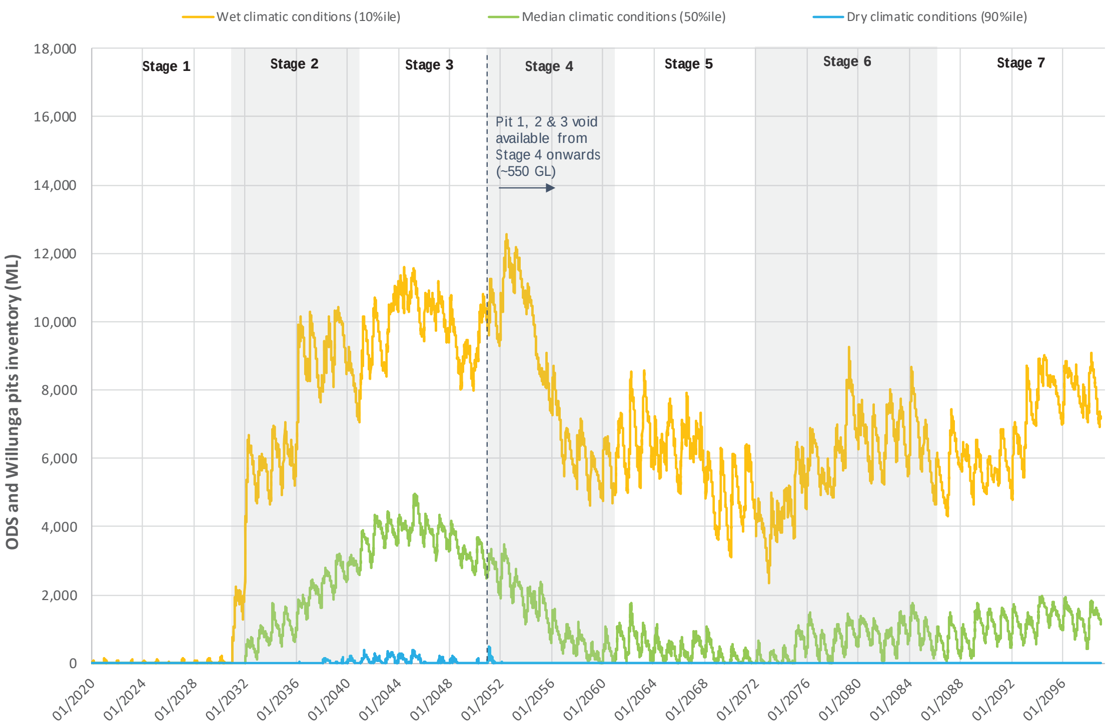

Figure A4: Forecast Combined Pit Inventory – Sensitivity Scenario 2

A.2.2 External Makeup Requirements

Figure A5 shows the total annual modelled demand for water from external sources over the 79-year simulation for Scenario 2. The modelling results show the following:

- During Stage 1, the requirement for external supply is highest. There is a:
  - 10% risk of requiring 2,150 ML/a (or more) from the pipeline.
  - 50% risk of requiring 1,450 ML/a (or more) from the pipeline.
- During Stage 2, the requirement for external supply increases during dry climatic conditions but reduces during median and wet climatic conditions. There is a:
  - 10% risk of requiring 2,250 ML/a (or more) from the pipeline.
  - 50% risk of requiring 890 ML/a (or more) from the pipeline.
- The external supply requirement reduces over the remainder of the Project. By Stage 5, there is little to no external water required under median climatic conditions.
- During Stage 6 and Stage 7, there is a 10% risk of requiring around 1,710 ML/a (or more) from the pipeline.

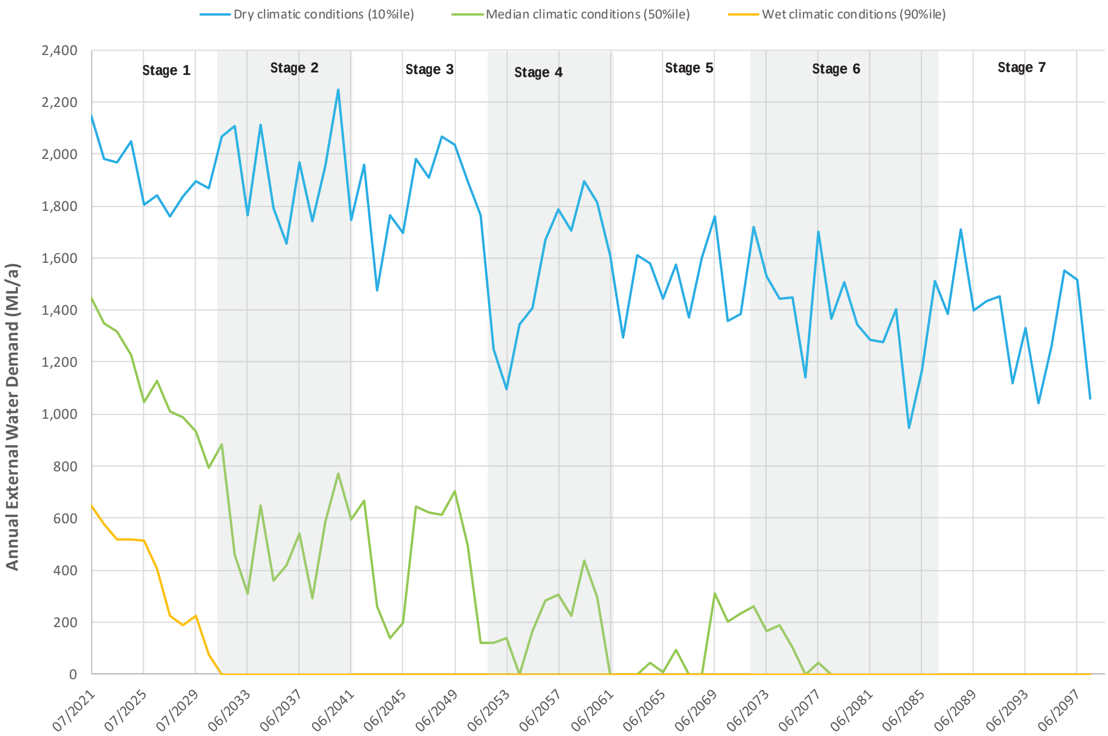

Figure A5: Forecast Annual External Water Requirements – Sensitivity Scenario 2

A.2.3 Controlled Releases

The predicted annual controlled release volumes from the mine affected water dams for Scenario 2 are provided in Figure A6. The results show that:

- For wet climatic conditions (10%ile), predicted annual controlled releases range between 500 and 2,120 ML/a, with the highest releases occurring during Stage 2 to Stage 5.
- For median climatic conditions (50%ile), predicted annual controlled releases range between 90 and 880 ML/a.
- For dry climatic conditions (90%ile), predicted annual controlled releases range between 10 and 370 ML/a.

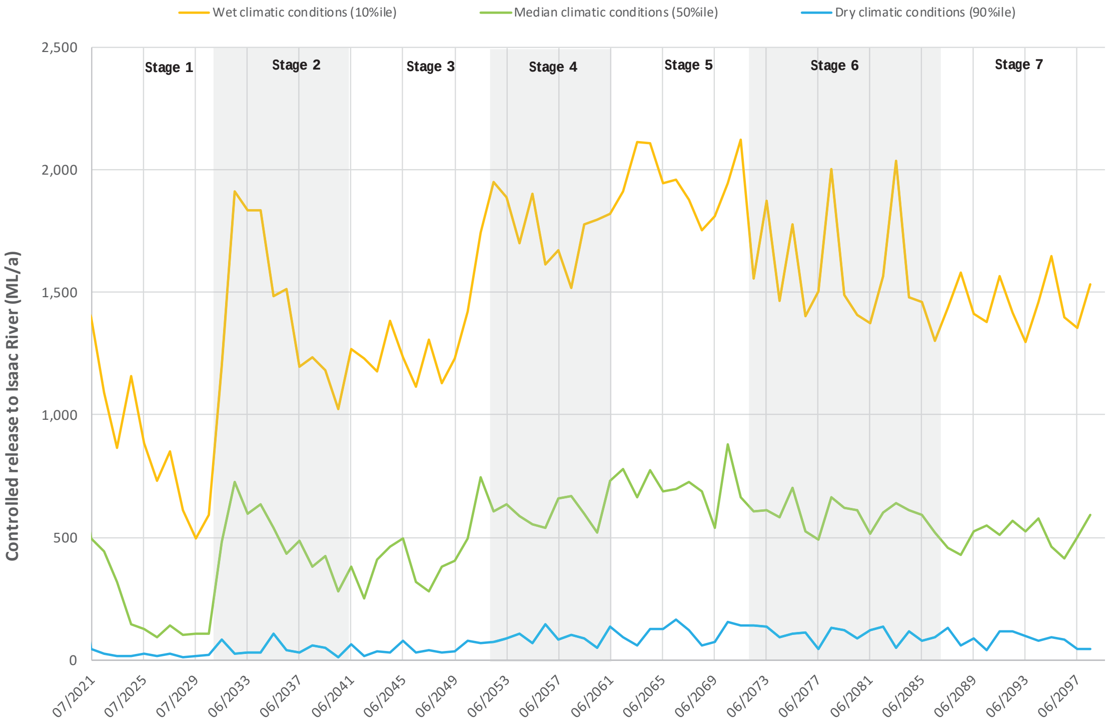

Figure A6: Forecast Annual Controlled Release Volumes – Sensitivity Scenario 2

A.3 Scenario 3: Global Increase of AWBM Soil Capacity by 20%

For the Scenario 3 sensitivity analysis, the soil capacity for each of the AWBM rainfall runoff parameter sets have been increased by 20%, resulting in reduced rainfall runoff. This impact of this change on the performance of the water management system is presented in the following sections.

A.3.1 In-pit Storage

Figure A7 shows the forecast inventory for the combined mining pits, respectively, over the 79-year simulation for the Scenario 3 sensitivity assessment. The forecast modelling results for the mining pit inventory are summarised as follows:

- For the 10th percentile results (wet climatic conditions), water begins to accumulate at the beginning of Stage 2 and reaches a peak inventory of around 8,740 ML during Stage 3 of the Project.
- For the 50th percentile results (median climatic conditions), water accumulates during Stage 2 and 3, then reduces to an inventory of around 500 ML by the end of the Project.
- By the end of Stage 3, a substantial amount of additional storage capacity (around 550 GL) will be available within the Pit 1/2/3 void as mining has been completed by this time. These voids would be used to storage excess water as required, depending on the prevailing climatic conditions.

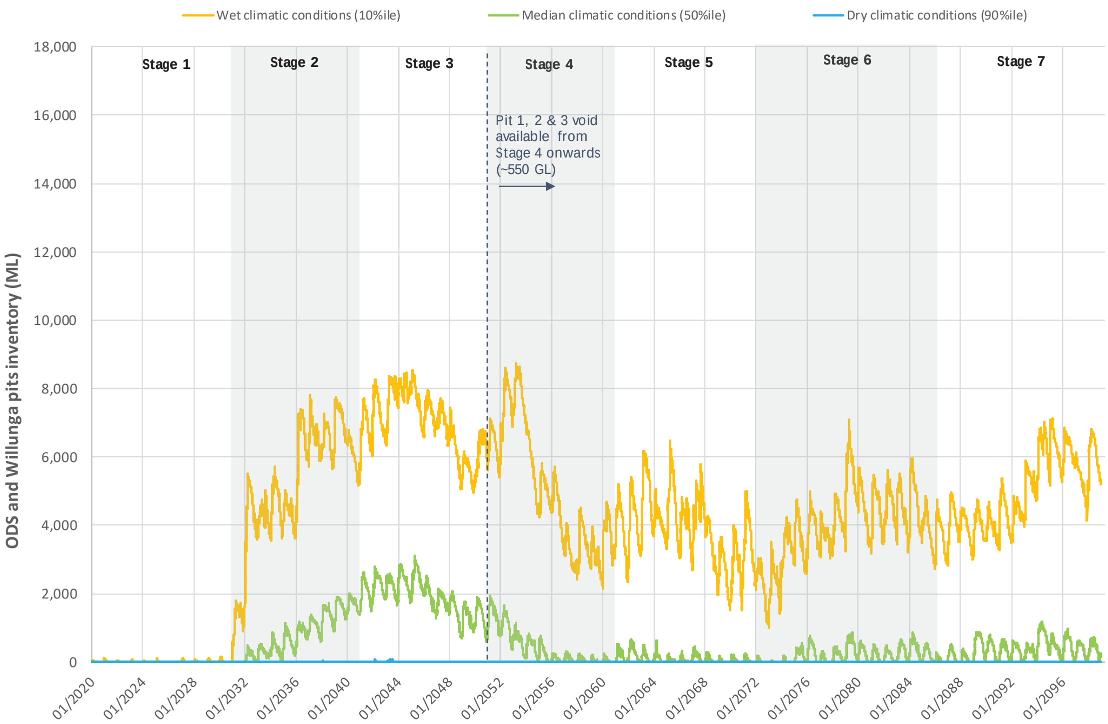

Figure A7: Forecast Combined Pit Inventory – Sensitivity Scenario 3

A.3.2 External Makeup Requirements

Figure A8 shows the total annual modelled demand for water from external sources over the 79-year simulation for Scenario 3. The modelling results show the following:

- During Stage 1, there is a:
  - 10% risk of requiring 2,180 ML/a (or more) from the pipeline.
  - 50% risk of requiring 1,520 ML/a (or more) from the pipeline.
- During Stage 2, the requirement for external supply is highest. There is a:
  - 10% risk of requiring 2,410 ML/a (or more) from the pipeline.
  - 50% risk of requiring 1,070 ML/a (or more) from the pipeline.
- The external supply requirement reduces over the remainder of the Project. By Stage 5, there is little to no external water required under median climatic conditions.
- During Stage 6 and Stage 7, there is a 10% risk of requiring around 1,950 ML/a (or more) from the pipeline.

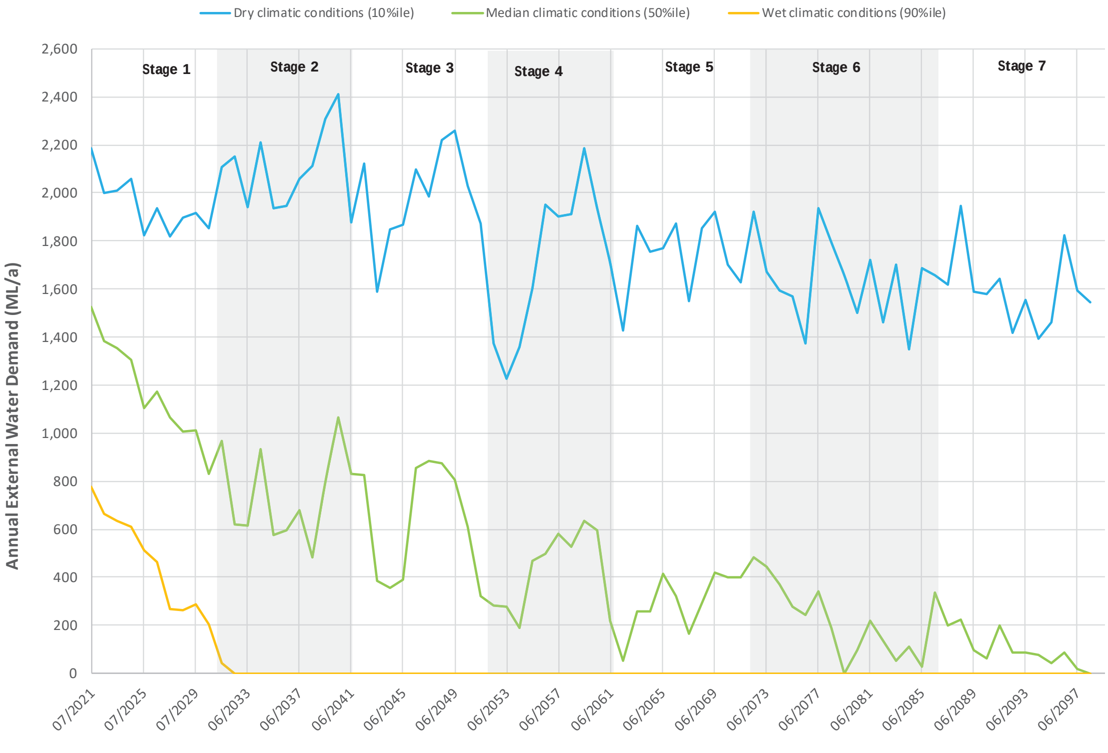

Figure A8: Forecast Annual External Water Requirements – Sensitivity Scenario 3

A.3.3 Controlled Releases

The predicted annual controlled release volumes from the mine affected water dams for Scenario 3 are provided in Figure A9. The results show that:

- For wet climatic conditions (10%ile), predicted annual controlled releases range between 450 and 2,090 ML/a, with the highest releases occurring during Stage 2 to Stage 5.
- For median climatic conditions (50%ile), predicted annual controlled releases range between 90 and 770 ML/a.
- For dry climatic conditions (90%ile), predicted annual controlled releases range between 10 and 370 ML/a.

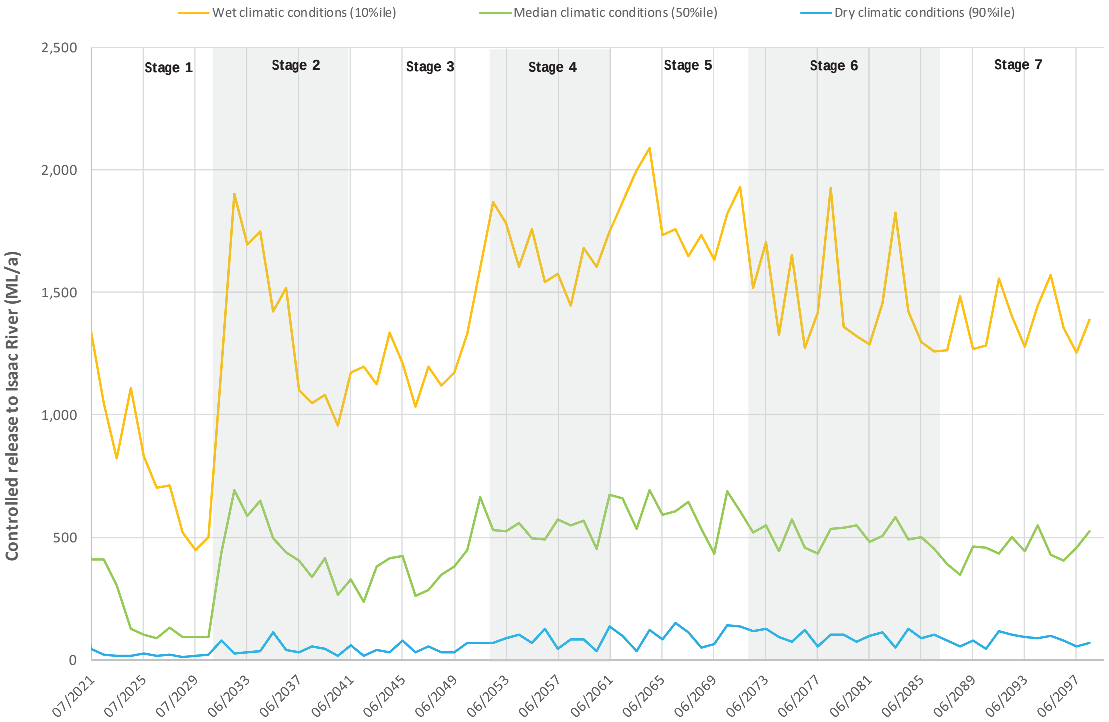

Figure A9: Forecast Annual Controlled Release Volumes – Sensitivity Scenario 3

A.4 Scenario 4: Global Decrease of AWBM Soil Capacity by 20%

For the Scenario 4 sensitivity analysis, the soil capacity for each of the AWBM rainfall runoff parameter sets have been decreased by 20%, resulting in increased rainfall runoff. This impact of this change on the performance of the water management system is presented in the following sections.

A.4.1 In-pit Storage

Figure A10 shows the forecast inventory for the combined mining pits, respectively, over the 79-year simulation for the Scenario 4 sensitivity assessment. The forecast modelling results for the mining pit inventory are summarised as follows:

- For the 10th percentile results (wet climatic conditions), water begins to accumulate at the beginning of Stage 2 and reaches a peak inventory of around 18,140 ML during Stage 3 of the Project.
- For the 50th percentile results (median climatic conditions), water accumulates during Stage 2 and 3, then reduces to an inventory of around 3,500 ML by the end of the Project.
- By the end of Stage 3, a substantial amount of additional storage capacity (around 550 GL) will be available within the Pit 1/2/3 void as mining has been completed by this time. These voids would be used to storage excess water as required, depending on the prevailing climatic conditions.

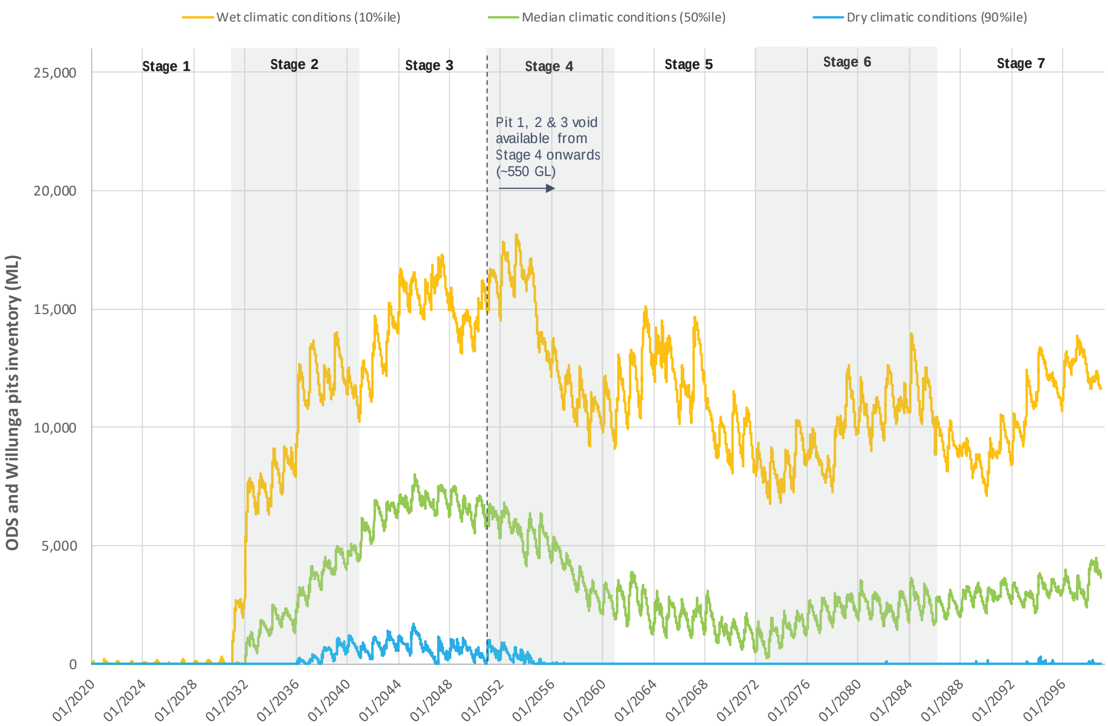

Figure A10: Forecast Combined Pit Inventory – Sensitivity Scenario 4

A.4.2 External Makeup Requirements

Figure A11 shows the total annual modelled demand for water from external sources over the 79-year simulation for Scenario 4. The modelling results show the following:

- During Stage 1, the requirement for external supply is highest. There is a:
  - 10% risk of requiring 2,090 ML/a (or more) from the pipeline.
  - 50% risk of requiring 1,310 ML/a (or more) from the pipeline.
- During Stage 2, the requirement for external supply increases during dry climatic conditions but reduces during median and wet climatic conditions. There is a:
  - 10% risk of requiring 2,020 ML/a (or more) from the pipeline.
  - 50% risk of requiring 670 ML/a (or more) from the pipeline.
- The external supply requirement reduces over the remainder of the Project. By Stage 5, there is little to no external water required under median climatic conditions.
- During Stage 6 and Stage 7, there is a 10% risk of requiring around 1,240 ML/a (or more) from the pipeline.

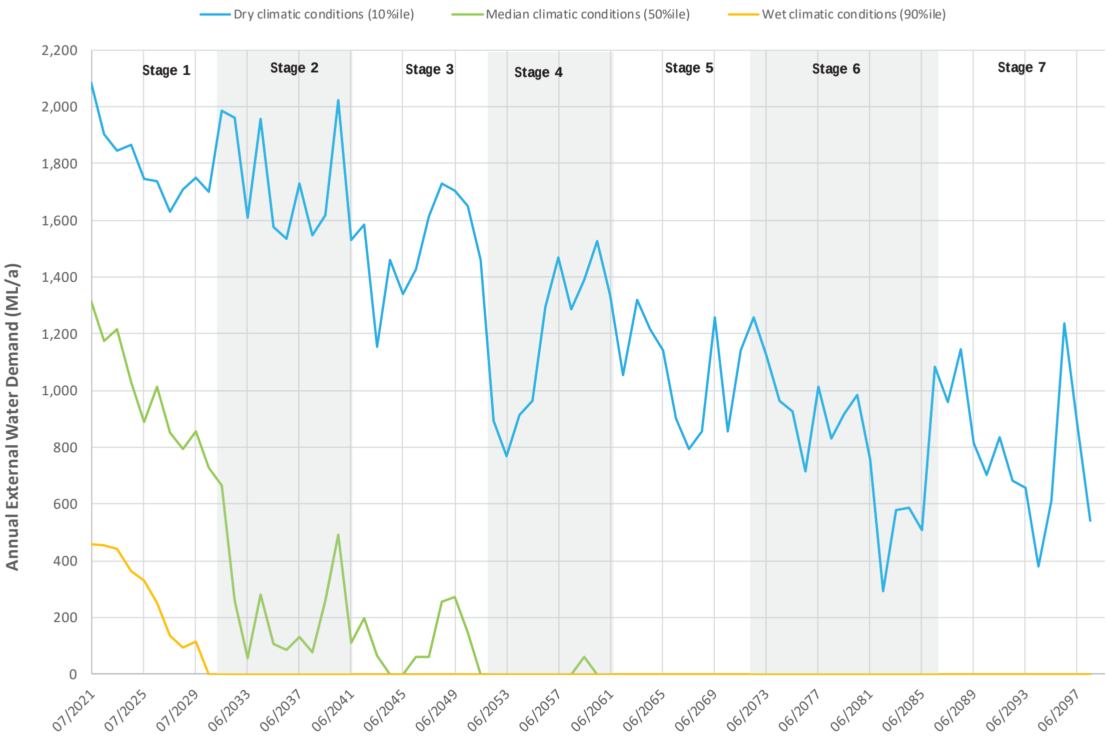

Figure A11: Forecast Annual External Water Requirements – Sensitivity Scenario 4

A.4.3 Controlled Releases

The predicted annual controlled release volumes from the mine affected water dams for Scenario 4 are provided in Figure A12. The results show that:

- For wet climatic conditions (10%ile), predicted annual controlled releases range between 570 and 2,380 ML/a, with the highest releases occurring during Stage 2 to Stage 6.
- For median climatic conditions (50%ile), predicted annual controlled releases range between 100 and 1,070 ML/a.
- For dry climatic conditions (90%ile), predicted annual controlled releases range between 15 and 380 ML/a.

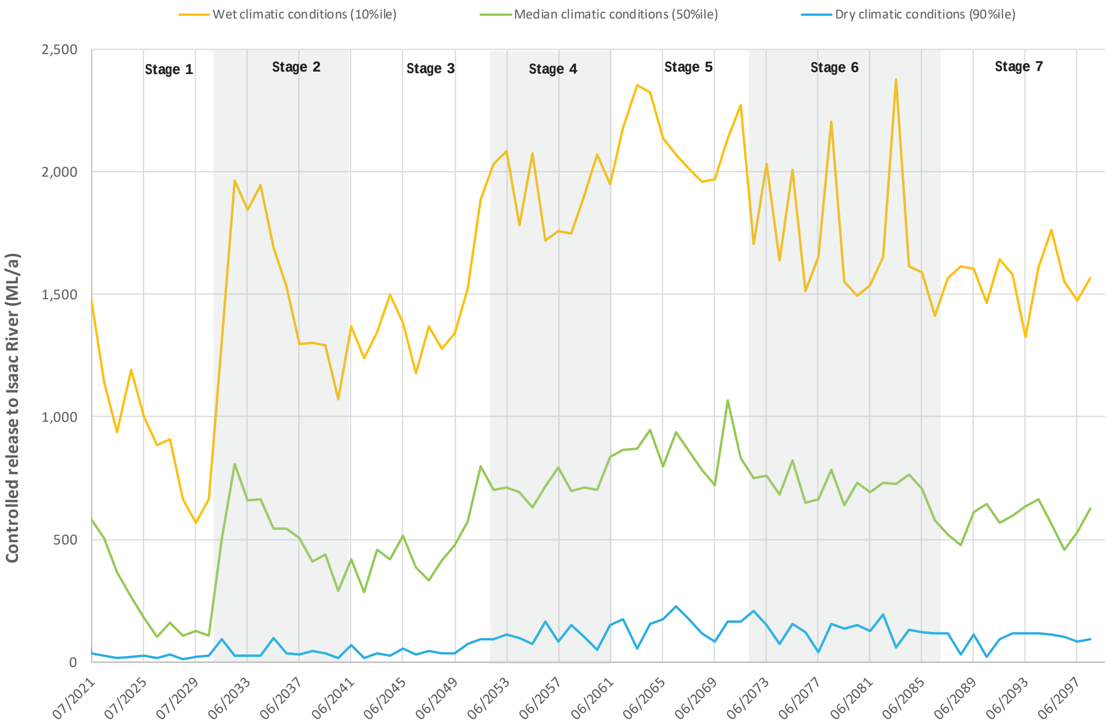

Figure A12: Forecast Annual Controlled Release Volumes – Sensitivity Scenario 4

A.5 Scenario 5: 25% Global Increase of Source Salinity by 25%

For the Scenario 5 sensitivity analysis, the salinity concentration applied to all water sources (including rainfall runoff) has been increased by 25%. This impact of this change on the performance of the water management system is presented in the following sections.

A.5.1 In-pit Storage

Figure A13 shows the forecast inventory for the combined mining pits, respectively, over the 79-year simulation for the Scenario 5 sensitivity assessment. The forecast modelling results for the mining pit inventory are summarised as follows:

- For the 10th percentile results (wet climatic conditions), water begins to accumulate at the beginning of Stage 2 and reaches a peak inventory of around 12,550 ML during Stage 3 of the Project.
- For the 50th percentile results (median climatic conditions), water accumulates during Stage 2 and 3, then reduces to an inventory of around 2,000 ML by the end of the Project.
- By the end of Stage 3, a substantial amount of additional storage capacity (around 550 GL) will be available within the Pit 1/2/3 void as mining has been completed by this time. These voids would be used to storage excess water as required, depending on the prevailing climatic conditions.

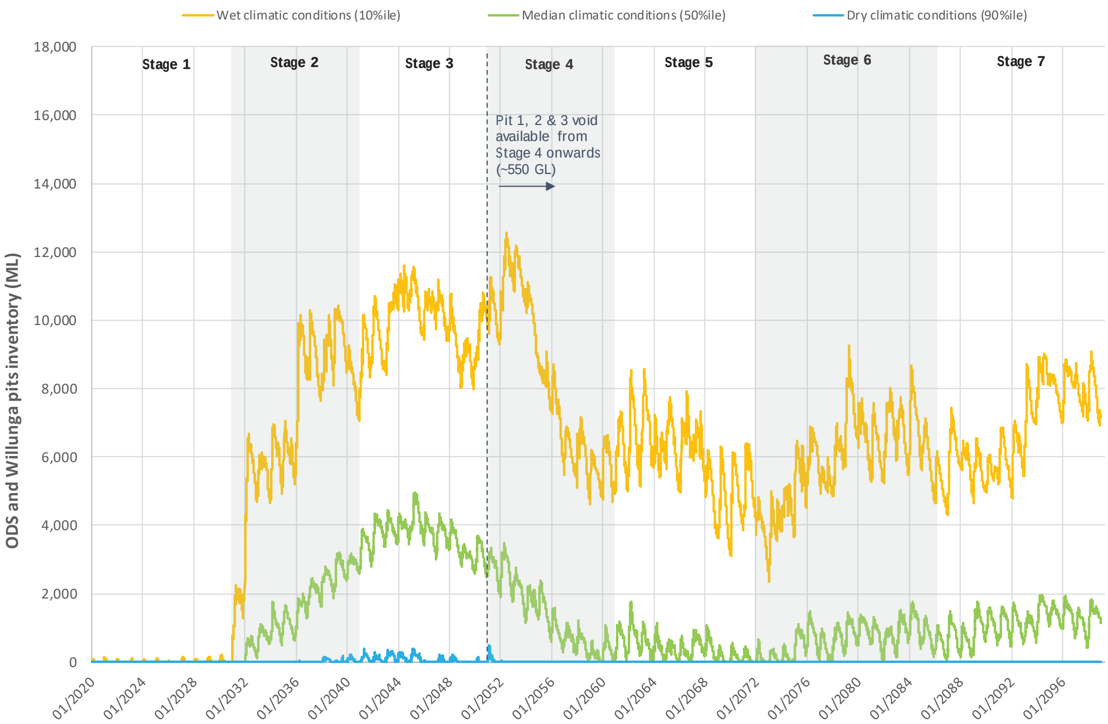

Figure A13: Forecast Combined Pit Inventory – Sensitivity Scenario 5

A.5.2 External Makeup Requirements

Figure A14 shows the total annual modelled demand for water from external sources over the 79-year simulation for Scenario 5. The modelling results show the following:

- During Stage 1, there is a:
    - 10% risk of requiring 2,120 ML/a (or more) from the pipeline.
    - 50% risk of requiring 1,430 ML/a (or more) from the pipeline.
- During Stage 2, the requirement for external supply is highest. There is a:
    - 10% risk of requiring 2,230 ML/a (or more) from the pipeline.
    - 50% risk of requiring 850 ML/a (or more) from the pipeline.
- The external supply requirement reduces over the remainder of the Project. By Stage 5, there is little to no external water required under median climatic conditions.
- During Stage 6 and Stage 7, there is a 10% risk of requiring around 1,700 ML/a (or more) from the pipeline.

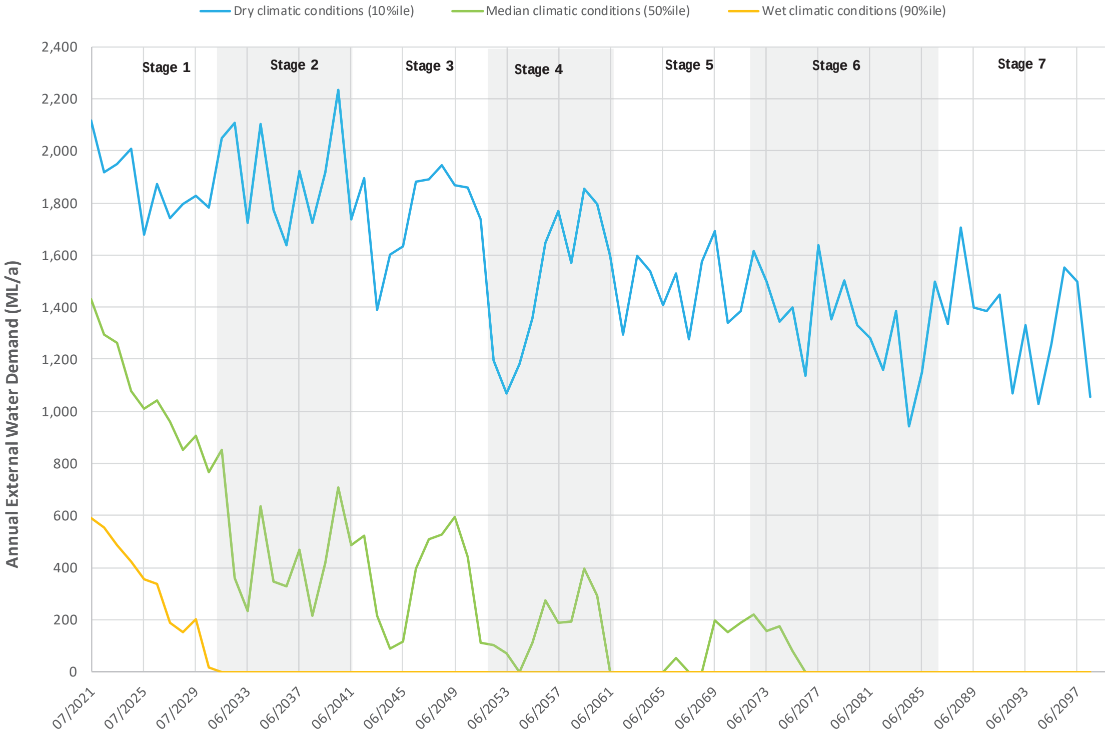

Figure A14: Forecast Annual External Water Requirements – Sensitivity Scenario 5

A.5.3 Controlled Releases

The predicted annual controlled release volumes from the mine affected water dams for Scenario 5 are provided in Figure A15. The results show that:

- For wet climatic conditions (10%ile), predicted annual controlled releases range between 460 and 2,140 ML/a, with the highest releases occurring during Stage 2 to Stage 5.
- For median climatic conditions (50%ile), predicted annual controlled releases range between 90 and 820 ML/a.
- For dry climatic conditions (90%ile), predicted annual controlled releases range between 10 and 370 ML/a.

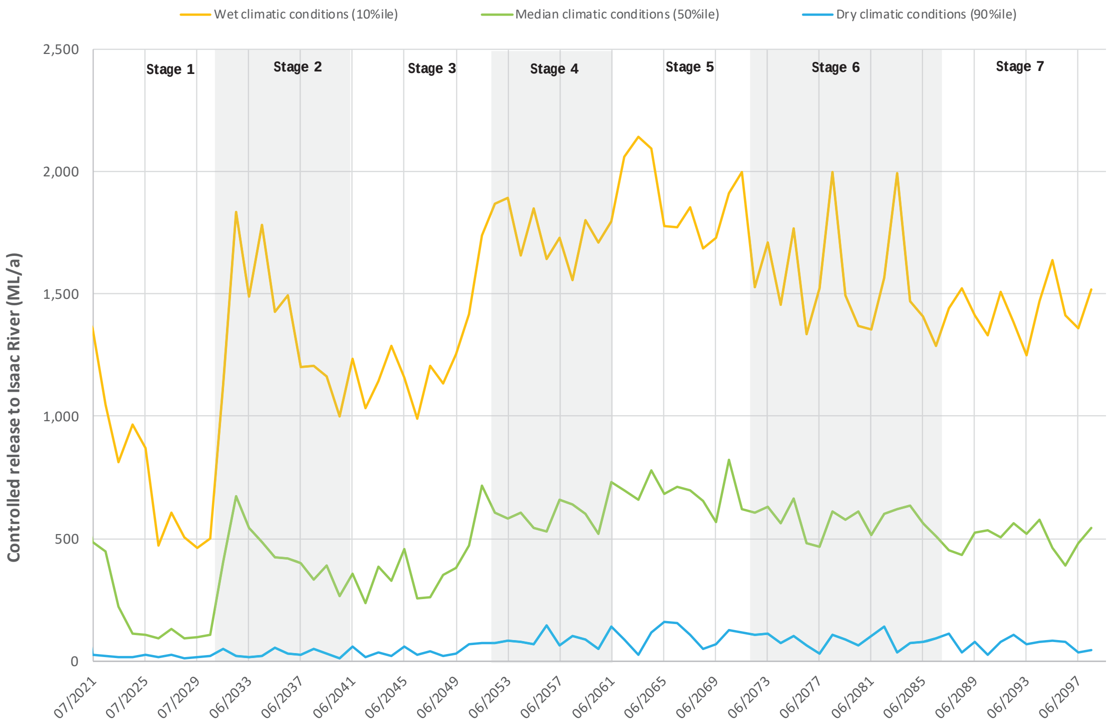

Figure A15: Forecast Annual Controlled Release Volumes – Sensitivity Scenario 5

Appendix B

Geomorphology Report

Olive Downs Coking Coal Project

Environmental Impact Statement

Technical Study Report

Geomorphology

Dr Christopher J Gippel

Final

July 2018

FLUVIAL SYSTEMS

Olive Downs Coking Coal Project

Geomorphology

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July 2018

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			Name/Position	Signature
A	30-Nov-2017	Draft for Review	Chris Gippel Director Geomorphologist	
B	9-May-2018	Draft for Review	Chris Gippel Director Geomorphologist	
C	23-July-2018	Final	Chris Gippel Director Geomorphologist	

Table of Contents

GLOSSARY OF TERMS

Term	Definition
Aggrade	Persistent deposition of sediment on the bed of stream channel. Opposite to Scour.
Alluvium (alluvial)	Sediment deposited distant from its source after transport by flowing water, as in a riverbed, floodplain, delta, or alluvial fan.
Bed shear stress (also Shear stress)	The force of moving water against the bed of the channel, calculated as a function of the product of slope and water flow depth. Used to indicate the likelihood that surface particles will be eroded or vegetative cover scoured.
Catchment	The area from which a surface watercourse or a groundwater system derives its water.
Composition (of riparian vegetation)	Represented by 3 structural classes - tree (woody and >3 m high) shrub (woody) and ground vegetation.
Cover (of riparian vegetation)	Foliar projective cover of the ground.
Cumulative impacts	Combination of individual effects of the same kind due to multiple actions from various sources over time.
Discharge	A release of water from a particular source.
Drainage	Natural or artificial means for the interception and removal of surface or subsurface water.
Ecology	The study of the relationship between living things and the environment.
Ecosystem	As defined in the *Environment Protection and Biodiversity Conservation Act 1999*, an ecosystem is a ‘dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit.’
Environment	As defined within the *Environmental Planning & Assessment Act, 1979*, all aspects of the surroundings of humans, whether affecting any human as an individual or in his or her social groupings.
Ephemeral	Existing for a short duration of time.
Fault	Break in the continuity of a coal seam or rock strata.
Filamentous algae	Colonies of microscopic plants growing in water that link together to form threads or mesh-like filaments; lacking roots, their growth and reproduction are dependent on the amount of nutrients in the water.
Fluvial	Of or found in a river.
Fragility (geomorphic)	Relative ease of adjustment of bed material, channel geometry, and channel planform when subjected to degradation or certain threatening activities (Cook and Schneider, 2006) (see also Resilience).
Geology	Science of the origin, history, and structure of the earth.
Geomorphic condition (of a stream)	Relative state of stream geomorphic characteristics relative to the state that is unimpacted by human disturbance (Fryirs, 2003).
Geomorphology	The science of the structure, origin, and development of the topographical features of the earth's surface.
Global Mapper™	A GIS application, especially suited to terrain analysis (see also Terrain analysis)

Term	Definition
Grid (in GIS)	An array of rectangular or square cells, with a numerical attribute value for the cell stored in its centroid; often refers to elevation but can describe any attribute (see also Raster).
Gully	The deep and narrow channel form that results from incision into soil or sediment.
Habitat	The place where a species, population or ecological community lives (whether permanently, periodically or occasionally).
Headwater	A stream type found in V-shaped valleys, and located within source zones for sediment.
Hydraulic	Refers to the physical properties of flow: velocity, depth and bed shear stress.
Hydrogeology	The study of subsurface water in its geological context.
Hydrology	The study of rainfall and surface water runoff processes.
Impact	Influence or effect exerted by a project or other activity on the natural, built and community environment.
Incision	Deepening of a channel by scour (erosion) (see also Scour)
Knickpoint	A local steep fall in channel bed elevation.
Large wood	Wood fallen into streams, larger than 0.1 m diameter and more than 1 m long.
LiDAR	Light Detection and Ranging (see ACRONYMS), also known as airborne laser scanning; a remote sensing tool that is used to map ground elevation.
Long profile	A plot of elevation against distance, in this case along a stream bed.
Multiresolution index of valley bottom flatness (MRVBF)	An algorithm to assist in the objective separation of floodplains from their surrounding hillslopes using slope and elevation percentile.
Polygon (in GIS)	A closed shape defined by a connected sequence of x,y coordinate pairs, where the first and last coordinate pair are the same and all other pairs are unique.
Pool	A deeper section of a stream that retains water.
Proposed development	Underground coal mining and associated activities within the Study Area. Referred to as the Spur Hill Underground Coking Coal Project.
Raster (in GIS)	A spatial data model that defines space as an array of equally sized cells arranged in rows and columns, and composed of single or multiple bands (see also Grid).
Regolith	The material that is found between unweathered bedrock and the ground surface, including weathered bedrock, deposits and soil.
Resilience (geomorphic)	Low fragility, with only minor changes likely, regardless of the level of damaging impact (Brierley et al., 2011).
Riparian	Relating to the banks of a natural waterway.
River Styles®	A geomorphic classification based on valley setting, level of floodplain development, bed materials and reach-scale physical features within the stream (see also Stream type)
Runoff	The portion of water that drains away as surface flow.
Scour	Persistent removal of sediment from the bed of a stream channel by fluvial erosion. Opposite to Aggrade.

Term	Definition
Slope (quantified)	Also known as gradient, expressed as a ratio of integers (vertical:horizontal), the vertical gain divided by the horizontal distance (m/m), or the angle of the incline (degrees).
Soil landscape	A mapping unit that reflects soil and landscape processes.
Stream	A general term that covers all morphological features, from small rivulets to large rivers, that perennially, intermittently or ephemerally convey concentrated water flow (see also Watercourse and Waterway).
Stream link	Lengths of stream between two nodes, where a node is the beginning of a First Order stream, the junction of two streams, or some other locally defined boundary.
Stream Order	According to the Strahler system, whereby a headwater stream is Order 1, and the Order increases by 1 when a stream of a given Order meets one of the same Order.
Stream power	Power per unit length of a stream reach dependent on the product of stream discharge and slope
Stream type	A geomorphic classification based on valley setting, level of floodplain development, bed materials and reach-scale physical features within the stream, consistent with River Styles® (see also River Styles®)
Study Area (of Geomorphology Technical Report)	Area mapped in this report.
Surface Facilities Area	Comprises surface land containing mining and non-mining infrastructure.
Surface water	Water flowing or held in streams, rivers and other wetlands in the landscape.
Terrain analysis	The automated analysis of landforms using digital elevation data sets.
Topographic Position Index (TPI) (in Terrain analysis)	Relative elevation of cells in a landscape, used to classify landforms.
Terrain Surface Classification (TSC) (in Terrain analysis)	Classifies landforms using three taxonomic criteria: slope gradient, local convexity, and surface texture.
Tributary	A river or stream flowing into a larger river or lake.
Vector (in GIS)	A coordinate-based data model that represents geographic features as points, lines, and polygons (see Polygon).
Watercourse	Any flowing stream of water, whether natural or artificially regulated (not necessarily permanent) (see also Stream and Waterway).
Waterway	Any flowing stream of water, whether natural or artificially regulated (not necessarily permanent) (see also Stream and Watercourse).

ACRONYMS

Acronym	Expansion
AHD	Australian Height Datum
DEM	Digital Elevation Model
EIS	Environmental Impact Statement

Acronym	Expansion
GIS	Geographic Information System
GPS	Global Positioning System
LiDAR	Light Detection and Ranging
MLA	Mining Lease Application
MRVFB	Multiresolution index of valley bottom flatness
ODK	Open Data Kit
SAGA	System for Automated Geoscientific Analyses
TSC	Terrain Surface Classification
TPI	Topographic Position Index

UNITS

Symbol	Unit
ha	Hectare
km	Kilometre
Km^2	Kilometres squared
m	Metre
m^2	Metres squared, or square metres
m^3	Metres cubed, or cubic metres
mm	Millimetre

Executive Summary

This report documented the geomorphological character of the Olive Downs Coking Coal Project Study Area using repeatable field and desktop methods. Characterisation of the geomorphology of the Study Area was approached at the landscape and stream reach/point scales. Streams were classified according to Strahler Stream Order and geomorphic type, and geomorphic features of the streams were measured in the field at the reach/point-scale.

The field data were collected from 54 sites within the period 13 to 16 June 2017. In general, the measurements were made using standard techniques from the literature. The intention was to capture morphological variability at the habitat scale. The field survey involved walking or using an All Terrain Vehicle (ATV) to access the streams at representative locations and following a sampling protocol. A comprehensive set of variables was measured at sites in the field. Most of the observations involved recording presence/absence or measuring a quantity. Some variables were quantified using a subjective visual estimation method. These variables included the relative strength of the channel form, channel connectivity to floodplain, bed material calibre, and vegetation cover and continuity.

Terrain analysis, the automated analysis of landforms using digital elevation data sets, was undertaken using a Light Detection and Ranging (LiDAR) derived Digital Elevation Model (DEM). This objective of this analysis was to classify landforms. Field and desktop data were used to classify streams according to geomorphic type, and geomorphic condition.

The streams of the Study Area comprised the Order 6 sand-bed Isaac River, other large sand-bed streams in North, One Mile, Boomerang and Phillips creeks, the smaller Order 3 sand-bed Ripstone creek, plus some small shallow streams with vegetated mud bed. Of the small western tributaries streams, a portion of Western Tributary A passes through Mining Lease Application (MLA) 700032. The catchment is large enough to generate sufficient runoff to form a defined channel, as designated by a blue line, so consideration would need to be given to diversion of the flow from this small stream channel around the pit to Isaac River.

The catchments and channels of One Mile Creek, Boomerang Creek, and Phillips Creek do not pass through the MLAs, so they would not be directly impacted by open cut mining activity, although there is potential for the floodplain areas of the lower reaches of Boomerang and Phillips creeks to be impacted by altered flood hydraulics of the Isaac River. On the other hand, a large area of Ripstone Creek catchment is upstream of MLA 700033, and the creek channel then passes into and through this domain on its way to joining Boomerang Creek, just upstream of its junction with Isaac River. Open cut mining would likely directly impact a portion of lower Ripstone Creek catchment, so part of this channel require diversion around the pit. Creek diversion design and monitoring was outside the scope of this report, and was done as part of the flood study investigation.

The surface geology of the Study Area comprised extensive undifferentiated sandy sediments and soils and Quaternary alluvium within river corridors. This suggests that sand bed rivers and streams would be naturally occurring in this region, and not necessarily the result of accelerated sediment delivery caused by land use change, although this process could have increased the rate of sand delivery to channels above background levels.

The majority of the wider Study Area has moderately stable surface soils. Erodible non-cohesive soils and dispersive soils occur in fragmented patches, with more concentrated areas of erodible soils occurring in Ripstone Creek catchment just upstream of the core Study Area, and in the corridor of Isaac River just upstream of the core Study Area. The terrain within the MLAs was less than 10 degrees, except for moderately steep slopes forming the banks of Ripstone Creek. The channels of the major watercourses Isaac River, lower Phillips Creek and lower North Creek had almost continuous very steep banks, while lower Boomerang Creek channel had continuous moderately steep channel banks. Landform classification provided a reasonable separation between likely floodplain landform and surrounding valley slope landform, although the indicators were inconclusive for lower Ripstone Creek in particular.

Isaac River displayed distinctive channel narrowing in the downstream direction through the Study Area. This downstream narrowing occurred despite a significant increase in catchment area. The channel did not maintain its capacity downstream by increasing in depth or slope, suggesting that the floodplain becomes increasingly hydraulically connected to the channel in the downstream direction. The downstream slope of Isaac River is relatively constant, falling 40 m over 70 km for an average slope of 0.000587. Sinuosity of the river is 1.29. Ripstone Creek narrowed in its lower reach, as it approached its junction with Boomerang Creek. The floodplain is likely to be more hydraulically connected to the channel in the lower reach. Channel dimensions were highly variable along Ripstone Creek. The downstream slope of Ripstone Creek is relatively constant, falling 33.2 m over 26.2 km for an average slope of 0.001275. Sinuosity of the creek is 1.51.

Isaac River and North Creek, being laterally unconfined with extensive floodplain connection, belong to the Low Sinuosity Sand type. The lowland reaches of Boomerang Creek and Phillips Creek are a similar type at a smaller scale, but by virtue of their higher sinuosity are Meandering Sand type. The upper section of Ripstone Creek is partly confined with extensive floodplain connection. Downstream of this the stream is Planform Controlled Meandering Sand as the floodplain connection becomes less extensive. The lower section of Ripstone Creek is the Floodout type. Here it emerges onto the lateral zone of the Isaac River floodplain, where the channel changes from sand bed to fine-grained bed and becomes an unconfined flow path characterised by discontinuous deep pools. At the most downstream end, where Ripstone Creek starts incising to meet Boomerang Creek bed level, the channel becomes longitudinally continuous and more defined in cross-section form. Here the creek is best described as Meandering Fine Grained type. Western Tributary streams were sampled on lowland locations where they are situated on the Isaac River floodplain. Here, the channels are small, varying from continuous to discontinuous.

Most of the stream reaches were in a stable, close to natural geomorphic condition. Some streams were potentially impacted by factors that reduced their condition, in particular high loads of sand in the bed, but without historical data concerning condition prior to the land cover and drainage being modified for agricultural and mining use, this remains uncertain. No knickpoints or zones of major geomorphic instability were observed.

The risk of erosion of the Isaac River channel and floodplain was assessed using the method of maximum permissible bed shear stress and velocity assessment, with the hydraulic variables modelled as part of the flood study. This assessment of the most critical areas found that while there could be isolated areas subject to somewhat higher risk of scour compared to the existing situation, the overall risk of rapid and significant geomorphic change in the Isaac River due to the proposed mining activity was low.

1.0 Introduction

1.1 Characteristics of the Olive Downs Coking Coal Project

Pembroke Resources Pty Ltd (Pembroke) is progressing the design and approval for the Olive Downs Coking Coal Project (the Project). The Project is located in the Bowen Basin, Central Queensland, approximately 40 kilometres (km) southeast of Moranbah (Figure 1).

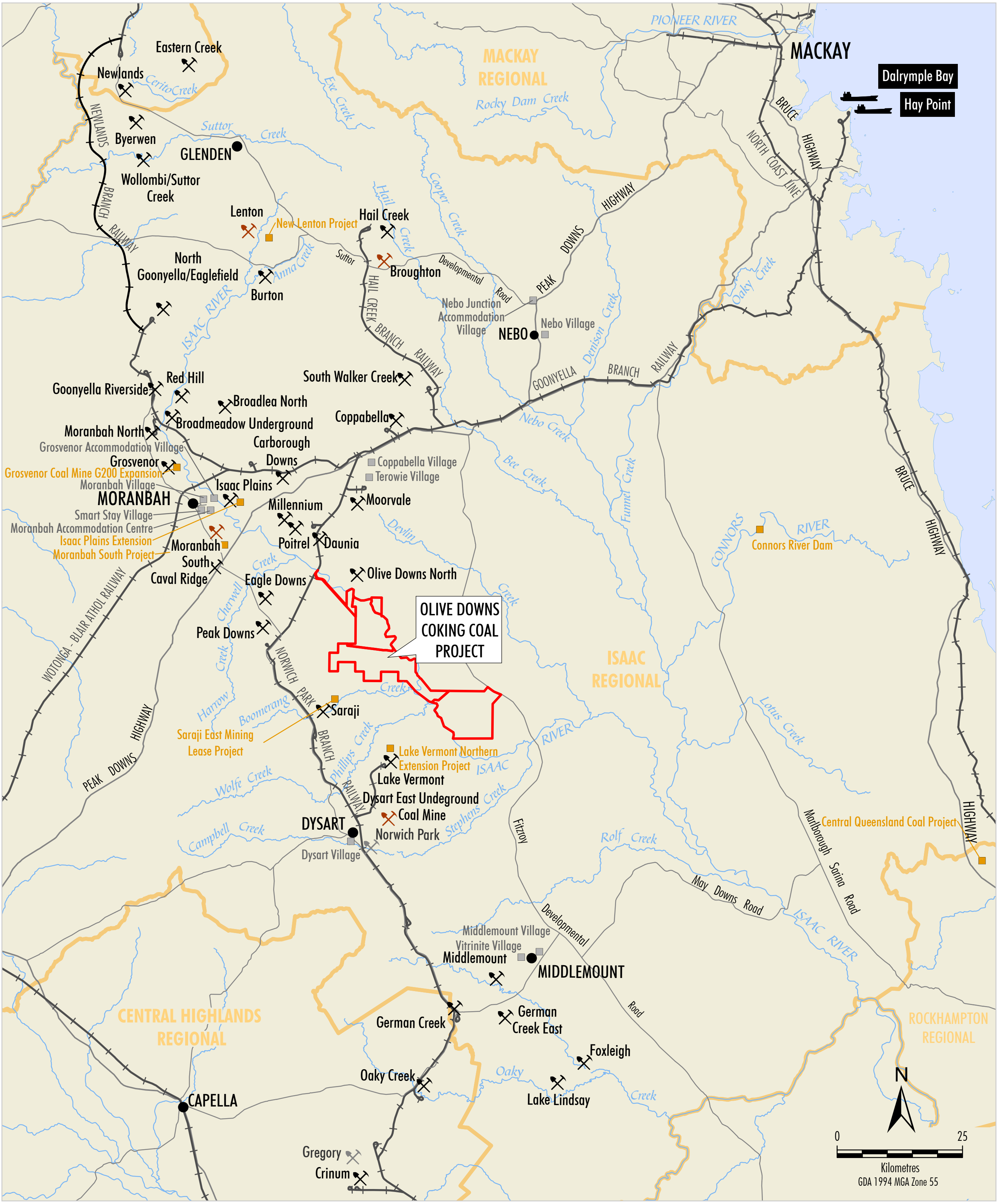
The Project is an open cut mining complex comprising five Mining Lease Applications (MLAs) that cover two mining areas that for some time have been known as Olive Downs South Domain and Willunga Domain, and associated linear infrastructure corridors (i.e. Isaac River haul road crossings, mine infrastructure areas (MIAs), coal handling and processing plant (CHPP), rail spur, water management infrastructure, electricity transmission line (ETL), and access roads) (Figure 2). The total extent of the of MLAs is approximately 26,402 hectares (ha).

The proposed mine plan will deliver up to 20 million tonnes per annum (Mtpa) of Run-Of-Mine (ROM) coal for more than 30 years. Approximately 90% of the product coal would be high quality metallurgical coal, with the remainder a thermal coal by-product. The main water demands for the Project, i.e. coal handling preparation plant (CHPP) water supply and dust suppression, would fluctuate with the rate of ROM coal feed to the CHPP and as the extent of the mining operation changes over time.

1.2 Scope and Objectives of this Technical Report

This report characterised the physical environment from a geomorphologic perspective. The scope of work for this Geomorphology Technical Report included, but was not limited to:

- Existing background data collection to provide a baseline of pre-mining geomorphic condition
- Field data collection within the Study Area, including, but not limited to:
    - fluvial features, including, but not limited to, incision, aggradation, knickpoints, pools, bedrock features, hydraulic controls, riffles, bed material, dimensions and profiles, riparian zones, and alluvium.
- Mapping of relevant remotely sensed, field-collected, and derived geomorphic and related attributes, including, but not limited to:
    - Stream Order and geomorphic type classification;
    - In-channel fluvial features; and
    - Riparian zone vegetation structure.
- Technical assessment of geomorphic-related factors, including, but not limited to:
    - existing geomorphic conditions and processes within the Study Area;
    - assessment of geomorphological condition and fragility of stream reaches within the Study Area;
    - assessment of potential impacts of the Project on geomorphic character of stream reaches in the Study Area; and
    - assessment of regional cumulative impacts on geomorphic characteristics of streams.
- Recommendations for mitigation and monitoring of geomorphic condition.



LEGEND

- Mining Lease Application Boundary
- Local Government Area
- Major Road
- Railway
- Port
- Approved/Operating Coal Mine
- Proposed Coal Mine
- Under Care and Maintenance
- Workforce Accommodation Facility
- Coordinated, Major and Other Relevant Project

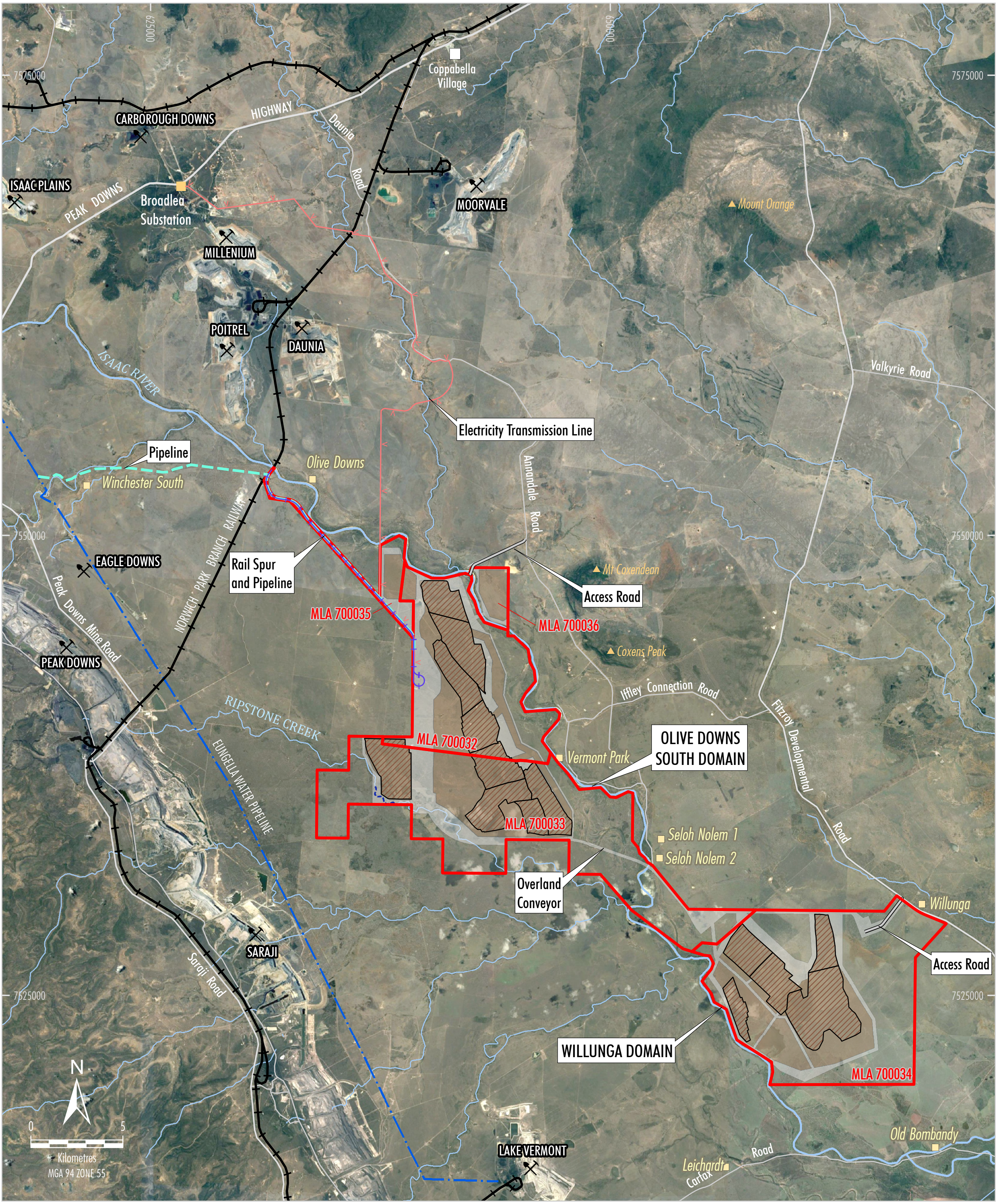
Source: Geoscience Australia - Topographical Data 250K (2006); Department of Natural Resources and Mines (2016)

PEMBROKE

OLIVE DOWNS COKING COAL PROJECT

Regional Location

Figure 1



LEGEND
- Mining Lease Application Boundary
- Approved/Operating Coal Mine
- Dwelling
- Eungella Pipeline Network
- Railway
- Proposed Access Road
- Proposed Electricity Transmission Line
- Proposed Rail
- Proposed Water Pipeline
- Proposed Creek Diversion
- Open Cut Pit Extent
- Out-of-Pit and In-Pit Waste Rock Emplacement
- Infrastructure Area

Source: Geoscience Australia - Topographical Data 250K (2006)
Department of Natural Resources and Mines (2016)
Orthophotography: Google Image (2016)

PEMBROKE

OLIVE DOWNS COKING COAL PROJECT

Project General Arrangement

Figure 2

1.3 Relevant Policy and Legislative Requirements

This Technical Report is an input to the Project Environmental Impact Statement (EIS) and has been prepared in accordance with the terms of reference set out by the Coordinator General (Department of State Development, 2017), in keeping with the requirements of a coordinated project for which an EIS is required under section 26(1)(a) of the State Development and Public Works Organisation Act 1971 (SDPWO Act).

The requirements for an EIS under the SDPWO Act were set out in Department of State Development (2017). With respect to providing an appropriate level of detail, the general requirement is for a level of detail that is proportional to the scale of the impacts on environmental values. Additionally, all available baseline information relevant to the environmental risks of the project must be provided, including details on the quality of the information, in particular with respect to its date, reliability and uncertainty.

This Technical Report addresses part of the environmental objectives to be met under the Environmental Protection Act 1994 (EP Act) for Land, Flora and Fauna (Department of State Development, 2017, p. 16), specifically '(a)…the environmental values of land including soils, subsoils, landforms and associated flora and fauna', whereby impact prediction must address '(b) the topography, geology, geomorphology of the project sites and adjoining areas'.

There is no legislative or policy requirement regarding the methodologies to be applied in undertaking geomorphological investigations for the purpose of an EIS. The methodologies employed in this Technical Report followed current best practice.

1.4 Report structure

This report is structured as follows:

Section 1	Introduction – outlines the Project and presents the purpose of the report
Section 2	Methodology – describes the methodology employed for this Geomorphology Technical Report
Section 3	Existing environment – describes the character of the existing geomorphologic environment
Section 4	Impact assessment – describes the potential impacts to geomorphologic character of the environment resulting from the proposed Project
Section 5	Mitigation - provides a summary of environmental mitigation, management and monitoring responsibilities in relation to management of geomorphologic aspects of the environment for the Project
Section 6	Monitoring and Evaluation
Section 7	Conclusion
Section 8	References

2.0 Review of Some Other Geomorphic Investigations in the Fitzroy Basin

As part of an assessment of the Baralaba North Continued Operations Project, WRM Water & Environment (2014) undertook a geomorphological study of part of the Dawson River, south of the Study Area. They described the general characteristics of the stream channels and used two dimensional TUFLOW hydraulic modelling undertaken on a 20 m grid to assess the geomorphic impact of the project for low frequency, high magnitude, events in the range 1 in 20 to 1 in 1000 year average recurrence interval (ARI). The geomorphic impact was assessed in terms of the hydraulic variables velocity, within both channel and floodplain, water level, and afflux. The impact of the project on the hydraulic characteristics of these large events was small, so it was assumed that the more frequent geomorphic channel forming events would be unaffected. WRM Water & Environment (2014) also compared aerial photographs taken over the period 1961 to 2011 and observed no measureable change in stream channel alignments despite the occurrence of 5 major flood events. A separate geomorphology assessment of the area by Water Solutions compared the design guideline limits for significant erosion and geomorphological change in the 'Guideline for Watercourse Diversion – Central Queensland Mining Industry' (DERM, 2011; White et al., 2014). These guidelines are based on generic acceptable thresholds for the hydraulic variables shear stress, velocity and stream power. The thresholds take in account vegetation cover, but not the bank or bed materials, which also have a major influence on resistance to erosion and sediment transport.

The Red Hill Mining Lease is located on the upper Isaac River, upstream and north of the Study Area, approximately 20 kilometres (km) north of Moranbah and 135 km south-west of Mackay. Alluvium (2011) undertook a geomorphic assessment as part of the EIS for proposed longwall mining by BHP Billiton Mitsubishi Alliance (BMA). Alluvium (2011) described the geomorphic character, behaviour and condition of the Isaac River and tributaries within the potentially impacted area. Watercourses included in the assessment were those mapped as blue lines on Geoscience Australia digital mapping at the scale of 1:100,000. They noted that the definition of watercourse in the Water Act 2000, given as "…*a river, creek or stream in which water flows permanently or intermittently – (a) in a natural channel, whether artificially improved or not, or (b) in an artificial channel that has changed the course of the watercourse…*" could exclude discontinuous channels. However, Alluvium (2011) used aerial photography and digital terrain data to determine the flow paths of watercourses mapped as discontinuities, and then classified watercourses as unchannelised (no channel), discontinuous channel and continuous channel.

Alluvium (2011) described the Isaac River as a low to moderate sinuosity, ephemeral, sand bed stream that is largely alluvial (i.e. adjustable bed and banks) downstream of the Burton Gorge. The river was terrace-confined, with the terrace a paleo floodplain likely to have been formed during climatic conditions that produced larger discharges than the contemporary flow regime (Alluvium, 2011). The modern active floodplain is a narrow (150 – 500 m wide) band on one or both sides of the channel that is 2 – 4 m lower in elevation than the terrace (2,000 – 5,000 m wide). The narrow floodplain contains the 1 in 100 year ARI event. The riparian vegetation was described as having a reasonably continuous overstorey, minimal understorey and variable groundcover, often dense, with exotic grasses dominant.

Alluvium (2011) considered the geomorphic condition of the Isaac River to be compromised by excess sand bedload, released from the catchment at accelerated rates through changed land use. Alluvium (2011) provided no evidence to support this claim, but contrary evidence is publicly available in the journal of Ludwig Leichardt, who, upon first sighting the Isaac River on 13 February 1845, described it as having a 'very sandy' bed (Leichardt, 1846).

The G200s Project involved additional underground longwall mining in the western portion of the existing Grosvenor mining lease, located directly north and adjacent to Moranbah township on the Isaac River (Hansen Bailey, 2016). The area of the Isaac River catchment to this point was estimated to be 1,800 square kilometres (km^2). Hansen Bailey (2016) described the Isaac River as ephemeral, with naturally elevated sediment loads and extensive sediment deposition associated with wet season flows in November to April. The assessment by Hansen Bailey (2016) involved a desktop study of a high resolution topographic data to determine flow paths, supported by a field investigation. Hansen Bailey (2016) described the Isaac River as incised, inundating the floodplain only under extreme floods, and having a fairly featureless sand bed with occasional vegetated bars within the channel.

Hansen Bailey (2016) assessed geomorphic character using AusRIVAS habitat assessment methodology (Parsons et al., 2002). This Australia-wide generic approach relies largely on subjective visual assessment to quantify a range of physical stream-related variables assumed relevant to the ecological assets of the river. Establishing the relevance of variables to a particular area would require prior knowledge of the local assets and their habitat requirements and preferences. Some variables would be irrelevant, or their relevance could not be established, in which case collecting and presenting such data would be pointless. On the Isaac River main channel, Hansen Bailey (2016) chose 7 sites over a distance of about 3 km, for an average spacing of about 500 m. The description of the Isaac River near Moranbah was similar to that near Red Hill Mining Lease (Alluvium, 2011). Here it was moderately sinuous with a broad floodplain, having continuous to semi-continuous remnant riparian vegetation invaded by exotics. The channel was U-shaped with stable convex banks, covered in a mud drape, which enhanced bank stability, also noted by Alluvium (2011). Bank undercutting was apparent in locations where the mud drape had been eroded. Several small, shallow pools were present but the sand bed was largely featureless apart from extensive vegetated bars.

The Lake Vermont Northern Extension Project is a proposed open cut mine extension located on Phillips Creek, a tributary of the Isaac River, approximately 170 km southwest of Mackay and approximately 15 km northeast of Dysart (Aarc, 2016). This project is immediately west of the Willunga Domain of the Olive Downs Coking Coal Project. Field stream morphology assessments were completed at 19 sites along an approximately 15 km long reach of Phillips Creek for an average spacing of about 830 m (Aarc, 2016). The survey provided a comprehensive assessment of the landform and channel characteristics (e.g. depth, width, composition, bank stability, etc.), riparian vegetation and aquatic habitat features. Habitat quality was assessed using a modified form of the AusRIVAS habitat assessment methodology. The geomorphic variables were measured at cross-sections. Phillips Creek had a relatively flat sand bed. Riparian vegetation was dominated by River Red Gum (*Eucalyptus camaldulensis*) and River She-oak (*Casuarina cunninghamiana*), typically with an associated presence of Moreton Bay Ash (*Corymbia tessellaris*). Bank stability was rated to range from very poor to good with average side slopes of 60° on both banks. The majority of the creek was found to be of moderate condition with occasional small- to moderately-sized areas of erosion. The downstream section of the creek was considered to be of poor or very poor condition due to impacts from creek crossings and livestock access, which have resulted in significant areas of erosion. Overall, Phillips Creek was rated as having a slightly to moderately disturbed ecosystem (Aarc, 2016).

The above studies used a range of desktop and field survey methodologies to undertake geomorphic assessment. The methods used in these previous studies were considered potentially useful for the Study Area, with the exception of the AusRIVAS habitat assessment methodology, which was excluded on the basis of its generic nature and lack of focus on geomorphic processes and forms. The above studies were of fairly short stream reaches 2 to 15 km long, while the Isaac River in the Project area is over 50 km long. This scale difference suggests that for practical reasons, a wider site spacing than 500 – 800 m would be appropriate for at least some streams within the Project area (notably, the Isaac River), provided the sampling density was adequate to capture the spatial variability in geomorphic character of the streams.

3.0 Methodology

3.1 Study Area

In this Geomorphology Technical Report the core Study Area is the area bounded by the five MLA areas comprising the Olive Downs Coking Coal Project: MLAs 700032, 700033, 700034, 700035 and 700036 (Figure 2, Figure 3). With respect to sediment and surface water fluxes, the MLA areas, being situated within catchments, are not closed systems, so potential geomorphological impacts of the proposed mining are not necessarily confined within them. Also, the geomorphic character of the slopes, floodplains and channels within the MLAs is strongly conditioned by processes occurring in the upstream catchment area. Thus, the Study Area was also considered within the context of the geomorphological character of the wider area of the Project, which includes the catchments of streams that drain to and from the core Study Area (Figure 2). The areal extent of the wider area depended on the variable under consideration, but the aim was to include the area likely to significantly influence, or be significantly influenced by, geomorphic processes occurring within the core Study Area.

A number of maps in this report show geomorphologically-relevant data extending outside the Study Area. In such cases, the information located outside the Study Area was included to show the continuity of the attribute being described, and/or to illustrate the regional context of the attribute.

Some field data were collected from stream sites outside the core Study Area boundary. This data collection was either:

- unintentional because the position of MLA boundary on the stream was known in the field to within approximately ±100 m; or
- intentional because the stream under survey near the MLA boundary was perceived in the field to potentially have geomorphological relevance to assessment of baseline conditions or Project impact assessment.

3.2 Measurement scales

Characterisation of the geomorphology of the Study Area was approached at two measurement scales:

1. Landscape, which covers geomorphological or geomorphologically-relevant characteristics such as landform terrain attributes and soil attributes at the regional and catchment scale.
2. Stream reach- and point-scale, which covers physical attributes of streams at the cross-section- and reach-scale (1 to 1,000 metres), plus the scale of stream type which varies from 10s to 1,000s of metres long.

An approach, based on standard methods, was devised to classify streams of the Study Area according to geomorphic type, and to measure the geomorphic features of the streams at the cross-section and reach-scale. This report provides sufficient technical information such that the methodology could be repeated in the Study Area at a later time by a third party. Also, the primary and secondary data from the work were provided in sufficient detail to allow a comparison of future geomorphological character with baseline (current) geomorphological character.

Characterisation of the fluvial geomorphological features of the Study Area was based on a combination of field survey and desktop analysis of existing data.

3.3 Data Sources

3.3.1 Primary data

A geomorphological field survey of the Project Area was undertaken by Dr Christopher Gippel of Fluvial Systems Pty Ltd over the period 13 – 16 June 2017. The field survey collected readily quantifiable data that either could not be readily obtained from remotely sensed data or was used to supplement or ground truth remotely sensed data.

3.3.2 Spatial data

The investigation relied heavily on detailed topographic data and aerial photography. Airborne Laser Scanning (ALS), also known as Light Detection and Ranging (LiDAR), data were acquired using fixed wing aircraft. The LiDAR data were supplied as three separate groups of files:

- 20 × 20 m grid of point elevations;
- 10 × 10 m grid of point elevations along stream corridors of Isaac River, Cherwill Creek, Boomerang Creek and Phillips Creek; and
- variably spaced cloud of point elevations within a 5 × 5 m grid of point elevations (nominally referred to here as a 5 × 5 m grid).

The areas covered by these three groups of survey data overlapped to a large extent (Figure 3). In general, the higher resolution data were preferred, but there was a small area (3.8 km^2) covering Isaac River 8 km upstream of the north-western extent of the Study Area where the 10 × 10 m grid data were preferred over the 5 × 5 m grid data.

The surface elevation of areas that were of interest beyond the LiDAR coverage was estimated from 3 arc-second (approximately 90 m) Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) data obtained from National Aeronautics and Space Administration (NASA) (http://www.jpl.nasa.gov/srtm). The SRTM data are affected by vegetation, and have a much poorer spatial and vertical resolution than LiDAR data.

Digital GIS layers of existing standard watercourse, road, rail, soil erodibility and underlying geology mapping of the region encompassing the Study Area were downloaded from Queensland Government Queensland Spatial Catalogue (QSpatial) (http://qldspatial.information.qld.gov.au/catalogue). Digital Atlas of Australian Soils data (1:2,000,000 scale) were downloaded from Australian Soil Resource Information System, CSIRO (http://www.asris.csiro.au/themes/Atlas.html). Australia 1:250,000 Geological Series maps, Bureau of Mineral Resources, Geology and Geophysics, Department of National Development, and Geological Survey of Queensland were downloaded as non-georeferenced images from Queensland Government Department of Natural Resources and Mines via QDEX Data (http://qdexdata.dnrm.qld.gov.au/flamingo/).

Watercourse data were from ‘Watercourse lines - North East Coast drainage division - central section’ published 5/05/2015, although the streamlines within the Study Area were compiled in 2009. The watercourses are connected and flow directed; a sub-type of connector flows through waterbodies to create a linear network for hydrological modelling. Features are attributed with perenniality, Strahler Stream Order, hierarchy (Major or Minor) and names where available. Features were captured or updated from the best available imagery with an attribute within the data describing the source and reliability. Data sources include Queensland ortho-photography, satellite Imagery (SPOT 5), and Geoscience Australia 1:250,000 scale watercourse lines. Features within this dataset have been progressively updated by drainage basin using imagery to 1:25,000 mapping specifications, but only 1:100,000 mapping specifications have been achieved for the Fitzroy basin. This watercourse layer is similar to digital layer ‘Wetland data - version 4 - wetland lines – Queensland’, which ostensibly maps the same watercourses at 1:100,000 scale. The difference is that the wetland lines depict many of the watercourses as discontinuous, and appear to be sourced directly from the Geoscience Australia 1:250,000 topographic map series. Thus, the process of updating maps to a more detailed scale resulted in fewer drainage lines being depicted as discontinuous, which is an important distinction as the Water Act 2000 defines a watercourse as being within a ‘channel’. For the purposes of this Technical Report, the blue lines on the ‘Watercourse lines - North East Coast drainage division - central section’ were all accepted as valid and included in the investigation. LiDAR data, field inspection, and topographically-derived drainage networks generated automatically by algorithms in Geographic Information System (GIS) all suggested the presence of additional or alternative dominant drainage lines in some parts of the Study Area. This was not surprising, especially in the low gradient floodplain areas where, during flood events, it would be expected for water to take paths additional to those indicated on topographic maps. For consistency, only the streams digitally mapped as blue lines at 1:100,000 scale were included for consideration in this Technical Report.

The ‘Queensland Floodplain Assessment Overlay’ (QFAO) represents a floodplain area within drainage sub-basins developed for use by local governments as a potential flood hazard area. It represents an estimate of areas potentially at threat of inundation by flooding, mapped at 1:100,000 scale. The data were developed through a process of drainage sub-basin analysis utilising data sources including 10 metre contours, historical flood records, vegetation and soils mapping and satellite imagery.

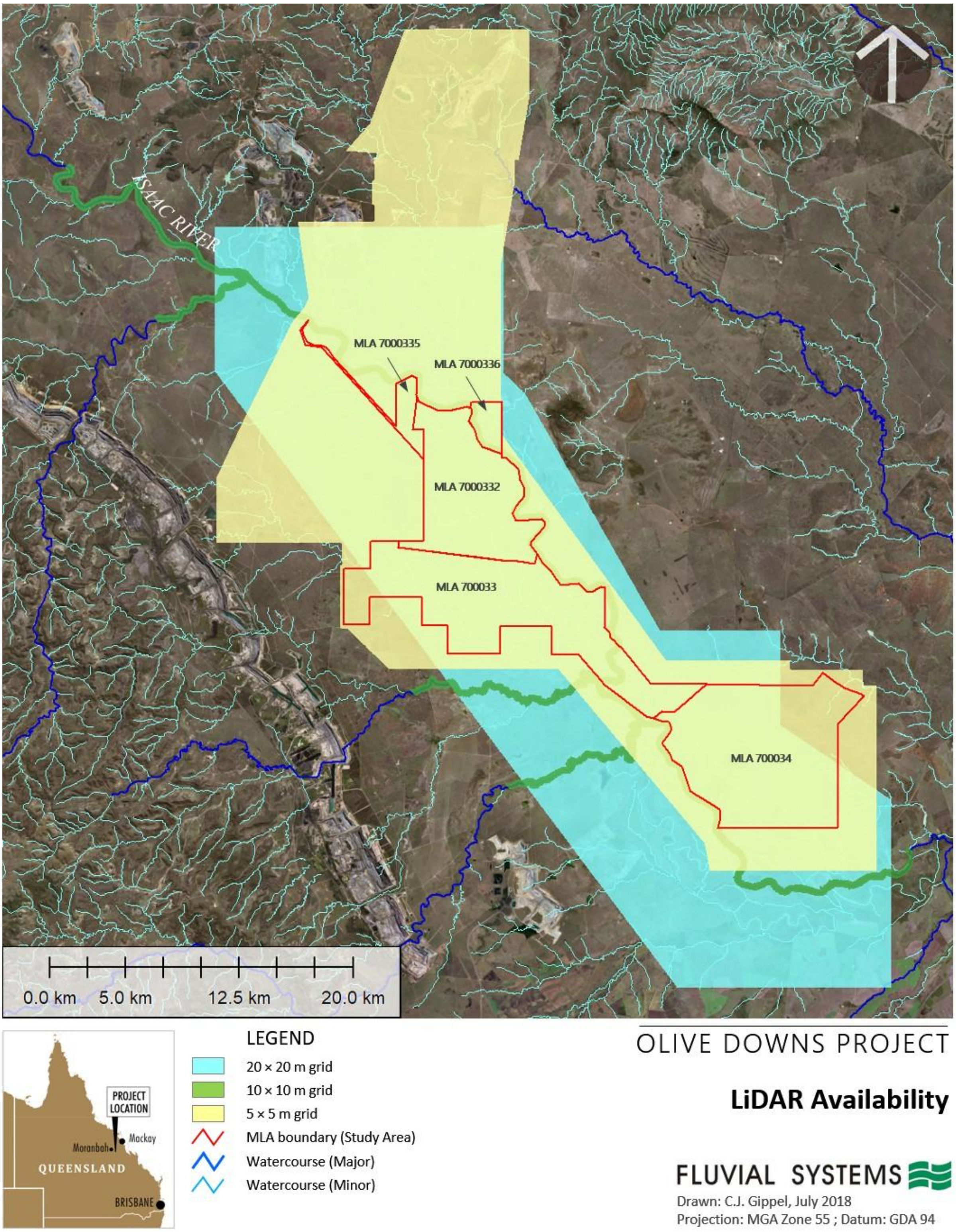


Figure 3. LiDAR data availability for the Study Area.

The Atlas of Australian Soils was compiled by H. Northcote and others of CSIRO in the 1960s to provide a consistent national description of Australia's soils. The maps were published at a scale of 1:2,000,000 but the original compilation was at scales from 1:250,000 to 1:500,000. The Digital Atlas of Australian Soils was created by the National Resource Information Centre (NRIC) in 1991 from scanned tracings of the published hardcopy maps. Mapped units in the Atlas are soil landscapes, usually comprising a number of soil types. The explanatory notes include descriptions of soils landscapes and component soils. Soil classification for the Atlas is based on the Factual Key (Northcote, 1979), which was the most widely used soil classification scheme prior to the Australian Soil Classification (Isbell, 2002). Ashton and McKenzie (2001) developed a conversion of the Atlas of Australian Soils to the Australian Soil Classification which remains unpublished but is available as a table (http://www.asris.csiro.au/themes/Atlas.html). The Australian Government Bioregional Assessment Programme, a collaboration between the Department of the Environment and Energy, the Bureau of Meteorology, CSIRO and Geoscience Australia, used the conversion table to develop the product ‘Spatial Data Conversion of the Atlas of Australian Soils to the Australian Soil Classification v01’, published in 2016. In this Technical Report, soils are mapped using the key soil descriptors of both systems.

Soil erodibility data were from ‘Fitzroy NRM region surface soil erodibility - Central Queensland’, published 24/04/2017. This raster dataset classifies surface soil erodibility on a 90 × 90 m grid at the sub-catchment scale. Soil erodibility is the susceptibility of soils to detachment and transportation by erosive agents. It is a composite expression of those soil properties that affect the behaviour of a soil and is a function of the mechanical, chemical and physical characteristics of the soil. Surface soil stability is categorised into five classes. The higher the number, the greater the erodibility:

0 = Not assessed

1 = Moderately stable surface soils

2 = Non-cohesive surface soils

3 = Dispersive surface soils

4 = Highly erodible surface soils

A related soil erodibility dataset is ‘Fitzroy NRM Region soil erodibility - Central Queensland’. This dataset maps the same variable at the same spatial scale, but includes sub-classes of erodibility, to give a total of 18 classes. This greater level of data resolution would not have provided a significant improvement in information for the purpose of this geomorphological assessment.

Underlying hard rock geology was from ‘Regional geology 1985 - Bowen Basin’, published in 2004. The data provide an interpretation of the extent of rock units underlying regolith, soil or basalt, and the location and type of geological structures which have affected the rock units. Surface geological units, which show Quaternary material, were from Australia 1:250,000 Geological Series. The relevant maps were Clermont Sheet SF 55-11, published 1968, and Saint Lawrence Sheet SF 55-12, published 1970. These two sheets were downloaded as non-georeferenced images covering the full map extents. These images were rectified against lines of latitude and longitude, and then cropped, in GIS.

3.4 Geomorphologically-relevant variables

Two main groups of variables were of interest to geomorphological characterisation of the Study Area:

- Landscape-scale variables
- Stream reach- and point-scale variables

3.4.1 Landscape-scale variables

Landscape-scale variables provide information to help explain catchment-scale geomorphological processes, and risks associated with mining impacts; they also provide contextual information to help explain local-scale physical processes and forms. Information was compiled at the landscape-scale regarding:

- Geology
- Soils
- Topography

3.4.2 Stream reach- and point-scale variables

Stream-reach and point-scale variables were used to characterise geomorphological processes and forms for the purpose of baseline classification of stream type, condition and fragility/resilience to disturbance. Variables were selected mainly on the basis of their relevance to stream classification, potential impacts of open-cut mining on streams, and characterisation to aid stream diversion design.

Fragility is the ease of adjustment of bed material, channel geometry, and channel planform when subjected to degradation or certain threatening activities, and resilience is the property of having low fragility (Cook and Schneider, 2006; Brierley et al., 2011). The determination of stream fragility is based on the adjustment potential of three main characteristics of each geomorphic category. These include the adjustment potential of each category's channel attributes (geometry, size and connection to floodplain), planform (lateral stability, number of channels and sinuosity) and bed character (bedform and bed materials) (Cook and Schneider, 2006). Different stream types have characteristic levels of fragility. Stream types with "Low fragility" are resilient or "unbreakable", those with "Medium fragility" have local adjustment potential, and those with "High fragility" have significant adjustment potential (Cook and Schneider, 2006). Following on from this, the conservation and rehabilitation priority of stream reaches can be determined on the basis of geomorphic fragility and condition. Streams reaches with high fragility and poor condition are rated low priority, while reaches low fragility that are in good geomorphic condition are rated the highest priority for protection.

River Styles® is a system for classifying stream geomorphic type based on valley setting, level of floodplain development, bed materials and reach-scale physical features within the stream (Brierley et al., 2011). The potential for physical recovery after disturbance depends on stream geomorphic condition, whereby streams in good condition (undisturbed and close to natural state) are more likely to be resilient and recover faster than those that are already degraded (Outhet and Cook, 2004; Brierley et al., 2011).

This Geomorphology Technical Report classified the streams in the Study Area according to river type and geomorphic condition, using an approach that was consistent with River Styles®. This required collection of data concerning valley setting, stream slope, channel dimensions and shape, and bed material type.

Geomorphic condition is strongly linked to the degree of naturalness and extent of cover of riparian vegetation (Outhet and Cook, 2004; Outhet and Young, 2004a). These considerations justify the inclusion, in geomorphologic assessments, of variables that characterise riparian and in-channel vegetation and related large woody debris, both of which contribute to the structural stability of streams (Abernethy and Rutherfurd, 2000; Gippel, 1995; Gippel et al., 1996). The influence of vegetation on stream processes declines rapidly with distance from the channel edge. This Geomorphology Technical Report defined the riparian zone as a distance of up to 50 m from the channel edge, which is consistent with that used by Munné et al. (2003) and Raven et al. (1998), and is practical for a rapid assessment approach.

The beds of ephemeral headwater streams are often vegetated with grasses[1] that resist erosion by increasing the inherent shear strength of soils and sediments (Hudson 1971; Tengbeh, 1983; Reid 1989; Prosser and Slade, 1994; Zierholz et al., 2001; Rai and Shrivastva, 2012). Blackham (2006) demonstrated that hydraulic conditions (absolute shear stress and duration of shear stress) in small- to medium-sized streams are rarely sufficient to scour well-grassed surfaces. In larger streams, rooted (especially emergent) macrophytes commonly act as a hydraulic/geomorphic agent in stream channels through their resistance to erosion, ability to trap sediment, and roughness effect (Guscio, 1965; Shih and Rahi, 1982; Groeneveld and French, 1995; Riis and Biggs, 2003; Horvath, 2004; O'Hare et al., 2011). Macrophyte growth is a function of numerous factors, but water flow is known to be a prime factor (Franklin et al., 2008). The effects of flow on macrophytes are usually considered in terms of the hydrological regime (frequency of disturbance and duration of stable flow conditions) and velocity (which is associated with mechanical damage and uprooting). Long periods of stable baseflow may encourage invasion by macrophytes. Periods of low flow can also keep macrophytes in check (Franklin et al., 2008). Both the abundance and diversity of macrophytes are stimulated at low to medium velocities, with growth being restricted at higher velocities (Madsen et al., 2001). Chambers et al. (1991) reported few if any macrophytes were found in waters with velocities exceeding 1 m/s, and Greening Australia (2007) noted that Typha spp. was not found in water deeper than 2 m. In some ephemeral streams trees can become established on the beds. Trees create diversity in hydraulic habitat when the stream is flowing, with the turbulence potentially causing bank erosion and bed scouring. Cover of in-channel vegetation was included in this Geomorphology Technical Report because of its important role in channel stability/instability, hydraulic habitat creation, and its sensitivity to hydrological conditions, which could potentially be impacted by mining.

[1] Meaning true grasses, of the family Poaceae (also called Gramineae).

Pools and riffles are the two habitat elements of streams that have received the most attention from a geomorphological and ecological perspective (Frissell et al., 1986; Maddock, 1999). Pools are commonly a focus of habitat assessments because of their ecological importance, especially as a refuge when streams stop flowing (Bond et al, 2008). Riffles act as hydraulic controls on pools in alluvial streams. Comprehensive mapping of pool and riffle morphology would require sampling and survey at a much more detailed spatial scale than that used in this investigation. Regardless, most of the streams in the Study area were sand bed and therefore lacked pool-riffle morphology. While general pool presence/absence was noted as part of the stream type classification, the field survey did not attempt to measure pool dimensions.

Based on the above considerations, reach- and point-scale variable groups considered relevant to this Geomorphology Technical Report were:

- Stream geomorphic type and condition,
- Riparian and in-channel vegetation,
- Channel slope,
- Channel dimensions, and
- Channel bed materials.

3.4.3 Sites of geomorphological significance

Geomorphological character is, for the most part, value-free in that a stream cannot be ranked in terms of importance based on their geomorphologic character alone. The main relevance of geomorphological character is the implications it has for the ecological character. The exception is geomorphological sites that either represent a specific characteristic of a region, or include an outstanding, rare, or possibly unique geomorphological feature. There is no standard method for classification, or a compiled list, of geomorphologically significant sites in Queensland. No published or anecdotal evidence was found indicating the existence of sites of geomorphological significance within the Study Area.

3.5 Field survey

3.5.1 Sampling approach

The objective of the field survey was to obtain sufficient information to enable characterisation of stream type, and stream geomorphic features. Stream type classification relies partly on attributes that can only be measured in the field, and partly on attributes that can be measured from maps and terrain data.

The objective of the field survey was to sample the range of streams marked by blue lines at 1:100,000 scale by assessing short lengths of representative stream sites. Aerial photography suggested that the Isaac River and major tributaries within the Project area were of consistent geomorphic type over long distances, such that sample site spacing over the orders one to ten kilometres would be adequate.

Like most geomorphic surveys, sampling locations were not chosen randomly due to the high potential for experiencing difficulty in accessing sites. The large size of the Project area deemed foot travel impractical for most areas, and travel by light Four Wheel Drive (4WD) vehicle or All Terrain Vehicle (ATV) was mostly limited to existing tracks. Thus, the general locations of field sites was largely determined by accessibility, while the exact location was subjectively determined as representative of the general reach geomorphic character, and distant from unusual local disturbances, such as vehicle or stock crossings.

The field data were collected within the period 13 to 16 June 2017. All of the measurements, estimates and data recording were made by C.J. Gippel. Data were recorded on a GPS-equipped tablet computer using a specially designed form compiled in ODK (Open Data Kit; http://opendatakit.org/). At each observation point, two photographs were taken with the tablet device, one looking downstream and one looking upstream. Each photograph was linked to the data from the site within the ODK form. For quality assurance purposes, a second set of photographs were taken independently with a GPS-enabled camera and location was also recorded independently using a Garmin etrex 10, set to record a tracklog, as well as manually entered waypoints at the sampled sites. This approach resulted in 54 sets of observations.

3.5.2 Field sampled variables

A comprehensive set of variables was measured at sites in the field (Table 1). In general, the measurements were done using standard techniques from the literature. Most of the observations involved recording presence/absence or measuring a quantity. As previously explained, the presence/absence of pools was noted, but these features were not measured. Exposed bedrock was rare, and so small relative to the scale of the river channel that it had minor impact on geomorphic process and form, so its presence was not recorded.

Table 1 Field measured geomorphologically-relevant variables.

Variable	Description of variable measurement
Flow conditions	Dry or flowing at the time of survey
Channel setting	Longitudinal continuity, number of channels, and degree of valley confinement
Valley shape	Perceived relative relief, shape of valley walls
Chanel shape variability	Strength of variability in form in cross-section and profile, and regularity of form in the downstream bed profile (3 classes each)
Bed material calibre	Presence of, and dominant, material for 7 classes (adapted from Brakensiek et al., 1979): • Mud (silt and clay) • Sand (0.06 - 2 mm) • Gravel (2 - 64 mm) • Cobble (64 - 256 mm) • Boulder (exceed 256 mm) • Exposed bedrock slab • Artificial (hard lined)
Large wood and log jams	Count of items over 20 m length of channel; large wood is ≥0.1 m diameter and ≥1 m long (Gippel, 1995); log jam is 3 or more locked pieces of large wood
Channel dimensions	Bed width, bankfull width, bankfull depth, measured using a rangefinder or tape
In-channel vegetation	Type for 6 classes - 4 macrophyte types, grass and trees - and cover (6 Braun-Blanquet classes)
Width of riparian vegetation	Left and right, up to a maximum of 50 m, measured using rangefinder
Continuity of riparian vegetation	Left and right, downstream continuity along the riparian zone (6 Braun-Blanquet classes)
Composition and cover of riparian vegetation	Left and right, type for 3 classes - tree (woody and >3 m high) shrub (woody) and ground vegetation – and cover within 5 × 5 m plots (6 Braun-Blanquet classes)
Other observations	Any feature not otherwise covered and considered potentially relevant to geomorphologic characterisation or geomorphologic condition

Some variables were quantified using a subjective visual estimation method. These variables included the relative strength of the variability in the channel shape; floodplain size and connectivity with the channel; bed material calibre (visual estimation was regularly calibrated against measurement), and vegetation cover and continuity. While error can be expected in such estimates, it was minimised by using the same experienced observer for every estimate and conducting the fieldwork over one relatively short period of time.

Vegetation cover and continuity were estimated using the Braun-Blanquet rank scale, which provides a rapid, robust and repeatable estimate of cover abundance (Wikum and Shanholtzer, 1978). Cover refers to foliar projective cover of the ground. The Braun-Blanquet scale was the same as the original, except that the lowest class was sub-divided to provide a class (<1% cover) to describe the situation where cover was essentially absent, as used by Causton (1988):

- <1% score = 0
- 1 – 5% score = 1
- >5 – 25% score = 2
- >25 – 50% score = 3
- >50 – 75% score = 4
- >75% score = 5

3.5.3 Derived riparian vegetation cover index

Riparian vegetation cover index derived from the raw field-collected data. At each sampling site, the cover abundances of riparian trees, T, shrubs, S, and ground cover, G, were rapidly estimated at plots approximately 5 × 5 m in size, with cover scored as an integer from 0 to 5 on the Braun-Blanquet rank scale. Vegetation cover of the left and right sides of the channel were measured separately.

A cover index was devised to rate both the degree of coverage of the ground by plants, and the vegetation structure. A high degree of cover was rated higher than a low degree of cover, and trees were rated more valuable than shrubs, and shrubs rated more valuable than ground cover. The coverage rating was based on the higher geomorphic stability, habitat availability, and energy and nutrients provided by greater plant abundance. The plant structure rating was based on the different capacity of trees, shrubs and ground cover to provide these same services, as well as the additional ability of trees to provide shade. For each plot, the raw cover abundance scores for trees, shrubs and ground cover were factored and summed, and then converted to a riparian cover abundance (C) score between 0 and 1 by dividing the total by 24.

$$C = \frac{3T+2S+G}{24} \quad (1)$$

An index score of at least 1.0 would be achieved if tree, shrub and ground cover were all in the 50 – 75% or >75% cover classes. A very well vegetated site might achieve a combined factored score exceeding 1.0, in which case the score would be rounded down to 1.0. The index scores were converted to combined cover classes equivalent to the classes used to collect the original data (Figure 4).

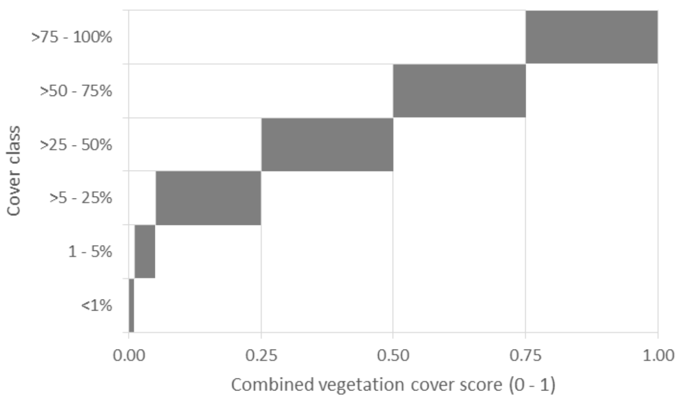


Figure 4. Scale for conversion of combined riparian vegetation cover index score to class.

3.5.4 Descriptive statistics

The field-collected data were described using descriptive statistics, including, mean, standard deviation, median, sum and count of data, and sum of a subset of data, or count of a subset of data, as a percentage of the total.

3.6 Terrain analysis

Geomorphology is concerned with both physical form and process. Process involves the dimension of time, so tends to be more difficult to measure and model than form. For this reason, geomorphologic assessments often interpret process on the basis of an analysis of physical form. Terrain analysis is concerned with the automated analysis of landforms using digital elevation data sets. The analysis involves application of algorithms within a GIS (Geographic Information System) at detailed scales over wide areas to map characteristics of interest (e.g. Gardner and Sawowsky, 1990; Wilson and Gallant, 1998; Wilson and Gallant, 2000; Lindsay, 2005; Drăguţ and Blaschke, 2006; MacMillan and Shary, 2009).

Terrain analysis was undertaken using two different GIS applications: Global Mapper™ V15.2.5 25 June 2014 Build (Blue Marble Geographics), and SAGA (System for Automated Geoscientific Analyses) GIS (http://www.saga-gis.org; Institute of Geography, Section for Physical Geography, Klimacampus and University of Hamburg, Germany) (Cimmery, 2007-2010; Böhner et al., 2006; Böhner et al., 2008).

3.6.1 Topography (digital elevation) definition

The topography of the Study Area was defined by a 5 × 5 m DEM derived from the supplied LiDAR data. For areas beyond the bounds of the LiDAR coverage, the DEM was extended using SRTM data. The classification of landforms is conventionally done at a coarser scale, so for this procedure a 25 × 25 m DEM was used.

3.6.2 Strahler Stream Order

Stream order was assigned according to the Strahler system, whereby a headwater stream is Order 1, and the order increases by 1 when a stream of a given order meets one of the same order. Stream order was an attribute provided for all stream links in the 1:100,000 digital watercourse dataset, but it contained numerous errors, mainly with Order 1 and Order 2 stream links, a large number of which were assigned Order 0, which is invalid. These errors were corrected for all stream links within the entire Isaac River catchment upstream of Stephens Creek.

3.6.3 Sub-catchment area

Sub-catchment areas were determined for the entire Isaac River catchment upstream of Stephens Creek, which joins the river downstream of the Study Area, using the ‘Generate Watershed’ function of Global Mapper™. This function uses the standard 8-direction pour point algorithm (D-8) (Jenson and Domingue, 1988) to generate a drainage network from the DEM. Depressions in the DEM were first filled to a depth of 7 m, then drainage was generated using parameter settings of minimum stream length 500 m and minimum sub-catchment area 2 km^2. This drainage network was intended to emulate that of the 1:100,000 blue line network, but differed in some areas with respect to stream length and position. These differences were unimportant as the DEM-derived drainage network was not used in the assessment, and the associated sub-catchment areas were an acceptable representation of the areas draining to the blue line network.

3.6.4 Slope

Slope was evaluated for the entire Study Area at 5 × 5 m resolution, and also along individual stream links, by sampling the grid along the channel thalweg at a 5 m spacing.

3.6.5 Landform Classification

One determinant of stream type classification is its landscape context, which is informed by landform classification. A number of different methods have been proposed for classifying landforms based on topographic data (e.g. Schmidt and Hewitt, 2004; Iwahashi and Pike, 2007; Niculiță and Niculiță, 2011). Landform classification can provide objective assistance to stream type classification, and to delineate hydrologic and geomorphic units such as valley bottoms (also known as floodplains, or alluvium) (Gallant and Dowling, 2003). The objectivity of automatic identification of floodplain extent is an advantage over subjective methods, although manual methods that combine hydraulic, slope and soils data can produce a rational and defendable result and might be preferred in cases where high quality and high resolution data are available.

In this report three methods of landform classification, all implemented in SAGA GIS, were investigated. Methods of landform classification are very scale-dependent, being sensitive to the resolution of the DEM and the algorithm parameter settings, so reproduction of the results reported in this Technical Report requires the same input data and parameter settings to be used.

Topographic Position Index (TPI) was proposed by Guisan et al. (1999) and elaborated by Weiss (2001). The algorithm calculates the difference between a cell elevation value and the average elevation of the neighbourhood around that cell to classify landforms belonging to a total of up to 10 classes. Positive values mean the cell is higher than its surroundings while negative values mean it is lower. The degree to which it is higher or lower, plus the slope of the cell, can be used to classify the cell into slope position. If it is significantly higher than the surrounding neighbourhood, then it is likely to be at or near the top of a hill or ridge. Significantly low values suggest the cell is at or near the bottom of a valley. TPI values near zero could mean either a flat area or a mid-slope area, so the cell slope can be used to distinguish the two (Jenness, 2006). An example application of TPI to landform classification in the Carpathian Mountains, Slovakia can be found in Barka et al. (2011).

Terrain Surface Classification (TSC) was proposed by Iwahashi and Pike (2007). The TSC algorithm uses elevation, slope, convexity and surface texture to classify landforms belonging to a total of up to 16 classes

The TPI and TSC are global landform classification systems devised for universal application to any terrain. Within a small area of moderate gradient and elevation range such as the Study Area, only a subset of the maximum possible landform classes would be expected to be present.

Multiresolution index of valley bottom flatness (MRVBF) was proposed by Gallant and Dowling (2003) mainly as a tool to assist in the objective separation of floodplains from their surrounding hillslopes. The algorithm uses the two terrain attributes slope and elevation percentile. Slope is computed as a percentage or 100 times the tangent of the slope angle. Elevation percentile is a ranking of the elevation of a grid point with respect to the surrounding cells in a circular region of user-specified radius. It is calculated as the ratio of the number of points of lower elevation to the total number of points in the surrounding region. Low values indicate the point is low in the local landscape since most of the surrounding points are higher. The MRVBF algorithm was developed using 25 m resolution DEMs. According to Gallant and Dowling (2003), values of MRVBF less than 0.5 are not valley bottom areas; values from 0.5 to 1.5 are considered to be the steepest and smallest resolvable valley bottoms for 25 m DEMs; flatter and larger valley bottoms are represented by values from 1.5 to 2.5, 2.5 to 3.5, and so on. Thus, there is no absolute threshold of MRVBF that unequivocally identifies a valley bottom, or floodplain, for all situations.

3.7 Stream geomorphic type and condition

3.7.1 Stream geomorphic type classification

The geomorphic stream type classification used here borrowed from, and is consistent with, the River Styles® framework (Brierley and Fryirs, 2000; Brierley and Fryirs, 2005; Brierley and Fryirs, 2006; Fryirs and Brierley, 2006). The River Styles® classification is based on valley setting (whether confined partly-confined or unconfined), level of floodplain development, bed materials and reach-scale physical features within the stream. The classification is largely subjective, based on a mix of topographic map and aerial photograph interpretation, supported by limited field inspection. Some quasi-objective criterion are used. One example is the separation of rivers into low sinuosity and meandering by the threshold of 1.3 for stream length divided by valley length.

The River Styles® framework was designed to cover all Australian stream types, and it is normally applied over the basin or regional scale, with most mapped streams being Order 3 or higher. Across regions or basins a range of different styles would be expected. Most of the styles apply to partly confined and unconfined (i.e. alluvial/lowland) valley settings where streams are relatively large and feature many distinctive units such as levees, pools and riffles, bars, islands, benches, cutoff channels, backswamps, wetlands and floodplains. The streams classed Major in the 1:100,000 Watercourse layer suit this classification system but small-scale Minor streams can be difficult to categorise using this system.

Stream type classification in the Study Area was done on the basis of field-collected data, aerial photography and terrain data for surveyed stream links. The subjective nature of classifying stream reaches into geomorphic types (or River Styles®) means that the procedure is uncertain and unlikely to be highly repeatable.

3.7.2 Stream geomorphic condition classification

Outhet and Cook (2004) defined geomorphic condition of a reach as:

> "*the capacity of a river to perform the biophysical functions that are expected for that river type within the valley setting that it occupies*"

Geomorphic condition relates primarily to the connections and linkages with the floodplain, reaches up and downstream and more importantly, assesses the effect of human disturbance on the current evolutionary stage (Cook and Schneider, 2006). For use in River Styles® assessments, Outhet and Cook (2004) classified geomorphic condition in according to three categories, with each having a number of identifying characteristics (Table 2).

Table 2 Categories of stream geomorphic condition defined by Outhet and Cook (2004). The term "Style" is equivalent to the term "stream type" used in this Geomorphology Technical Report. Some additions were made to the descriptions to suit the assessment (in italics).

Geomorphic condition	Description
Good condition Stream exhibits all of these characteristics	• River character and behaviour fits the natural setting, presenting a high potential for ecological diversity, similar to the pre-development intact state. • There is no general bed incision or aggradation. The reach has already recovered from major natural and human disturbances and has adjusted to the present flow regime. It has stopped evolving and has adjusted to prevailing catchment boundary conditions. • The patterns and forms of the geomorphic units are typical for the Style. • The Style is consistent with the natural setting and controls. • The reach has self-adjusting river forms and processes, allowing fast recovery from natural and human disturbance. • There is intact and effective vegetation coverage relative to the reference reaches, giving resistance to natural disturbance and accelerated erosion. • The reach has all good condition attributes without artificial controls.
Moderate condition Stream exhibits one or more of these characteristics	• Localised degradation of river character and behaviour, typically marked by modified <u>patterns</u> of geomorphic units. • Degraded <u>forms</u> of geomorphic units, as marked by, for example, inappropriate grain size distribution. • Patchy effective vegetation coverage relative to the reference reaches (allowing some localised accelerated erosion).
Poor condition Stream exhibits one or more of these characteristics	• Abnormal or accelerated geomorphic instability (reaches are prone to accelerated and/or inappropriate patterns or rates of planform change and/or bank and bed erosion). • Excessively high volumes of coarse bedload which blanket the bed, reducing flow diversity. • Absent or geomorphically ineffective coverage by vegetation relative to the reference reaches (allowing most locations to have accelerated rates of erosion) or the reach is weed infested.

3.8 Impact assessment

3.8.1 Types of geomorphic response (event type) to mining related changes

There are four main mining-related agents of change that could cause an impact on geomorphological processes and forms in the Study Area:

- Removal of a stream channel and its catchment
- Removal of part of a stream, requiring diversion of the stream around the pit
- Hydrological change in the distribution of stream flows
- Hydraulic change, whereby alteration of the channel or floodplain morphology causes a change in bed shear stress, velocity and water depth, which in turn could alter sediment transport, and bed and bank erosion processes.

These potential agents of change could bring about a number of generic geomorphic responses (Table 3) that would constitute an environmental impact with possible implications for environmental values. Some of these risks were assessed directly or indirectly by other relevant technical specialists (see other technical specialists reports for details).

Table 3 Potential generic geomorphic responses to open cut mining-related causes.

Potential geomorphic response (event type)	Mining-related risks (see below for explanation)
1. Change in stream type, irreversible over management time scales (< 100 years)	1, 2
2. Change of alignment of channel	2
3. Simplification of channel morphology and habitat-scale hydraulics	2
4. Increase in sediment accumulation in channel bed	4, 5
5. Increase in sediment scouring in channel bed	3, 5
6. Increase in rate, or change in location, of bank erosion	5
7. Increase in rate of floodplain scour	3
8. Increase in cover (density) of vegetation on channel bed (baseflow shift from high depth of water to shallow depth)	4, 6
9. Decrease in cover (density) of vegetation on channel bed (baseflow shift from shallow depth of water to dry, or from shallow to deep)	4, 5, 6

Open cut mining related causes:

1. Removal of part or all of a stream channel and its catchment due to excavation of pit
2. Stream diversion construction to replace removed stream channel
3. Loss of active floodplain area due to excavation of pit
4. Decrease in stream flow due to artificially reduced catchment area
5. Increase in stream flow due to artificially increased catchment area
6. Management of natural surface water inflows and outflows from the mine site

The flood study undertaken by Hatch (2018) assessed the impacts of hydrological change in the distribution of stream flows, and management of natural surface water inflows and outflows from the mine site. In particular, Hatch (2018) addressed the design, and assessment of the impact, of the proposed diversion of Ripstone Creek. These potential risks are not further considered in this report. The main focus of geomorphic impact assessment in this Geomorphology Technical Report was on the potential for hydraulic change, whereby alteration of the Isaac River floodplain morphology could cause a change in bed shear stress, velocity and water depth, which in turn could alter sediment transport, and bed and bank erosion processes.

3.8.2 Method of maximum permissible velocity

Chow (1981, p. 164) noted that:

> "*The behavior of flow in an erodible channel is influenced by so many physical factors and by field conditions so complex and uncertain that precise design of such channels at the present stage of knowledge is beyond the realm of theory*."

Since that time there have been developments in the level of sophistication of river channel modelling capacity, but there have been no major advancements in relevant theory. The methodology used in this assessment is the traditional one, as described in Chow (1981, pp. 164-191) and other popular channel hydraulics texts. The two methods that have been most commonly applied to this type of problem are the:

- method of permissible velocity, and
- method of bed shear stress (also known as tractive force)

It is important to realize that while these approaches have been applied extensively in the river engineering industry throughout the world for decades, like all empirically based approaches, they remain subject to uncertainty.

The maximum permissible velocity (U_{max}) is the greatest mean channel velocity (U) that will not cause erosion of the channel body. A channel is stable when:

$$U < U_{max}$$

Chow (1981, p. 165) noted that maximum permissible velocity is "*very uncertain and variable*". When other conditions are the same, a deeper channel will convey water at a higher mean velocity than a shallow one. This is because the scouring is related to bottom velocities, which for the same mean velocity, are higher in the shallow channel. Tables of maximum permissible velocity appear in many channel design, engineering and hydraulics publications (e.g. Chang, 1988), and they are all based on values for canals given by Fortier and Scoby (1926), and from the USSR (Anon, 1936), although some agencies have adjusted these standard values on the basis of local empirical knowledge (e.g. Stallings, 1999) (Table 4).

Chow (1981) did not define what was meant by "*water transporting fine suspended solids*", but it would appear from Ritzema (1994, p. 769) that this refers only to very high concentrations of suspended solids, in the order of >20,000 mg/L, while the term 'clear water' essential means water with concentrations of suspended solids <1,000 mg/L. 'Clear water' would apply in nearly all situations in Australia.

The values given in Table 4 assume a bare channel surface (i.e. no grass or other lining or vegetation). Vegetation failure usually occurs at much higher levels of flow intensity than for soil (Fischenich, 2001) (Table 5, Table 6). The values given in Table 5 and Table 6 are average values for channels, and assume a reasonable depth of flow. In shallow flow situations, as would generally occur on floodplains, it is reasonable to assume that surfaces covered with sod forming grass would generally tolerate velocities of up to 2 m/s.

Flows with long durations often have a more significant effect on erosion than short-lived flows of higher magnitude (Fischenich and Allen, 2000, p. 2-23). Fischenich (2001, p. 6) recommended application of a factor of safety to U_{max} "*when flow duration exceeds a couple of hours*". Graphs are provided in Fischenich (2001) for factoring according to event duration (Figure 5). The duration of flood events naturally varies, although in general the higher the magnitude, the longer is the duration. The relationships imply that the maximum permissible velocity could be very low if the curves asymptote to zero velocity. Of course, the suggestion of a zero maximum permissible velocity is a contradiction in terms, but this raises the idea that there is no such thing as a maximum permissible velocity below which erosion does not occur (Chow, 1981, p. 166).

Anon (1936) gave correction factors for U_{max} for channels greater than 1 m deep (factor >1), and less than 1 m deep (factor <1). A factor of 0.8 would apply to flow 0.25 m deep, 0.9 would apply to flow 0.5 m deep, 1.1 would apply to flow 1.5 m deep, and 1.2 would apply to flow 2.5 m deep. The maximum factor plotted on the graph is 1.3, which would apply to flow 4 m deep. Extrapolation using a power function suggests a correction factor of 1.4 for flow 6 m deep, 1.5 for flow 8.5 m deep, and 1.6 for flow 12 m deep.

Tabulated values of U_{max} are for straight channels, and for sinuous channels U_{max} should be reduced. Lane (1955) recommended reductions in U_{max} of 5% for slightly sinuous channels, 13% for moderately sinuous channels, and 22% for very sinuous channels.

Table 4. Maximum permissible velocities for channels formed in a range of materials. Assumes a flow depth of 1 metre. Note: no vegetative cover.

Bed material (USDA soil description)	Maximum permissible velocity (m/s)		
	Clear water[3]	Water transporting fine suspended solids[3]	Values used in Virginia (USA)[4]
Ordinary firm loam[1]	0.8	1.1	0.9
Stiff clay, very colloidal[2]	1.1	1.5	1.0
Alluvial silts, colloidal	1.1	1.5	-
Alluvial silts, non-colloidal	0.6	1.1	-
Sandy loam, non-colloidal	0.5	0.8	-
Fine gravel	0.8	1.5	-

1. Plastic clay soil; mixture of clay, sand, and/or gravel, with minimum fines (silt and clay) content of 36% (Stallings, 1999).

2. Moderately to highly plastic clay; mixtures of clay, sand, and/or gravel, with minimum clay content of 36% (Stallings, 1999).

3. Fortier and Scoby (1926) – see Chow (1981, p. 165). The term 'clear water' essentially means water with concentrations of suspended solids <1,000 mg/L (Ritzema, 1994).

4. Stallings (1999).

Table 5. Maximum permissible velocities for channels with slopes of 0 – 5% in easily eroded soils lined with grass (assume average, uniform stands of each type of cover). Source: Adapted from Chow (1981, p. 185), using data from the U.S. Soil Conservation Service.

Cover	Maximum permissible velocity (m/s)
Sod forming grass: *Cynodon dactylon* (Bermuda grass)	1.8
Sod forming grass: *Bouteloua dactyloides* (Buffalo grass), *Poa pratensis* (Kentucky bluegrass), *Bromus inermis* (smooth broome), *Bouteloua gracilis* (blue grama)	1.5
Grass mixture	1.2
Bunch grass: *Lespedeza cuneate* (Chinese bushclover or Sericea lespedeza), *Eragrostis curvula* (African, or weeping love grass), *Bothriochloa ischaemum* (yellow bluestem), *Pueraria lobata* (kudzu), *Medicago sativa* (alfalfa or lucerne), Digitaria (crabgrass)	0.8
Annuals	0.8

Table 6. Maximum permissible velocities for channels lined with grass. Source: Fischenich (2001) using data from various sources.

Cover	Maximum permissible velocity (m/s)
Class A turf	1.8 – 2.4
Class B turf	1.2 – 2.1
Class C turf	1.1
Long native grasses (U.S.A.)	1.2 – 1.8
Short native grasses (U.S.A.)	0.9 – 1.2

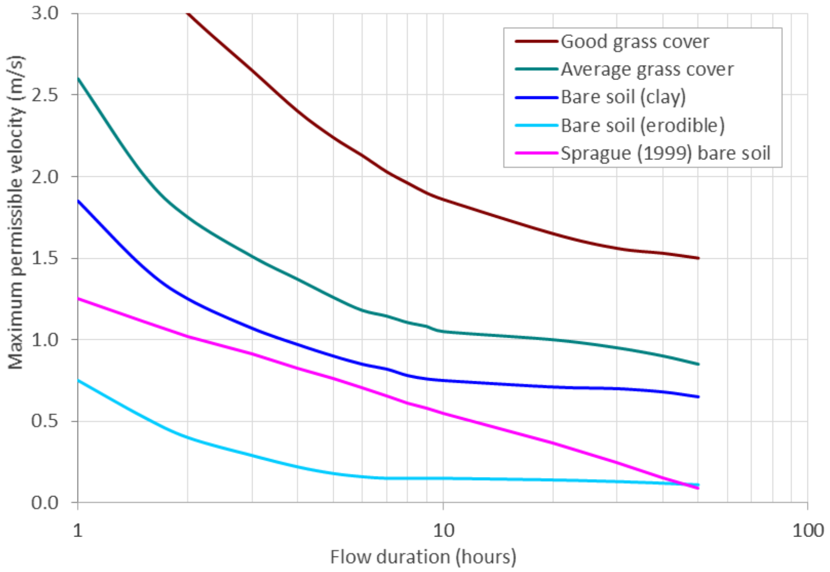


Figure 5. Erosion limits as a function of flow duration. Based on a plots from Fischenich (2001, p. 6) and Sprague (1999).

3.8.3 Method of maximum permissible bed shear stress

Mean bed shear stress (N/m^2) (τ) is:

$$\tau = \rho g R S$$

where,

R = hydraulic radius of the channel, equal to A/P where A is the cross-sectional area of the flow, and P is the length of the wetted perimeter; in a spatial flood model R of a cell can be represented by water depth at the cell (m).

S = the energy slope of the water; in a spatial flood model S can be approximated by the water surface slope at the cell (m/m).

ρ = the density of the water (usually assumed to be 1,000 kg/m^3)

g = the acceleration due to gravity (9.8 m/s^2)

Maximum permissible shear stress (τ_{max}) is the maximum unit shear stress (τ) that will not cause serious erosion of the channel.

A channel is stable when:

$$\tau < \tau_{max}$$

Tables of maximum permissible shear stress appear in many channel design, engineering and hydraulics publications (e.g. Chow, 1981; Chang, 1988), and they are all based on values given by the U.S. Bureau of Reclamation (Lane, 1952; Carter, 1953) (Table 7).

When soil is covered by vegetation its resistance to scour is considerably enhanced (Table 8 and Table 9). A critical shear stress in the range 100 – 200 N/m^2 is a reasonable guide to the shear stress required to remove typical native or pasture grass cover found on floodplains and hence initiate stripping of the floodplain surface.

Tabulated values of maximum permissible shear stress are for straight channels, and for sinuous channels the maximum permissible shear stress should be reduced. Lane (1955) recommended reductions of 10% for slightly sinuous channels, 25% for moderately sinuous channels, and 40% for very sinuous channels.

It should be noted that unit bed shear stress is not uniformly distributed along the wetted perimeter. Computed values of shear stress based on average cross-section conditions may be adjusted to account for local variability and instantaneous values higher than mean (Fischenich, 2001). A number of procedures exist for this purpose. Most commonly applied are empirical methods based upon channel form and irregularity. According to Chow (1981, p. 170), for trapezoidal channels, the maximum shear stress on the sides of a channel is close to $0.76\ \tau$. Fischenich (2001) recommended that for straight channels, the local maximum shear stress can be assumed to be $1.5\ \tau$.

Table 7. Maximum permissible bed shear stress for channels formed in fine-grained material. Note: no vegetative cover.

Bed material (USDA soil description)	Maximum permissible shear stress (N/m^2)	
	Clear water[3]	Water transporting fine suspended solids[3]
Ordinary firm loam[1]	3.6	7.2
Stiff clay, very colloidal[2]	12.5	22.0
Alluvial silts, colloidal	12.5	22.0
Alluvial silts, non-colloidal	2.3	7.2
Sandy loam, non-colloidal	1.8	3.6
Fine gravel	3.6	15.3

1. Plastic clay soil; mixture of clay, sand, and/or gravel, with minimum fines (silt and clay) content of 36% (Stallings, 1999).

2. Moderately to highly plastic clay; mixtures of clay, sand, and/or gravel, with minimum clay content of 36% (Stallings, 1999).

3. Chow (1981, p. 165). The term 'clear water' essentially means water with concentrations of suspended solids <1,000 mg/L (Ritzema, 1994).

Table 8. Maximum permissible shear stress for channels lined with grass. Source: Fischenich (2001) using data from various sources.

Cover	Maximum permissible shear stress (N/m^2)
Class A turf	177
Class B turf	101
Class C turf	48
Long native grasses (U.S.A.)	57 – 81
Short native grasses (U.S.A.)	34 – 45

Temporal variations in bed shear stress occur in turbulent flows, and these can be 10 – 20% higher than the mean value. Fischenich (2001) suggested that computed bed shear stress values be adjusted by factor of 1.15.

Bed shear stress is higher in sinuous reaches than in straight reaches. Simple 1-D hydraulic modeling such as HEC-RAS does not usually account for this, so Fischenich (2001) suggested an adjustment be made to the computed bed shear stress values, to calculate the maximum shear stress on the bend (τ_{bend}) as a function of the planform characteristics:

$$\tau_{bend} = 2.65\tau(R_c/W)^{-0.5}$$

where R_c is the radius of curvature and W is the top width of the channel. When assessing channel stability, the computed shear stress values do not need to be adjusted for sinuosity in this way if a sinuosity correction factor is applied to the maximum permissible shear stress value, as described previously (i.e. either approach can be applied to a case, but not both).

Table 9. Summary table of threshold shear stress for erosion of vegetated surfaces from various studies. Source: modified from Blackham (2006).

Vegetation type	Erosion threshold (N/m^2)
Aquatic (swampy) vegetation (Prosser and Slade, 1994)	105
Tussock and sedge (Prosser and Slade, 1994)	240
Disturbed tussock and sedge (Prosser and Slade, 1994)	180
Bunch grass† 20 - 25 cm high (Prosser et al., 1995)	184
Bunch grass† 2 - 4 cm high (Prosser et al., 1995)	104
Bunch grass† (Hudson, 1971)	80 – 170*
Bunch grass† [Ree, 1949 in (Reid, 1989)]	80 – 90*
Cynodon dactylon (Bermuda grass) (Hudson, 1971)	110 – 200*
Cynodon dactylon (Bermuda grass) [Ree, 1949 in (Reid, 1989)]	120 – 180*
Bouteloua dactyloides (Buffalo grass), *Poa pratensis* (Kentucky bluegrass) (Hudson, 1971)	110 – 200*
Bouteloua dactyloides (Buffalo grass [Ree, 1949 in (Reid, 1989)]	110 – 180*

† Any of various grasses of many genera that grow in tufts or clumps rather than forming a sod or mat.

* These ranges summarise data for a variety of soil types/hillslopes. See Reid (1989) and Hudson (1971) for more details.

3.8.4 Australian Coal Association Research Program (ACARP) design criteria for stream diversion design in the Bowen Basin

ACARP guidelines for diversion design were based on the findings of a series of research projects conducted between 1999 and 2002 on performance of existing diversions (White et al., 2014). One of the elements of the ACARP guidelines often used for diversion design is a table of hydraulic criteria. The criteria form part of the Department of Natural Resources and Mines (2014) guidelines for diversions.

The table of hydraulic design criteria in DNRM (2014, p. 33) is reproduced here (Table 10). The reference cited for the critical hydraulic values provided by DNRM (2014) was Hardie and Lucas (2002).

A similar table of criteria was provided in SKM (2009). Parsons Brinkerhoff (2010) and Kellogg Brown & Root (2013) (Table 11), quoting the source as Hardie and Lucas (2002) [also referred to as ACARP (2002)] and/or Vernon (2008) [also referred to as DERM (2008) and a later version as DERM (2011)]. The table differs from that provided by DNRM (2014) (Table 10) in values for stream power and bed shear stress for the 50 year ARI flood.

A third table of criteria was provided by White et al. (2014), also citing Hardie and Lucas (2002) as the source. This table was referred to by White et al. (2014) as "*(…ACARP design criteria)…adopted by Queensland regulators in 2002*". In this case, differing sets of criteria were provided for the three different stream types incised, limited capacity and partly bedrock controlled (Table 12). While 'incised' and 'partially bedrock controlled' have conventional meanings with respect to geomorphic stream type, White et al. (2014) did not define the meaning of 'limited capacity'. 'Capacity' could refer to sediment transport or discharge, or both, and the term 'limited' is relative. The criteria values suggest 'limited capacity' refers to channels on the lower end of the energy spectrum and relatively small in size relative to their flood discharge magnitudes, but they could also be of an expected size with high roughness.

Table 10. Guideline values for average stream powers, velocity and shear stresses for streams within the Bowen Basin. Source: DNRM (2014, p. 33).

Flood scenario	Stream power (W/m^2)	Velocity (m/s)	Bed shear stress (N/m^2)
2 year ARI (no vegetation)	<35	<1.0	<40
2 year ARI (vegetated)	<60	<1.5	<40
50 year ARI	<150	<2.5	<50

Table 11. Guideline values for average stream powers, velocity and shear stresses for streams within the Bowen Basin. Source: Vernon (2008).

Flood scenario	Stream power (W/m^2)	Velocity (m/s)	Bed shear stress (N/m^2)
2 year ARI (no vegetation)	<35	<1.0	<40
2 year ARI (vegetated)	<60	<1.5	<40
50 year ARI	<220	<2.5	<80

Table 12. Typical values for dependent variables identified for sample stream reaches; ACARP design criteria adopted by Queensland Government in 2002. Source: White et al. (2014).

Stream type/ Flood scenario	Stream power (W/m^2)	Velocity (m/s)	Bed shear stress (N/m^2)
Incised			
2 year ARI	20 - 60	1.0 – 1.5	<40
50 year ARI	50 - 150	1.5 – 2.5	<100
Limited capacity			
2 year ARI	<60	0.5 – 1.1	<40
50 year ARI	<100	0.9 – 1.5	<50
Bedrock controlled			
2 year ARI	50 - 100	1.3 – 1.8	<55
50 year ARI	100 - 350	2.0 – 3.0	<120

The ACARP guidelines are similar to the criteria recommended by the maximum permissible velocity method. The maximum permissible velocity for a stable unvegetated channel ranges from 0.5 – 1.1 m/s depending on soil type, and 0.8 – 2.4 m/s for vegetated surfaces, although lower values would be appropriate for long duration floods. ACARP guidelines recommended maximum velocities for the 2 year ARI event of 1.0 m/s for unvegeted channels and 1.5 m/s for vegetated surfaces. ACARP recommended a higher tolerable velocity of 2.5 m/s for the 50 year ARI event, whether vegetated or not. Allowing a higher limit of velocity for the larger 50 year ARI flood, even though its longer duration would present a higher risk of channel erosion, was presumably related to the infrequent occurrence of such events. Either the impacts of these large events were not observed in the investigations used to formulate the criteria, or a risk approach was taken, whereby the higher consequence of a 50 year ARI flood was traded for its lower likelihood.

The maximum permissible bed shear stress for a stable unvegetated channel ranges from 2 – 13 N/m^2 depending on soil type, and 30 - 240 N/m^2 for vegetated surfaces, although lower values would be appropriate for long duration floods. ACARP guidelines recommended maximum bed shear stress of 40 N/m^2 for the 2 year ARI event and 50 or 80 N/m^2 for the 50 year ARI event, and these limits apply to both vegetated and unvegetated channels. It seems inconsistent to specify the same thresholds for bed shear stress for vegetated and unvegetated channels when it is well established in the literature that vegetation cover markedly increases resistance to scour and sediment transport.

3.8.5 Erosion risk criteria for bed shear stress and velocity for the Isaac River in the Study Area

Floodplain soils and bank sediments of the Isaac River are sandy loams. Unvegetated ‘Sandy loam, non-colloidal’ has maximum permissible velocity of 0.5 m/s (Table 4). Correction for slight sinuosity using the method of Lane (1955) requires reduction by 5%, to give a maximum permissible velocity of 0.48 m/s. This threshold would fall to around 0.2 m/s for flood durations exceeding 5 hours. Well-vegetated floodplain surfaces should be expected to tolerate velocities of at least 2 m/s without initiation of scour. This would apply for flood durations of 2 – 7 hours.

‘Sandy loam, non-colloidal’ has maximum permissible shear stress of 1.8 N/m^2 (Table 7). Correction for slight sinuosity using the method of Lane (1955) requires reduction by 10%, to give a maximum permissible shear stress of 1.6 N/m^2. Well-vegetated floodplain surfaces should be expected to tolerate shear stresses of 100 N/m^2 to 200 N/m^2 without initiation of scour.

Based on information from the literature and local soil type, values of maximum permissible velocity and bed shear stress were assigned to risk categories for initiation of fluvial scour of floodplain soils in the Study Area (Table 13). The maximum permissible velocity and bed shear stress methods, like the ACARP guidelines, specify thresholds of hydraulic criteria that should be interpreted as mean velocities within a defined cross-sectional area, either on a floodplain or within a channel. Higher values would be tolerable for brief periods, or in parts of the cross-section. These thresholds should not be interpreted to mean that there is a single value of velocity or bed shear stress below which a channel is morphologically absolutely stable. These thresholds implicitly integrate what would conventionally be considered categories of risk of scour over management time scales.

Table 13. Risk categories of maximum permissible velocity and bed shear stress for initiation of fluvial scour of river bank and floodplain soils in the Isaac River in the Study Area. These hydraulic criteria are mean cross-sectional values.

Risk of initiation of scour	Bank and floodplain (well-vegetated)		Bank and floodplain (exposed soil)	
	Shear stress (N/m^2)	Velocity (m/s)	Shear stress (N/m^2)	Velocity (m/s)
Low	< 100	< 2.0	< 1.6	< 0.48
Moderate	101 – 200	2.1 – 4.0	1.7 – 4.0	0.48 – 1.0
High	> 200	> 4.0	> 4.0	> 1.0

4.0 Existing environment

4.1 Landscape-scale characteristics

4.1.1 Catchment topography

The Study Area lies within the Isaac River catchment down to its junction with Stephens Creek, a total area of approximately 6,407 km^2 (Figure 6). Within this catchment, land surface elevation ranges from 131 m to 697 mAHD. The Study Area lies within the lowland topographic zone of the catchment, with an elevation range of 150 m to 208 mAHD.

4.1.2 Drainage system

The Isaac River is an Order 6 watercourse at its junction with Stephens Creek, another Order 6 watercourse, below which it is an Order 7 watercourse (Figure 8). Isaac River catchment has a high stream density in the northern and western headwater areas. The lowland zone, in which the Study Area is situated, has a low stream density. Of the main streams in this area, in their lower reaches, Boomerang Creek is Order 5, Phillips Creek and North Creek are Order 4 and Ripstone Creek is Order 3 (Figure 8).

4.1.3 Sub-catchment division

The DEM-derived catchment boundaries and associated areas (Figure 8) are approximate, as they were determined from a composite DEM with three different native resolutions, including a coarse SRTM DEM. Catchment boundaries were more uncertain in the low gradient downstream floodplain zones of catchments. The current boundaries of the headwater catchments of One Mile and Boomerang creeks were uncertain due to landform modifications and possible drainage diversion associated with open cut mining. This uncertainty does not materially affect the interpretations or results of this Technical Report.

North Creek joins the Isaac River just downstream of the upstream boundary of the Study Area (Figure 8). North Creek does not flow through MLA 700032 so would not be directly impacted by open cut mining activity, although there is potential for the floodplain of its lower reaches to be impacted by altered flood hydraulics of the Isaac River, and mine-related infrastructure could cross the lower reaches of this creek.

Downstream of North Creek, four small tributaries drain to the Isaac River from the east. Due to uncertain drainage divides, three of these were combined to form Eastern Tributaries A, while the other was labelled Eastern Tributary B (Figure 8). Eastern Tributary B is located almost entirely within MLA 700033 or MLA 700034. In the long term, around half of this catchment would ultimately be excised from the natural drainage system and be subsumed by the open cut mining area (Figure 9). On the other side of the river, the area of westward-draining tributary catchment is much larger. This area includes three small tributary areas, here labelled Western Tributaries A, B and C, the main tributary Boomerang Creek, with its tributaries Ripstone Creek and One Mile Creek, plus Phillips Creek (Figure 8).

Of the western tributaries streams, a portion of Western Tributary A passes through MLA 700032 or MLA 700035 (Figure 9). The catchment is large enough to generate sufficient runoff to form a defined channel, as designated by a blue line, so consideration would need to be given to diversion of the flow from this small stream channel around the pit to Isaac River. A large proportion of Western Tributary B is located within MLA 700032 or MLA 700033 (Figure 9). The majority of the catchment would ultimately be excised from the natural drainage system and be subsumed by the open cut mining area. Almost the entire area of Western Tributary C is located within MLA 700033 (Figure 9). This tributary might not be subject to direct impact of open cut mining but could be subject to indirect impacts.

The catchments and channels of One Mile Creek, Boomerang Creek, and Phillips Creek do not pass through the MLAs, so they would not be directly impacted by open cut mining activity, although there is potential for the floodplain areas of the lower reaches of Boomerang and Phillips creeks to be impacted by altered flood hydraulics of the Isaac River. On the other hand, a large area of Ripstone Creek catchment is upstream of MLA 700033, and the creek channel then passes into and through this MLA on its way to joining Boomerang Creek, just upstream of its junction with Isaac River (Figure 8). Open cut mining would likely directly impact a portion of lower Ripstone Creek catchment (Figure 9), so consideration would need to be given to diversion of the flow from this stream channel around the pit.

Downstream of Phillips Creek catchment, a lowland area labelled Southwestern Tributaries drains eastwards to the right side of Isaac River, entering the river downstream of MLA 700034 (Figure 8). Also in this downstream area, on the left side of the river, three small tributaries, here labelled Southern Tributaries A, B and C, drain in a roughly southeast direction, partially within MLA 700034, joining Isaac River downstream of the MLA 700034 (Figure 8). Open cut mining will impact Southern Tributaries A and B by excising parts of their catchment areas (Figure 9).

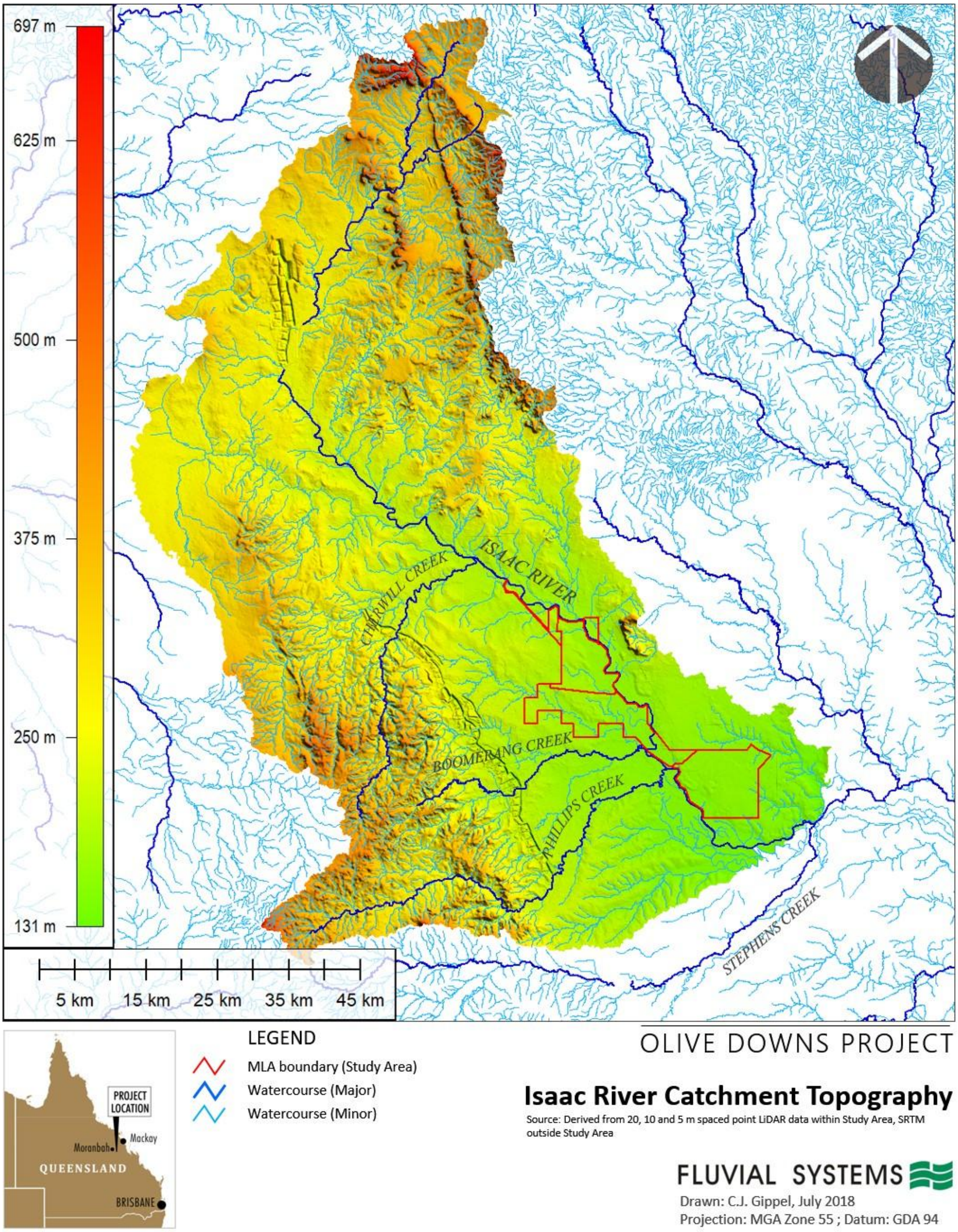


Figure 6. Isaac River regional topography.

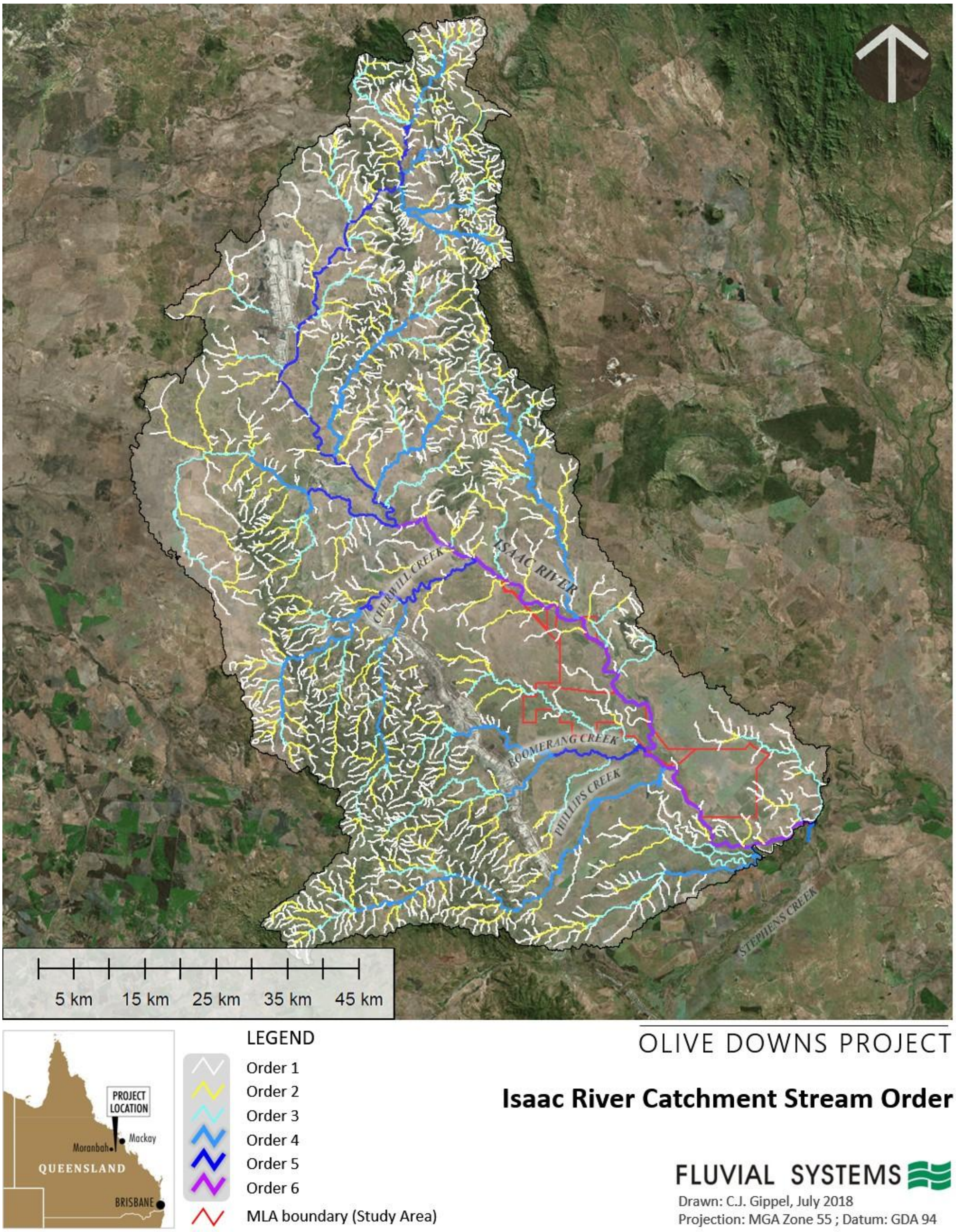


Figure 7. Isaac River catchment drainage system Stream Order.

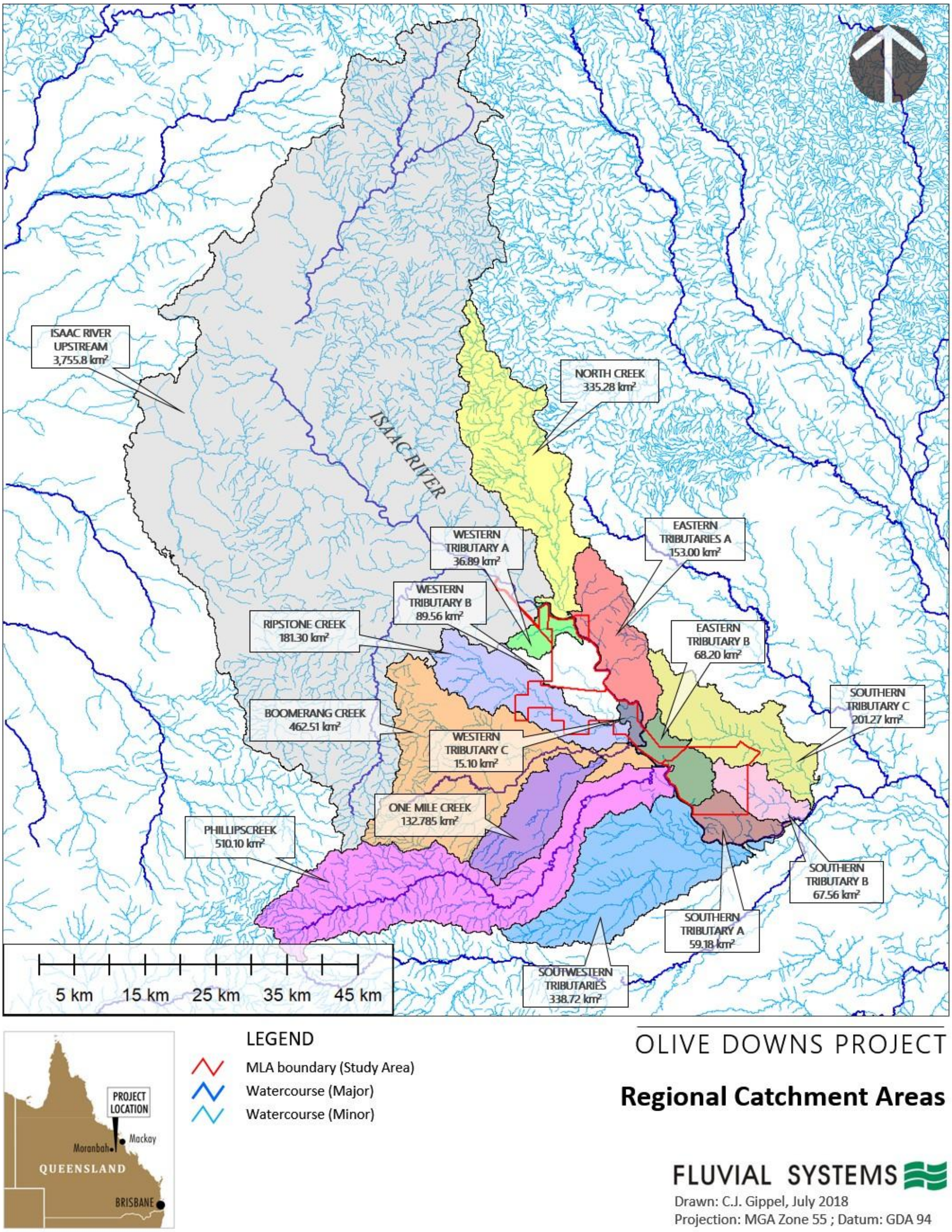


Figure 8. Isaac River regional catchments.

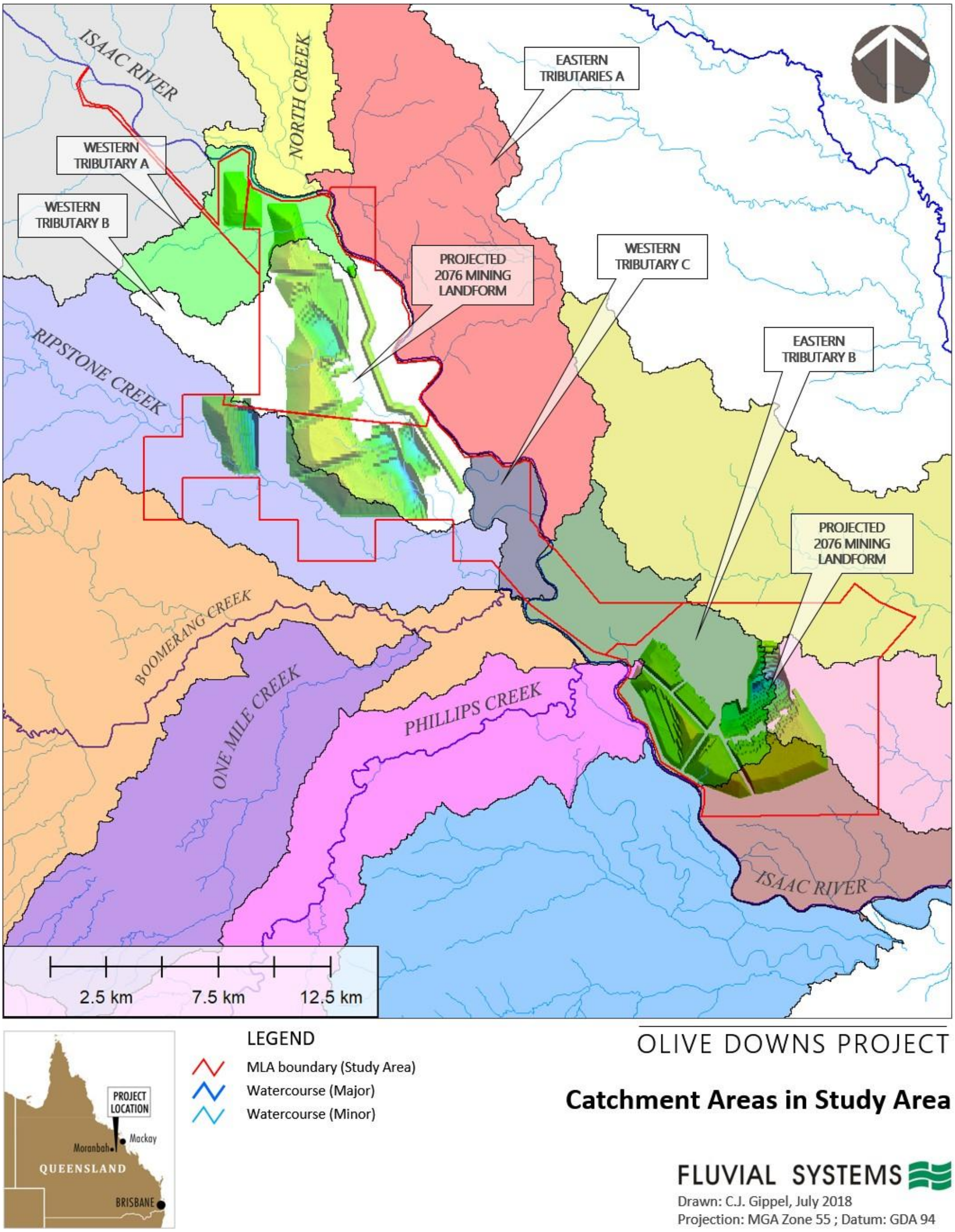


Figure 9. Isaac River catchments in the vicinity of the Study Area. Mining landforms at 2076 are indicative of maximum extent of modification only.

4.1.4 Geological classification

The sediments and volcanics of the Bowen Basin were deposited over most of the area during Permian times (Wright, 1968). Marine and non-marine sequences are represented. Thick terrestrial deposits (mainly shale and sandstone) were laid down during the Triassic. Subsequently a period of orogeny occurred during which the Bowen Basin rocks were folded, faulted, and intruded to varying degrees throughout the area. After the orogeny, the whole area except the Surat Basin in the south was exposed to erosion during Jurassic and Cretaceous times. Igneous activity occurred first with the intrusion of basaltic and andesitic material, and subsequently with the intrusion mainly of granite and diorite associated with extensive faulting, commonly aligned north-north-west and north-east. Erosion continued throughout most of the area in the Cretaceous (Wright, 1968). The geology of the wider Study Area is represented by rocks of the Early-Late Permian, Early-Mid Triassic and Early Cretaceous Periods (Figure 10).

The Australia 1:250,000 Geological Series depict surface geological units, which in the Study Area comprised extensive undifferentiated sandy sediments and soils and Quaternary alluvium within river corridors (Figure 11). This suggests that sand bed rivers and streams would be naturally occurring in this region, and not necessarily the result of accelerated sediment delivery caused by land use change, although this process could have increased the rate of sand delivery to channels above background levels.

4.1.5 Soil classification

The main Australian Soil Classification soil type along the Isaac River corridor is Chromosol, also know in the Australian Soil Atlas classification as Brown and Black Duplex Soils (Figure 12). Soils on the slopes are mainly either Sodosols (Yellow Duplex) or Vertosols (Cracking Clays). There are patches of Kandosol (Massive Earths), and an area of Tenosol (Sands) associated with a patch of Triassic Carborough Sandstone (Clematis Group) (Figure 12).

The majority of the wider Study Area has moderately stable surface soils (Figure 13). Erodible non-cohesive soils and dispersive soils occur in fragmented patches, with more concentrated areas of erodible soils occurring in Ripstone Creek catchment just upstream of the core Study Area, and in the corridor of Isaac River just upstream of the core Study Area (Figure 13).

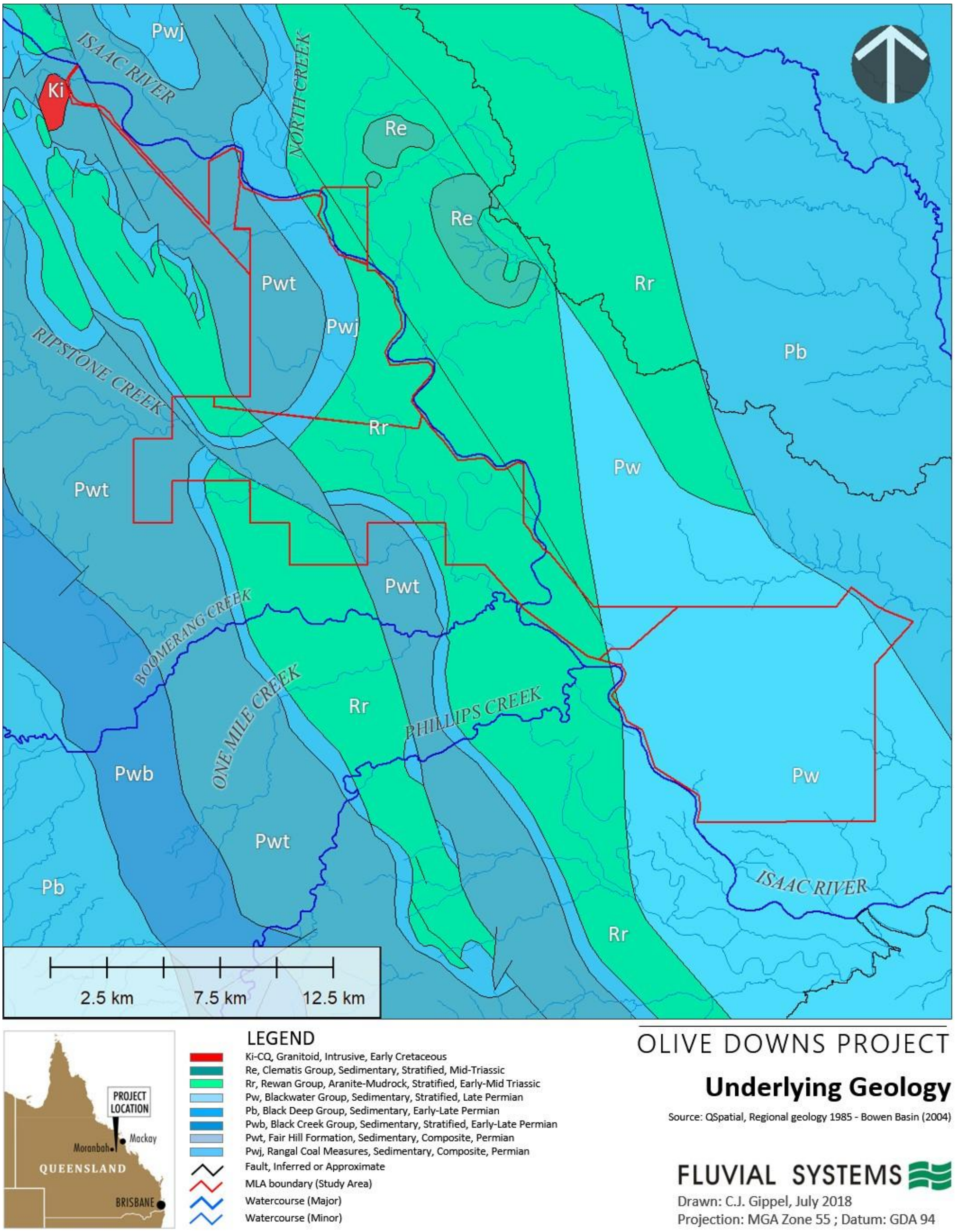


Figure 10. Underlying geology of the Study Area. The mapping does not show the distribution of Quaternary sediments overlying hard rock.

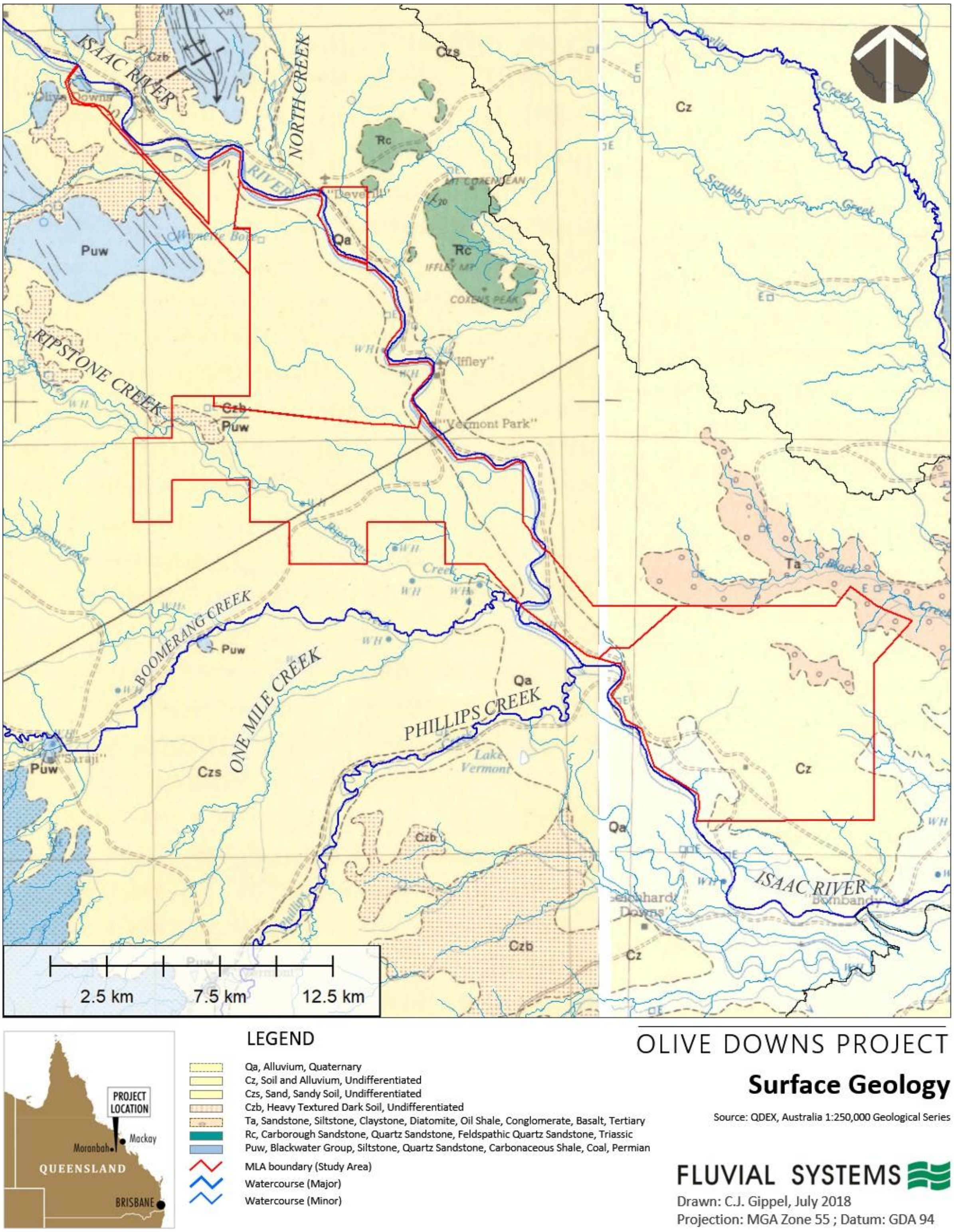


Figure 11. Surface geology of the Study Area. Scanned non-georeferenced source images were rectified and cropped in GIS.

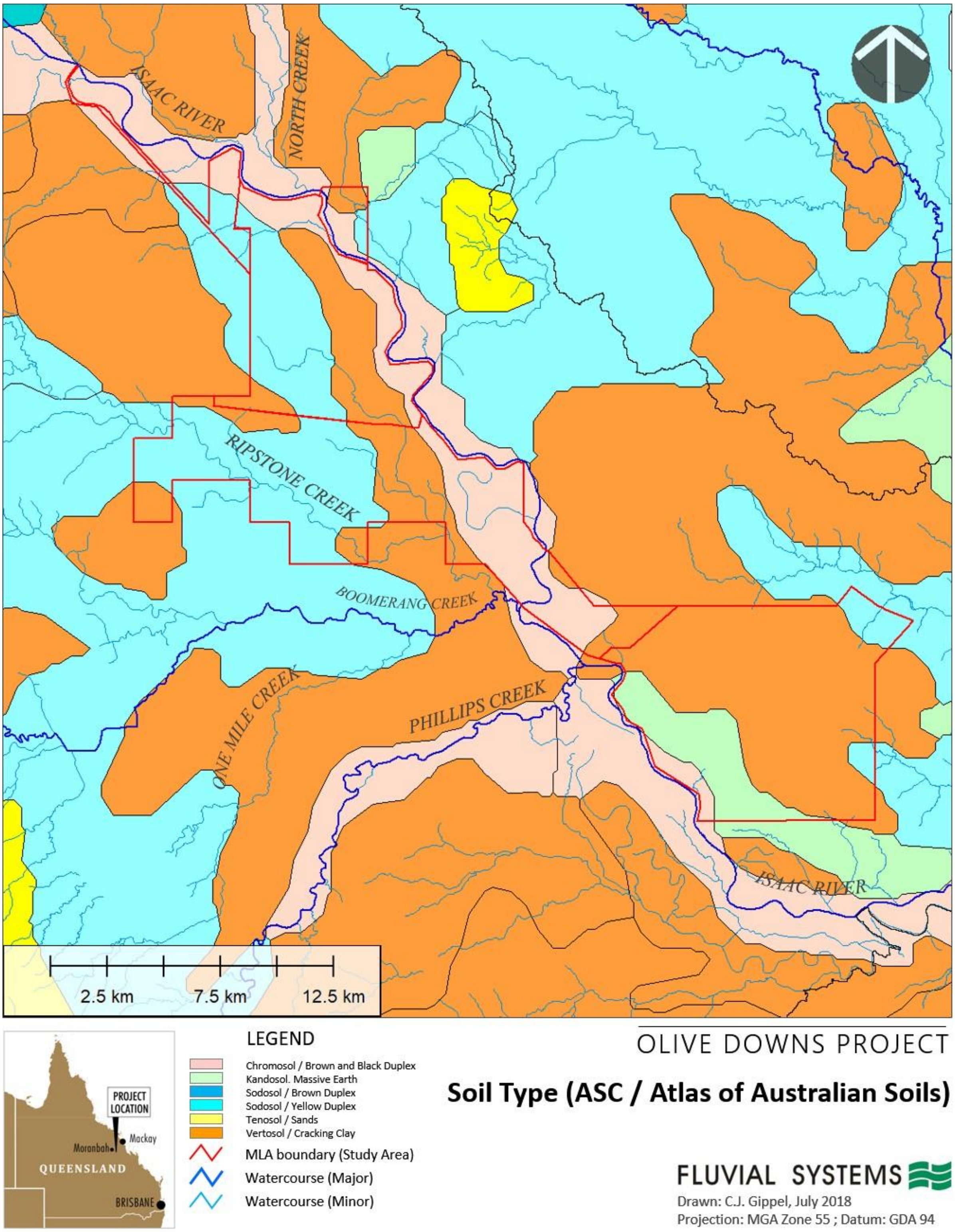


Figure 12. Soil Types in the Study Area.

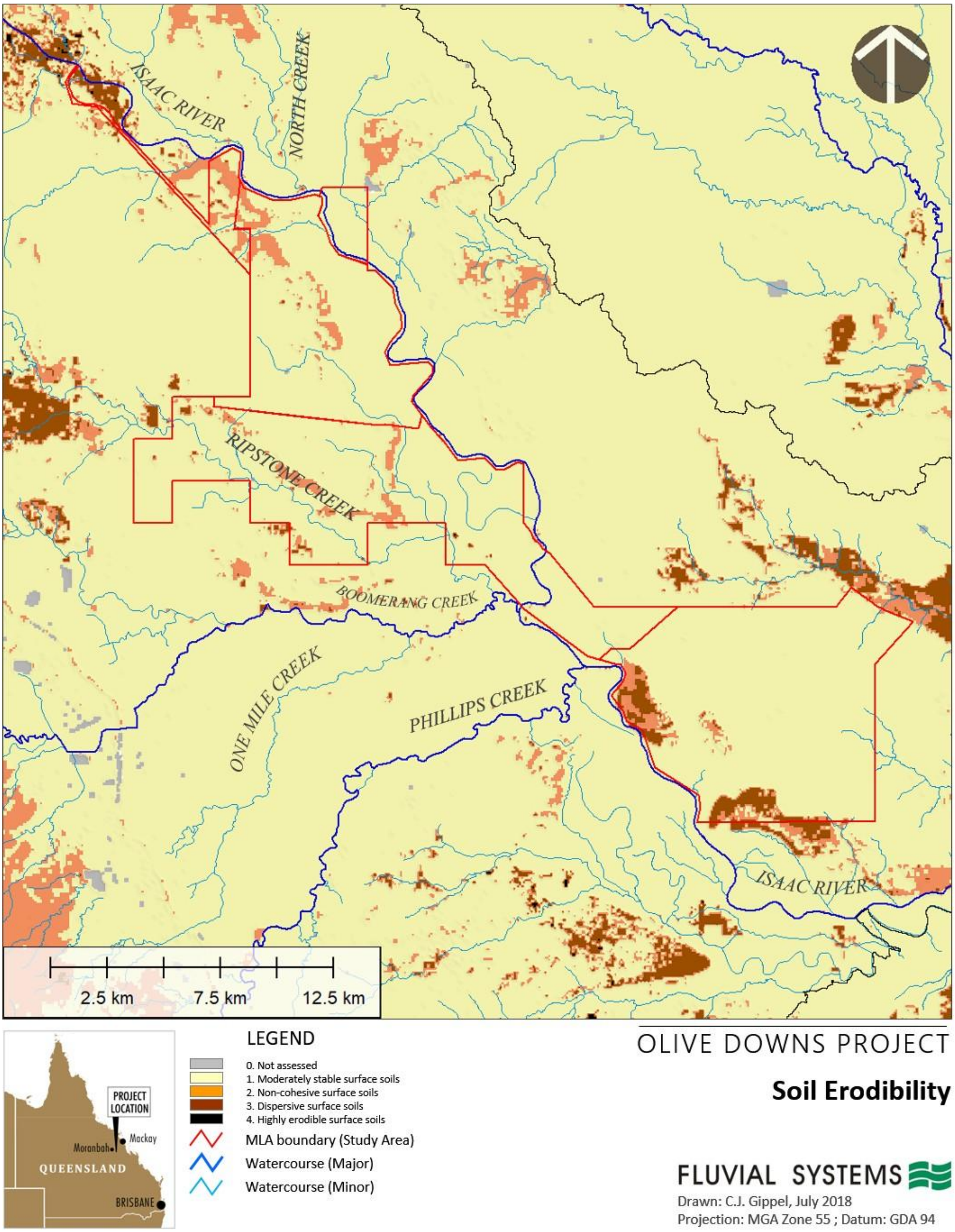


Figure 13. Soil Erodibility in the Study Area.

4.1.6 Land slope

The terrain within the MLAs was less than 10 degrees, except for moderately steep slopes forming the banks of Ripstone Creek (Figure 14). Over the plains of the wider Study Area, slopes were gentle, with steeper slopes associated with isolated hills and open cut mines to the south west. The channels of the major watercourses Isaac River, lower Phillips Creek and lower North Creek had almost continuous very steep banks, while lower Boomerang Creek channel had continuous moderately steep channel banks.

4.1.7 Landform classification

The main objective of landform classification was to identify the degree of confinement of the watercourses which mainly requires separation of floodplains from valley slopes.

Application of the Topographic Position Index (TPI) with default parameter values classified the Study Area into only two of ten possible landform classes - Plains and Open Slopes. This class resolution was too coarse to identify floodplains. The Terrain Surface Classification (TSC) classified the Study Area into four of sixteen possible landform classes. These four classes belonged to terrain series IV, coarse texture and low convexivity (Figure 15). Thus, the landform classes identified by TSC in the wider Study Area were distinguished only by slope. The 25 × 25 m spatial resolution was too coarse to identify the smaller channels, but TSC distinguished the Isaac River channel from its surrounding floodplain, although not as well as slope mapped at 5 × 5 m spatial resolution (Figure 14). The Queensland Floodplain Assessment Overlay (QFAO) represents an estimate of areas potentially at threat of inundation by flooding, mapped at 1:100,000 scale. When compared with the boundary of QFAO, the TSC agreed with the boundary between floodplain and valley side slopes along the larger watercourses, although some valleys with low slopes were classified in the same group as floodplain land (Figure 15).

Within the terrain of the wider Study Area, the MRVBF was generally a poor distinguisher of floodplain land (Figure 16). Within the overall gently sloping terrain of the wider Study Area, when compared with the boundary of QFAO, MRVBF index values that normally indicate floodplain land suggested a much wider floodplain extent (Figure 15).

Landform classification provided a reasonable separation between likely floodplain landform and surrounding valley slope landform, although the indicators were inconclusive for lower Ripstone Creek in particular. Although the QFAO suggested that Ripstone Creek had no floodplain, the TSC and MRVBF indicated that it flowed through a floodplain corridor. QFAO was devised principally as an indicator of flood hazard from the perspective of risk to people, agriculture and infrastructure, rather than as a model of floodplain morphology, so some smaller floodplains with low intensity land use might not have been mapped as having significant flood risk.

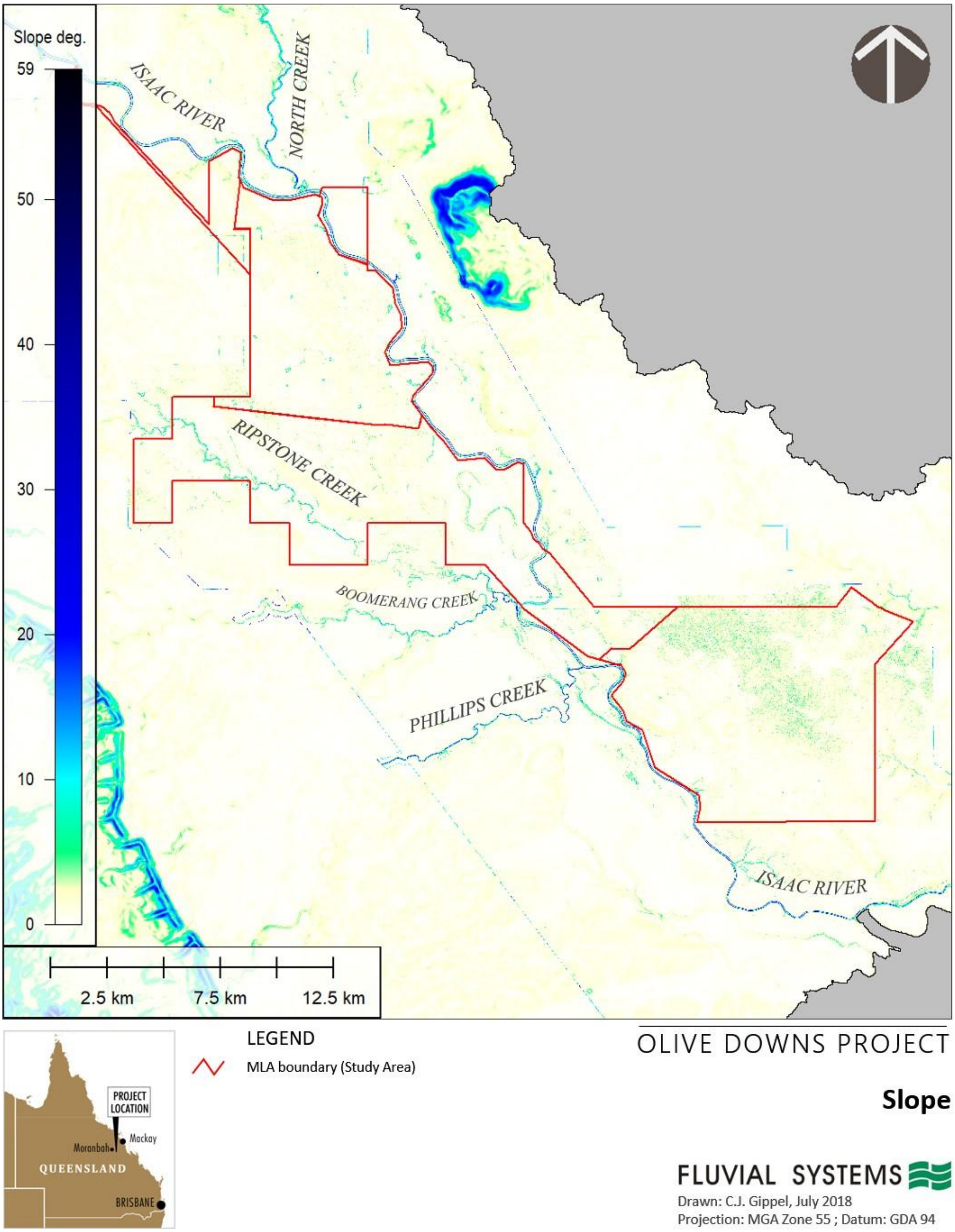


Figure 14. Land slope over the wider Study Area within the Isaac River catchment at 5 × 5 m resolution DEM. Linear discontinuities are artefacts of boundaries of LiDAR data sets.

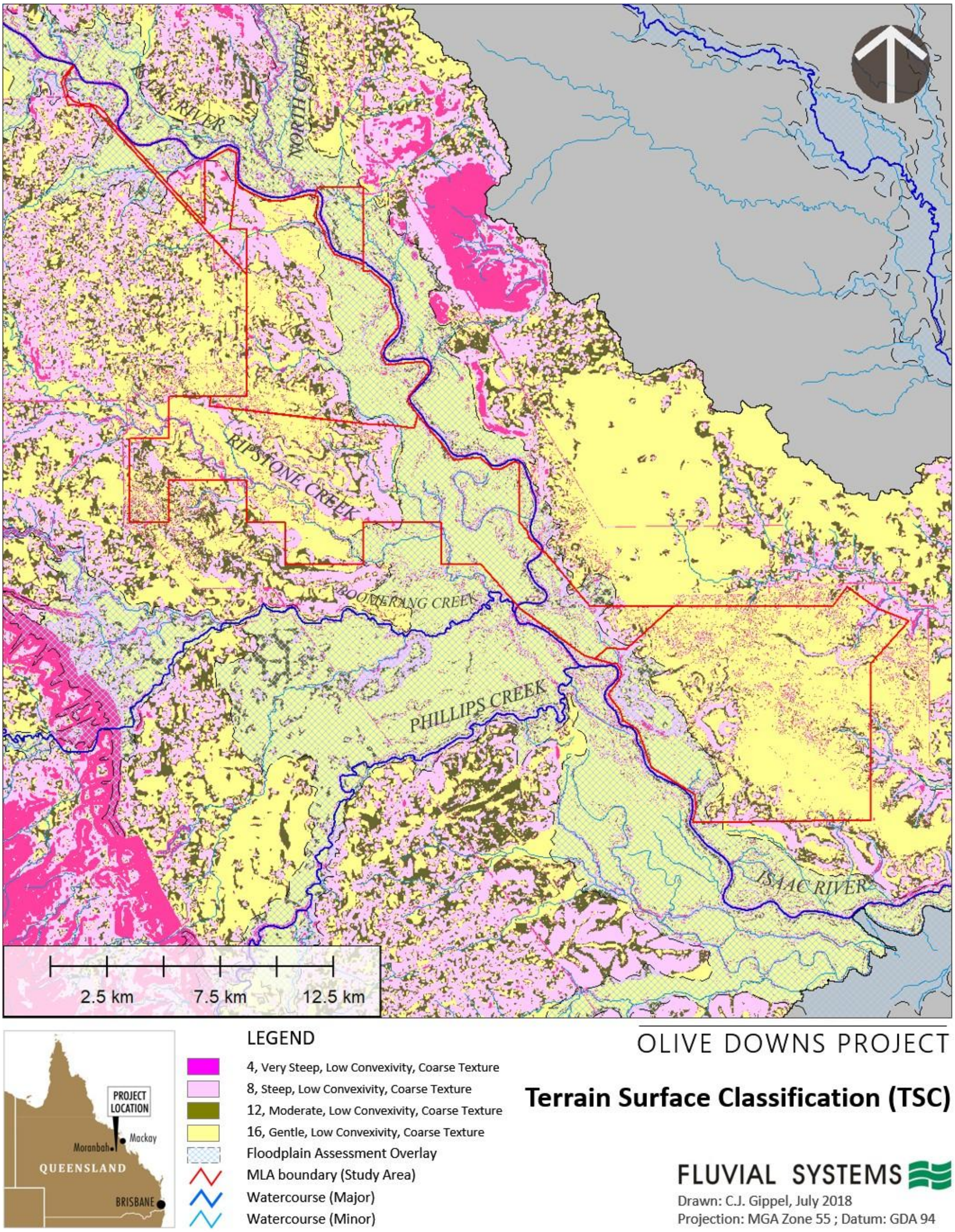


Figure 15. Terrain Surface Classification over the wider Study Area at 25 × 25 m resolution DEM, compared with Queensland Floodplain Assessment Overlay (QFAO).

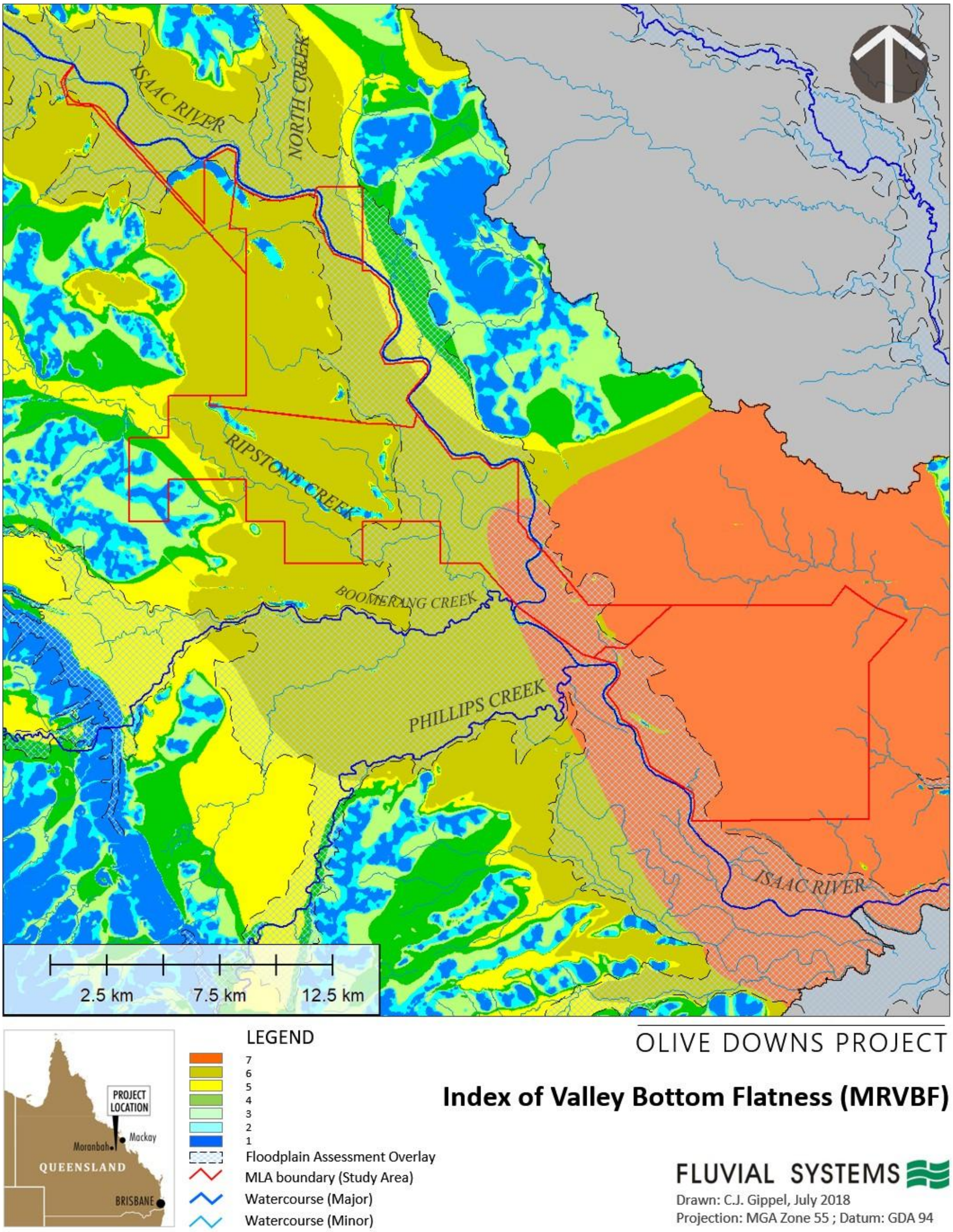


Figure 16. Multispectral index of valley bottom flatness (MRVBF) classification over the wider Study Area at 25 × 25 m resolution DEM, compared with Queensland Floodplain Assessment Overlay (QFAO).

4.2 Stream reach- and point-scale characteristics

4.2.1 Sampled sites

A total of 54 sites were sampled in the field. This comprised 25 sites on Isaac River and 17 sites on Ripstone Creek (Figure 17). Western Tributaries A, B and C were small and were sampled at one or two locations, while only the lower reaches of North, Boomerang and Phillips creeks were sampled as these were outside the core Study Area and not subject to direct impacts of mining (Figure 17).

4.2.2 Isaac River site characteristics

The geomorphic character of Isaac River was relatively constant throughout the Study Area. It was a large sand-bed river, wider in the upstream reaches (Figure 18) than in the lower reaches (Figure 19) of the Study Area, with occasional vegetated (treed) islands (Figure 20) (Table 14). The bed morphology was relatively homogeneous, being fairly flat, with shallow pools (<1 m deep) and low amplitude bar forms (Figure 18, Figure 19). The bed was composed primarily of quartz and feldspathic sand-sized material, but there was a small quantity of mud, gravel and cobbles present in places (Table 14). The banks were steep (Figure 18, Figure 19, Figure 20) and, despite being composed of erodible clayey, silty, sand (Figure 21), the general absence of bare slumped bank faces suggested they were relatively resistant to fluvial erosion. This is likely explained by almost complete coverage by vegetation, in particular thick dense grass (Figure 18, Figure 19). Large wood was not present through the upstream half of the surveyed reach, and was present at low density on the lower half of the reach (Figure 19, Table 14). The riparian vegetation structure had good tree coverage in most places, and where tree cover was low, the extensive shrub and ground cover provided for an overall riparian vegetation cover index value that was medium or high at all locations (Table 15).

4.2.3 Ripstone Creek site characteristics

The geomorphic character of Ripstone Creek was relatively unchanged through the majority of the Study Area, where it had a well-defined channel of variable width and depth, and sand bed (Figure 22, Table 16). The sand-bed of the creek was relatively thick, but had significant variation in form due to the common presence of trees and large wood in the bed which would create hydraulic resistance and turbulence under high flow conditions (Figure 22). The bed material was primarily of quartz and feldspathic sand, but there was a small quantity of surface mud present, and one site with a small quantity of gravel present. In the lower reaches of Ripstone Creek the channel became less well-defined and the dominant bed material changed from sand to mud (Figure 23, Table 16). Further downstream, where the creek approached its junction with Boomerang Creek, the channel again became well defined (Figure 24). Large wood was present in a relatively high density over the upper reaches (Figure 22, Table 16) but was not common in the lower reaches (Figure 23, Table 16). The riparian vegetation structure had variable tree cover. Where tree cover was low, the extensive shrub and ground cover provided for an overall riparian vegetation cover index value that was medium or high at most sites, but some sites with low ground cover had low overall riparian vegetation cover index values (Table 17).

4.2.4 North, Boomerang and Phillips creeks site characteristics

North (Figure 25), Boomerang (Figure 26) and Phillips (Figure 27) creeks were similar in geomorphic character. These creeks were similar in character to Isaac River, but at a smaller scale (Table 18, Table 19).

4.2.5 Western Tributaries site characteristics

Western Tributaries A and B were small scale streams, with channel form alternating between ill-defined, weakly defined or well-defined (Table 18). Western Tributary A was ill-defined over most of its course, but became well-defined as it incised into the Isaac River floodplain as it neared its junction with the river (Figure 28). Western Tributary B Site 1 had a larger catchment area than at Site 2 on a small tributary. At Site 1 the stream comprised a series of well-defined pools strung along an otherwise ill-defined drainage line, while Site 2 had ill-defined morphology and lacked pools (Figure 29). Western Tributaries A and B were low gradient, with areas of ponded water and moist bed material that encouraged the growth of emergent macrophytes and grass in the bed (Table 19). Trees were not common in the riparian zones and there was very little large wood in the channels (Table 18, Table 19).

Western Tributary C, although 80 m wide at bankfull level (Figure 30, Table 19), drained a small catchment area located entirely on the floodplain of Isaac River. This watercourse, being a largely in-filled former course of the Isaac River, was a floodplain lagoon rather than a creek.

4.2.6 Isaac River and Ripstone Creek downstream patterns of channel morphology

Isaac River displayed distinctive channel narrowing in the downstream direction through the Study Area (Figure 31). Over a distance of about 70 km the bed width narrowed from ~50 – 70 m to ~20 – 40 m, and the bankfull channel width narrowed from ~100 – 120 m to ~40 – 60 m (compare Figure 18 and Figure 19). This downstream narrowing occurred despite a significant increase in catchment area. The channel did not maintain its capacity downstream by increasing in depth or slope (Figure 31), suggesting that the floodplain becomes increasingly hydraulically connected to the channel in the downstream direction. Thus, events that just inundate the floodplain of the lower area will be contained within the channel in the upper area. The observed bed width of the Isaac River in the upper part of the Study Area is comparable with the observations made by Hardie et al. (1994) approximately 65 km upstream, near the Isaac River Diversion, adjacent to Goonyellah Riverside Coal Mine. Here, the low flow sand bed was 40 m wide, and including low benches, the bed was 60 – 85 m wide.

The downstream slope of Isaac River through the Study Area was relatively constant, falling 40 m over 70 km (Figure 31) for an average slope of 0.000587. Sinuosity of the river in the Study Area was 1.29.

Ripstone Creek narrowed in its lower reaches (Figure 31) (compare Figure 22 and Figure 23). This suggests that the floodplain is likely to be more hydraulically connected to the channel in the lower reaches, although it becomes less connected in the lowest reach where it incices into the floodplain towards its junction with Billabong Creek (Figure 24). Channel dimensions were highly variable along Ripstone Creek (Figure 31).

The downstream slope of Ripstone Creek was relatively constant, falling 33.2 m over 26.2 km (Figure 31) for an average slope of 0.001275. Sinuosity of the creek in the Study Area was 1.51.

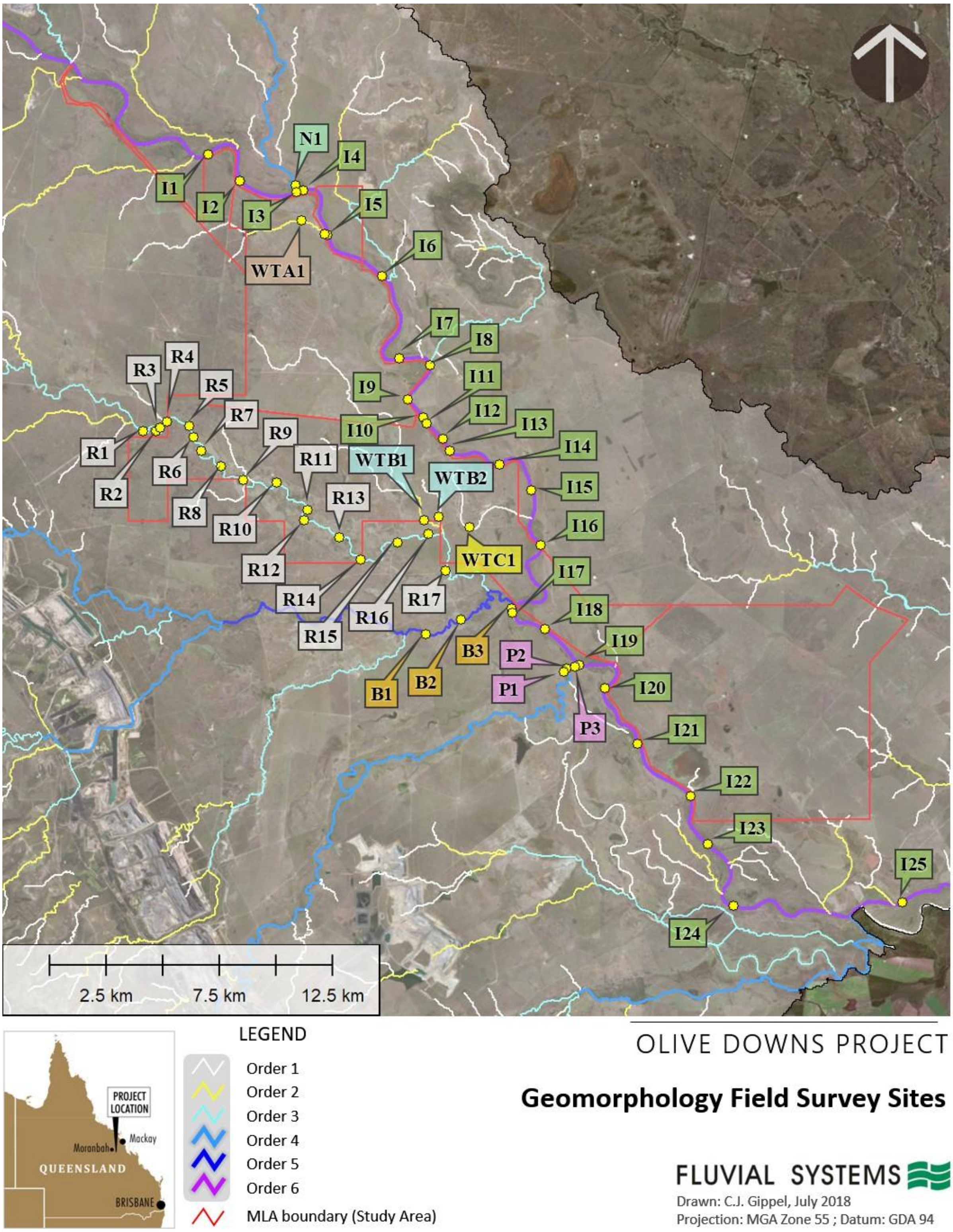


Figure 17. Geomorphology survey sample sites. Data were recorded at 54 observation points.

Figure 18. Isaac River, typical cross-section and bed morphology at two sites in the upper reaches of the Study Area.

Figure 19. Isaac River, typical cross-section and bed morphology at two sites in the lower reaches of the Study Area.

Figure 20. Isaac River, example of mid-channel vegetated island.

Figure 21. Isaac River, exposed clayey, silty, sand bank material at a cutting.

Figure 22. Typical sites on upper Ripstone Creek.

Figure 23. Two sites on lower Ripstone Creek.

Figure 24. The lowest surveyed site on Ripstone Creek.

Figure 25. Lower reach of North Creek near its junction with the Isaac River.

Figure 26. Most upstream surveyed site on Billabong Creek.

Figure 27. Most upstream surveyed site on Phillips Creek.

Figure 28. Western Tributary A upper (top) and lower (bottom) sites.

Figure 29. Western Tributary B sites.

Figure 30. Western Tributary C, an in-filled former course of the Isaac River.

Table 14. Field data collected for Isaac River sites, location, channel form, bed material and large wood.

Site	Stream	Latitude	Longitude	Longitudinal continuity	X-sec definition	Valley setting	Bed material (present)	Bed material (dominant)	Large wood (pc./100 m)
I1	Isaac	-22.152535	148.335229	continuous	strong	Unconfined/extensive	mud, sand, gravel, cobble	sand	0
I2	Isaac	-22.163178	148.348664	continuous	strong	Unconfined/extensive	mud, sand, gravel, cobble	sand	0
I3	Isaac	-22.167631	148.372991	continuous	strong	Unconfined/extensive	mud, sand, gravel	sand	0
I4	Isaac	-22.166787	148.375641	continuous	strong	Unconfined/extensive	mud, sand, gravel	sand	0
I5	Isaac	-22.184475	148.386137	continuous	strong	Unconfined/extensive	mud, sand, gravel, cobble	sand	0
I6	Isaac	-22.200938	148.409569	continuous	strong	Unconfined/extensive	mud, sand, gravel, cobble	sand	0
I7	Isaac	-22.233849	148.416858	continuous	strong	Unconfined/extensive	mud, sand, gravel, cobble	sand	0
I8	Isaac	-22.236367	148.429919	continuous	strong	Unconfined/extensive	mud, sand, gravel	sand	0
I9	Isaac	-22.250082	148.420538	continuous	strong	Unconfined/extensive	mud, sand, gravel	sand	0
I10	Isaac	-22.257293	148.426937	continuous	strong	Unconfined/extensive	mud, sand, gravel	sand	0
I11	Isaac	-22.259448	148.428361	continuous	strong	Unconfined/extensive	mud, sand, gravel	sand	0
I12	Isaac	-22.265757	148.435273	continuous	strong	Unconfined/extensive	mud, sand	sand	0
I13	Isaac	-22.270476	148.438502	continuous	strong	Unconfined/extensive	sand	sand	0
I14	Isaac	-22.276003	148.459647	continuous	strong	Unconfined/extensive	mud, sand, gravel	sand	15
I15	Isaac	-22.286015	148.473186	continuous	strong	Unconfined/extensive	sand, gravel	sand	0
I16	Isaac	-22.307938	148.477057	continuous	strong	Unconfined/extensive	sand, gravel	sand	0
I17	Isaac	-22.334933	148.465202	continuous	strong	Unconfined/extensive	sand, gravel, cobble	sand	5
I18	Isaac	-22.341437	148.478818	continuous	strong	Unconfined/extensive	sand, gravel	sand	10
I19	Isaac	-22.355557	148.493482	continuous	strong	Unconfined/extensive	mud, sand, gravel, cobble	sand	15
I20	Isaac	-22.36489	148.504561	continuous	strong	Unconfined/extensive	sand, gravel, cobble	sand	30
I21	Isaac	-22.386966	148.518524	continuous	strong	Unconfined/extensive	mud, sand, gravel, cobble	sand	40
I22	Isaac	-22.407842	148.541101	continuous	strong	Unconfined/extensive	mud, sand, gravel, cobble	sand	30
I23	Isaac	-22.426896	148.548448	continuous	strong	Unconfined/extensive	sand, gravel	sand	10
I24	Isaac	-22.451345	148.559295	continuous	strong	Unconfined/extensive	sand, gravel	sand	35
I25	Isaac	-22.450023	148.631573	continuous	strong	Unconfined/extensive	sand, gravel	sand	25

Table 15. Field data collected for Isaac River sites, channel dimensions, instream bed vegetation structure, riparian vegetation structure. Point slope is DEM-derived and uncertain.

Site	Bed width (m)	Bankfull width (m)	Bankfull depth (m)	Slope (Deg.)	Slope (%)	Instream bed vegetation presence	Macrophyte bed cover	Tree/grass bed vegetation cover	Riparian buffer width	Riparian buffer continuity	Riparian tree cover	Riparian vegetation cover index
I1	64.4	124.3	6.6	0.15	0.0027	-	-	-	>50 m	continuous	25 - 50%	50 - 75%
I2	57	119.0	8.4	0.49	0.0086	-	-	-	>50 m	continuous	25 - 50%	50 - 75%
I3	59.2	100.7	7.1	0.92	0.0160	-	-	-	>50 m	continuous	25 - 50%	75 - 100%
I4	62	117.0	6.7	0.64	0.0111	-	-	-	>50 m	continuous	50 - 75%	75 - 100%
I5	56.7	103.8	8.1	0.68	0.0118	-	-	-	>50 m	continuous	25 - 50%	50 - 75%
I6	53.9	103.0	7.9	1.31	0.0229	-	-	-	>50 m	continuous	25 - 50%	50 - 75%
I7	60.5	103.0	8.2	0.36	0.0064	-	-	-	>50 m	continuous	50 - 75%	50 - 75%
I8	65.5	99.3	7.0	3.52	0.0615	-	-	-	>50 m	continuous	25 - 50%	50 - 75%
I9	72.3	117.0	7.8	14.88	0.2657	-	-	-	>50 m	continuous	5 - 25%	50 - 75%
I10	54.2	97.5	7.8	0.58	0.0102	-	-	-	>50 m	continuous	25 - 50%	50 - 75%
I11	60.4	95.2	9.0	0.62	0.0108	-	-	-	>50 m	continuous	50 - 75%	75 - 100%
I12	52.8	91.0	8.1	0.58	0.0102	-	-	-	>50 m	continuous	25 - 50%	75 - 100%
I13	58	96.0	7.6	5.09	0.0890	-	-	-	>50 m	continuous	50 - 75%	50 - 75%
I14	42.6	60.0	9.5	10.80	0.1907	-	-	-	>50 m	continuous	50 - 75%	75 - 100%
I15	55.4	118.0	5.0	0.16	0.0028	-	-	-	>50 m	continuous	50 - 75%	75 - 100%
I16	79.4	120.0	6.9	3.79	0.0663	-	-	-	>50 m	continuous	25 - 50%	75 - 100%
I17	38.1	88.0	7.0	0.37	0.0065	-	-	-	>50 m	continuous	25 - 50%	75 - 100%
I18	49.3	81.4	9.6	0.87	0.0152	-	-	-	>50 m	continuous	50 - 75%	50 - 75%
I19	48.3	82.3	7.8	0.50	0.0088	-	-	-	>50 m	continuous	75 - 100%	50 - 75%
I20	55	98.9	8.9	0.81	0.0142	-	-	-	>50 m	continuous	50 - 75%	75 - 100%
I21	43.7	102.1	9.0	0.94	0.0165	-	-	-	>50 m	continuous	25 - 50%	75 - 100%
I22	50.3	101.7	8.4	1.07	0.0187	trees	-	5 – 25%	>50 m	continuous	5 - 25%	50 - 75%
I23	39.1	64.2	8.0	17.47	0.3147	-	-	-	>50 m	continuous	25 - 50%	50 - 75%
I24	40.5	57.8	7.9	8.65	0.1522	-	-	-	>50 m	continuous	25 - 50%	75 - 100%
I25	24.7	45.3	4.7	17.25	0.3106	-	-	-	>50 m	continuous	75 - 100%	75 - 100%

Table 16. Field data collected for Ripstone Creek sites, location, channel form, bed material and large wood.

Site	Stream	Latitude	Longitude	Longitudinal continuity	X-sec definition	Valley setting	Bed material (present)	Bed material (dominant)	Large wood (pc./100 m)
R1	Ripstone	-22.262582	148.307157	yes	strong	Partly confined/extensive	sand, gravel	sand	115
R2	Ripstone	-22.262584	148.3127	yes	strong	Partly confined/extensive	mud, sand, gravel	sand	40
R3	Ripstone	-22.26124	148.314612	yes	strong	Partly confined/extensive	mud, sand, gravel	sand	90
R4	Ripstone	-22.258962	148.317627	yes	strong	Partly confined/extensive	mud, sand, gravel	sand	30
R5	Ripstone	-22.260721	148.327215	yes	strong	Partly confined/extensive	mud, sand, gravel	sand	25
R6	Ripstone	-22.265167	148.328755	yes	strong	Partly confined/extensive	mud, sand, gravel	sand	50
R7	Ripstone	-22.270566	148.332018	yes	strong	Partly confined/extensive	mud, sand, gravel	sand	60
R8	Ripstone	-22.276691	148.340494	yes	strong	Partly confined/pockets	mud, sand, gravel	sand	100
R9	Ripstone	-22.282125	148.350223	yes	strong	Partly confined/moderate	mud, sand	sand	80
R10	Ripstone	-22.283262	148.364268	yes	strong	Partly confined/moderate	mud, sand	sand	40
R11	Ripstone	-22.29406	148.377682	yes	strong	Partly confined/moderate	mud, sand	sand	30
R12	Ripstone	-22.297994	148.376194	yes	strong	Partly confined/moderate	mud, sand	sand	35
R13	Ripstone	-22.30502	148.391279	yes	strong	Partly confined/moderate	mud, sand	sand	10
R14	Ripstone	-22.313771	148.400203	yes	strong	Partly confined/moderate	sand, gravel	sand	30
R15	Ripstone	-22.30699	148.416048	yes	strong	Unconfined/extensive	mud, sand	mud	10
R16	Ripstone	-22.303465	148.429072	no	ill-defined	Unconfined/extensive	mud	mud	0
R17	Ripstone	-22.318171	148.436574	yes	strong	Partly confined/extensive	mud, sand	mud	60

Table 17. Field data collected for Ripstone Creek sites, channel dimensions, instream bed vegetation structure, riparian vegetation structure. Point slope is DEM-derived and uncertain.

Site	Bed width (m)	Bankfull width (m)	Bankfull depth (m)	Slope (Deg.)	Slope (%)	Instream bed vegetation presence	Macrophyte bed cover	Tree/grass bed vegetation cover	Riparian buffer width	Riparian buffer continuity	Riparian tree cover	Riparian vegetation cover index
R1	21	41.4	2.7	3.35	0.0586	trees	-	25 – 50%	>50 m	continuous	5 - 25%	25 - 50%
R2	8.3	16.4	3	9.12	0.1605	-	-	-	>50 m	continuous	50 - 75%	50 - 75%
R3	11.8	20.1	3.3	2.52	0.0439	trees	-	25 – 50%	>50 m	continuous	25 - 50%	50 - 75%
R4	9	21.3	3.6	10.68	0.1885	trees	-	25 – 50%	>50 m	continuous	25 - 50%	50 - 75%
R5	10.5	16.9	3.1	5.75	0.1007	-	-	-	>50 m	continuous	5 - 25%	50 - 75%
R6	12.3	42.9	1.5	1.88	0.0328	trees	-	25 – 50%	>50 m	continuous	5 - 25%	25 - 50%
R7	9.8	18.2	2.9	2.73	0.0477	trees	-	25 – 50%	>50 m	continuous	25 - 50%	50 - 75%
R8	6	12.2	1.9	9.18	0.1616	-	-	-	>50 m	continuous	5 - 25%	50 - 75%
R9	8	22.4	2.3	3.94	0.0689	trees	-	5 – 25%	>50 m	continuous	25 - 50%	50 - 75%
R10	7.6	37	4.2	3.57	0.0623	-	-	-	>50 m	continuous	25 - 50%	50 - 75%
R11	12.2	21.2	3.1	4.31	0.0753	trees	-	5 – 25%	>50 m	continuous	25 - 50%	25 - 50%
R12	9.6	21	3.6	15.45	0.2765	trees	-	5 – 25%	>50 m	continuous	50 - 75%	50 - 75%
R13	20	38.6	3.3	9.3	0.1637	-	-	-	>50 m	continuous	5 - 25%	50 - 75%
R14	5.6	10	1.4	4.44	0.0776	grass, trees	-	5 – 25%	>50 m	continuous	5 - 25%	50 - 75%
R15	1.5	3.5	0.5	1.86	0.0325	grass, trees	-	5 – 25%	>50 m	continuous	25 - 50%	25 - 50%
R16	5.3	7.6	0.4	1.28	0.0224	grass	-	>75%	>50 m	continuous	<1%	25 - 50%
R17	2.3	11.4	2.4	2.59	0.0453	grass	-	5 – 25%	>50 m	continuous	5 - 25%	50 - 75%

Table 18. Field data collected for Boomerang, Phillips and North creeks and Western Tributary sites, location, channel form, bed material and large wood.

Site	Stream	Latitude	Longitude	Longitudinal continuity	X-sec definition	Valley setting	Bed material (present)	Bed material (dominant)	Large wood (pc./100 m)
B1	Boomerang	-22.343259	148.428256	yes	strong	Unconfined/extensive	sand	sand	0
B2	Boomerang	-22.337741	148.443155	yes	strong	Unconfined/extensive	sand	sand	20
B3	Boomerang	-22.333304	148.464829	yes	strong	Unconfined/extensive	mud, sand	sand	25
P1	Phillips	-22.358194	148.486999	yes	strong	Unconfined/extensive	mud, sand, gravel	sand	10
P2	Phillips	-22.356918	148.488135	yes	strong	Unconfined/extensive	mud, sand	sand	5
P3	Phillips	-22.356186	148.491885	yes	strong	Unconfined/extensive	mud, sand	sand	10
N1	North	-22.164845	148.372613	yes	strong	Unconfined/extensive	mud, sand	sand	0
WTA1	West Trib. A	-22.178767	148.375134	no	ill-defined	Unconfined/extensive	mud, sand	mud	5
WTA2	West Trib. A	-22.184259	148.384871	yes	strong	Unconfined/extensive	mud, sand	sand	10
WTB1	West Trib. B	-22.298037	148.427400	no	strong	Unconfined/extensive	mud	mud	0
WTB2	West Trib. B	-22.296651	148.433633	no	ill-defined	Partly confined/moderate	mud	mud	0
WTC1	West Trib. C	-22.300933	148.446696	yes	weak	Partly confined/extensive	mud	mud	60

Table 19. Field data collected for Boomerang, Phillips and North creeks and Western Tributary sites, channel dimensions, instream bed vegetation structure, riparian vegetation structure. Point slope is DEM-derived and uncertain.

Site	Bed width (m)	Bankfull width (m)	Bankfull depth (m)	Slope (Deg.)	Slope (%)	Instream bed vegetation presence	Macrophyte bed cover	Tree/grass bed vegetation cover	Riparian buffer width	Riparian buffer continuity	Riparian tree cover	Riparian vegetation cover index
B1	7.5	44	4.5	10.43	0.1842	-	-	-	>50 m	continuous	50 - 75%	50 - 75%
B2	6.7	43	5.1	9.19	0.1618	-	-	-	>50 m	continuous	5 - 25%	25 - 50%
B3	9.2	45.7	7.6	5.99	0.1049	-	-	-	>50 m	continuous	50 - 75%	50 - 75%
P1	9.2	35	7	8.14	0.143	-	-	-	>50 m	continuous	75 - 100%	50 - 75%
P2	11.7	42.4	7	7.22	0.1267	-	-	-	>50 m	continuous	75 - 100%	50 - 75%
P3	9.3	32.6	8.5	11.52	0.2037	-	-	-	>50 m	continuous	50 - 75%	75 - 100%
N1	10.5	17	3.4	7.69	0.135	-	-	-	>50 m	continuous	50 - 75%	75 - 100%
WTA1	na	na	na	0.86	0.015	emergent macrophytes, grass	5 – 25%	>75%	>50 m	continuous	1 - 5%	50 - 75%
WTA2	2.5	31	6.2	13.76	0.2448	grass	-	<1%	>50 m	continuous	50 - 75%	50 - 75%
WTB1	8	10.7	1.2	1.31	0.0228	emergent macrophytes	25 – 50%	-	>50 m	continuous	<1%	25 - 50%
WTB2	11	40	0.4	0.56	0.0098	grass	-	>75%	>50 m	continuous	<1%	25 - 50%
WTC1	18.6	80	1.5	1.36	0.0238	emergent macrophytes, trees	50 – 75%	5 – 25%	>50 m	continuous	5 - 25%	25 - 50%

Figure 31. Downstream pattern of field-measured channel width and depth, and DEM-derived elevation of Isaac River and Ripstone Creek in the Study Area. Elevation is along 1:100,000 watercourse lines at 5 m intervals from 5 × 5 m DEM. Substantial islands were present at two sites labelled 'part' on Isaac River. Data refer to the main channel only.

4.2.7 Stream geomorphic type

Stream geomorphic type (equivalent to River Styles®) (Figure 32) was determined for the watercourses in the Study Area using the field gathered data and terrain analysis. Descriptions of the typical geomorphic units associated with the types were taken from River Styles® literature, and the streams in the Study Area did not necessarily possess all of these characteristics. The fragility ratings for each type were also taken from River Styles® literature.

Isaac River (Figure 18, Figure 19, Figure 20) and North Creek (Figure 25), being laterally unconfined with extensive floodplain connection, belong to the Low Sinuosity Sand type. The lowland reaches of Boomerang Creek (Figure 26) and Phillips Creek (Figure 27) are a similar type at a smaller scale, but by virtue of their higher sinuosity are Meandering Sand type.

The upper section of Ripstone Creek, from R1 to R7, is partly confined with extensive floodplain connection. Downstream of R7 to R14 the floodplain connection is less extensive. This upper part of Ripstone Creek down to R14 (Figure 22) is Planform Controlled Meandering Sand. The lower section of Ripstone Creek from R15 to R16 emerges from a confined valley and fans out over the lateral zone of the Isaac River floodplain (Figure 33). The mapped 1:100,000 blue line in this area should not be interpreted as a major flow path, as flood flow is likely to spread widely over this area. Here, the observed channel changed from sand bed to fine-grained bed and became an unconfined flow path characterised by discontinuous deep pools (Figure 23). At the local scale the creek had characteristics of chain-of-ponds geomorphic stream type, but it did not fit the usual upland valley setting, or lowland setting confined by a palaeochannel. Thus, it was more accurately classified as Floodout type (Figure 33). At the most downstream section from R17, where Ripstone Creek starts incising to meet Boomerang Creek bed level, the channel becomes longitudinally continuous and more defined in cross-section form (Figure 24). Here the creek was classified as Meandering Fine Grained type.

Western Tributary streams were sampled on lowland locations where they are proximal to or on the Isaac River floodplain. Here, the channels are small, varying from continuous to discontinuous. Western Tributary A, at WTA1 and further upstream (Figure 28), is an ill-defined Low Sinuosity Fine Grained stream draining low relief terrain. Further downstream, the channel starts incising towards the Isaac River (Figure 28). In this section the sandy bed material means WTA was classified as Low Sinuosity Sand type.

Site WTB1 is on a drainage line that has a much bigger catchment than at the site WTB2 on a small ill-defined Low Sinuosity Fine Grained tributary drainage line. The channel at WTB1 is better defined, also formed in mud, with a sequence of pools linked by short shallow well-vegetated sections (Figure 29), also of Low Sinuosity Fine Grained type.

Western Tributary C is a cutoff meander loop on the margin of the Isaac River floodplain (Figure 30, Figure 33). It is infilled with sediment and of a smaller scale than the current Isaac River channel. As such, it was not classified as belonging to a geomorphic stream type, rather, it was considered a geomorphic unit of the Isaac River.

Valley confinement	Partly confined	Laterally unconfined				
Channel / floodplain	Continuous single channel	No channel or poorly defined, discontinuous	Continuous single channel			
Sinuosity	Low	Low or not relevant	Low		High	
Dominant particle size	Sand	Silt/clay	Silt/clay	Sand	Silt/clay	Sand
Typical geomorphic units	Mainly dominated by a planar bed and large pools with irregular LWD riffles common. High LWD loading which is required for bed scour and geomorphic unit diversity. Benches, point and bank attached bars; Floodplain multi-surfaced, dominated by cutoffs, terraces and levees with some irregular flat topped pockets	Alluvial fan confined by valley walls. Featureless swampy or grassed fill surface	Lateral bars, sand sheets, inset features, benches, chute channels; Floodplain continuous with flood channels and palaeochannels	Benches, small pools, small bars if any; Floodplain flat-topped, levees, swamp, palaeochannels, flood runners	Pools and LWD riffles, small fine grained point bars and mid-channel bars (if any), occasional benches, chute channels, and islands; Floodplain continuous with levees, palaeochannels, many recent oxbows (billabongs) and back swamps. Often higher floodplain level or terraces	Pool-riffle sequences (LWD riffles), large sandy point and bank attached bars, benches, scroll bars, chute channels, islands; Floodplain multi-surfaced with cut-offs, flood channels and many abandoned channels. Back swamps on distal floodplains. Ridges and swales. Terraces
Slope	Low-Mod	Mod-High	Low	Low	Low	Low
Energy	Low-Mod	Low	Low	Low	Low	Low
Fragility to threats	Mod	High	Mod	High	High	High
Geomorphic type	Planform Controlled Meandering Sand	Floodout	Low Sinuosity Fine Grained	Low Sinuosity Sand	Meandering Fine Grained	Meandering Sand

Figure 32. Stream geomorphic types identified within the Study Area. The geomorphic types and class attribute descriptions are borrowed from River Styles® framework.

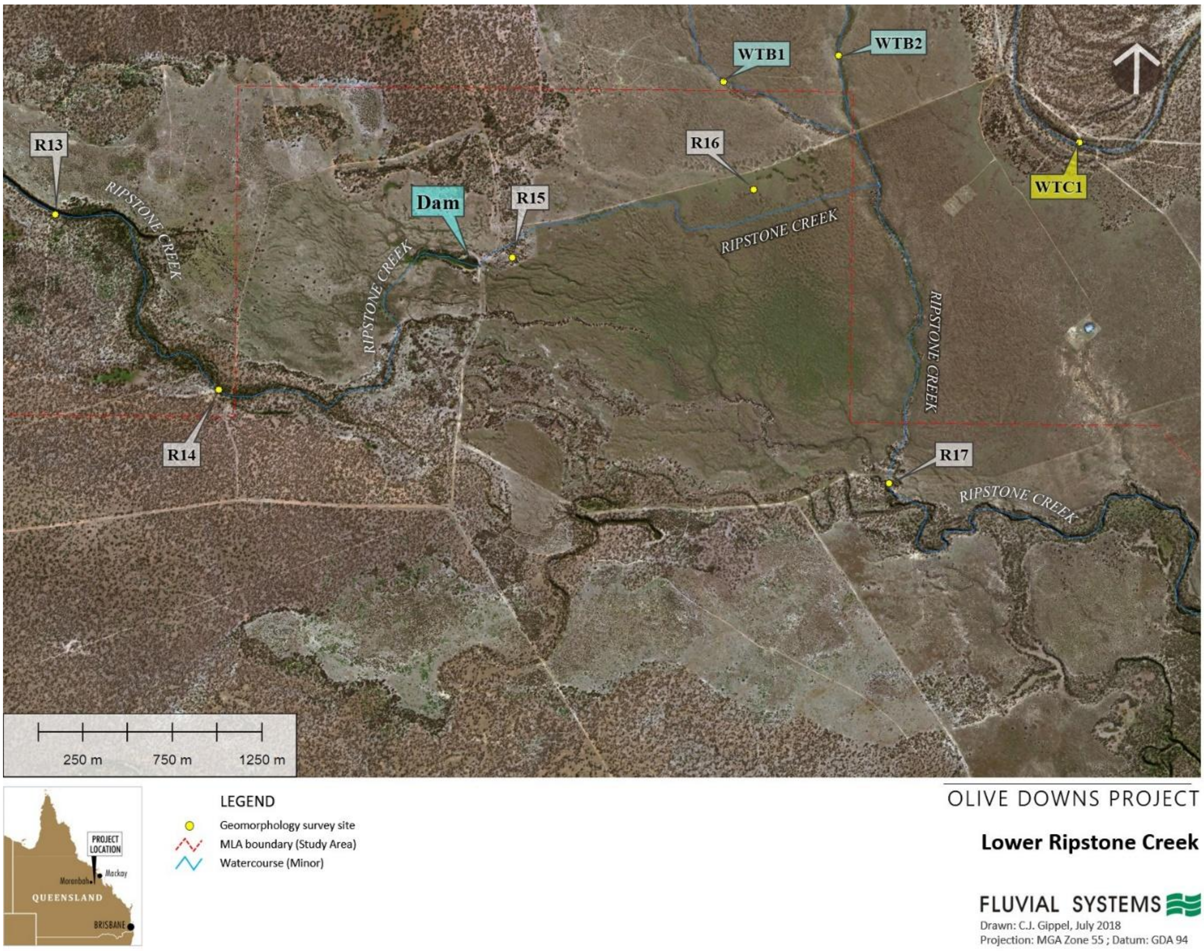


Figure 33. Lower Ripstone Creek, showing surveyed sites and 1:100,000 watercourse blue lines.

4.2.8 Stream geomorphic condition

Stream geomorphic condition was determined for the field survey sites within the Study Area using a number of stream type-independent criteria (Table 2). All of the sites fitted within the description of Good geomorphic condition. It should be noted that assessing whether a stream has geomorphic character different to its expected character is highly subjective and uncertain, unless data or evidence is available to indicate the expected character (i.e. either the undisturbed character from a time prior to pastoral settlement, or a character naturally adjusted to the current hydrological and sediment regime). The level of bank erosion observed was within what would be expected for an undisturbed or lightly disturbed stream, and longitudinal discontinuities, known as knickpoints, were not observed. Riparian vegetation cover was continuous and structurally sound at nearly all sites, although exotic species were present.

One of the descriptors of Poor geomorphic condition used by Outhet and Cook (2004) is ‘Excessively high volumes of coarse bedload which blanket the bed, reducing flow diversity’. While this was a universal characteristic of all of the larger streams (Order 3 and higher) of the Study Area, no evidence was uncovered to suggest that this was unnatural. This challenges the claim by Alluvium (2011) that the sand bed of the Isaac River was evidence of geomorphic degradation due to altered catchment land use. The sub-surface geology of the wider Study Area is dominated by sandstone, and the surface geology is almost entirely sandy deposits or sandy soils. No gullies were observed in the Study Area that would indicate land degradation of the scale that would be required to modify a river system from pool-riffle gravel-cobble bed to amorphous sand sheet.

Information about the geomorphic condition of the Isaac River prior to European settlement can be gleaned from the journal of explorer Ludwig Leichardt on his 1844/45 expedition through the area on his way to Port Essington (Leichardt, 1846). The following paragraph details Leichardt’s impression upon sighting the Isaac River for the first time on 13 Feb 1845:

> “*Feb. 13. — The morning was very cloudy. I continued my course to the northward, and, coming to a watercourse, followed it down in the hopes of finding water: it led us to the broad deep channel of a river, but now entirely dry. The bed was very sandy, with reeds and an abundance of small Casuarinas. Large flooded-gums and Casuarinas grew at intervals along its banks, and fine openly timbered flats extended on both sides towards belts of scrub. The river came from the north and north-west, skirting some fine ranges, which were about three miles from its left bank. As the river promised to be one of some importance I called it the “Isaacs,” in acknowledgment of the kind support we received from F. Isaacs, Esq. of Darling Downs*.”

Leichardt did not provide exact coordinates for the location where his party first came upon the Isaac River, but the journal entries around that time allow an approximation to be made. His camp at the time was to the west on Hughes Creek, an upper tributary of Boomerang Creek. Leichardt referred to Boomerang Creek as Hughes Creek all the way to its junction with the Isaac River. On 14 Feb a member of the party found a lagoon “…*on the left bank of the Isaacs, at a short half-mile from its junction with Hughs’s Creek*”. On 15 Feb Leichardt’s party “…*travelled down to the above-mentioned lagoon, which was about ten miles east by north from our camp; its latitude, was by calculation, about 22 degrees 20 or 21* [minutes]*; for several circumstances had prevented me from taking observations*”. This location places Leichardt on a currently existing lagoon on the western bank of the Isaac River, between latitudes 22° 20’ 27” and 22° 20’ 49”, 1 km south of the junction of Billabong Creek and Isaac River. That same day, Leichardt “…*set out with Mr. Gilbert and Brown to examine the country around the range which I had observed some days before and named “Coxen’s Peak and Range*”. Coxen’s Peak, 4.2 km NE of Iffley Station on the Isaac River, retains the same name today.

On the side trip to Coxens Peak and Range, Leichardt observed:

> “*The whole extent of country between the range and the coast, seemed to be of sandstone, either horizontally stratified, or dipping off the range; with the exception of some local disturbances, where basalt had broken through it. Those isolated ranges, such as Coxen’s Range — the abruptness of which seemed to indicate igneous origin — were entirely of sandstone. The various Porphyries, and Diorites, and Granitic, and Sienitic rocks, which characterize large districts along the eastern coast of Australia, were missing; not a pebble, except of sandstone, was found in the numerous creeks and watercourses. Pieces of silicified wood were frequent in the bed of the Isaacs*”.

Thus, Leichardt was fascinated by the ubiquitous presence of sandstone in the area, and, unlike the east coast rivers he was familiar with, the lack of material other than sand in the creek beds. During the field investigation undertaken for this Geomorphology Technical Report silicified wood was observed within occasional small outcrops of sedimentary rock at the base of the banks of the Isaac River (Figure 34), and isolated surface accumulations of gravel and cobble usually contained pieces of silicified wood.

After exploring Coxen's Range, Leichhardt returned westward to the Isaac River. On the way back to the camp at the lagoon, which they reached on 17 Feb, they noted a waterhole dug into the river bed and fortified by branches by Aborigines at latitude 22° 11', which places them just downstream of the junction of North Creek. On 21 Feb they decamped from the lagoon and headed upstream. The next day they sighted a flock of cockatoos at a point "…*About eight miles north-west from the junction of North Creek with the river*".

Leichardt's journal from 13 to 21 Feb 1845 clearly places him on the Isaac River within the Study area, between Billabong Creek junction and North Creek junction. His description of the river is similar to how it would currently be described, except for Leichardt's expected observation of more abundant, and perhaps more diverse, riparian flora and fauna.

It appears that following the publication of Leichardt's report of his expedition (Leichardt, 1846), pastoralists were quick to settle the Dawson, McKenzie and Isaac river area (Frere, 1945). This development occurred prior to Queensland being declared a separate state in 1859. The only readily available historical photograph of the Isaac River is from 1878, probably around 30 years after settlement, which shows a bullock wagon loaded with goods having just crossed the bed of the river (Figure 35). The National Library of Australia gives the location of this photograph as 22.22732°S,148.393929°E, which is not on the river, but 3.8 km WNW of Iffley Station, so the given location is approximate. Flowing water obscures the bed of the river in the photograph, but the channel morphology and riparian vegetation appear similar to the condition of the river when it was inspected in the field.

Despite evidence that the Isaac River and tributaries naturally have sand beds, it is possible, but not demonstrable, that land surface disturbance due to pastoral and mining activity has accelerated transport of sand from the land surface to the stream channel network and resulted in greater than expected volumes of sand in the bed.

Figure 34. Isaac River, localised outcrop of bedrock containing pieces of silicified wood. Lower photograph is close-up view of centre of scene of upper photograph.

Figure 35. Bullock team pulling a wagon full of goods, Isaac River, ca. 1878. Source: Trove, National Library of Australia, URL http://trove.nla.gov.au/version/167821903 (accessed 4 December, 2017).

5.0 Impact assessment – Isaac River

5.1 Hydraulic data

A 2-D hydraulic model was developed by Hatch (2018) to simulate the hydraulic characteristics of a number of flood scenarios at the Olive Downs Coking Coal Project site for the existing and developed case. Mapped and tabulated model output data were provided of hydraulic variables for 2 yr, 10 yr, and 50 yr ARI events. The data indicated that the 2 yr event was in-channel through the Project area. The 10 yr event broke out of the banks in some areas through Olive Downs South, while there were sections where a wide elevated levee remained above flood level. For the base case and the developed case, the 50 yr ARI flood fully inundated the channel and floodplain. The model confirmed the field observation of a significant downstream contraction in channel size, despite increasing tributary contributions.

On the basis of the flooding behaviour, and identified areas with the highest potential for accelerated scour or deposition associated with the development, 6 cross-sections and 3 long-profiles (Figure 36) were selected for assessment of geomorphic risk. Data were provided along all transects at 11 – 15 m intervals for the variables:

- Ground level
- Water level
- Velocity
- Stream power
- Bed shear stress

For each variable, the data for each transect represented the maximum value of the variable at the point on the transect.

Bed material transport was not evaluated here, but it is sufficient to note that the sand in the bed of the Isaac River will be mobile over a wide range of discharges. The bed is likely to be sufficiently mobile in moderate to large floods that sand will be mixed in the flow and available for deposition on the banks and floodplain surface in areas with low velocity, or as the flood recedes.

5.2 Results

The velocity and bed shear stress data for each cross-section and long profile were plotted with water surface and ground elevations (Figure 37, Figure 38, Figure 39, Figure 40, Figure 41, Figure 42, Figure 43, Figure 44, and Figure 45). For completeness, stream power was also plotted, even though this variable was not assessed using stability criteria. Modelled hydraulic conditions along the long profiles were highly variable, as the profile alignments crossed variable terrain at various distances from the river bank and within the river channel. While the long profile data complemented the cross-section data, specific reference to results from the long profiles was not necessary in order to describe the major predicted changes in channel and floodplain hydraulics due to the proposed development. Thus, this results section focuses on the cross-sections.

The data file for Cross-section 6, existing case, 50 yr ARI event, had missing velocity data (Figure 42).

Under both existing and developed cases, under the 2, 10 and 50 yr ARI events, the Isaac River channel had mean cross-section bed shear stress less than 100 N/m^2, although most individual values in the central channel area were close to, and a few exceeded,100 N/m^2. The channel bed is bare sand, so it would be mobile under these shear stresses. The geomorphological field investigation observed the banks to be generally well-vegetated and stable, with occasional areas on the outside of bends showing evidence of scour. This is part of the normal process of channel migration and adjustment.

Under existing conditions, the floodplain was not inundated under the 2 yr ARI flood event. Under the 10 and 50 yr ARI events, most areas of the floodplain had mean bed shear stress <10 N/m^2, with some areas in flood channels of 20 – 40 N/m^2. Cross-section 2 had a wide area on the left floodplain with bed shear stress approaching 50 N/m^2. The data suggest that under existing conditions, the floodplain is dominantly a depositional environment.

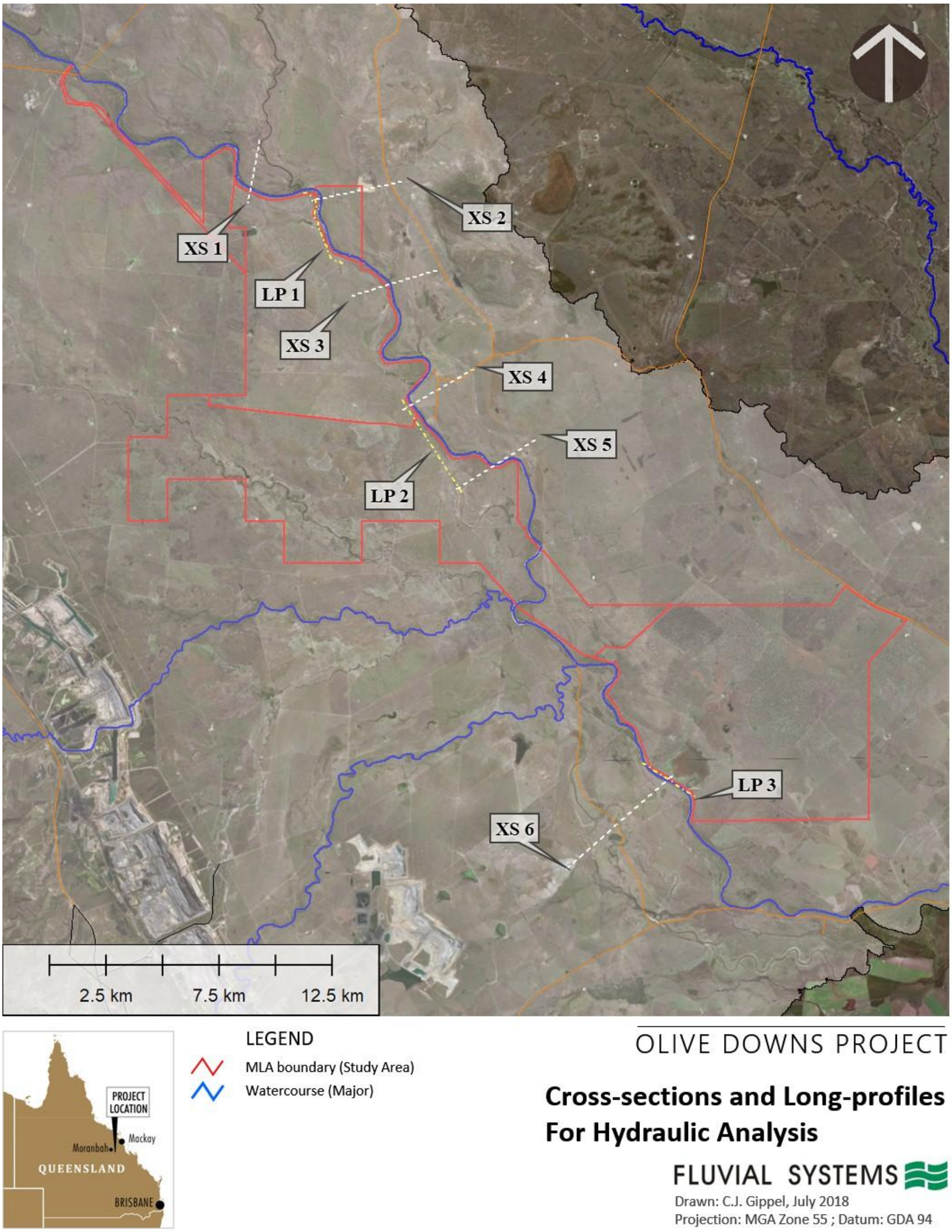


Figure 36. Locations of cross-sections and long-profiles evaluated in this preliminary assessment.

Under the developed case, a 50 yr ARI event would cause inundation of a left-bank terrace at Cross-section 2; this area would not be inundated under existing conditions. However, the bed shear stress on this terrace would be low, with most areas having less than 10 N/m^2, and all areas less than 20 N/m^2. In comparison, under existing conditions the bed shear stress on the left floodplain mostly exceeded 10 N/m^2 and reached up to 50 N/m^2 (this area of floodplain would be removed from the flow path under the developed case). A similar situation is represented by Cross-section 5, where the right bank floodplain was not inundated by the 50 yr ARI event under existing conditions, but would experience widespread inundation under the developed case. However, under the 50 yr ARI event for the developed case, the bed shear stress on the floodplain would be relatively low, with most areas having less than 20 N/m^2, and all areas less than 30 N/m^2.

A proposed embankment at Cross-section 4 would elevate bed shear stress through confinement of the flow. Bed shear stress on the areas of the floodplain impacted by confinement due to development would reach a maximum of 30 N/m^2 for the 50 yr ARI flood scenario. The maximum permissible shear stress method suggests that the floodplain surfaces most impacted by development, represented by Cross-sections 2, 4 and 5, if maintained with complete and dense vegetation cover, should remain at a low risk of fluvial scour. If the vegetative cover is weakened by drought or grazing pressure, the risk of scour would increase markedly.

Comparisons of modelled velocity with maximum permissible velocity threshold of 2 m/s were similar to the comparisons between modelled bed shear stress and maximum permissible bed shear stress. The main areas of significant risk were Cross-sections 2, 4 and 5 under the 50 yr ARI flood scenario. At Cross-section 2, velocity increased on the banks and reached 1 m/s on the confined floodplain surface. At Cross-section 4, velocity increased by a factor of two on the right-bank confined floodplain surface, although velocity did not exceed 2 m/s. Similarly, the velocity did not exceed 1.5 m/s on the area of right bank floodplain of Cross-section 5 inundated under the 50 yr ARI flood scenario.

Overall, the impact of the development on hydraulic variables would be small enough that a rapid catastrophic geomorphic response would not be expected. However, the channel will slowly adjust to the altered hydraulic conditions through minor changes in bed and floodplain levels or channel widths. The greatest risk to rapid catastrophic geomorphic change is loss of structural integrity and coverage of the channel bank and floodplain vegetation.

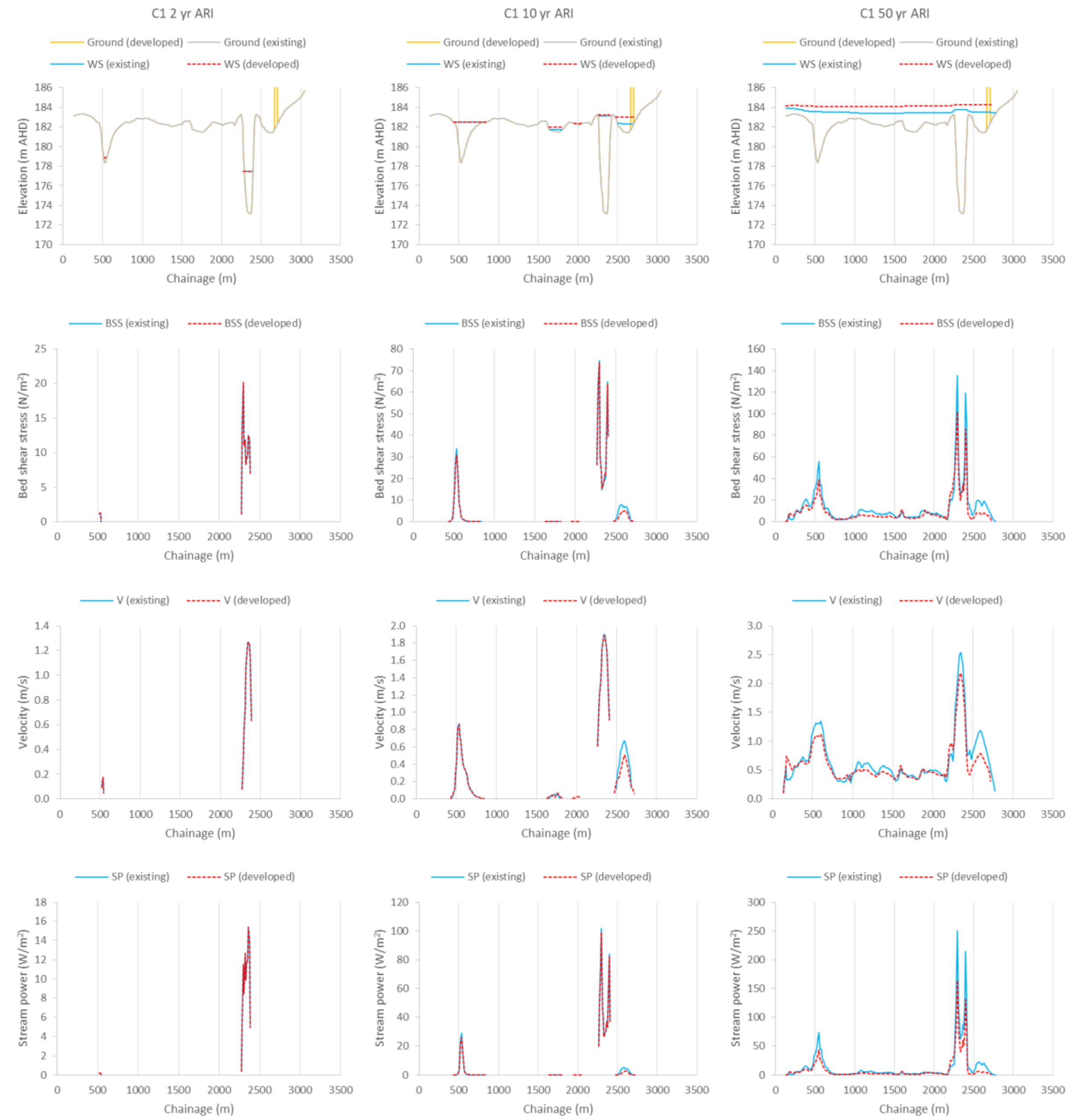


Figure 37. Cross-section 1 hydraulic character for 2 year, 10 year and 50 year ARI events. Note that Y-axis scales vary between flow scenarios.

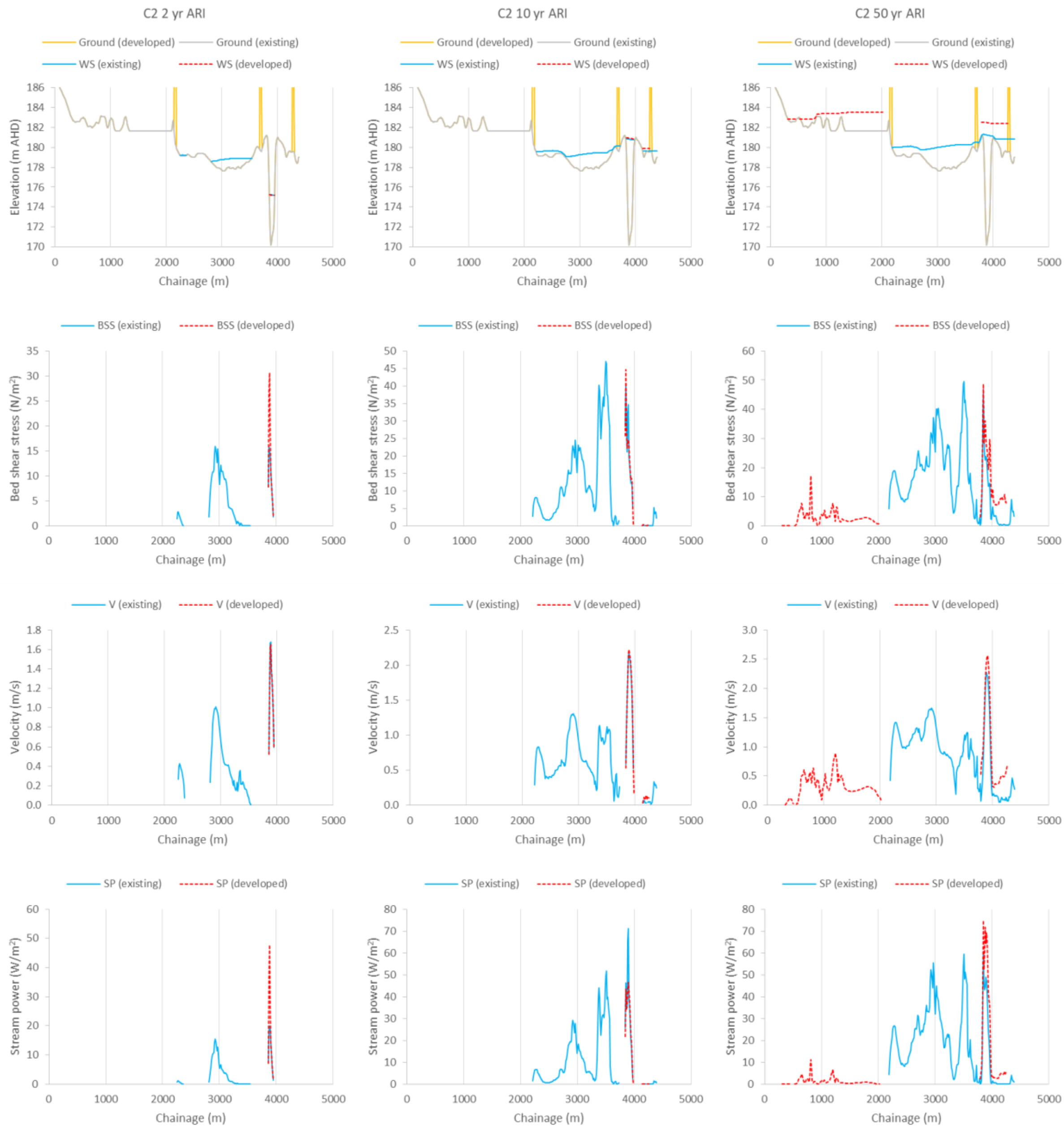


Figure 38. Cross-section 2 hydraulic character for 2 year, 10 year and 50 year ARI events. Note that Y-axis scales vary between flow scenarios.

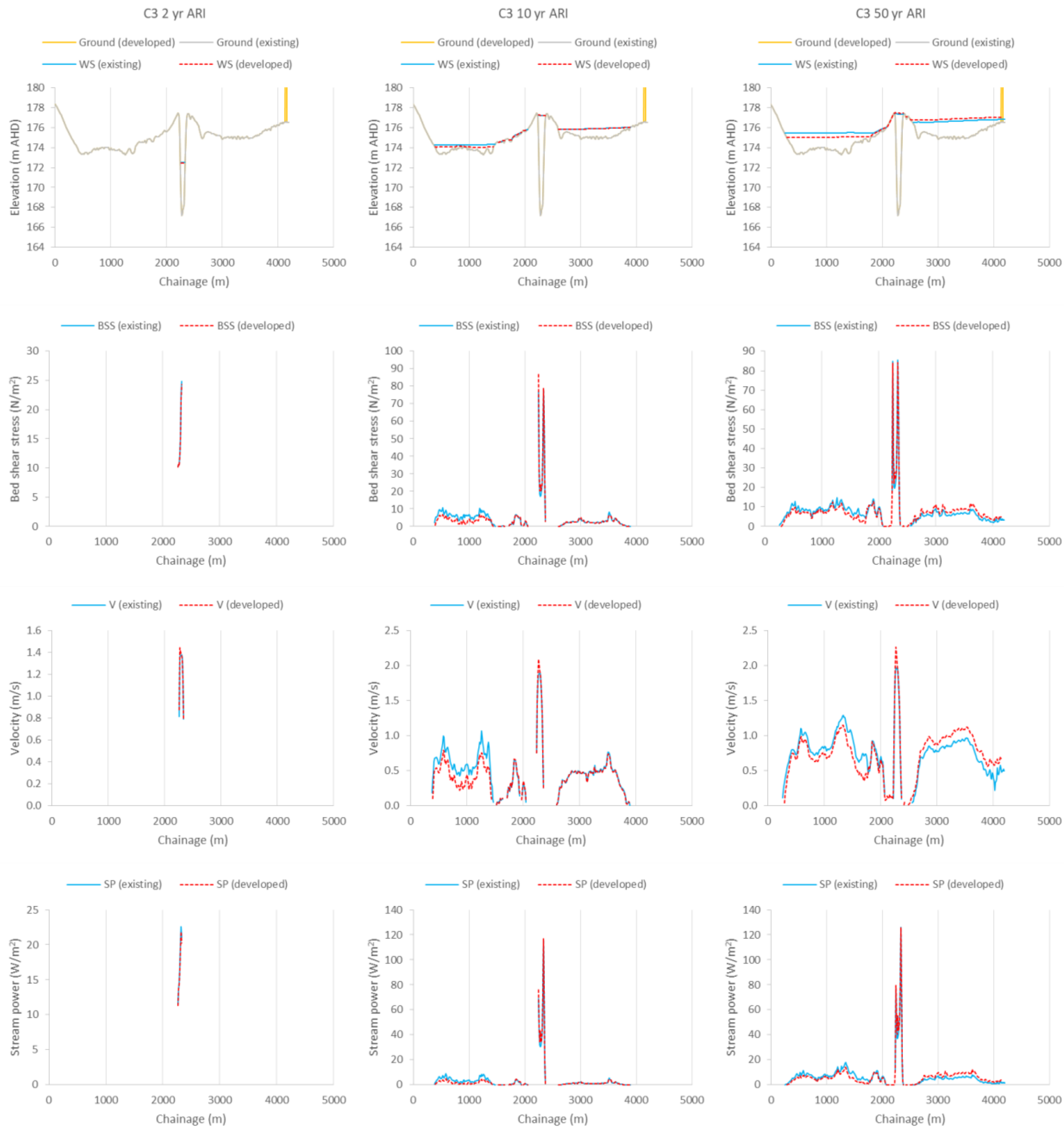


Figure 39. Cross-section 3 hydraulic character for 2 year, 10 year and 50 year ARI events. Note that Y-axis scales vary between flow scenarios.

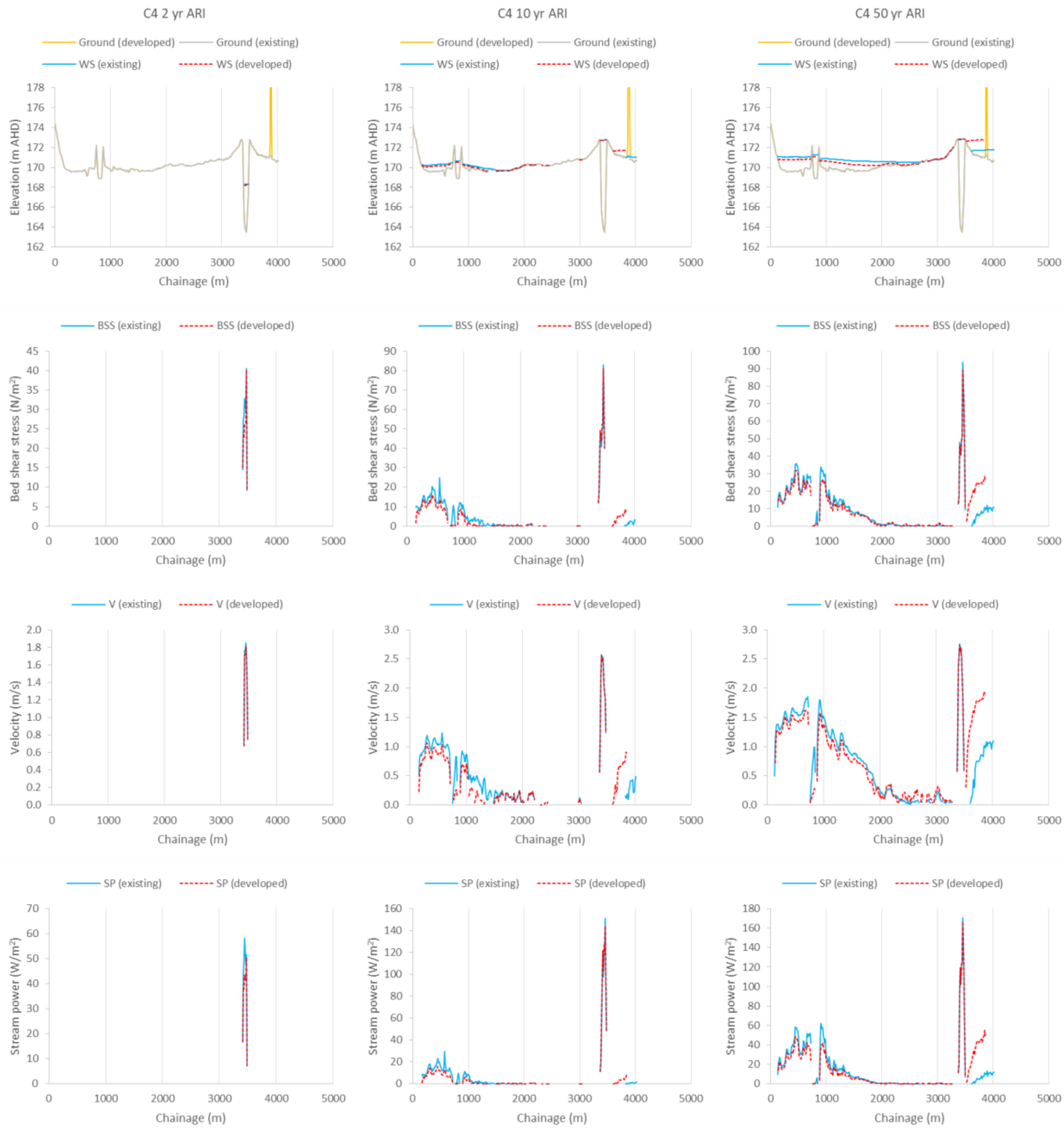


Figure 40. Cross-section 4 hydraulic character for 2 year, 10 year and 50 year ARI events. Note that Y-axis scales vary between flow scenarios.

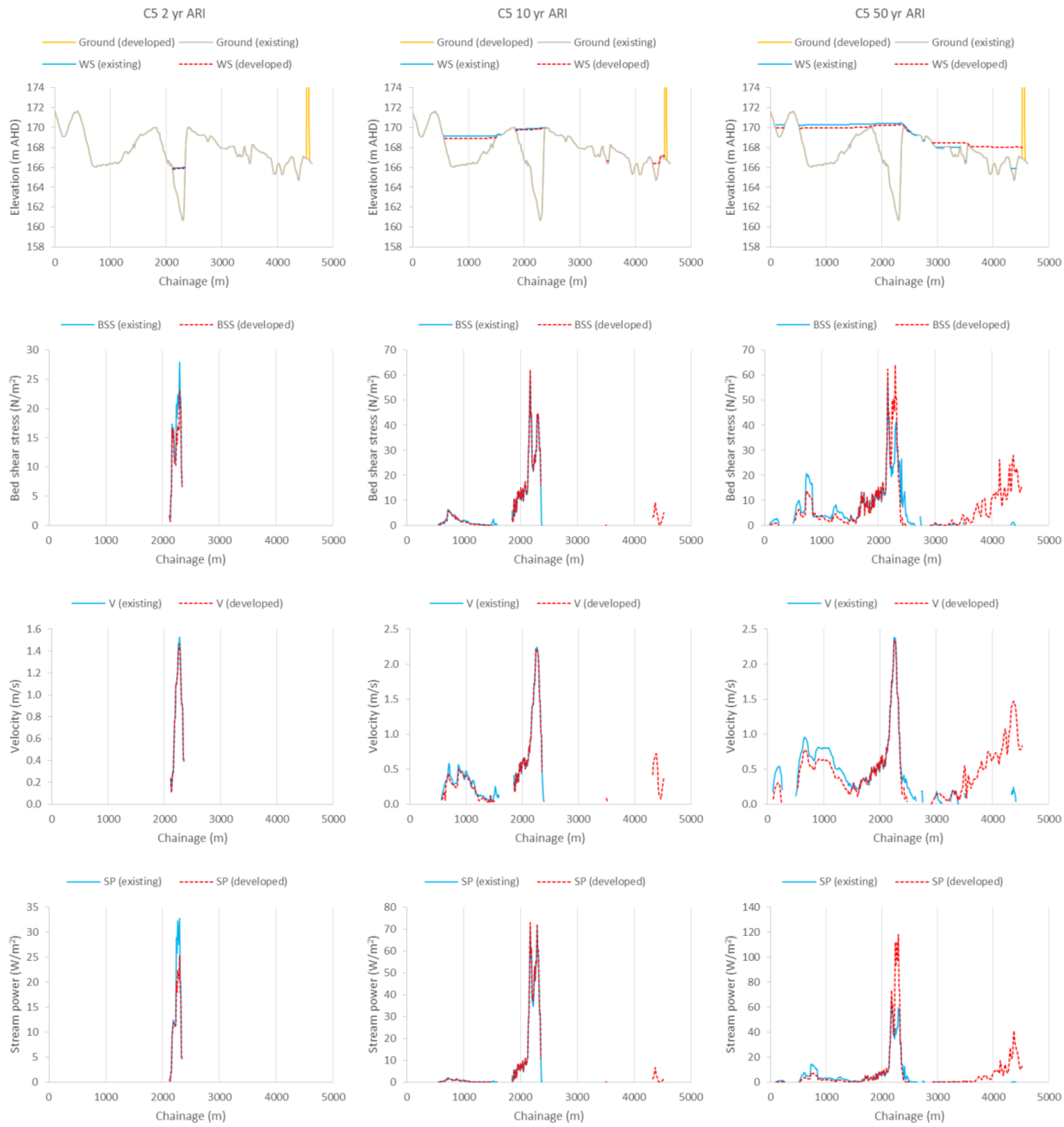


Figure 41. Cross-section 5 hydraulic character for 2 year, 10 year and 50 year ARI events. Note that Y-axis scales vary between flow scenarios.

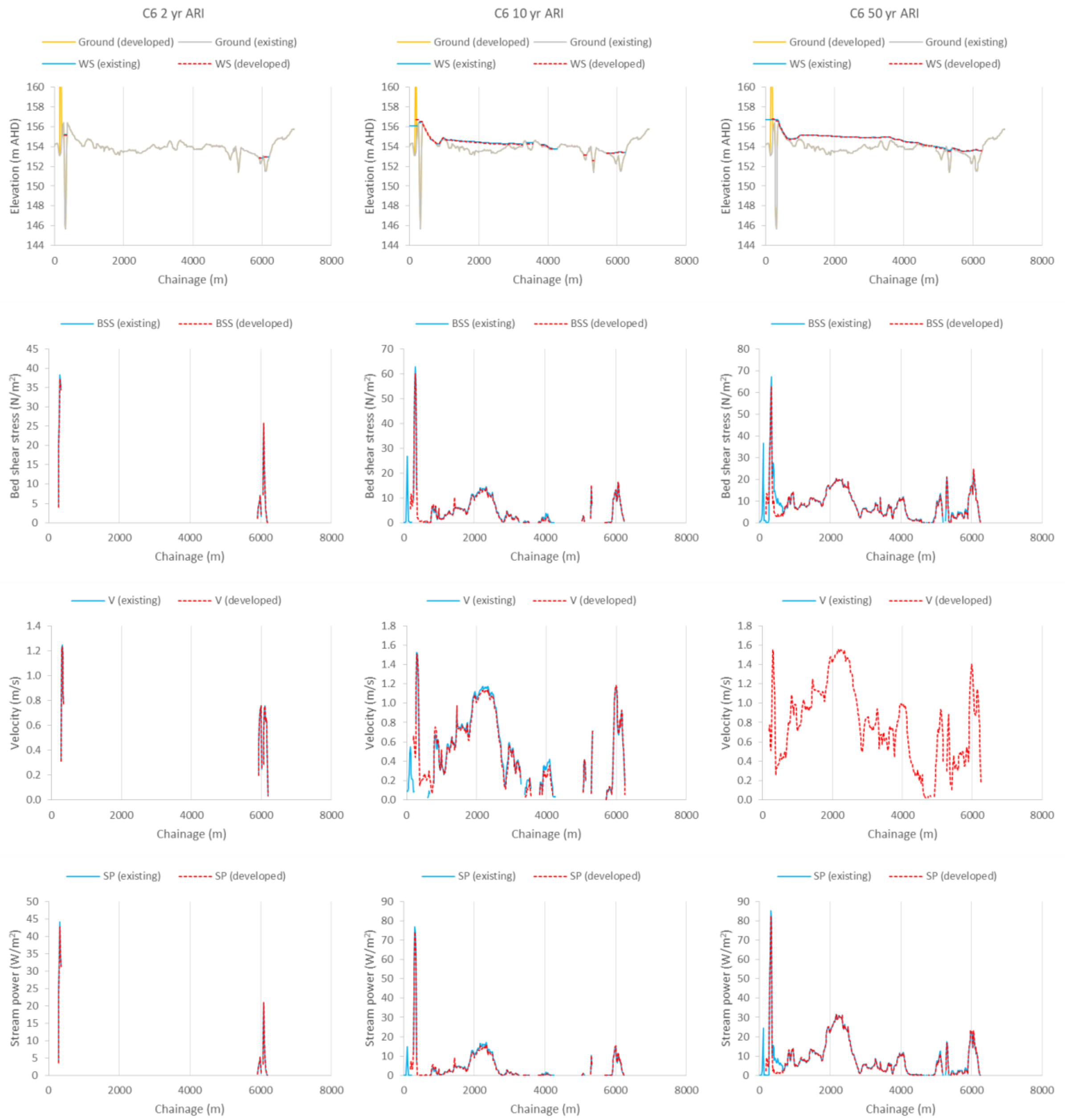


Figure 42. Cross-section 6 hydraulic character for 2 year, 10 year and 50 year ARI events. Note that Y-axis scales vary between flow scenarios. Note that velocity data are missing for existing scenario 50 year ARI event.

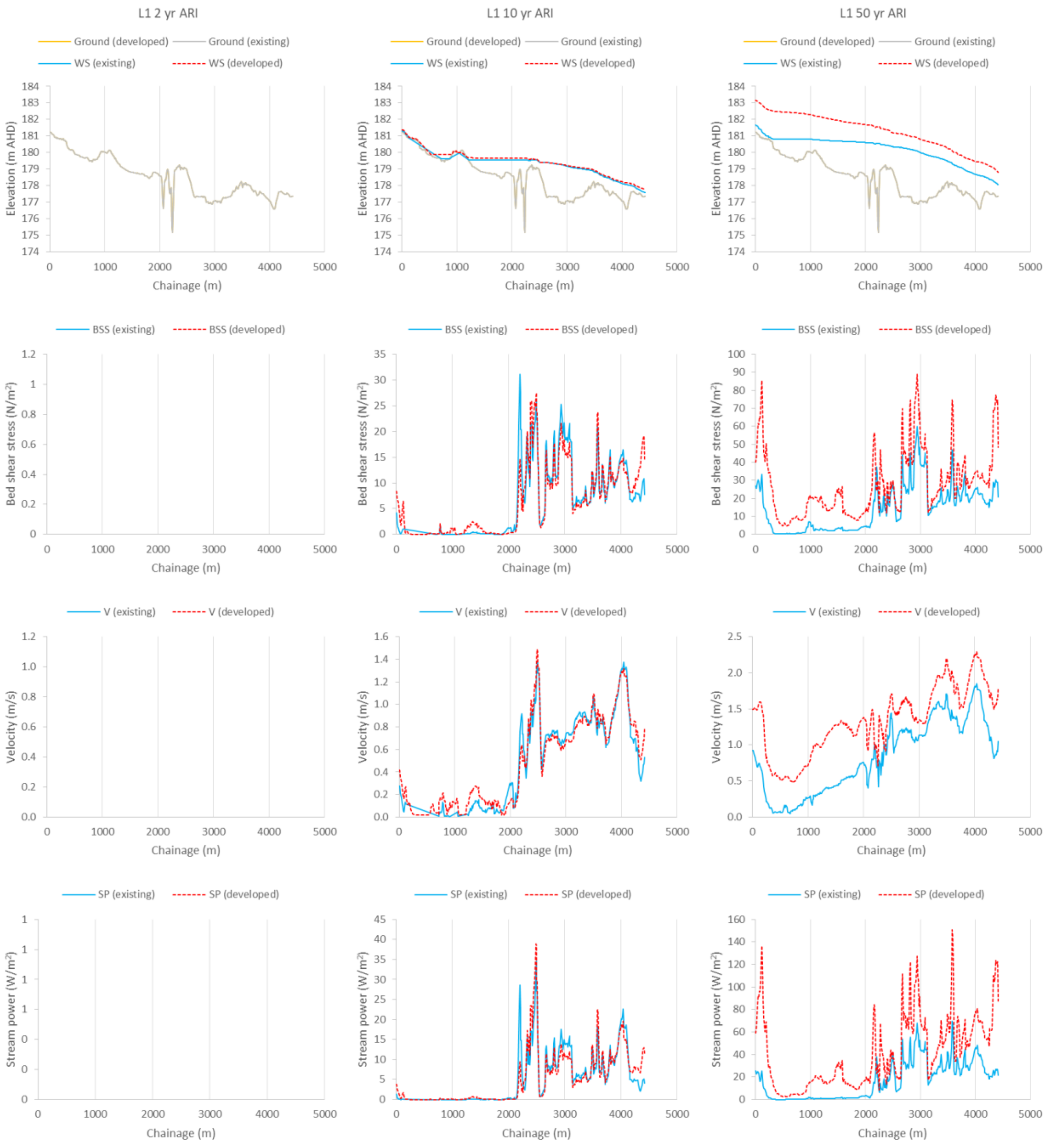


Figure 43. Long-profile 1 hydraulic character for 2 year, 10 year and 50 year ARI events. Note that Y-axis scales vary between flow scenarios.

Figure 44. Long-profile 2 hydraulic character for 2 year, 10 year and 50 year ARI events. Note that Y-axis scales vary between flow scenarios.

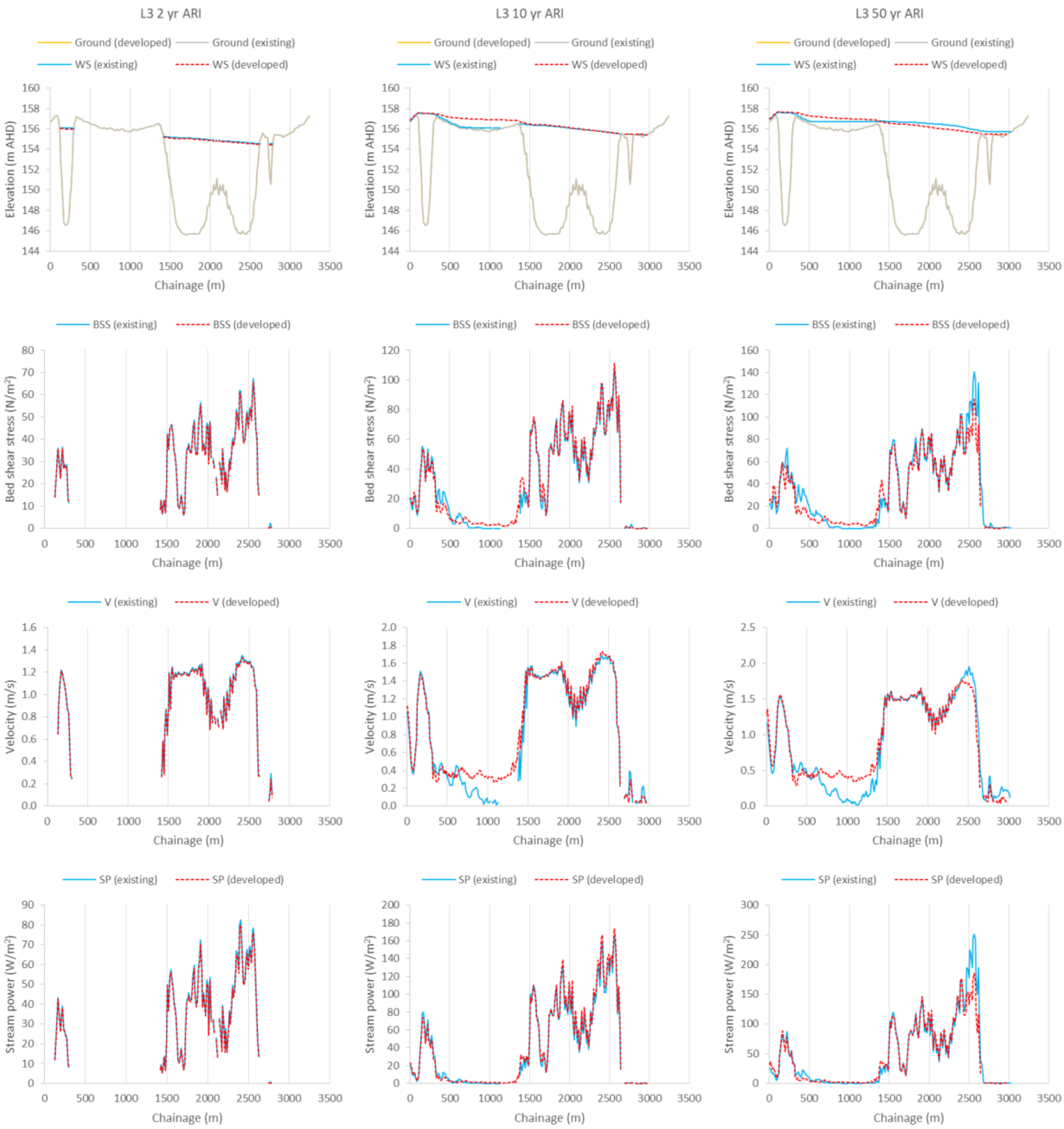


Figure 45. Long-profile 3 hydraulic character for 2 year, 10 year and 50 year ARI events. Note that Y-axis scales vary between flow scenarios.

6.0 Monitoring and Mitigation

6.1 Monitoring

Geomorphic monitoring should be undertaken using objective, scientifically sound methods, following a BACI (Before/After/Control/Intervention) design. The foundation of the recommended approach is topographic survey of Isaac River channel and floodplain, repeated every year for 3 years, and then either every five years, or after every flood event exceeding the 5 yr ARI event. This should be done using LiDAR technology, flown when the river flow is very low. It will be necessary to identify control reaches that are also monitored, preferably upstream of the mine, The monitoring principle is to characterise the degree of change at the control reaches of Isaac River and use this to set the tolerance for change in the intervention reach of the Isaac River through the Mining Lease Areas. After each survey, a monitoring report is to be prepared that uses scientific methods to evaluate the data, including statistical analysis to test for significance of differences across a range of geomorphic variables derived from the survey data.

Methods that use subjective visual assessments of geomorphic variables (e.g. erosion severity, or geomorphic condition score sheets) are not recommended, as in general, they are not founded on a sound basis of geomorphic theory, do not utilise a scientifically valid sampling strategy, observations are not repeatable within acceptable tolerances, and the data are not open to rigorous statistical testing.

6.2 Mitigation

Mitigation is to eliminate or reduce the frequency, magnitude, or severity of exposure to risks, or to minimise the potential impact of a threat. This can be achieved through vegetation management, maintaining complete vegetation cover over bank and floodplain surfaces. Mitigation measures would be triggered by unexpectedly large change in channel morphology identified through monitoring. The most appropriate response would need to be assessed at the time.

7.0 Conclusion

Repeatable field and desktop methods were used to characterise geomorphological attributes of of the Olive Downs Coking Coal Project Study Area. Most of the stream reaches were in a stable, close to natural geomorphic condition. Some streams were potentially impacted by factors that reduced their condition, in particular high loads of sand in the bed, but without historical data concerning condition prior to the land cover and drainage being modified for agricultural and mining use, this remains uncertain. No knickpoints or zones of major geomorphic instability were observed.

Most of the stream reaches were in a stable, close to natural geomorphic condition. Some streams were potentially impacted by factors that reduced their condition, in particular high loads of sand in the bed, but without historical data concerning condition prior to the land cover and drainage being modified for agricultural and mining use, this remains uncertain. No knickpoints or zones of major geomorphic instability were observed.

The risk of erosion of the Isaac River channel and floodplain was assessed using the method of maximum permissible bed shear stress and velocity assessment, with the hydraulic variables modelled as part of the flood study. This assessment of the most critical areas found that while there could be isolated areas subject to somewhat higher risk of scour compared to the existing situation, the overall risk of rapid and significant geomorphic change in the Isaac River due to the proposed mining activity was low.

Geomorphic monitoring should include topographic survey of Isaac River channel and floodplain, repeated every year for 3 years, and then either every five years, or after every flood event exceeding the 5 yr ARI event. This should be done using LiDAR technology, flown when the flow is very low. A Before-After, Control-Intervention monitoring design should be used, with tolerable limits of change in the intervention reaches set by the observed degree of change in control reaches.

Mitigation measures would be triggered by unexpectedly large change in channel morphology identified through monitoring. The most appropriate response would need to be assessed at the time.

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