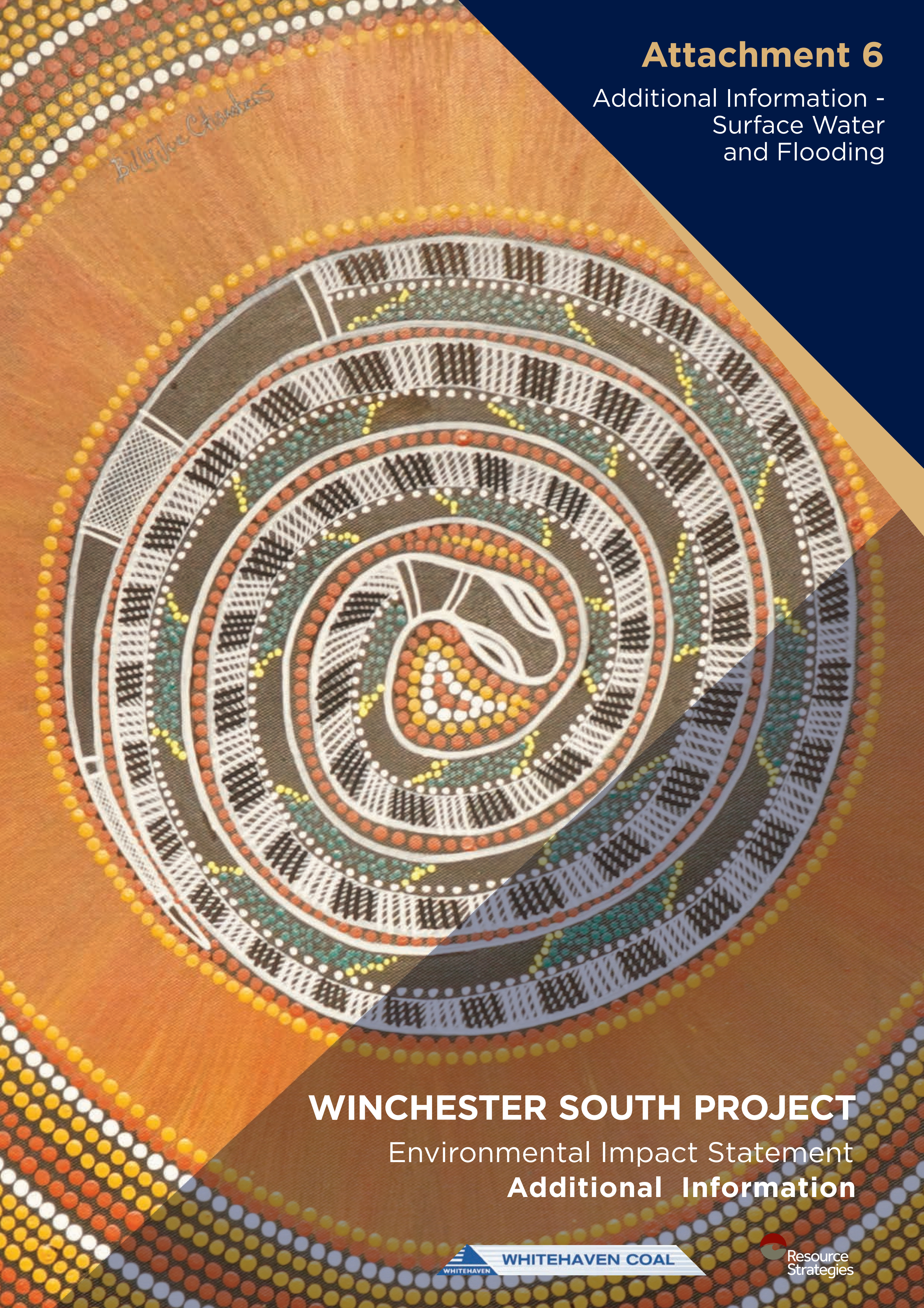

Attachment 6

Additional Information - Surface Water and Flooding

WINCHESTER SOUTH PROJECT

Environmental Impact Statement
Additional Information

WHITEHAVEN COAL

Resource Strategies

Winchester South Project

Surface Water and Flooding Assessment

Whitehaven Coal Limited

0869-08-E6, 13 October 2022

Report Title	Winchester South Project Surface Water and Flooding Assessment
Client	Whitehaven Coal Limited
Report Number	0869-08-E6

Revision Number	Report Date	Report Author	Reviewer
6	13/10/2022	AMC	MGB

For and on behalf of WRM Water & Environment Pty Ltd
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Principal Engineer

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Glossary

Term	Definition
AEP	Annual Exceedance Probability (%) - the chance of a given rainfall total which is accumulated over a given time period will be exceeded in any one year
ANZECC	Australian and New Zealand Environment and Conservation Council
ANZG	Australian and New Zealand Governments
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
AR&R	Australian Rainfall and Runoff - a national guideline used for design flood estimation in Australia. Considered a key source of technical information for designing infrastructure to withstand the impact of extreme rainfall, flooding and storm surge.
AS/NZS	Australian Standard/New Zealand Standard
AWBM	Australian Water Balance Model
BOM	Commonwealth Bureau of Meteorology
CHPP	coal handling and preparation plant
CL	continuing loss
CSG	Coal Seam Gas
DEHP	Queensland Department of Environment and Heritage Protection
DES	Queensland Department of Environment and Science
DGV	default guideline values
DoR	Queensland Department of Resources
EA	Environmental Authority
EC	Electrical Conductivity
EIS	Environmental Impact Statement
EPBC Act	Commonwealth Environment Protection and Biodiversity Conservation Act 1999
EP Act	Environmental Protection Act 1994
EPP (Water)	The Environmental Protection (Water and Wetland Biodiversity) Policy 2019
ESC	erosion and sediment control
ESCP	erosion and sediment control plan
EV	environmental value
FSL	full supply level
GDA 94	Australian Geodetic Datum 1994
ha	hectare

Term	Definition
IL	initial loss
km	kilometres
km^2	square kilometres
LIDAR	Light Detection and Ranging
m	metre
m^2	Square metre
m^3	Cubic metres
mAHD	metres Australian Height Datum
m/s	metres per second
m^3/s	cubic metres per second
mg/L	milligrams per litre
MIA	Mining Infrastructure Area
ML	megalitres
ML	mining lease
MLA	mining lease application
ML/year	megalitres per year
ML/d	megalitres per day
mm	millimetres
mm/hr	millimetres per hour
mm/month	millimetres per month
Mtpa	million tonnes per annum
MOL	maximum operating level
MOV	maximum operating volume
NTU	Nephelometric Turbidity Units
NWQMS	National Water Quality Management Strategy
OPSIM	A computer-based *OP*erational *SIM*ulation water balance model
REMP	Receiving Environment Monitoring Program
ROM	run-of-mine
SDPWO Act	State Development and Public Works Organisation Act 1971
SILO	Scientific Information for Land Owners
SO_4	sulphate
t/ha/annum	tonnes per hectare per annum
TDS	total dissolved solids
TSS	total suspended solids

Term	Definition
TUFLOW	1-dimensional and 2-dimensional flood simulation software
WMS	water management system
WQG	Water Quality Guidelines
WQO	Water Quality Objectives
WRM	WRM Water & Environment Pty Ltd
XP-RAFTS	Rainfall runoff routing hydrological model used for hydrologic and hydraulic analysis of stormwater drainage and conveyance systems.
µS/cm	microSiemens per centimetre

1 Introduction

1.1 BACKGROUND

The Winchester South Project (the Project) is located approximately 30 kilometres (km) south east of Moranbah, in the Isaac Regional Council Local Government Area (LGA) (Figure 1.1), within the Bowen Basin Coalfield (Figure 1.2), in Queensland. The Project involves the development of an open cut metallurgical coal mine in an existing mining precinct. Products would include metallurgical coal for the steel industry and thermal coal for energy production.

Whitehaven WS Pty Ltd (Whitehaven WS) is the proponent for the Project, and is a wholly owned subsidiary of Whitehaven Coal Limited (Whitehaven). In 2021, Whitehaven WS submitted the Winchester South Project Environmental Impact Statement (the EIS) for assessment under the State Development and Public Works Organisation Act 1971 (SDPWO Act). The EIS was placed on public notification by the Office of the Coordinator General (OCG) from 4 August 2021 until 15 September 2021. During and following this period, government advisory agencies, organisations and members of the public provided submissions on the Draft EIS to the OCG.

Subsequent to the public notification of the Draft EIS, Whitehaven WS reviewed the mine plan and mine schedule with the aim of reducing environmental impacts of the Project and challenging the Project final landform in response to comments raised in submissions. This review also considered new geological data, coal quality data and the outcomes of processing trials to further refine the mine plan.

On 3 December 2021, the Coordinator General formally requested (in accordance with section 34A of the SDPWO Act) Additional Information on the environmental effects of the Project and other matters relating to the Project.

This Surface Water and Flooding Assessment forms part of the Additional Information and provides an assessment of the optimised mine plan and mine schedule and responses to issues raised in submissions.

This report presents the following:

- An overview of the regulatory framework which applies to the Project;
- A description of the existing surface water environment surrounding the Project, and the associated environmental values (EVs);
- A detailed description of the proposed strategy to manage water in and around the Project and details of the expected performance of the proposed water management system;
- A detailed description of the flood behaviour of waterways in the vicinity of the Project, and details of flood protection levees; and
- A discussion of the potential surface water impacts of the Project and the proposed measures to manage and mitigate these impacts. This includes a cumulative impact assessment of the Project considering potential compounding interactions with similar impacts from other projects within an appropriate region of influence.

1.2 PROJECT DESCRIPTION

The proposed open cut mining domains are generally aligned from north to south, and are located on the western side of the Isaac River (Figure 1.2).

Staged mine plans are provided in Main Text of the EIS, and show the Project would be progressively developed and rehabilitated over its life. The extent of the Project open cut mining area, waste rock emplacements and infrastructure areas (i.e. the Project disturbance footprint) is approximately 7,130 hectares (ha).

The mine infrastructure area (MIA) would include, but not necessarily be limited to, a coal handling and preparation plant (CHPP), administration buildings, substation and electricity distribution infrastructure, crib facilities, bathhouse, warehouse, workshops and re-fuelling facilities, communication facilities and other associated amenities. The CHPP would include the coal processing plant, CHPP workshops and offices and other associated facilities.

Existing local and regional infrastructure would be used to transport product coal via rail to the port for export, including the Goonyella rail system to the Dalrymple Bay Coal Terminal or the Abbot Point Coal Terminal (via the Newlands rail system) and/or the Blackwater rail system to the Gladstone coal port.

The main activities associated with the development of the Project include:

- development and operation of an open cut coal mine within mining lease application (MLA) 700049, MLA 700050 and MLA 700051;
- development and operation of an infrastructure corridor within MLA 700065, located outside mineral development licence (MDL) 183;
- use of open cut mining equipment to extract run-of-mine (ROM) coal with a current forecast rate of approximately 15 million tonnes per annum (Mtpa) (and up to 17 Mtpa);
- a mine life of approximately 31 years which includes:
    - 1 year of construction at the beginning of the Project
    - 28 years of active mining
    - 2 years of waste movement at the end of the Project
- placement of waste rock (i.e. overburden and interburden) in out-of-pit waste rock emplacements and within the footprint of the open cut voids;
- construction and operation of the MIA, including a CHPP, ROM pads, workshops, offices, raw and product handling systems, coal processing plant and train load-out facility;
- construction and operation of a Project rail spur and loop to connect the Project to the Norwich Park Branch Railway, including product coal stockpiles for loading of product coal to trains for transport to ports;
- progressive rehabilitation of out of pit waste rock emplacement areas;
- progressive backfilling and rehabilitation of the mine voids with waste rock behind the advancing open cut mining operations (i.e. in-pit emplacements);
- installation of a raw water supply pipeline;
- construction of a mine access road (including associated railway crossing) from the Eagle Downs Mine Access Road, off Peak Downs Mine Road, to the MIA;
- co-disposal of coal rejects from the Project CHPP within the footprint of the open cut voids and/or out of pit emplacement areas;

- progressive development and augmentation of sediment dams and storage dams, pumps, pipelines and other water management equipment and structures (including up catchment diversions, drainage channel realignments and levees);
- progressive construction and use of soil stockpile areas, laydown areas and gravel/borrow areas (e.g. for road base and ballast material);
- progressive development of haul roads, light vehicle roads and services;
- wastewater and sewage treatment by a sewage treatment plant;
- 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* (DES, 2013); and
- other associated minor infrastructure, plant and activities.

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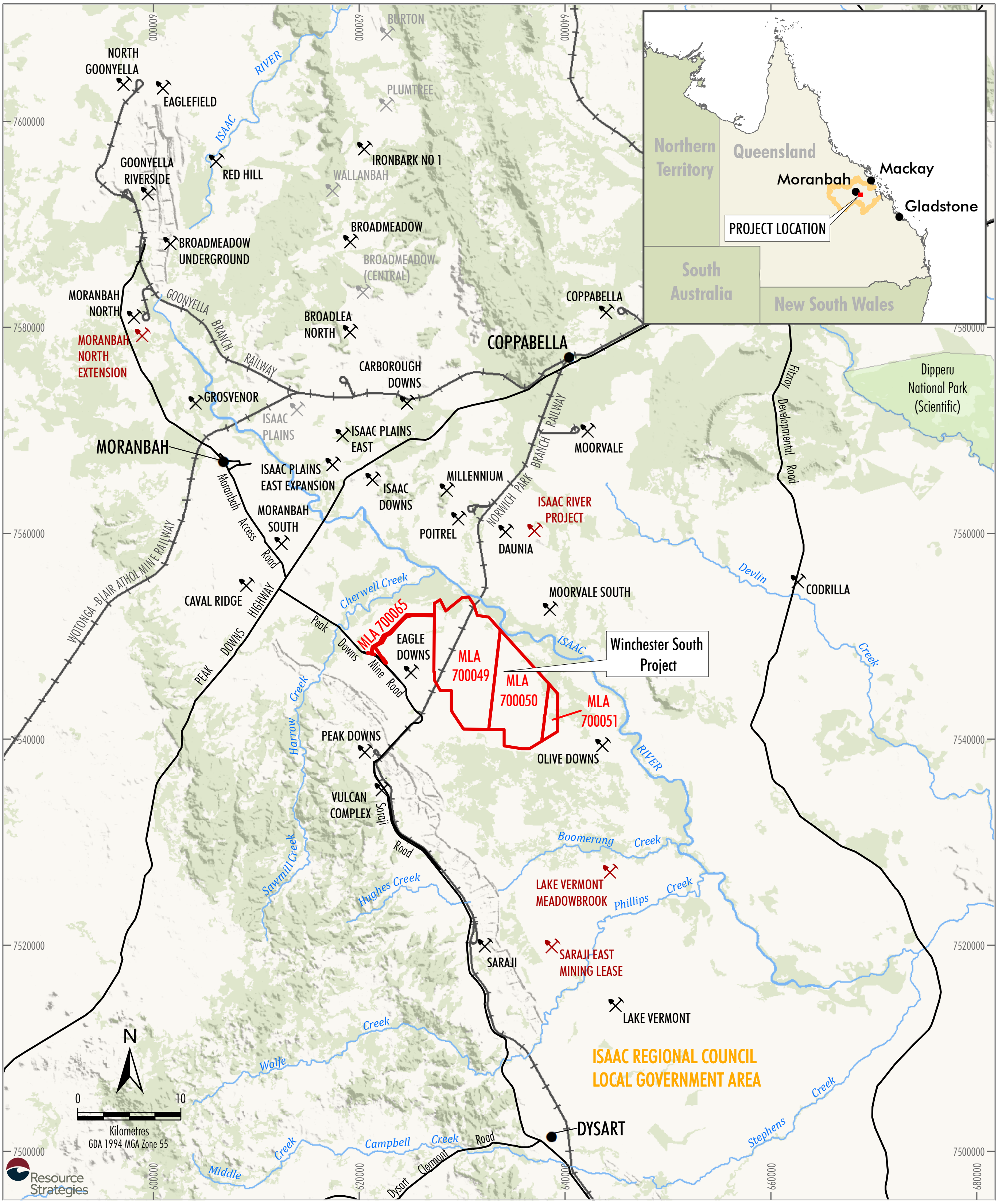

LEGEND
- Mining Lease Application Boundary
- Approved/Operating
- Proposed
- Care and Maintenance
- Local Government Area Boundary
- Railway
- Road

Source: The State of Queensland (2018 - 2020); Geoscience Australia (2018).

WHITEHAVEN COAL

WINCHESTER SOUTH PROJECT

Project Location

Figure 1

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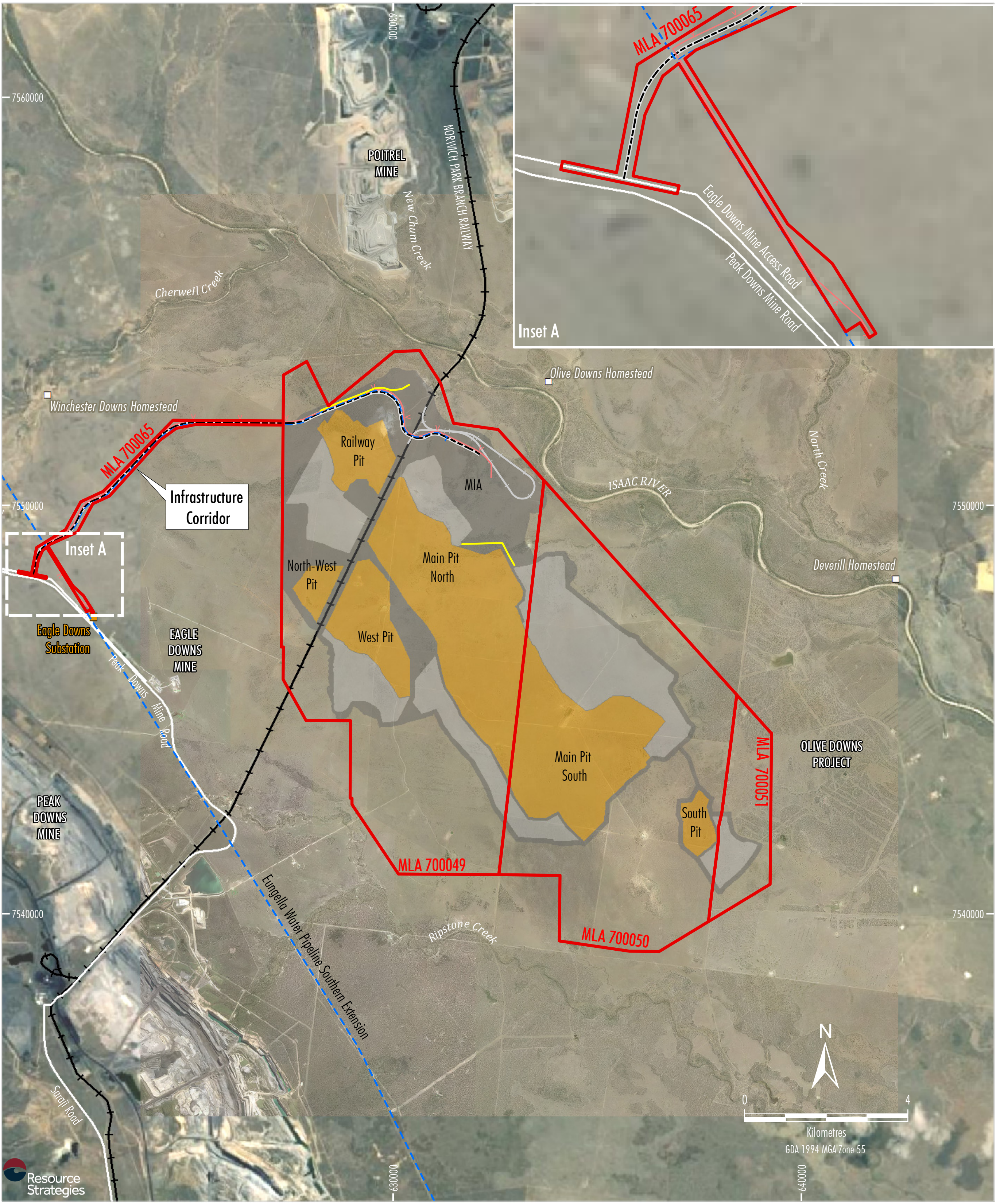


LEGEND

- Mining Lease Application Boundary
- Eungella Water Pipeline Southern Extension
- Railway
- Substation

Project Component*

- Indicative Infrastructure Area
- Indicative Out-of-pit Waste Rock Emplacement
- Indicative Open Cut Pit Including In-pit Waste Rock Emplacement
- Indicative Mine Access Road
- Indicative Rail Spur and Loop
- Indicative Electricity Transmission Line
- Indicative Raw Water Supply Pipeline
- Indicative Flood Levee

*Note: * Excludes some project components such as water management infrastructure, access tracks, topsoil stockpiles, explosives magazines, power reticulation, temporary offices, other ancillary works and construction disturbance.*

Source: The State of Queensland (2018 - 2020); Whitehaven (2020)
Orthophoto: Google Image (2019); Whitehaven (2017)

WHITEHAVEN COAL

WINCHESTER SOUTH PROJECT

Project General Arrangement

Figure 2

1.3 TERMS OF REFERENCE

This Surface Water and Flooding Assessment forms part of an Environmental Impact Statement (EIS) which has been prepared in accordance with Part 4 of the SDPWO Act. This assessment has been prepared to satisfy the requirements of the *Terms of reference for an environmental impact statement – Winchester South Project* issued by the Coordinator General on 4 September 2019.

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 relevant to surface water and flooding. Table 1.1 lists the elements of the TOR relevant to this assessment and the sections of this report where those TORs are addressed.

Table 1.1 -Terms of Reference for the EIS relevant to surface water and flooding

Key issue	Requirement	Report section
10 Project description		
10.13 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.		Section 6.3 & Main Text of the EIS
11 Assessment of project specific matters		
Water quality – existing environment		
11.36 -	Describe the water related environmental values and describe the existing surface water and groundwater quality regime within the study area in terms of water body interaction and high/low freshwater flows. Describe the baseline condition of the existing waters in, upstream and downstream of the site and describe the water quality requirements of existing and potential water users in areas potentially affected by the proposed project	Section 3.1
11.37 -	With reference to the *Environmental Protection (Water and Wetland Biodiversity) Policy 2019* (EPP (Water and Wetland Biodiversity)), section 9 of the *EP Act*, Schedule 8 of the *EP Regulation* and SPP *State Interest Guideline – Water Quality* and other guidelines, identify the environmental values of surface water (including wetlands) and groundwater within the project site and surrounding area, including immediately downstream that may be affected by the project, including any human uses of the water and any cultural values.	Section 3.2
11.38 -	At an appropriate scale, detail the chemical, physical and biological characteristics of surface waters and groundwater within the area that may be affected by the project, including within and adjacent to the site. Water quality parameters should be appropriate to the downstream, and upstream uses and environmental values that may be affected. Include a description of water quality variability within the study area associated with climatic and seasonal factors, variability of freshwater flows and extreme events using suitable reference locations and sufficient data to adequately establish baseline condition.	Section 4.4

Key issue	Requirement	Report section
Water quality – impact assessment		
11.39 -	The assessment of impacts on water is to be in accordance with DES guideline *Application requirements for activities with impacts to water* (ESR/2015/1837) and DES EIS information guideline for an environmental statement – water (or updates as they become available).	Main Text of EIS
11.41 -	Identify the predicted quantity and quality (including location, timing and duration) of all potential discharges of water and wastewater sewage by the project, whether as point sources (such as controlled and uncontrolled discharges from regulated dams) or diffuse sources (such as seepage from waste rock dumps/waste management areas or irrigation to land of treated sewage effluent). Assess the potential impacts of any discharges on the quality and quantity of receiving waters (including groundwater) taking into consideration the assimilative capacity of the receiving environment and the practices and procedures that would be used to avoid or minimise impacts. Refer to DES Receiving environment monitoring program guideline for use with environmentally relevant activities under the EP Act.	Section 5.11 & Section 7.3.6
11.42 -	Describe the cumulative impacts of the proposed project, in conjunction with existing development and possible future development (as described by approved plans and existing project approvals), to water quality.	Section 10.6
Water quality – mitigation measures		
11.44 -	Describe how the achievement of the water quality objectives would be monitored, audited, reported, and how corrective/ preventative actions would be managed in accordance with EPP (Water and Wetland Biodiversity).	Section 2.2.1, Section 10.7 & Main Text of EIS
11.45 -	Describe the proposed management of existing, altered and/or constructed waterbodies including any watercourse, waterway, lake or spring on the project site to maintain water quality. Describe all methods and management to avoid and minimise impacts occurring to groundwater.	Section 7.3, Section 10.7 & Main Text of EIS
11.46 -	Describe measurable criteria, standards and/or indicators that will be used to assess the condition of the ecological values and health of surface water environments, mitigation strategies and contingency plans for: a) potential accidental discharges of contaminants and sediments during construction and operation b) stormwater run-off from the project facilities and associated infrastructure c) flooding of relevant river systems, and other extreme events d) management of acid sulphate soils	Section 10.6 & Section 10.7
11.47 -	Describe erosion and sedimentation characteristics at the project areas and what erosion and sedimentation controls are proposed for all parts of the proposed project to avoid and/or mitigate impacts on water quality during construction, operation and decommissioning. Demonstrate that impacts are avoided, mitigated or appropriately managed, including the use of development free buffers.	Section 5.5, Section 5.7, Section 6.4 & Section 6.7

Key issue	Requirement	Report section
Water resources – existing environment		
11.48 -	Describe the water related environmental values and describe the existing surface water and groundwater resources regime within the study area and the adjoining waterways in terms of water levels, discharges and flows. Describe existing and potential users of water in areas potentially affected by the proposed project, including municipal, agricultural, industrial, mining, recreational and environmental uses of water.	Section 3 & Section 4.5
11.49 -	Describe any existing and/or constructed waterbodies including any watercourse, waterway lake or spring within and adjacent to the project.	Section 4.2
Water resources - impact assessment		
11.51 -	The assessment of impacts on water is to be in accordance with DES guideline Application requirements for activities with impacts to water (ESR/2015/1837) (or updates as they become available).	Main Text of EIS
11.52 -	Provide details of proposed monitoring, impoundment, extraction, discharge, injection, use or loss of surface water or groundwater (including volumes and rates).	Section 6.9 & Section 7.3
11.53 -	Provide details of existing and proposed changes to stormwater regimes, including changes to flow paths/patterns such as significant diversion or interception of overland flow and locations of interference/ disturbance of watercourses and floodplain areas. Include maps of suitable scale showing the location of diversions, changes to flow and other water-related infrastructure in relation to mining infrastructure including water storages, sediment dams, water treatment plants, levees, drains, diversions, bunds, monitoring points and release points.	Section 5 & Main Text of EIS
11.54 -	Describe watercourse diversion design, operation and monitoring consistent with relevant parts of Department of Natural Resources, Mines and Energy's guideline: *Works that interfere with water in a watercourse – watercourse diversions*.	Section 4.2 & Section 5.6
11.55 -	Provide an assessment of the impact on the receiving environment and aquatic and ecological communities from any interference with waters such as redirection of flood waters through the installation of levees or construction of other facilities and infrastructure.	Section 10.4
11.56 -	Describe any quantitative standards and indicators which will be used to describe the ecological values and health of surface water environments.	Section 10.7.4
11.57 -	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. The models should address the range of climatic conditions that may be experienced at the site throughout all phases of the project, and adequately assess the potential cumulative impacts of the project on water resources including to the post-decommissioning phase. The models should include a site water balance (including any voids) to determine the upper and lower bounds of future water levels after mine closure, and the calculated trends of water quality in the voids over time. This should enable a description of the project's impacts at the local scale and in a regional context including proposed: a) surface waters	Section 7, Section 8.6 & Section 8.7

Key issue	Requirement	Report section
	i. changes in flow regimes from diversions, water take and discharges ii. alterations to riparian vegetation and bank and channel morphology iii. direct and indirect impacts arising from the project iv. management of mine affected water	
11.58 -	Provide information on the proposed water usage by the project, including details about: a) the ultimate supply required to meeting the demand for full occupancy of the development, including timing of demands b) the quality and quantity of all water supplied to the site during the construction and operational phases based on minimum yield scenarios for water reuse, rainwater reuse and any bore water volumes c) a water balance analysis d) a site plan outlining actions to be taken in the event of failure of the main water supply.	Section 7.3.4 & Section 10.3
11.59 -	Determination of potable water demand must be made for the project, including the temporary demands during the construction period. Include details of any existing town water supply to meet such requirements. Detail should also be provided to describe any proposed on-site water storage and treatment for use by the site office during construction and operational phases.	Section 5.11, Section 0 & Main Text of EIS
11.60 -	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 water management protocol that may apply.	Section 5.9, Section 7.3.4, Section 10.3 & Section 11.2
11.61 -	Describe the cumulative impacts of the proposed project, in conjunction with existing development and possible future development (as described by approved plans and existing project approvals), to water resources, including management of impacts on underground water rights under the Water Act 2000.	Section 10.6
Water resources – mitigation measures		
11.62 -	Provide detailed designs for all infrastructure utilised in the treatment of on-site water including how any onsite water supplies are to be treated, contaminated water is to be disposed of and any decommissioning requirements and timing of temporary water supply/treatment infrastructure is to occur.	Section 5.11 & Main Text of EIS
11.63 -	Describe measures that would be used to avoid, minimise or mitigate any impacts on surface water and groundwater resources.	Section 10 & Main Text of EIS
11.64 -	Describe how the achievement of the water resources objectives would be monitored, audited, reported, and how corrective/ preventative actions would be managed.	Section 10 & Main Text of EIS
11.65 -	Provide a policy outline of compensation, mitigation and management measures where impacts are identified.	Main Text of EIS

Key issue	Requirement	Report section
Hazards health and safety – impact assessment		
11.129 -	Describe flood risk from rainfall events for a range of annual exceedance probabilities (including Probable Maximum Flood) for the site and assess how the project may change flooding characteristics.	Appendix C, Section 9.1, Section 9.2 and Section 9.3
11.130 -	The assessment should consider all infrastructure associated with the project including culverts or levees, roads and linear infrastructure and all proposed measures to avoid or minimise risks to life, property, community (including damage to other properties) and the environment during flood events.	Appendix C, Section 9.1, Section 9.2 and Section 9.3
Flooding and regulated dams – existing environment		
11.137 -	Describe likelihood and history of flooding onsite and in proximity to the site, including the extent, levels and frequency and current flood risk for a range of annual exceedance probabilities up to the probable maximum flood for potentially affected waterways and assess (through flood modelling and any additional data) how the project may potentially change flooding characteristics and be affected by floods. The flood modelling assessment should consider local and regional flooding and all infrastructure associated with the project including levees, roads and linear infrastructure and all proposed measures to avoid or minimise impacts.	Section 9
Flooding and regulated dams – impact assessment		
11.138 -	List and describe all dams and levees proposed on the project site and undertake a category assessment of each dam or levee according to the criteria outlined in the *DES Manual for assessing consequence categories and hydraulic performance of structures* (ESR/2016/1933).	Section 5.5, Section 6.12 & Section 9.1.5
Flooding and regulated dams – mitigation measures		
11.139 -	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 9.1.5
11.140 -	Describe how risks associated with dam or storage failure, seepage through the floor, embankments of the dams, and/or with overtopping of the structures will be avoided, minimised or mitigated to protect people, property and the environment.	Section 6.12, Section 10.1 & Main Text of EIS

1.4 REPORT STRUCTURE

This report is structured as follows:

- Section 2 describes the regulatory framework that would apply to surface water management for the Project;
- Section 3 describes the EVs of the regional receiving waters;
- Section 4 describes the existing surface water environment including the regional and local drainage characteristics;
- Section 5 describes the proposed surface water management system including the management objectives and principles;
- Section 6 describes the site water balance model configuration;
- Section 7 provides a summary of the water balance model results for the site water management system;
- Section 8 presents the outcomes from the residual void water balance assessment;
- Section 9 presents the outcomes from the flood modelling assessment;
- Section 10 describes the outcomes from the impact assessment for surface water (including cumulative impacts);
- Section 11 presents of summary of findings for the surface water and flooding assessment;
- Section 12 presents the references used throughout the report;
- Appendix A describes the setup and configuration of the flood model;
- Appendix B presents the results of water balance sensitivity assessment;
- Appendix C presents the stream power and shear stress flood maps;
- Appendix D presents the Isaac River flood maps, including the impacts of the Project;
- Appendix E presents the XPRafts design discharge box and whisker plots; and
- Appendix F presents the Geomorphology Assessment prepared by Fluvial Systems.

2 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.

2.1 COMMONWEALTH

2.1.1 Environment Protection and Biodiversity Conservation Act 1999

The Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) outlines the requirements relating to the management and protection of matters of national environmental significance (MNES). On 17-18 July 2019, the Department of Environment and Energy (DEE) (now the Department of Agriculture, Water and the Environment [DAWE]) determined that the following Project actions were controlled actions under the EPBC Act:

- Winchester South Project Electricity Transmission Line, near Moranbah, Queensland (EPBC 2019/8458);
- Winchester South Project Water Pipeline, near Moranbah, Queensland (EPBC 2019/8459); and
- Winchester South Project Mine Site and Access Road, 30 km south-east of Moranbah, Queensland (EPBC 2019/8460).

Note that only the Winchester South Coal Mine Site and Access Road controlled action (EPBC 2019/8460) includes 'a water resource, in relation to coal seam gas development and large coal mining development (sections 24D & 24E)' as a controlling provision, which is of relevance to the Surface Water and Flooding Assessment.

2.1.2 Independent Expert Scientific Committee

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

The IESC provides independent, expert scientific advice on CSG 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 CSG and large coal mining development proposals where there is a significant impact on water resources, including assessment against the Significant Impact Guidelines 1.3: Coal seam gas and large coal mining developments - impacts on water resources (Department of the Environment [DotE], 2013). The core purpose of the guideline is to determine whether a 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 17-18 July 2019, the Project 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 Commonwealth Minister for Environment (the Minister).

The report sections where the IESC information checklist for individual proposals have been addressed are outlined in Table 2.1.

Table 2.1 – IESC information checklist - surface water

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, Section 4 & Main Text of EIS
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 5, Section 10 & Main Text of EIS
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 4, Section 10, Appendix A & Appendix F
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.	Section 9 & Appendix C
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.	Groundwater Assessment
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 & Appendix C
Use methods in accordance with the most recent publication of *Australian Rainfall and Runoff* (Ball et al. 2016).	Appendix C, Section C1
Develop and describe a program for review and update of the models as more data and information becomes available.	Section 7.6 & Main Text of EIS
Describe and justify model assumptions and limitations and calibrate with appropriate surface water monitoring data.	Section 6 & Appendix C

Project information	Report section
Provide an assessment of the risks and uncertainty inherent in the data used in the modelling, particularly with respect to predicted scenarios.	Section 7.5
Provide a detailed description of any methods and evidence (e.g. expert opinion, analogue sites) employed in addition to modelling.	Section 7.5 & Attachment 4 of the EIS
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 3 & Section 4.4
Identify processes to determine surface water guidelines and quantity thresholds which incorporate seasonal variation but provide early indication of potential impacts to assets.	Section 7
Propose mitigation actions for each identified significant impact.	Table 6.4
Describe the adequacy of proposed measures to prevent or minimise impacts on water resources and water-dependent assets.	Section 7, Section 8 & 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 & Appendix F
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.	Section 9

Project information	Report section
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 4.3 & Section 6.3
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 3, Section 4.4, Section 10.7 & Appendix A
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.	Appendix F
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.	Aquatic Ecology and Stygofauna Assessment
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]).	Groundwater Assessment
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]).	

Project information	Report section
Provide an outline of the water-dependent assets and associated environmental objectives and the modelling approach to assess impacts to the assets.	Section 3.2
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 4.4
Water dependent assets – impacts, risk assessment and management of risk	
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 2.2.1, Section 8, Section 10, Main Text of EIS, Groundwater Assessment, Terrestrial Ecology Assessment, Aquatic Ecology and Stygofauna Assessment & Integrated Assessment of Impacts on Groundwater Dependent Ecosystems
Describe the potential range of drawdown at each affected bore, and clearly articulate the scale of impacts to other water users.	
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.	
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.	
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.	
Assess the overall level of risk to water-dependent assets through combining probability of occurrence with severity of impact.	
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.	
Propose mitigation actions for each identified impact, including a description of the adequacy of the proposed measures and how these will be assessed.	
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, Main Text of EIS, Groundwater Assessment, Terrestrial Ecology Assessment, Aquatic Ecology and Stygofauna Assessment & Integrated Assessment of Impacts on Groundwater Dependent Ecosystems
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)).	

Project information	Report section
Water and salt balance, and water management quality	
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.	Section 7
Describe the water requirements and on-site water management infrastructure, including modelling to demonstrate adequacy under a range of potential climatic conditions.	Section 6.8 & Section 7.3
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 7
Provide salt balance modelling that includes stores and the movement of salt between stores, and takes into account seasonal and long-term variation.	Section 7.4
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 & Main Text of EIS
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; and • 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 4
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; • the likely spatial magnitude and timeframe over which impacts will occur, and significance of cumulative impacts; and • opportunities to work with other water users to avoid, minimise or mitigate potential cumulative impacts.	Section 10.6

Project information	Report section
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, Section 10.7 & Main Text of EIS
Identify measures to detect and monitor cumulative impacts, pre and post development, and assess the success of mitigation strategies.	
Identify cumulative impact environmental objectives.	
Describe appropriate reporting mechanisms.	
Propose adaptive management measures and management responses.	
Final landforms 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 8 & Main Text of EIS
Assess the adequacy of modelling, including surface water and groundwater quantity and quality, lake behaviour, timeframes and calibration.	
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.	
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).	Geochemistry Assessment
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.	

2.2 QUEENSLAND

2.2.1 Queensland Environmental Protection Act 1994

The *Environmental Protection Act 1994* (EP Act) regulates the carrying out of mining activities authorised under the *Mineral Resources Act 1989* (MR Act). 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).*

2.2.1.1 Environmental Authority

Whitehaven WS has applied for an environmental authority (EA) under the EP Act. If granted, the EA will contain conditions that will govern the carrying out of environmentally relevant activities (ERAs) for the Project.

In the context of surface water management, the EA will set out conditions that will be relevant to the Project, including conditions that relate to:

- 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.

2.2.1.2 Model Mining Conditions

New mining project applications should apply the model mining conditions as outlined in *Model mining conditions* (DES, 2017a). The purpose of the model mining conditions is to provide a set of model conditions to form the general environmental protection commitments in EAs granted for mining activities regulated 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) forms the basis of the requirements for the Project water management system design.

2.2.1.3 Environmental Protection (Water and Wetland Biodiversity) Policy 2019

The *Environmental Protection (Water and Wetland Biodiversity) Policy 2019* (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 EVs and sets Water Quality Guidelines (WQGs) and Water Quality Objectives (WQOs).

The processes to identify EVs and to determine WQGs and WQOs in Queensland waters are based on the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (Australian and New Zealand Environment and Conservation Council [ANZECC] & Agriculture and Resource Management Council of Australia and New Zealand [ARMCANZ] guidelines).

2.2.1.4 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 EVs and WQOs for waters in the Isaac River Sub-basin, and they are listed under Schedule 1 of EPP (Water). Refer to Section 3 for further details.

2.2.1.5 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 criteria for consequence category assessment and certification of regulated structures associated with an ERA under the EP Act. The manual details the hydraulic design requirements for regulated structures and has been used as a reference in the preliminary design of the water management system and preliminary sizing of dams associated with the Project.

2.2.1.6 Guideline - Application Requirements for Activities with Impacts to Water

The Guideline Application requirements for activities with impacts to water (DES, 2021) focuses on the types of impacts that 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 provide details on a number of surface water-related issues, including:

- discharges and releases;
- unplanned and uncontrolled releases;
- water infrastructure;
- wetlands;
- Great Barrier Reef catchment waters;
- hydrology of receiving waters; and
- mixing zones.

Table 2.2 lists the elements of the guideline relevant to this assessment and the sections of this report where those elements are addressed.

The guideline refers to the new DES guideline "*Reef discharge standards for industrial activities*" (DES, 2022). DES (2022) was introduced on 1 June 2021 to help applicants address the new Reef discharge standard for industrial activities outlined in Section 41AA of the *Environmental Protection Regulation 2019*, that commenced on 1 June 2021. As the Initial Advice Statement (IAS) was submitted in February 2019 (more than two years prior to the introduction of DES (2022)), the guideline has not been considered as part of this Surface Water Assessment.

The guideline also refers to the department's technical guideline "*Wastewater releases to Queensland waters*", which is discussed in Section 2.2.1.7.

Table 2.2 – Guideline - Application requirement for activities with impact to water

Item	Report section
Discharges and releases • Identify the location, depth and configuration of all potential discharge points	Section 5.10
• Details of the contaminants and waste water to be released	Section 5.10, Section 6.11 & Section 7.3.5
Unplanned and uncontrolled releases • Identify activities that could lead to direct or indirect impacts and unplanned/uncontrolled release of contaminants to waters, such as, spills and leaks or stream bed and/or bank disturbance and describe the magnitude of the disturbance	Section 5.7, Section 5.10 & Section 6.11
• Identify the location, depth and configuration (if relevant) of the areas where the unplanned/uncontrolled release could be discharged to waters	Section 5.7 & Section 5.8
• Identify infrastructure (including containment devices) with the potential to release unplanned/uncontrolled contaminants to waters	Section 5.7 & Section 5.8
• Identify the potential contaminant type and quantities that could be released from infrastructure identified in dot point above	Section 5.11 & Section 7.3.6
Water infrastructure • Provide detail 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, sediment ponds, wastewater storage ponds, levees, levees, heap leach pads and any other water management infrastructure • All structures which are dams or levees associated with the operation of an ERA must have their hazard category assessed based on the potential environmental harm that would result from failure event scenarios, as per the 'Manual for assessing consequence categories and hydraulic performance of dams'. This will determine whether they are regulated structures. The design for a regulated structure must be determined by a suitably qualified and experienced person with relevant professional experience.	Section 5.5, Section 5.6, Section 5.7 & Section 5.8
Wetlands • Applicants must describe how the existing EVs of any wetlands on, or adjacent to, the site will be maintained, or enhanced	Refer to Terrestrial Ecology Assessment, Aquatic Ecology Assessment and Integrated Assessment of Impacts on Groundwater Dependent Ecosystems

Item	Report section
Great Barrier Reef catchment waters • Applicants should describe if the relevant activity will, or may have a residual impact to water quality in the Great Barrier Reef catchment waters from dissolved inorganic nitrogen or fine sediment. Applicants should refer to the department's guideline 'Reef discharge standards for industrial activities' (ESR/2021/5627) for more information on what to provide in an application to address section 41AA of the EP Regulation.	Not applicable (see above)
Hydrology of receiving waters • Describe, preferably through the use of water quality monitoring or modelling, how the proposed ERA will impact on the hydrology of receiving waters	Section 10.4, Section 10.6.3.2 & Section 10.7
Mixing zones • For planned/controlled release to water, describe the impact to any initial mixing zone(s)	Section 7.3.5

2.2.1.7 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) WQGs and the intent of the EPP (Water).

This guideline requires the following information:

- a description of the proposed activity;
- a description the receiving environment;
- prediction of the outcomes or impacts of the proposed wastewater release; and
- specification -of circumstances, limits and monitoring conditions.

Table 2.3 lists the elements of the guideline relevant to this assessment and the sections of this report where those elements are addressed.

2.2.2 Water Act 2000

In Queensland, the Water Act 2000 (Water Act) is the primary statutory document that manages and governs the allocation and use of non-tidal water resources. The Water Act is primarily administered by the Department of Resources (DoR) and the Department of Energy and Water Supply (DEWS).

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

- 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. DoR administers a watercourse identification map of Queensland 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 4.2.4, along with the existing determinations previously made.

Table 2.3 – Wastewater releases 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 4.4 & 6.10
• Assess the characteristics of the proposed release	Section 6.11 & 7.3.5
• Check the location and configuration of the proposed release	Section 5.10
Step 2 – Describe the receiving environment	
• Identify water bodies potentially affected by the proposed release	Section 5.10
• Provide all relevant information on the receiving environment	Section 4
• Consideration of temporary streams	Section 4
• Identify all relevant EV and WQO's	Section 3
• Ensure all government planning requirements applying to the water bodies have been considered	Section 2
• Check the location and configuration of the proposed release	Section 5.10
Step 3 – Predict outcomes of the proposed wastewater release	
• Assess whether contaminants are potentially toxic	Section 6.10
• Consideration of an initial mixing zone	Section 5.10.1
• Predict the assimilative capacity and sustainable load	Section 6.11 & 7.3.5 & 10.5.2.3
• Consider other potential impacts	Section 10
Step 4 – Set circumstances, limits and monitoring conditions	
• Specify any circumstances related to the approved wastewater release	Section 6.11
• Derive end-of-pipe limit from approved release loads and characteristics	Section 6.11
• Include a receiving environment monitoring program (REMP) requirement	Section 10.7.4
• Include reporting requirements for approved activity	Section 10.7

2.2.2.1 Water Plan (Fitzroy Basin) 2011

The Water Plan (Fitzroy Basin) 2011 was developed under the Water Act legislation to:

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

2.2.2.2 Water Regulation 2016

Water Regulation 2016 prescribes administrative and operational matters for the Water Act, including matters that relate to:

- water rights and planning;
- statutory authorisations to take or interfere with water;
- water licenses;
- water allocations;
- water supply and demand management; and
- declarations about watercourses.

2.2.2.3 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;
- stating flood mitigation responsibilities; and
- protecting the interests of customers of service providers.

3 Environmental values

The EPP (Water), which is subordinate legislation to the Queensland Environmental Protection Act 1994 (EP Act), provides a framework for identifying EVs for a waterway and deciding WQOs to protect or enhance those EVs. EVs for water are the qualities of water that make it suitable for supporting aquatic ecosystems and human water uses. These EVs need to be protected from the effects of habitat alteration, contaminated runoff and releases and changed flow to ensure healthy aquatic ecosystems and waterways that are safe for community use.

The main waterway in the vicinity of the Project is the Isaac River and is located within the Isaac and lower Connors River main channel region of the Isaac River Sub-Basin (WQ1301). The other waterway in the general vicinity of the Project is Ripstone Creek and is located within the Isaac western upland tributaries region of the Isaac River Sub-Basin. The EVs for this region are the same as for the main channel region, except for the addition of the aquaculture EV.

The EVs selected for protection include:

- aquatic ecosystem protection (slightly to moderately disturbed ecosystems as described in the WQGs);
- irrigation, farm use and stock watering;
- human consumption;
- primary, secondary and visual recreation;
- drinking water;
- industrial use;
- cultural and spiritual values; and
- aquaculture (Ripstone Creek only).

In summary, the key EVs for water that are to be protected are:

- physical, chemical and biological integrity of the watercourses within the catchment and their amenity as potential water sources for human use and to support aquatic ecosystems and aquaculture (Ripstone Creek only);
- the qualitive and quantitative integrity of local groundwater as a potential water source for agriculture or other suitable uses; and
- the integrity of raw water supplies and associated infrastructure in the region.

3.1 WATER QUALITY OBJECTIVES

The indicators and water quality guidelines relevant to the above environmental values are listed in the Queensland Water Quality (QWQ) Guidelines and ANZG (2018). The conditions of waterways located in the vicinity of the Project are classified as slightly to moderately disturbed ecosystems under the QWQ Guidelines (DEHP, 2013).

The WQOs relevant to the identified EVs are provided in Table 3.1. Where different EVs have different WQOs, the most conservative value has been adopted. WQOs are displayed for physio-chemical parameters only.

Table 3.1 – Water quality objectives, Isaac and Lower Connors River Main Channel

Parameter	WQO	Relevant EV
Ammonia N	< 0.9 mg/L	Aquatic ecosystem[a]
Oxidised N	< 0.06 mg/L	Aquatic ecosystem[b]
Organic N	< 0.42 mg/L	Aquatic ecosystem[b]
Total nitrogen	< 0.5 mg/L	Aquatic ecosystem[b]
Filterable Reactive Phosphorus (FRP)	< 0.02 mg/L	Aquatic ecosystem[b]
Total Phosphorus	< 0.05 mg/L	Aquatic ecosystem[b]
Chlorophyll a	< 0.005 mg/L	Aquatic ecosystem[b]
Dissolved oxygen	85-110% saturation > 4 mg/L at surface	Aquatic ecosystem[b] Drinking water[c]
Turbidity	< 50 NTU	Aquatic ecosystem[b]
Suspended solids	< 55 mg/L	Aquatic ecosystem[b]
pH	pH 6.5-8.5	Aquatic ecosystem[b]
Conductivity (EC) baseflow	< 720 µS/cm	Aquatic ecosystem[b]
Conductivity (EC) high flow	< 250 µS/cm	Aquatic ecosystem[b]
Sulphate	< 25 mg/L	Aquatic ecosystem[b]
Total Dissolved Solids	< 2000 mg/L	Stock watering[d]
Colour	50 Hazen Units	Drinking water[c]
Total Hardness	150 mg/L as CaCO3	Drinking water[c]
Sodium	< 30 mg/L	Drinking water[c]
Aluminium	< 20 mg/L < 5 mg/L < 0.055 mg/L (pH > 6.5)	Irrigation[g,e] Stock watering[f] Aquatic ecosystem[a]
Arsenic	2.0 mg/L 0.5 mg/L up to 5 mg/L < 0.013 mg/L	Irrigation[g, e] Stock watering[f] Aquatic ecosystem[b]
Beryllium	< 0.5 mg/L	Irrigation[g,e]
Boron	< 5 mg/L < 0.94 mg/L	Stock watering[f] Aquatic ecosystem[k]
Cadmium	< 0.01 mg/L < 0.0002 mg/L	Stock watering[f] Aquatic ecosystem[a]
Chromium	< 1 mg/L < 1 mg/L < 0.001 mg/L	Irrigation[g,e] Stock watering[f] Aquatic ecosystem[a]
Cobalt	< 0.1 mg/L < 0.0014 mg/L	Irrigation[g,e] Aquatic ecosystem[h]
Copper	< 5 mg/L < 1 mg/L < 0.0014 mg/L	Irrigation[g,e] Stock watering (cattle)[f] Aquatic ecosystem[a]
Fluoride (total)	< 2 mg/L	Irrigation[g,e]

Parameter	WQO	Relevant EV
Iron	< 10 mg/L < 0.70 mg/L	Irrigation[g,e] Aquatic ecosystem[l]
Lead	< 5 mg/L < 0.1 mg/L < 0.0034 mg/L	Irrigation[g,e] Stock watering[f] Aquatic ecosystem[a]
Lithium	< 2.5 mg/L	Irrigation[g]
Manganese	< 10 mg/L < 1.9 mg/L	Irrigation[g,e] Aquatic ecosystem[a]
Mercury	< 0.002 mg/L < 0.0002 mg/L	Irrigation[g] Aquatic ecosystem[i]
Molybdenum	< 0.05 mg/L < 0.034 mg/L	Irrigation[g,e] Aquatic ecosystem[h]
Nickel	< 2 mg/L < 1 mg/L < 0.011 mg/L	Irrigation[g,e] Stock watering[f] Aquatic ecosystem[a]
Selenium	< 0.05 mg/L < 0.02 mg/L < 0.005 mg/L	Irrigation[g,e] Stock watering[f] Aquatic ecosystem[a]
Silver	< 0.001 mg/L	Aquatic ecosystem[a]
Uranium	< 0.1 mg/L < 0.001 mg/L	Irrigation[g,e] Aquatic ecosystem[i]
Vanadium	< 0.5 mg/L < 0.01 mg/L	Irrigation[g,e] Aquatic ecosystem[i]
Zinc	< 5 mg/L < 0.008 mg/L	Irrigation[g,e] Aquatic ecosystem[a]
Nitrate as N	< 1.1 mg/L	Stock watering[j]

a/ Table 3.4.1 of ANZG (2018): trigger values for slightly-moderately disturbed systems (95% level of protection)
b/ Table 2 of Isaac River Sub-Basin EVs and WQOs: Aquatic ecosystem – moderately disturbed
c/ Table 4 of Isaac River Sub-Basin EVs and WQOs: Drinking water EV
d/ Table 10 of Isaac River Sub-Basin EVs and WQOs: Stock watering EV: salinity
e/ short-term trigger value
f/ Table 11 of Isaac River Sub-Basin EVs and WQOs: Stock watering EV: heavy metals and metalloids
g/ Table 9 of Isaac River Sub-Basin EVs and WQOs: Irrigation EV: heavy metals and metalloids
h/ Section 8.3.7 of ANZG (2018): low reliability guideline
i/ Based on Limit of Reporting (LOR) for ICPMS/CV FIMS analytical methods
j/ Based on ambient WQGs (2006) for total nitrogen –standard trigger value for contemporary environmental authorities in Bowen Basin
k/ Based on 95% level of protection in Toxicant default guideline values for aquatic ecosystem protection: Boron in fresh water (ANZG, 2020)
l/ Based on 95% level of protection in Toxicant default guideline values for aquatic ecosystem protection: Total iron in fresh water (ANZG, 2020)
mg/L = milligrams per litre, NTU = Nephelometric Turbidity Units, µS/cm = microSiemens per centimetre.

3.2 AQUATIC ECOSYSTEM ENVIRONMENTAL VALUES

An Aquatic Ecology and Stygofauna Assessment has been prepared for the Project (Ecological Service Professionals [ESP], 2022) and provides details relating to the aquatic ecosystem EVs.

4 Existing surface water environment

4.1 REGIONAL DRAINAGE CHARACTERISTICS

The Project is located within the Isaac sub-catchment of the greater Fitzroy Basin. The Isaac River is the main watercourse in the vicinity of the Project area, and flows in a south-easterly direction to the east of the Project.

The catchment commences at the Denham Range located about 75 km to the north of the Project. The Isaac River flows in a south-westerly direction through the Carborough and Kerlong Ranges before turning in a south-easterly direction near the Goonyella Riverside Mine. The Connors River, which has a catchment area similar to the upstream Isaac River, flows into the Isaac River approximately 105 km downstream of the Project. The Isaac River finally converges with the Mackenzie River a further 45 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. Figure 4.1 presents the location of the Project and Isaac River catchment upstream of the Connors River confluence. Figure 4.2 presents the drainage characteristics of the Upper Isaac River to the Deverill flow gauge.

The greater Isaac-Connors sub-catchment area is approximately 22,364 square kilometres (km^2) (to the Mackenzie River confluence), out of a total Fitzroy River catchment of 142,665 km^2. That is, it represents around 15% of the overall Fitzroy River catchment.

The catchment area of the Isaac River to the Project area is around 4,100 km^2. This represents around 2.9% of the overall Fitzroy River catchment and 18.3% of the Isaac-Connors sub-catchment.

The maximum Project disturbance footprint is approximately 70 km^2 and represents 0.05% and 0.3% of the overall Fitzroy River and Isaac-Connors catchment areas, respectively.

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 and drainage lines in the vicinity 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 4.3 is a photograph of the Isaac River near the upstream extent of the Project area, at the Norwich Park Branch Railway crossing. Figure 4.4 is a photograph of the Isaac River near the mid-extent of the Project area. Both photographs were taken in November 2019.

The Isaac River catchment upstream of the Project comprises mainly scattered to medium dense bushland, grazing land and the township of Moranbah. There are several existing coal mines in the upstream Isaac River catchment including Burton, North Goonyella, Grosvenor, Goonyella-Riverside, Broadmeadow, Broadlea, Isaac Plains, Carborough Downs, Caval Ridge, Peak Downs, Poitrel, Daunia, Millennium and Moranbah North.

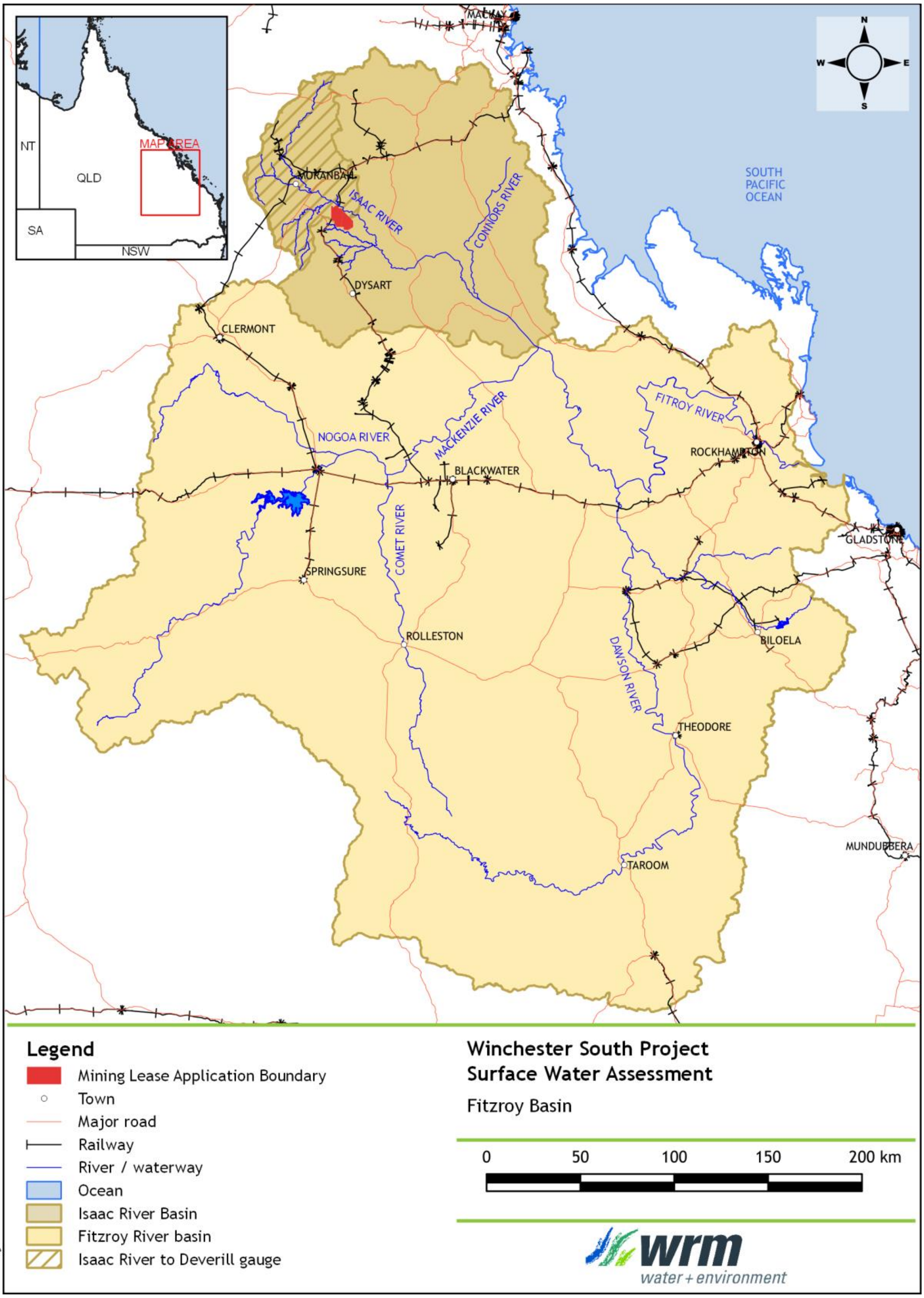


Figure 4.1 – Fitzroy River catchment

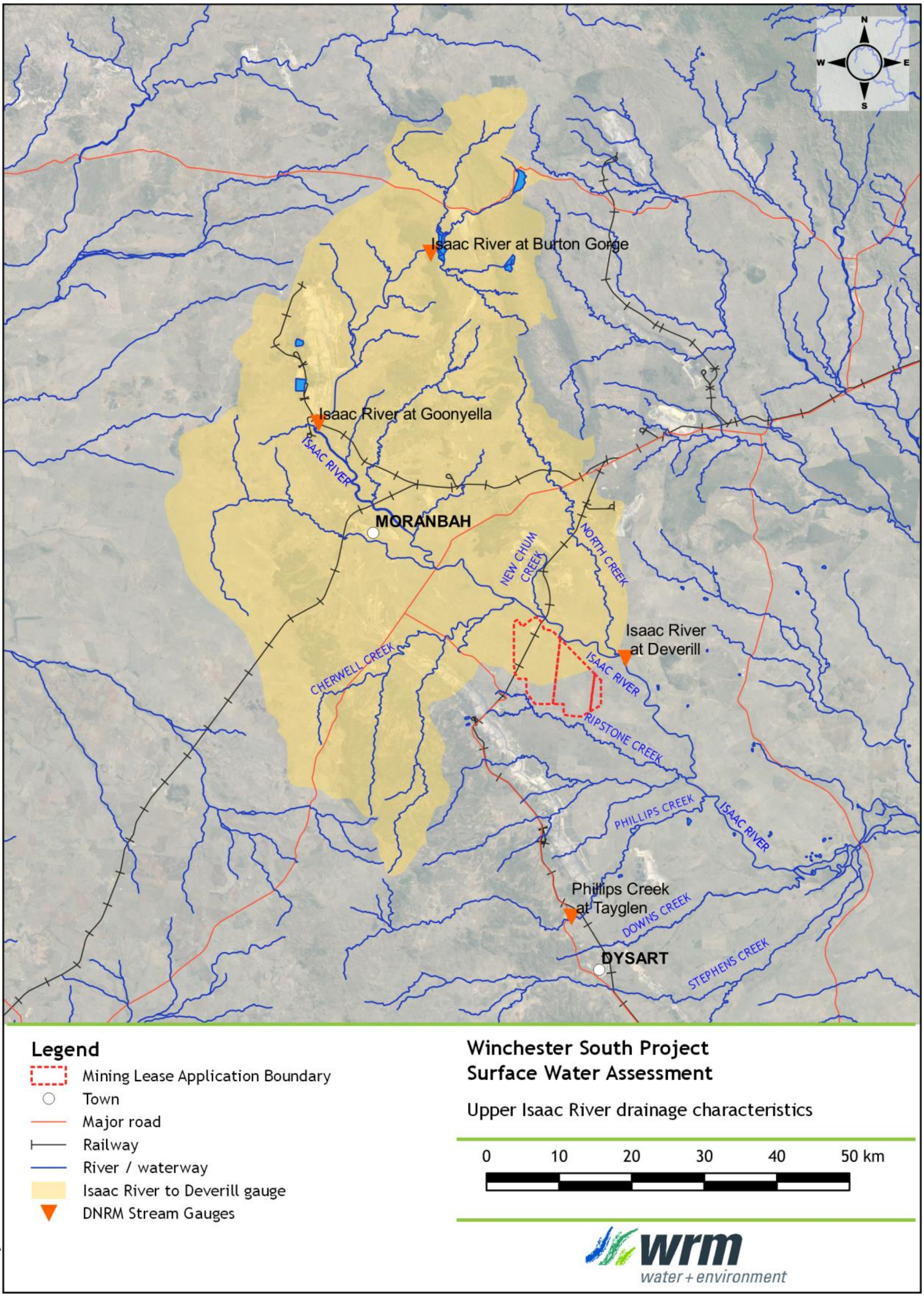


Figure 4.2 – Upper Isaac River drainage characteristics

Figure 4.3 – Isaac River at the Norwich Park Branch railway crossing, looking upstream (Site Photo 1)

Figure 4.4 – Isaac River upstream of Unnamed Tributary 2, looking upstream (Site Photo 2)

4.2 LOCAL DRAINAGE

The majority of the Project area drains directly to the Isaac River through various unnamed drainage features and minor tributaries of the Isaac River. The closest local named watercourse is Ripstone Creek. These local drainage features are presented in Figure 4.5.

4.2.1 Isaac River channel characteristics

Figure 4.6 shows typical cross sections of the Isaac River channel adjacent to the Project (cross-section locations are shown in Figure 4.5). The channel has an average bed width of 35 metres (m) varying between 25 m and 45 m and is approximately 11 m deep. The bed slope and hydraulic gradient from Moranbah township to the Cherwell Creek confluence is very uniform at 0.08%. Under the Strahler ordering system, the Isaac River is a fifth order stream upstream of the Grosvenor Creek confluence and a sixth order stream downstream of the confluence (including the reach that drains past the Project).

The bed of the river channel is characterised by extensive sand sheet deposits indicating it is sediment choked. Sand point bars are evident on the inside of bends and vegetated benches are located on one or both sides of the river along the straight sections. A number of well vegetated sand islands are located in the river channel indicating that some of the old benches have eroded forming channels either side of the old river bank. SedNet modelling of the catchment undertaken by Dougall et al, (2006) indicated hillslope erosion to be a dominant input over gully and river bank erosion. Total predicted sediment inputs range from 0.31 to 1.25 tonnes per hectare per annum (t/ha/annum).

An exposed bedrock control consisting of shale is located on the left hand bank (looking downstream) some 600 m upstream of the Peak Downs Highway. An island has formed in the channel with the bedrock control on one channel and a sandy channel on the other.

The banks of the river consist of a sandy loam and have eroded to near vertical for a depth of 1 m to 2 m along much of its length and 1 vertical (V):4 horizontal (H) to 1V:5H batters above this depth. The bank batters are well vegetated with established and mature trees, mostly eucalypts and casuarinas, and buffel grass understorey. The active benches consist of scattered trees and buffel grass with the overbank areas cleared for grazing.

The Project does not involve any mining activities or infrastructure in the Isaac River. No diversion of the Isaac River is proposed and therefore *Guideline: Works that interfere with water in a watercourse for a resource activity— watercourse diversions authorised under the Water Act 2000* (DoR, 2019) is not relevant. Notwithstanding, the principles of DoR (2019) would be considered as part of the detailed design of the post-mining landform drainage paths.

4.2.2 Isaac River geomorphic investigations

A Geomorphology Assessment has been prepared for the EIS (see Appendix F) by Fluvial Systems (2020).

Furthermore, as part of the Olive Downs Project EIS, Fluvial Systems (Fluvial Systems, 2018) undertook a geomorphological study of a reach of the Isaac River and its tributaries approximately 15 km downstream of the Project area.

Key outcomes from this study are as follows:

- The surface geology of the study area for the geomorphology study 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.

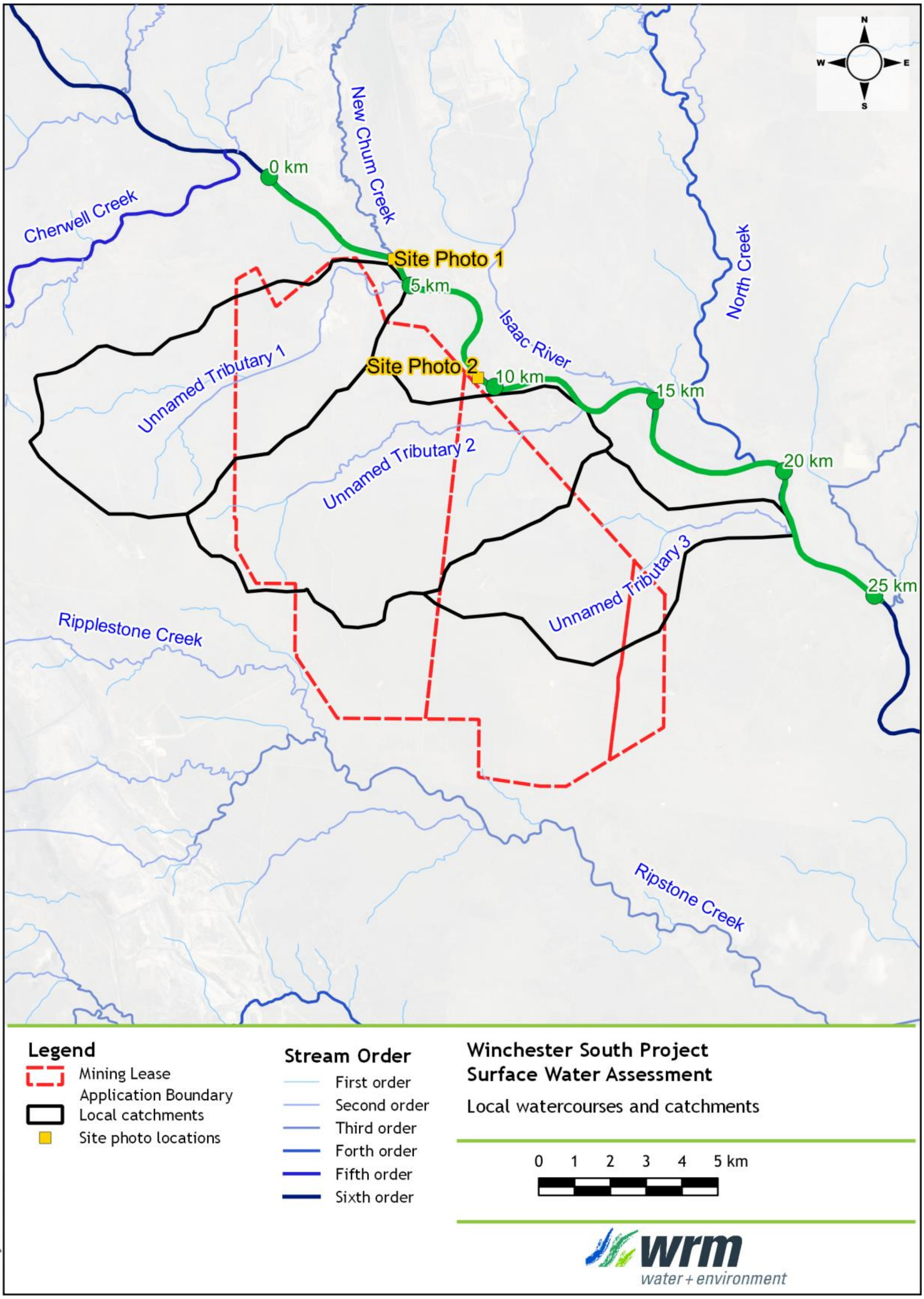


Figure 4.5 – Local watercourse catchments

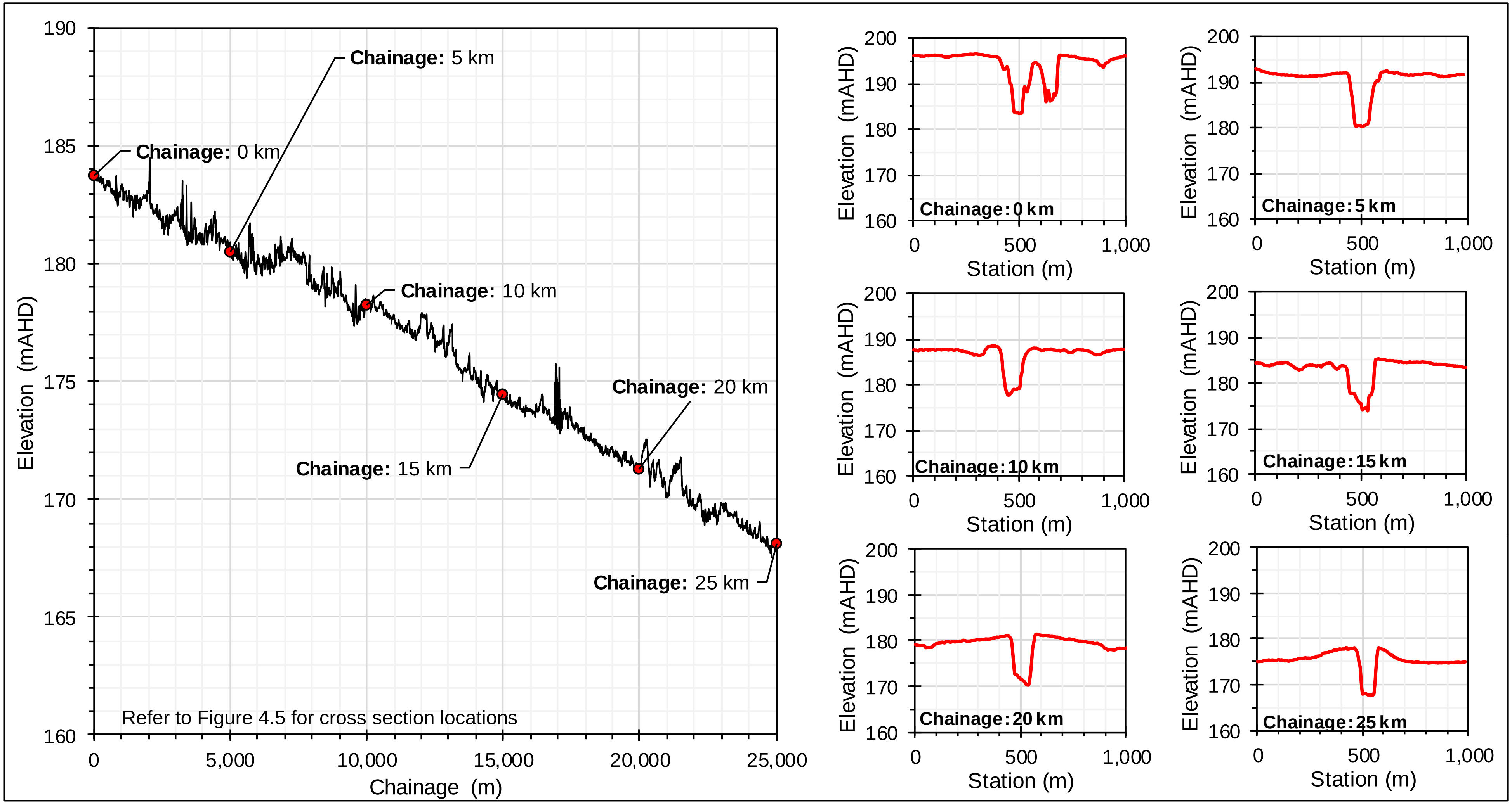


Figure 4.6 - Isaac River cross sections

- The majority of the wider study area for the geomorphology study 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 geomorphology study area, and in the corridor of the Isaac River just upstream of the core geomorphology 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.

A number of photographs from the Fluvial Systems (2018) geomorphology study have been reproduced in Figure 4.7.

Figure 4.7 – Photos of the Isaac River – Fluvial Systems (2018)

4.2.3 Ripstone Creek

Ripstone Creek runs west to east to the south of the Project area. 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 upstream of the Project. Ripstone Creek also includes a second order tributary (Ripplestone Creek), that runs west to east to the south of the Project area.

4.2.4 Watercourse classification

The Ordered Drainage 100K mapping layer from the Queensland Government Qspatial website identifies riverine systems, watercourses, waterways or drainage lines (here referred to collectively as waterways) for the Project area and is presented in Figure 4.8. There are 6 waterways mapped within the vicinity of the Project, including:

- one waterway of (Strahler) stream order six (6) (Isaac River) to the east of the Project area;
- one waterway of stream order five (5) (Cherwell Creek), located to the north of the Project area;
- one waterway of stream order two/three (Ripstone Creek), located to the south the Project area; and
- three waterways of stream order one/two, minor drainage features that drain through the Project area directly to the Isaac River.

The DoR (2017) watercourse identification map identifies the Isaac River, Cherwell Creek and Ripstone Creek as waterways that exhibit the characteristics of a watercourse as defined by the Water Act (refer Section 2.2.2).

The majority of the minor waterways that drain through the Project area directly to the Isaac River are identified either as "drainage features" and therefore are not considered watercourses.

A watercourse determination for the minor waterways in the vicinity of the Project area was requested by the previous tenement owner to the then Department of Environment and Resource Management (DERM) in 2012. DERM determined the following:

- There were two main features (or waterways) identified (identified as Feature 1 and Feature 2).
- Only the downstream sections of both Feature 1 and Feature 2 were considered to possess the characteristics of a watercourse (under the Water Act 2000).
- The waterways are considered "drainage features" (and not watercourses) upstream of the identified locations.

Additional field assessments of waterways providing for fish passage were completed by ESP in February 2022. The supplementary field surveys were undertaken to identify and determine any waterways for fish passage in the vicinity of the Project and the findings are generally consistent with the extents of the determined "watercourses" presented in Figure 4.8.

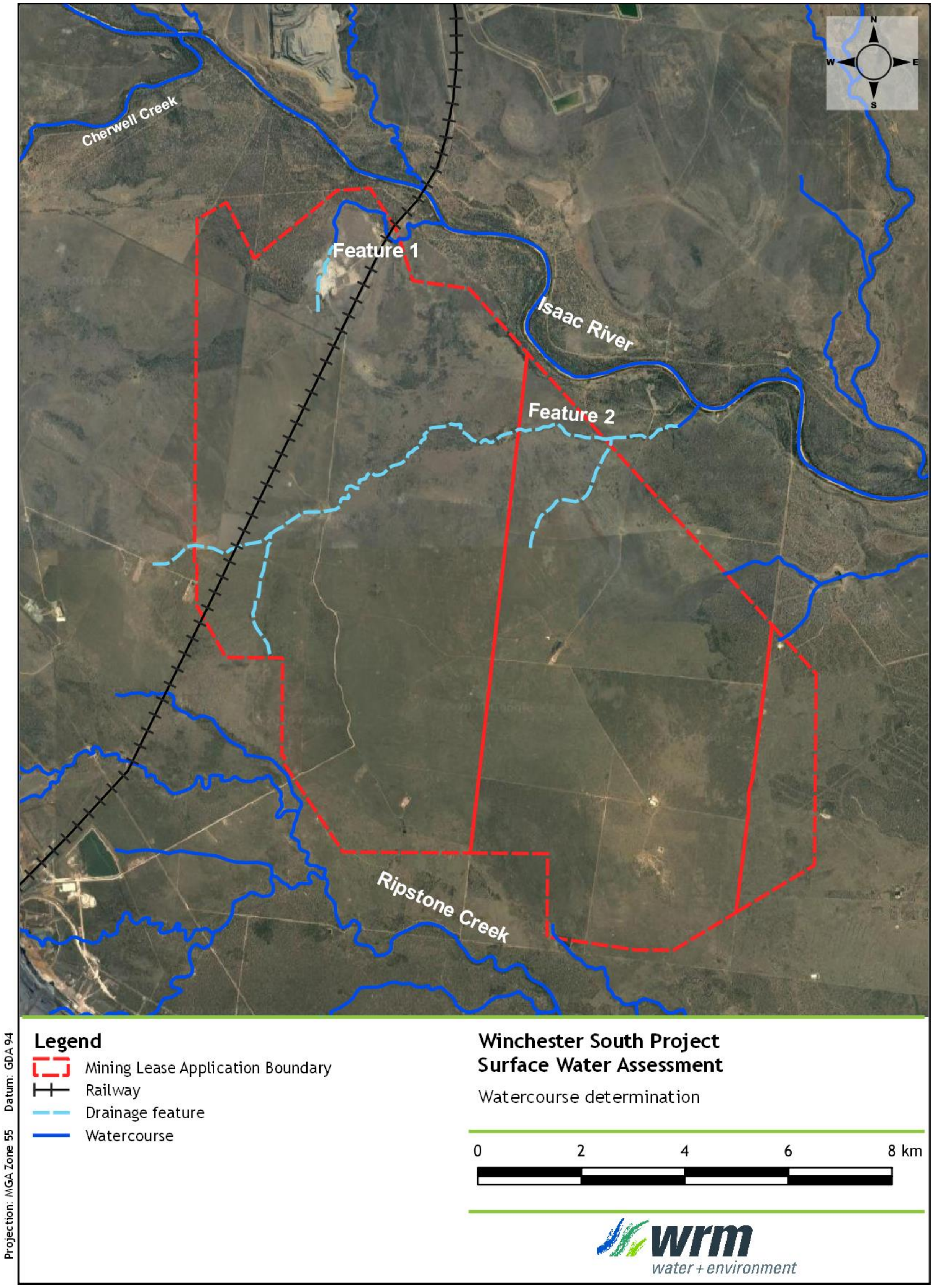


Figure 4.8 – Waterway mapping and watercourse classifications

4.3 STREAMFLOW

The DoR records Isaac River water levels at the Goonyella (upstream) and Deverill (downstream) gauges. The details of these gauges are provided in Table 4.1. Figure 4.2 shows the Isaac River catchment to the Deverill gauging station adjacent to the Project.

Table 4.1 - DoR stream gauges along the Isaac River in the vicinity of the Project

Gauge no.	Gauge name	AMTD (km)	Catchment area (km^2)	Distance from Project (km)	Start	End
130414A	Goonyella	242.8	1,214	45 km (upstream)	24/05/1983	23/04/2021
130410A	Deverill	147.7	4,092	8 km (downstream)	20/05/1968	-

Historical flow and river height monitoring data at the Goonyella and Deverill gauges provide an indication of the local flow regime. The mean river height data shown in Figure 4.9 and Figure 4.10 suggests that flow at the Goonyella gauge 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.

Surveyed cross section and rating data for the Deverill gauging station in March 2020 (DoR, 2020) indicates that sediment covers the bottom 0.25m of the gauge range (above cease-to-flow). The (CTF) level for the gauge is 0.65m, therefore any recorded flow between 0.65m and 0.9m would be subsurface flow through the sand bed.

The mean river height data shown in Figure 4.10 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.

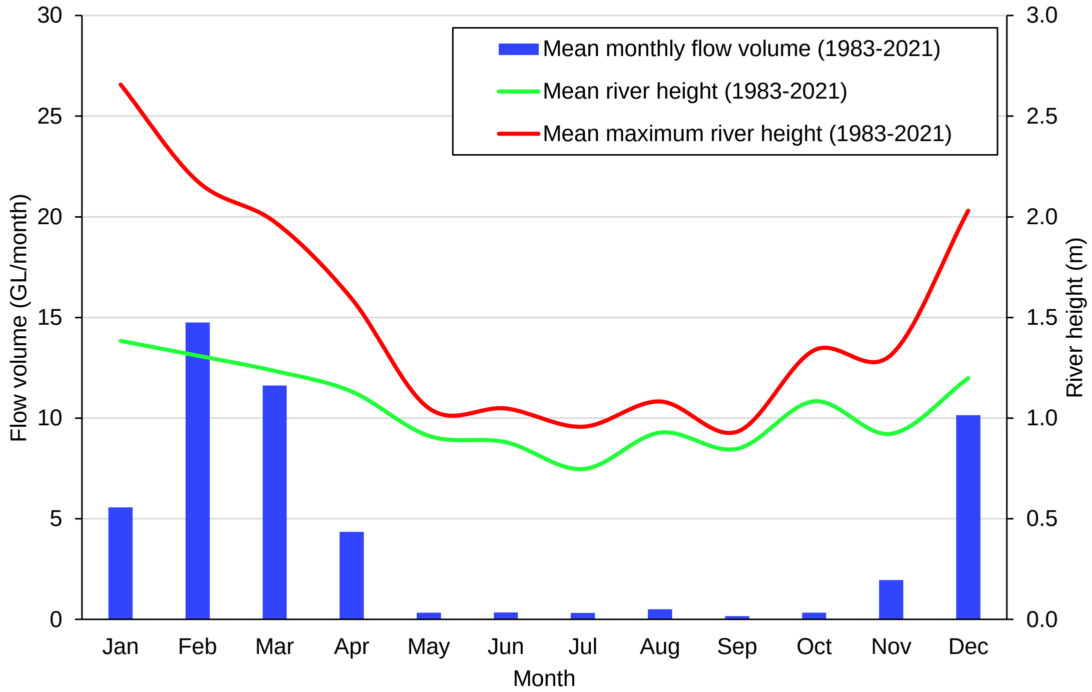


Figure 4.9 - Flow volume and river height in the Isaac River at Goonyella (DoR station 130414A, located upstream)

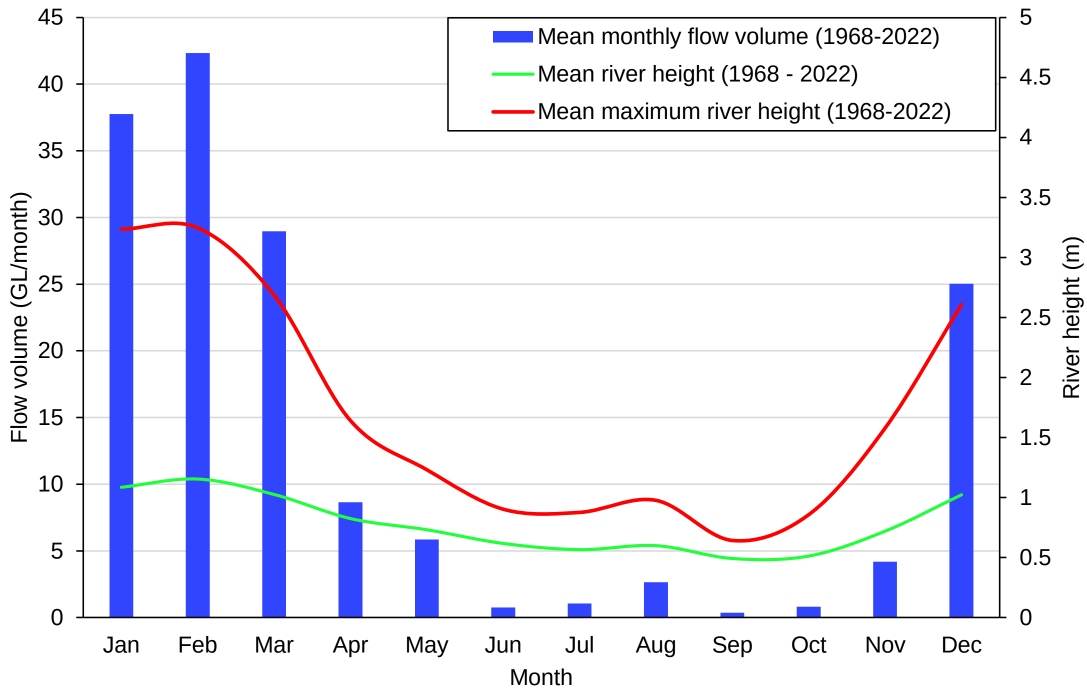


Figure 4.10 - Flow volume and river height in the Isaac River at Deverill (DoR station 130410A, located downstream)

Figure 4.11 shows a ranked plot of the daily stream flows in the Isaac River recorded at the Goonyella and Deverill gauging stations. The following is of note with respect to the recorded stream flows:

- The Isaac River is ephemeral with flows recorded only on 22% of days at Goonyella and 27% of days at Deverill. Flows above 100 megalitres per day (ML/d) occur for less than 8.5% of days at Goonyella and 10% of days at Deverill. A flow of 100 ML/d would not fully inundate the bed of the Isaac River at either location.
- The mean daily flow (all days) is 298 ML/d and 753 ML/d at Goonyella and Deverill, respectively.
- The highest recorded flow (2,165 m3/s) at the Goonyella gauge occurred in January 2021, which reached a gauge height of 9.9 m. The highest recorded flow (2,638 m3/s) at the Deverill gauge occurred in March 1988 where the river reached a gauge height of 11.4 m.

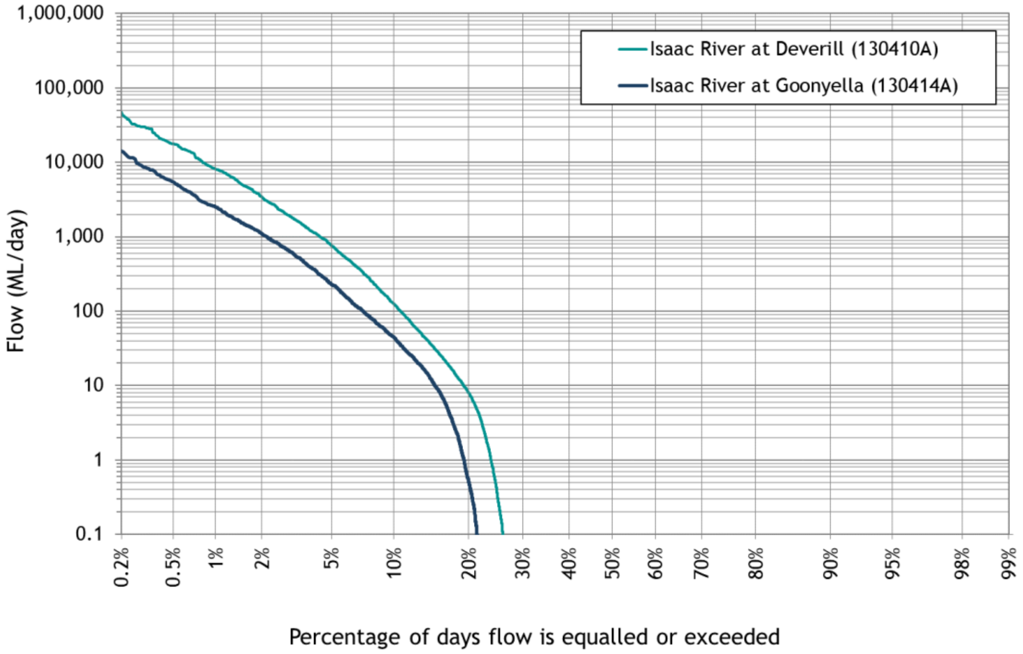


Figure 4.11 – Stream flow duration curves, Isaac River at Deverill and Goonyella gauging stations

4.4 WATER QUALITY

The Isaac River catchment has seen significant changes in land use over the past 50 years. Widespread land clearing and coal mine development have occurred throughout the catchment. The extent to which these activities have affected water quality is difficult to ascertain. Coal mines have historically discharged mine-affected water immediately following significant rainfall events, but few records are available of the timing and quality of these releases. Typically, under normal conditions, water is conserved on-site to provide water for site use.

Water quality monitoring results in the vicinity of the Project are available from a number of gauging stations, in addition to the baseline monitoring that has been undertaken by Whitehaven WS at the Project area and at the neighbouring Olive Downs Project. Details on the various gauges are displayed in Table 4.2 and their locations are shown in Figure 4.12.

Table 4.2 – Water quality data monitoring locations

Site name	Watercourse	Location		Data source	Duration of record	No. of samples	Analytes
		Easting (GDA94 Z55)	Northing (GDA94 Z55)				
Burton Gorge	Isaac River	616,225	7,607,969	DoR	24 Jun 1963 - 6 Dec 1985	19	Range[1]
Goonyella	Isaac River	600,501	7,582,839	DoR	12 Dec 1983 - 25 Mar 2013	33	Range[2]
Deverill	Isaac River	642,713	7,548,620	DoR	6 Jul 1964 - 18 Mar 2020	49	Range[3]
Red Hill Mine Upper Isaac	Isaac River	607,968	7,599,274	BMA (Red Hill Mining Lease EIS)	18 Nov 2010 - 4 Apr 2011	45	Range[4]
Red Hill Mine Lower Isaac	Isaac River	600,772	7,581,218	BMA (Red Hill Mining Lease EIS)	14 Nov 2010 - 4 Apr 2011	51	Range[4]
Olive Downs ISDS	Isaac River	674,831	7,519,709	Pembroke	22 Dec 2016 - 24 Apr 2019	Continuous monitoring station	Temp, EC, pH
SW1 (Pembroke)	Isaac River	639,138	7,548,409	Pembroke	15 Aug 2017 - 26 Mar 2019	10	Range[4]
SW2 (Pembroke)	Isaac River	641,008	7,549,014	Pembroke	19 Jul 2017 - 26 Mar 2019	12	Range[4]
SW3 (Pembroke)	Isaac River	642,739	7,547,7726	Pembroke	15 Aug 2017 - 26 Mar 2019	18	Range[4]
SW4 (Pembroke)	Ripstone Creek	636,806	7,537,472	Pembroke	20 Jul 2017 & 13 Nov 2018	2	Range[4]
SW5 (Pembroke)	Ripstone Creek	645,648	7,532,150	Pembroke	13 Nov 2018	1	Range[4]
SW6 (Pembroke)	Ripstone Creek	644,154	7,531,910	Pembroke	20 Jul 2017 & 13 Nov 2018	2	Range[4]
SW8 (Pembroke)	Boomerang Creek	649,936	7,530,350	Pembroke	20 Jul 2017 - 14 Feb 2019	4	Range[4]
SW11 (Pembroke)	Isaac River	660,142	7,516,508	Pembroke	13 Sep 2017 - 26 Mar 2019	9	Range[4]
SW12 (Pembroke)	Isaac River	674,831	7,519,709	Pembroke	13 Sep 2017 - 26 Mar 2019	14	Range[4]
SW1 (WHC)	Unnamed tributary of Isaac River	628,333	7,546,912	Whitehaven WS	25 Mar 2019 - 25 Jan 2022	5	Range[5]
SW2 (WHC)	Unnamed tributary of Isaac River	635,908	7,549,015	Whitehaven WS	25 Mar 2019 - 25 Jan 2022	10	Range[5]

Site name	Watercourse	Location		Data source	Duration of record	No. of samples	Analytes
		Easting (GDA94 Z55)	Northing (GDA94 Z55)				
SW3 (WHC)	Unnamed tributary of Isaac River	631,065	7,552,777	Whitehaven WS	25 Mar 2019 - 25 Jan 2022	6	Range[5]
SW4 (WHC)	Isaac River	630,897	7,553,963	Whitehaven WS	2 Mar 2019 - 25 Jan 2022	11	Range[5]
SW5 (WHC)	Isaac River	636,999	7,549,588	Whitehaven WS	2 Mar 2019 - 25 Jan 2022	7	Range[5]
SW7 (WHC)	Ripstone Creek	626,052	7,542,660	Whitehaven WS	3 Mar 2019	1	Range[5]
SW8 (WHC)	Unnamed tributary of Isaac River	637,665	7,546,277	Whitehaven WS	29 Apr 2019	1	Range[5]
SW9 (WHC)	Farm Dam on unnamed tributary of Isaac River	639,408	7,541,752	Whitehaven WS	2 May 2019 - 15 Jun 2021	11	Range[5]

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, Potassium as K, Sodium as Na, Sulphate as SO4, Boron as B, Fluoride as F, Iron as Fe soluble, Silica as SiO2 soluble.

Range 2: 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, Chromium as Cr, Copper as Cu, Cyanide as CN, Fluoride as F, Iron as Fe soluble, Lead as Pb, Manganese as Mn soluble, Mercury as Hg, Nickel as Ni, Selenium as Se, Silica as SiO2 soluble, Zinc as Zn soluble.

Range 3: 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, Kjeldahl Nitrogen, 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 4: 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, 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 5: pH, Sodium Adsorption Ratio, Electrical Conductivity @ 25°C, Total Dissolved Solids (Calc.), Total Suspended Solids, Turbidity, Hardness (Total) as CaCO3, Alkalinity (Hydroxide) as CaCO3, Alkalinity (Carbonate as CaCO3), Alkalinity (Bicarbonate as CaCO3), Alkalinity (Total) as CaCO3, Sulphate as SO4 – Turbidimetric, Chloride, Calcium (dissolved), Magnesium (dissolved), Sodium (dissolved), Potassium (dissolved), Aluminium (dissolved), Antimony (dissolved), Arsenic (dissolved), Beryllium (dissolved), Barium (dissolved), Cadmium (dissolved), Chromium (dissolved), Cobalt (dissolved), Copper (dissolved), Lead (dissolved), Manganese (dissolved), Molybdenum (dissolved), Nickel (dissolved), Selenium (dissolved), Silver (dissolved), Strontium (dissolved), Uranium (dissolved), Vanadium (dissolved), Zinc (dissolved), Boron (dissolved), Iron (dissolved), Aluminium (total), Antimony (total), Arsenic (total), Beryllium (total), Barium (total), Cadmium (total), Chromium (total), Cobalt (total), Copper (total), Lead (total), Manganese (total), Molybdenum (total), Nickel (total), Selenium (total), Silver (total), Strontium (total), Uranium (total), Vanadium (total), Zinc (total), Boron (total), Iron (total), Mercury (dissolved), Mercury (total), Silicon as SiO_2 (dissolved), Fluoride, Ammonia as N, Nitrite (as N), Nitrate (as N), Nitrite + Nitrate (as N), Total Kjeldahl Nitrogen, Total Phosphorus as P, Total Anions, Total Cations, Ionic Balance, Bromide.

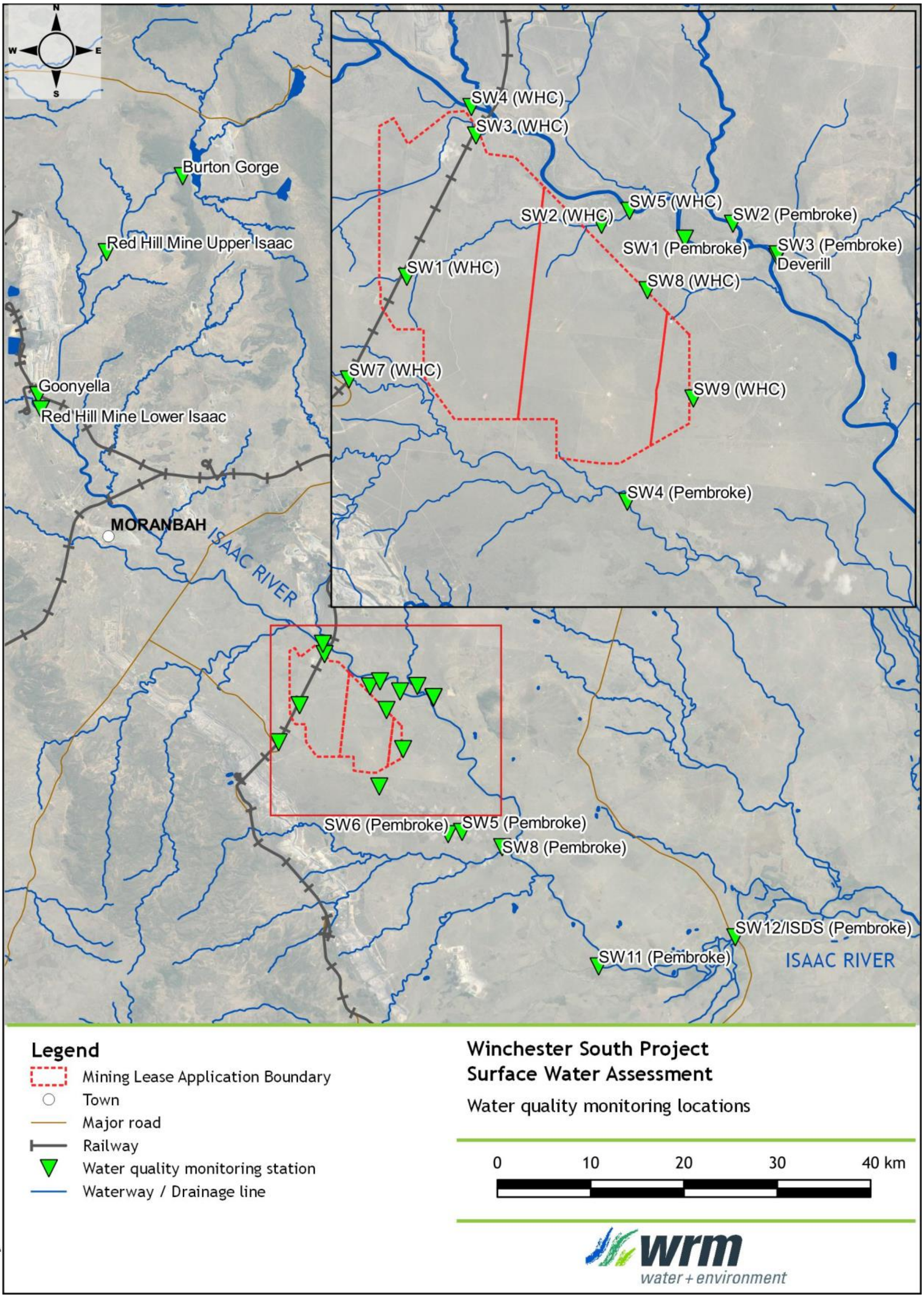


Figure 4.12 – Water quality monitoring locations

4.4.1 Regional Isaac River water quality

Publicly available regional water quality data for the Isaac River at the Burton Gorge, Goonyella and Deverill gauging stations and at Red Hill Mining Lease (Lower and Upper Isaac River locations) have been analysed and a comparison of the water quality statistics at these sites are displayed in Table 4.3 and Table 4.4. These sites were selected because complete datasets (i.e. individual sample analysis results) are publicly available as opposed to only summary data being publicly available.

The Red Hill, Isaac River (Burton Gorge) and Isaac River (Goonyella) stations are located downstream of the Goonyella, North Goonyella, Broadlea and Burton mines and therefore measured water quality may be affected by mine releases. The Red Hill, Isaac River (Burton Gorge) and Isaac River (Goonyella) stations are about 70 km, 85 km and 50 km upstream of the Project, respectively. However, these stations provide an indication of water quality, including metal toxicants, in the Isaac River upstream of the Project.

Table 4.3 shows that some readings at the DoR monitoring locations along the Isaac River are at or above the regional default guideline values (DGVs), including the following:

- Dissolved aluminium at Goonyella and Deverill (80th percentile);
- Dissolved copper at Goonyella and Deverill (median and 20th/80th percentile);
- EC at Goonyella (80th percentile) exceeds the DGV based on the model water conditions;
- Dissolved iron at Burton Gorge (median and 80th percentile);
- Nitrate at all three gauges (median and 80th percentile values);
- Total suspended solids at all Burton Gorge and Goonyella (80th percentile values);
- Turbidity at Burton Gorge (median and 20th/80th percentile) and Goonyella/Deverill (median and 80th percentile); and
- Dissolved zinc at Goonyella/Deverill (median and 20th/80th percentile).

Table 4.4 shows that some readings at the Red Hill Mining Lease monitoring locations are at or above the regional DGVs, including the following:

- Total aluminium at both sites (median and 80th percentile);
- Ammonia at both sites (80th percentile);
- Dissolved aluminium at both sites (median and 20th/80th percentile);
- Dissolved chromium at Lower Isaac River (80th percentile);
- Dissolved copper at Upper Isaac River (80th percentile) and Lower Isaac River (median and 80th percentile);
- Filterable reactive phosphorus at both sites (median and 20th/80th percentile);
- Total iron at both sites (median and 80th percentile);
- Dissolved iron at Lower Isaac River (80th percentile);
- Dissolved silver at Upper Isaac River (80th percentile);
- Total suspended solids at both sites (median and 20th/80th percentile values); and
- Turbidity at both sites (median and 20th/80th percentile values).

The review of the regional water quality data indicates that there are some water quality indicators that are consistently above the DGVs, in particular aluminium (dissolved), copper (total and dissolved), filterable reactive phosphorus, zinc (dissolved), iron (total and dissolved), TSS and turbidity.

This indicates that the current DGV’s may not necessarily reflect the typical background water quality within the Upper Isaac River.

Table 4.3 - Regional Isaac River water quality summary - DoR gauges

Parameter	Unit	Isaac River @ Burton Gorge				Isaac River @ Goonyella				Isaac River @ Deverill				Default Guideline Value (refer Table 3.1)
		No. of samples	20th %ile value	Median value	80th %ile value	No. of samples	20th %ile value	Median value	80th %ile value	No. of samples	20th %ile value	Median value	80th %ile value	
Aluminium (dissolved)	mg/L	-	-	-	-	13	0.004	0.050	0.056	14	0.03	0.05	0.15	< 0.055 (aquatic)
Boron (total)	mg/L	4	0.030	0.030	0.034	30	0.04	0.08	0.12	21	0.04	0.06	0.096	< 5 (stock)
Copper (dissolved)	mg/L	-	-	-	-	13	0.012	0.030	0.050	16	0.006	0.030	0.036	< 0.0014 (aquatic)
Electrical Conductivity	µS/cm	19	169	458	644	33	195	512	1,140	49	120	261	398	< 720 (baseflow) < 250 (high flow)
Fluoride (total)	mg/L	19	0.10	0.19	0.22	33	0.10	0.20	0.32	46	0.1	0.14	0.2	< 2 (irrigation)
Iron (dissolved)	mg/L	5	0.4	1.0	7.0	30	0.01	0.04	0.234	17	0.02	0.06	0.34	< 0.7 (aquatic)
Manganese (dissolved)	mg/L	-	-	-	-	13	0.012	0.030	0.050	16	0.006	0.030	0.036	< 1.9 (aquatic)
Nitrate (total)	mg/L	-	-	-	-	15	0.008	0.01	0.02	13	0.001	0.01	0.01	< 1.1 (aquatic)
pH	-	9	0.4	1.5	3.6	30	0.98	1.96	3.48	12	0.004	0.02	0.25	6.5-8.5 (aquatic)
Phosphorus (total)	mg/L	19	7.4	7.8	8.0	33	7.2	7.7	8.0	49	7.19	7.6	8	< 50 (aquatic)
Sodium (total)	mg/L	19	18	33	58	33	21	67	188	49	12	22	40	< 30 (drinking)
Sulphate (total)	mg/L	13	2.7	4.3	9.8	33	4.7	10.0	75.4	42	6.92	10	18.8	< 25 (aquatic)
Total Dissolved Solids	mg/L	19	122	255	353	33	114	280	622	47	81	155	224	< 2,000 (stock)
Total Suspended Solids	mg/L	15	10	230	2,002	33	14	74	2,752	41	10	135	1,340	< 55 (aquatic)
Turbidity	NTU	4	66	100	100	32	16	100	147	19	11	50	910	< 50 (aquatic)
Zinc (dissolved)	mg/L	-	-	-	-	12	0.01	0.015	0.02	14	0.01	0.01	0.06	< 0.008 (aquatic)

NOTE: values that were recorded as below the limit of reporting, have been assumed to be equal to the limit of reporting, for the purpose of this statistical analysis.

Table 4.4 - Regional Isaac River water quality summary - Red Hill Mining Lease gauges

Parameter	Unit	Red Hill Mining Lease - Upper Isaac River				Red Hill Mining Lease - Lower Isaac River				Default Guideline Value (refer Table 3.1)
		No. of samples	20th %ile value	Median value	80th %ile value	No. of samples	20th %ile value	Median value	80th %ile value	
Aluminium (total)	mg/L	43	3.5	9.3	16.1	51	3.6	8.5	16.0	< 5 (stock)
Aluminium (dissolved)	mg/L	36	0.16	0.415	3.6	41	0.12	0.42	3.2	< 0.055 (aquatic)
Ammonia (total)	mg/L	42	0.005	0.02	0.038	51	0.005	0.01	0.03	< 0.02 (aquatic)
Arsenic (total)	mg/L	43	0.001	0.0025	0.0025	51	0.001	0.0025	0.0025	< 2.0 (irrigation) < 0.5 (stock)
Arsenic (dissolved)	mg/L	36	0.0005	0.0005	0.0005	41	0.0005	0.0005	0.0005	< 0.013 (aquatic)
Beryllium (total)	mg/L	1	0.0025	0.0025	0.0025	1	0.0025	0.0025	0.0025	< 0.5 (irrigation)
Boron (total)	mg/L	43	0.03	0.05	0.07	51	0.04	0.05	0.07	< 5 (stock)
Boron (dissolved)	mg/L	43	0.03	0.04	0.06	51	0.025	0.04	0.06	< 0.94 (aquatic)
Cadmium (total)	mg/L	43	0.00025	0.00025	0.00025	51	0.00025	0.00025	0.00025	< 0.01 (stock)
Cadmium (dissolved)	mg/L	36	0.00005	0.00005	0.0001	41	0.00005	0.00005	0.00005	< 0.0002 (aquatic)
Cobalt (total)	mg/L	43	0.003	0.006	0.012	51	0.004	0.007	0.012	< 0.1 (irrigation)
Cobalt (dissolved)	mg/L	36	0.0005	0.0005	0.0005	41	0.0005	0.0005	0.0005	< 0.0014 (aquatic)
Chromium (total)	mg/L	43	0.009	0.016	0.028	51	0.01	0.016	0.034	< 1 (stock)
Chromium (dissolved)	mg/L	43	0.0005	0.0005	0.001	51	0.0005	0.0005	0.002	< 0.001 (aquatic)
Copper (total)	mg/L	36	0.007	0.011	0.016	41	0.007	0.011	0.018	<1 (stock)
Copper (dissolved)	mg/L	43	0.002	0.002	0.0036	51	0.002	0.003	0.005	< 0.0014 (aquatic)
Electrical Conductivity	µS/cm	36	140	166	210	41	170	220	330	< 720 (baseflow) < 250 (high flow)
Filterable Reactive Phosphorus	mg/L	7	0.19	0.29	0.40	10	0.33	0.43	0.68	< 0.02 (aquatic)
Fluoride (total)	mg/L	43	0.05	0.10	0.10	51	0.05	0.1	0.1	< 2 (irrigation)
Iron (total)	mg/L	43	6.0	12.0	18.6	51	6.5	11.0	21.0	< 10 (irrigation)
Iron (dissolved)	mg/L	43	0.09	0.26	0.85	51	0.09	0.24	0.67	< 0.7 (aquatic)
Lead (total)	mg/L	43	0.0025	0.006	0.008	51	0.0025	0.005	0.01	< 0.1 (stock)
Lead (dissolved)	mg/L	43	0.0005	0.0005	0.0005	51	0.0005	0.0005	0.0005	< 0.0034 (aquatic)
Manganese (total)	mg/L	42	0.1672	0.2625	0.4476	50	0.171	0.251	0.481	< 10 (irrigation)

Parameter	Unit	Red Hill Mining Lease - Upper Isaac River				Red Hill Mining Lease - Lower Isaac River				Default Guideline Value (refer Table 3.1)
		No. of samples	20th %ile value	Median value	80th %ile value	No. of samples	20th %ile value	Median value	80th %ile value	
Manganese (dissolved)	mg/L	43	0.0005	0.0025	0.0056	51	0.0005	0.002	0.003	1.9 (aquatic)
Mercury (total)	mg/L	43	0.00005	0.00005	0.00005	51	0.00005	0.00005	0.00005	< 0.002 (irrigation)
Mercury (dissolved)	mg/L	43	0.00005	0.00005	0.00005	51	0.00005	0.00005	0.00005	< 0.0002 (irrigation)
Molybdenum (total)	mg/L	43	0.0025	0.0025	0.0025	51	0.0025	0.0025	0.0025	< 0.05 (irrigation)
Molybdenum (dissolved)	mg/L	43	0.0005	0.0005	0.0025	51	0.0005	0.001	0.0025	< 0.034 (aquatic)
Nickel (total)	mg/L	43	0.010	0.016	0.029	51	0.011	0.019	0.033	< 1 (stock)
Nickel (dissolved)	mg/L	43	0.002	0.002	0.003	51	0.002	0.002	0.004	< 0.011 (aquatic)
Nitrate (total)	mg/L	43	0.005	0.020	0.040	51	0.02	0.05	0.14	1.1 (aquatic)
pH	-	43	7.6	7.8	8.1	51	7.4	7.8	8.0	6.5-8.5 (aquatic)
Selenium (total)	mg/L	43	0.001	0.0025	0.0025	51	0.001	0.0025	0.006	< 0.02 (stock)
Selenium (dissolved)	mg/L	43	0.0005	0.0025	0.005	51	0.002	0.0025	0.0025	< 0.005 (aquatic)
Silver (dissolved)	mg/L	35	0.00005	0.00005	0.0025	40	0.00005	0.00005	0.0025	< 0.00005 (aquatic)
Sulphate (total)	mg/L	43	1	2	5.6	51	2	5	19	< 25 (aquatic)
Total Dissolved Solids	mg/L	43	104	200	276	51	140	254	358	< 2,000 (stock)
Total Suspended Solids	mg/L	43	226	343	514	51	251	380	650	< 55 (aquatic)
Turbidity	NTU	43	218	450	882	51	290	597	1,270	< 50 (aquatic)
Uranium (total)	mg/L	36	0.00025	0.0005	0.0009	41	0.00025	0.0005	0.0011	< 0.1 (irrigation)
Uranium (dissolved)	mg/L	36	0.00005	0.0002	0.0002	41	0.00005	0.0002	0.0002	< 0.001 (aquatic)
Vanadium (total)	mg/L	36	0.019	0.0285	0.05	41	0.02	0.029	0.05	< 0.5 (irrigation)
Vanadium (dissolved)	mg/L	36	0.0025	0.0025	0.005	41	0.0025	0.0025	0.0025	< 0.01 (aquatic)
Zinc (total)	mg/L	43	0.0162	0.024	0.037	51	0.017	0.03	0.041	< 5 (irrigation)
Zinc (dissolved)	mg/L	43	0.0025	0.0025	0.005	51	0.0025	0.0025	0.005	< 0.008 (aquatic)

NOTE: values that were recorded as below the limit of reporting, have been assumed to be equal to the limit of reporting, for the purpose of this statistical analysis.

DoR has collected daily EC data at the Isaac River at the Deverill and Yatton gauges. EC, which is a measure of the salt concentration, has been used to define the potential water quality impacts of the Project. The Deverill gauge is located near the downstream 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. Instantaneous or daily EC was not recorded at the upstream Goonyella gauge during its period of operation.

Figure 4.13 presents a time history of recorded instantaneous EC and stream flow for the Isaac River at Deverill gauging station. Figure 4.14 details the relationship between instantaneous flow and EC at the Isaac River at Deverill gauging station. The data collected by DoR at the Deverill gauging station spans the period from 2011 to 2022 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 varies 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 4.15 presents a time history of recorded instantaneous EC and stream flow for the Isaac River at Yatton gauging station. Figure 4.16 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 2022. 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 m3/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.
- The recorded low flow EC is generally less than at Deverill.

4.4.2 Local water quality

4.4.2.1 Project-specific water quality data

Baseline water quality sampling for the Project has been undertaken between 2 March 2019 and 25 January 2022. Analyses for a range of physio-chemical parameters were completed at sites SW1, SW2, SW3, SW4, SW5, SW7, SW8 and SW9.

For the Project-specific surface water monitoring sites, samples were collected directly from the open body of water by hydrogeologist.com.au. Field water quality parameters (pH, EC and temperature) were measured using a TPS-81 field meter that was calibrated daily using standard solutions. It should be noted that results have only been included in Table 4.5, Table 4.6, Table 4.7, Table 4.8 and Table 4.9 for SW1, SW2, SW3, SW4, SW5, SW7, SW8 and SW9 when data could be suitably collected (e.g. SW1 was attempted to be sampled in June 2020, however the baseline monitoring location was dry).

Frequent monitoring was undertaken for each of the surface water sites. However, they were often dry and therefore, quarterly sampling of each site was not possible. These samples were not included in the sample count in Table 4.5 to Table 4.9. To supplement the baseline water quality dataset, an extensive dataset was collated for the Isaac River which includes data collected from surrounding mining operations. Refer to Section 4.4.2.3 for details.

Samples were collected in the field by hydrogeologist.com.au using laboratory supplied containers. Where required, samples were filtered in the field using either disposable syringes and 45 micron disc filters, or steri-cups and vacuum pump for the more turbid samples. The samples were immediately stored on ice and refrigerated where possible. All samples were freighted on ice in laboratory supplied eskies under a chain of custody with TNT. Samples were freighted from Moranbah to ALS (Mackay) and analysed at ALS (Brisbane), a National Association of Testing Authorities (NATA) certified laboratory.

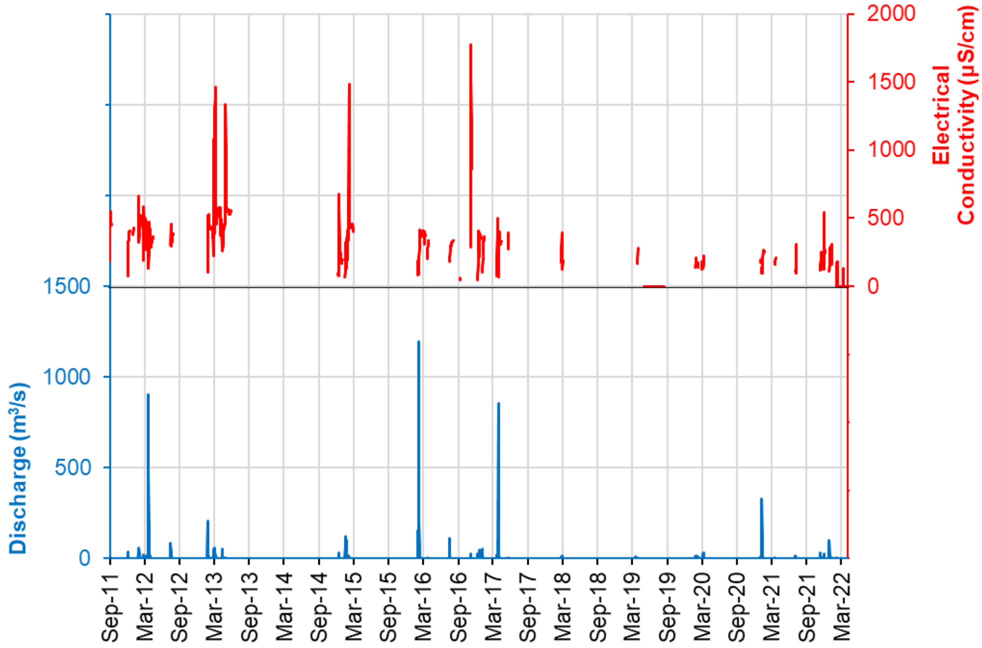


Figure 4.13 - Electrical Conductivity and flow (Isaac River at Deverill gauge)

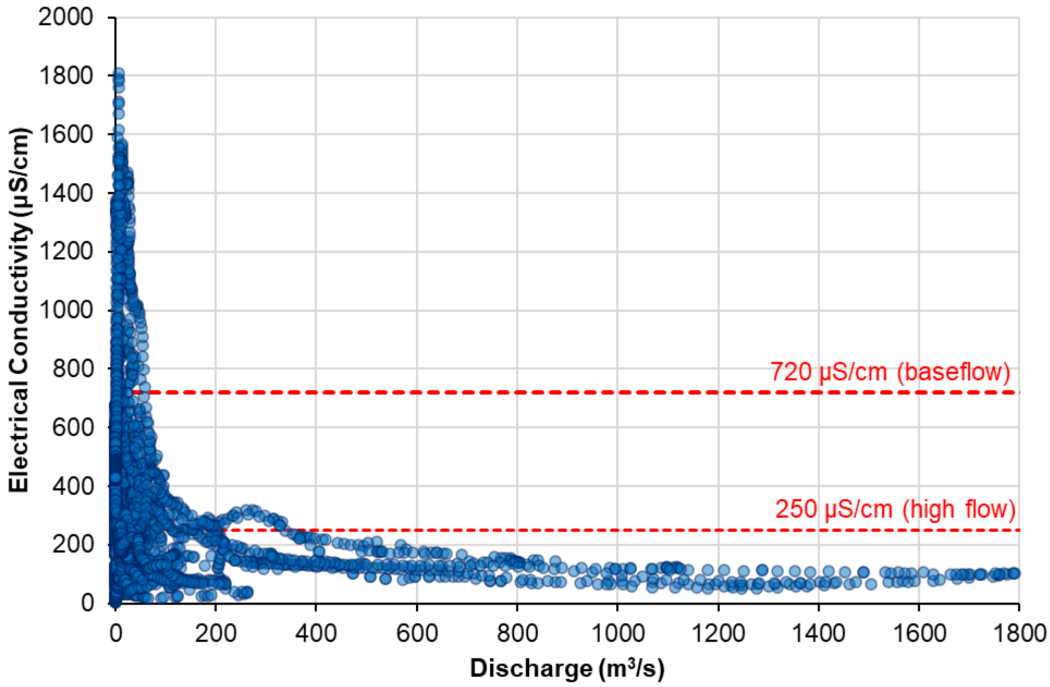


Figure 4.14 - Flow vs Electrical Conductivity (Isaac River at Deverill gauge)

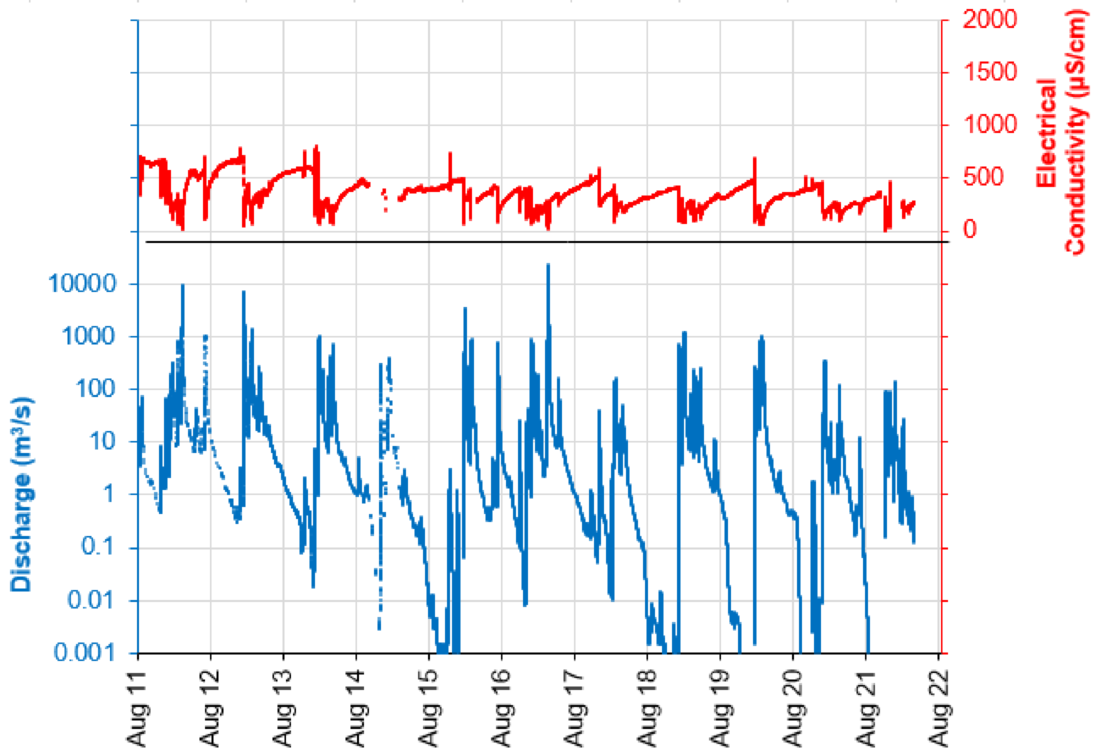


Figure 4.15 - Electrical Conductivity and flow (Isaac River at Yatton gauge)

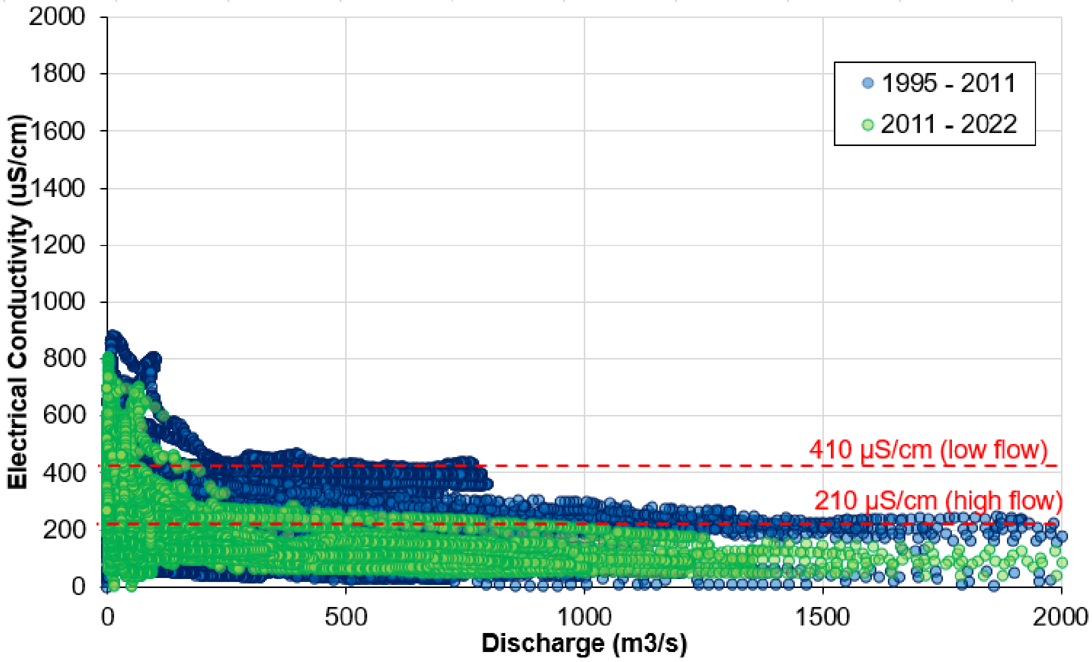


Figure 4.16 - Flow vs Electrical Conductivity (Isaac River at Yatton gauge)

Table 4.5, Table 4.6 and Table 4.8 show that a number of the baseline water quality samples do not meet the DGVs for the region. In particular for the Isaac River, these include the following:

- EC – single sample exceeded;
- TSS;
- Turbidity;
- Aluminium (total and dissolved);
- Cobalt (dissolved);
- Copper (dissolved);
- Manganese (dissolved);
- Iron (total and dissolved);
- Uranium (dissolved); and
- Ammonia.

These background exceedances of the regional DGVs are also generally reflected in the other sampling locations in Ripstone Creek and the unnamed tributaries of the Isaac River. In addition, there were multiple exceedances at these locations for the following:

- Copper (dissolved);
- Zinc (dissolved); and
- Vanadium (dissolved).

4.4.2.2 Olive Downs Project water quality data

Water quality sampling data for the neighbouring Olive Downs Project has been provided by Pembroke Olive Downs Pty Ltd (Pembroke). Water quality monitoring has been undertaken at various location in the Isaac River and surrounding waterways (including Ripstone Creek) between July 2017 and January 2022.

The water quality sampling results are provided in Tables A1 to A7 in Appendix A. Similar to the Project-specific data, the Olive Downs Project water quality samples show that a number of the baseline water quality samples do not meet the DGVs for the region. In particular for the Isaac River, these include (but not limited to) the following:

- pH;
- TSS;
- Turbidity;
- Dissolved oxygen;
- Aluminium (total and dissolved); and
- Iron (total and dissolved).

These background exceedances of the regional DGVs are also generally reflected in the other sampling locations in Ripstone Creek and the unnamed tributaries of the Isaac River. In addition, there were multiple exceedances at these locations for the following:

- Copper (dissolved);
- Zinc (dissolved);
- Vanadium (dissolved);
- Reactive phosphorus; and
- TSS.

Table 4.5 - Local water quality sampling data - SW1/SW2

Parameter	Unit	SW1					SW2										Default Guideline Value (refer Table 3.1)
		25/3/19	29/4/19	26/5/19	23/6/19	24/1/22	25/3/19	29/4/19	26/5/19	23/6/19	28/7/19	28/6/20	15/9/20	9/3/21	28/9/21	25/1/22	
pH	-	7.92	8.56	8.39	8.51	8.26	8.55	8.02	7.96	8.31	8.05	8.17	7.5	7.78	7.97	8.14	6.5-8.5 (aquatic)
Electrical Conductivity	µS/cm	230	392	377	497	508	294	189	251	292	299	294	430	652	204	281	< 720 (baseflow) < 250 (high flow)
Total Dissolved Solids	mg/L	150	255	245	323	330	191	123	163	190	194	191	280	424	133	183	< 2,000 (stock)
Total Suspended Solids	mg/L	111	8	56	39	101	435	26	27	48	-	132	202	152	88	52	< 55 (aquatic)
Turbidity	NTU	609	12	81	44	46.4	543	170	75	46	-	127	396	94.3	290	43.8	< 50 (aquatic)
Total Hardness	mg/L	56	145	96	70	171	99	80	105	112	121	127	165	205	66	109	<150 (drinking)
Sulphate as SO4	mg/L	4	<1	3	6	<1	3	<1	2	2	2	1	<1	5	1	2	25 (aquatic)
Sodium (dissolved)	mg/L	31	40	52	90	51	17	6	8	10	13	13	28	38	16	13	< 30 (drinking)
Aluminium (dissolved)	mg/L	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.13	<0.01	< 0.055 (aquatic)
Arsenic (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	0.002	0.003	0.001	0.001	<0.001	<0.001	<0.001	0.003	0.003	<0.001	0.002	< 0.013 (aquatic)
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	<0.0001	< 0.0002 (aquatic)
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	< 0.001 (aquatic)
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	0.004	0.003	<0.001	<0.001	< 0.0014 (aquatic)
Copper (dissolved)	mg/L	0.004	0.003	0.005	0.006	0.002	0.005	0.002	0.003	0.004	0.002	0.002	0.003	0.002	0.003	0.002	< 0.0014 (aquatic)
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	<0.001	< 0.0034 (aquatic)
Manganese (dissolved)	mg/L	0.005	0.004	0.002	0.002	0.056	0.022	0.093	0.081	0.034	0.174	0.010	0.895	1.39	0.016	0.075	1.9 (aquatic)
Molybdenum (dissolved)	mg/L	0.004	0.002	0.004	0.004	0.003	0.002	<0.001	0.001	<0.001	0.001	<0.001	0.002	0.003	<0.001	0.001	< 0.034 (aquatic)
Nickel (dissolved)	mg/L	0.003	0.003	0.003	0.004	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.009	0.009	0.001	0.003	< 0.011 (aquatic)
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	<0.01	< 0.005 (aquatic)
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	<0.001	<0.001	< 0.001 (aquatic)
Uranium (dissolved)	mg/L	<0.001	<0.001	0.002	0.002	0.002	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.002	<0.001	<0.001	< 0.001 (aquatic)
Vanadium (dissolved)	mg/L	<0.01	0.01	0.02	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 (aquatic)
Zinc (dissolved)	mg/L	0.013	<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	<0.005	< 0.008 (aquatic)
Boron (dissolved)	mg/L	0.08	0.16	0.2	0.15	0.2	0.15	0.06	0.06	0.06	0.07	0.07	0.11	0.19	<0.05	0.13	< 0.94 (aquatic)

Parameter	Unit	SW1					SW2										Default Guideline Value (refer Table 3.1)
		25/3/19	29/4/19	26/5/19	23/6/19	24/1/22	25/3/19	29/4/19	26/5/19	23/6/19	28/7/19	28/6/20	15/9/20	9/3/21	28/9/21	25/1/22	
Iron (dissolved)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.12	<0.05	< 0.7 (aquatic)
Aluminium (total)	mg/L	18.2	0.66	4.5	1.7	1.98	3.9	8.6	4.0	0.7	2.1	3.7	12.5	7.76	14.5	1.5	< 5 (stock)
Arsenic (total)	mg/L	0.001	0.001	0.001	<0.001	0.003	0.004	0.004	0.001	0.002	0.001	0.002	0.007	0.005	0.003	0.003	< 2.0 (irrigation) < 0.5 (stock)
Beryllium (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	<0.001	<0.001	< 0.5 (irrigation)
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	<0.0001	< 0.01 (stock)
Chromium (total)	mg/L	0.046	0.001	0.009	0.005	0.004	0.005	0.01	0.005	0.002	0.003	0.004	0.015	0.002	0.017	0.002	< 1 (stock)
Cobalt (total)	mg/L	0.006	<0.001	0.002	0.001	0.002	0.004	0.004	0.003	0.002	0.003	0.004	0.015	0.007	0.005	0.002	< 0.1 (irrigation)
Copper (total)	mg/L	0.021	<0.001	0.01	0.013	0.004	0.009	<0.001	0.008	0.01	0.005	0.006	0.015	0.006	0.012	0.003	<1 (stock)
Lead (total)	mg/L	0.004	<0.001	<0.001	<0.001	<0.001	0.003	0.003	0.002	0.001	0.001	0.004	0.009	0.003	0.005	0.002	< 0.1 (stock)
Manganese (total)	mg/L	0.178	0.023	0.077	0.046	0.212	0.386	0.267	0.204	0.155	0.317	0.45	1.99	2.04	0.21	0.272	< 10 (irrigation)
Molybdenum (total)	mg/L	0.001	0.003	0.004	0.004	0.003	0.002	<0.001	<0.001	<0.001	0.001	<0.001	0.002	0.004	<0.001	<0.001	< 0.05 (irrigation)
Nickel (total)	mg/L	0.04	0.004	0.01	0.008	0.009	0.009	0.01	0.007	0.005	0.005	0.007	0.024	0.013	0.015	0.005	< 1 (stock)
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	<0.01	< 0.02 (stock)
Uranium (total)	mg/L	<0.001	<0.001	0.002	0.002	0.002	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.001	0.002	<0.001	<0.001	< 0.1 (irrigation)
Vanadium (total)	mg/L	0.05	0.01	0.03	0.02	0.02	0.02	0.02	0.01	<0.01	<0.01	0.02	0.04	0.02	0.03	<0.01	< 0.5 (irrigation)
Zinc (total)	mg/L	0.023	<0.005	0.007	0.026	0.015	0.02	0.056	0.022	0.043	0.006	0.018	0.022	0.02	0.025	0.008	< 5 (irrigation)
Boron (total)	mg/L	0.08	0.16	0.23	0.13	0.21	0.15	0.05	0.07	<0.05	0.1	0.05	0.11	0.25	<0.05	0.13	< 5 (stock)
Iron (total)	mg/L	17.5	0.6	2.9	1.3	1.48	3.9	8.4	3.3	0.8	2.0	4.3	16.7	3.35	12.8	2.08	< 10 (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	<0.0001	< 0.0002 (irrigation)
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	<0.0001	< 0.002 (irrigation)
Fluoride (total)	mg/L	0.8	0.8	1.3	1.3	0.6	0.4	0.2	0.2	0.2	0.2	0.3	0.4	0.4	0.2	0.2	< 2 (irrigation)
Ammonia (total)	mg/L	0.03	0.04	0.04	0.04	0.14	<0.01	0.26	0.01	0.03	0.03	0.01	0.85	0.61	0.08	0.04	< 0.02 (aquatic)
Nitrate as N	mg/L	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	< 1.1 (aquatic)
Phosphorus as P (total)	mg/L	0.25	0.04	0.13	0.14	0.12	0.2	0.2	0.14	0.11	0.22	0.27	0.69	0.84	0.28	0.09	< 50 (aquatic)
Bromide	mg/L	0.052	0.098	0.162	0.294	0.206	0.127	0.018	0.038	0.049	-	0.095	0.41	0.405	0.04	0.056	-

Table 4.6 - Local water quality sampling data - SW3

Parameter	Unit	SW3 2/3/19	SW3 29/4/19	SW3 26/5/19	SW3 18/6/20	SW3 28/9/21	SW3 25/1/22	Default Guideline Value (refer Table 3.1)
pH	-	7.83	8.42	7.93	8.24	8.28	8.11	6.5-8.5 (aquatic)
Electrical Conductivity	µS/cm	669	374	438	372	396	501	< 720 (baseflow) < 250 (high flow)
Total Dissolved Solids	mg/L	435	243	285	242	257	326	< 2,000 (stock)
Total Suspended Solids	mg/L	194	64	573	44	80	73	< 55 (aquatic)
Turbidity	NTU	180	72	399	46	57.8	55.6	< 50 (aquatic)
Total Hardness	mg/L	211	158	142	148	155	171	<150 (drinking)
Sulphate as SO4	mg/L	<1	<1	<1	4	<1	4	25 (aquatic)
Sodium (dissolved)	mg/L	70	19	35	25	28	30	< 30 (drinking)
Aluminium (dissolved)	mg/L	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	< 0.055 (aquatic)
Arsenic (dissolved)	mg/L	0.005	0.002	0.002	0.001	0.001	0.004	< 0.013 (aquatic)
Cadmium (dissolved)	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.0002 (aquatic)
Chromium (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.001 (aquatic)
Cobalt (dissolved)	mg/L	0.002	<0.001	0.001	<0.001	<0.001	0.002	< 0.0014 (aquatic)
Copper (dissolved)	mg/L	0.002	0.002	0.003	0.002	0.003	<0.001	< 0.0014 (aquatic)
Lead (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.0034 (aquatic)
Manganese (dissolved)	mg/L	0.546	0.070	0.062	0.021	0.01	0.78	1.9 (aquatic)
Molybdenum (dissolved)	mg/L	0.003	0.002	0.003	0.001	0.001	0.001	< 0.034 (aquatic)
Nickel (dissolved)	mg/L	0.008	0.004	0.005	0.003	0.002	0.006	< 0.011 (aquatic)
Selenium (dissolved)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.005 (aquatic)
Silver (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.001 (aquatic)
Uranium (dissolved)	mg/L	0.002	<0.001	0.002	<0.001	0.001	<0.001	< 0.001 (aquatic)
Vanadium (dissolved)	mg/L	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	< 0.01 (aquatic)
Zinc (dissolved)	mg/L	0.006	<0.005	0.005	<0.005	<0.005	<0.005	< 0.008 (aquatic)
Boron (dissolved)	mg/L	0.14	0.07	0.08	<0.05	0.07	0.11	< 0.94 (aquatic)
Iron (dissolved)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	< 0.7 (aquatic)
Aluminium (total)	mg/L	5.9	2.5	17.2	2.0	2.71	1.04	< 5 (stock)

Parameter	Unit	SW3						Default Guideline Value (refer Table 3.1)
		2/3/19	29/4/19	26/5/19	18/6/20	28/9/21	25/1/22	
Arsenic (total)	mg/L	0.008	0.003	0.004	0.002	0.002	0.006	< 2.0 (irrigation) < 0.5 (stock)
Beryllium (total)	mg/L	-	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.5 (irrigation)
Cadmium (total)	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.01 (stock)
Chromium (total)	mg/L	0.009	0.003	0.022	0.003	0.004	0.001	< 1 (stock)
Cobalt (total)	mg/L	0.006	0.002	0.01	<0.001	0.002	0.004	< 0.1 (irrigation)
Copper (total)	mg/L	0.007	<0.001	0.015	0.003	0.006	<0.001	<1 (stock)
Lead (total)	mg/L	0.004	0.002	0.009	<0.001	0.002	0.002	< 0.1 (stock)
Manganese (total)	mg/L	0.814	0.185	0.481	0.051	0.088	1.08	< 10 (irrigation)
Molybdenum (total)	mg/L	0.003	0.002	0.002	0.001	0.001	0.001	< 0.05 (irrigation)
Nickel (total)	mg/L	0.016	0.007	0.025	0.005	0.007	0.008	< 1 (stock)
Selenium (total)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.02 (stock)
Uranium (total)	mg/L	0.002	<0.001	0.003	<0.001	0.001	<0.001	< 0.1 (irrigation)
Vanadium (total)	mg/L	0.02	0.01	0.04	<0.01	0.02	<0.01	< 0.5 (irrigation)
Zinc (total)	mg/L	0.011	0.023	0.027	0.005	0.01	<0.005	< 5 (irrigation)
Boron (total)	mg/L	0.15	0.07	0.1	<0.05	<0.05	0.12	< 5 (stock)
Iron (total)	mg/L	5.8	2.4	14.2	1.65	2.21	1.84	< 10 (irrigation)
Mercury (dissolved)	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.0002 (irrigation)
Mercury (total)	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.002 (irrigation)
Fluoride (total)	mg/L	0.7	0.4	0.5	0.3	0.4	0.3	< 2 (irrigation)
Ammonia (total)	mg/L	0.04	0.05	0.03	0.03	0.02	0.89	< 0.02 (aquatic)
Nitrate as N	mg/L	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	< 1.1 (aquatic)
Phosphorus as P (total)	mg/L		0.16	0.58	0.04	0.13	0.36	< 50 (aquatic)
Bromide	mg/L	-	0.04	0.16	0.05	0.022	0.098	-

Table 4.7 - Local water quality sampling data - SW3/SW4

Parameter	Unit	SW4											Default Guideline Value (refer Table 3.1)
		2/3/19	25/3/19	29/4/19	26/5/19	23/6/19	28/7/19	18/6/20	9/3/21	28/9/21	15/6/21	25/1/22	
pH	-	7.85	7.44	8.16	8.17	8.3	8.08	8.33	7.73	8.33	8.05	7.98	6.5-8.5 (aquatic)
Electrical Conductivity	µS/cm	818	160	349	414	438	436	399	398	579	435	355	< 720 (baseflow) < 250 (high flow)
Total Dissolved Solids	mg/L	532	104	227	269	285	283	259	259	376	283	231	< 2,000 (stock)
Total Suspended Solids	mg/L	301	69	39	18	34	-	29	28	24	52	23	< 55 (aquatic)
Turbidity	NTU	403	690	106	22.2	28.1	-	20	57.8	29.6	28.1	20.3	< 50 (aquatic)
Total Hardness	mg/L	214	39	99	126	142	138	146	99	208	140	92	<150 (drinking)
Sulphate as SO4	mg/L	39	5	11	9	8	8	1	20	17	16	14	25 (aquatic)
Sodium (dissolved)	mg/L	87	16	32	34	35	36	30	40	50	40	37	< 30 (drinking)
Aluminium (dissolved)	mg/L	0.06	0.44	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.055 (aquatic)
Arsenic (dissolved)	mg/L	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	< 0.013 (aquatic)
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	< 0.0002 (aquatic)
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 (aquatic)
Cobalt (dissolved)	mg/L	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.0014 (aquatic)
Copper (dissolved)	mg/L	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	<0.001	< 0.0014 (aquatic)
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	< 0.0034 (aquatic)
Manganese (dissolved)	mg/L	0.75	0.017	0.065	0.093	0.004	0.129	0.017	0.174	0.13	0.01	0.004	1.9 (aquatic)
Molybdenum (dissolved)	mg/L	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.002	<0.001	< 0.034 (aquatic)
Nickel (dissolved)	mg/L	0.006	0.002	0.002	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.002	< 0.011 (aquatic)
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	< 0.005 (aquatic)
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 (aquatic)
Uranium (dissolved)	mg/L	0.002	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.001 (aquatic)
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 (aquatic)
Zinc (dissolved)	mg/L	<0.005	0.008	<0.005	<0.005	<0.005	<0.005	<0.005	0.01	<0.005	<0.005	<0.005	< 0.008 (aquatic)
Boron (dissolved)	mg/L	0.14	<0.05	0.06	0.06	0.05	0.06	<0.05	0.08	0.06	<0.05	0.08	< 0.94 (aquatic)
Iron (dissolved)	mg/L	<0.05	0.2	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	< 0.7 (aquatic)
Aluminium (total)	mg/L	14.1	12.6	0.8	0.6	0.6	2.3	0.33	1.97	0.85	0.82	0.59	< 5 (stock)

Parameter	Unit	SW4											Default Guideline Value (refer Table 3.1)
		2/3/19	25/3/19	29/4/19	26/5/19	23/6/19	28/7/19	18/6/20	9/3/21	28/9/21	15/6/21	25/1/22	
Arsenic (total)	mg/L	0.009	0.002	0.001	0.001	0.001	<0.001	<0.001	0.002	0.002	<0.001	<0.001	< 2.0 (irrigation) < 0.5 (stock)
Beryllium (total)	mg/L	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.5 (irrigation)
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	< 0.01 (stock)
Chromium (total)	mg/L	0.023	0.017	<0.001	<0.001	<0.001	0.004	<0.001	0.001	0.001	0.001	<0.001	< 1 (stock)
Cobalt (total)	mg/L	0.012	0.005	0.002	0.001	0.002	0.002	<0.001	0.001	0.001	<0.001	<0.001	< 0.1 (irrigation)
Copper (total)	mg/L	0.015	0.012	<0.001	0.002	0.002	0.006	0.002	0.003	0.003	0.003	0.001	<1 (stock)
Lead (total)	mg/L	0.016	0.006	0.001	<0.001	<0.001	0.002	<0.001	0.001	<0.001	<0.001	<0.001	< 0.1 (stock)
Manganese (total)	mg/L	1.15	0.178	0.247	0.239	0.197	0.233	0.088	0.275	0.258	0.048	0.083	< 10 (irrigation)
Molybdenum (total)	mg/L	0.004	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	< 0.05 (irrigation)
Nickel (total)	mg/L	0.027	0.016	0.004	0.003	0.003	0.007	0.003	0.005	0.006	0.003	0.004	< 1 (stock)
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	< 0.02 (stock)
Uranium (total)	mg/L	0.003	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.1 (irrigation)
Vanadium (total)	mg/L	0.03	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.5 (irrigation)
Zinc (total)	mg/L	0.039	0.026	0.021	0.006	<0.005	0.032	0.007	0.013	<0.005	0.006	0.031	< 5 (irrigation)
Boron (total)	mg/L	0.15	<0.05	0.06	0.06	<0.05	0.1	<0.05	0.1	<0.05	<0.05	0.06	< 5 (stock)
Iron (total)	mg/L	21.5	14.1	1.3	0.9	1.1	2.8	0.88	1.55	0.85	1.06	0.58	< 10 (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	< 0.0002 (irrigation)
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	< 0.002 (irrigation)
Fluoride (total)	mg/L	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	< 2 (irrigation)
Ammonia (total)	mg/L	2.55	<0.01	0.03	0.01	0.02	0.38	<0.01	0.04	0.02	0.03	<0.01	< 0.02 (aquatic)
Nitrate as N	mg/L	<0.01	0.44	0.09	0.01	<0.01	0.06	<0.01	<0.01	<0.01	0.01	<0.01	< 1.1 (aquatic)
Phosphorus as P (total)	mg/L	-	0.3	0.08	0.04	0.08	0.09	<0.05	0.08	0.1	0.03	0.04	< 50 (aquatic)
Bromide	mg/L	-	0.036	0.082	0.098	0.095	-	0.102	0.13	0.11	0.082	0.112	-

Table 4.8 - Local water quality sampling data - SW5/SW7/SW8

Parameter	Unit	SW5							SW7	SW8	Default Guideline Value (refer Table 3.1)
		2/3/19	25/3/19	29/4/19	26/5/19	23/6/19	2/3/21	25/1/22	3/3/19	29/4/19	
pH	-	7.46	7.45	8.4	7.55	7.78	8	7.71	7.25	8.43	6.5-8.5 (aquatic)
Electrical Conductivity	µS/cm	317	211	474	495	340	1050	256	234	402	< 720 (baseflow) < 250 (high flow)
Total Dissolved Solids	mg/L	206	137	308	322	221	682	166	152	261	< 2,000 (stock)
Total Suspended Solids	mg/L	165	61	32	11	109	36	14	1,460	59	< 55 (aquatic)
Turbidity	NTU	251	174	22.9	22.9	146	42.9	5.9	2,700	43.1	< 50 (aquatic)
Total Hardness	mg/L	102	69	191	200	106	480	57	65	159	<150 (drinking)
Sulphate as SO4	mg/L	2	6	1	1	3	<1	11	5	<1	25 (aquatic)
Sodium (dissolved)	mg/L	24	16	28	27	25	34	29	24	25	< 30 (drinking)
Aluminium (dissolved)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.11	<0.01	< 0.055 (aquatic)
Arsenic (dissolved)	mg/L	0.002	0.002	0.002	0.002	0.002	0.006	<0.001	0.001	0.002	< 0.013 (aquatic)
Cadmium (dissolved)	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.0002 (aquatic)
Chromium (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.001 (aquatic)
Cobalt (dissolved)	mg/L	0.002	0.002	0.003	0.005	0.009	0.014	0.001	<0.001	<0.001	< 0.0014 (aquatic)
Copper (dissolved)	mg/L	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	0.005	< 0.0014 (aquatic)
Lead (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.0034 (aquatic)
Manganese (dissolved)	mg/L	1.29	0.587	1.26	2.91	3.19	5.17	0.335	0.001	0.024	1.9 (aquatic)
Molybdenum (dissolved)	mg/L	0.001	<0.001	0.001	<0.001	<0.001	0.001	<0.001	0.001	0.002	< 0.034 (aquatic)
Nickel (dissolved)	mg/L	0.003	0.002	0.002	0.003	0.004	0.012	0.002	0.002	0.003	< 0.011 (aquatic)
Selenium (dissolved)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.005 (aquatic)
Silver (dissolved)	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.001 (aquatic)
Uranium (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.002	< 0.001 (aquatic)
Vanadium (dissolved)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	< 0.01 (aquatic)
Zinc (dissolved)	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.009	<0.005	<0.005	< 0.008 (aquatic)
Boron (dissolved)	mg/L	0.07	0.05	0.06	0.05	<0.05	0.1	0.06	0.13	0.09	< 0.94 (aquatic)
Iron (dissolved)	mg/L	0.05	<0.05	<0.05	0.29	4.67	1.92	<0.05	0.1	<0.05	< 0.7 (aquatic)
Aluminium (total)	mg/L	4.35	3.4	0.14	0.34	2.29	0.33	0.16	18	1.28	< 5 (stock)

Parameter	Unit	SW5							SW7	SW8	Default Guideline Value (refer Table 3.1)
		2/3/19	25/3/19	29/4/19	26/5/19	23/6/19	2/3/21	25/1/22	3/3/19	29/4/19	
Arsenic (total)	mg/L	0.005	0.003	0.003	0.003	0.005	0.007	0.001	0.006	0.002	< 2.0 (irrigation) < 0.5 (stock)
Beryllium (total)	mg/L	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	< 0.5 (irrigation)
Cadmium (total)	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.01 (stock)
Chromium (total)	mg/L	0.008	0.004	<0.001	<0.001	0.003	<0.001	<0.001	0.012	0.001	< 1 (stock)
Cobalt (total)	mg/L	0.006	0.004	0.003	0.007	0.008	0.015	0.002	0.01	0.001	< 0.1 (irrigation)
Copper (total)	mg/L	0.006	0.004	<0.001	0.002	0.005	0.002	<0.001	0.025	<0.001	<1 (stock)
Lead (total)	mg/L	0.006	0.002	<0.001	<0.001	0.003	<0.001	<0.001	0.017	<0.001	< 0.1 (stock)
Manganese (total)	mg/L	1.51	0.697	1.38	3.11	2.28	5.4	0.39	0.402	0.066	< 10 (irrigation)
Molybdenum (total)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.002	< 0.05 (irrigation)
Nickel (total)	mg/L	0.009	0.006	0.003	0.004	0.007	0.012	0.003	0.018	0.004	< 1 (stock)
Selenium (total)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.02 (stock)
Uranium (total)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	0.002	< 0.1 (irrigation)
Vanadium (total)	mg/L	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	0.01	< 0.5 (irrigation)
Zinc (total)	mg/L	0.01	0.019	0.013	0.011	0.02	0.011	<0.026	0.041	0.007	< 5 (irrigation)
Boron (total)	mg/L	0.07	0.05	0.06	0.06	<0.05	0.12	0.06	0.16	0.09	< 5 (stock)
Iron (total)	mg/L	11.7	4.8	2.4	4.9	11	7.1	0.63	17	1.13	< 10 (irrigation)
Mercury (dissolved)	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.0002 (irrigation)
Mercury (total)	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.002 (irrigation)
Fluoride (total)	mg/L	0.3	0.2	0.2	0.2	0.2	0.2	0.1	0.4	0.3	< 2 (irrigation)
Ammonia (total)	mg/L	1.34	<0.01	0.03	0.15	1.05	15.5	0.01	0.06	0.07	< 0.02 (aquatic)
Nitrate as N	mg/L	0.08	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.13	<0.01	< 1.1 (aquatic)
Phosphorus as P (total)	mg/L	-	0.12	0.08	0.08	0.14	0.3	0.04	-	0.24	< 50 (aquatic)
Bromide	mg/L	-	0.033	0.102	0.124	0.074	0.225	0.076	-	0.064	-

Table 4.9 - Local water quality sampling data -SW9

Parameter	Unit	SW9										Default Guideline Value (refer Table 3.1)
		2/5/19	26/5/19	23/6/19	28/7/19	20/11/19	18/6/20	15/9/20	8/12/20	9/3/21	15/6/21	
pH	-	8.72	8.61	8.59	8.28	8.44	8.39	8.5	8.91	8.93	8.94	6.5-8.5 (aquatic)
Electrical Conductivity	µS/cm	574	632	665	692	861	883	994	1560	1770	2600	< 720 (baseflow) < 250 (high flow)
Total Dissolved Solids	mg/L	373	411	432	450	560	574	646	1010	1150	1690	< 2,000 (stock)
Total Suspended Solids	mg/L	91	104	90	-	38	121	109	170	63	810	< 55 (aquatic)
Turbidity	NTU	93.6	128	119	-	132	119	94.1	190	118	976	< 50 (aquatic)
Total Hardness	mg/L	143	150	156	168	173	159	156	146	144	165	<150 (drinking)
Sulphate as SO4	mg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<10	25 (aquatic)
Sodium (dissolved)	mg/L	44	46	46	50	72	85	109	183	224	422	< 30 (drinking)
Aluminium (dissolved)	mg/L	<0.01	<0.01	0.02	<0.01	0.04	0.04	<0.01	0.03	0.12	0.06	< 0.055 (aquatic)
Arsenic (dissolved)	mg/L	0.004	0.005	0.004	0.003	0.007	0.006	0.007	0.013	0.018	0.021	< 0.013 (aquatic)
Cadmium (dissolved)	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.0002 (aquatic)
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 (aquatic)
Cobalt (dissolved)	mg/L	0.001	0.001	0.001	0.001	0.001	<0.001	0.001	0.001	0.002	0.003	< 0.0014 (aquatic)
Copper (dissolved)	mg/L	0.003	0.003	0.004	0.003	0.003	0.001	0.002	0.003	0.003	0.004	< 0.0014 (aquatic)
Lead (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.0034 (aquatic)
Manganese (dissolved)	mg/L	0.007	0.009	0.013	0.028	0.029	0.008	0.002	0.032	0.02	0.037	1.9 (aquatic)
Molybdenum (dissolved)	mg/L	0.001	0.002	0.001	0.001	0.002	0.002	0.004	0.004	0.005	0.009	< 0.034 (aquatic)
Nickel (dissolved)	mg/L	0.004	0.005	0.006	0.006	0.007	0.006	0.007	0.008	0.011	0.017	< 0.011 (aquatic)
Selenium (dissolved)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.005 (aquatic)
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 (aquatic)
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 (aquatic)
Vanadium (dissolved)	mg/L	0.02	0.02	0.01	<0.01	0.01	<0.01	<0.01	0.03	0.03	0.03	< 0.01 (aquatic)
Zinc (dissolved)	mg/L	<0.005	<0.005	<0.005	<0.005	0.006	0.006	<0.005	0.007	0.007	0.017	< 0.008 (aquatic)
Boron (dissolved)	mg/L	0.17	0.15	0.15	0.16	0.28	0.24	0.29	0.52	0.59	0.62	< 0.94 (aquatic)
Iron (dissolved)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.11	<0.05	< 0.7 (aquatic)
Aluminium (total)	mg/L	1.36	2.92	1.80	1.97	2.40	1.42	0.74	2.15	2.34	10.3	< 5 (stock)

Parameter	Unit	SW9										Default Guideline Value (refer Table 3.1)
		2/5/19	26/5/19	23/6/19	28/7/19	20/11/19	18/6/20	15/9/20	8/12/20	9/3/21	15/6/21	
Arsenic (total)	mg/L	0.005	0.005	0.005	0.004	0.008	0.007	0.01	0.016	0.02	0.029	< 2.0 (irrigation) < 0.5 (stock)
Beryllium (total)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.5 (irrigation)
Cadmium (total)	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.01 (stock)
Chromium (total)	mg/L	0.002	0.005	0.003	0.005	0.004	0.003	0.001	0.004	0.005	0.03	< 1 (stock)
Cobalt (total)	mg/L	0.003	0.005	0.004	0.006	0.004	0.004	0.004	0.004	0.005	0.023	< 0.1 (irrigation)
Copper (total)	mg/L	0.004	0.008	0.007	0.007	0.005	0.003	0.005	0.013	0.006	0.025	<1 (stock)
Lead (total)	mg/L	0.001	0.002	0.002	0.003	0.002	0.002	0.003	0.001	0.002	0.01	< 0.1 (stock)
Manganese (total)	mg/L	0.314	0.367	0.531	0.76	0.378	0.504	1	0.299	0.313	0.732	< 10 (irrigation)
Molybdenum (total)	mg/L	0.002	0.001	0.001	0.001	0.002	0.002	0.003	0.004	0.005	0.009	< 0.05 (irrigation)
Nickel (total)	mg/L	0.007	0.01	0.009	0.01	0.01	0.008	0.01	0.015	0.015	0.049	< 1 (stock)
Selenium (total)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.02 (stock)
Uranium (total)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	0.002	< 0.1 (irrigation)
Vanadium (total)	mg/L	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.03	0.03	0.08	< 0.5 (irrigation)
Zinc (total)	mg/L	0.007	0.02	0.013	0.008	0.01	0.013	0.006	0.016	0.018	0.033	< 5 (irrigation)
Boron (total)	mg/L	0.22	0.17	0.14	0.23	0.26	0.21	0.3	1.57	0.63	0.85	< 5 (stock)
Iron (total)	mg/L	2.7	3.9	3.3	4.5	4.2	2.8	2.82	3.05	3.56	23.6	< 10 (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	< 0.0002 (irrigation)
Mercury (total)	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	< 0.002 (irrigation)
Fluoride (total)	mg/L	0.3	0.3	0.3	0.9	0.5	0.5	0.6	1	1	1.4	< 2 (irrigation)
Ammonia (total)	mg/L	-	0.16	0.35	0.46	0.20	0.04	0.08	0.04	0.1	0.15	< 0.02 (aquatic)
Nitrate as N	mg/L	-	<0.01	0.03	0.49	0.19	<0.01	<0.01	0.02	0.01	<0.01	< 1.1 (aquatic)
Phosphorus as P (total)	mg/L	-	0.38	0.22	0.38	0.38	0.25	0.63	0.94	0.57	1.65	< 50 (aquatic)
Bromide	mg/L	0.082	0.105	0.09	-	0.170	0.185	0.23	<0.050	0.63	1.08	-

4.4.2.3 Review of composite Isaac River datasets

Between the Project and neighbouring Olive Downs Project water quality datasets, there is an adequate number of water quality samples for the Isaac River. These separate datasets have been collated and statically analysed for comparison against the regional DGVs.

For this assessment, the following monitoring points for the reach of the Isaac River adjacent to the Project have been combined and analysed (refer to Figure 4.12 for locations):

- SW4 (WHC) – 7 samples
- SW5 (WHC) - 5 samples
- SW1 (Pembroke) – 10 samples
- SW3 (Pembroke) – 18 samples

This composite water quality sample dataset (combination of Project specific and Olive Downs Project data) represents the water quality in a 17 km reach of the Isaac River over a two year period at these four locations. A statistical analysis and comparison with the regional DGV's is provided in Table 4.10.

Table 4.10 shows that the DGVs for dissolved aluminium, iron, selenium (dissolved) and turbidity are below the measured 80th percentile values and below the 20th percentile values for ammonia in the vicinity of the Project. This indicates that there may be justification to apply site-specific WQOs for these five parameters. Further discussion on the setting of site-specific WQOs for these give parameters is provided in Section 10.7.3.

Table 4.10 - Isaac River water quality summary - composite dataset

Parameter	Unit	Composite Isaac River dataset				Default Guideline Value (refer Table 3.1)
		No. of samples	20th %ile value	Median value	80th %ile value	
Aluminium (total)	mg/L	38	0.15	0.37	3.36	< 5 (stock)
Aluminium (dissolved)	mg/L	38	<0.010	0.040	0.116	< 0.055 (aquatic)
Ammonia (total)	mg/L	40	0.03	0.06	0.18	< 0.02 (aquatic)
Arsenic (total)	mg/L	39	<0.001	0.002	0.003	< 2.0 (irrigation) < 0.5 (stock)
Arsenic (dissolved)	mg/L	40	<0.001	<0.001	0.002	< 0.013 (aquatic)
Beryllium (total)	mg/L	10	<0.001	<0.001	<0.001	< 0.5 (irrigation)
Boron (total)	mg/L	38	<0.05	<0.05	0.07	< 5 (stock)
Boron (dissolved)	mg/L	38	<0.05	<0.05	0.06	< 0.94 (aquatic)
Cadmium (total)	mg/L	40	<0.0001	<0.0001	0.0001	< 0.01 (stock)
Cadmium (dissolved)	mg/L	40	<0.0001	<0.0001	0.0001	< 0.0002 (aquatic)
Cobalt (total)	mg/L	38	<0.001	0.001	0.004	< 0.1 (irrigation)
Cobalt (dissolved)	mg/L	38	<0.001	<0.001	0.001	< 0.0014 (aquatic)
Chromium (total)	mg/L	40	<0.001	0.001	0.004	< 1 (stock)
Chromium (dissolved)	mg/L	40	<0.001	<0.001	0.001	< 0.001 (aquatic)
Copper (total)	mg/L	40	<0.001	0.001	0.004	<1 (stock)
Copper (dissolved)	mg/L	40	<0.001	<0.001	0.001	< 0.00014 (aquatic)

Parameter	Unit	Composite Isaac River dataset				Default Guideline Value (refer Table 3.1)
		No. of samples	20^{th} %ile value	Median value	80^{th} %ile value	
Electrical Conductivity	µS/cm	39	287	343	442	< 720 (baseflow) < 250 (high flow)
Filterable Reactive Phosphorus	mg/L	25	<0.01	<0.01	0.01	< 0.02 (aquatic)
Fluoride (total)	mg/L	40	0.2	0.2	0.2	< 2 (irrigation)
Iron (total)	mg/L	38	0.60	1.41	6.68	< 10 (irrigation)
Iron (dissolved)	mg/L	38	0.05	0.16	0.38	< 0.18 (aquatic)
Lead (total)	mg/L	40	<0.001	0.001	0.003	< 0.1 (stock)
Lead (dissolved)	mg/L	40	<0.001	<0.001	0.001	< 0.0034 (aquatic)
Manganese (total)	mg/L	38	0.22	0.44	1.09	< 10 (irrigation)
Manganese (dissolved)	mg/L	38	0.05	0.33	0.95	1.9 (aquatic)
Mercury (total)	mg/L	40	<0.0001	<0.0001	0.0001	< 0.002 (irrigation)
Mercury (dissolved)	mg/L	40	<0.0001	<0.0001	0.0001	< 0.0002 (irrigation)
Molybdenum (total)	mg/L	38	<0.001	<0.001	0.001	< 0.05 (irrigation)
Molybdenum (dissolved)	mg/L	38	<0.001	<0.001	0.001	< 0.034 (aquatic)
Nickel (total)	mg/L	40	0.001	0.003	0.007	< 1 (stock)
Nickel (dissolved)	mg/L	40	0.001	0.002	0.002	< 0.011 (aquatic)
pH	-	39	7.31	7.67	8.26	6.5-8.5 (aquatic)
Phosphorus (total)	mg/L	38	0.02	0.06	0.11	< 50 (aquatic)
Selenium (total)	mg/L	38	<0.01	<0.01	0.01	< 0.02 (stock)
Selenium (dissolved)	mg/L	38	<0.01	<0.01	0.01	< 0.005 (aquatic)
Sulphate (total)	mg/L	40	3	5	8	< 25 (aquatic)
Total Dissolved Solids	mg/L	12	206	264	303	< 2,000 (stock)
Total Suspended Solids	mg/L	39	11	19	48	< 55 (aquatic)
Turbidity	NTU	37	11	30	144	< 50 (aquatic)
Uranium (total)	mg/L	37	<0.001	<0.001	0.001	< 0.1 (irrigation)
Uranium (dissolved)	mg/L	37	<0.001	<0.001	0.001	< 0.001 (aquatic)
Vanadium (total)	mg/L	38	<0.01	<0.01	0.01	< 0.5 (irrigation)
Vanadium (dissolved)	mg/L	38	<0.01	<0.01	0.01	< 0.01 (aquatic)
Zinc (total)	mg/L	40	<0.005	0.006	0.020	< 5 (irrigation)
Zinc (dissolved)	mg/L	40	<0.005	<0.005	0.005	< 0.008 (aquatic)

NOTE: values that were recorded as below the limit of reporting, have been assumed to be equal to the limit of reporting, for the purpose of this statistical analysis.

4.5 EXISTING WATER USE ENTITLEMENTS

There are 7 licences to take water from the Isaac River downstream of the Project which have been issued for mining, irrigation, stock watering, domestic supply and water harvesting. Detailed information regarding individual licences for Isaac River surface water users was obtained through analysis of water licences data provided by DoR. 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 of the volume, source and purpose of the licences are included in Table 4.11.

There are also several historical riparian water access notifications along the Isaac River which authorise stock and domestic supplies only. Section 96 of the Water Act states that an owner of land adjoining a watercourse may take water for domestic and stock purposes without the need for a permit or licence.

The above information indicates that there is currently minimal use of surface water from the Isaac River downstream of the Project, and water use is limited to mining, irrigation and stock watering.

Table 4.11 - 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	405577	Licence to take water	Issued	30/06/2111	Irrigation; Stock Intensive	60 ML	14/ROP89	Immediately downstream of Isaac & Connors River confluence (Approx. 100 km d/s of Project)
Fitzroy Basin	Isaac River	405578	Licence to take water	Issued	30/06/2111	Irrigation	150 ha	14/ROP89	Immediately downstream of Isaac & Connors River confluence (Approx. 100 km d/s of Project)
Fitzroy Basin	Isaac River	45321U	Licence to take water	Issued	30/06/2111	Irrigation	40 ha	14/ROP89	Immediately downstream of Isaac & Connors River confluence (Approx. 100 km d/s of Project)
Fitzroy Basin	Isaac River	43173WL	Licence to take water	Issued	30/06/2111	Water harvesting	NULL	18/SP113322	Adjacent to Isaac River & North Creek confluence (Approx. 5 km d/s of Project)
Fitzroy Basin	Isaac River	43174L	Licence to take water	Issued	30/06/2111	Water harvesting	NULL	18/SP113322	Adjacent to Isaac River & North Creek confluence (Approx. 5 km d/s of Project)
Fitzroy Basin	Isaac River	54781U	Licence to take water	Issued	30/06/2111	Irrigation	40 ha	6/RP860051	Immediately upstream of Isaac & Mackenzie River confluence (Approx. 125 km d/s of Project)
Fitzroy Basin	Isaac River	617184	Licence to take water	Issued	15/03/219	Construction	5 ML	11/KL135	Adjacent to Isaac River & North Creek confluence (Approx. 10 km d/s of Project)

5 Proposed surface water management strategy and infrastructure

5.1 OVERVIEW

This section describes the objectives and principles of the proposed water management system for the proposed mining operations at the Project, including a description of the infrastructure and systems that have been designed to achieve the objectives and principles.

5.2 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 5.1.

Table 5.1 - Types of water

Water type	Definition
Mine-affected water	In accordance with the DES's *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 water, 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.

Water type	Definition
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. EC, 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.
Contaminated water	Contaminated water includes runoff from areas containing explosives, hazardous chemicals, corrosive substances, toxic substances, gases and dangerous goods, as well as flammable and combustible liquids (including petroleum products).
Potable water	Treated water suitable for human consumption.

5.3 SURFACE WATER MANAGEMENT OBJECTIVES

The objective of the site water management system is to manage all types of water on-site to meet operational, social and environmental objectives.

There are two key water management system objectives:

- Minimise mine-affected water accumulation, minimise the risk of uncontrolled discharges and maintain sufficient water for the operation in dry times; and
- Successfully engage with external stakeholders to be a good custodian of society's water resources. The priority issues are the site's impact on surface water and groundwater.

Specific objectives for each water type are as follows:

- ***External water:*** Ensure that external water allocation and associated infrastructure is sufficient to meet Project demands particularly under low rainfall conditions.
- ***Mine-affected water***:
    - Manage controlled releases of mine-affected water to prevent environmental harm.
    - Minimise uncontrolled discharges in wet periods to maintain adequate water supplies for site demand during dry periods.
    - Understand, manage and minimise the potential impact of the water management system on the regional groundwater system.
- ***Sediment water:*** Maintain the quality of water discharging from erosion and sediment control structures to as close to background levels as reasonably possible.
- ***Clean water:*** Separate from the mine-affected and sediment water systems as much as reasonable and feasible and allow it to pass uninterrupted through the catchment.
- ***Contaminated water:*** Ensure full separation from other water sources and manage under the specifications of *AS1940 – Storage and Handling of Flammable and Combustible Liquids*.

5.4 SURFACE WATER MANAGEMENT PRINCIPLES

The general principles to manage surface water for the Project are as follows:

- The fullest separation possible of clean, sediment water, mine-affected water runoff, within the limitations of operational requirements.
- Minimise the area of surface disturbance, thus minimising the volume of sediment or mine-affected runoff.
- Collect and contain on-site all potential mine-affected water into dedicated mine water storages. The mine water storages will be used as the primary water source for the dust suppression requirements.
- Retain and reuse on-site any sediment water runoff that has high sediment concentrations whenever possible. If not, release it in a controlled manner (i.e. following settlement) in compliance with the proposed EA conditions.
- Prioritise the use of poor quality water over better quality water, where practical.

5.5 PROPOSED WATER MANAGEMENT INFRASTRUCTURE

Figure 5.1 to Figure 5.6 show indicative locations of the key features of the Project, including infrastructure related to the management of water on the Project site for six different phases of mining (Phase 1 to Phase 6). The main components of water-related infrastructure include:

- sediment dams to collect and treat runoff from out-of-pit waste rock emplacement areas;
- erosion and sediment control structures to manage disturbed areas that do not drain to a water storage (further detail regarding these structures will be provided in an Erosion and Sediment Control Plan [ESCP]);
- 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 6.4.

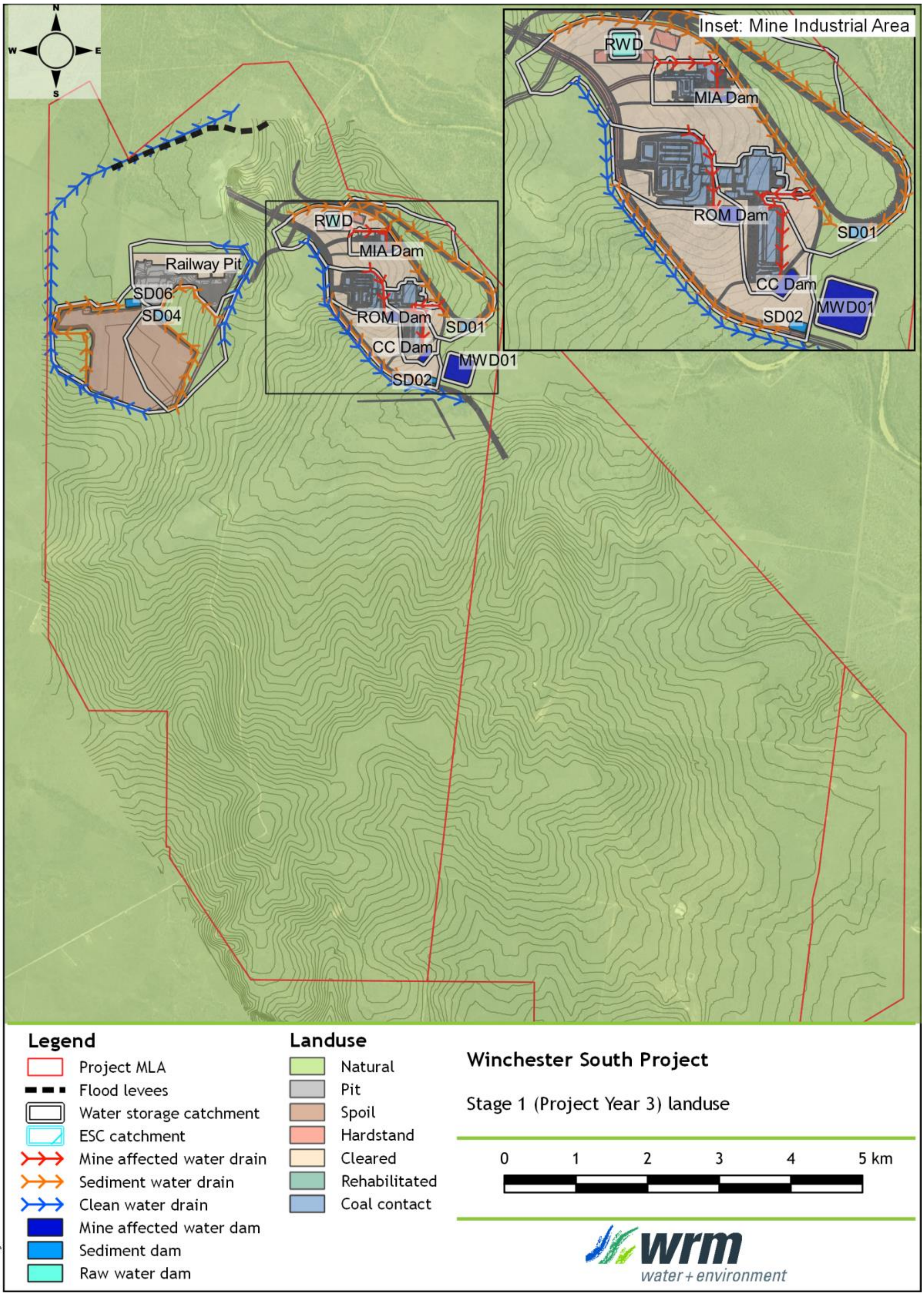


Figure 5.1 – Proposed Project water management system – Phase 1

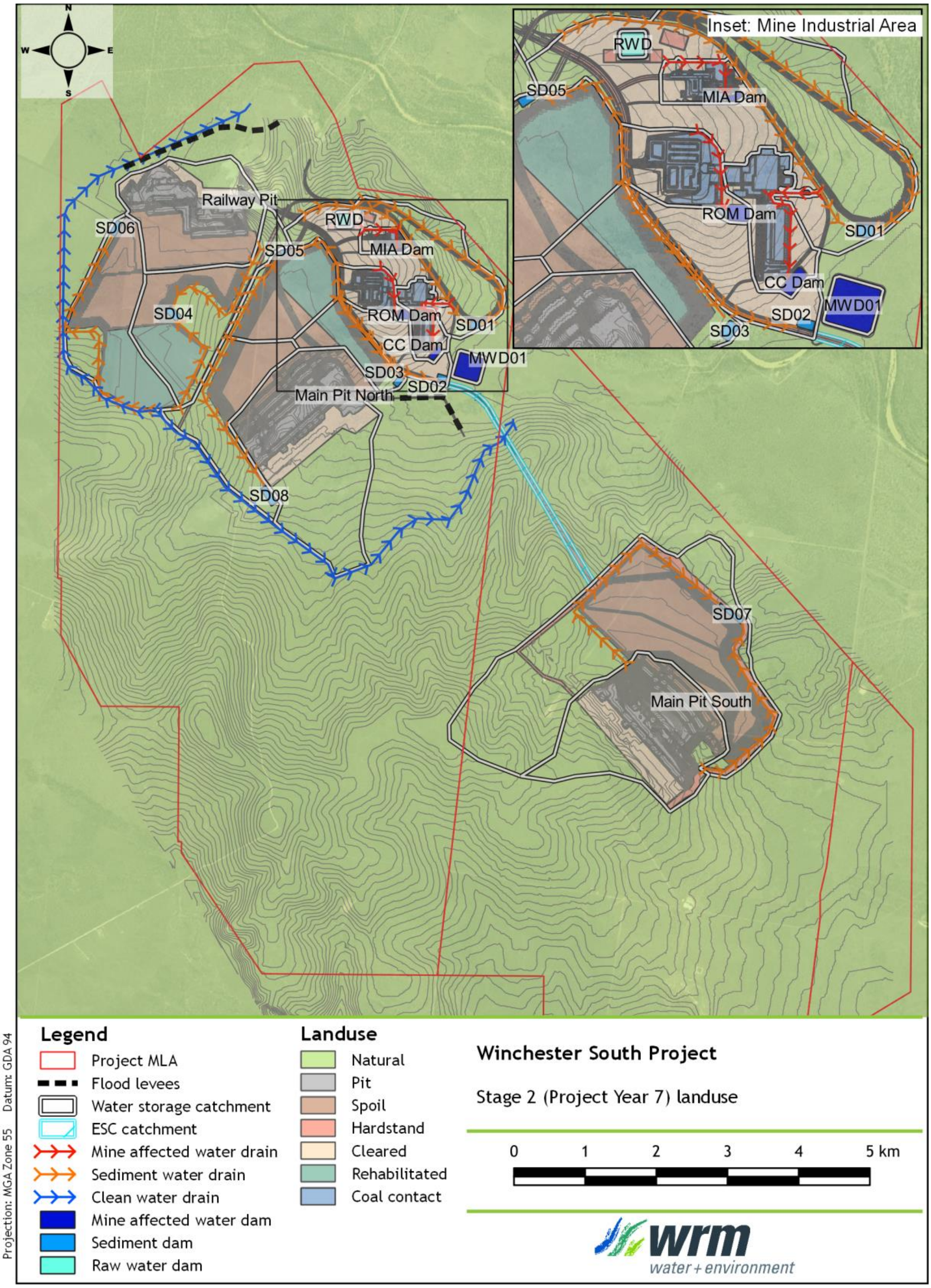


Figure 5.2 – Proposed Project water management system – Phase 2

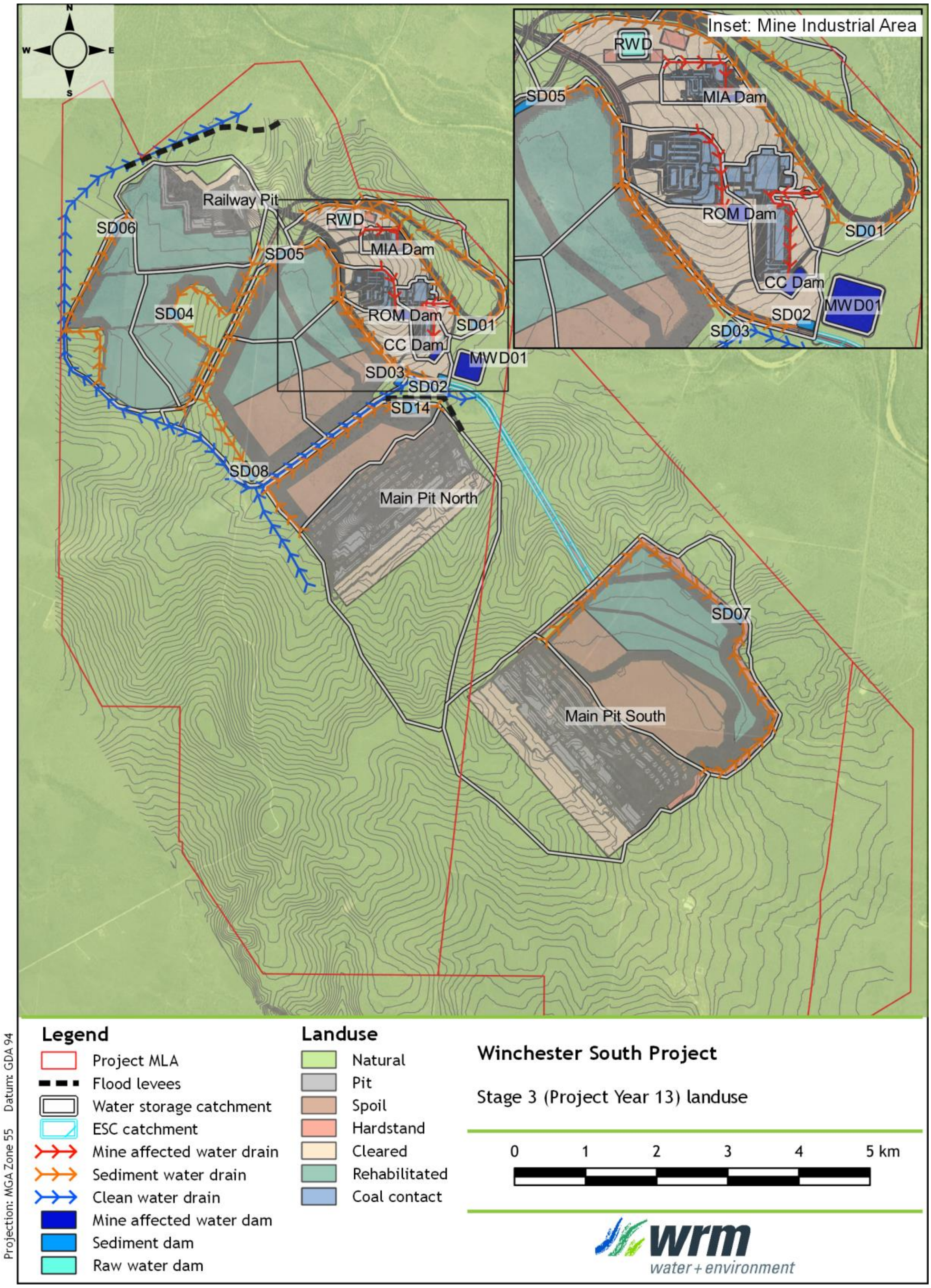


Figure 5.3 – Proposed Project water management system – Phase 3

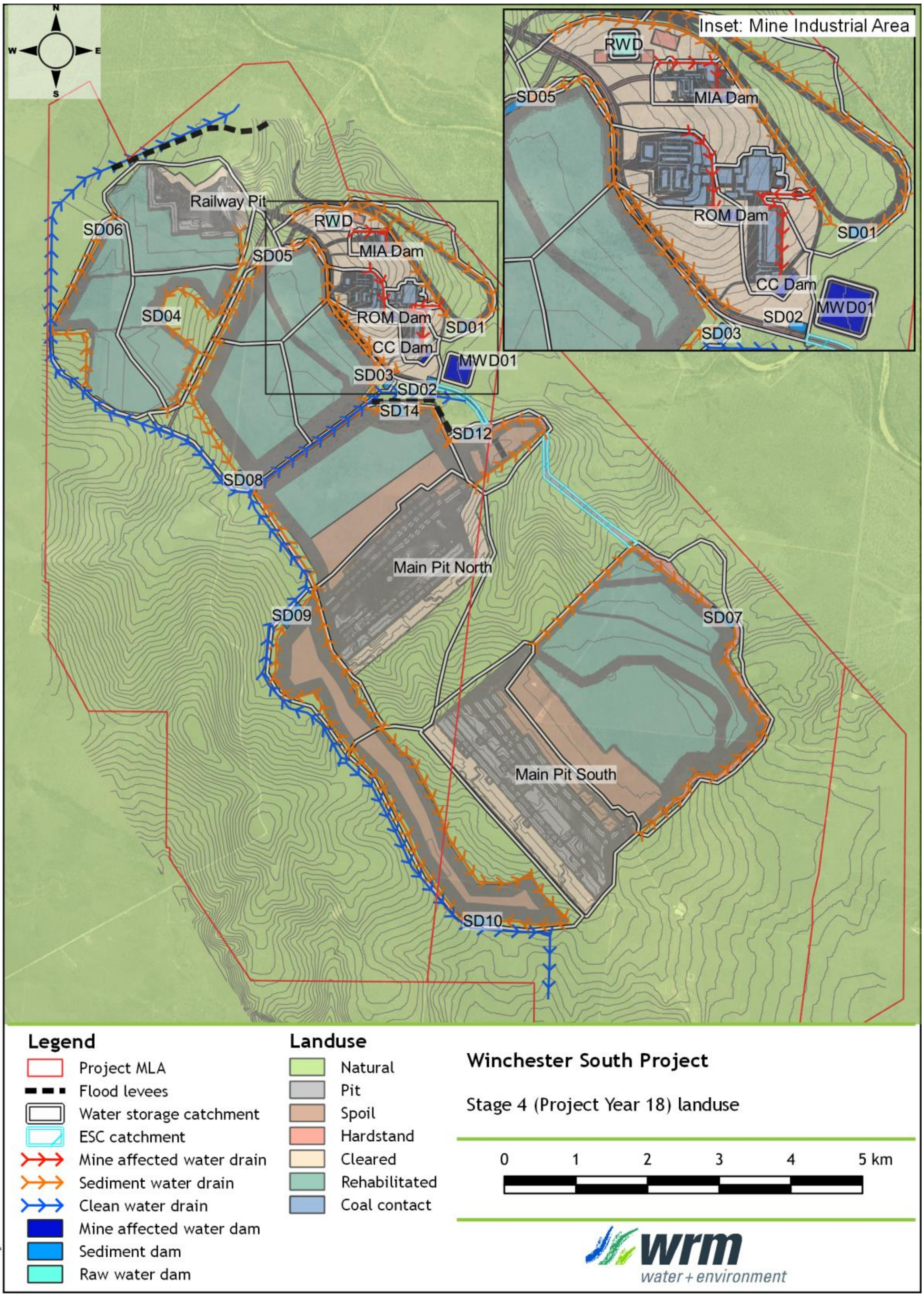


Figure 5.4 – Proposed Project water management system – Phase 4

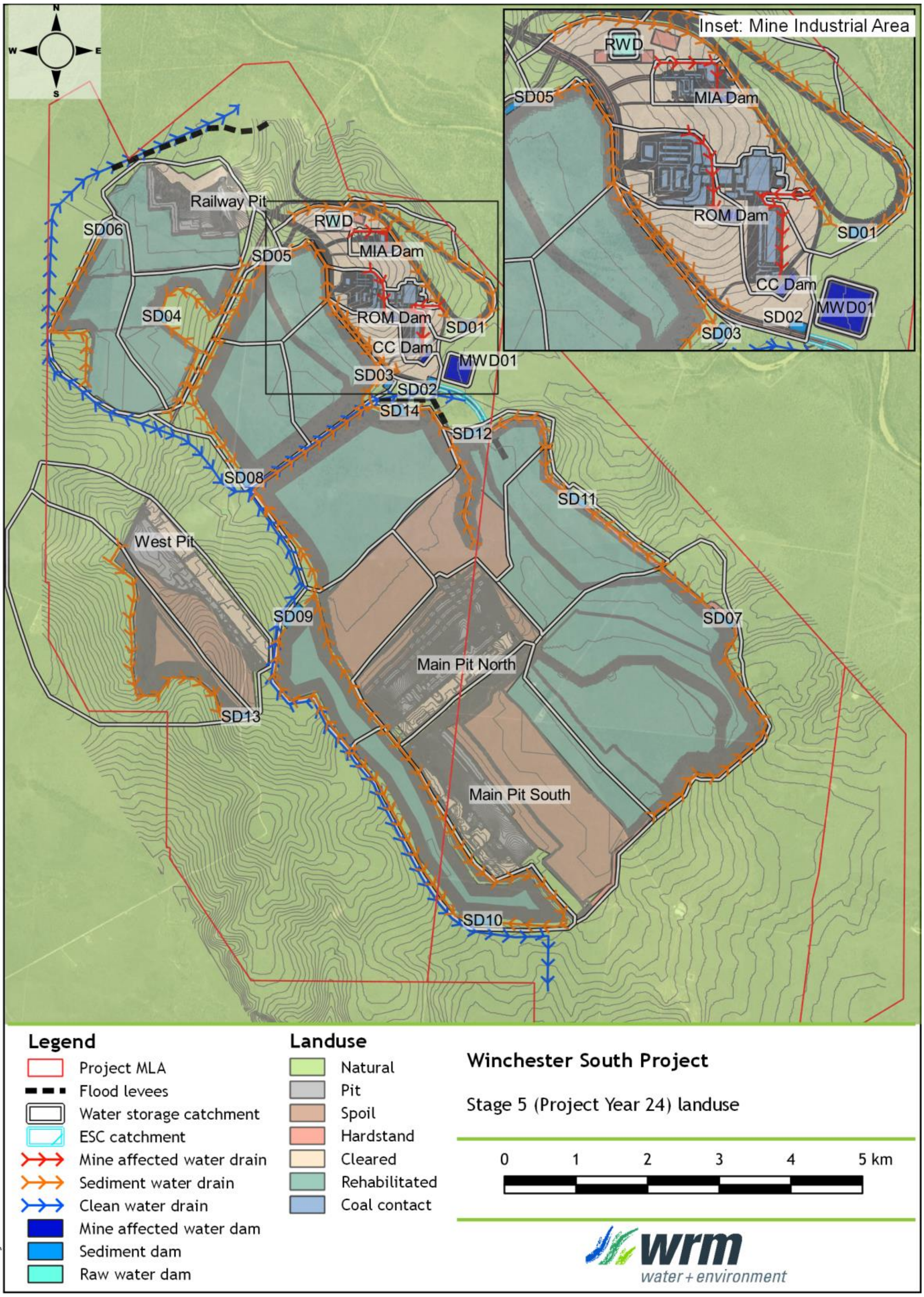


Figure 5.5 – Proposed Project water management system – Phase 5

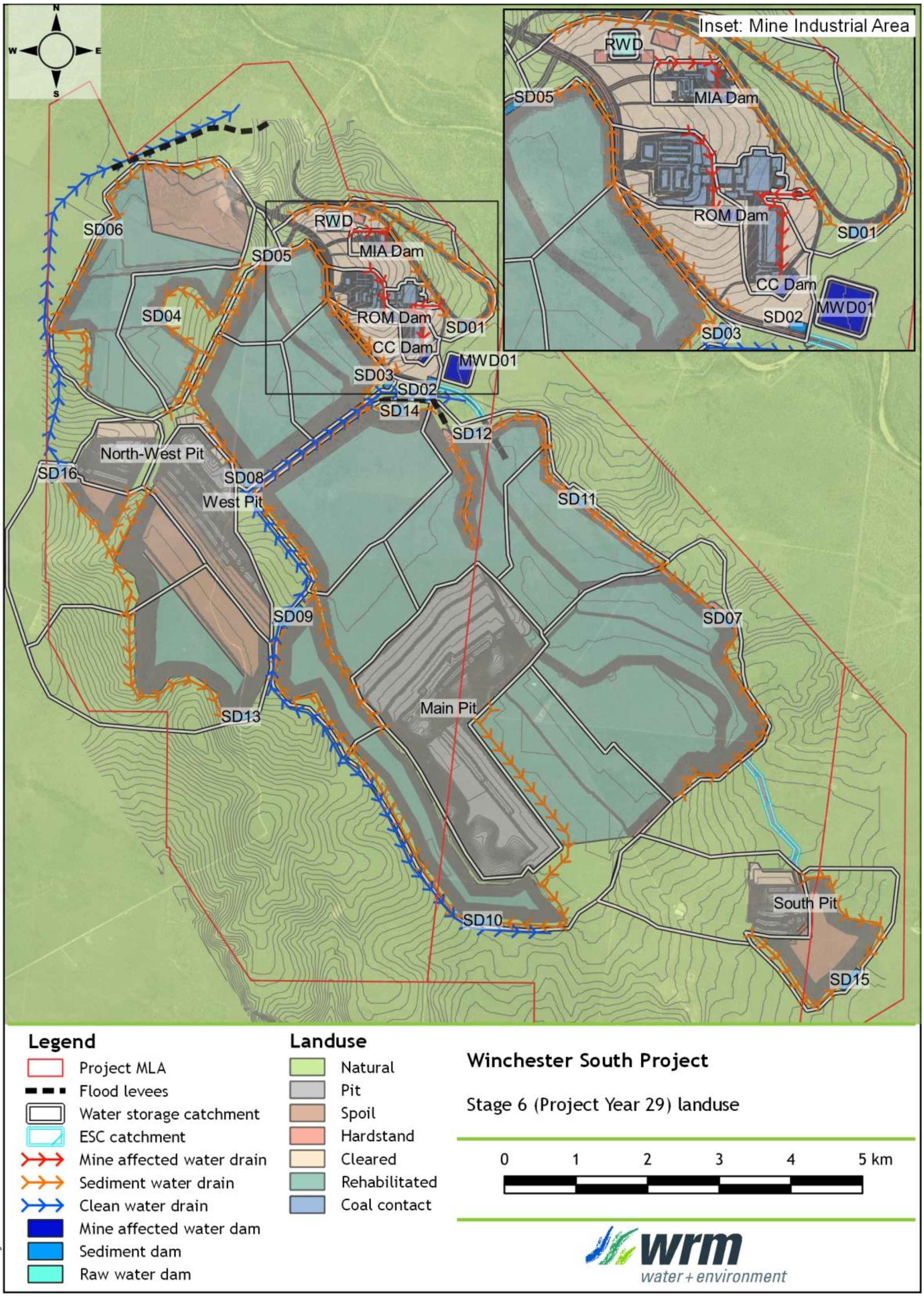


Figure 5.6 – Proposed Project water management system – Phase 6

5.6 CATCHMENT RUNOFF WATER MANAGEMENT

5.6.1 Clean water diversions

A series of clean up-catchment diversions are proposed to capture and divert catchment runoff water around the mining areas. The indicative locations of the proposed drains for the various mine phases are shown on Figure 5.1 to Figure 5.6. The purpose of the clean water diversions is to divert runoff from upslope catchment areas away from the mine water management system.

Following feedback from regulatory agencies, Whitehaven WS has updated the Project mine planning to incorporate a clean water drain that is more sympathetic to the pre mining drainage line (i.e. by establishing a clean water drain through a channel in the waste rock emplacement). Temporary erosion and sediment controls would be implemented on this drain until it is adequately rehabilitated and the water quality is appropriate to flow directly off-site.

The proposed design criteria for the clean water diversion drains have been set to minimise the risk of overflows into the water management system and minimise the risk of scour and erosion within the drains during flow events. The adopted design criteria are as follows:

- 1% AEP design event discharge.
- Batter slopes of 1 vertical to 3 horizontal (1V:3H).
- Bed width of 10 m.
- Scour protection at appropriate locations.

The final alignment and sizing of the clean water diversion drains will be confirmed as part of the detailed design process.

Whitehaven WS may implement alternative clean water diversions over the life of the Project to divert water around active operations. This could potentially include diversions/embankments that are located further upslope than the indicative locations shown on Figure 5.1 to Figure 5.6 (within the proposed Project footprint) and/or clean water dams and associated pumping infrastructure.

5.6.2 Flood protection levees

A flood levee is proposed for the Project to prevent floodwater from Isaac River from entering the mine water management system (specifically, the open cut pits). The locations of the proposed levees are shown in Section 9.

The temporary levees would be regulated structures under the EP Act and EA and would therefore be required to have a crest above the 0.1% Annual Exceedance Probability (AEP) event. An assessment of the temporary levees against the requirements of the EP Act is given in Section 9.

5.7 SEDIMENT WATER MANAGEMENT SYSTEM

5.7.1 Overview

Sediment water containment (runoff from spoil [i.e. waste rock] and areas yet to be rehabilitated) would be managed in accordance with an ESCP. The ESCP would adopt the three cornerstones of erosion and sediment control.

- Drainage control – prevention or reduction of soil erosion caused by concentrated flows and appropriate management and separation of the movement of diverted and surface water through the area of concern.
- Erosion control – prevention or minimisation of soil erosion (from dispersive, nondispersive or competent material) caused by rain drop impact and exacerbated overland flow on disturbed surfaces.

- Sediment control – trapping or retention of sediment either moving along the land surface, contained within runoff (i.e. from up-slope erosion) or from windborne particles.

The Project will require a combination of the three control measures to effectively manage sediment and erosion at the site. The locations and number of sediment dams provided in this assessment is conceptual only and would not significantly affect the overall mine water balance provided the dam volumes remain consistent. Details of sizing and placement of sediment dams would be finalised during detailed design of the Project.

Detailed information relating to the proposed erosion and sediment control measures will be developed prior to the commencement of operations. This will include the development of ESC implementation plans during both the construction phase and operations.

5.7.2 Sediment dam locations and sizing

Catchment runoff from both active and newly rehabilitated waste rock emplacements will be managed in accordance with an ESCP. The sediment dams have been sized in accordance with the International Erosion Control Association (IECA) method (IECA, 2018), and have been based on the following design standards and methodology:

- "Type D" sediment dams;
- total sediment dam 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 dam settling volume based on 85^{th} percentile 5-day duration rainfall (32.6 mm) 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. Further, the water collected by the sediment dams could be captured and retained for reuse on-site where possible (e.g. dust suppression, CHPP demand) if water quality is a suitable for the intended use.

If required, sedimentation and treatment within the sediment dams may be enhanced through flocculation prior to discharge.

A summary of the conceptual sediment dam capacities and the surface areas (based on average 5 m depth) is provided in Table 5.2.

Table 5.2 - Conceptual sediment dam capacities and surface areas

Dam Name	Max. catchment area (ha)	Settling volume (ML)	Solids storage volume (ML)	Total volume required (ML)	Dam surface area (ha)
SD01	251	36	18	55	1.25
SD02	65	9	5	14	0.38
SD03	175	25	13	38	1.01
SD04	235	34	17	51	1.37
SD05	150	22	11	33	0.87
SD06	491	71	36	107	2.85
SD07	912	132	66	199	5.30
SD08	269	39	20	59	1.56
SD09	327	48	24	71	1.90

Dam Name	Max. catchment area (ha)	Settling volume (ML)	Solids storage volume (ML)	Total volume required (ML)	Dam surface area (ha)
SD10	702	102	51	153	4.08
SD11	295	43	21	64	1.71
SD12	336	49	24	73	1.95
SD13	621	90	45	135	3.60
SD14	411	60	30	90	2.39
SD15	226	33	16	49	1.31
SD16	424	62	31	92	2.46

5.8 MINE-AFFECTED WATER MANAGEMENT

Containment of mine-affected water is provided by the following proposed storages:

- Mine Water Dam (MWD);
- MIA Dam;
- CC Dam; and
- ROM Dam.

Mine-affected water from active pits and active areas will primarily be stored in MWD. Additional in-pit storage within inactive mining pits will be available from Phase 2 onwards:

- Railway Pit will be available for in-pit storage between Phase 2 and Phase 5; and
- Main Pit will be available for in pit storage in Phase 6.

Figure 5.7 shows the indicative timing for mine water storage availability over the life of the Project. Whilst mine-affected water would be stored in MWD as a first priority, there is sufficient capacity within Railway Pit and Main Pit during the periods identified to temporarily store any excess mine-affected water without affecting mining operations.

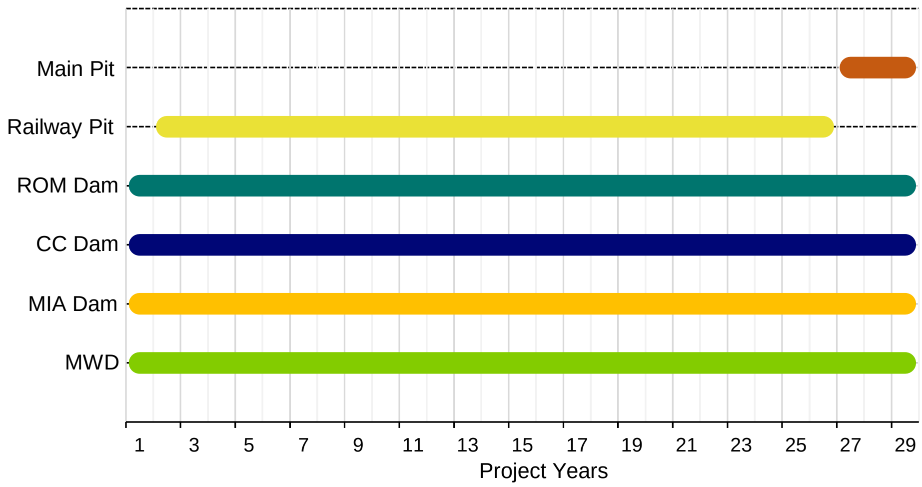


Figure 5.7 - Indicative timing of mine water storages/pits

5.9 EXTERNAL RAW WATER SUPPLY

The Project would utilise external raw water to supplement mine water demands when required. External raw water would be stored in raw water dam (RWD) until it is used on-site.

5.10 RELEASE OF WATER TO THE RECEIVING ENVIRONMENT

Water from the Project may only enter the receiving environment via sediment dam overflows. Model predictions of volumes and salt concentration from sediment dam overflows are provided in Section 7.

Controlled releases of mine-affected water would occur if required via MWD, CC Dam and Railway Pit (Phase 2 to Phase 5 only) into the Isaac River. It is proposed that there would be one controlled release point (RP) for each of the mine-affected water storages.

5.10.1 Controlled release mixing zones

Controlled release of water from the water management system will occur directly to the Isaac River from a number of mine affected water storages directly to the Isaac River through a gravity discharge arrangement. The maximum distance between the controlled release point and the Isaac River is around 2 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 6.11. 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), consistent with contemporary Environmental Authorities for neighbouring operations.

5.11 SEWAGE AND EFFLUENT DISPOSAL

Site wastewater would be treated in a packaged sewage treatment plant, located in the MIA. The plant would be designed to meet a Class A effluent quality for dust suppression and fire-fighting purposes. The biosolids produced would be stored on-site and collected by a licensed contractor for disposal off-site at a licensed facility.

A packaged irrigation system will be used to discharge treated effluent. The irrigation area would be located with Project mining tenements and designed to be located outside the “existing and approved” conditions 0.1% AEP flood extent to minimise the potential for dispersion on-site.

Until the sewage treatment plant is operational, sewage from temporary ablution blocks would be pumped by a licensed contractor and transported to a local council sewage treatment plant. This approach would also be used for other ancillary buildings outside the sewerage system.

Effluent would 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 would be stored within wet weather storage tanks until such time as irrigation could recommence.

Alternatively, treated effluent may be discharged into the mine affected water system.

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 plant would be designed and installed in accordance with the Queensland Government guidelines and relevant Australian Standards.

6 Water balance model configuration

6.1 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 6.1.

Table 6.1 - 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 pits	Haul road dust suppression demand
Raw water supply	Miscellaneous raw water demands
	Dam overflows

6.2 SIMULATION METHODOLOGY

The Project water management system will change over the approximate 29-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 phases. Three- to six-year representative periods have been selected to reflect the average conditions over the mine phase.

The modelled mining phases are summarised in Table 6.2 and shown in Figure 5.1 to Figure 5.5.

Table 6.2 - Representative mine phases

Phase	Model Period	Representative Year	Duration
1	PY1-PY6	PY4	6 years
2	PY7-PY11	PY8	5 years
3	PY12-PY16	PY14	5 years
4	PY17-PY21	PY19	5 years
5	PY22-PY26	PY25	5 years
6	PY27-PY29	PY29	3 years

Note: The timing of the stages and representative years are indicative only and may be subject to change.

6.3 RAINFALL AND EVAPORATION

Long term daily rainfall and evaporation data for the Project was obtained from the SILO database (https://www.longpaddock.qld.gov.au/silo/) for the period January 1889 to July 2020 (131 years). Average monthly rainfall and evaporation (mm) are shown in Figure 6.1. Morton's lake evaporation was adopted to represent evaporation for the simulation of the site water balance.

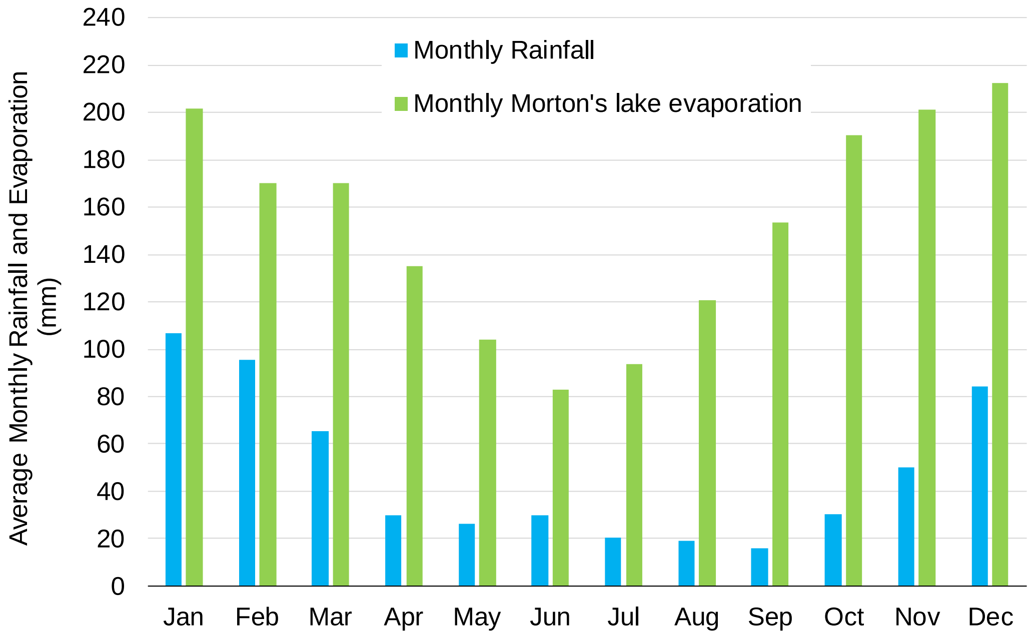


Figure 6.1 – Average monthly rainfall and evaporation from SILO database

6.4 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 5 and is presented in Figure 5.1 to Figure 5.5. A schematized plan for the modelled Project's water management system configuration is shown in Figure 6.2.

A summary of the mine-affected water and clean water storages within the proposed water management system is provided in Table 6.3. Refer to Section 5.7 for details regarding the proposed sediment dams.

A summary of the modelled water management system configuration is provided in Table 6.4.

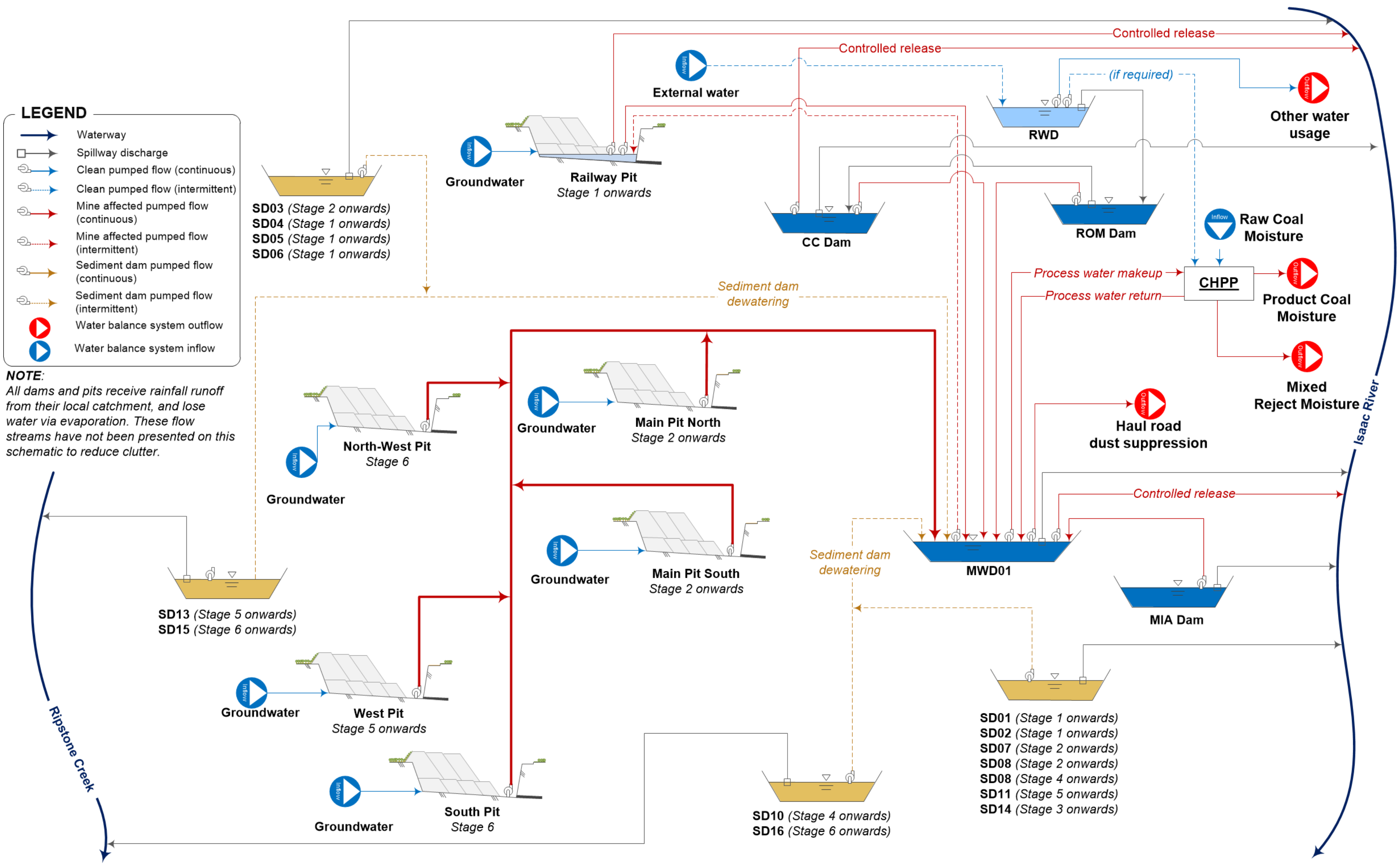


Figure 6.2 - Water management system schematic

Table 6.3 – Proposed storage details

Dam Name	Storage type	Commencement date	Overflows to
SD01	Sediment dam	Phase 1	Isaac River
SD02	Sediment dam	Phase 1	Isaac River
SD03	Sediment dam	Phase 2	Isaac River
SD04	Sediment dam	Phase 1	Isaac River (via pumping)
SD05	Sediment dam	Phase 2	Isaac River
SD06	Sediment dam	Phase 2	Isaac River
SD07	Sediment dam	Phase 2	Isaac River
SD08	Sediment dam	Phase 2	Isaac River
SD09	Sediment dam	Phase 4	Isaac River
SD10	Sediment dam	Phase 4	Ripstone Creek
SD11	Sediment dam	Phase 5	Isaac River
SD12	Sediment dam	Phase 4	Isaac River
SD13	Sediment dam	Phase 5	Ripstone Creek
SD14	Sediment dam	Phase 3	Isaac River
SD15	Sediment dam	Phase 6	Ripstone Creek
SD16	Sediment dam	Phase 6	Ripstone Creek
MWD	Mine-affected water dam	Phase 1	Isaac River
MIA Dam	Mine-affected water dam	Phase 1	Isaac River
ROM Dam	Mine-affected water dam	Phase 1	CC Dam
CC Dam	Mine-affected water dam	Phase 1	Isaac River
RWD	Raw water dam	Phase 1	Isaac River

Table 6.4 - Modelled water management system configuration

Item	Node Name	Operating Rules
1.0	***External Water Supply***	
1.1	External raw water	• Supplementary supply to site demands • Supplies CHPP raw water demand via RWD (25% of net usage)
2.0	***Supply to Demands***	
2.1	Haul road dust suppression	• Demand supplied from MWD
2.2	CHPP demand	• Mine water demand supplied by MWD (75% of net usage) • Raw water demand supplied by RWD (25% of net usage)
2.3	Other mine demand	• Demand supplied from MWD01

Item	Node Name	Operating Rules
3.0	***Transfer of pit water***	
3.1	Railway Pit	• Receives groundwater inflows • Pit dewatering is directed to MWD *Converted to an in-pit storage in Stage 2 (see item 4.2) and backfilled in Stage 6*
3.2	Main Pit North	• Receives groundwater inflows • Pit dewatering is directed to MWD *Main Pit North and Main Pit South combined in Stage 5. Main Pit will replace Railway Pit as the primary in-pit storage in Stage 6.*
3.3	Main Pit South	• Receives groundwater inflows • Pit dewatering is directed to MWD *Main Pit North and Main Pit South combined in Stage 6*
3.4	West Pit	• Receives groundwater inflows • Pit dewatering is directed to MWD
3.5	South Pit	• Receives groundwater inflows • Pit dewatering is directed to MWD
3.6	North-West Pit	• Receives groundwater inflows • Pit dewatering is directed to MWD
4.0	***Operation of mine water dams***	

4.1	MWD	• Supplies water to the haul road dust suppression, CHPP and other site demands
		• Receives pit dewatering inflows from the following:
		  ○ Railway Pit (Stage 1 only)
		  ○ Main Pit North
		  ○ Main Pit South
		  ○ West Pit
		  ○ South Pit
		  ○ North-West Pit
		• Receives external water via RWD (if required)
		• Receives make-up water from the following storages (in order of priority):
		  ○ Railway Pit (Stage 1 only)
		  ○ Main Pit North
		  ○ Main Pit South
		  ○ West Pit
		  ○ South Pit
		  ○ North-West Pit
		  ○ MIA Dam
		  ○ ROM dam
		  ○ CC Dam
		  ○ Sediment dams
		• Dewaters to Railway Pit if MWD01 is above its MOV

4.2	MIA Dam	• Collects runoff from the MIA • Dewaters to MWD to maintain the dam at the dead storage volume • Overflows to Isaac River
4.3	Railway Pit	• Receives pumped inflows from MWD when MWD is above its MOV (Stage 2 onwards)
4.4	ROM Dam	• Collects catchment runoff from the ROM Pad • Dewaters to MWD
4.5	CC Dam	• Collects catchment runoff from the coal contact area • Dewaters to MWD

Item	Node Name	Operating Rules
5.0	***Operation of sediment dams***	
5.1	SD01	• Dewaters to MWD (when available) • Overflows to Isaac River
5.2	SD02	• Dewaters to MWD (when available) • Overflows to Isaac River
5.3	SD03	• Dewaters to MWD (when available) • Overflows to Isaac River
5.4	SD04	• Dewaters to MWD (when available) • Overflows to Isaac River (via pumping)
5.5	SD05	• Dewaters to MWD (when available) • Overflows to Isaac River
5.6	SD06	• Dewaters to MWD (when available) • Overflows to Isaac River
5.7	SD07	• Dewaters to MWD (when available) • Overflows to Isaac River
5.8	SD08	• Dewaters to MWD (when available) • Overflows to Isaac River
5.9	SD09	• Dewaters to MWD (when available) • Overflows to Isaac River
5.10	SD10	• Dewaters to MWD (when available) • Overflows to Ripstone Creek
5.11	SD11	• Dewaters to MWD (when available) • Overflows to Isaac River
5.12	SD12	• Dewaters to MWD (when available) • Overflows to Isaac River
5.13	SD13	• Dewaters to MWD (when available) • Overflows to Ripstone Creek
5.14	SD14	• Dewaters to MWD (when available) • Overflows to Isaac River
5.15	SD15	• Dewaters to MWD (when available) • Overflows to Ripstone Creek
5.16	SD16	• Dewaters to MWD (when available) • Overflows to Ripstone Creek
6.0	***Operation of raw water dams***	
6.1	RWD	• Supplies raw water CHPP demand • Pumped make up to MWD when no other site water is available • Receives inflows from an external raw water source

6.5 SITE STORAGE CHARACTERISTICS

Table 6.5 shows the capacities of the proposed dams at the Project. These proposed dam capacities are preliminary only and will be confirmed as part of the detailed design process for the Project. ‘Trigger’ volumes related to the management of water dams at the Project are defined as follows:

- **Total Storage Volume (TSV)** is the overall storage capacity of the dam from the base to the spillway level.
- **Maximum Operating Volume (MOV)** is the volume that, when exceeded, triggers the dam to be dewatered (either offsite or to another dam at the site). The operating volume determines the “operating water level” of the dams.
- **Dead Storage Volume (DSV)** is the volume that, below which, the dam cannot be dewatered due to operational or physical constraints (approximately 10% of the TSV).

Table 6.5 – Proposed dam storage capacities

Dam Name	DSV (ML)	MOV (ML)	TSV (ML)
MWD	100	750	1,000
MIA Dam	10	75	100
ROM Dam	4	32	40
CC Dam	10	60	100
RWD	20	100	200

6.6 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 groundwater 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;
- Spoil emplacement, representing uncompacted emplaced waste rock material;
- Rehabilitated, representing established rehabilitated waste rock emplacement areas;
- Roads and hardstand areas;
- Cleared, representing disturbed surfaces and pre-strip areas ahead of mining;
- Open cut mining pit floor; and
- Isaac River, representing the Isaac River catchment to the Deverill gauge (calibrated to recorded data).

The adopted AWBM parameters are shown in Table 6.6. These parameters have been based on parameters typical for coal mines in this part of the Bowen Basin.

Table 6.6 - Adopted AWBM parameters

Parameter	Natural	Active spoil	Rehabilitated	Hardstand	Cleared	Mining Pit	Isaac River
C1 (mm)	60	15	12	12	12	12	15.4
C2 (mm)	90	100	221	54	54	38	91.2
C3 (mm)	180	100	0	0	0	0	181.0
A1	0.2	0.1	0.1	0.1	0.1	0.1	0.134
A2	0.4	0.4	0.9	0.9	0.9	0.9	0.433
A3	0.4	0.5	0	0	0	0	0.433
BFI	0	0.9	0.7	0	0	0	0.35
K_{base}	0	0.8	0.8	0	0	0	0.6
K_{surf}	0	0.1	0	0	0	0	0.1
C_{av}	7.2%	10.1%	5.8%	17.0%	17.0%	21.8%	9.5%

6.7 CATCHMENT AREA AND LAND USE CLASSIFICATIONS

Figure 5.1 to Figure 5.5 show the adopted catchments and land use for Phase 1 to Phase 6. Catchment areas for each storage are shown in Table 6.7.

Table 6.7 - Adopted catchment areas

Dam Name	Catchment area (ha)					
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
Raw water dams						
RWD	4.3	4.3	4.3	4.3	4.3	4.3
Sediment dams						
SD01	251.1	251.1	251.1	251.1	251.1	251.1
SD02	65.3	65.3	65.3	65.3	65.3	65.3
SD03	-	74.1	171.0	172.4	174.6	169.5
SD04	161.4	234.6	234.9	234.7	234.2	234.7
SD05	-	145.7	145.5	149.7	146.5	143.6
SD06	151.7	225.5	221.2	230.2	230.9	490.9
SD07	-	735.3	682.4	911.8	786.8	716.3
SD08	-	179.9	268.4	269.2	245.2	247.8
SD09	-	-	-	169.6	327.4	310.6
SD10	-	-	-	400.8	275.3	702.4
SD11	-	-	-	-	294.9	294.8
SD12	-	-	-	92.2	269.6	335.5
SD13	-	-	-	-	620.5	537.7
SD14	-	-	157.7	384.3	411.2	393.3
SD15	-	-	-	-	-	226.9
SD16	-	-	-	-	-	423.7
All sediment dams	**629**	**1,911**	**2,198**	**3,331**	**4,333**	**5,544**

<table>
<tr><th rowspan="2">Dam Name</th><th colspan="6">Catchment area (ha)</th></tr>
<tr><th>Phase 1</th><th>Phase 2</th><th>Phase 3</th><th>Phase 4</th><th>Phase 5</th><th>Phase 6</th></tr>
<tr><td>Mine water dams</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>MWD01</td><td>15.0</td><td>15.0</td><td>15.0</td><td>15.0</td><td>15.0</td><td>15.0</td></tr>
<tr><td>MIA Dam</td><td>21.7</td><td>21.7</td><td>21.7</td><td>21.7</td><td>21.7</td><td>21.7</td></tr>
<tr><td>ROM Dam</td><td>49.3</td><td>49.3</td><td>49.3</td><td>49.3</td><td>49.3</td><td>49.3</td></tr>
<tr><td>CC Dam</td><td>50.5</td><td>50.5</td><td>50.5</td><td>50.5</td><td>50.5</td><td>50.5</td></tr>
<tr><td>All mine water dams</td><td>136</td><td>136</td><td>136</td><td>136</td><td>136</td><td>136</td></tr>
<tr><td>Mine pits</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Railway Pit[a]</td><td>117.8</td><td>256.8</td><td>264.8</td><td>257.2</td><td>259.1</td><td>-</td></tr>
<tr><td>Main Pit North</td><td>-</td><td>429.4</td><td>726.8</td><td>529.8</td><td>329.9</td><td rowspan="2">616.0[b]</td></tr>
<tr><td>Main Pit South</td><td>-</td><td>348.5</td><td>646.3</td><td>453.3</td><td>663.2</td></tr>
<tr><td>West Pit</td><td>-</td><td>-</td><td>-</td><td>-</td><td>343.9</td><td>217.2</td></tr>
<tr><td>South Pit</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>307.1</td></tr>
<tr><td>North-West Pit</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>97.1</td></tr>
<tr><td>All mine pits</td><td>118</td><td>1,035</td><td>1,638</td><td>1,240</td><td>1,596</td><td>1,237</td></tr>
<tr><td>Total</td><td>884</td><td>3,082</td><td>3,972</td><td>4,708</td><td>6,066</td><td>6,918</td></tr>
</table>

[a] Railway Pit converted to an in-pit storage in Stage 2
[b] Main Pit North and Main Pit South combined and converted to an in-pit storage in Stage 5

6.8 SITE WATER DEMANDS

6.8.1 Coal handling and preparation plant

Based on advice from Whitehaven WS and benchmarked against similar operations (where coal processing would involve the dewatering of fines rejects similar to the Project), a net CHPP water demand of 166 litres per tonne of ROM coal (L/ROM t) has been adopted for the Project. The adopted production profile and corresponding net water demand rates are shown in Table 6.8.

Further, it is assumed that 25% of CHPP demand is sourced from RWD with the remainder sourced from the MWD.

Table 6.8 - Forecast annual production data

Year	ROM Coal Production (Mt)	MWD01 CHPP Demand (ML)	RWD CHPP Demand (ML)	Total Net CHPP Demand (ML)
PY1	0.0	0.0	0.0	0.0
PY2	1.0	124.5	41.5	166.0
PY3	4.7	589.5	196.5	786.0
PY4	12.9	1,610.1	536.7	2,146.8
PY5	15.0	1,867.5	622.5	2,490.0
PY6	16.7	2,079.1	693.0	2,772.2
PY7	15.3	1,904.9	635.0	2,539.8
PY8	17.0	2,116.5	705.5	2,822.0
PY9	15.5	1,929.7	643.2	2,573.0
PY10	15.1	1,879.8	626.6	2,506.4
PY11	16.4	2,041.8	680.6	2,722.4
PY12	16.0	1,992.0	664.0	2,656.0

Year	ROM Coal Production (Mt)	MWD01 CHPP Demand (ML)	RWD CHPP Demand (ML)	Total Net CHPP Demand (ML)
PY13	15.8	1,967.1	655.7	2,622.8
PY14	15.8	1,967.1	655.7	2,622.8
PY15	17.0	2,116.5	705.5	2,822.0
PY16	17.0	2,116.5	705.5	2,822.0
PY17	15.8	1,967.1	655.7	2,622.8
PY18	15.2	1,892.4	630.8	2,523.2
PY19	15.3	1,904.9	635.0	2,539.8
PY20	15.3	1,904.9	635.0	2,539.8
PY21	17.0	2,116.5	705.5	2,822.0
PY22	16.7	2,079.1	693.0	2,772.2
PY23	15.8	1,971.3	657.1	2,628.4
PY24	13.9	1,730.4	576.8	2,307.2
PY25	17.0	2,116.5	705.5	2,822.0
PY26	14.8	1,839.3	613.1	2,452.4
PY27	10.0	1,248.9	416.3	1,665.2
PY28	8.7	1,078.4	359.5	1,437.8
PY29	9.3	1,154.3	384.8	1,539.1

6.8.2 Haul road dust suppression

Daily haul road dust suppression watering rates for Phases 1 to 6 were estimated based on haul road surface area and daily rainfall and evaporation rates. 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 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 a haul road width of 35 m would be watered; and
- The haul road length is estimated to be:
  - 2.6 km in Phase 1
  - 9.5 km in Phase 2
  - 10.6 km in Phase 3
  - 13.9 km in Phase 4
  - 17.3 km in Phase 5
  - 20.6 km in Phase 6.

The modelled averaged monthly dust suppression is shown in Figure 6.3. The average annual haul road dust suppression usage is shown in Table 6.9.

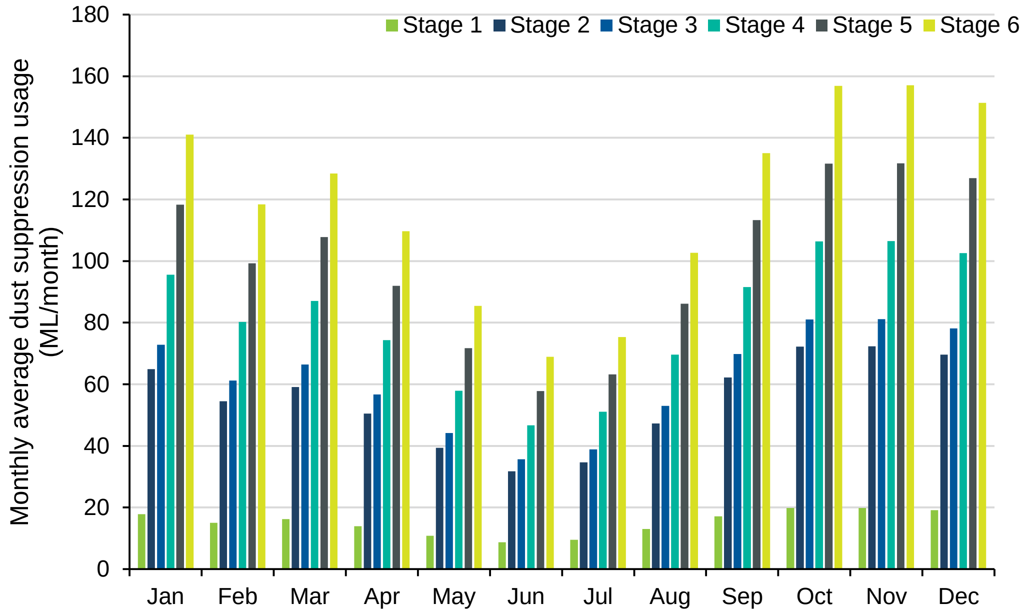


Figure 6.3 - Mean monthly haul road dust suppression

Table 6.9 - Haul road dust suppression demand

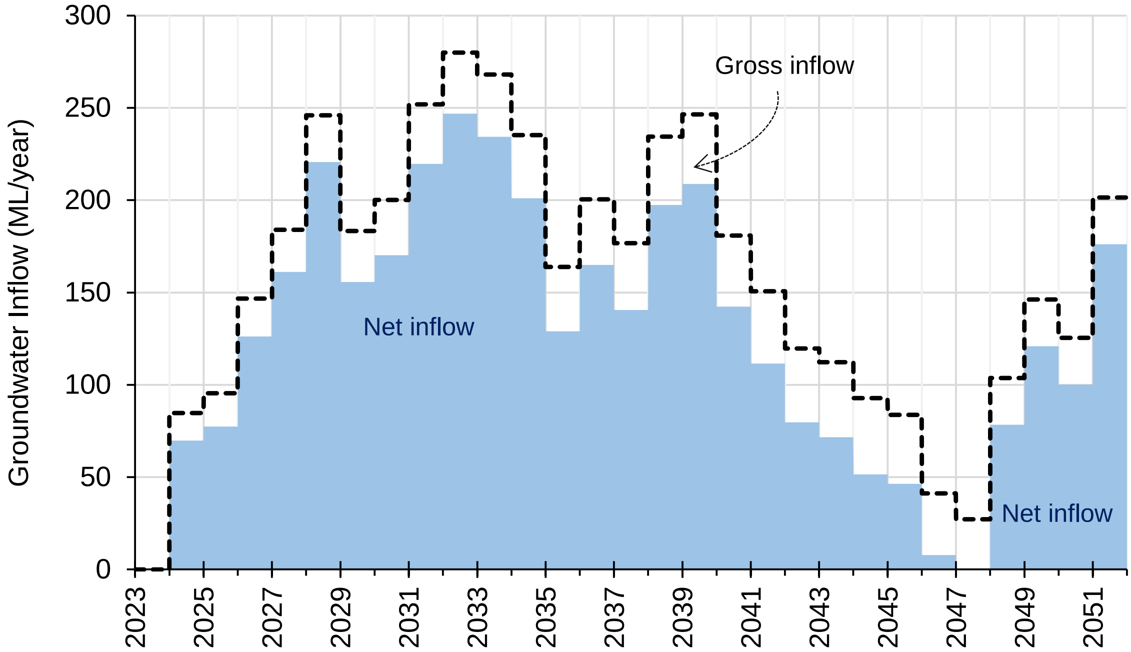
Month	Mean haul road dust suppression demand (ML)					
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
Jan	18	65	73	96	118	141
Feb	15	54	61	80	99	118
Mar	16	59	66	87	108	128
Apr	14	50	57	74	92	110
May	11	39	44	58	72	85
Jun	9	32	36	47	58	69
Jul	10	35	39	51	63	75
Aug	13	47	53	70	86	103
Sep	17	62	70	92	113	135
Oct	20	72	81	106	132	157
Nov	20	72	81	106	132	157
Dec	19	70	78	103	127	151
Total	**181**	**658**	**739**	**969**	**1,200**	**1,430**

6.8.3 Other water usage

An additional minimum raw water demand of 200 megalitres per year (ML/year) for other miscellaneous water uses around the site was adopted for the duration of the Project. Other water uses include potable water demand, fire water demand and vehicle washdown. Other raw water demand could be met with mine water supplies (if quality is suitable for intended purpose), reducing the reliance on external water supply.

6.9 GROUNDWATER INFLOWS

The adopted groundwater inflows to the open cut pits are based on predictions provided by SLR Consulting (SLR) (2022) and have been provided annually between 2023 to 2051. A summary of the predicted groundwater inflows is provided in Figure 6.4. Groundwater inflows have been distributed equally among the active mining pits and have been adjusted to account for losses due to face evaporation (net inflows).



Note: Net groundwater inflows will be distributed among the active mine pits.

Figure 6.4 – Estimated annual groundwater inflows (data source: SLR, 2022)

6.10 SALINITY PARAMETERS

The Project water balance model is configured to use salinity as an indicator of water quality. This has been achieved by assigning representative EC values to runoff from catchments and other sources of water (Table 6.10).

Table 6.10 – Adopted salinity concentrations

Water Source/ Land Use	EC (µS/cm)	Justification
Isaac River flows	80-800 (dependent on flow)	Flow vs EC relationship developed based on recorded EC at Deverill Gauging Station between 2011 and 2020, representative of the EC for Isaac River flows. Refer to Section 6.10.1 for further details.
Natural	300	Value adopted for Olive Downs Project Surface Water Assessment, representative of the EC for natural runoff.
Hardstand	900	Value adopted for Lake Vermont Northern Extension Surface Water Assessment, representative of the EC for hardstand runoff.
Mining pit	4,500	Value adopted for Lake Vermont Northern Extension Surface Water Assessment, representative of the EC for mining pit runoff.
Active spoil	520	Based on median value from contemporary geochemical water quality sampling results for overburden and interburden (Terrenus, 2020), representative of the EC for active spoil runoff.
Rehabilitated	300	Assumed to be similar to natural/undisturbed, representative of the EC for rehabilitation runoff.
Cleared	300	Assumed to be similar to natural/undisturbed, representative of the EC for cleared land runoff.
Pit groundwater inflows	13,230	Based on the average salinity recorded at 8 bores and 54 lab samples which targeted the Leichhardt and Vermont coal seams, representative of the EC for pit groundwater inflows across the site.
Raw water (pipeline)	200	Based on recorded data at a nearby operations, representative of the EC for raw water supply.
ROM coal moisture	10,000	Salinity of ROM coal unknown, assumed based on pit groundwater inflow salinity diluted by surface water runoff, representative of the EC for ROM coal moisture.

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.

6.10.1 Isaac River salinity

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 6.5. This relationship flow-EC relationship for the Isaac River has been incorporated into the water balance model.

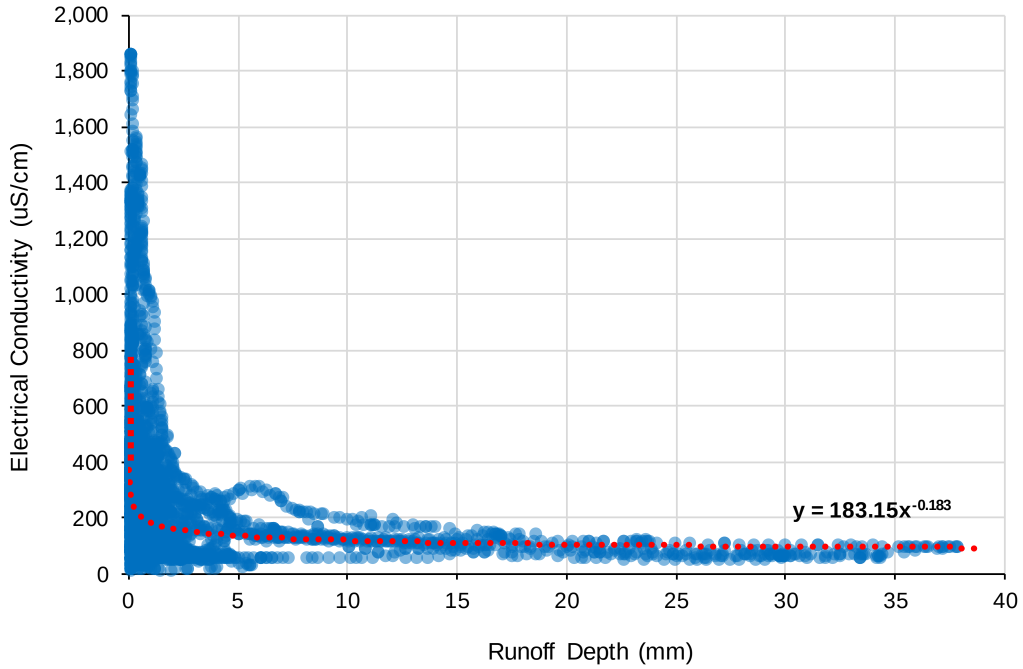


Figure 6.5 – Relationship between EC and excess rainfall depth at Deverill Gauge

6.11 CONTROLLED RELEASES

Water release conditions have been developed for releases to the Isaac River based on the *Model Mining Conditions* (DES, 2017a). The water balance model has been configured to simulate these release conditions, using salt measured as electrical conductivity as the target contaminant. Daily flows in Isaac River at the Deverill gauge were estimated using the calibrated Isaac River AWBM parameters presented in Table 6.6.

The proposed release conditions have been based on those recently approved for the neighbouring Isaac Downs and Olive Downs projects. The variable receiving flow triggers (with appropriate dilution ratios) is consistent with majority of approved EAs for mining operations within the upper Isaac River catchment (refer to Table 10.5 for details), including the recently approved Isaac Downs and Olive Downs projects. This approach allows for flexibility and opportunity to take advantage of the large dilution capacity available within the Isaac River during larger flow events. A summary of the proposed release conditions is provided in Table 6.11.

The proposed controlled releases strategy comprises MWD, CC Dam and Railway Pit (Phase 2 to Phase 4 only), which would have the ability to discharge water to the Isaac River through a gravity pipe system or pumping system. There would be one controlled RP for each of the mine-affected water storages.

The release point dams are proposed to be turkey's nest type dams around 5 m deep. A gravity discharge solution is preferred for MWD and CC Dam 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 (i.e. for Railway Pit) or to supplement to gravity release system would be considered during the detailed design process.

Site operating procedures and Trigger Action Response Plans (TARPs) for controlled releases will be developed prior to operations commencing and would be detailed in the site Water Management Plan. This will include the development of a real-time release "calculator" to allow operators to determine appropriate release windows, volume and quality.

Table 6.11 – Proposed mine-affected water controlled 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)[a]	Electrical conductivity release limits
Isaac River	**MWD** (RP1) **CC Dam** (RP2) **Railway Pit** (RP3)	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

[a] The specified maximum release rate represents the combined discharge rate from all release points.

6.12 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:

- MWD;
- MIA Dam; and
- CC Dam.

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 (Section 7.3.6.1).

It has been assumed that all mine affected water storages will be appropriately designed and constructed to minimise the risk of seepage. As such, seepage from the mine affected water dams has not been modelled in the following sections.

7 Water management system assessment

7.1 OVERVIEW

The OPSIM model for the Project was used to assess the performance of the site 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 7.3.1);
- mine water inventory – the risk of accumulation (or reduction) of the overall mine water inventory (Section 7.3.2);
- in-pit storage – the risk of accumulation of water in the mining pits, and the associated water volumes (Section 7.3.3);
- external raw water demand – the risk and associated volumes of requiring imported external raw water to supplement site mine water supplies (Section 7.3.4);
- controlled releases and 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 7.3.5 and Section 7.3.6); and
- overall salt balance – the average salt inflows and outflows of the water management system based on all model realisations (Section 7.4).

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.).

7.2 INTERPRETATION OF 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 approximate 29 years of mine life, based on 104 simulated realisations. The model climate dataset spans a 131-year period from January 1889 to July 2020. When running simulations using the water balance model, the long-term timeseries is automatically disaggregated into 104 "realisations" (or unique climate sequences) equal in length to the Project simulation duration (29 years). For example, the first realisation (or climate sequence) would be January 1889 to December 1917, the second January 1890 to December 1918, and so on.

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

7.3 WATER BALANCE MODEL RESULTS

7.3.1 Overall water balance

Water balance results for all of the 104 model realisations are presented in Table 7.1, averaged over each model phase. The results presented in Table 7.1 are the average of all realisations and will include wet and dry periods distributed throughout the mine life. Rainfall yield for each phase is affected by the variation in climatic conditions within the adopted climate sequence.

Table 7.1 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 gradually increase between Phase 1 and Phase 6.
- External raw water requirements are highest in Phase 2 to Phase 5 due to the higher production rates.
- The change in stored volume per phase is small in comparison to the inflow and outflow volumes and therefore the water management system is generally in balance.

Table 7.1 - Average annual water balance - all realisations

Process	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
Inflows (ML/year)						
Rainfall Runoff	787	2,120	2,527	2,903	3,414	3,925
Net Groundwater	109	205	167	123	37	132
External raw water	1,526	2,403	2,330	2,241	2,376	1,464
Total inflows	**2,422**	**4,728**	**5,024**	**5,267**	**5,826**	**5,521**
Outflows (ML/year)						
Evaporation	405	556	672	728	795	858
Dust Suppression	181	660	744	978	1,212	1,443
Other water usage	200	200	200	200	200	200
Net MAW CHPP demand	1,045	1,975	2,031	1,956	1,948	1,161
Net Raw CHPP demand	348	658	677	652	649	386
Controlled releases	0	0	1	1	0	0
MAW dam overflows	0	0	0	0	0	0
Sediment dam overflows	246	598	579	800	955	1,248
Total outflows	**2,426**	**4,648**	**4,903**	**5,315**	**5,759**	**5,296**
Change in Site Water Inventory	**-4**	**80**	**121**	**-48**	**68**	**225**

Note: Totals may not add due to rounding.

7.3.2 Mine-affected water inventory

Figure 7.1 shows the combined forecast inventory for the key mine-affected water storages over the 29-year forecast, including the active in-pit storages (Railway Pit in Phase 2 to 5 and Main Pit in Phase 6). To prevent uncontrolled discharges from the mine water storages, MOVs have been set for the out-of-pit mine-affected water storages. The MOV 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 TSV, which is the combined capacity of these dams.

The model results show the following:

- For the 1st percentile results (very wet climatic conditions), the peak inventory in the mine-affected water storages reaches a volume of around 9,500 ML.
- For the 50th percentile results (median climatic conditions), the peak inventory in the mine-affected water storages reaches a volume of around 1,580 ML.
- Mine-affected water would not need to be stored in the inactive pits for 50th percentile (median) climatic conditions.

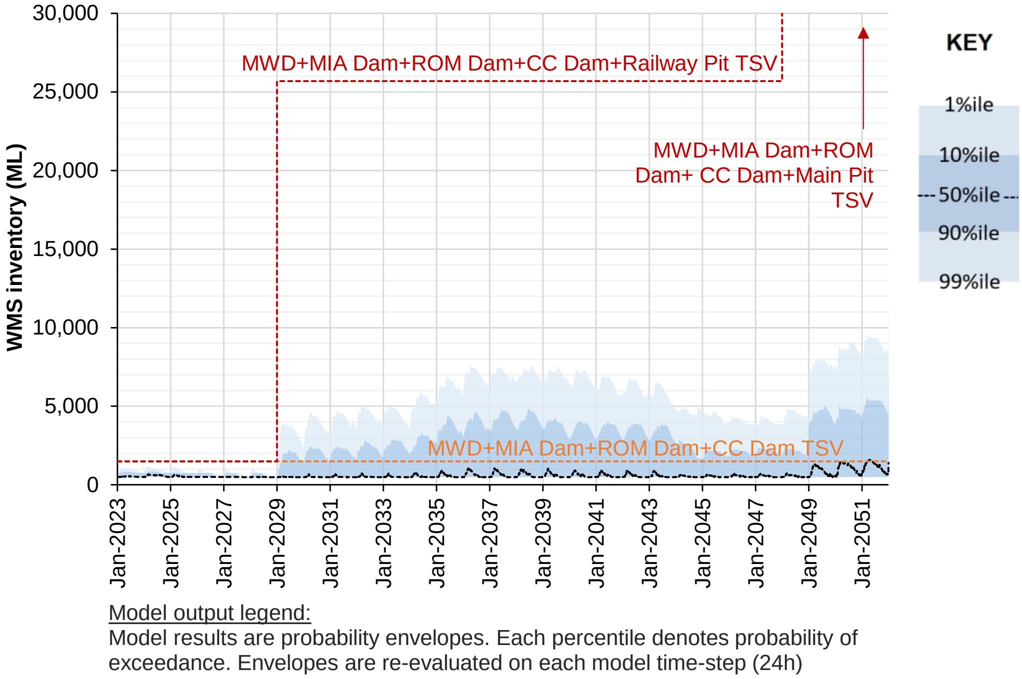


Figure 7.1 - Forecast water management system inventory

Figure 7.2 demonstrates that the combined modelled peak inventory for MWD, MIA Dam, CC Dam and ROM Dam in Phase 1 is around 370 ML less than the combined TSV of 1,490 ML under very wet climatic conditions).

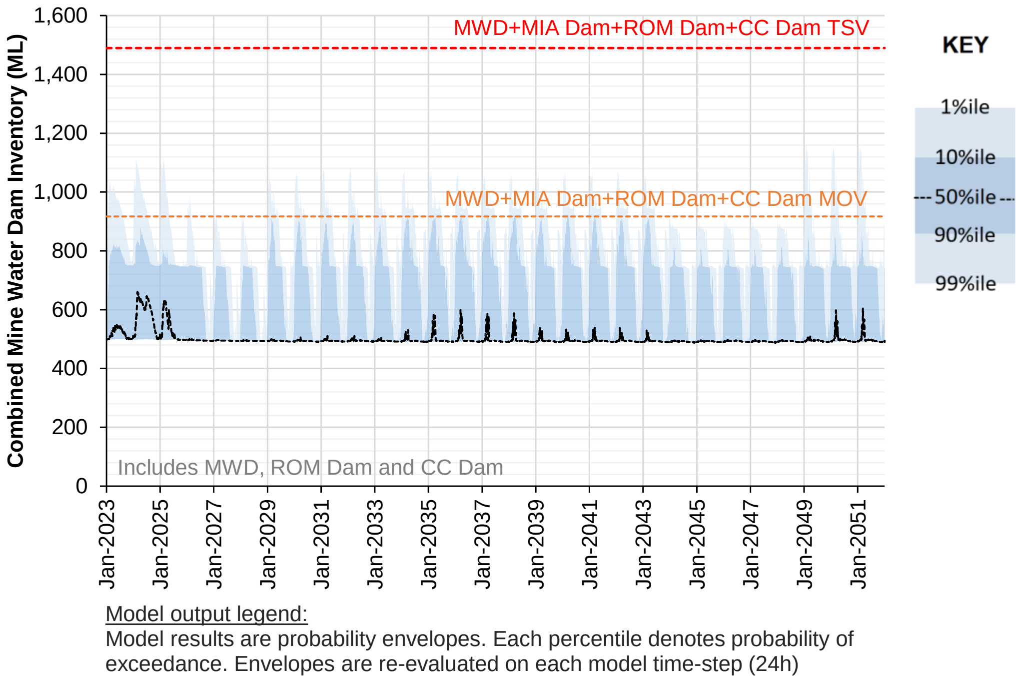


Figure 7.2 – Forecast inventory for MWD, MIA Dam, CC Dam and ROM Dam

7.3.3 Pit inundation characteristics

Figure 7.3 shows the forecast active pit inventory over the 29-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 active pit inventory are summarised as follows:

- For the 1st percentile results (very wet climatic conditions), the active pits reach a peak inventory of around 3,550 ML by the end of the Project.
- For the 10th percentile results (wet climatic conditions), the active pits reach a peak inventory of around 880 ML by the end of the Project.
- For the 50th percentile results (median climatic conditions) and drier, the active pits will not store significant volumes of water.

Aside from Phase 1, the active pit inventory will recover after each wet season for all climatic conditions assessed. The active pit inventory in Phase 1 will annually recover for climatic conditions drier than the 10th percentile. Figure 7.4 shows the active pit inundation risk for each of the six representative years (refer to Table 6.2). The following is of note regarding this result:

- Figure 7.4 shows that the greatest risk of active pit inundation will occur during Phase 2 to Phase 4. This is due to a pumping bottleneck from Main Pit back to Railway Pit (via MWD). The Main Pit area accounts for the majority of catchment runoff reporting to the mine-affected water circuit, all of which must be redirected back to Railway Pit. This issue is rectified in Phase 6 when Main Pit replaces Railway Pit as the inactive in-pit storage.
- The risk in Phase 1 is attributed to the comparative lack of mine water storage (no inactive voids are available for mine water storage).

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

- 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 to temporarily store any excess mine-affected water until there is sufficient out-of-pit storage available.

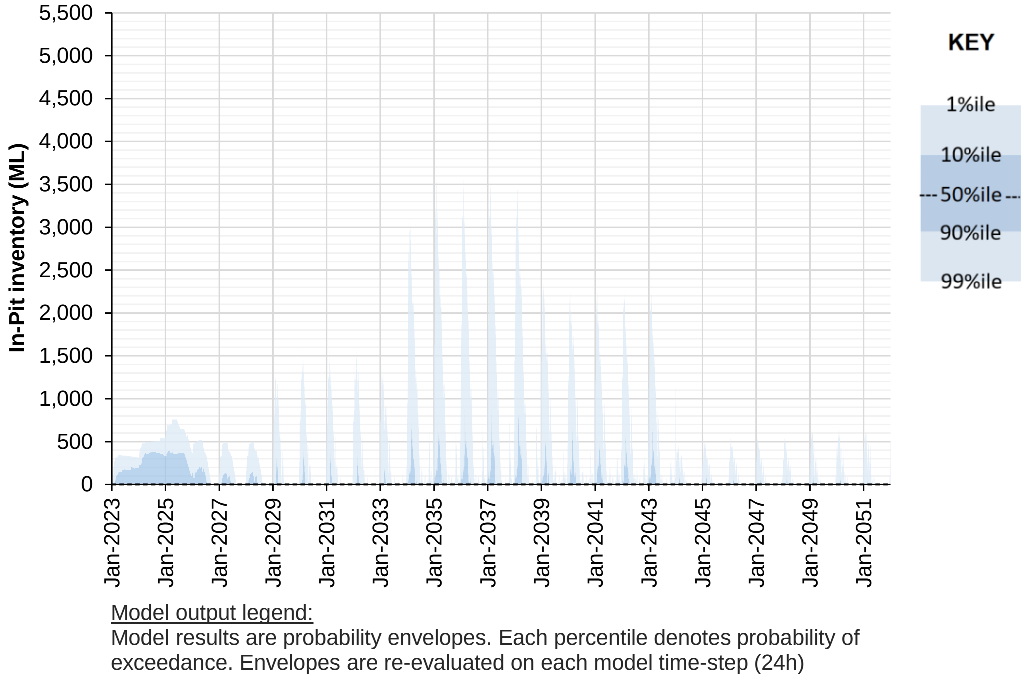


Figure 7.3 – Forecast active pit inventory

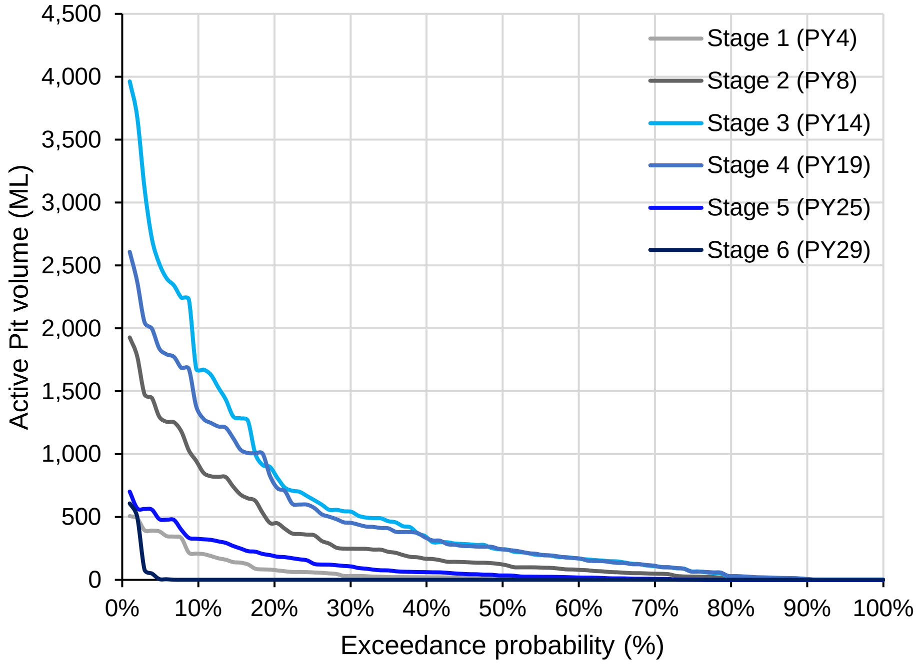


Figure 7.4 – Forecast active pit inundation risk

7.3.4 External raw water requirements

Water from external sources is required to meet operational water demands, primarily during extended dry climatic periods and periods of low groundwater inflows.

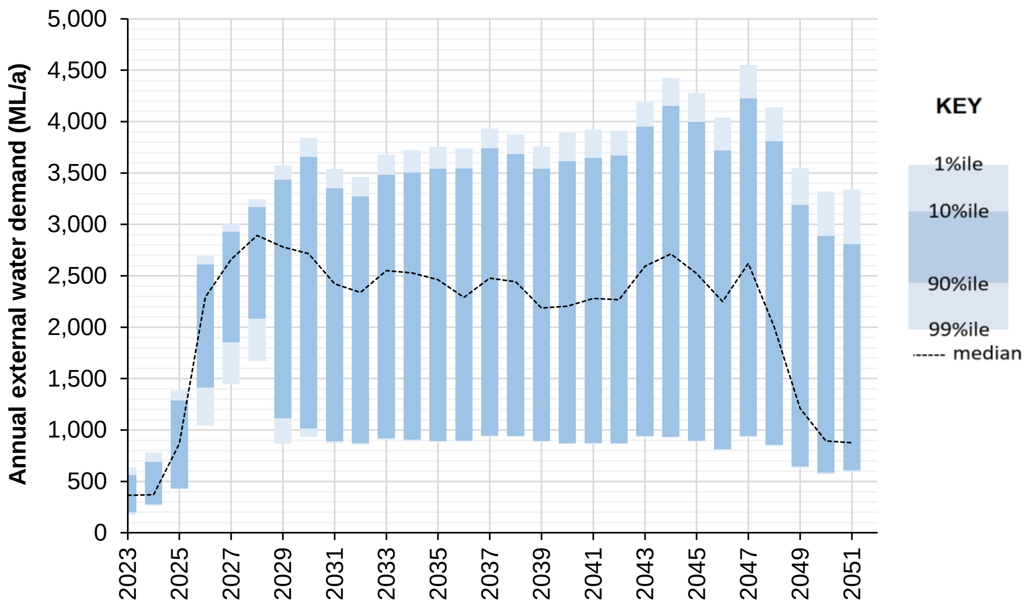
A key objective of the mine site water management system is to maximise the reuse of captured surface water runoff and groundwater inflows. Recycling mine-affected water would minimise the volume of water from external sources that is required to satisfy site demands. However, the volume of water captured 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 7.5 shows the total annual modelled demand for water from external sources over the 29-year simulation.

The modelling results show the following:

- During mining, the requirement for external raw water supply increases during dry climatic conditions but reduces during median and wet climatic conditions. There is a:
  - 1% likelihood of requiring 4,550 ML/year (or more) from external sources.
  - 10% likelihood of requiring 4,230 ML/year (or more) from external sources.
  - 50% likelihood of requiring 2,890 ML/year (or more) from external sources.
- The external raw water requirement would peak in Phase 5.
- The median external raw water supply requirement is generally consistent over the life of the project, until it sharply declines in Phase 6.

The modelling results show that external raw water requirements generally reduce over the life of the Project. This is primarily due to the continual increase in water captured from mine disturbance areas over time.



Model output legend:
Model results are probability envelopes. Each percentile denotes probability of exceedance. Envelopes are re-evaluated on an annual basis

Figure 7.5 – Forecast annual external raw water demand

Whitehaven WS would source water from either an external water supplier (e.g. Sunwater) via a water supply pipeline or via water sharing with surrounding mining operations. Therefore, it is not expected that there would be any impacts to the availability of water resources from the Isaac River or regional water availability due to the Project.

7.3.5 Controlled releases

The water balance model is configured to release water in accordance with the rules outlined in Section 6.11. The predicted annual controlled release volumes from the mine-affected water dams are provided in Figure 7.6. The results show that controlled releases would only be required for very wet (1 percentile) climatic conditions.

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 7.7 shows a ranked plot of the minimum modelled daily dilution ratio on release days, for all realisations. The results show that:

- The minimum modelled dilution ratio that occurred from all release categories throughout all realisations is 407;
- 50% of release days exceed a minimum dilution ratio of 5,550; and
- The dilution ratio is sufficient to have no significant impact on water quality in the Isaac River.

Figure 7.8 shows a ranked plot of modelled Isaac River salinity during controlled release events. It shows that, on controlled release days:

- The upstream Isaac River salinity ranges between 105 and 320 µS/cm;
- The controlled releases will have a negligible impact on the Isaac River salinity; and
- The mixed Isaac River salinity is well below the proposed receiving water salinity limits (2,000 µS/cm). The mixed salinity is also below the high flow WQO (250 µS/cm) on 95% of all controlled release days.

The modelling results show that the proposed controlled release strategy will have a negligible impact on downstream Isaac River water quality. Given this, a cumulative impact assessment including potential releases from other mining operations in the upper Isaac River catchment is not warranted.

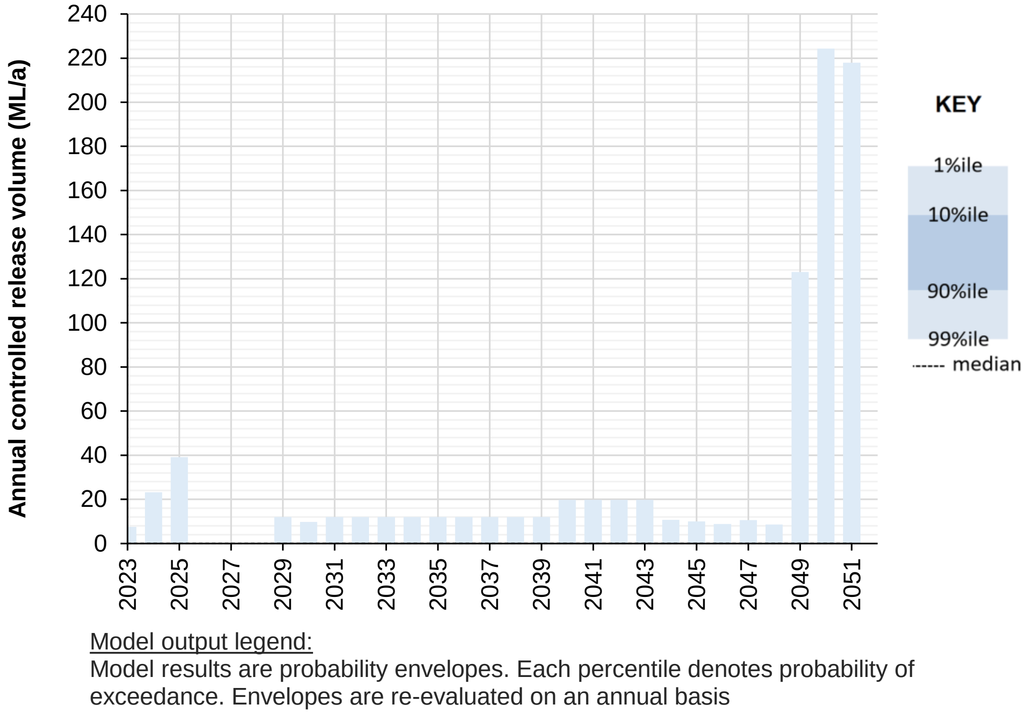


Figure 7.6 - Forecast controlled release annual volumes

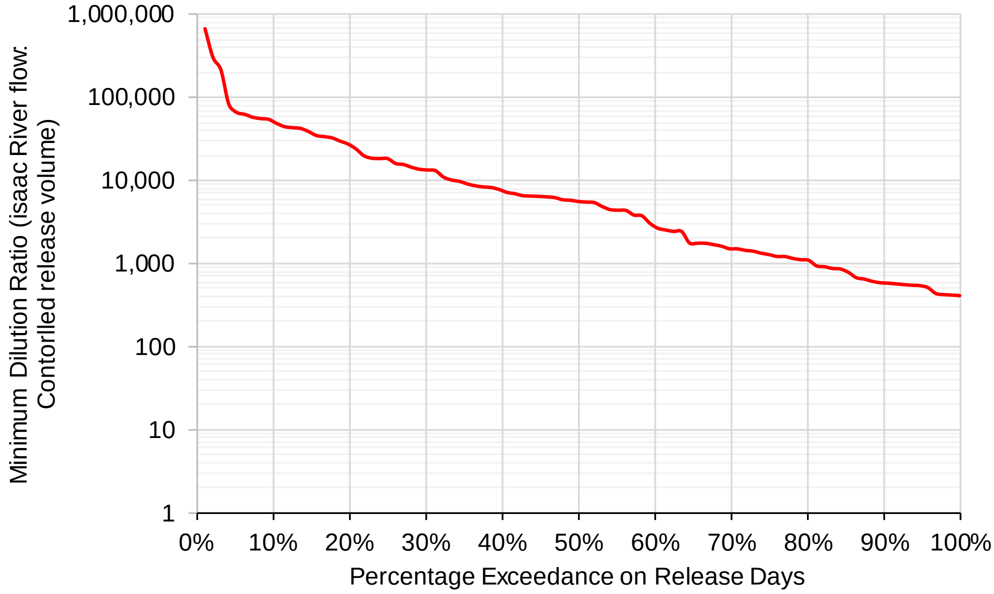


Figure 7.7 - Ranked plot of minimum dilution ratios on release days

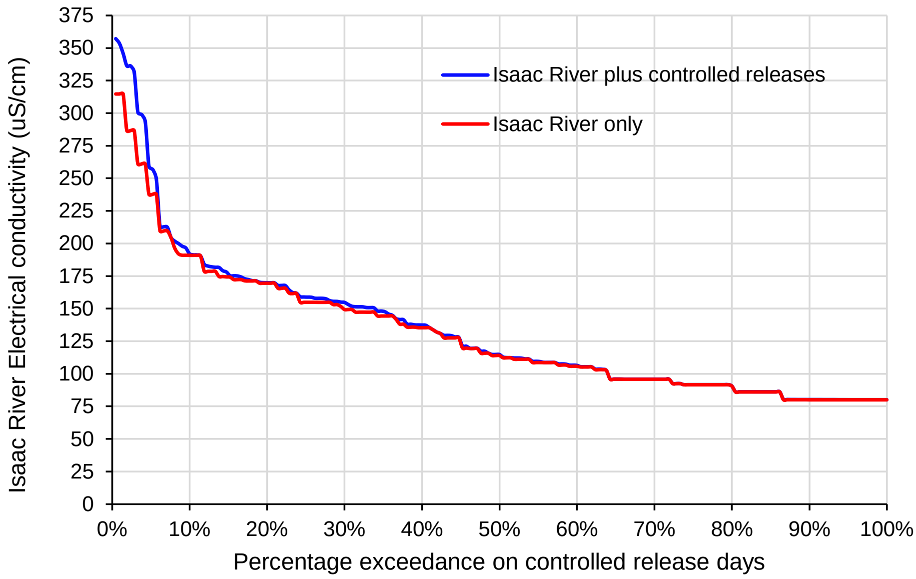


Figure 7.8 - Ranked plot of Isaac River salinity during controlled releases

7.3.6 Uncontrolled spillway discharges

7.3.6.1 Mine-affected water dams

The Project water balance model was used to assess the risk of uncontrolled off-site overflows from the mine-affected water management system. The mine-affected water dams that could potentially overflow directly to the receiving environment if rainfall exceeded a 1% AEP rainfall event volume:

- MWD;
- MIA Dam; and
- CC Dam.

Based on the water balance model results, MWD, MIA Dam and CC Dam would not have any uncontrolled spillway discharges to the Isaac River for any climatic conditions assessed over the life of the Project.

7.3.6.2 Sediment dams

The adopted design standard for sediment dams does not provide 100% containment for captured runoff. Hence overflows would 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. Sediment dams have been modelled using a passive overflow rather than active release (to regain storage capacity within 5 days).

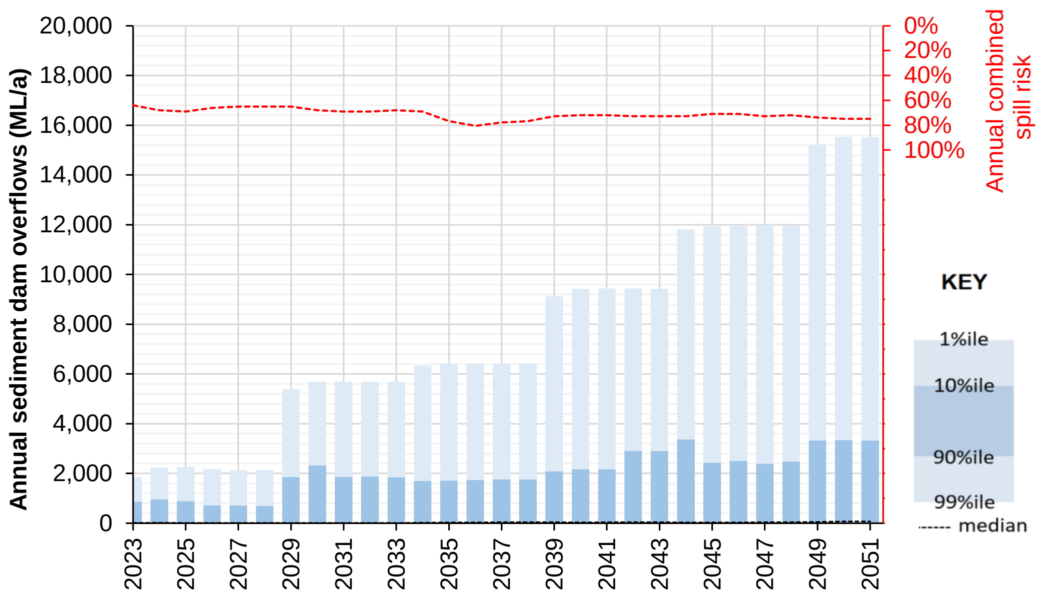
The predicted annual combined sediment dam overflows and annual spill risks under this scenario are provided in Table 7.2 and shown on Figure 7.9. The results show that:

- Annual sediment dam spill overflows will increase over the Project life, as the disturbed area expands.
- During very wet climatic conditions (1st percentile) where rainfall events frequently exceed the dam design standard, modelled sediment dam overflows are between 1,860 ML/year at the start of the Project and 15,540 ML/year by the end of the Project.

- During wet climatic conditions (10th percentile) where rainfall events often exceed the dam design standard, modelled sediment dam overflows are between 700 ML/year and 3,370 ML/year.
- The annual risk of sediment dam overflows ranges from 64% at the commencement of the Project to 80% by the end of the life of the Project.

Table 7.2 - Annual sediment dam spill volumes

	Year	Annual sediment dam spill volume (ML/a)			
		1%ile (very wet) climate conditions	10%ile (wet) climate conditions	50%ile (median) climate conditions	90%ile (dry) climate conditions
Phase 1	Year 1	1,859	867	7	0
	Year 2	2,234	963	15	0
	Year 3	2,263	889	13	0
	Year 4	2,166	723	10	0
	Year 5	2,135	705	7	0
Phase 2	Year 6	2,135	700	7	0
	Year 7	5,391	1,853	9	0
	Year 8	5,690	2,325	13	0
	Year 9	5,690	1,858	13	0
	Year 10	5,695	1,875	14	0
Phase 3	Year 11	5,689	1,850	13	0
	Year 12	6,333	1,700	24	0
	Year 13	6,414	1,716	34	0
	Year 14	6,415	1,744	35	0
	Year 15	6,414	1,761	36	0
Phase 4	Year 16	6,414	1,761	41	0
	Year 17	9,130	2,085	42	0
	Year 18	9,434	2,173	31	0
	Year 19	9,434	2,173	42	0
	Year 20	9,434	2,917	45	0
Phase 5	Year 21	9,433	2,904	45	0
	Year 22	11,811	3,369	31	0
	Year 23	11,932	2,436	31	0
	Year 24	11,946	2,503	33	0
	Year 25	11,994	2,393	45	0
Phase 6	Year 26	11,978	2,486	45	0
	Year 27	15,221	3,330	52	0
	Year 28	15,535	3,336	76	0



Model output legend:
Model results are probability envelopes. Each percentile denotes probability of exceedance. Envelopes are re-evaluated on an annual basis

Figure 7.9 – Forecast annual sediment dam overflows

Figure 7.10 shows the impact of the sediment dams overflows on the Isaac River quality. The predicted increase in Isaac River salinity due to sediment dam overflows is generally less than 7%.

The maximum modelled increases in downstream Isaac River salinity typically occur when a sediment dam overflow occurs during lower flow conditions in the Isaac River (less than 50 ML/d), as there is less dilution capacity available within the Isaac River flow. To minimise the potential impact on downstream Isaac River salinity from sediment dam overflows, the following management and mitigation measures are proposed for sediment dams that are at risk of overflowing:

- If the Isaac River flow is less than 50 ML/d and/or the salinity within a sediment dam is greater than 2,000 µs/cm:
  - Pump back the sediment dam to the water management system; or
  - Treat the sediment dam water through flocculation prior to discharge.

With the implementation of this mitigation strategy, the potential impact of sediment dam discharges on the Isaac River salinity would be negligible.

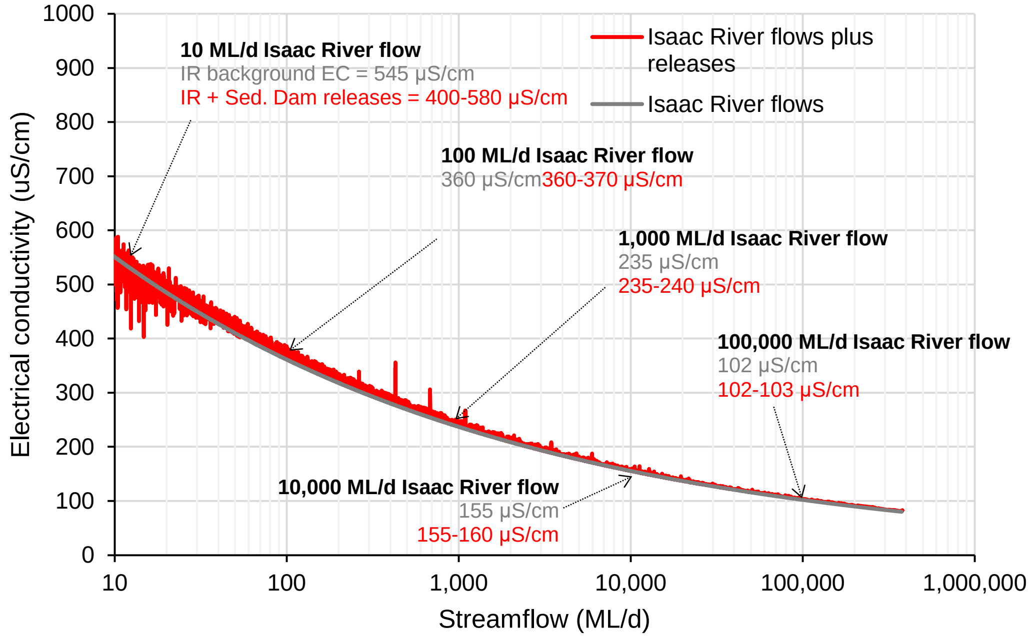


Figure 7.10 - Impact of sediment dam overflows on Isaac River water quality

The Project Geochemistry Assessment (Terrenus, 2021) undertook an analysis of the salinity and pH and summarised waste rock, as a bulk material, is expected to generate low to moderate-salinity surface water run-off and seepage following surface exposure. Weathered waste rock is generally expected to be more saline than unweathered waste rock, however potential waste rock and seam samples had the greatest range of $EC_{1:2}$ values, with the weathered overburden samples being generally more saline compared to other sample types. Less than 3% of samples were saline ($EC_{1:2}$ >1,600 µS/cm) - all of which were extremely to distinctly weathered overburden samples from less than 10 m depth. Terrenus (2021) concluded with the implementation of the proposed management and mitigation measures, the waste rock (including the slightly elevated salinity of weathered waste rock) is regarded as posing a low risk of environmental harm.

The Project Geochemistry Assessment (Terrenus, 2021) describes that the total metal and metalloid are “very low compared to average element abundance in soil in the earth’s crust”. Soluble multi-element results indicate that (Terrenus, 2021):

- The concentrations of all elements tested are less than the water quality guideline values for livestock drinking water.
- Some waste rock testing produced slightly elevated concentrations of some soluble elements (Al, As, Cu, Se and Zn) compared to water quality guideline values for slightly to moderately disturbed freshwater aquatic ecosystems (95% species protection) (ANZECC & ARMCANZ, 2000).

Terrenus (2021) also describes that:

- The geochemistry testwork results represent an ‘assumed worst case’ scenario due to the inherent conservatism of the laboratory testwork.
- As is typically the case for many coal mines in the Bowen Basin, the concentration of metals/metalloids in surface run-off and seepage from waste rock (and coal reject) material would be significantly less than the laboratory results from these ‘pulped’ samples in the field.

- Slightly elevated concentrations of some metals/metalloids from waste rock and coal reject is common at coal mines in the Bowen Basin and generally do not result in any significant water quality issues.

Coal rejects would preferentially be emplaced in-pit during the Project, however disposal of coal rejects within the out-of-pit waste rock emplacement may be required (e.g. at the commencement of the Railway Pit and Main Pit when there is no in-pit storage available). Coal rejects would be trucked from the reject bin and placed within out-of-pit waste rock emplacements and buried by at least 10 m of waste rock (Terrenus, 2021). In this way, the coal rejects would not report to the final landform surface and would not interact with surface water runoff in the final landform.

To mitigate and manage the potential low degree of environmental risk of coal rejects within out-of-pit emplacements (e.g. coal reject cells), runoff from coal reject emplacement areas would, prior to capping, report to the mine-affected water management system rather than the sediment-laden water management system. Coal rejects in-pit emplacement would also be buried by at least 10 m of waste rock. The management of coal rejects would be controlled in accordance with the requirements of the Waste Management Plan to be developed for the Project.

Whitehaven would undertake validation geochemical test-work for coal reject from the CHPP during development of the Project, particularly during the first two years of CHPP operation and whenever new seams/plys are being processed. Test-work would comprise a broad suite of environmental geochemical parameters, such as pH, EC (salinity), acid-base account parameters and total and soluble metals/metalloids (Terrenus, 2021).

Review of the geochemistry testwork against baseline surface water monitoring (Section 4.4) indicates that the various metals are naturally elevated above guideline values for aquatic ecology (95% species protection) in the Isaac River, Ripstone Creek and the ephemeral tributaries within the Project area (including the majority of those described in the Geochemistry Assessment). Accordingly, and in consideration of the very small volumes of sediment dam overflows relative to flows in the Isaac River, the management of runoff from waste rock emplacements as 'sediment water' is not considered to pose a downstream risk to the environment. Notwithstanding, monitoring of sediment dam water quality would be undertaken as described in Section 10.7.4.

7.4 OVERALL SALT BALANCE

Figure 7.11 shows a schematic of the salt inputs and outputs for the Project. Sources of salt for the Project includes the groundwater inflows, catchment runoff, direct rainfall, and external raw water. Salt outputs for the Project includes losses through the CHPP in the coal rejects and product coal, site demands (including dust suppression and other water usage), discharges through the controlled release strategy and discharges from sediment dams 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 7.3 shows the average annual salt balance for the Project, for each phase. The results indicate the following:

- The largest contributor to the Project salt load is through rainfall runoff from the various surfaces on-site. Large salt loads are also sourced via groundwater inflows and external raw water sources;
- The largest losses of salt from the Project are generally within the CHPP processing circuit (product coal and coarse rejects). 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 would not accumulate onsite during operations.

Table 7.3 - Average annual salt balance - all realisations

Process	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
Inflows (t/year)						
Rainfall Runoff	392	1,805	2,372	2,733	2,461	3,938
Net Groundwater	1,010	1,901	1,541	1,137	341	1,226
External water	214	336	326	314	333	205
Total inflows	**1,616**	**4,043**	**4,239**	**4,184**	**3,134**	**5,370**
Outflows (t/year)						
Evaporation	0	0	0	0	0	0
Dust Suppression	175	892	1,001	1,291	1,038	2,128
Other water usage	28	29	29	29	29	30
Net MAW CHPP demand	1,185	2,691	2,766	2,615	1,660	1,678
Net Raw CHPP demand	50	94	98	94	94	57
Controlled releases	0	0	0	0	0	0
MAW dam overflows	0	0	0	0	0	0
Sediment dam overflows	76	188	189	230	256	337
Total outflows	**1,513**	**3,894**	**4,082**	**4,259**	**3,077**	**4,230**
Change in Site Salt Tonnage	**103**	**149**	**157**	**-75**	**58**	**1,140**

Note: Totals may not add due to rounding.

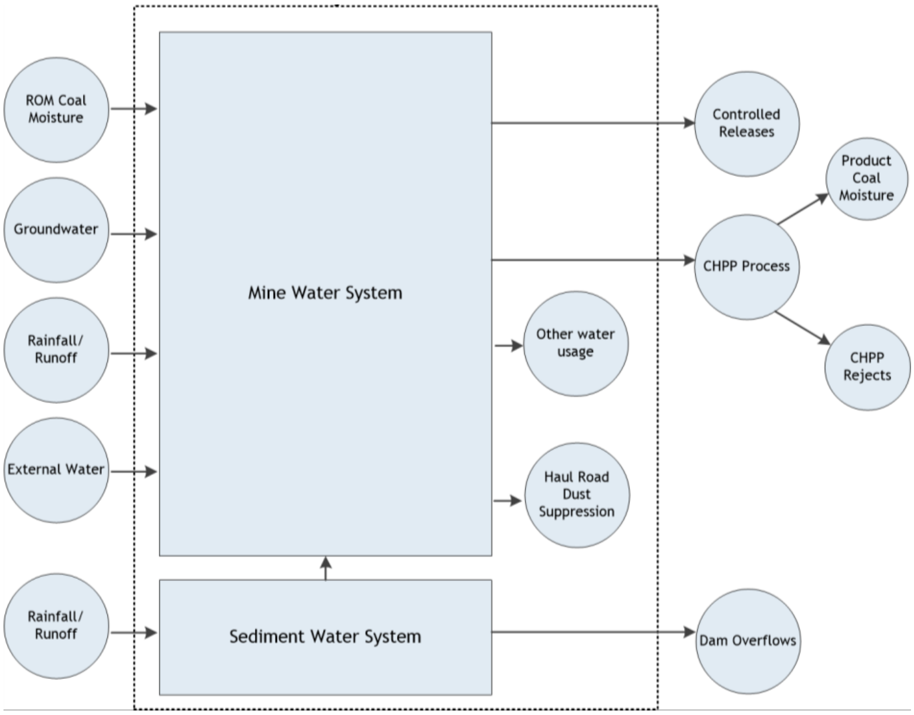


Figure 7.11 - Simplified surface water salt balance schematic

7.5 MODEL SENSITIVITY ASSESSMENT

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

- *Scenario 1*: Global increase in AWBM soil capacity by 20%.
- *Scenario 2*: Global decrease in AWBM soil capacity by 20%.

The results from these sensitivity analyses are provided in Appendix B and summarised in Table 7.4.

Table 7.4 – Sensitivity assessment summary

Scenario	Description	Mine water containment	External water requirement	Offsite releases
Scenario 1	Global increase in AWBM soil capacity by 20%	The WMS inventory would be slightly decreased under Scenario 1.	The external water requirement is generally similar to the base case, however, the median requirement would be marginally increased.	The controlled release volumes are not notably different from the base case. No uncontrolled releases are projected to occur for any of the modelled simulations.
Scenario 2	Global decrease in AWBM soil capacity by 20%	The WMS inventory would be slightly increased under Scenario 2.	The external water requirement is generally similar to the base case, however, the median requirement would be marginally decreased.	The controlled release volumes are not notably different from the base case. No uncontrolled releases are projected to occur for any of the modelled simulations.

7.6 ADAPTIVE MANAGEMENT OF THE WATER MANAGEMENT SYSTEM

The site water balance model results presented above represent the application of the proposed water management system rules over the life of the Project, 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 site water inventory in a way that would reduce the risks of impacts to surface water resources and quality.

A site water balance model would be developed once the mine is operational and would be updated periodically using site monitoring data.

8 Residual void behaviour

8.1 OVERVIEW

In response to feedback from regulatory and community stakeholders, Whitehaven WS has reviewed the Project mine plan and sequence with the aim of reducing the number of residual voids in the final landform, which includes backfilling of the South Pit Void for the optimised final landform.

As such, following the cessation of mining at the Project, there would be three residual voids (Figure 8.1). Water levels in the residual voids would 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 residual voids. The historical rainfall and evaporation sequences (133 years) were repeated 5 times to create an indicative long-term climate record. The volume of water in the voids is calculated at each time step as the sum of direct rainfall to the water surface, catchment runoff and groundwater inflows, less evaporation losses.

8.2 RESIDUAL VOID CONFIGURATION

The residual void configuration and contributing catchment areas are shown in Figure 8.1 and Table 8.1. The final catchment draining to the residual voids would be minimised using up-catchment diversion drains, as shown in Figure 8.1. A depth varying storage evaporation factor has been applied to each void to simulate the expected change in evaporation as residual void water levels vary. The storage evaporation factors are as follows:

- Bottom of void - 0.6.
- 10 m from top of void – 0.9.
- Top of void - 1.0.

Table 8.1 -Contributing catchment to residual void

Residual void	Contributing surface catchment (ha)			Baseflow only catchment (Rehabilitation) (ha)
	Spoil Area	Rehabilitation Area	Total Area	
North-west Void	10.4	56.5	66.9	35.7
West Void	35.2	278.6	313.8	156.9
Main Void	233.5	748.8	982.3	1,435

The AWBM parameters present in Table 6.6 have been adopted for the residual void assessment.

8.3 RESIDUAL VOID GEOMETRY

The stage-storage curve for the three residual voids have been based on the final landform terrain model provided by Whitehaven WS. The geometries of the residual voids are summarised in Table 8.2.

Table 8.2 - Modelled residual void geometry

Residual void	Depth (m)	Top surface area (ha)	Total storage volume (ML)
North-west Void	96	43.0	18,374
West Void	120	97.7	52,935
Main Void	134	619.4	256,863

8.4 GROUNDWATER INFLOWS

Groundwater inflows into each of the three residual voids were provided by SLR (2022) as a time series over 250 years. These inflow rates take into account the movement of water between the residual voids through the backfilled in-pit waste rock.

Groundwater inflows to the voids are initially negative whilst the groundwater level in the surrounding spoil rises post-mining (i.e. water that flows into the residual voids flows toward the surrounding spoil until it is saturated) (SLR, 2022). Groundwater to the residual voids have been reduced to 0 ML/d in the model during these periods. The resulting groundwater inflow ranges from:

- North-west Void: 0 ML/d to 0.55 ML/d.
- West Void: 0.1 ML/d to 0.9 ML/d.
- Main Void: 0 ML/d to 1.8 ML/d.

As described above, the groundwater inflows to the residual voids have been modelled as two inflows components for each void: 'backfilled spoil' and 'rest of pit'. The representative EC values assigned to each of the groundwater inflow components are summarised in Table 8.3.

Table 8.3 - Residual void groundwater inflow salinity concentrations

Groundwater inflow component	Void	EC (µS/cm)	Justification
Backfilled spoil	All voids	1,012	Based on 90th percentile concentration from contemporary geochemical water quality sampling results for overburden and interburden (Terrenus, 2020).
Rest of Pit	North-west / West Void	8,400	Based on the 50th percentile concentration from groundwater bore sampling data that targeted the coal seams and interburden near the North-west Void and West Void (Terrenus, 2020).
	Main Void	13,230	Based on the average salinity recorded at 8 bores and 54 lab samples which targeted the Leichhardt and Vermont coal seams, representative of the EC for pit groundwater inflows at Main Void.

8.5 RUNOFF SALINITY

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

- Unrehabilitated spoil: 520 μS/cm.
- Rehabilitated landform: 300 μS/cm.

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

8.6 BENEFICIAL USE

Initial modelling results indicate that the water quality in the residual voids for the optimised final landform may be suitable for a beneficial use (e.g. cattle production).

Ann annual extraction rate of 70 ML/year has been applied across the residual voids. This is based on an average cattle water consumption rate of 15,000 L per year per head, at an adopted cattle carrying capacity of 2.4 hectare per Animal Equivalent (AE) and a resulting 4,700 AE cattle.

This beneficial use demand has been split across the residual voids to provide a 100% reliable supply of water, in the following proportions:

- North-west Void – 15%
- West Void – 40%
- Main Void – 45%

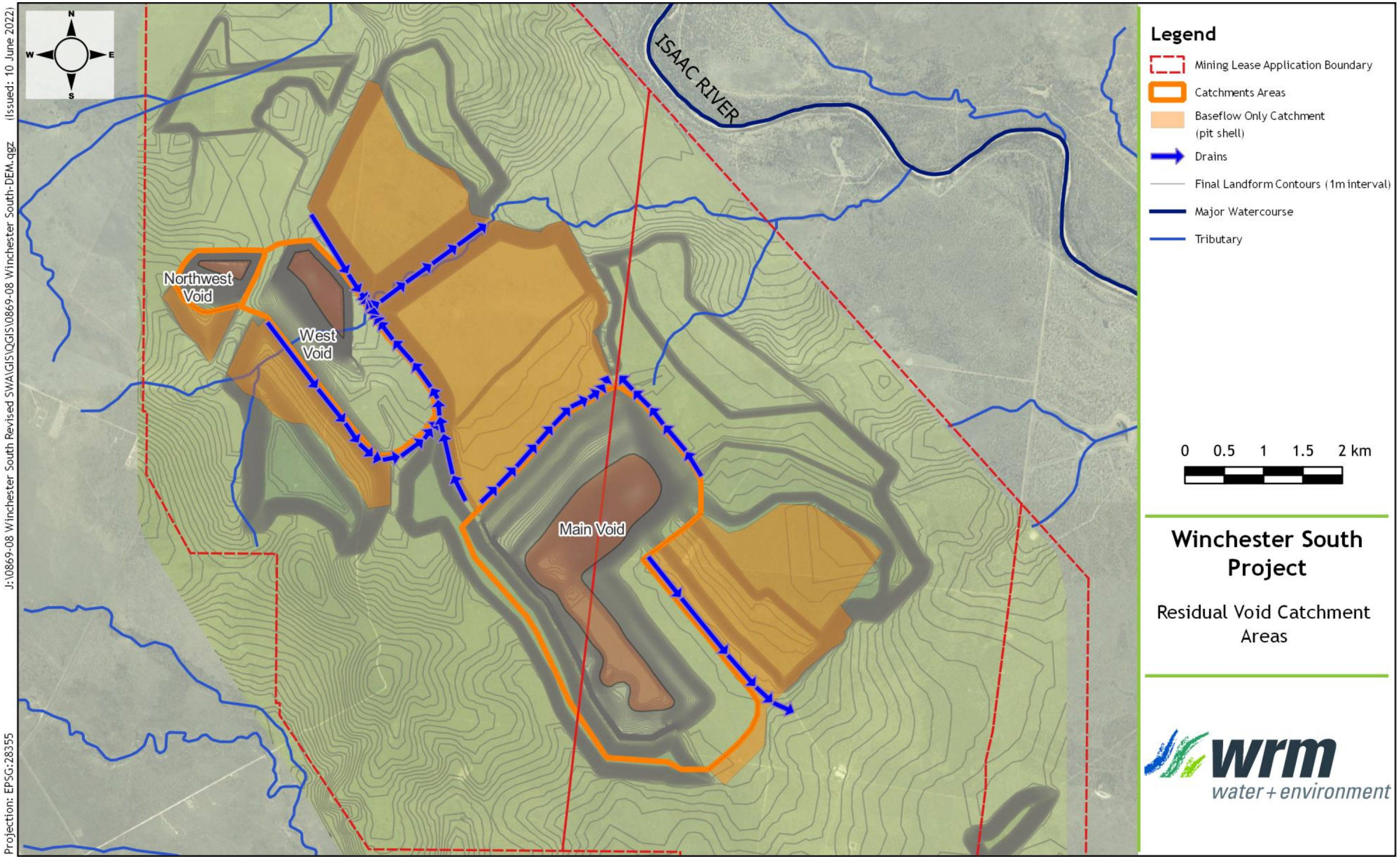


Figure 8.1 – Residual void catchment plan

8.7 MODEL RESULTS

8.7.1 Long-term water level behaviour

Figure 8.2 to Figure 8.4 show the simulated long-term water levels in the residual voids. Table 8.4 shows a summary of the storage details of the residual voids and the results of the water balance modelling.

Table 8.4 - Residual void modelling results summary

Void	Elevation (mAHD)			
	Pit floor level	Overflow level*	Modelled average long-term water level	Modelled peak long-term water level
North-west Void	114	210	125.0	131.4
West Void	76	196	101.3	108.7
Main Void	74	208	139.6	148.7

* 'Overflow level' refers to the maximum *in-situ* relative level of each void.

The model results show the following:

- North-west Void (Figure 8.2):
  - The water level reaches equilibrium between 118 metres Australian Height Datum (mAHD) and 131 mAHD after around 100 years, and generally varies between these levels throughout the remaining 400 years of the simulation.
  - The maximum modelled water level is around 78 m below the North-west Void FSL.
  - The residual void pit lake is able to provide 15% of the 70 ML/year beneficial use demand.
- West Void (Figure 8.3):
  - The water level reaches equilibrium between 90 mAHD and 109 mAHD after around 100 years, and generally varies between these levels throughout the remaining 400 years of the simulation.
  - The maximum modelled water level is around 87 m below the West Void FSL.
  - The residual void pit lake is able to provide at least 40% of the 70 ML/year beneficial use demand.
- Main Void (Figure 8.4):
  - The water level reaches equilibrium between 128 mAHD and 148 mAHD after around 100 years, and generally varies between these levels throughout the remaining 400 years of the simulation.
  - The maximum modelled water level is around 59 m below the Main Void FSL.
  - The residual void pit lake is able to provide at least 45% of the 70 ML/year beneficial use demand.

The model results show that all of the residual voids reach equilibrium after around 100 years, with maximum predicted water levels levels which are between 59 and 87 m below their FSL.

The predicted residual void equilibrated water levels are generally consistent with the results of the numerical groundwater modelling undertaken for the Groundwater Assessment (SLR, 2022). At equilibrium, the majority of the water stored within the voids is located within Main Void (around 89%), with around 10% stored within West Void and around 1% stored within North-west Void.

8.7.2 Long-term salinity

As there is a mechanism for salt removal from the residual voids through beneficial use demand, the long-term salinity of the residual void pit lake in each of the voids is significantly lower than is typically predicted with closed-loop systems.

The model results show the following:

- North-west Void (Figure 8.2)
  - The salinity of the pit lake reaches an equilibrium within the first 100 years of the simulation.
  - The modelled salinity is mostly within the range of 2,000 to 6,000 µS/cm, with some periods of higher salinity (up to 18,000 µS/cm) when the stored volume within the void is lower.
- West Void (Figure 8.3)
  - The salinity of the pit lake reaches an equilibrium within the after 150 years of simulation.
  - The modelled salinity is mostly within the range of 2,000 to 4,000 µS/cm, with some periods of higher salinity (up to 8,500 µS/cm) when the stored volume within the void is lower.
- Main Void (Figure 8.4)
  - The salinity of the pit lake does not reach an equilibrium with the 500 years of simulation.
  - The modelled salinity is mostly within the range of 1,000 to 4,000 µS/cm, with some periods of higher salinity (up to 6,500 µS/cm) when the stored volume within the void is lower.

The peak residual void water body salinities reported were those observed during the simulation period. The modelling indicates that the salinities within North-west Void and West Void achieve an equilibrium due to the beneficial use demand. Main Void salinity concentration is trending upwards after the 500 year simulation, but the annual increases are relatively small (around 1,000 µS/cm per year).

The results of the water balance model indicates that the proposed beneficial use demand can provide a sustainable and reliable supply of suitable quality water for cattle consumption, with only relatively small period of elevated salinity when North-west Void and West Void inventories are lower. Main Void would still be able to reliably supply suitable quality water during these periods.

If there are periods of low volume and elevated salinity in North-west Void and West Void, the water within these voids could be pumped into Main Void as a management measure, due to the significantly larger volume of lower salinity water within the Main Void.

Under these circumstances, Main Void would still be able to supply suitable water quality, as the relatively small salt loads transferred from North-west Void and West Void would only have a minor impact on Main Void salinity. Pumping all the higher salinity water from North-west Void and West Void into Main Void would only increase Main Void salinity by around 100 µS/cm (on average).

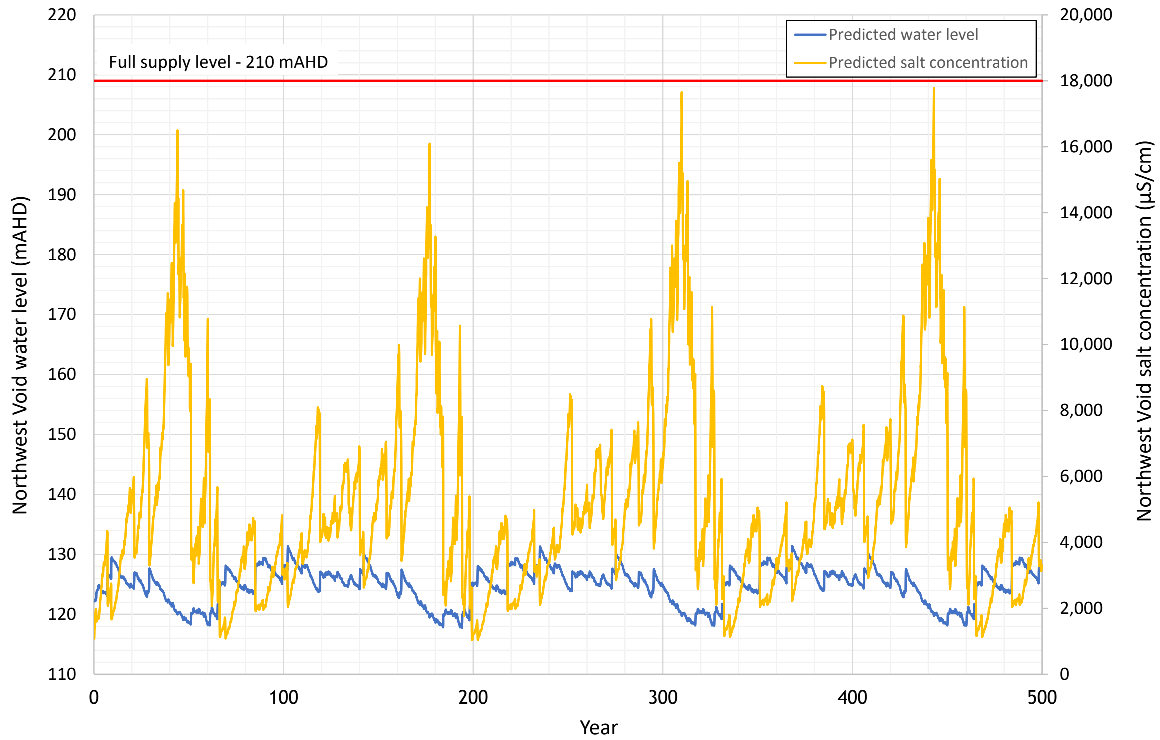


Figure 8.2 - Residual void water level and salt concentration - North-west Void

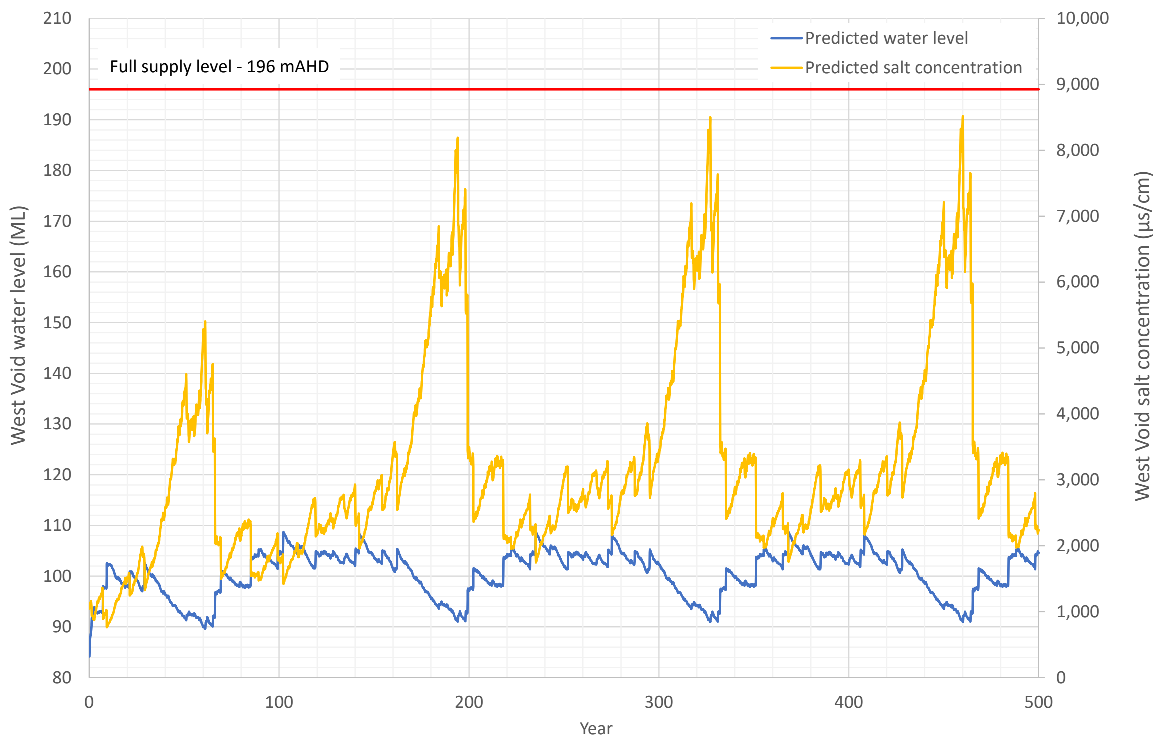


Figure 8.3 - Residual void water level and salt concentration - West Void

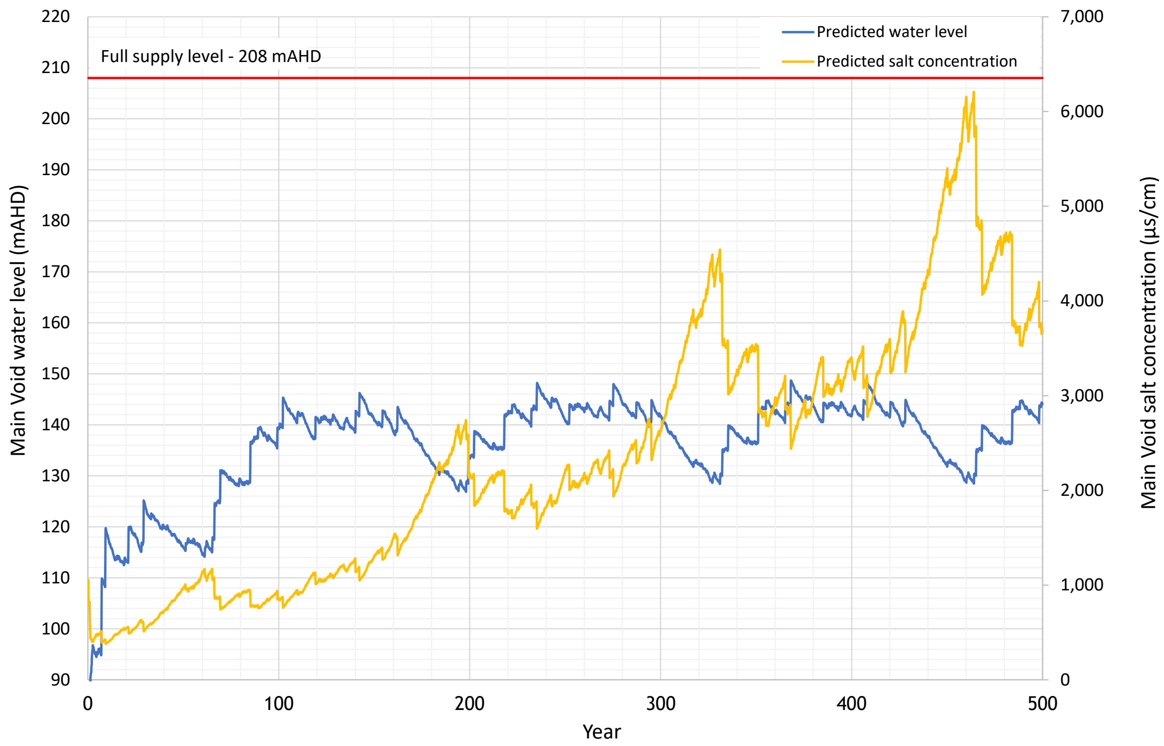


Figure 8.4 - Residual void water level and salt concentration - Main Void

8.8 STORM EVENT BEHAVIOUR

8.8.1 Overview

An assessment of the impact of storm events on the water level in the residual voids has been undertaken. The potential for discharge of void water has been assessed for the following design rainfall events using 72-hour (3 day) rainfall depths:

- 1 in 100 AEP; and
- 1 in 1,000 AEP;
- Probably Maximum Precipitation (PMP).

8.8.2 Initial conditions

The maximum water levels simulated in the residual void water balance modelling were conservatively adopted as the initial conditions for the storm event analysis. The following values were adopted for each void:

- North-west Void - initial volume of 590 ML (131.4 mAHD).
- West Void - initial volume of 4,060 ML (108.7 mAHD).
- Main Void - initial volume of 30,480 ML (148.7 mAHD).

8.8.3 Design rainfall depths

Design rainfall depths for the 1 in 100 AEP, 1 in 1,000 AEP rainfall events were estimated using standard procedures in Australian Rainfall and Runoff (ARR) (Ball *et al.*, 2016).

The rainfall depth for the PMP design event for a duration of 24 hours was estimated using the standard methodology given in the *Guidebook to the Estimation of Probable Maximum Precipitation: Generalised Tropical Storm Method (GTSMR)* (BOM, 2005) based on the Project location.

8.8.4 Assessment outcomes

Runoff volumes were calculated assuming no losses from the total catchment areas adopted in the water balance model. Table 8.5 show the results of the storm event analysis for the residual voids.

The results show that even during storm events with rainfall depths equivalent to the PMP design event, there would be minimal impact on the level of water in the residual voids. Simulated water level increases for such an event are in the order of 11 m to 17 m. The PMP design event final water levels are between 48 m and 65 m below the overflow levels across all the residual voids.

Table 8.5 - Storm event behaviour - summary of results

Storm event (AE)	Rainfall depth (mm)	Runoff volume (ML)	Final volume (ML)	Change in water level (m)	Final water level (mAHD)
North-west Void					
1 in 100	339	227	817	3.0	134.4
1 in 1000	535	358	948	4.5	135.9
PMP	1,850	1,238	1,828	12.9	144.3
West Void					
1 in 100	339	1,064	5,126	3.7	112.4
1 in 1000	535	1,679	5,741	5.7	114.4
PMP	1,850	5,805	9,867	17.4	126.1
Main Void					
1 in 100	339	3,330	33,813	2.8	151.5
1 in 1000	535	5,255	35,738	4.2	152.9
PMP	1,850	18,173	48,655	10.7	159.4

8.9 CLIMATE CHANGE ASSESSMENT - POST-MINING

8.9.1 Methodology and sensitivity parameters

The potential impacts of climate change on residual void behaviour were assessed using 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). The CSIRO report provides guidance on the possible projections of future climate for the Australian 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, wind speed and potential evapotranspiration. CSIRO (2015) presents a number of possible approaches to quantify risks associated with climate change impacts.

For this assessment, the conservative Representative Concentration Pathway 8.5 (RCP8.5) emissions scenario has been adopted. The year 2090 was selected as the representative year, being approximately 40 years post-mine closure. Potential changes in climate have been obtained using the projection builder tool provided in the Climate Change Australia website. Climate variable inputs for the 'best case', 'maximum consensus' case 'and 'worst case' as defined by CSIRO (2015) for the RCP8.5 climate change scenarios are provided in Table 8.6. Year 2090 is the current limit of climate change projections as defined by CSIRO (2015).

Rainfall is expected to change by between plus 19.1% and minus 34.0% and evapotranspiration is expected to increase by between 8.3% and 15.2%. The climate variable inputs (rainfall and evaporation) to the water balance model were adjusted to undertake the climate change impact assessment. All three scenarios have been assessed for the proposed residual voids.

Table 8.6 - Projections of change to climate - Year 2090 (RCP8.5)

Void	Climate model	Annual change (%)	
		Rainfall	Evapotranspiration
Best case	GFDL-ESM2M	-34.0%	14.5%
Maximum consensus	ACCESS1-0	-15.4%	15.2%
Worst case	NorESM1-M	19.1%	8.3%

8.9.2 Potential climate change impacts

8.9.2.1 Overview

Potential climate change impacts to the residual void water balance were assessed by simulating the 'best' case, 'maximum consensus case' and 'worst' case climate scenarios for the Year 2090 climate changes projection. The water balance model climate inputs (rainfall and evaporation) were factored by the values given in Table 8.6.

8.9.2.2 Potential impact on residual void water levels

The water balance modelling results show that the residual voids water levels will be lower than under baseline climatic conditions for the 'best case" and "maximum consensus" climate scenarios. This is expected given the significant decrease in rainfall and increase in evapotranspiration for these climate scenarios. For the "best case" climate scenario, the model predicts that all three residual voids will empty within the first 50 years of the simulation.

For the "worst case" climate scenario, the residual void water levels will be higher than under baseline climatic conditions.

The impact of the potential changes in rainfall and evapotranspiration for the proposed residual void water levels are presented in Figure 8.5 to Figure 8.7. The results show the following (with the baseline results shown for reference):

- For the 'best case' climate scenario:
    - *North-west Void*: The equilibrium and peak water level are around 8 m lower than under baseline climate conditions.
    - *West Void*: The equilibrium and peak water level are around 18 m lower than under baseline climate conditions.
    - *Main Void*: The equilibrium and peak water level are around 40 m lower than under baseline climate conditions.
- For the 'maximum consensus' case climate scenario:
    - *North-west Void*: The equilibrium and peak water level are around 6 m lower than under baseline climate conditions.
    - *West Void*: The equilibrium and peak water level are around 11 m lower than under baseline climate conditions.
    - *Main Void*: The equilibrium and peak water level are around 19 m lower than under baseline climate conditions.

- For the ‘worst’ case climate scenario:
  - *North-west Void*: The equilibrium and peak water level are around 6 m higher than under baseline climate conditions.
  - *West Void*: The equilibrium and peak water level are around 12 m higher than under baseline climate conditions.
  - *Main Void*: The equilibrium and peak water level are around 8 m higher than those under baseline climate conditions.

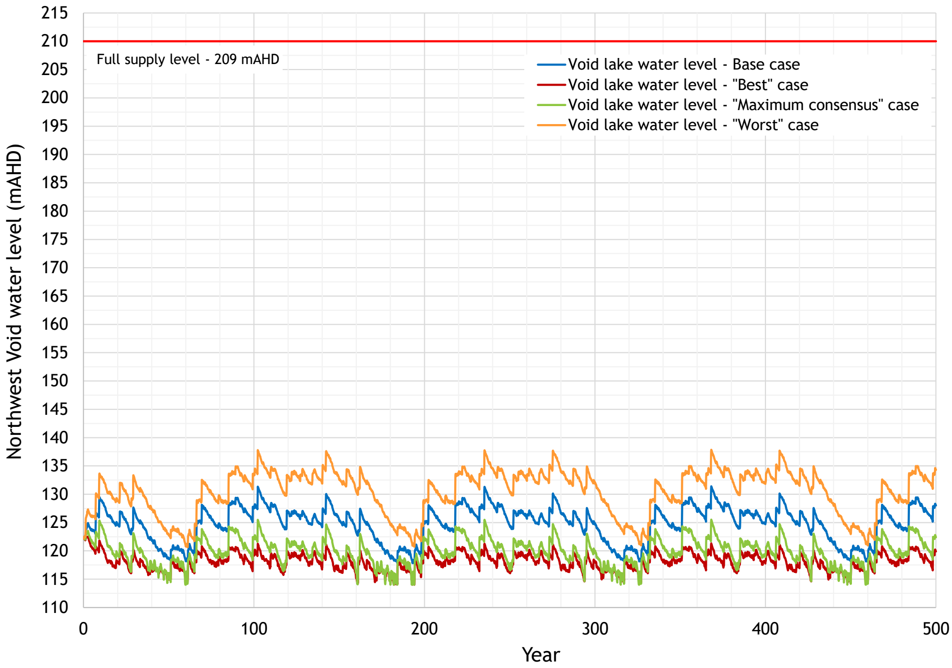


Figure 8.5 - North-west Void water level - climate change assessment

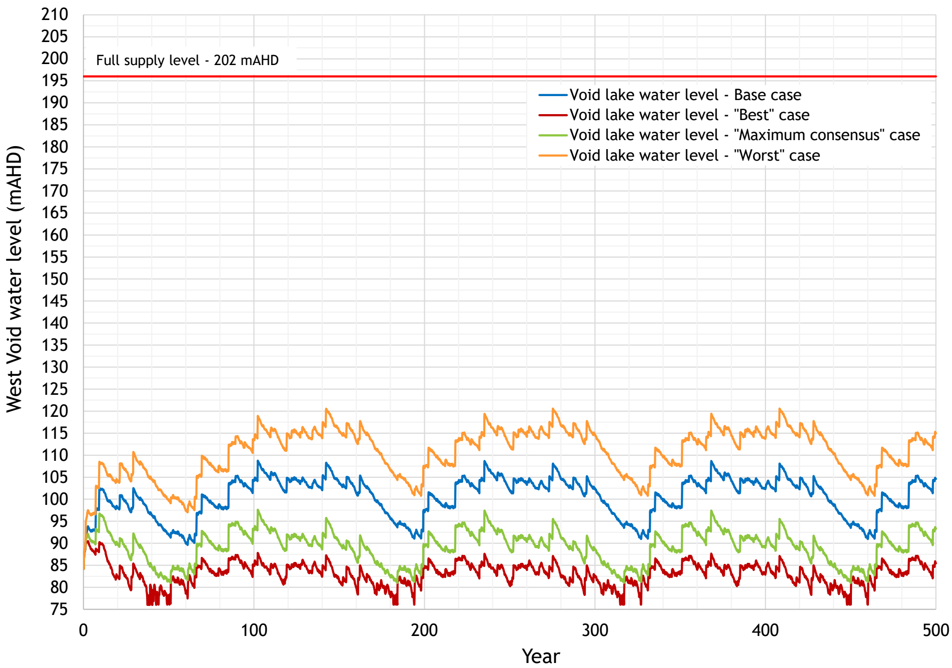


Figure 8.6 - West Void water level - climate change assessment

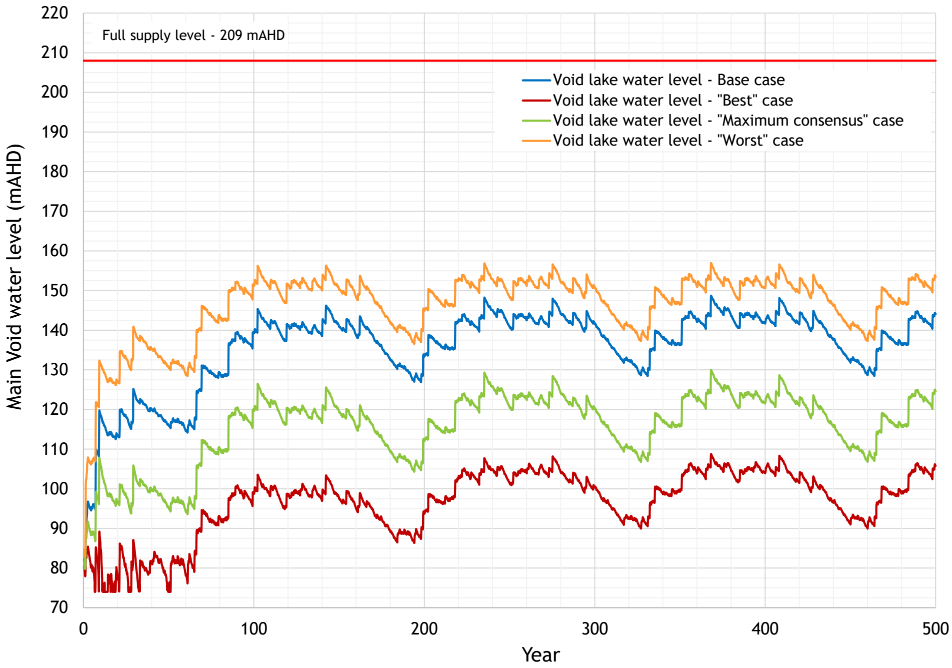


Figure 8.7 – Main Void water level – climate change assessment

8.9.2.3 Potential impact on residual void salinity

The water balance modelling results show that, in most cases, the residual voids salinity will be similar to or higher than under baseline climatic conditions. This is expected given the significant decrease in rainfall and increase in evapotranspiration for these climate scenarios, resulting in lower stored volumes and higher concentrations.

The impact of the potential changes in rainfall and evapotranspiration for the proposed residual void salt concentrations are presented in Figure 8.8to Figure 8.10. The results show the following (with the baseline results shown for reference):

- For the 'best case' climate scenario:
  - *North-west Void*: The salinity range is similar to baseline climate conditions, except for a higher peak concentration within the first 15 years of the simulation.
  - *West Void*: The salinity range is similar to baseline climate conditions, except is does not exhibit as high concentrations peak during extended drought conditions.
  - *Main Void*: The salinity range is higher than baseline climate conditions, with a peak concentration of around 8,400 µS/cm at the end of the 500 year simulation (compared with 6,200 µS/cm).
- For the 'maximum consensus' case climate scenario:
  - *North-west Void*: The salinity range is similar to baseline climate conditions.
  - *West Void*: The salinity range is similar to baseline climate conditions.
  - *Main Void*: The salinity range is higher than baseline climate conditions, with a peak concentration of around 9,000 µS/cm at the end of the 500 year simulation (compared with 6,200 µS/cm).

- For the ‘worst’ case climate scenario:
  - *North-west Void*: The salinity range is slightly higher than baseline climate conditions.
  - *West Void*: The salinity range is significantly than baseline climate conditions, with a peak concentration of around 24,000 µS/cm at the end of the 500 year simulation (compared with 8,500 µS/cm).
  - *Main Void*: The salinity range is similar to baseline climate conditions.

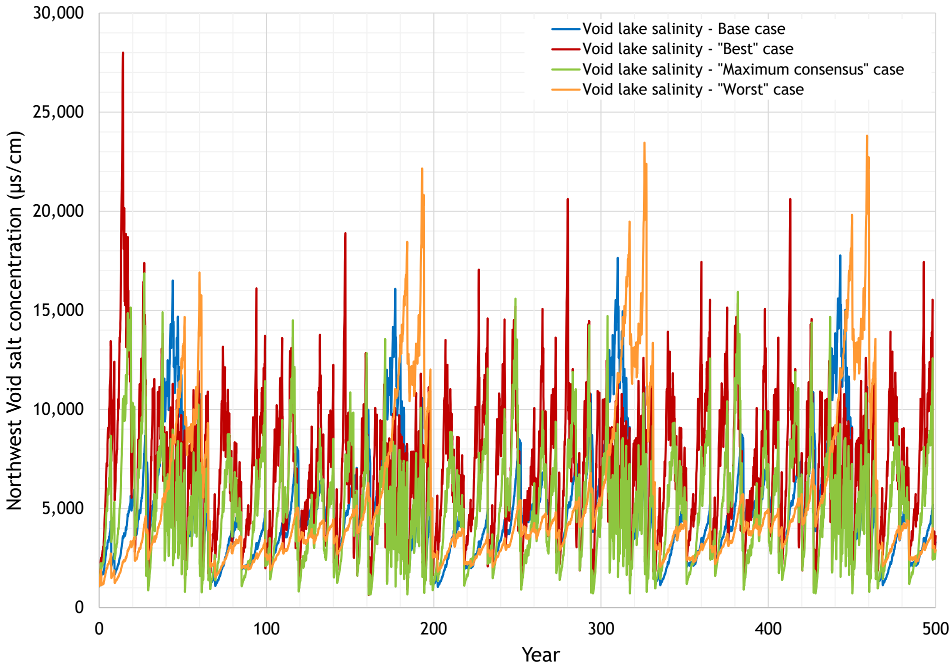


Figure 8.8 - North-west Void salt concentration - climate change assessment

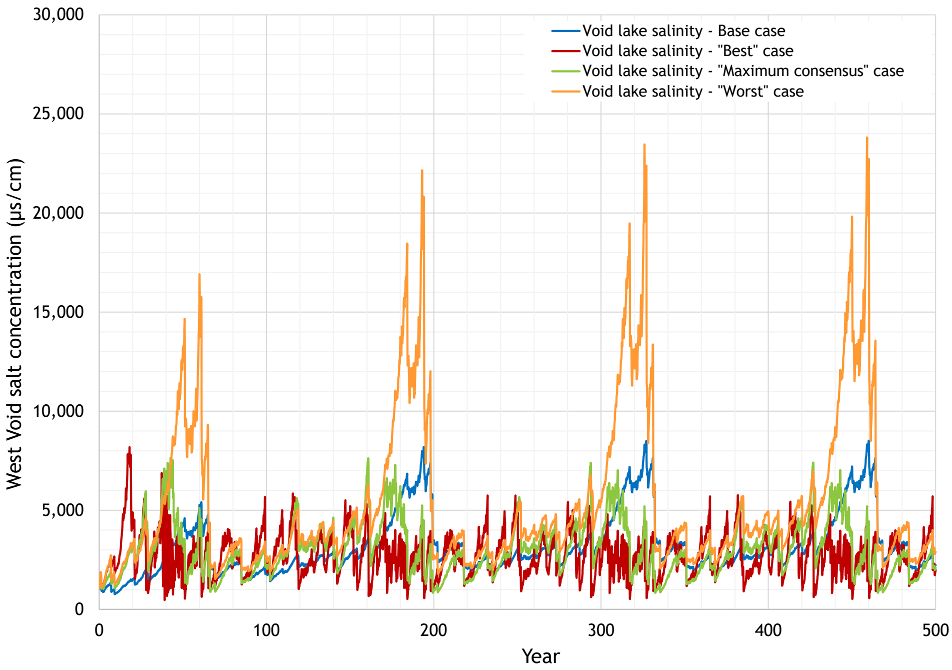


Figure 8.9 - West Void salt concentration - climate change assessment

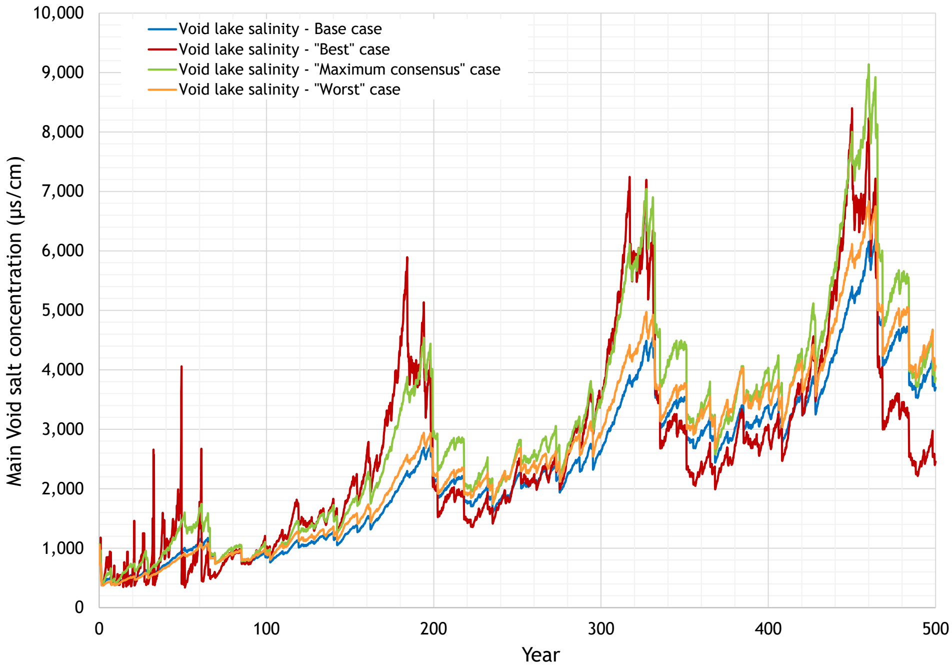


Figure 8.10 – Main Void salt concentration – climate change assessment

9 Flood modelling assessment

9.1 ISAAC RIVER OPERATIONAL CONDITIONS

9.1.1 Overview

The calibrated Isaac River hydraulic model described in Appendix C was used to estimate design peak flood levels, depths, extents and velocities along the Isaac River and its tributaries for various events from 5% AEP design event to the Probable Maximum Flood (PMF).

Table 9.1 shows the design discharges for the Isaac River at Deverill for the 10%, 5%, 1%, 0.1% and PMF events estimated using the calibrated hydrological model described in Appendix C. Design peak discharges were estimated using the XPRafts model, based on design rainfalls and Areal Reduction Factors (ARFs) obtained for the centroid of the Isaac River catchment to Deverill, and the validated design rainfall losses given in Table C.11.

Table 9.1 – XPRafts design discharges, Isaac River at Deverill

Design event	XPRafts Ensemble mean peak discharge (m^3/s)	XPRafts adopted design peak discharge (m^3/s)[1]	Critical storm duration (hours)	Temporal pattern
10% AEP	1,935	1,936	24	6
5% AEP	2,787	2,886	24	7
1% AEP	5,051	5,068	24	9
0.1% AEP	10,009	10,180	24	2
PMF	36,474	36,474	36	*NA*

NA – not applicable for PMF event
[1] – Adopted design peak discharge calculated from the temporal pattern which generated a peak discharge closest to, but higher than, the ensemble mean.

9.1.2 Model scenarios

The Project is located to the south of the Isaac River and is close to several approved mining projects. The approximate locations of flood protection levees and waste rock emplacement footprints of these approved mining projects are shown in Figure C.12.

As part of the Olive Downs Project, a new rail line connecting to the existing Goonyella rail line is proposed (location shown in Figure C.12).

These approved mining projects and infrastructure would have some impacts on the design flood levels within the Project area. Therefore, the following model scenarios were considered:

- **Scenario 1 (Existing Conditions)** – Existing conditions with the approved flood protection levees and waste rock emplacements (modelled as a 'glass wall' in the hydraulic model) of the neighbouring approved mining projects, including:
  - Poitrel Mine;
  - Daunia Mine;
  - Moorvale South Project; and
  - Olive Downs Project.

  The modelled Olive Downs levee alignment and emplacement footprint is based on the modified area provided by Pembroke. This modified area (which is different to that presented in the Olive Downs Project EIS) mitigates the potential flood impacts of the Olive Downs Project. Notwithstanding, the Project flooding impacts are isolated to small area around the proposed flood protection levees, and therefore there would be no cumulative flooding impacts with the Olive Downs Project.

  The proposed rail spur for the Olive Downs Project has been also included in the Scenario 1 (alignment, geometry and associated culvert crossings associated with this rail spur were provided by Pembroke, under the existing data sharing agreement with Whitehaven WS).

- **Scenario 2 (Proposed Conditions)** – the existing conditions with the proposed temporary levees for the Project and the MWD and ROM Dam embankments.

9.1.3 Design flood extents, depths and levels

Appendix D provides the results of the flood modelling for the Isaac River 5% AEP to PMF peak flood extents, depths and levels in the vicinity of the Project for both Scenario 1 (Existing Conditions) and Scenario 2 (Proposed Conditions).

The flood maps in Appendix D show that the proposed temporary levees for the Project would not interact with peak water levels up to and including 5% AEP design event. Flood impacts would only occur for the 1% AEP event and higher.

Figure 9.1 and Figure 9.2 show the 1% and 0.1% AEP peak flood level differences comparing Scenario 1 and 2. The flood modelling results show the following:

- For the 1% AEP event,
  - Peak flood levels do not interact with the proposed flood protection levee between reporting location A1 to A2. Peak flood levels at reporting location A3 were decreased by 0.06 m;
  - Peak flood levels do not interact with the proposed flood protection levee between reporting location B1 to B3.
- For the 0.1% AEP event,
  - Peak flood levels at reporting locations A1 to A2 increase by up to 0.46 m (at point A1) and decrease by 0.17 m (at point A3) due to the proposed flood protection levee; and
  - Peak flood levels at reporting locations B1 to B3 decrease by around to 0.04 m due to the proposed flood protection levee.

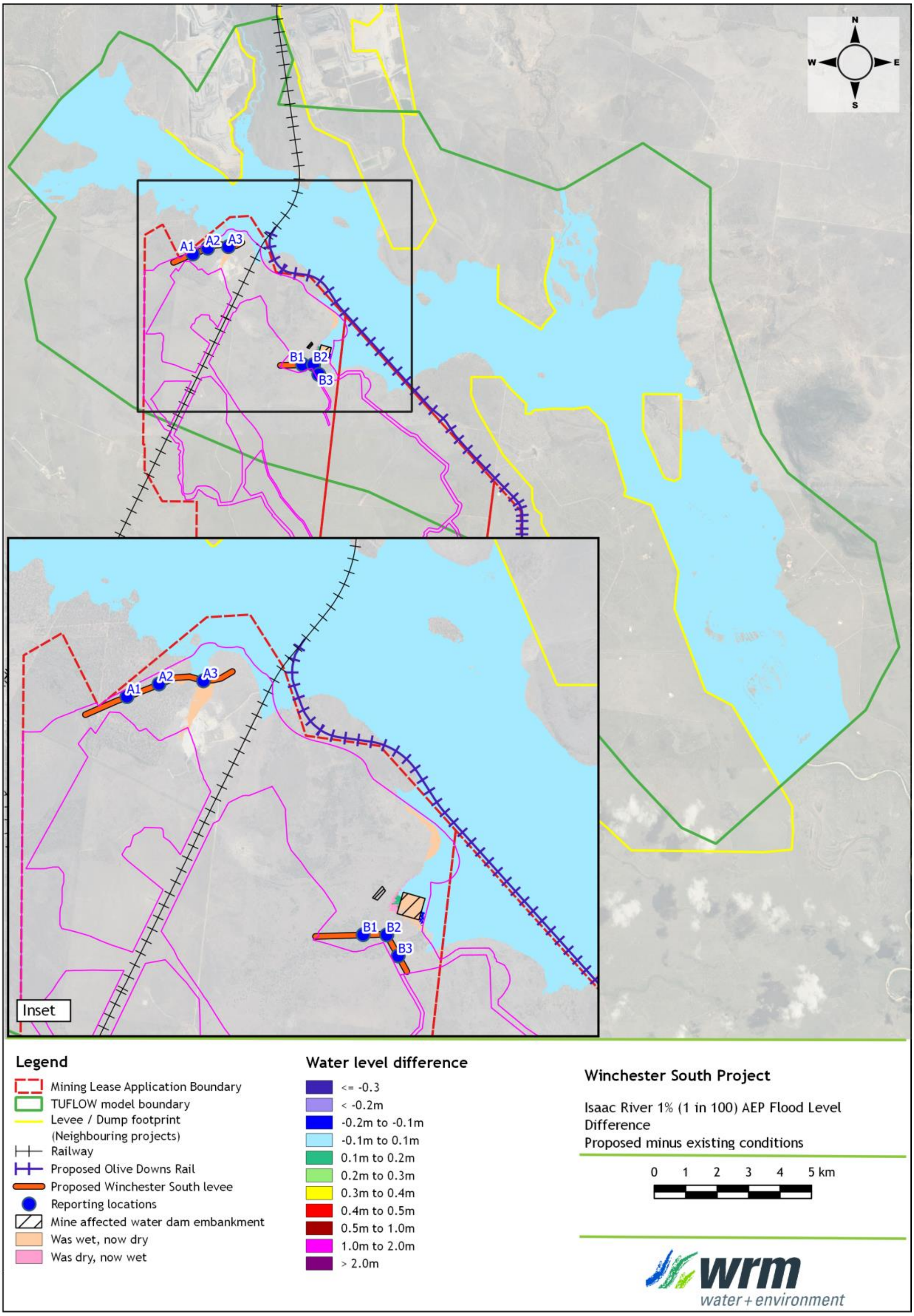


Figure 9.1 – 1% AEP change in peak water level, proposed minus existing conditions

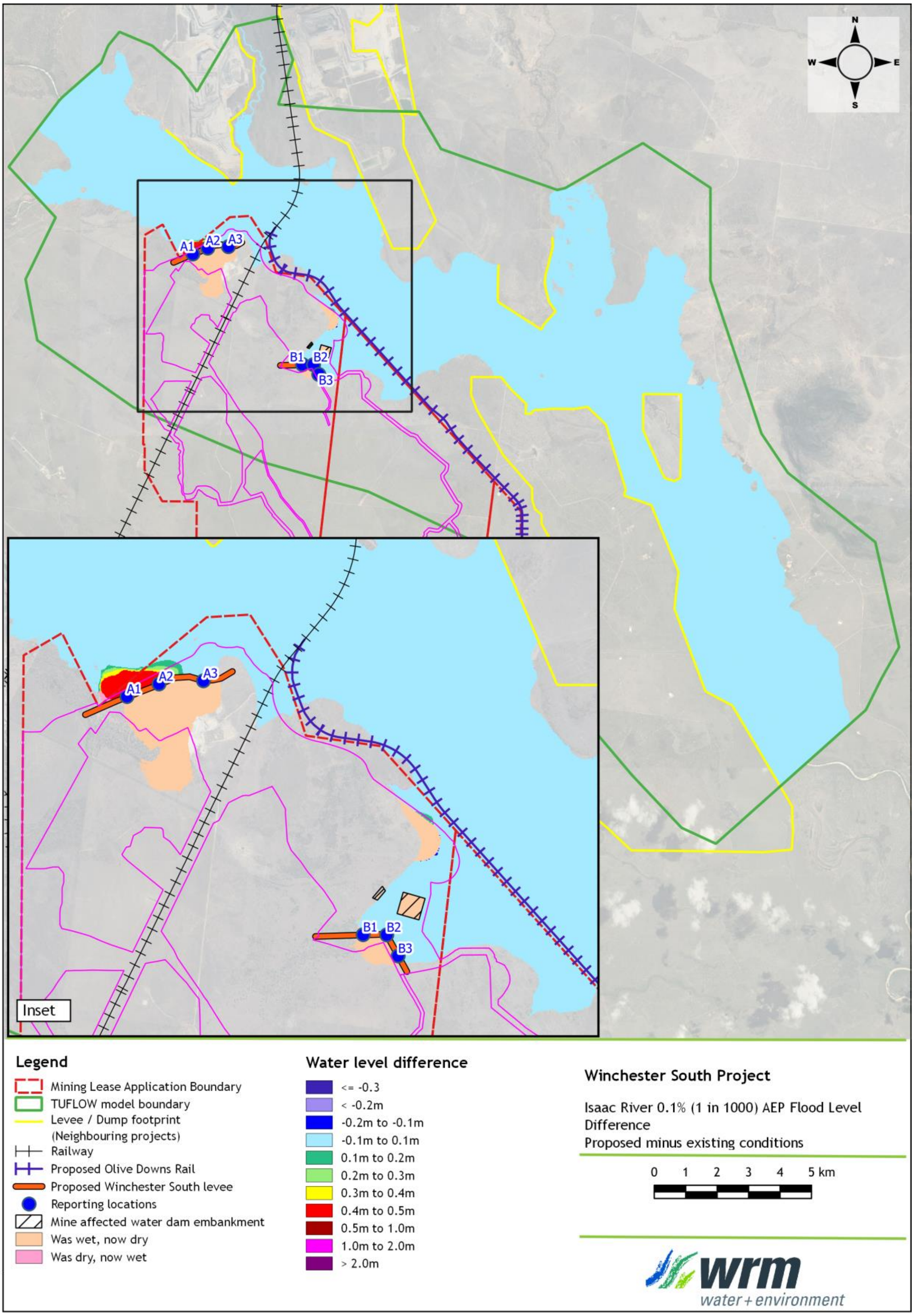


Figure 9.2 – 0.1% AEP change in peak water level, proposed minus existing conditions

9.1.4 Design velocities

Appendix D provides the results of the flood modelling including the Isaac River 5% AEP to PMF peak flood velocities in the vicinity of the Project for Scenario 1 (Existing Conditions) and Scenario 2 (Proposed Conditions).

The flood maps in Appendix D show that the proposed temporary levees would not interact with flood velocities up to and including 5% AEP design event. Flood impacts would only occur for the 1% AEP event and higher.

Figure 9.3 and Figure 9.4 show the 1% and 0.1% AEP peak flood velocity differences comparing Scenario 1 and 2. The flood modelling results show the following:

- For the 1% AEP event:
  - Peak flood levels do not interact with the proposed flood protection levee between reporting location A1 to A2. Peak flood velocities at reporting location A3 were decreased by 0.12 m/s; and
  - Peak flood levels do not interact with the proposed flood protection levee between reporting location B1 to B3.
- For the 0.1% AEP event:
  - Peak flood levels at reporting locations A1 to A3 increase by up to 0.14 m/s (at point A2) and decrease by 0.12 m/s (at point A3) due to the proposed flood protection levee; and
  - Peak flood levels at reporting locations B1 to B3 fluctuate by about 0.05 m/s due to the proposed flood protection levee.

9.1.5 Flood protection levee assessment

The proposed temporary levees on Isaac River would be regulated structures designed with a crest level above the 0.1% AEP design event plus freeboard.

The model results show that the proposed temporary levee alignments and extents would prevent the inundation of the open cut pits throughout the life of the Project to the required design standard. The changes to the flood regime (i.e. levels) due to the Project are largely limited within the mining lease application area, with a minor excursion (360 m) to the north of the northern temporary levee. As there would be no changes to flood levels or velocity at any key infrastructure (e.g. residences, roads, rail), the Project would not result in any flooding impacts to key infrastructure.

Detailed design plans of the proposed temporary levees together with a consequence assessment and certification by a suitably qualified and experienced person(s) would be prepared prior to construction of the temporary levees for assessment and approval by the administering authority in accordance with proposed EA conditions.

During the detailed design phase, the model results would be used to identify potential locations of high flow velocity and scour potential. This information would be used to inform the appropriate level of scour protection along the proposed temporary levees.

9.1.6 MWD and CC Dam embankment assessment

The proposed MWD and CC Dam embankments would be designed with a crest level above the 0.1% AEP design event plus freeboard. The model results demonstrate that the MWD and CC Dam embankment would not be inundated by Isaac River floodwater for all events up to and including the 0.1% AEP design event.

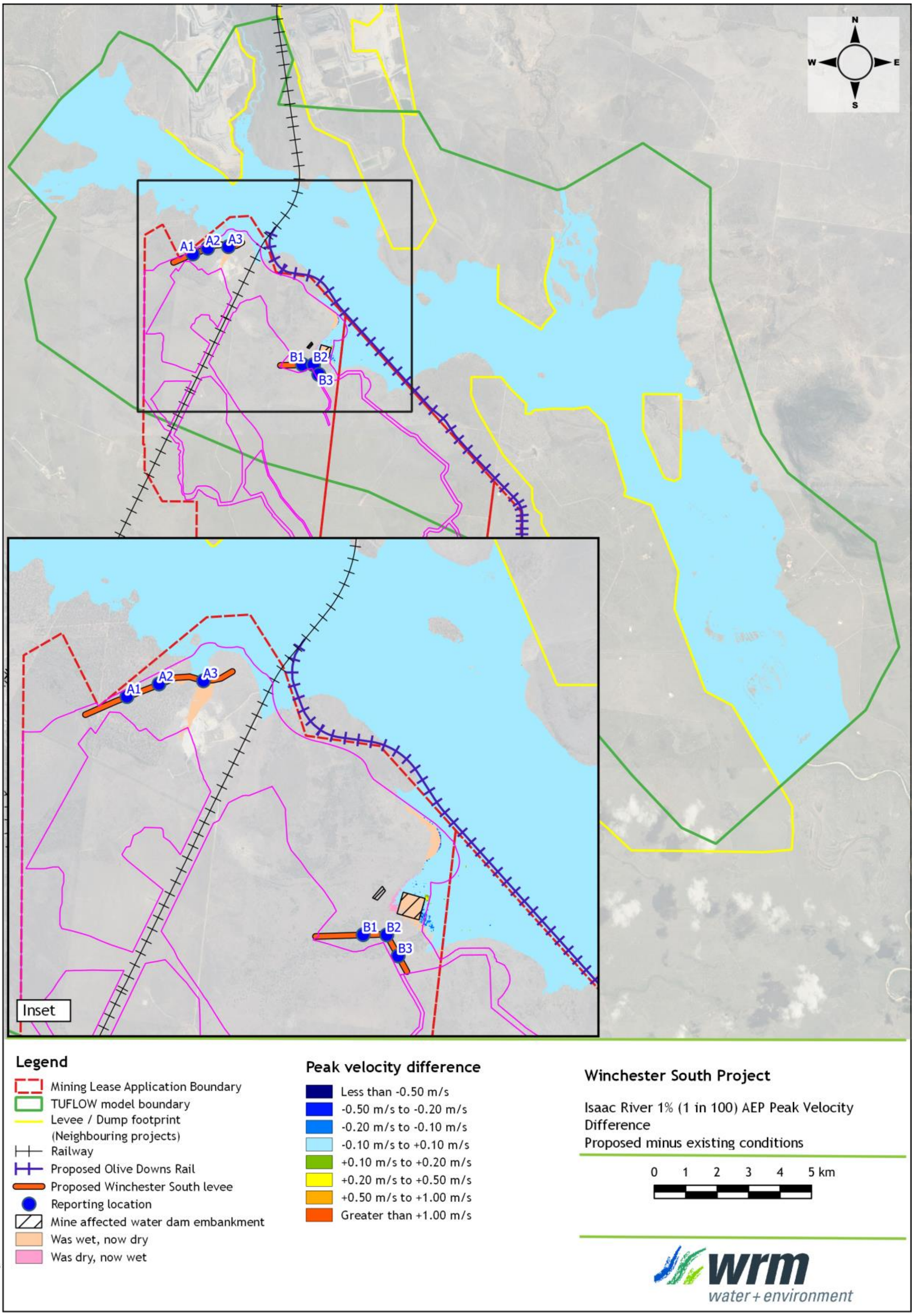


Figure 9.3 – 1% AEP change in peak velocity, proposed minus existing conditions

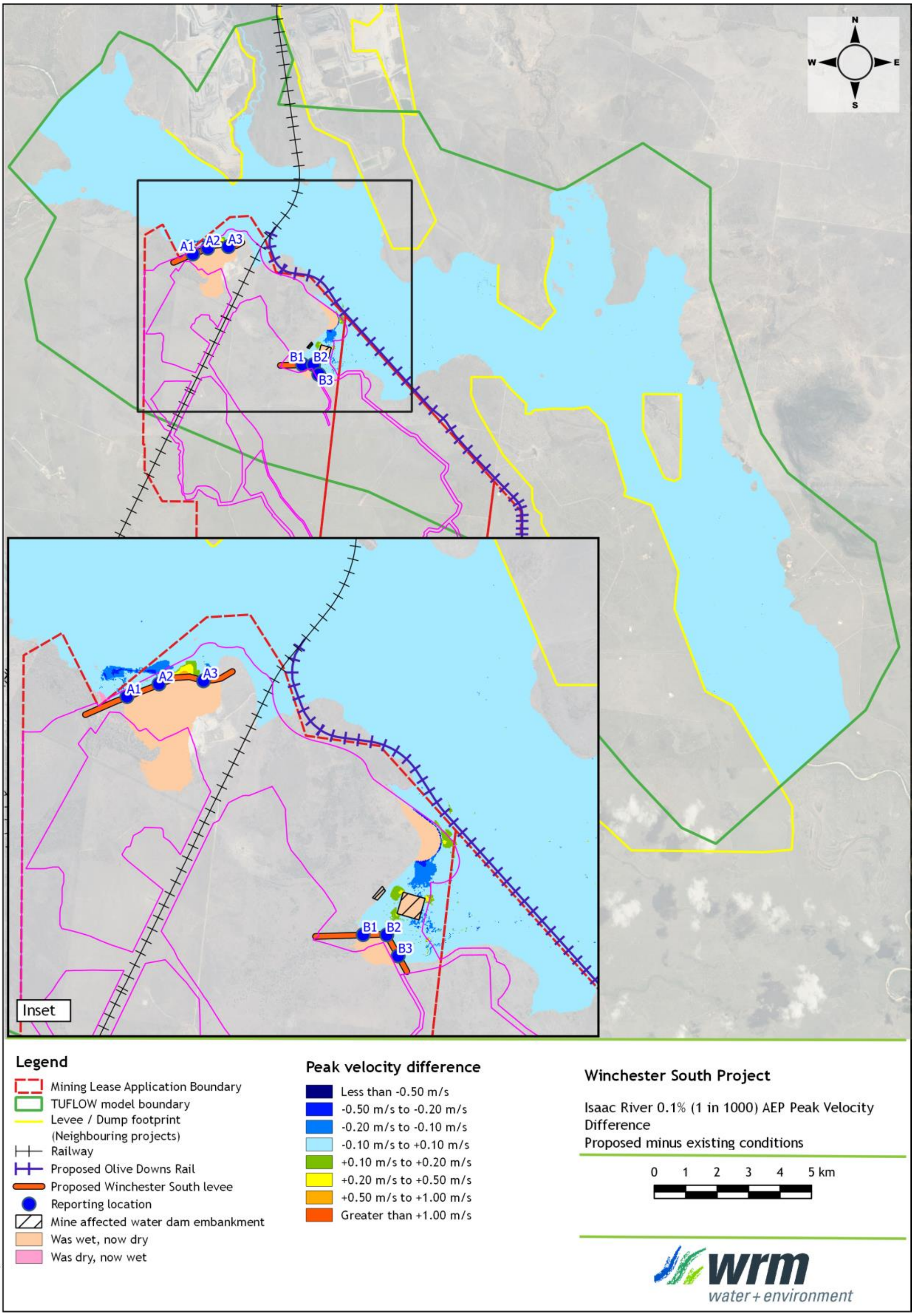


Figure 9.4 – 0.1% AEP change in peak velocity, proposed minus existing conditions

9.1.7 Climate change assessment

9.1.7.1 Overview

The impact of climate change on design discharges was assessed for the 0.1% AEP event. In accordance with AR&R 2019 guidelines (Ball *et al.*, 2019), the design rainfall in the XPRafts model was increased by 12%. This was based on a 30 year planning horizon and a high Representative Concentration Pathway producing an estimated temperature increase of between 1.5 and 3.0 degrees Celsius. For the climate change case, the 0.1% AEP XPRafts design peak discharge at Isaac River at Deverill gauge increases by 16% compared to the current climate case.

9.1.7.2 Impact of climate change on design flood levels

The Isaac River TUFLOW model was run for the 0.1% AEP with climate change event using the XPRafts design discharges. Figure 9.5 shows the impact on Isaac River 0.1% AEP climate change peak flood level differences comparing Scenario 1 and 2. The flood modelling results show that the impact of the Project for will not be significantly different under the climate change scenario, when compared to the current climate scenario.

9.2 POST-MINING ISAAC RIVER

The temporary flood levees for protection from the Isaac River floodplain would be removed (subject to confirmation prior to cessation of mining operations) and returned to pre-mining conditions as part of the final landform. Therefore, these structures have been removed from the post-mining conditions TUFLOW model.

The potential impacts as a result of the post-mining conditions landform configuration are generally minimal and would not greatly affect the natural channel morphology of Isaac River for events up to the 1% AEP. During extreme events, such as the 0.1% AEP, impacts on the floodplain as a result of the landform configuration are minor and generally confined to within the Project area.

The post-mining conditions peak flood levels and velocities have been compared to the Existing conditions predicted peak flood levels and velocities. Figure 9.6 and Figure 9.7 show the 1% and 0.1% AEP peak flood level differences comparing Post-mining condition to existing conditions. Figure 9.8 and Figure 9.9 show the 1% and 0.1% AEP peak flood velocity differences comparing post-mining condition to existing conditions.

Figure D.19 to Figure D.22 in Appendix D provide the depth of flooding and peak velocities in Isaac River under post-mining Conditions for the 1% AEP and 0.1% AEP flood events.

For the 1% AEP event, the Isaac River has minimal interaction with the final landform.

For the 0.1% AEP event:

- Peak velocities and water levels along Isaac River and overbank flooding areas in the vicinity of the Project area are similar to existing conditions with some minor localised changes. These impacts dissipate well before reaching the Olive Downs Project area and are not expected to have any cumulative impact on flood flows in Isaac River.
- The peak velocity along the interface between the flood extent and the final landform is generally less than 0.3 m/s.
- The Isaac River 0.1% AEP inundation extent lies outside of the residual voids.

Figure D.23 to Figure D.26 in Appendix D provide the depth of flooding and peak velocities in Isaac River, as well as impact mapping, under post-mining Conditions for the PMF flood event. The Isaac River PMF event inundation extent lies outside of the residual voids.

The modelling results demonstrate the residual voids would not be inundated in the post-mining phase. While the peak flood velocities are not considered excessive, appropriate scour protection measures would be considered as part of the final landform detailed design process.

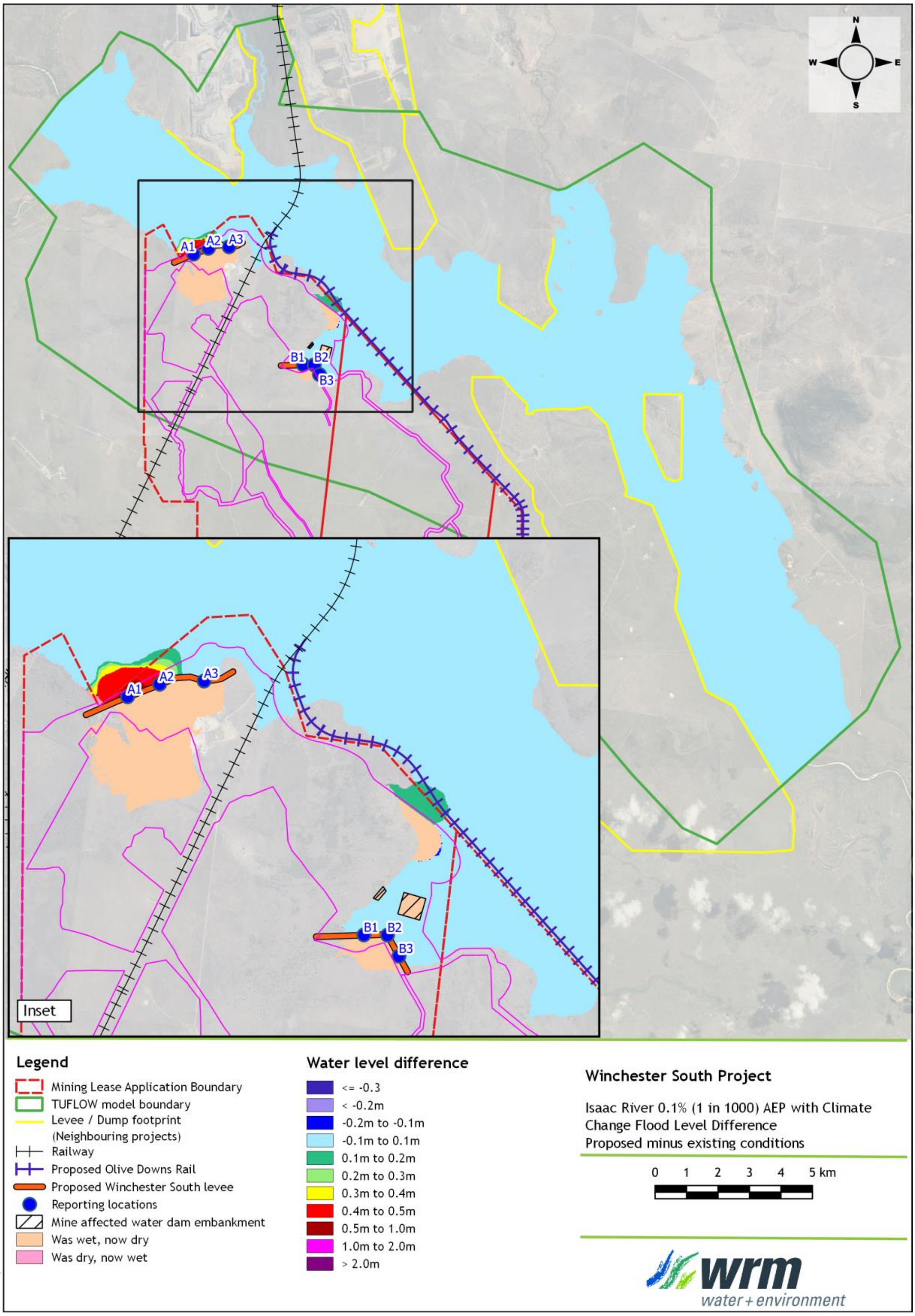


Figure 9.5 – 0.1% AEP change in peak water level due climate change scenario, proposed minus existing conditions

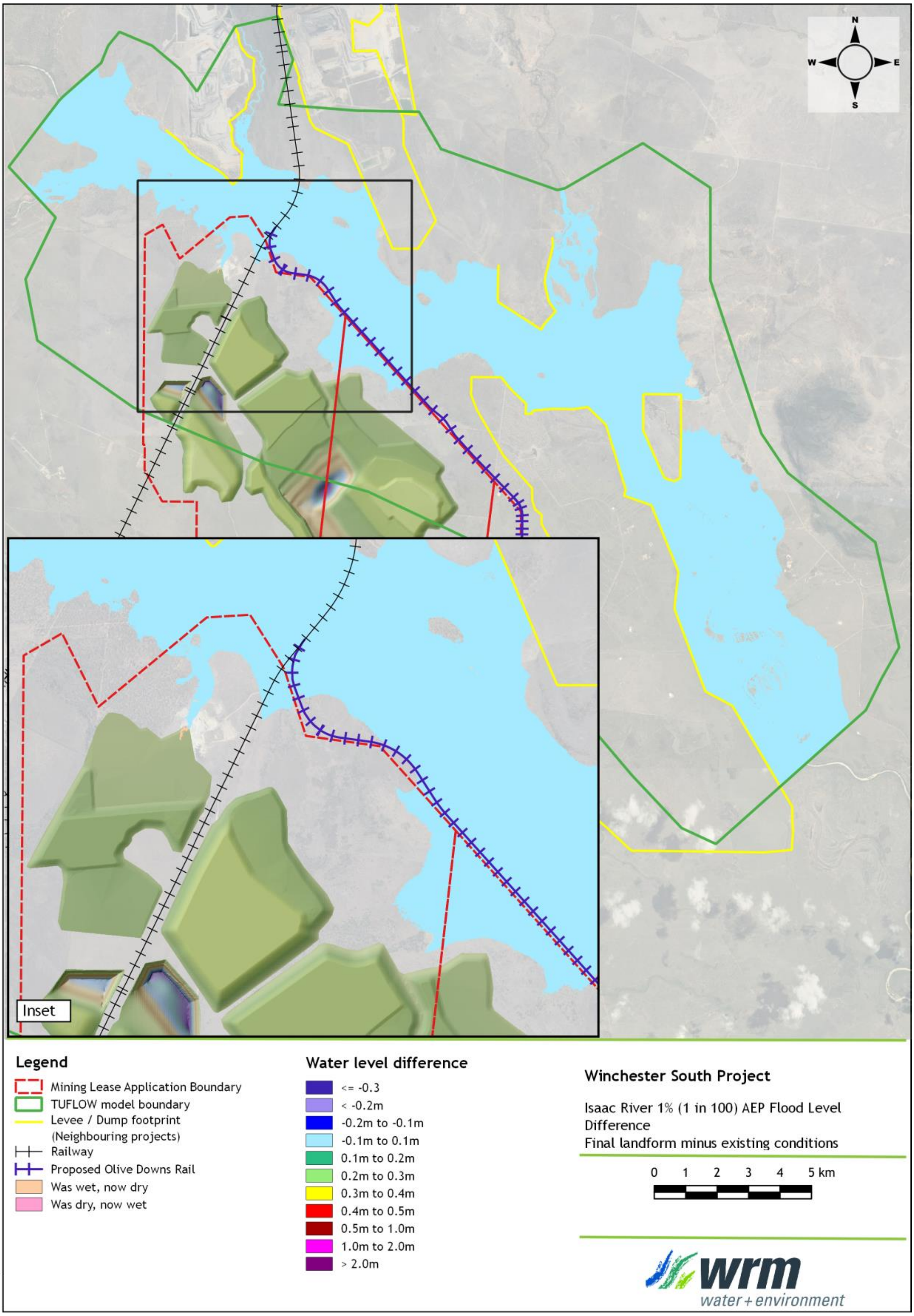


Figure 9.6 – 1% AEP change in peak water level, post-mining minus existing conditions

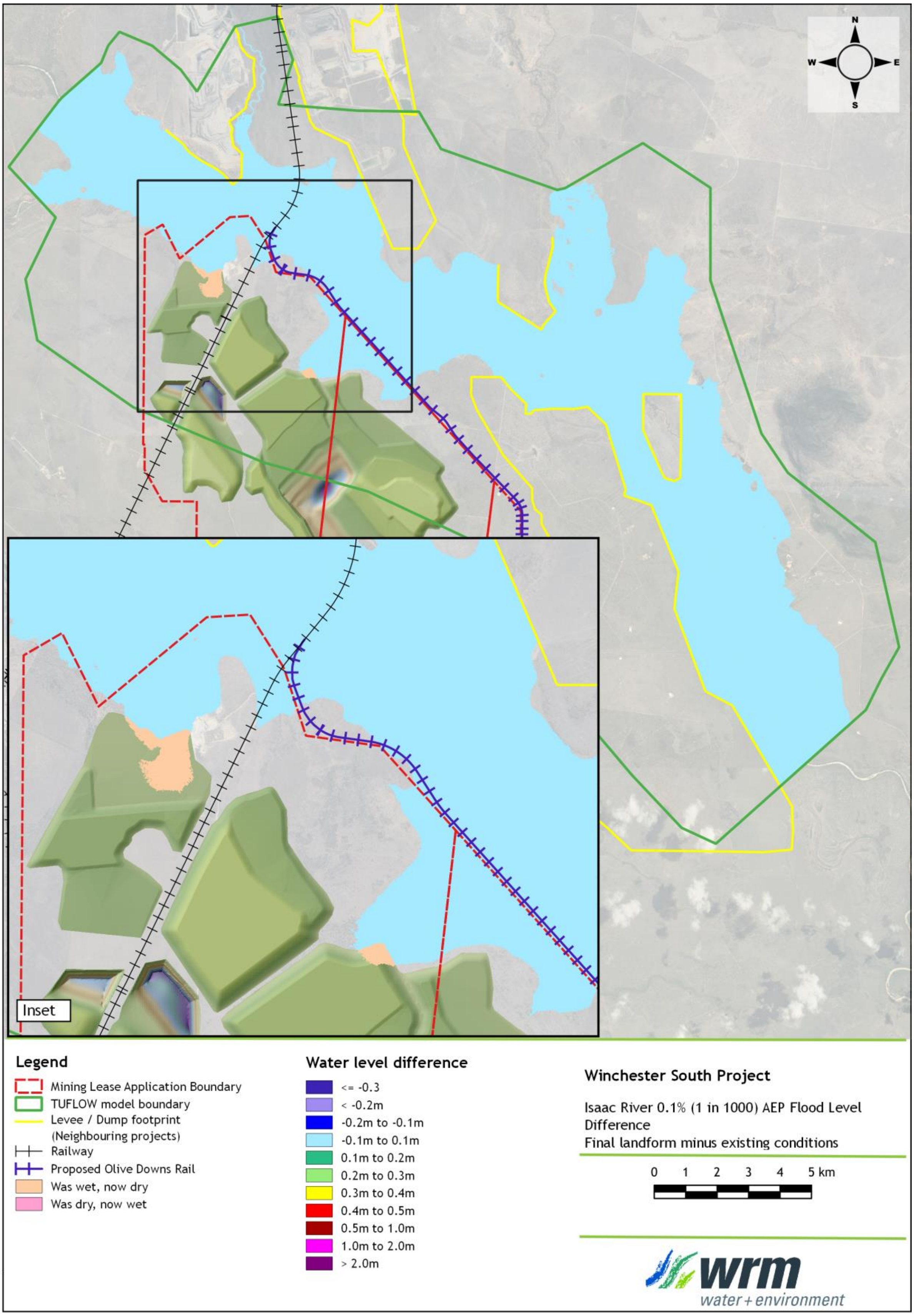


Figure 9.7 – 0.1% AEP change in peak water level, post-mining minus existing conditions

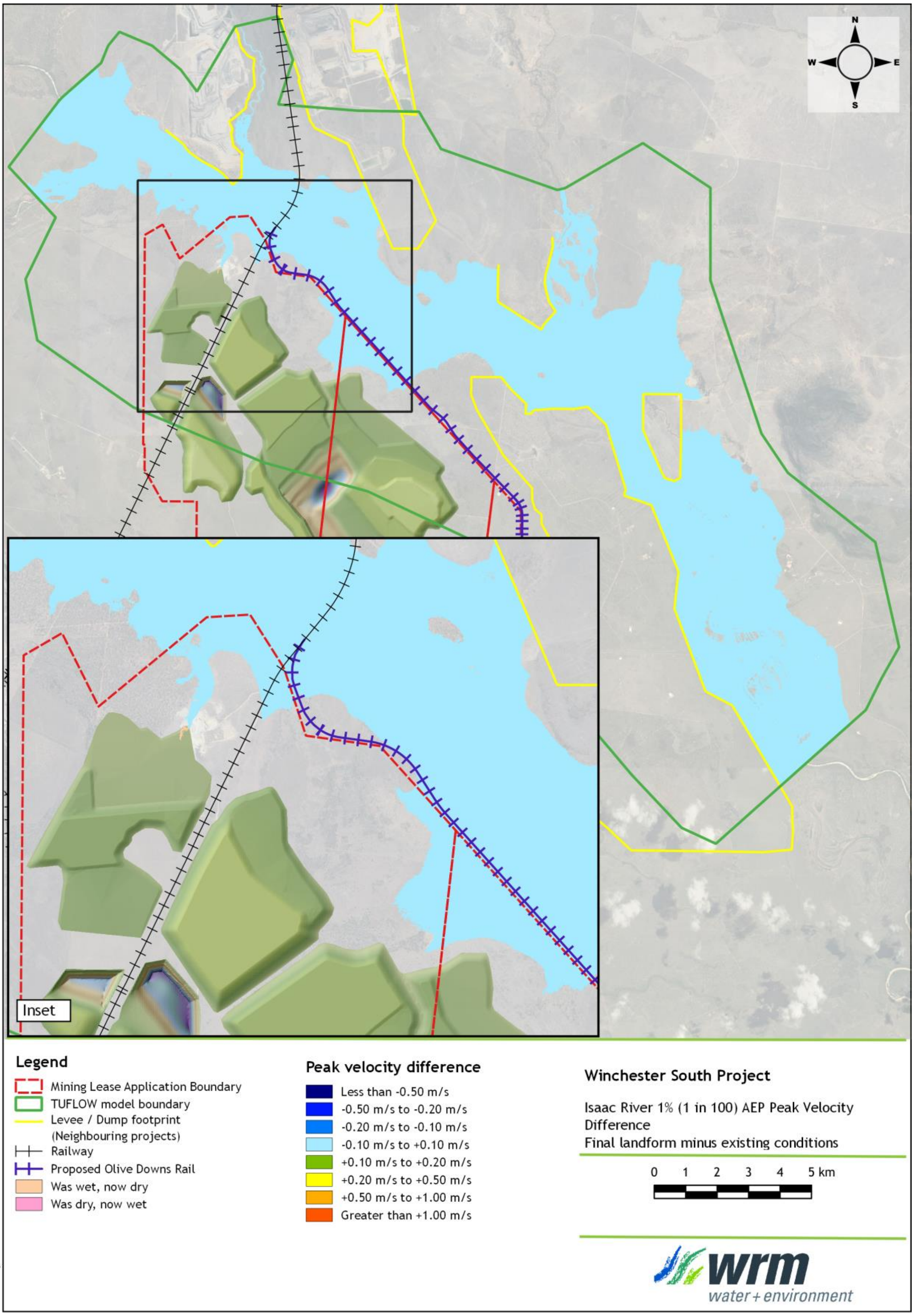


Figure 9.8 – 1% AEP change in peak velocity, post-mining minus existing conditions

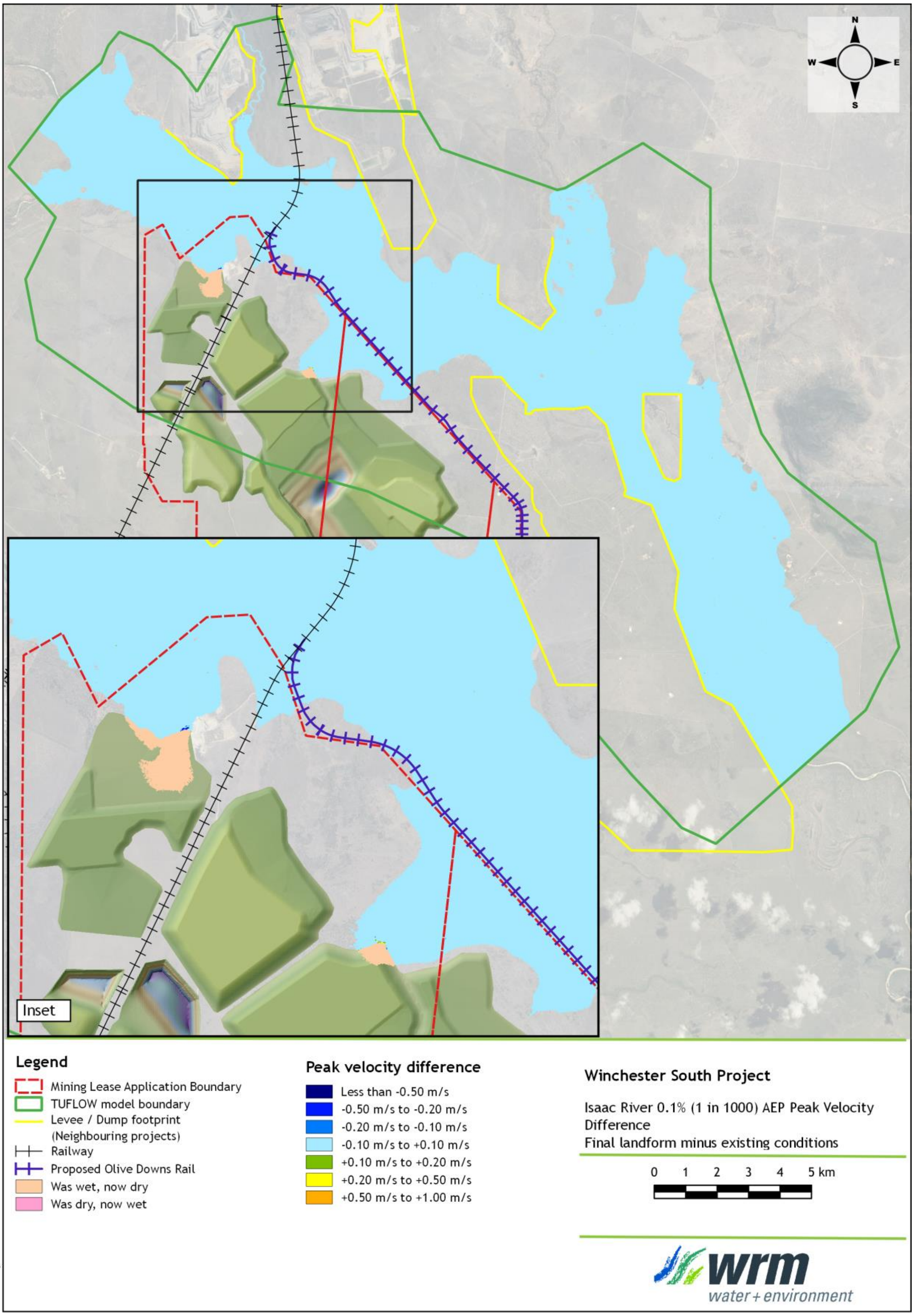


Figure 9.9 – 0.1% AEP change in peak velocity, post-mining minus existing conditions

9.3 DESIGN FLOOD LEVELS IN RIPSTONE CREEK

9.3.1 Overview

The Ripstone Creek hydraulic model described in Appendix C was used to estimate design peak flood levels, depths, extents and velocities along Ripstone Creek and its tributaries for the 0.1% AEP design event. For the 0.1% AEP, ten temporal patterns were adopted from Jordan *et al*. (2005).

Table 9.2 shows the design discharges for Ripstone Creek for the 0.1% AEP events estimated using the calibrated hydrological model described in Appendix C. Design peak discharges were estimated using the XPRafts model, based on design rainfalls and ARFs obtained for the centroid of the Ripstone Creek catchment to Isaac River, and the validated design rainfall losses given in Table C.11.

Table 9.2 – XPRafts design discharges, Ripstone Creek

Key location	Event	XPRafts adopted design peak discharge (m^3/s)	Critical storm duration (hours)	Temporal pattern
Ripstone Creek at RC31	0.1%	695	6	-[1]

[1] Temporal pattern adopted based on Jordan et al. (2005).

9.3.2 Impact assessment

The Project is located to the north of Ripstone Creek and is in the vicinity of the approved Olive Downs Project. The approximate locations of flood protection levees and waste emplacement footprints of these approved mining projects are shown in Figure C.14. The Olive Downs Project would interact with the Ripstone Creek design flood levels. Therefore, the Olive Downs Project footprint has be included in the Ripstone Creek flood model. There is an approved diversion of Ripstone Creek for the Olive Downs Project that is outside the extent of the TUFLOW model (i.e. to the south), however it is not expected to materially impact on the flood model results.

Based on the existing conditions model runs, the Ripstone Creek 0.1% AEP peak flood extent would not interact with the Project (Figure 9.10). Therefore, the Project would have no impacts on the Ripstone Creek floodplain.

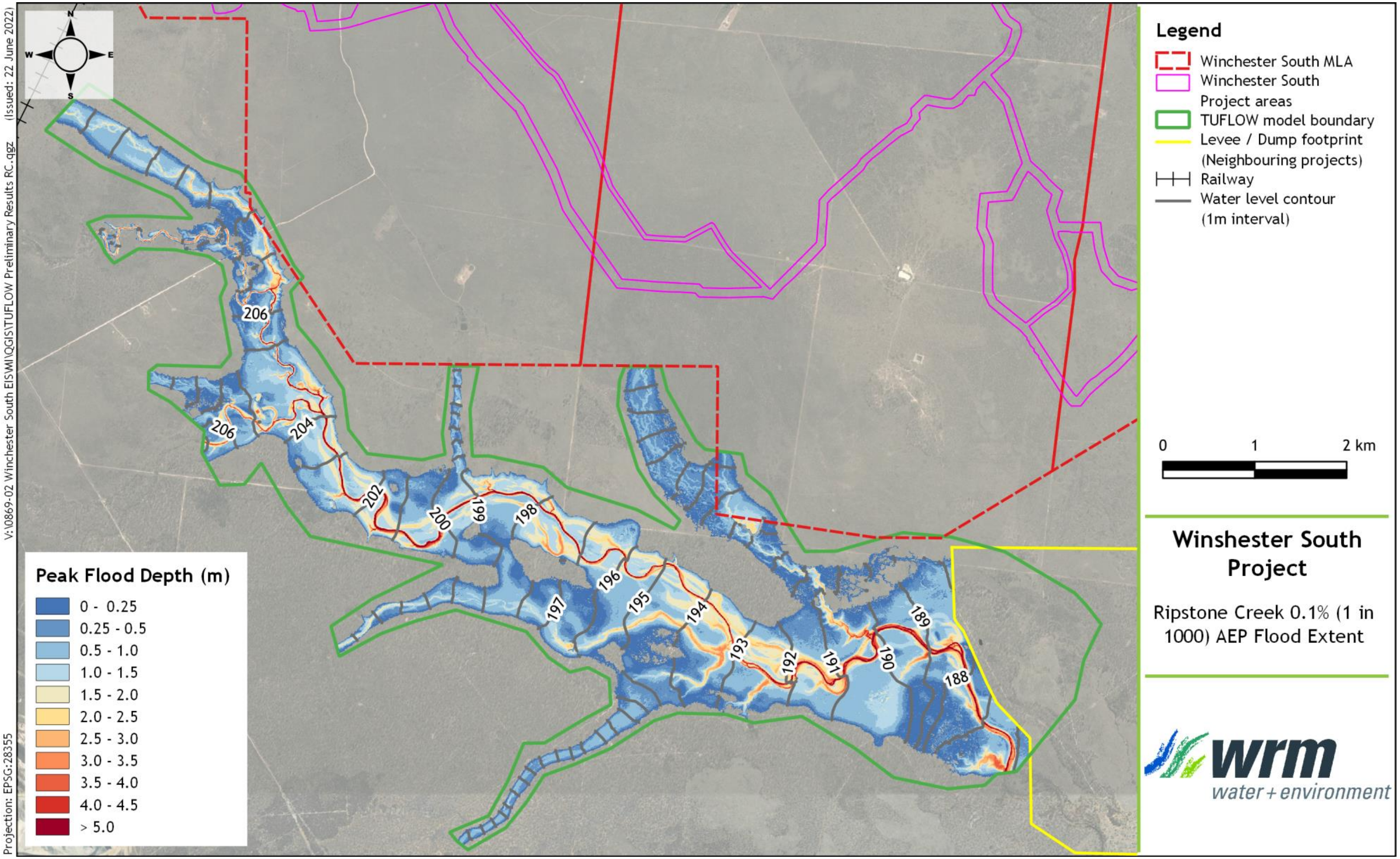


Figure 9.10 – 0.1% AEP peak water level, existing conditions

10 Assessment of impacts, and mitigation and management measures

10.1 POTENTIAL IMPACTS

The potential impacts of the Project on surface water quality and resource include:

- impacts on flows and the flooding regime in the Isaac River and Ripstone Creek;
- impacts on regional water availability due to the need to obtain water from external sources to meet operational water requirements of mining operations;
- impacts on stream flows due to catchment area excision;
- adverse impacts on the surface water quality of on local and regional water quality;
- adverse impacts on EVs in the Isaac River and Ripstone Creek; and
- cumulative impacts of all projects in the region on the EVs 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 and was previously peer reviewed and deemed to be appropriate for EIS-level assessment. Certain aspects of the Project, such as changes to landforms due to construction of waste rock emplacements, would create changes to the environment that are permanent, although this does not mean that any such change would necessarily be detrimental to the EVs of surface water resources.

10.2 FLOODING IMPACTS – ISAAC RIVER AND RIPSTONE CREEK

Potential impacts of the Project on flood levels and flood velocities in the Isaac River and Ripstone Creek are addressed in Section 9 of this report.

There are no significant impacts on flood levels and velocities in the Isaac River channel and floodplain during operations and post-mining. The Project would only interact with the Isaac River for the rarer flood event (1% AEP and rarer design events). The impacts identified on the Isaac River floodplain for these rare events are generally localised and relatively small in magnitude.

There are no impacts on flood levels and velocities in Ripstone Creek, as the Project is located well outside of the Ripstone Creek floodplain.

10.3 REGIONAL WATER AVAILABILITY IMPACTS

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

The water balance modelling results indicate that between 366 ML/year and 2,950 ML/year would be required from an external raw water supply, under median climatic conditions.

Whitehaven WS would source water from either an external water supplier (e.g. Sunwater) via a water supply pipeline or via water sharing with surrounding mining operations. Therefore, it is not expected that there would be any impacts to the availability of water resources from the Isaac River or regional water availability due to the Project.

10.4 STREAM FLOW IMPACTS

10.4.1 During active mining operations

During mining operations, the water management system would capture runoff from areas that would have previously flowed to the receiving waters of the Isaac River and Ripstone Creek. The captured catchment area would change as the mine develops. A breakdown of the catchment areas reporting to the whole of mine water management system is provided in Table 10.1. Note that areas managed under the ESCP have been included in the total captured catchment area.

The total catchment areas of the Isaac River and Ripstone Creek immediately downstream their confluence are approximately 5,166 km^2 and 286 km^2, respectively. The maximum catchment areas excised by the Project represent:

- Between 0.2% and 1.0% of the Isaac River catchment (to the Isaac River and Ripstone Creek confluence).
- Up to 4.5% of the Ripstone Creek catchment.

Table 10.1 – Catchment area captured with the water management system during operations

Receiving waters	Total catchment area (km^2)	Captured catchment area (km^2)					
		Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
Isaac River	5,166	9	31	37	40	53	46
Ripstone Creek	286	-	-	3	7	8	13

Given that areas managed under the ESCP would drain from the site, and the sediment dam catchments typically have higher runoff coefficients than under natural conditions, the loss of stream flows would likely be less than the total loss of catchment area (proportionally).

On this basis, the loss of catchment flows in the Isaac River and Ripstone Creek would be indiscernible. Therefore, the potential impact on water quantity in the Isaac River and Ripstone Creek due to the excision of catchment is considered negligible.

The final design and location of the clean water management system would be finalised during detailed design of the Project and implemented in consideration of operational constraints. The clean water management system would be designed to meet the objectives and principles of the water management system described in Section 5. Where clean water is captured within disturbed areas of the Project, it would be managed as part of the mine water management system or sediment water management system, as appropriate.

10.4.2 Post-mining landform

At the completion of mining, permanent drainage of waste rock emplacement areas would be installed to minimise capture of surface runoff into the residual voids in general accordance with the indicative configuration shown in Figure 8.1. The majority of the disturbed area would be rehabilitated and allowed to drain back to the Isaac River and Ripstone Creek. A residual area of approximately 13.7 km^2 would continue to drain to the residual 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 final landform would have the following impacts on catchment area:

- The catchment draining to the Isaac River (to the Isaac River/Ripstone Creek confluence) would reduce by around 13.7 km^2 (compared to pre-mining conditions), a decrease of less than 0.3%.
- The catchment draining to Ripstone Creek would reduce by around 4.3 km^2 (compared to pre-mining conditions), a decrease of around 1.5%.
- The loss of catchment flows in the Isaac River and Ripstone Creek would be indiscernible, and as such the potential impact on water quantity in Isaac River and Ripstone Creek due to the final landform is considered negligible.

It should be noted that the number and size of the residual voids has been minimised as part of the Project design.

Table 10.2 – Post-mining final landform - captured catchment area

Receiving waters	Pre-mining waterway catchment area (km^2)	Post-mining Draft EIS Final Landform Captured Catchment Area (km^2)	Post-mining Optimised Final Landform Captured Catchment Area (km^2)	Post-mining waterway catchment area (km^2)
Isaac River	5,166	14.3	13.7	5,152
Ripstone Creek	286	7.5	4.3	282

It should be noted that due to the revised mine planning (e.g. backfilling of the South Pit Void), the catchment excision from the Isaac River and Ripstone Creek associated with the optimised final landform for the Project has been reduced by 0.6 km^2 and 3.2 km^2, respectively, in comparison to the final landform proposed for the Draft EIS.

The Geomorphology Assessment (Fluvial Systems, 2020) prepared for the Project (Appendix F) concludes that the predicted overall geomorphic impact of the Project would be relatively minor. The Project would have negligible impact on the Isaac River; it would reduce the length of some small First and Second Order drainage features, but these would be reinstated to some extent in the post-mining landform. Thus, the regional cumulative impacts of the Project on geomorphic characteristics of streams would be negligible (Fluvial Systems, 2020).

10.5 REGIONAL WATER QUALITY AND ENVIRONMENTAL VALUES

10.5.1 Overview

Section 5 describes the objectives and principles of the water management system, which have been developed to protect water quality and the EVs of the waterways potentially affected by the Project.

The general principles of the water management system, are as follows:

- A clean water management system that separates clean water from mine-affected and sediment water wherever possible. Descriptions of the proposed diversions and temporary levee infrastructure (i.e. locations) are provided in Sections 5.6 and 9.1.5.
- A sediment water management system that contains sediment-laden runoff within sediment dams. Water collected in the sediment dams would be managed in accordance with the ESCP and used for dust suppression or would overflow to receiving watercourses after a period of settling when rainfall exceeds the design standard. Details of the on-site water management system are provided in Section 5.7.
- A mine-affected water management system that contains potentially saline runoff from the pit and infrastructure areas (including ROM and product coal stockpiles) in mine-affected water dams. Mine-affected water would be used as a priority in meeting makeup demand in the CHPP and for dust suppression. Water from the mine-affected water management system may only be released to the downstream environment in compliance with the proposed EA discharge conditions. Details of the proposed mine-affected water management system and its expected performance are provided in Section 7.
- A contaminated water management system that collects and contains all potentially contaminated water on-site. This water would be recycled for use on-site without releasing it to the receiving environment (Section 5.11).

10.5.2 Performance of the water management system

10.5.2.1 Mine-affected water

An assessment of the proposed water management system is given in Section 7. The results of the water balance modelling indicate that, under the current model assumptions and configuration, there is less than a 1% annual probability 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 very 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

During operations, progressive rehabilitation of the out-of-pit waste rock emplacements would minimise the potential generation of sediment. An ESCP would be developed and implemented throughout construction and operation of the Project. A 'best practice' approach would be adopted that is consistent with the 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 would be intercepted and treated by sediment dams. In larger events that exceed the design standards, these dams would overflow following a period of settlement.

The Geochemistry Assessment (Terrenus, 2020) indicates that the runoff draining to the sediment dams should have low to moderate salinity. Overflows would only occur during significant rainfall events which would also generate large volumes of runoff from surrounding undisturbed catchments. Hence it is unlikely that sediment dam overflows would have a measurable impact on receiving water quality or EVs due to the dilution runoff.

The Geochemistry Assessment also included an assessment of the characteristics of the potential waste rock material. Terrenus (2020) concluded that some waste rock materials may be sodic with potential for dispersion and erosion (to varying degrees). If required, sedimentation and treatment within the sediment dams may be enhanced through flocculation prior to discharge. However, with the implementation of the proposed management and mitigation measures (e.g. feasible selective handling and design of landforms), the waste rock would pose a low risk of environmental harm.

Coal rejects from the CHPP would be co-disposed with waste rock and would be buried with by at least 10 m of waste rock. Reject material would be co-disposed in locations such that any runoff or infiltration would report to the Project water management system for mine water. Therefore, when placed amongst waste rock the overall risk of environmental harm and health-risk that emplaced coal reject poses is low (Terrenus, 2020).

Water quality in these dams would be monitored regularly to monitor for potential contaminants reporting to the sediment dams.

To minimise the potential impact on downstream Isaac River salinity from sediment dam overflows, the following management and mitigation measures are proposed for sediment dams that are at risk of overflowing:

- If the Isaac River flow is less than 50 ML/d and/or the salinity within a sediment dam is greater than 2,000 µs/cm:
    - Pump back the sediment dam to the water management system; or
    - Treat the sediment dam water through flocculation prior to discharge.

With the implementation of this mitigation strategy, the potential impact of sediment dam discharges on the Isaac River salinity would be negligible. Given this, a cumulative impact assessment including sediment water releases from other mining operations in the upper Isaac River catchment is not warranted.

10.5.2.3 Controlled releases

An assessment of the dilution ratio of controlled releases to the 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 7.7 shows a ranked plot of the minimum modelled daily dilution ratio on controlled release days, for all realisations. The results show that the minimum modelled dilution ratio that occurred from all release categories throughout all realisations is 407. Figure 7.8 shows a ranked plot of modelled Isaac River salinity during controlled release days, demonstrating that the mixed Isaac River salinity is well below the proposed receiving water salinity limits (2,000 µS/cm) and below the high flow WQO (250 µS/cm on all controlled release days).

This outcome indicates that controlled releases would have a negligible impact on Isaac River water quality. Given this, a cumulative impact assessment including potential releases from other mining operations in the upper Isaac River catchment is not warranted.

The potential impacts of the proposed controlled releases on the downstream tributaries were assessed in the Geomorphology Technical Study (Fluvial Systems, 2020) for the Draft EIS. The Geomorphology Technical Study was prepared by Dr Christopher Gippel and included a comprehensive review of the geomorphology of the tributaries downstream of the proposed controlled discharge points.

The Geomorphology Technical Study for the Draft EIS described the proposed monitoring and management strategy for the tributaries, which would be undertaken using objective, scientifically sound methods, following a BACI (Before/After/Control/Intervention) design. Visual inspections would be undertaken following each controlled release event. A topographic survey (using LiDAR) would be undertaken if either of the following are observed:

- a channel exceeding 0.2 m deep for a length of 10 m or more; or
- initiation of a knickpoint higher than 0.3 m.

Appropriate mitigation measures would be applied in response to any observed geomorphic impacts. The appropriate mitigation would be assessed at the time and would range from doing nothing (self-sealing), to assisted recovery (e.g. plant vegetation and soft engineering such as coir matting and stakes), to hard engineering (e.g. rock rip-rap) (Fluvial Systems, 2020).

10.6 CUMULATIVE IMPACTS – SURFACE WATER

10.6.1 Overview

The objective of a cumulative impact assessment is to identify the potential for impacts from the Project that may have compounding interactions with similar impacts from other projects within a suitable region of influence of the Project. The cumulative impact assessment considers projects that are proposed, under development or already in operation.

There are two levels at which cumulative impacts may be relevant for surface water:

- *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 an additive effect on the receiving environment. This assessment has considered all existing and proposed projects located adjacent to or upstream of the Project within the upper 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.

10.6.2 Relevant projects

10.6.2.1 Existing projects

Projects that are currently operating within the Isaac River catchment upstream or adjacent to the Project have been included in the localised cumulative impact assessment for the Project and are listed in Table 10.3.

10.6.2.2 New or developing projects

Relevant projects that have been considered include:

- Projects within the predicted area of influence of the Project, as listed on the Department of State Development, Infrastructure and Planning (DSDIP) website that are undergoing assessment under the SDPWO Act for which an Initial Advice Statement (IAS) or an EIS are available;
- Projects within the predicted area of influence of the Project, which are listed on the website of the DES that are undergoing assessment under the EP Act for which an IAS or an EIS are available; and
- Projects within the predicted area 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* 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 EAs.
- In some cases, discharge limits and operating conditions of coal mines were not adequately protecting downstream EVs.

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 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.
- EAs 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.

Table 10.3 – Existing project considered in the localised cumulative impact assessment

Project	Proponent	Description	Operational status	Relationship to the Project area	
				Timing	Location
Burton Mine	Peabody Energy Australia (PEA)	Open cut coal mine	Ceased production	May have overlapping operational phases with the construction and operations of the Project, although unlikely given the current operational status.	60 km to the north-northwest of the Project area. Located within Isaac River catchment (upstream).
Moorvale Mine	PEA	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the Project.	17 km to the northeast of the Project area. Located within Isaac River catchment (upstream).
Eaglefield Mine	PEA	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the Project.	60 km to the northwest of the Project area. Located within Isaac River catchment (upstream).
North Goonyella Mine	PEA	Underground coal mine	Operating	May have overlapping operational phases with the construction and operations of the Project.	60 km to the northwest of the Project area. Located within Isaac River catchment (upstream).
Millennium Mine	PEA	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the Project.	12 km to the north-northwest of the Project area. Located within Isaac River catchment (upstream).
Goonyella Riverside Mine	BHP	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the Project.	47 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.	36 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.	30 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.	17 km to the north of the Project area. Located within Isaac River catchment (upstream).
Isaac Plains Complex	Stanmore Coal	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the Project.	23 km to the northwest of the Project area. Located within Isaac River catchment (upstream).
Poitrel Mine	BMA	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the Project.	6.5 km to the north 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.	5.7 km to the north of the Project area. Located within Isaac River catchment (upstream).
Caval Ridge Mine	BMA	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the Project.	10 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.	7 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.	13.5 km to the south of the Project area. Located within Isaac River catchment (adjacent).
Norwich Park Mine	BMA	Open cut coal mine	Ceased production	May have overlapping operational phases with the construction and operations of the Project, although unlikely given the current operational status.	42 km to the southeast of the Project area. Located within Isaac River catchment (downstream).
Lake Vermont Mine	Jellinbah Group	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the Project.	25 km to the south-southeast of the Project area. Located within Isaac River catchment (downstream).

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	South32	Underground coal mine	Construction on hold - site under care and maintenance	May have overlapping operational phases with the construction and operations of the Project.	2.6 km to the west of the Project area. Located within Isaac River catchment (upstream).
Red Hill Mining Project	BMA	Underground coal mine	Approved project (on hold)	May have overlapping operational phases with the construction and operations of the Project.	43 km to the north-northwest of the Project area. Located within Isaac River catchment.
Moorvale South Project	PEA	Open cut coal mine	Approved project	May have overlapping operational phases with the construction and operations of the Project	15 km to the northwest of the Project area. Located within Isaac River catchment.
Olive Downs Project	Pembroke	Open cut coal mine	Approved project	May have overlapping operational phases with the construction and operations of the Project	6 km to the northeast of the Project area. Located within Isaac River catchment.
Isaac Downs Project	Stanmore Coal	Open cut coal mine	EIS active	May have overlapping operational phases with the construction and operations of the Project	8.5 km to the northwest of the Project area. Located within Isaac River catchment.
New Lenton Coal Project	New Hope Corporation	Open cut coal mine	EIS lapsed	May have overlapping operational phases with the construction and operations of the Project	65 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	14.5 km to the south of the Project area. Located within Isaac River catchment.
Lake Vermont Meadowbrook Project	Jellinbah Group	Underground Coal Mine	EIS active	May have overlapping operational phases with the construction and operations of the Project	4 km to the south-east of the Project area. Located within Isaac River catchment.
Bowen Gas Project	Arrow Energy	CSG field and 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.
Ironbark No. 1 (Ellensfield)	Fitzroy Resources	Underground Coal Mine	Approved project	May have overlapping operational phases with the construction and operations of the Project	35 km to the north of the Project area.

With these measures in place, a strong and strategic 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 Project would be managed through a 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 WQOs in the EPP (Water).

A 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 6.11) have taken into consideration the conditions at the nearby mines.

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 9.0.
  - suspended solids range between 258 to 1,500 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.

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 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 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-affected water from the Project is expected to have negligible cumulative impact on surface water quality and associated environmental values.

In addition, the modelling results presented in Section 7.5.3 support the proposed controlled release strategy would have a negligible impact on downstream Isaac River water quality. Given this, a cumulative impact assessment including the other mining operations in the upper Isaac River catchment is not warranted.

Table 10.5 – Environmental Authority Release conditions at coal mines in the vicinity of the Project

Mine	EA	Location	Receiving water contaminant trigger levels	Mine affected water quality limits	Conditions relating to receiving waters
Isaac Plains Coal Mine	EPML00932713	Isaac River U/S of the Project area	• EC: 1,000 µS/cm • pH: 6.5 - 8.0 • Suspended Solids: TBD • Sulphate: 1,000 mg/L	• EC: 720-8,000 µS/cm • pH: 6.5 - 9.0 • Turbidity: No limit • Suspended Solids: No limit • Sulphate: 250-400 (flow dependant)	Releases allowed when minimum flow in the receiving water (Isaac River) is greater than 4 m^3/s
Millennium Coal Mine	EPML00819213	Isaac River U/S of the Project area	• EC: 1,000 µS/cm • pH: 6.5 - 8.0 • Suspended Solids: TBD • Sulphate: 1,000 mg/L	• EC: 1,400 µS/cm • pH: 6.5 - 9.0 • Turbidity: N/A • Suspended Solids: 258 mg/L • Sulphate: 1,000 mg/L	Release calculated as percentage of flow in receiving waters (1% in Isaac River and 20% in New Chum Creek)
Poitrel Coal Mine	EPML00963013	Isaac River U/S of the Project area	• EC: 1,000 µS/cm • pH: 6.5 - 8.0 • Turbidity: 750 NTU • Suspended Solids: TBD • Sulphate: 250 mg/L	• EC: 720-7,200 µS/cm • pH: 6.5 - 8.5 • Turbidity: 500 NTU • Suspended Solids: N/A • Sulphate: 250-1,000 mg/L	Releases allowed when minimum flow in the receiving water (Isaac River) is greater than 14 m^3/s
Daunia Coal Mine	EPML00561913	Isaac River U/S of the Project area	• EC: 864 µS/cm - cease release • pH: 6.5 - 8.5 • Sulphate: 1,000 mg/L	• EC: 5,000 µS/cm • pH: 6.5 - 9.0 • Sulphate: 1,000 mg/L	Releases allowed when minimum flow in the receiving water (Isaac River via New Chum Creek) is greater than 3 m^3/s
Caval Ridge Coal Mine	EPML00562013	Isaac River U/S of the Project area	• EC: 2,000 µS/cm • pH: 6.5 - 9.0 • Sulphate: 1,000 mg/L	• EC: 10,000 µS/cm • pH: 6.5 - 9.5 • Sulphate: N/A	Releases allowed when minimum flow in the receiving water (3 m^3/s in Isaac River and 0.5 m^3/s in Cherwell Creek
Eagle Downs Coal Mine	EPML00586713	Isaac River U/S of the Project area	• EC: 1,000 µS/cm • pH: 6.5 - 8.0 • Turbidity: N/A • Suspended Solids: TBD • Sulphate: 100 mg/L	• EC: 1,200 µS/cm • pH: 6.5 - 9.0 • Turbidity: N/A • Suspended Solids: 80th percentile of background of u/s sites • Sulphate: 1,000 mg/L	
Moorvale Coal Mine	EPML00802813	Isaac River U/S of the Project area	• EC: 1,000 µS/cm • pH: 6.5 - 9.0 • Turbidity: 4,000 NTU	• EC: 2,500 µS/cm • pH: 6.5 - 9.0 • Turbidity: 4000 NTU • Suspended Solids: N/A • Sulphate: 1,000 mg/L	Releases allowed when minimum flow in the receiving water (0.02 m^3/s in North Creek)

Mine	EA	Location	Receiving water contaminant trigger levels	Mine affected water quality limits	Conditions relating to receiving waters
Lake Vermont Mine	EPML00659513	Isaac River D/S of the Project area	• EC: 1,000 µS/cm • pH: 6.5 - 8.0 • Suspended Solids: 1,500 mg/L • Sulphate: 300 mg/L	*Isaac River RP's* • EC: 1,500 µS/cm • Sulphate: 300 mg/L *Phillips Creek RP's* • EC: 720-5,500 µS/cm (flow dependant) • Sulphate: 300-1,500 µS/cm (flow dependant)	Releases allowed when minimum flow in the receiving water (Isaac River) is greater than 7.5 m^3/s
Peak Downs Coal Mine	EPML00318213	Isaac River U/S of the Project area	• EC: 2,000 µS/cm • pH: 6.5 - 9.0	• EC: 10,000 µS/cm • pH: 6.5 - 9.5 • Sulphate: N/A (correlated with EC)	Releases allowed when minimum flow in the receiving water (3 m^3/s in Isaac River and 0.1 m^3/s in Boomerang Creek)
Saraji Coal Mine	EPML00862313	Isaac River U/S of the Project area	• EC: 2,000 µS/cm • pH: 6.5 - 9.0	• EC: 10,000 µS/cm • pH: 6.5 - 9.5	Releases allowed when minimum flow in the receiving water (3 m^3/s in Isaac River, 0.1 m^3/s in Hughes Creek/One Mile Creek/Spring Creek/Phillips Creek)
Norwich Park Coal Mine	EPML00865013	Isaac River D/S of the Project area	• EC: 2,000 µS/cm • pH: 6.5 - 9.0 • Sulphate: 1,000 mg/L	• EC: 10,000 µS/cm • pH: 6.5 - 9.5 • Sulphate: N/A (correlated with EC)	Releases allowed when minimum flow in the receiving water (Scotts Creek/Stephens Creek/Rolf Creek) is greater than 1 m^3/s
Olive Downs Project	EA0001976	Isaac River adjacent to the Project area	• EC: 2,000 µS/cm • pH: 6.5 - 9.0 • TSS: TBA • Turbidity: TBA • Sulphate: 545 mg/L	• EC: 1,000-7,200 µS/cm • pH: 6.5 - 9.0 • Turbidity: 300 NTU • Sulphate: 1,000 mg/L	Releases allowed when minimum flow in the receiving water (Isaac River) is greater than 4 m^3/s

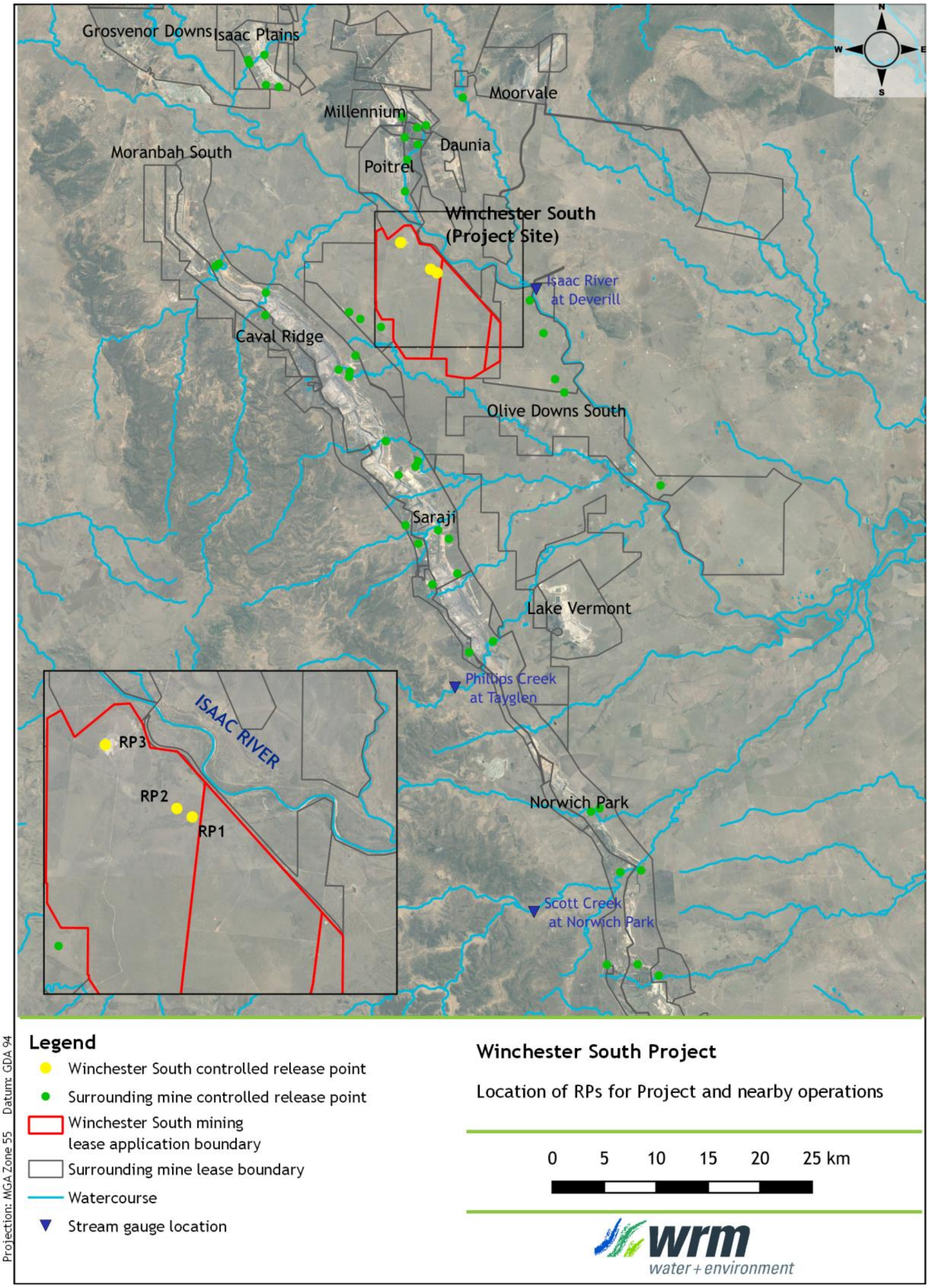


Figure 10.1 – Cumulative impact assessment – location of nearby release points

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-affected 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 significantly 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-affected water releases were aquatic ecosystem toxicity from salinity is the primary issue of concern.

Bowen Gas Project EIS

The Project lies within the study area of the Bowen Gas Project (BGP), and there are two water treatment facilities proposed as part of the BGP development. The indicative locations of the water treatment facilities 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 Olive Downs Project.

The impact assessments for the BGP indicated that surface water resources within the BGP area had been impacted by different historic and current land uses such as agriculture, mining and urban development. The impact assessments 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 impact assessments would allow for CSG water to be discharged without having any significant impact to the receiving environment.

Given that the proposed water treatment facilities 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 would result in a loss of catchment to the Isaac River during operations and post-mining. The surface runoff volume lost from the catchment would generally be in proportion to the excision of the catchment area. The Project area is less than 1.0% of the catchment area of the Isaac River to the Isaac River/Ripstone Creek confluence. Of this, around 70% of this area is managed through the ESCP and then released to the downstream environment following treatment.

The cumulative impact assessment includes mining operations within the Isaac River that are adjacent or downstream of the Project, including Lake Vermont Mine and Norwich Park Mine. The catchment of the Isaac River to the Stephens Creek confluence is around 7,782 km^2.

There are approximately 17 existing coal mines upstream of the Project that also capture runoff from the Isaac River catchment, as shown in Figure 10.2. The total estimated captured area of all these projects (including the Project) combined represents around of 9.5% of the Isaac River catchment to the Isaac River/ Stephens Creek confluence. If the same percentage of ESCP for the Project is applied to the other mines, then the estimated captured catchment areas reduce to around 30% of the total area (around 2.9% of the Isaac River catchment to the Isaac River/ Stephens Creek confluence).

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, that would reduce the impacts on surface water resources.

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 Isaac River/ Stephens Creek confluence is provided in Table 10.6, which indicates the following:

- The combined total catchment area of the existing mines (including the Project) represents around 9.5% of the total catchment area of the Isaac River to the Isaac River/ Stephens Creek confluence.
- The combined mine affected catchment area (estimated) represents less than 2.9% of the total Isaac River catchment area to the Isaac River/ Stephens Creek confluence.

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 – Catchments areas of existing project considered in the cumulative impact assessment

Catchment	Total catchment area (km^2)	Estimated mine-affected catchment area (km^2)
Project area	53	17
Other mining operations (estimated)	686	206
Combined (estimated)	739	223
Isaac River	**7,782**	

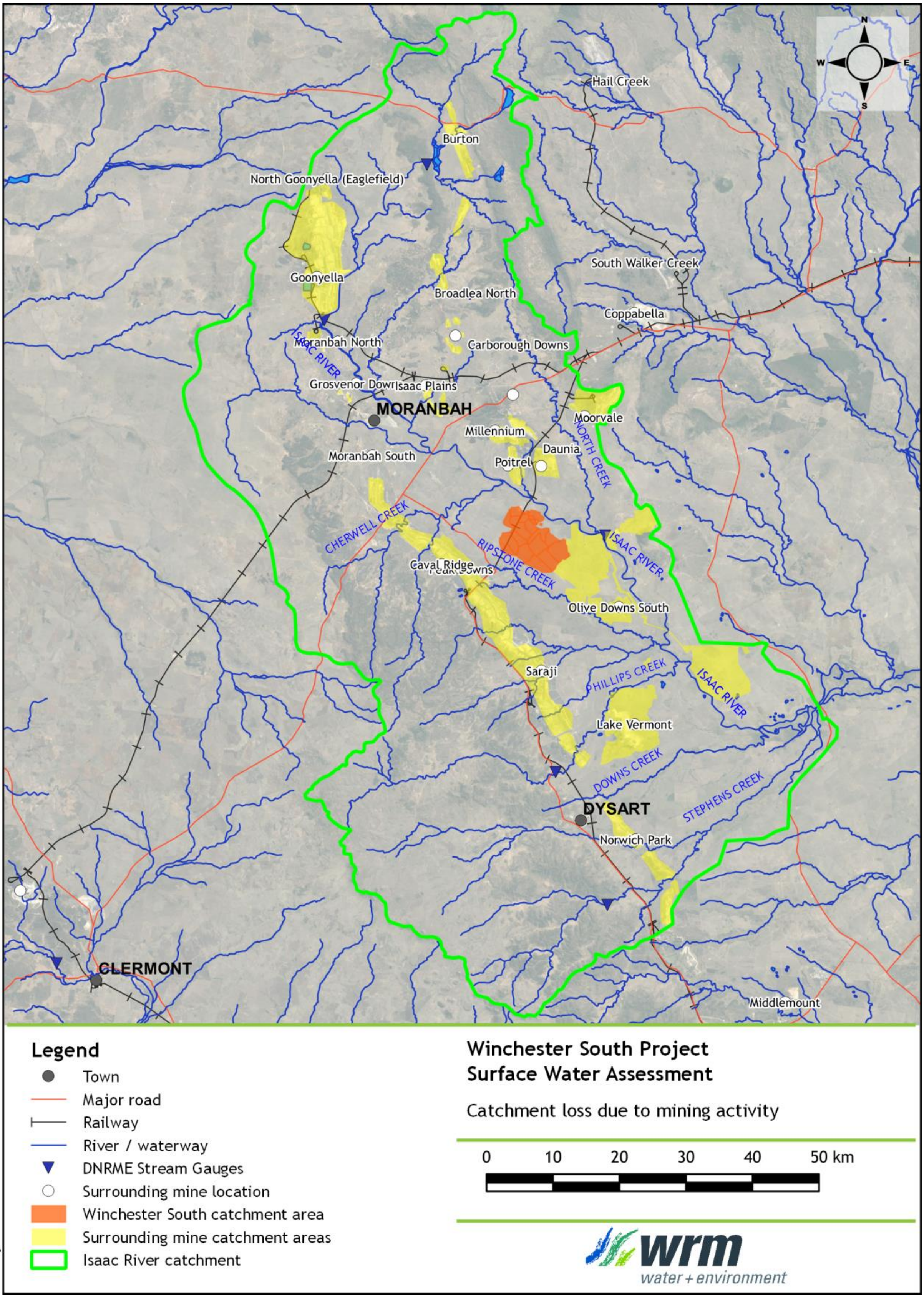


Figure 10.2 – Cumulative impact assessment – location of existing mine upstream of the Project within the Isaac River catchment

10.7 SURFACE WATER MONITORING PROGRAM

10.7.1 Overview

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

The surface water monitoring protocols would:

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

10.7.2 Water quality monitoring locations

The proponent has previously monitored a number of surface water locations in the vicinity of the Project (as detailed in Section 4.4.2.1). The Surface Water Monitoring Program would include the continued monitoring of a number of these sites to monitor surface water flows and quality upstream and downstream of the Project.

The water quality monitoring program would also include monitoring of dams which contain mine-affected water and discharge to the receiving environment. This includes the following dams:

- MWD;
- CC Dam; and
- Railway Pit.

Locations of the proposed surface water monitoring locations are shown in Figure 10.3 and summarised in Table 10.7.

Table 10.7 – Proposed surface water monitoring program

Site name	Waterway	Location	
		Easting (GDA94 Z55)	Northing (GDA94 Z55
SW2	Unnamed tributary of Isaac River	635,908	7,549,015
SW3	Unnamed tributary of Isaac River	631,065	7,552,777
SW4	Isaac River	630,897	7,553,963
SW7	Ripstone Creek	626,052	7,542,660
SW5	Isaac River	636,999	7,549,588
SW8	Isaac River	640,300	7,547,829
SW9	Ripstone Creek	636,357	7,537,931
SW10	Unnamed tributary of Isaac River	640,641	7,543,375
SW11	ML boundary U/S Unnamed tributary of Ripstone Creek	639,081	7,540,363

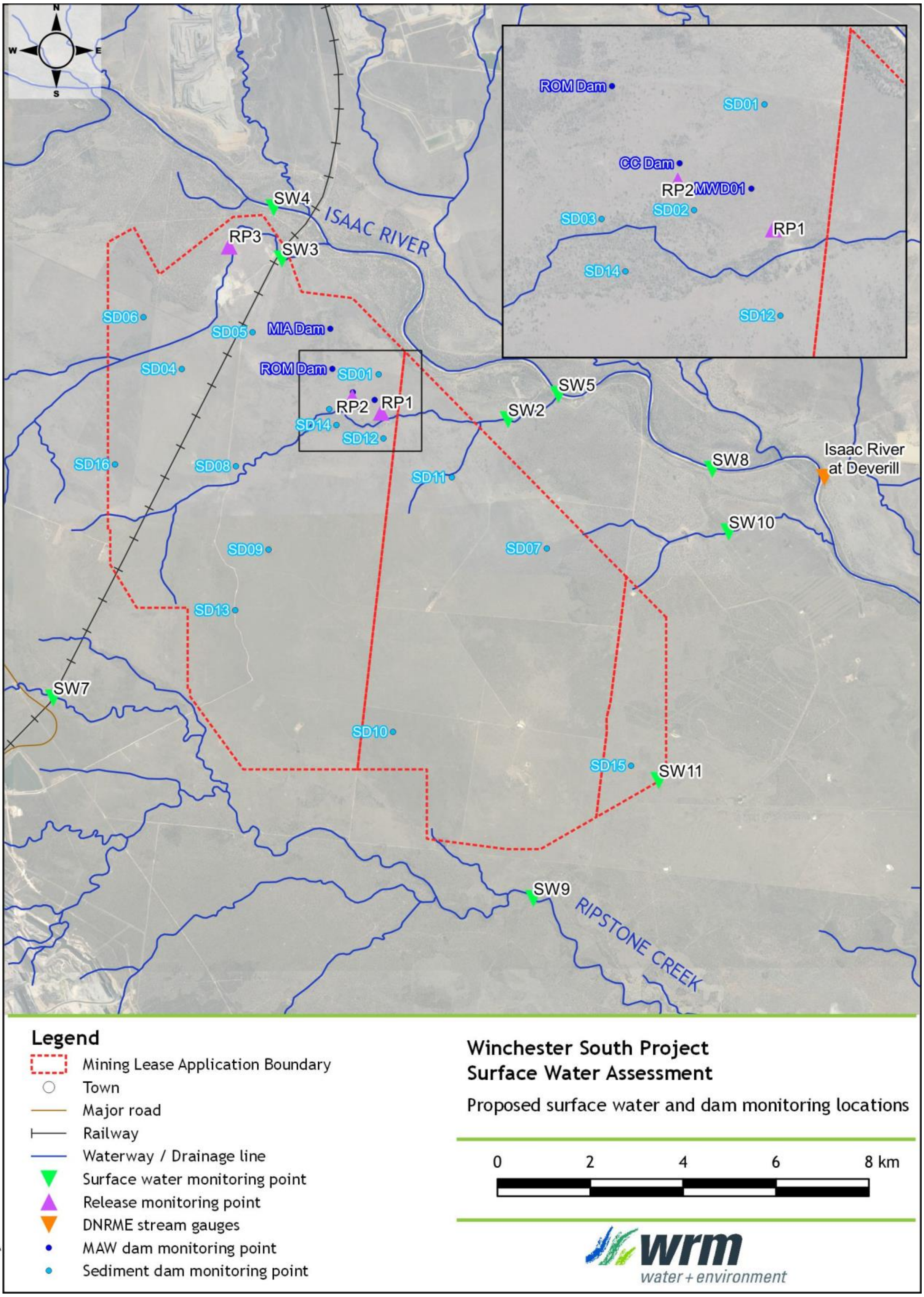


Figure 10.3 – Proposed surface water monitoring locations

10.7.3 Water quality monitoring schedule

Table 10.8, Table 10.9 and Table 10.10 defines the proposed frequency and parameters to be sampled at the proposed release points during the discharge of mine-affected water. The proposed EC and sulphate (as SO_4) mine-affected water release limits (refer Table 10.10) are consistent with the approved limits applied at the majority of mining operations in the vicinity of the Project, including the recently approved Isaac Downs and Olive Downs projects. Refer to Table 10.3 for a summary of the approved release limits for operating coal mines in the vicinity of the Project.

Table 10.11 defines the proposed frequency and parameters to be sample across the dams which can discharge mine-affected water to the receiving environment. The proposed water quality monitoring program provides regular monitoring of key mine site storages.

The event-based sampling would enable quantification of pollutant loads from the site and their corresponding impact on the water quality of receiving waters (consistent with standard contemporary requirements of EAs). On-site quarterly sampling from the water storages allows for any potential issues with respect to pollutant generation on-site to be identified in advance ensuring appropriate remedial action can be taken.

The local water quality samples from the composite Winchester South and Olive Downs dataset show that the local concentrations for a number of key parameters are significantly elevated above the DGVs. As such, the proposed WQO's for four parameters (dissolved aluminium, dissolved iron, dissolved selenium and ammonia) have been set based on the 80th percentile value from the local composite dataset. The remaining parameters are based on the guideline values from the Model water conditions for coal mines in the Fitzroy Basin (DES, 2013).

Table 10.8 – Mine-affected water release limits

Parameter	Units	Minimum	Maximum
EC	µS/cm	n/a	Variable[1]
pH	pH units	6.5	9.0
Sulphate (SO_4^{2-})	mg/L	n/a	Variable[1]

Note: 1/ Release limits for EC and SO_4 are dependent on receiving water flow (see Table 10.10)

Table 10.9 – Release contaminant trigger investigation levels

Parameter	Trigger level (µg/L)	Monitoring frequency
Aluminium	116	Commencement of release and thereafter weekly during releases
Arsenic	13	
Cadmium	0.2	
Chromium	1	
Copper	1.2	
Iron	380	
Lead	4	
Mercury	0.2	
Nickel	11	
Zinc	8	
Boron	830	
Cobalt	90	
Manganese	1,900	
Molybdenum	34	
Selenium	1	
Silver	0.5	
Uranium	1	
Vanadium	10	
Ammonia	180	
Nitrate	1,100	
Petroleum hydrocarbons (C6-C9)	20	
Petroleum hydrocarbons (C10-C36)	100	
Fluoride	2,000	

Table 10.10 – Proposed controlled release rules

Receiving waters	Release point (RP)	Gauging station	GS Latitude (dec. degree, GDA94)	GS Longitude (dec. degree, GDA94)	Receiving water flow criteria for discharge	Maximum release rate (for all combined RPs)	EC and SO_4 release limits
Isaac River	RP1	130414A Isaac River @ Deverill	-22.164296°S	148.350830°E	Medium Flow after natural flow events that exceed 4 m^3/s	0.5 m^3/s	1,000 µS/cm 300 mg/L SO_4^{2-}
					Medium Flow after natural flow events that exceed 10 m^3/s	1.0 m^3/s	1,200 µS/cm 300 mg/L SO_4^{2-}
	RP2				High Flow after natural flow events that exceed 50 m^3/s	2.0 m^3/s	4,000 µS/cm 400 mg/L SO_4^{2-}
					High Flow after natural flow events that exceed 100 m^3/s	3.0 m^3/s	6,000 µS/cm 400 mg/L SO_4^{2-}
	RP3				Very high flow after natural flow events that exceed 300 m^3/s	5.0 m^3/s	10,000 µS/cm 400 mg/L SO_4^{2-}

Table 10.11 – Water storage monitoring

Location	Parameter	Monitoring frequency
MWD	All parameters identified in Table 10.8 and Table 10.9	Quarterly
CC Dam	All parameters identified in Table 10.8 and Table 10.9	Quarterly
Railway Pit	All parameters identified in Table 10.8 and Table 10.9	Quarterly

10.7.4 Sediment dam monitoring

Surface runoff and seepage from waste rock emplacements, including any rehabilitated areas during operations, 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, TSS, turbidity and a broad suite of soluble metals/metalloids (Table 10.12). Table 10.12 also defines the proposed frequency and parameters to be sample across the sediment dams.

The sediment dam monitoring would be used to validate the anticipated quality of water runoff reporting to sediment dams. Initially, the sediment dam monitoring would occur on a regular (e.g. quarterly) 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. Whitehaven would also undertake event-based sampling of the relevant sediment dam as soon as practicable after a sediment dam overflow.

If water quality sampling of sediment dam water shows contaminant concentrations materially higher than those predicted by the geochemical characterisation study and exceed the release contaminant trigger investigation levels (Table 10.9), the following mitigation measures would be implemented:

- Pump back all sediment dam water to the water management system; or
- Treat the sediment water through flocculation prior to release.

The locations and number of sediment dams provided in this assessment is conceptual only, and would not significantly affect the overall mine water balance provided the dam volumes remain consistent. Details of sizing and placement of sediment dams would be finalised during detailed design of the Project.

Table 10.12 – Sediment dam monitoring

Location	Parameter	Monitoring frequency
SD01	All parameters identified in Table 10.8 and Table 10.9	Quarterly[1,2]
SD02	All parameters identified in Table 10.8 and Table 10.9	Quarterly[1,2]
SD03	All parameters identified in Table 10.8 and Table 10.9	Quarterly[1,2]
SD04	All parameters identified in Table 10.8 and Table 10.9	Quarterly[1,2]
SD05	All parameters identified in Table 10.8 and Table 10.9	Quarterly[1,2]
SD06	All parameters identified in Table 10.8 and Table 10.9	Quarterly[1,2]
SD07	All parameters identified in Table 10.8 and Table 10.9	Quarterly[1,2]
SD08	All parameters identified in Table 10.8 and Table 10.9	Quarterly[1,2]
SD09	All parameters identified in Table 10.8 and Table 10.9	Quarterly[1,2]
SD10	All parameters identified in Table 10.8 and Table 10.9	Quarterly[1,2]
SD11	All parameters identified in Table 10.8 and Table 10.9	Quarterly[1,2]
SD12	All parameters identified in Table 10.8 and Table 10.9	Quarterly[1,2]
SD13	All parameters identified in Table 10.8 and Table 10.9	Quarterly[1,2]
SD14	All parameters identified in Table 10.8 and Table 10.9	Quarterly[1,2]
SD15	All parameters identified in Table 10.8 and Table 10.9	Quarterly[1,2]
SD16	All parameters identified in Table 10.8 and Table 10.9	Quarterly[1,2]

1 Monitoring would be undertaken quarterly for the first two years of the Project to inform to validate the anticipated quality of water runoff reporting to sediment dams. The frequency of monitoring and suite of parameters for the sediment dam monitoring would be reviewed and updated accordingly as part of the ESCP.

2 Whitehaven would undertake event-based sampling of the relevant sediment dam as soon as practicable after a sediment dam overflow.

10.7.5 Receiving Environment Monitoring Program

A Receiving Environment Monitoring Program (REMP) would be prepared in consideration of the relevant guidelines and would specify the proposed monitoring program for the local receiving waters. The REMP would incorporate the historical and proposed monitoring as described in 4.4.2, Section 10.7.2 and Section 10.7.3.

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

A set of proposed receiving water contaminant triggers levels have been developed, based on the conditions recently approved in the EA at the neighbouring Olive Downs Project. These trigger levels are presented in Table 10.13 and are proposed to be measured at the upstream and downstream Isaac River monitoring stations (SW4 and SW5, respectively).

Monitoring at these locations would assist with controlled release operations, allow for an accurate evaluation of the impact of any releases from the Project, and allow for identification of any upstream influences that are not associated with the Project.

Table 10.13 – Receiving water contaminant trigger levels

Parameter	Units	Trigger level	Monitoring locations	Monitoring frequency
pH	-	6.5 – 9.0	SW4 & SW5	Daily during release
EC	µS/cm	2,000		
Sulphate (SO_4^{2-})	mg/L	545		

10.7.6 Adaptive and Trigger Management Actions

10.7.6.1 Controlled Releases

If there is an exceedance of the trigger levels specified in Table 10.13 during a controlled release event, Whitehaven would compare the downstream results in the receiving waters to the trigger values specified in Table 10.13 and:

(1) where the trigger values are not exceeded then no action is to be taken; or

(2) where the downstream results exceed the trigger values specified Table 10.13 for any quality characteristic, compare the results of the downstream site to the data from background monitoring sites and:

   (a) if the result is less than the background monitoring site data, then no action is to be taken; or

   (b) if the result is greater than the background monitoring site data, complete an investigation into the potential for environmental harm and provide a written report to the administering authority within 90 days of receiving the result, outlining:

      (i) details of the investigations carried out; and

      (ii) actions taken to prevent environmental harm.

If an exceedance is identified, Whitehaven would notify the administering authority in writing within 24 hours of receiving the result. Whitehaven would notify the administering authority as soon as practicable and no later than 24 hours after commencing a controlled release of mine-affected water to the receiving environment, including the relevant details of the controlled release.

If the release limits defined in Table 10.10 and Table 10.13 are exceeded, Whitehaven would notify the administering authority within 24-hours of receiving the results. Within 28 days of a controlled release that exceeds the proposed limits outlined in Table 10.10 and Table 10.13, Whitehaven would provide a report to the administering authority detailing:

(1) the reason for the release;

(2) the location of the release;

(3) the total volume of the release and which (if any) part of this volume was non-compliant;

(4) the total duration of the release and which (if any) part of this period was non-compliant;

(5) all water quality monitoring results (including all laboratory analyses);

(6) identification of any environmental harm as a result of the non-compliance;

(7) all calculations; and

(8) any other matters pertinent to the water release event.

10.7.6.2 Sediment Dam Overflows

In the event of a sediment dam overflow, the water quality monitoring results preceding and following overflow events for the relevant sediment dam would be reviewed. Whitehaven would also undertake event-based sampling of the relevant sediment dam as soon as practicable after a sediment dam overflow. Whitehaven would compare the sediment dam water quality results against the trigger values specified in Table 10.8 and Table 10.9 and:

(1) where the trigger values are not exceeded then no action is to be taken; or

(2) where the downstream results exceed the trigger values specified Table 10.8 and Table 10.9 for any quality characteristic, compare the results of the downstream site to the data from background monitoring sites and:

   (a) if the result is less than the background monitoring site data, then no action is to be taken; or

   (b) if the result is greater than the background monitoring site data, complete an investigation into the potential for environmental harm and provide a written report to the administering authority within 90 days of receiving the result, outlining:

      (i) details of the investigations carried out; and

      (ii) actions taken to prevent environmental harm.

If the trigger levels defined in Table 10.8 and Table 10.9 are exceeded due to a sediment dam overflow, Whitehaven would notify the administering authority within 24 hours of receiving the results. The trigger levels and actions outlined above would be reviewed as part of the annual review of the ESCP.

11 Summary of findings

11.1 OVERVIEW

The potential impacts of the Project on surface water quality and resources would 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 would be implemented to continually monitor the environmental performance of the site water management system and maintains the proposed 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 phases of mine development, using historical climate data from the SILO climate database.

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

Whitehaven WS would seek to obtain adequate external water requirements (e.g. water sharing with surrounding mining operations or sourcing from an external water supplier). The water balance model results show that there is a greater than 78% probability that an external water supply of 3,800 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 and water sharing agreements with surrounding operations would be sought by Whitehaven WS over the life of the Project to meet water demands. Alternatively, production would be reduced until sufficient supplies are available. Water required from external sources would be obtained through water sharing agreements with surrounding operations or under appropriate Water Access Licences to minimise potential adverse impacts on water availability for other licensed water users.

Overall, the water balance modelling results indicate that sufficient out-of-pit and in-pit storage has been provided to prevent uncontrolled spillway discharges to the downstream environment and to ensure the pit can be dewatered.

The model results show that there 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 FLOODING BEHAVIOUR

There are no significant impacts on flood levels and velocities in the Isaac River channel and floodplain under both operational and post-mining conditions. The Project (under both operational and post-mining scenarios) would only interact with the Isaac River for rarer flood events (1% AEP and rarer design events). The impacts identified on the Isaac River floodplain for these rare events are generally localised and relatively small in magnitude.

While the peak flood velocities are not considered excessive, appropriate scour protection measures would be considered as part of the optimised final landform detailed design process and detailed in the ESCP and/or Progressive Rehabilitation and Closure Plan (PRCP) for the Project. If erosion of the final landform is identified due to flooding event, a range of mitigation measures could be implemented from self-healing, to assisted recovery (e.g. plant vegetation and soft engineering such as coir matting and stakes) or to hard-engineering (e.g. rock rip-rap) as recommended in Section 6.2 of the Geomorphology Assessment (Fluvial Systems, 2020).

There are no impacts on flood levels and velocities in Ripstone Creek, as the Project is located well outside of the Ripstone Creek floodplain.

11.4 IMPACTS ON DOWNSTREAM WATER QUALITY

In accordance with the DES's Model Mining Conditions, any water that comes into contact with coal or other carbonaceous material will be captured in the Project mine water management system. Surface water runoff from all other areas that are disturbed by mining operations (including out-of-pit waste rock emplacements) would be via sediment dams in accordance with an ESCP.

As described above, there would be no uncontrolled spills from the Project mine water management system. In addition, the site water management system has been designed such that controlled releases from the Project are only required rarely, and any such releases would have a negligible impact on receiving water quality. Notwithstanding, controlled releases would be managed in accordance with the management and monitoring measures described in Section 10.7.

The assessment in Section 7.3.6.2 shows predicted increases of salinity in the Isaac River of less than 7% during sediment dam releases. With the implementation of the proposed mitigation strategy, the potential impact of sediment dam discharges on the Isaac River salinity would be negligible. Given this, a cumulative impact assessment including sediment water releases from other mining operations in the upper Isaac River catchment is not warranted.

The management of runoff from waste rock emplacements as 'sediment water' is not considered to pose a downstream risk to the environment. Notwithstanding, monitoring of sediment dam water quality would be undertaken as described in Section 10.7.4.

An ESCP and WMP will be developed and implemented throughout construction and operation of the Project. If implemented effectively, environmental risks from disturbed area runoff (i.e. sediment-laden runoff) are expected to be low. The WMP for the Project would also include a program for monitoring and review of the effectiveness of the water management system.

11.5 IMPACT OF CONTROLLED RELEASES ON TRIBUTARIES

The potential impacts of the proposed controlled releases on the downstream tributaries were assessed in the Geomorphology Technical Study (Fluvial Systems, 2020) for the Draft EIS. The Geomorphology Technical Study was prepared by Dr Christopher Gippel and included a comprehensive review of the geomorphology of the tributaries downstream of the proposed controlled discharge points.

The Geomorphology Technical Study for the Draft EIS described the proposed monitoring and management strategy for the tributaries, which would be undertaken using objective, scientifically sound methods, following a BACI (Before/After/Control/Intervention) design. Visual inspections would be undertaken following each controlled release event. A topographic survey (using LiDAR) would be undertaken if either of the following are observed:

- a channel exceeding 0.2 m deep for a length of 10 m or more; or
- initiation of a knickpoint higher than 0.3 m.

Appropriate mitigation measures would be applied in response to any observed geomorphic impacts. The appropriate mitigation would be assessed at the time and would range from doing nothing (self-sealing), to assisted recovery (e.g. plant vegetation and soft engineering such as coir matting and stakes), to hard engineering (e.g. rock rip-rap) (Fluvial Systems, 2020).

11.6 REDUCTION IN DOWNSTREAM FLOWS DURING OPERATIONS

The Project would 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:

- Less than 1.0% of the Isaac River catchment to the confluence of the Isaac River and Ripstone Creek.
- Less than 4.5% of the Ripstone Creek catchment.

Furthermore, only a small proportion of the excised catchments are captured in pit and mine-affected dam catchments, and the remainder drains off-site through the sediment water management system. Therefore, the effective reduction in downstream flow during operations would be closer to 0.3% Isaac River and 1.4% in Ripstone Creek. These reductions would be unlikely to be measurable and are considered insignificant.

11.7 LONG-TERM REDUCTION IN CATCHMENT RUNOFF

At the completion of mining, surface runoff from rehabilitated out-pf-pit waste rock emplacement areas would be released from the Project area. An area of approximately 13.7 km^2 would drain to the residual voids. The changed topography following completion of the Project would have the following impacts on catchment areas:

- the catchment draining to the Isaac River (to the confluence of the Isaac River and Ripstone Creek) would reduce by around 13.7 km^2 (compared to pre-mining conditions), a decrease of less than 0.3%.
- the catchment draining to Ripstone Creek would reduce by around 4.3 km^2 (compared to pre-mining conditions), a decrease of around 1.5%.

The loss of catchment flows in the Isaac River and Ripstone Creek would be indiscernible, and as such the potential impact on water quantity in Isaac River and Ripstone Creek due to the final landform is considered negligible.

11.8 RESIDUAL VOIDS

Water balance simulation of the residual voids shows that the water surface is expected to reach an equilibrium water level well below the residual void overflow level. The equilibrated residual void water body would generally take around 100 years to reach an equilibrium level.

A storm event analysis showed that even at peak equilibrium level, a PMP design storm event would have minimal impact on residual void water levels, and they would remain between 48 m and 65 m below the overflow levels across all the residual voids.

11.9 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 been 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 EVs.

In any case, the site water management system has been designed such that controlled releases from the Project are only required rarely, and any such releases would have a negligible impact on receiving water quality.

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Appendix A Olive Downs Project baseline water quality samples

Table A.1 - Local water quality sampling data - Olive Downs Project (SW1)

Parameter	Unit	SW1										Default Guideline Value (refer Table 3.1)
		15/8/17	14/9/17	12/10/17	16/11/17	14/12/17	25/1/18	13/11/18	21/12/18	14/2/19	26/3/19	
pH	-	8.29	8.21	8.32	8.36	8.24	7.87	7.4	7.48	8.85	7.43	6.5-8.5 (aquatic)
Electrical Conductivity	µS/cm	389	398	467	475	464	449	281	430	475	177	< 720 (baseflow) < 250 (high flow)
Total Suspended Solids	mg/L	11	11	16	13	12	66	107	30	36	8	< 55 (aquatic)
Turbidity	NTU	7.4	8.3	15.2	62.3	30	123	806	138	116	31.3	< 50 (aquatic)
Dissolved Oxygen	% sat.	59.3	52.4	56.5	60.8	42	44.5	55.7	-	37	48.8	85-110% (aquatic)
Total Hardness	mg/L	98	109	132	160	186	-	70	118	141	46	150 (drinking)
Sulphate as SO4	mg/L	6	4	8	3	3	4	15	6	11	6	25 (aquatic)
Sodium (dissolved)	mg/L	33	38	57	53	41	37	23	21	32	15	< 30 (drinking)
Aluminium (dissolved)	mg/L	0.02	0.08	0.11	0.15	0.05	0.05	0.14	0.83	0.03	-	< 0.055 (aquatic)
Arsenic (dissolved)	mg/L	<0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.002	0.001	0.001	< 0.013 (aquatic)
Cadmium (dissolved)	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	0.0001	0.0001	0.0001	< 0.0002 (aquatic)
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 (aquatic)
Cobalt (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	0.001	-	< 0.0014 (aquatic)
Copper (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.001	0.002	0.001	< 0.0014 (aquatic)
Lead (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	0.001	0.001	< 0.0034 (aquatic)
Molybdenum (dissolved)	mg/L	0.001	0.001	<0.001	<0.001	0.001	0.001	0.001	0.001	0.001	-	< 0.034 (aquatic)
Nickel (dissolved)	mg/L	<0.001	<0.001	0.001	0.002	0.002	0.001	0.002	0.004	0.002	0.001	< 0.011 (aquatic)
Selenium (dissolved)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.01	-	< 0.005 (aquatic)
Silver (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	0.001	-	< 0.001 (aquatic)
Uranium (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	0.001	-	< 0.001 (aquatic)
Vanadium (dissolved)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.01	-	< 0.01 (aquatic)
Zinc (dissolved)	mg/L	<0.005	<0.005	<0.005	<0.005	0.01	<0.005	0.005	0.005	0.005	0.005	< 0.008 (aquatic)
Boron (dissolved)	mg/L	<0.05	<0.05	<0.05	0.06	0.06	<0.05	0.05	0.08	0.05	-	< 0.94 (aquatic)
Iron (dissolved)	mg/L	0.08	0.14	0.09	0.18	0.12	0.07	0.21	0.8	0.05	-	< 0.7 (aquatic)
Aluminium (total)	mg/L	0.28	0.3	0.27	0.21	0.36	1.1	12	3.3	1.48	-	< 5 (stock)

Parameter	Unit	SW1										Default Guideline Value (refer Table 3.1)
		15/8/17	14/9/17	12/10/17	16/11/17	14/12/17	25/1/18	13/11/18	21/12/18	14/2/19	26/3/19	
Arsenic (total)	mg/L	<0.001	0.001	0.001	0.002	0.001	0.002	0.003	0.003	0.002	0.001	< 2.0 (irrigation) < 0.5 (stock)
Cadmium (total)	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	0.0005	0.0001	0.0001	< 0.01 (stock)
Chromium (total)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.015	0.004	0.002	0.003	< 1 (stock)
Cobalt (total)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.007	0.002	0.001	-	< 0.1 (irrigation)
Copper (total)	mg/L	<0.001	<0.001	0.001	<0.001	<0.001	0.002	0.01	0.004	0.002	0.002	<1 (stock)
Lead (total)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.014	0.004	0.001	0.001	< 0.1 (stock)
Molybdenum (total)	mg/L	<0.001	0.001	0.001	0.001	<0.001	0.002	0.001	0.001	0.001	-	< 0.05 (irrigation)
Nickel (total)	mg/L	<0.001	0.001	0.002	0.002	0.002	0.003	0.018	0.007	0.003	0.003	< 1 (stock)
Selenium (total)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.01	-	< 0.02 (stock)
Uranium (total)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	0.001	-	< 0.1 (irrigation)
Vanadium (total)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.01	0.01	-	< 0.5 (irrigation)
Zinc (total)	mg/L	<0.005	<0.005	0.025	<0.005	<0.005	<0.005	0.032	0.007	0.005	0.006	< 5 (irrigation)
Boron (total)	mg/L	<0.05	0.05	0.05	0.06	0.05	0.07	0.07	0.12	0.11	-	< 5 (stock)
Iron (total)	mg/L	0.28	0.42	0.4	0.44	0.81	2.71	20.7	5.61	2.13	-	< 10 (irrigation)
Fluoride (total)	mg/L	0.2	0.2	0.2	0.2	<0.1	0.2	0.2	0.2	0.2	0.2	< 2 (irrigation)
Ammonia (total)	mg/L	0.04	0.1	0.05	0.03	0.12	0.21	0.12	0.1	0.05	0.14	< 0.02 (aquatic)
Nitrate as N	mg/L	<0.01	<0.01	<0.01	<0.01	0.02	0.02	0.05	0.01	0.01	0.05	< 1.1 (aquatic)
Phosphorus as P (total)	mg/L	0.02	0.02	0.03	0.04	0.02	0.1	0.45	0.11	0.09	0.03	< 50 (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	< 0.02 (aquatic)

Table A.2 - Local water quality sampling data - Olive Downs Project (SW2)

Parameter	Unit	SW2												Default Guideline Value (refer Table 3.1)
		19/7/17	15/8/17	14/9/17	12/10/17	15/2/18	14/3/18	13/4/18	23/5/18	13/11/18	17/12/18	14/2/19	26/3/19	
pH	-	8.32	8.24	8.07	7.74	6.37	7.07	6.67	7.43	6.51	-	7.94	6.72	6.5-8.5 (aquatic)
Electrical Conductivity	µS/cm	399	479	493	516	124	203	319	261	171	-	269	312	< 720 (baseflow) < 250 (high flow)
Total Suspended Solids	mg/L	24	28	58	51	14	24	17	25	34	842	13	62	< 55 (aquatic)
Turbidity	NTU	55.3	56.2	132	82	30.2	109	51.7		99.1	-	30.7	80.7	< 50 (aquatic)
Dissolved Oxygen	% sat.	73.1	39.8	33.1	94.9	24.8	3.1	16.1	4	71.4	-	55.2	8.6	85-110% (aquatic)
Total Hardness	mg/L	130	137	162	190	32	74	106	124	65	21	83	82	150 (drinking)
Sulphate as SO4	mg/L	2	1	1	<1	<1	<1	<1	<1	1	1	1	1	25 (aquatic)
Sodium (dissolved)	mg/L	30	33	38	50	4	15	17	28	7	12	20	13	< 30 (drinking)
Aluminium (dissolved)	mg/L	0.04	0.07	0.07	0.13	0.61	0.36	0.05	0.05	1.83	0.4	0.3	-	< 0.055 (aquatic)
Arsenic (dissolved)	mg/L	<0.001	<0.001	<0.001	0.002	0.001	0.001	0.001	<0.001	0.002	0.001	0.002	0.004	< 0.013 (aquatic)
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	< 0.0002 (aquatic)
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 (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	-	< 0.0014 (aquatic)
Copper (dissolved)	mg/L	0.002	0.002	0.002	0.002	0.002	0.001	<0.001	0.002	0.003	0.002	0.001	0.002	< 0.0014 (aquatic)
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)
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	-	< 0.034 (aquatic)
Nickel (dissolved)	mg/L	<0.001	0.001	<0.001	0.002	0.003	0.002	0.002	0.002	0.004	0.001	0.003	0.006	< 0.011 (aquatic)
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	-	< 0.005 (aquatic)
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 (aquatic)
Uranium (dissolved)	mg/L	<0.001	<0.001	0.002	0.002	-	<0.001	<0.001	<0.001	0.001	0.001	0.001	-	< 0.001 (aquatic)
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 (aquatic)
Zinc (dissolved)	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.017	0.005	0.005	0.005	< 0.008 (aquatic)
Boron (dissolved)	mg/L	<0.05	0.05	0.05	0.08	<0.05	<0.05	0.06	0.1	0.06	0.05	0.05	-	< 0.94 (aquatic)
Iron (dissolved)	mg/L	<0.05	<0.05	<0.05	0.16	0.52	0.3	0.06	0.09	1.19	0.28	1.05	-	< 0.7 (aquatic)
Aluminium (total)	mg/L	0.8	0.74	1.3	1.01	1.11	3.76	0.58	0.58	4.18	15.9	1.31	-	< 5 (stock)

Parameter	Unit	SW2												Default Guideline Value (refer Table 3.1)
		19/7/17	15/8/17	14/9/17	12/10/17	15/2/18	14/3/18	13/4/18	23/5/18	13/11/18	17/12/18	14/2/19	26/3/19	
Arsenic (total)	mg/L	<0.001	<0.001	0.001	0.002	0.002	0.002	0.002	0.001	0.003	0.002	0.003	0.007	< 2.0 (irrigation) < 0.5 (stock)
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)
Chromium (total)	mg/L	<0.001	<0.001	0.001	0.001	0.001	0.003	<0.001	<0.001	0.002	0.011	0.001	0.003	< 1 (stock)
Cobalt (total)	mg/L	<0.001	<0.001	0.002	0.002	<0.001	0.002	<0.001	<0.001	0.002	0.009	0.001	-	< 0.1 (irrigation)
Copper (total)	mg/L	<0.001	0.003	0.004	0.003	0.004	0.004	0.001	0.001	0.005	0.018	0.002	0.005	<1 (stock)
Lead (total)	mg/L	<0.001	<0.001	0.001	<0.001	<0.001	0.002	<0.001	<0.001	0.001	0.008	0.001	0.003	< 0.1 (stock)
Molybdenum (total)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	0.001	-	< 0.05 (irrigation)
Nickel (total)	mg/L	0.002	<0.001	0.003	0.004	0.004	0.005	0.002	0.002	0.006	0.016	0.003	0.009	< 1 (stock)
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	-	< 0.02 (stock)
Uranium (total)	mg/L	<0.001	<0.001	0.002	0.002	-	<0.001	<0.001	<0.001	0.001	0.001	0.001	-	< 0.1 (irrigation)
Vanadium (total)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.03	0.01	-	< 0.5 (irrigation)
Zinc (total)	mg/L	<0.005	0.011	0.006	<0.005	<0.005	0.012	<0.005	<0.005	0.01	0.041	0.007	0.009	< 5 (irrigation)
Boron (total)	mg/L	0.06	<0.05	0.07	0.08	<0.05	<0.05	0.06	0.06	0.05	0.05	0.07	-	< 5 (stock)
Iron (total)	mg/L	0.73	0.65	1.54	1.55	1.2	3.95	1.12	1.12	4.31	14.9	2.56	-	< 10 (irrigation)
Fluoride (total)	mg/L	0.2	0.2	0.3	0.3	<0.1	0.2	0.2	0.3	0.2	0.2	0.3	0.2	< 2 (irrigation)
Ammonia (total)	mg/L	<0.01	<0.01	0.04	0.04	0.16	0.08	0.12	0.05	0.05	0.05	0.12	0.02	< 0.02 (aquatic)
Nitrate as N	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	0.01	0.2	0.01	0.01	< 1.1 (aquatic)
Phosphorus as P (total)	mg/L	0.05	0.04	0.09	0.14	0.25	0.09	0.04	0.05	0.18	0.47	0.14	0.28	< 50 (aquatic)
Reactive Phosphorus as P	mg/L	<0.01	<0.01	<0.01	<0.01	-	<0.01	<0.01	<0.01	0.01	0.03	0.01	0.03	< 0.02 (aquatic)

Table A.3 - Local water quality sampling data - Olive Downs Project (SW3)

Parameter	Unit	SW3									Default Guideline Value (refer Table 3.1)
		15/8/17	14/9/17	12/10/17	16/11/17	14/12/17	25/1/18	15/2/18	14/3/18	13/4/19	
pH	-	8.04	7.17	7.51	7.67	8.18	8.08	6.4	7.44	7.0	6.5-8.5 (aquatic)
Electrical Conductivity	µS/cm	330	311	317	313	322	358	218	225	297	< 720 (baseflow) < 250 (high flow)
Total Suspended Solids	mg/L	11	10	<5	<5	<5	6	38	<5	<5	< 55 (aquatic)
Turbidity	NTU	7.7	1.7	0.5	35.7	4.4	12.4	498	10.4	15.2	< 50 (aquatic)
Dissolved Oxygen	% sat.	41.5	30.7	23.8	33.6	42.2	57.2	27.1	29.8	17.3	85-110% (aquatic)
Total Hardness	mg/L	65	72	79	86	105		48	57	82	150 (drinking)
Sulphate as SO4	mg/L	8	6	5	4	5	5	9	6	5	25 (aquatic)
Sodium (dissolved)	mg/L	34	32	39	38	36	39	19	23	30	< 30 (drinking)
Aluminium (dissolved)	mg/L	0.09	0.07	0.05	0.05	0.02	0.02	0.52	0.12	0.04	< 0.055 (aquatic)
Arsenic (dissolved)	mg/L	<0.001	<0.001	0.001	0.001	0.001	0.001	<0.001	<0.001	0.001	< 0.013 (aquatic)
Cadmium (dissolved)	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.0002 (aquatic)
Chromium (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.001 (aquatic)
Cobalt (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	< 0.0014 (aquatic)
Copper (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	< 0.0014 (aquatic)
Lead (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.0034 (aquatic)
Molybdenum (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.034 (aquatic)
Nickel (dissolved)	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.002	0.001	0.002	< 0.011 (aquatic)
Selenium (dissolved)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.005 (aquatic)
Silver (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	<0.001	< 0.001 (aquatic)
Uranium (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	<0.001	< 0.001 (aquatic)
Vanadium (dissolved)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.01 (aquatic)
Zinc (dissolved)	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	< 0.008 (aquatic)
Boron (dissolved)	mg/L	<0.05	<0.05	<0.05	<0.05	0.06	<0.05	<0.05	<0.05	0.06	< 0.94 (aquatic)
Iron (dissolved)	mg/L	0.06	0.09	0.39	0.63	0.61	0.47	0.31	0.09	0.15	< 0.7 (aquatic)
Aluminium (total)	mg/L	0.11	0.27	0.15	0.12	0.04	0.07	10.5	0.39	0.22	< 5 (stock)

Parameter	Unit	SW3									Default Guideline Value (refer Table 3.1)
		15/8/17	14/9/17	12/10/17	16/11/17	14/12/17	25/1/18	15/2/18	14/3/18	13/4/19	
Arsenic (total)	mg/L	<0.001	<0.001	0.002	0.002	<0.001	0.002	0.004	<0.001	0.001	< 2.0 (irrigation) < 0.5 (stock)
Cadmium (total)	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< 0.01 (stock)
Chromium (total)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.011	0.001	<0.001	< 1 (stock)
Cobalt (total)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	<0.001	0.001	< 0.1 (irrigation)
Copper (total)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.011	<0.001	<0.001	<1 (stock)
Lead (total)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.009	<0.001	<0.001	< 0.1 (stock)
Molybdenum (total)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	< 0.05 (irrigation)
Nickel (total)	mg/L	<0.001	0.002	0.001	0.001	<0.001	0.002	0.015	0.002	0.002	< 1 (stock)
Selenium (total)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.02 (stock)
Uranium (total)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	<0.001	< 0.1 (irrigation)
Vanadium (total)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	< 0.5 (irrigation)
Zinc (total)	mg/L	<0.005	<0.005	0.017	<0.005	<0.005	0.008	0.026	<0.005	<0.005	< 5 (irrigation)
Boron (total)	mg/L	<0.05	0.05	<0.05	<0.05	<0.05	0.05	<0.05	<0.05	0.05	< 5 (stock)
Iron (total)	mg/L	0.15	0.35	0.65	0.91	0.8	1.41	12.6	0.44	0.57	< 10 (irrigation)
Fluoride (total)	mg/L	0.2	0.1	0.2	0.1	<0.1	0.1	0.2	0.1	0.2	< 2 (irrigation)
Ammonia (total)	mg/L	0.04	0.03	0.05	0.04	0.2	<0.01	0.17	0.06	0.06	< 0.02 (aquatic)
Nitrate as N	mg/L	<0.01	<0.01	<0.01	0.25	<0.01	<0.01	0.02	0.03	<0.01	< 1.1 (aquatic)
Phosphorus as P (total)	mg/L	0.01	0.02	0.02	0.03	0.02	0.04	0.28	0.07	0.03	< 50 (aquatic)
Reactive Phosphorus as P	mg/L	<0.01	<0.01	<0.01	-	<0.01	<0.01	-	<0.01	<0.01	< 0.02 (aquatic)

Table A.4 - Local water quality sampling data - Olive Downs Project (SW3) cont'

Parameter	Unit	SW3									Default Guideline Value (refer Table 3.1)
		23/5/18	28/6/18	24/7/18	21/8/18	11/9/18	13/11/18	17/12/18	14/2/19	26/3/19	
pH	-	7.45	6.92	7.12	7.47	7.08	6.68	-	8.52	7.02	6.5-8.5 (aquatic)
Electrical Conductivity	µS/cm	295	334	360	343	371	251	-	301	214	< 720 (baseflow) < 250 (high flow)
Total Suspended Solids	mg/L	13	14	19	12	19	30	832	26	24	< 55 (aquatic)
Turbidity	NTU	-	10.1	31.2	32.2	28.1	187	-	42	15.3	< 50 (aquatic)
Dissolved Oxygen	% sat.	5.1	62.9	45.2	53.8	78.5	35.6	-	65	24.3	85-110% (aquatic)
Total Hardness	mg/L	96	84	94	103	64	75	21	87	68	150 (drinking)
Sulphate as SO4	mg/L	5	3	3	4	3	9	2	2	3	25 (aquatic)
Sodium (dissolved)	mg/L	34	36	30	27	24	18	12	22	13	< 30 (drinking)
Aluminium (dissolved)	mg/L	0.04	0.01	0.01	0.01	0.03	1.77	0.2	0.06	-	< 0.055 (aquatic)
Arsenic (dissolved)	mg/L	<0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.002	0.001	< 0.013 (aquatic)
Cadmium (dissolved)	mg/L	<0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	< 0.0002 (aquatic)
Chromium (dissolved)	mg/L	<0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	< 0.001 (aquatic)
Cobalt (dissolved)	mg/L	<0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	-	< 0.0014 (aquatic)
Copper (dissolved)	mg/L	<0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	< 0.0014 (aquatic)
Lead (dissolved)	mg/L	<0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	< 0.0034 (aquatic)
Molybdenum (dissolved)	mg/L	<0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	-	< 0.034 (aquatic)
Nickel (dissolved)	mg/L	0.001	0.001	0.001	0.001	0.001	0.003	0.001	0.001	0.002	< 0.011 (aquatic)
Selenium (dissolved)	mg/L	<0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	-	< 0.005 (aquatic)
Silver (dissolved)	mg/L	<0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	-	< 0.001 (aquatic)
Uranium (dissolved)	mg/L	<0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	-	< 0.001 (aquatic)
Vanadium (dissolved)	mg/L	<0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	-	< 0.01 (aquatic)
Zinc (dissolved)	mg/L	<0.005	0.005	0.005	0.005	0.005	0.016	0.005	0.005	0.005	< 0.008 (aquatic)
Boron (dissolved)	mg/L	0.07	0.09	0.05	0.05	0.05	0.06	0.05	0.05	-	< 0.94 (aquatic)
Iron (dissolved)	mg/L	0.33	0.37	0.33	0.2	0.49	0.77	0.16	0.2	-	< 0.7 (aquatic)
Aluminium (total)	mg/L	0.26	0.08	0.06	0.15	0.38	5.67	18.1	0.66	-	< 5 (stock)

Parameter	Unit	SW3									Default Guideline Value (refer Table 3.1)
		23/5/18	28/6/18	24/7/18	21/8/18	11/9/18	13/11/18	17/12/18	14/2/19	26/3/19	
Arsenic (total)	mg/L	0.001	0	0.002	0.001	0.002	0.004	0.002	0.002	0.003	< 2.0 (irrigation) < 0.5 (stock)
Cadmium (total)	mg/L	<0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	< 0.01 (stock)
Chromium (total)	mg/L	<0.001	0.001	0.001	0.001	0.001	0.006	0.014	0.001	0.001	< 1 (stock)
Cobalt (total)	mg/L	<0.001	0	0.001	0.001	0.001	0.004	0.01	0.001	-	< 0.1 (irrigation)
Copper (total)	mg/L	<0.001	0	0.001	0.001	0.001	0.004	0.017	0.001	0.001	<1 (stock)
Lead (total)	mg/L	<0.001	0.001	0.001	0.001	0.001	0.004	0.008	0.001	0.001	< 0.1 (stock)
Molybdenum (total)	mg/L	<0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	-	< 0.05 (irrigation)
Nickel (total)	mg/L	0.002	0	0.001	0.001	0.001	0.008	0.017	0.002	0.004	< 1 (stock)
Selenium (total)	mg/L	<0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	-	< 0.02 (stock)
Uranium (total)	mg/L	<0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	-	< 0.1 (irrigation)
Vanadium (total)	mg/L	<0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01	-	< 0.5 (irrigation)
Zinc (total)	mg/L	<0.005	0.005	0.013	0.005	0.005	0.013	0.036	0.005	0.005	< 5 (irrigation)
Boron (total)	mg/L	0.05	0.07	0.05	0.05	0.06	0.05	0.05	0.07	-	< 5 (stock)
Iron (total)	mg/L	1.28	1.73	2.31	1.11	1.4	7.39	16.6	1.62	-	< 10 (irrigation)
Fluoride (total)	mg/L	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.3	0.2	< 2 (irrigation)
Ammonia (total)	mg/L	0.15	0.04	0.41	0.43	0.12	0.03	0.05	0.05	0.06	< 0.02 (aquatic)
Nitrate as N	mg/L	<0.01	0.01	0.03	0.01	0.01	0.03	0.2	0.01	0.01	< 1.1 (aquatic)
Phosphorus as P (total)	mg/L	0.02	0.07	0.04	0.09	0.03	0.16	0.44	0.06	0.02	< 50 (aquatic)
Reactive Phosphorus as P	mg/L	<0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	< 0.02 (aquatic)

Table A.5 - Local water quality sampling data - Olive Downs Project (SW4/SW5/SW6/SW8)

Parameter	Unit	SW4		SW5	SW6		SW8				Default Guideline Value (refer Table 3.1)
		20/7/17	13/11/18	13/11/18	20/7/17	21/12/18	20/7/17	13/11/18	21/12/18	14/2/19	
pH	-	8.38	7.7	8.1	8.33	-	8.47	7.8	6.95	7.69	6.5-8.5 (aquatic)
Electrical Conductivity	µS/cm	781	428	191	1,230	-	2,020	1,120	958	477	< 720 (baseflow) < 250 (high flow)
Total Suspended Solids	mg/L	5	23	80	28	-	<5	12	527	50	< 55 (aquatic)
Turbidity	NTU	4.9	88.2	824	95.4	-	14.5	26.8	2,240	252	< 50 (aquatic)
Dissolved Oxygen	% sat.	78	54.1	59.5	62.2	-	59.5	93.7	-	30.1	85-110% (aquatic)
Total Hardness	mg/L	147	105	43	149	-	300	164	133	67	150 (drinking)
Sulphate as SO4	mg/L	57	26	3	156	-	410	158	144	47	25 (aquatic)
Sodium (dissolved)	mg/L	105	42	18	197	-	300	154	136	66	< 30 (drinking)
Aluminium (dissolved)	mg/L	0.05	1.23	0.6	0.08	0.28	0.11	0.67	0.45	0.37	< 0.055 (aquatic)
Arsenic (dissolved)	mg/L	<0.001	0.004	0.003	<0.001	0.003	<0.001	0.002	0.001	0.001	< 0.013 (aquatic)
Cadmium (dissolved)	mg/L	<0.0001	0.0001	0.0001	<0.0001	0.0001	<0.0001	0.0001	0.0001	0.0001	< 0.0002 (aquatic)
Chromium (dissolved)	mg/L	<0.001	0.001	0.001	<0.001	0.001	<0.001	0.001	0.001	0.001	< 0.001 (aquatic)
Cobalt (dissolved)	mg/L	<0.001	0.002	0.001	<0.001	0.001	<0.001	0.001	0.001	0.001	< 0.0014 (aquatic)
Copper (dissolved)	mg/L	0.002	0.002	0.003	0.002	0.001	0.002	0.002	0.012	0.002	< 0.0014 (aquatic)
Lead (dissolved)	mg/L	<0.001	0.001	0.001	<0.001	-	<0.001	0.001	0.001	0.001	< 0.0034 (aquatic)
Molybdenum (dissolved)	mg/L	0.002	0.001	0.001	0.003	-	0.002	0.001	0.001	0.001	< 0.034 (aquatic)
Nickel (dissolved)	mg/L	0.002	0.005	0.004	0.003	-	0.002	0.004	0.004	0.002	< 0.011 (aquatic)
Selenium (dissolved)	mg/L	<0.01	0.01	0.01	<0.01	-	<0.01	0.01	0.01	0.01	< 0.005 (aquatic)
Silver (dissolved)	mg/L	<0.001	0.001	0.001	<0.001	-	<0.001	0.001	0.001	0.001	< 0.001 (aquatic)
Uranium (dissolved)	mg/L	<0.001	0.001	0.001	0.001	-	0.001	0.001	0.001	0.001	< 0.001 (aquatic)
Vanadium (dissolved)	mg/L	<0.01	0.01	0.01	<0.01	-	<0.01	0.01	0.01	0.01	< 0.01 (aquatic)
Zinc (dissolved)	mg/L	<0.005	0.005	0.005	<0.005	-	<0.005	0.012	0.007	0.005	< 0.008 (aquatic)
Boron (dissolved)	mg/L	0.1	0.1	0.07	0.11	0.07	0.08	0.1	0.09	0.05	< 0.94 (aquatic)
Iron (dissolved)	mg/L	<0.05	1.18	0.42	<0.05	-	0.07	0.69	0.31	0.28	< 0.7 (aquatic)
Aluminium (total)	mg/L	0.11	1.23	24.1	1.15	0.75	0.43	2.67	14.7	8.53	< 5 (stock)

Parameter	Unit	SW4		SW5	SW6		SW8				Default Guideline Value (refer Table 3.1)
		20/7/17	13/11/18	13/11/18	20/7/17	21/12/18	20/7/17	13/11/18	21/12/18	14/2/19	
Arsenic (total)	mg/L	<0.001	0.002	0.008	<0.001	0.004	<0.001	0.005	0.004	0.003	< 2.0 (irrigation) < 0.5 (stock)
Cadmium (total)	mg/L	<0.0001	0.0001	0.0001	<0.0001	0.0001	<0.0001	0.0001	0.0001	0.0001	< 0.01 (stock)
Chromium (total)	mg/L	0.011	0.001	0.019	<0.001	0.001	<0.001	0.002	0.021	0.011	< 1 (stock)
Cobalt (total)	mg/L	<0.001	0.002	0.014	0.001	0.001	<0.001	0.003	0.011	0.004	< 0.1 (irrigation)
Copper (total)	mg/L	<0.001	0.002	0.019	0.003	0.001	0.002	0.004	0.014	0.007	<1 (stock)
Lead (total)	mg/L	<0.001	0.001	0.018	<0.001	-	<0.001	0.002	0.01	0.006	< 0.1 (stock)
Molybdenum (total)	mg/L	0.002	0.001	0.001	0.003	-	0.002	0.001	0.001	0.001	< 0.05 (irrigation)
Nickel (total)	mg/L	0.002	0.005	0.023	0.004	-	0.003	0.006	0.022	0.011	< 1 (stock)
Selenium (total)	mg/L	<0.01	0.01	0.01	<0.01	-	<0.01	0.01	0.01	0.01	< 0.02 (stock)
Uranium (total)	mg/L	<0.001	0.001	0.001	0.001	-	0.001	0.001	0.001	0.001	< 0.1 (irrigation)
Vanadium (total)	mg/L	<0.01	0.01	0.04	<0.01	-	<0.01	0.01	0.03	0.02	< 0.5 (irrigation)
Zinc (total)	mg/L	<0.005	0.022	0.053	<0.005	-	<0.005	0.006	0.033	0.027	< 5 (irrigation)
Boron (total)	mg/L	0.09	0.09	0.08	0.11	0.1	0.08	0.09	0.13	0.08	< 5 (stock)
Iron (total)	mg/L	0.2	2.32	25.1	1.04	-	0.31	3.94	20.1	9.64	< 10 (irrigation)
Fluoride (total)	mg/L	0.3	0.2	0.2	0.4	-	0.3	0.2	0.3	0.2	< 2 (irrigation)
Ammonia (total)	mg/L	<0.01	0.06	0.48	<0.01	0.07	0.02	0.02	0.11	0.06	< 0.02 (aquatic)
Nitrate as N	mg/L	<0.01	0.01	0.02	<0.01	-	<0.01	0.01	0.01	0.01	< 1.1 (aquatic)
Phosphorus as P (total)	mg/L	0.02	0.1	0.96	0.07	-	0.05	0.07	0.43	0.31	< 50 (aquatic)
Reactive Phosphorus as P	mg/L	<0.01	0.01	0.03	<0.01	-	<0.01	0.01	0.01	0.01	< 0.02 (aquatic)

Table A.6 - Local water quality sampling data - Olive Downs Project (SW11/SW12)

Parameter	Unit	SW11									SW12			Default Guideline Value (refer Table 3.1)
		13/9/17	12/10/17	16/11/17	14/12/17	14/3/18	13/11/18	17/12/18	14/2/19	26/3/19	13/9/17	12/10/17	16/11/17	
pH	-	8.32	7.21	7.22	7.26	7.1	8.17	-	7.55	7.85	7.73	7.44	7.73	6.5-8.5 (aquatic)
Electrical Conductivity	µS/cm	595	590	515	515	262	439	-	456	182	612	631	571	< 720 (baseflow) < 250 (high flow)
Total Suspended Solids	mg/L	16	<5	17	15	16	56	49	72	88	11	<5	16	< 55 (aquatic)
Turbidity	NTU	26.4	8.8	84.3	35.2	101	477	-	304	491	12.5	1.7	77.6	< 50 (aquatic)
Dissolved Oxygen	% sat.	57.9	25.5	29.5	7	34.6	97.3	-	27.5	64.4	44.8	79.3	22.8	85-110% (aquatic)
Total Hardness	mg/L	110	142	125	146	61	74	102	76	45	119	166	132	150 (drinking)
Sulphate as SO4	mg/L	47	39	36	27	13	42	28	43	12	36	14	15	25 (aquatic)
Sodium (dissolved)	mg/L	78	83	65	63	23	49	52	52	18	64	85	67	< 30 (drinking)
Aluminium (dissolved)	mg/L	0.28	0.2	0.14	0.16	0.27	0.1	0.01	0.1	-	0.12	0.11	0.11	< 0.055 (aquatic)
Arsenic (dissolved)	mg/L	<0.001	0.001	0.002	0.002	<0.001	0.001	0.001	0.001	0.001	<0.001	0.003	0.001	< 0.013 (aquatic)
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	< 0.0002 (aquatic)
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 (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	< 0.0014 (aquatic)
Copper (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	0.002	0.002	0.001	0.002	0.002	<0.001	<0.001	<0.001	< 0.0014 (aquatic)
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)
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	< 0.034 (aquatic)
Nickel (dissolved)	mg/L	<0.001	0.002	0.002	0.003	0.001	0.003	0.002	0.002	0.002	0.002	0.002	0.002	< 0.011 (aquatic)
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	< 0.005 (aquatic)
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 (aquatic)
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 (aquatic)
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 (aquatic)
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)
Boron (dissolved)	mg/L	0.05	<0.05	0.05	0.07	<0.05	0.06	0.07	0.05	-	0.05	0.06	<0.05	< 0.94 (aquatic)
Iron (dissolved)	mg/L	0.15	0.34	0.19	0.38	0.17	0.16	0.06	0.11	-	0.1	0.87	0.18	< 0.7 (aquatic)
Aluminium (total)	mg/L	0.84	0.43	0.59	0.62	2.7	9.02	3.14	7.95	-	0.55	0.21	0.63	< 5 (stock)

Parameter	Unit	SW11									SW12			Default Guideline Value (refer Table 3.1)
		13/9/17	12/10/17	16/11/17	14/12/17	14/3/18	13/11/18	17/12/18	14/2/19	26/3/19	13/9/17	12/10/17	16/11/17	
Arsenic (total)	mg/L	<0.001	0.002	0.002	0.003	0.001	0.003	0.003	0.003	0.003	<0.001	0.003	0.002	< 2.0 (irrigation) < 0.5 (stock)
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)
Chromium (total)	mg/L	0.001	<0.001	<0.001	0.001	0.005	0.012	0.004	0.009	0.021	<0.001	<0.001	0.001	< 1 (stock)
Cobalt (total)	mg/L	<0.001	<0.001	0.001	0.001	0.001	0.005	0.002	0.004	-	<0.001	0.001	0.001	< 0.1 (irrigation)
Copper (total)	mg/L	0.002	0.001	0.008	<0.001	0.004	0.008	0.003	0.008	0.012	0.002	<0.001	0.002	<1 (stock)
Lead (total)	mg/L	<0.001	<0.001	<0.001	<0.001	0.002	0.007	0.002	0.005	0.006	<0.001	<0.001	<0.001	< 0.1 (stock)
Molybdenum (total)	mg/L	<0.001	0.001	0.001	<0.001	<0.001	0.001	0.001	0.001	-	<0.001	<0.001	<0.001	< 0.05 (irrigation)
Nickel (total)	mg/L	0.003	0.002	0.003	0.002	0.005	0.015	0.007	0.011	0.018	0.002	0.002	0.003	< 1 (stock)
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	< 0.02 (stock)
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	< 0.1 (irrigation)
Vanadium (total)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.01	0.01	-	<0.01	<0.01	<0.01	< 0.5 (irrigation)
Zinc (total)	mg/L	<0.005	<0.005	0.012	0.009	0.013	0.02	0.009	0.024	0.025	<0.005	<0.005	<0.005	< 5 (irrigation)
Boron (total)	mg/L	0.06	<0.05	0.06	<0.05	<0.05	0.06	0.07	0.08	-	0.07	0.07	<0.05	< 5 (stock)
Iron (total)	mg/L	0.94	0.85	0.92	1.5	3.2	11.1	4.62	9.34	-	0.67	1.29	1.41	< 10 (irrigation)
Fluoride (total)	mg/L	0.2	0.2	0.2	<0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	< 2 (irrigation)
Ammonia (total)	mg/L	0.05	0.14	0.03	0.1	0.1	0.12	0.03	0.05	0.04	0.04	0.07	0.03	< 0.02 (aquatic)
Nitrate as N	mg/L	<0.01	<0.01	0.13	<0.01	0.19	0.08	0.01	0.01	0.27	<0.01	<0.01	0.18	< 1.1 (aquatic)
Phosphorus as P (total)	mg/L	0.03	0.03	0.04	0.03	0.12	0.27	0.12	0.25	0.3	0.04	0.11	0.07	< 50 (aquatic)
Reactive Phosphorus as P	mg/L	<0.01	<0.01	-	<0.01	<0.01	0.01	0.01	0.01	0.02	<0.01	0.02	-	< 0.02 (aquatic)

Table A.7 – Local water quality sampling data – Olive Downs Project (SW12)

Parameter	Unit	SW12											Default Guideline Value (refer Table 3.1)
		14/12/17	25/1/18	14/3/18	23/5/18	28/6/18	24/7/18	21/8/18	13/11/18	17/12/18	14/2/19	26/3/19	
pH	-	7.9	8.1	7.03	7.44	7.37	7.54	7.24	7.75	-	7.23	7.98	6.5-8.5 (aquatic)
Electrical Conductivity	µS/cm	556	784	237	414	433	461	372	389	-	435	177	< 720 (baseflow) < 250 (high flow)
Total Suspended Solids	mg/L	10	51	28	27	10	45	238	33	30	23	82	< 55 (aquatic)
Turbidity	NTU	40.6	104	125		1.2	62.4	541	292	-	151	335	< 50 (aquatic)
Dissolved Oxygen	% sat.	11.8	31	12.7	3.2	43.5	53.9	-	52	-	3.3	58.7	85-110% (aquatic)
Total Hardness	mg/L	157		64	104	105	103	84	71	88	70	40	150 (drinking)
Sulphate as SO4	mg/L	6	8	12	9	6	8	21	34	18	41	10	25 (aquatic)
Sodium (dissolved)	mg/L	75	85	21	30	33	32	37	44	42	50	16	< 30 (drinking)
Aluminium (dissolved)	mg/L	0.12	0.05	0.23	0.04	0.01	0.05	0.19	0.14	0.06	0.22	-	< 0.055 (aquatic)
Arsenic (dissolved)	mg/L	0.002	0.002	<0.001	<0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	< 0.013 (aquatic)
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	< 0.0002 (aquatic)
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 (aquatic)
Cobalt (dissolved)	mg/L	<0.001	<0.001	<0.001	<0.001	0.001	0.001	0.002	0.001	0.001	0.001	-	< 0.0014 (aquatic)
Copper (dissolved)	mg/L	<0.001	<0.001	0.001	<0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.002	< 0.0014 (aquatic)
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	< 0.0034 (aquatic)
Molybdenum (dissolved)	mg/L	<0.001	0.002	<0.001	<0.001	0.001	0.001	0.001	0.001	0.001	0.001	-	< 0.034 (aquatic)
Nickel (dissolved)	mg/L	0.002	0.003	0.002	0.002	0.001	0.002	0.003	0.003	0.002	0.002	0.002	< 0.011 (aquatic)
Selenium (dissolved)	mg/L	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.01	0.01	0.01	0.01	-	< 0.005 (aquatic)
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 (aquatic)
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 (aquatic)
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 (aquatic)
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	< 0.008 (aquatic)
Boron (dissolved)	mg/L	0.09	0.08	<0.05	0.06	0.07	0.06	0.05	0.05	0.06	0.05	-	< 0.94 (aquatic)
Iron (dissolved)	mg/L	0.25	0.07	0.16	0.14	0.07	0.05	0.13	0.23	0.3	0.27	-	< 0.7 (aquatic)
Aluminium (total)	mg/L	0.56	1.27	2.83	0.87	0.07	0.93	7.04	4.97	1.31	6.26	-	< 5 (stock)

Parameter	Unit	SW12											Default Guideline Value (refer Table 3.1)
		14/12/17	25/1/18	14/3/18	23/5/18	28/6/18	24/7/18	21/8/18	13/11/18	17/12/18	14/2/19	26/3/19	
Arsenic (total)	mg/L	0.002	0.003	0.001	0.001	0.001	0.001	0.003	0.002	0.004	0.004	0.003	< 2.0 (irrigation) < 0.5 (stock)
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	< 0.01 (stock)
Chromium (total)	mg/L	<0.001	0.003	0.005	0.001	0.001	0.002	0.012	0.006	0.002	0.007	0.02	< 1 (stock)
Cobalt (total)	mg/L	<0.001	0.002	0.002	0.001	0.001	0.001	0.007	0.004	0.002	0.003	-	< 0.1 (irrigation)
Copper (total)	mg/L	<0.001	0.002	0.004	<0.001	<0.001	0.002	0.009	0.005	0.001	0.004	0.012	<1 (stock)
Lead (total)	mg/L	<0.001	<0.001	0.002	<0.001	0.001	0.001	0.006	0.004	0.002	0.004	0.005	< 0.1 (stock)
Molybdenum (total)	mg/L	<0.001	0.002	<0.001	<0.001	0.001	0.001	0.001	0.001	0.001	0.001	-	< 0.05 (irrigation)
Nickel (total)	mg/L	0.004	0.005	0.005	0.003	0.001	0.003	0.014	0.009	0.004	0.009	0.017	< 1 (stock)
Selenium (total)	mg/L	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.01	0.01	0.01	0.01	-	< 0.02 (stock)
Uranium (total)	mg/L	<0.001	<0.001	<0.001	<0.001	0.001	0.001	0.001	0.001	0.001	0.001	-	< 0.1 (irrigation)
Vanadium (total)	mg/L	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.02	0.01	0.01	0.01	-	< 0.5 (irrigation)
Zinc (total)	mg/L	<0.005	0.006	0.01	<0.005	0.01	0.007	0.017	0.013	0.005	0.013	0.027	< 5 (irrigation)
Boron (total)	mg/L	0.09	0.1	<0.05	0.06	0.07	0.05	0.06	0.05	0.06	0.07	-	< 5 (stock)
Iron (total)	mg/L	1.6	2.55	3.7	1.8	0.62	1.48	9.83	6.55	4.39	8.06	-	< 10 (irrigation)
Fluoride (total)	mg/L	<0.1	0.3	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	< 2 (irrigation)
Ammonia (total)	mg/L	0.06	0.02	0.1	0.02	0.04	0.13	1.88	0.15	0.03	0.04	0.08	< 0.02 (aquatic)
Nitrate as N	mg/L	<0.01	<0.01	0.05	<0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	< 1.1 (aquatic)
Phosphorus as P (total)	mg/L	0.04	0.14	0.11	0.06	0.07	0.06	0.31	0.15	0.09	0.15	0.29	< 50 (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	< 0.02 (aquatic)

Appendix B Water balance model - sensitivity assessment results

B1 Scenario 1 – Global increase in AWBM soil capacity by 20%

For the Scenario 1 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.

B1.1 MINE-AFFECTED WATER INVENTORY

Figure B.1 shows the combined forecast inventory for the key mine-affected water storages over the 29-year forecast, including the active in-pit storages (Railway Pit in Phase 2 to 5 and Main Pit in Phase 6). To prevent uncontrolled discharges from the mine water storages, MOVs have been set for the out-of-pit mine-affected water storages. The MOV 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 TSV, which is the combined capacity of these dams.

The model results show the following:

- For the 1 percentile results (very wet climatic conditions), the peak inventory in the mine-affected water storages reaches a volume of around 7,975 ML.
- For the 50th percentile results (median climatic conditions), the peak inventory in the mine-affected water storages reaches a volume of around 1,180 ML.
- Mine-affected water would not need to be stored in the inactive pits for 50th percentile (median) climatic conditions for extended periods of time for the 29-year simulation.

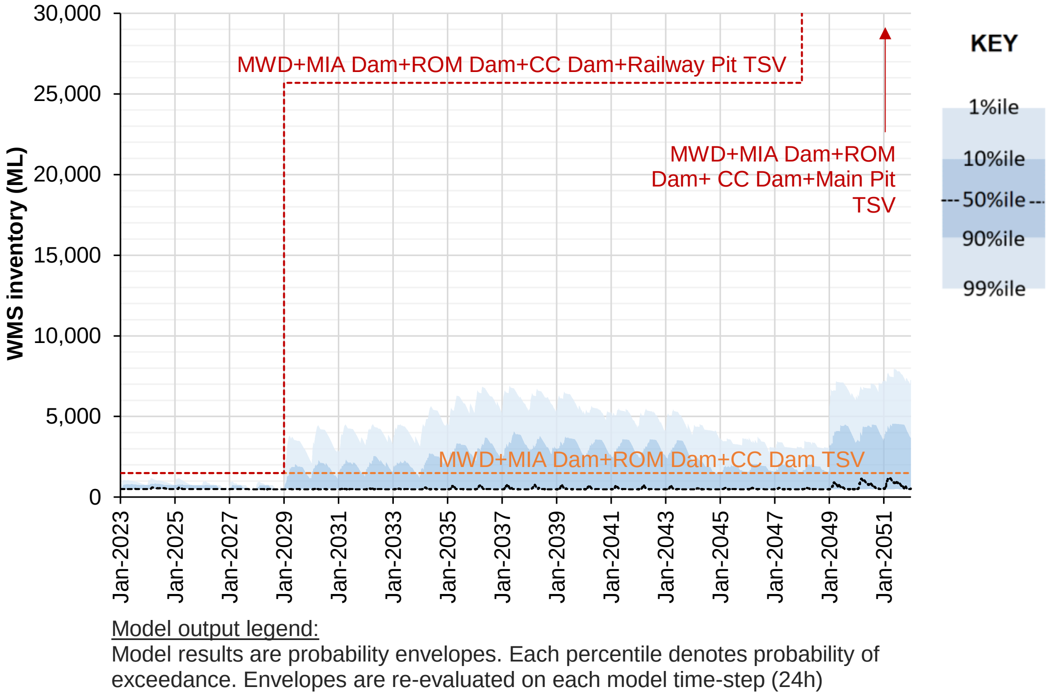

Figure B.1 – Forecast water management system inventory – Sensitivity Scenario 1

B1.2 EXTERNAL MAKEUP REQUIREMENTS

Figure B.2 shows the total annual modelled demand for water from external sources over the 29-year simulation.

The modelling results show the following:

- During mining, the requirement for external raw water supply increases during dry climatic conditions but reduces during median and wet climatic conditions. There is a:
    - 1% likelihood of requiring 4,580 ML/year (or more) from external sources.
    - 10% likelihood of requiring 4,330 ML/year (or more) from external sources.
    - 50% likelihood of requiring 3,100 ML/year (or more) from external sources.
- The median external raw water supply requirement is generally consistent over the life of the project, until it sharply declines in Phase 6.

The modelling results show that external raw water requirements generally reduce over the life of the Project. This is primarily due to the continual increase in water captured from mine disturbance areas over time.

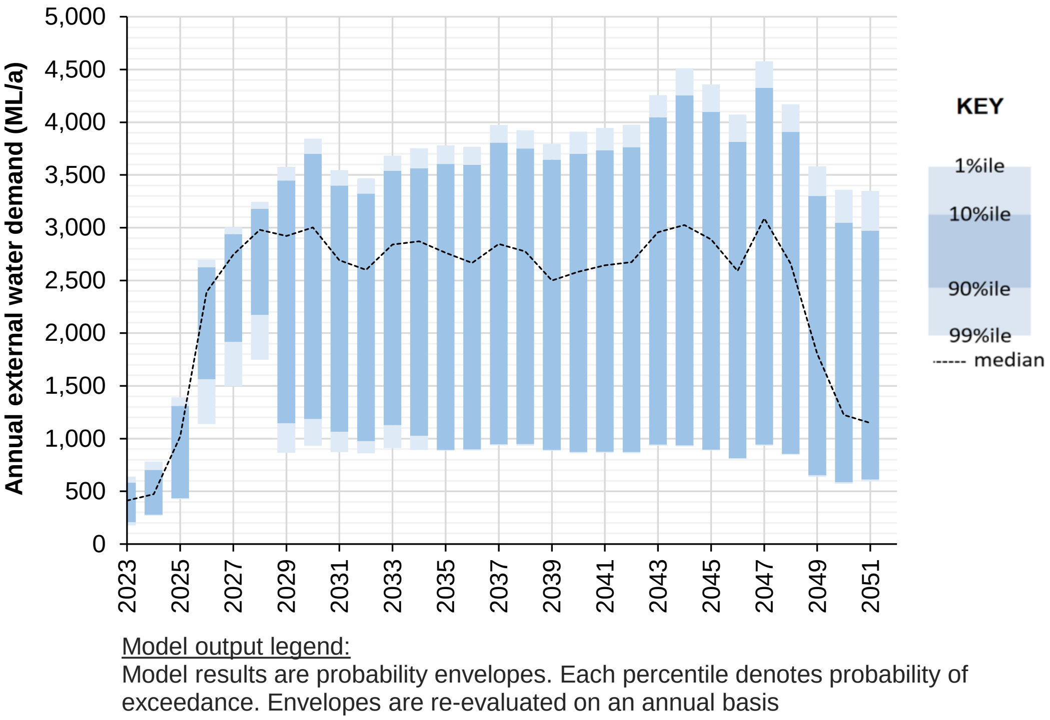

Figure B.2 – Forecast annual external water requirements – Sensitivity Scenario 1

B1.3 CONTROLLED RELEASES

The water balance model is configured to release water in accordance with the rules outlined in Section 6.11. The predicted annual controlled release volumes from the mine-affected water dams are provided in Figure B.3. The results show that controlled releases would only be required for very wet (1 percentile) climatic conditions.

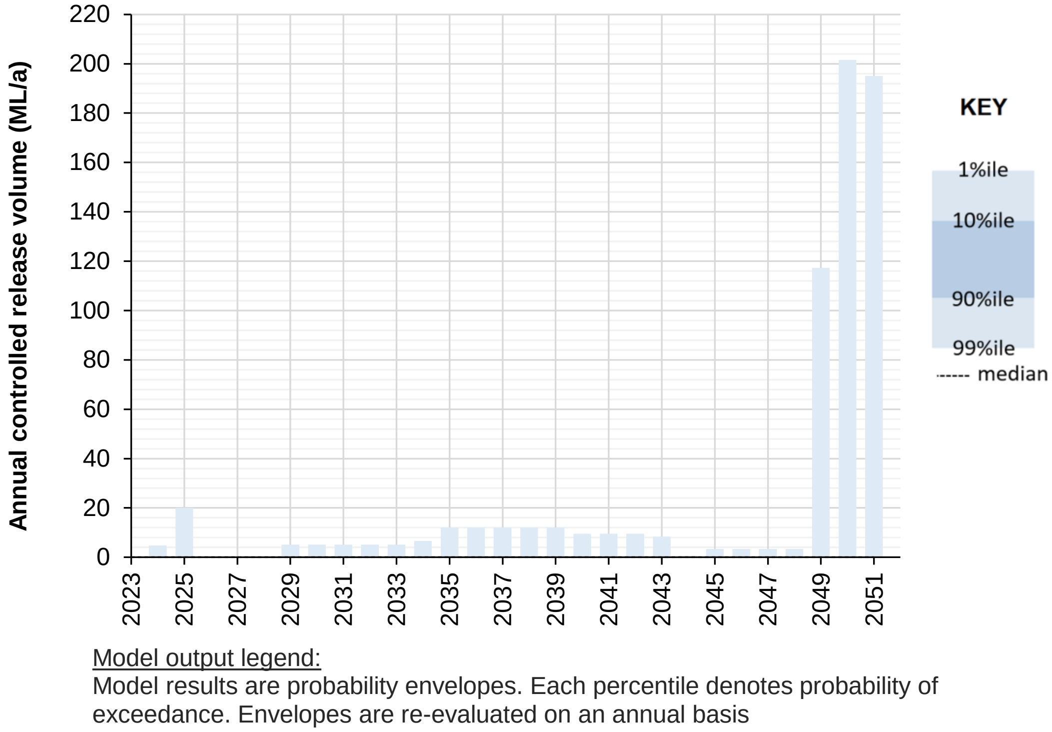

Figure B.3 – Forecast annual controlled release volumes – Sensitivity Scenario 1

B1.4 UNCONTROLLED MINE AFFECTED WATER SPILLWAY DISCHARGES

Based on the water balance modelling results, MWD, MIA Dam and CC Dam would not have any uncontrolled spillway discharges to the Isaac River for any climatic conditions assessed over the life of the Project for the Scenario 1 sensitivity analysis.

B2 Scenario 2 – Global decrease in AWBM soil capacity by 20%

For the Scenario 2 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.

B2.1 MINE-AFFECTED WATER INVENTORY

Figure B.4 shows the combined forecast inventory for the key mine-affected water storages over the 29-year forecast, including the active in-pit storages (Railway Pit in Phase 2 to 5 and Main Pit in Phase 6). To prevent uncontrolled discharges from the mine water storages, MOVs have been set for the out-of-pit mine-affected water storages. The MOV 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 TSV, which is the combined capacity of these dams.

The model results show the following:

- For the 1 percentile results (very wet climatic conditions), the peak inventory in the mine-affected water storages reaches a volume of around 12,920 ML.
- For the 50th percentile results (median climatic conditions), the peak inventory in the mine-affected water storages reaches a volume of around 2,190 ML.
- Mine-affected water would not need to be stored in the inactive pits for 50th percentile (median) climatic conditions until the final three years of the 29-year simulation.

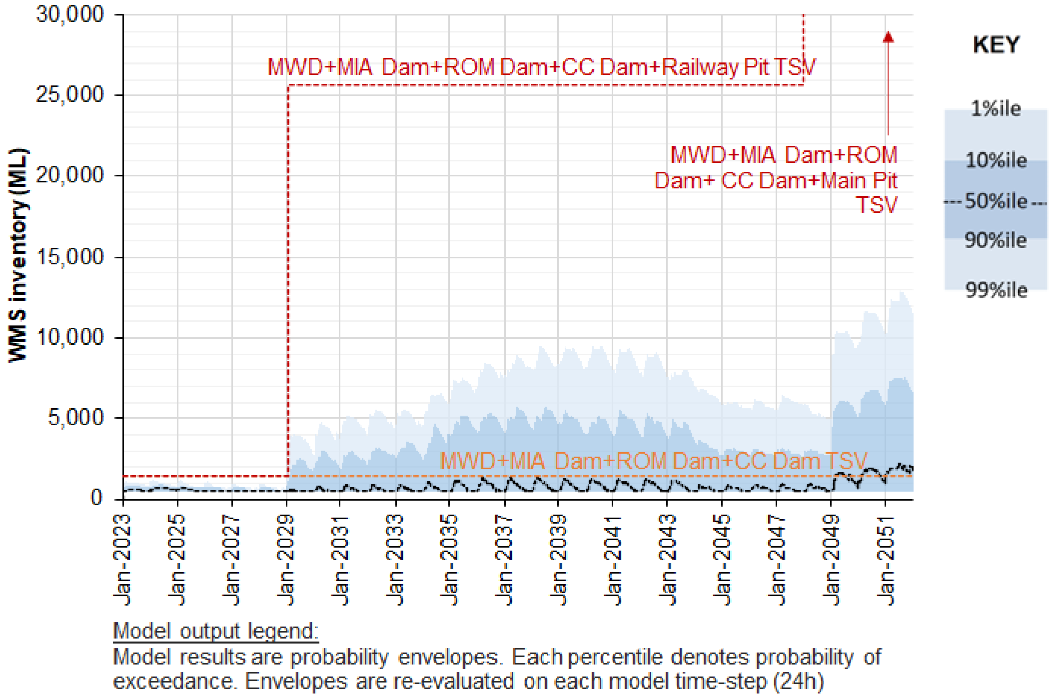

Figure B.4 – Forecast water management system inventory – Sensitivity Scenario 2

B2.2 EXTERNAL MAKEUP REQUIREMENTS

Figure B.5 shows the total annual modelled demand for water from external sources over the 29-year simulation.

The modelling results show the following:

- During mining, the requirement for external raw water supply increases during dry climatic conditions but reduces during median and wet climatic conditions. There is a:
  - 1% likelihood of requiring 4,460 ML/year (or more) from external sources.
  - 10% likelihood of requiring 3,990 ML/year (or more) from external sources.
  - 50% likelihood of requiring 2,770 ML/year (or more) from external sources.
- The median external raw water supply requirement is generally consistent over the life of the project, until it sharply declines in Phase 6.

The modelling results show that external raw water requirements generally reduce over the life of the Project. This is primarily due to the continual increase in water captured from mine disturbance areas over time.

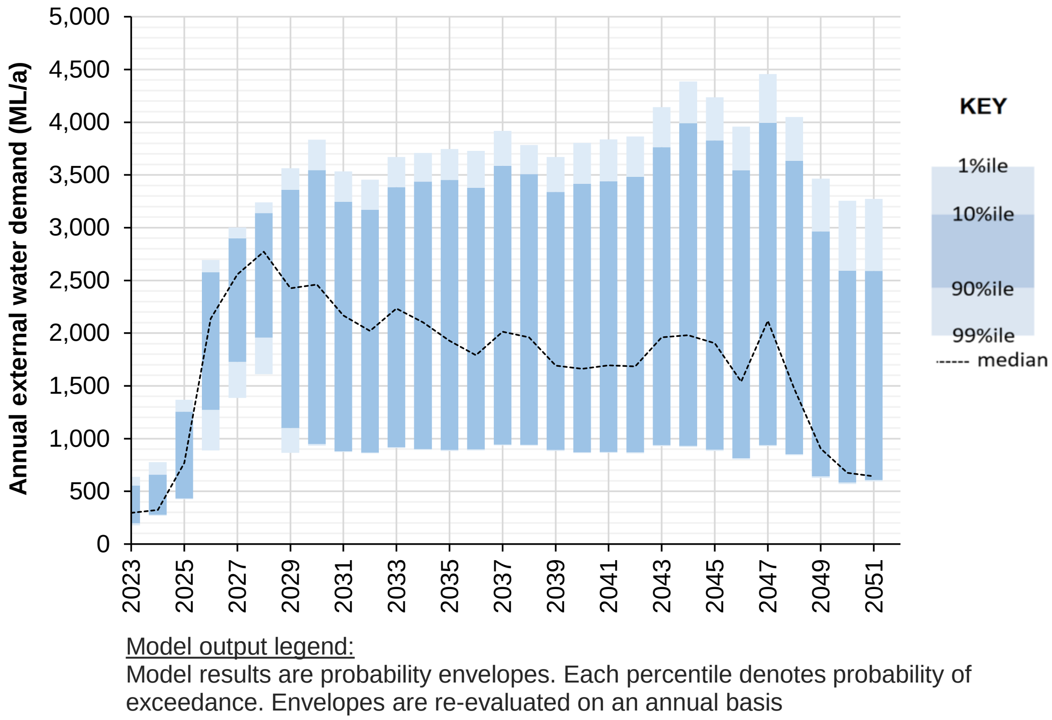

Figure B.5 – Forecast annual external water requirements – Sensitivity Scenario 2

B2.3 CONTROLLED RELEASES

The water balance model is configured to release water in accordance with the rules outlined in Section 6.11. The predicted annual controlled release volumes from the mine-affected water dams are provided in Figure B.6. The results show that controlled releases would only be required for very wet (1 percentile) climatic conditions.

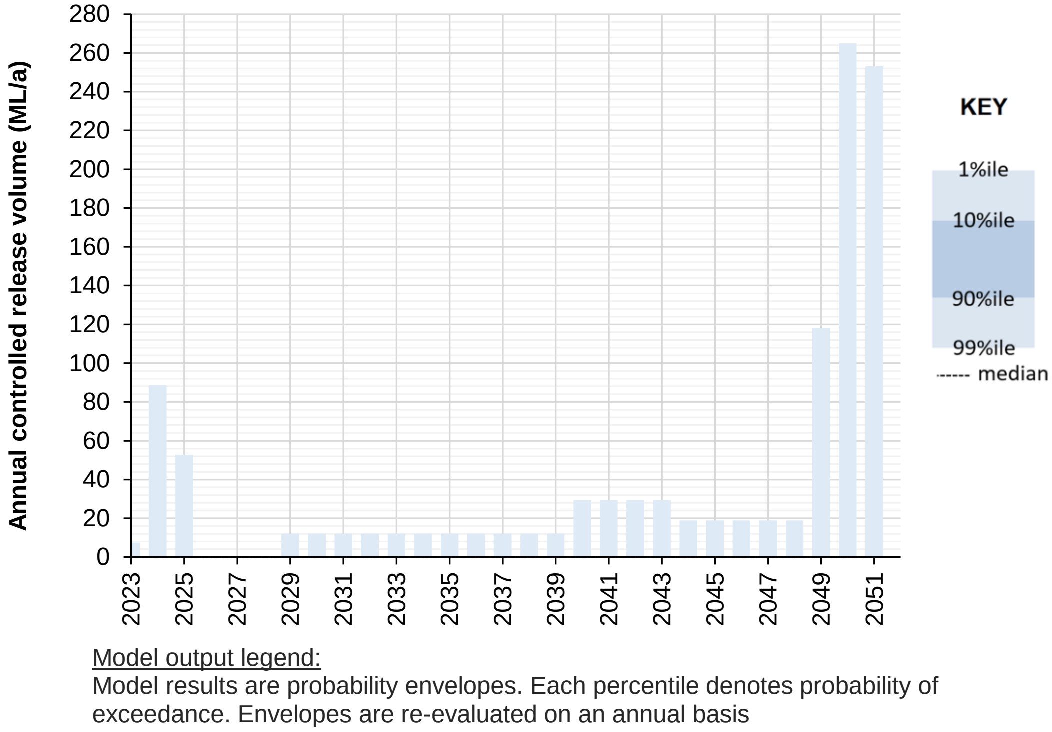

Figure B.6 – Forecast annual controlled release volumes – Sensitivity Scenario 2

B2.4 UNCONTROLLED MINE AFFECTED WATER SPILLWAY DISCHARGES

Based on the water balance modelling results, MWD, MIA Dam and CC Dam would not have any uncontrolled spillway discharges to the Isaac River for any climatic conditions assessed over the life of the Project for the Scenario 2 sensitivity analysis.

Appendix C Hydrologic and hydraulic modelling

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C1 Hydrology

C1.1 OVERVIEW

Two hydrological models were developed for the Winchester South Project (the Project) using the XPRafts runoff-routing model (Innovyze, 2019). The two hydrological models are:

- Isaac River XPRAFTS Model – which includes the Isaac River catchment to the North Creek confluence; and
- Ripstone Creek XPRAFTS Model - which includes the catchments of the Ripstone Creek.

This section of the report describes the model development, configuration and calibration of both hydrological models.

The Isaac River XPRafts model was calibrated to hydrographs recorded at the Deverill and Goonyella gauging stations for three historical flood events (2008, 2010 and 2017). The flood events (2008, 2010 and 2017) were adopted as these events occurred within the last 15 years, there is adequate calibration data available and events are considered relatively large events.

The calibrated Isaac River XPRafts model was used to estimate 10%, 5%, 1% and 0.1% Annual Exceedance Probability (AEP) peak design discharges, as well as the probable maximum flood (PMF) discharge based on design rainfall data (rainfall depths, areal reduction factors and temporal patterns) applied in accordance with ensemble event procedures in Australian Rainfall and Runoff (AR&R) (Ball et al., 2019). The peak design discharges for the 10%, 5% and 1% AEP events were validated against the peak discharges estimated using a Flood Frequency Analysis (FFA) of the recorded annual maximums at the Deverill gauging station.

There are no recorded continuous streamflow data available for calibration of the streams within the Ripstone Creek XPRAFTS Model. As a result, the Ripstone Creek modelled XPRafts design discharges have been verified against Isaac River Flood Frequency Estimates (RFFE) and Rational Method techniques for the 1% AEP design flood event (refer to Section C1.5.9).

The two validated XPRafts models were used to estimate design discharges for input into the hydraulic model.

C1.2 FLOOD FREQUENCY ANALYSIS

C1.2.1 Methodology

A Log Pearson III (LP3) distribution was fitted to an annual series of recorded peak flood discharges at the Queensland Department of Resources (DoR's) Deverill gauging station using the Bayesian inference methodology recommended in the AR&R (Ball et al., 2019). FLIKE software (BMT, 2017) was used to generate the FFA, giving the option to censor lows flows to improve the LP3 fit for the larger events. For the purposed of the FFA, an October to September water year was adopted.

The Isaac River hydraulic model developed for this study provided an opportunity to review the high flow rating at the stream gauge. The review identified that the gauge is poorly located as the creek banks are perched with the adjacent floodplain flowing at substantially different levels to the recorded levels in the Isaac River. The hydraulic model provided an opportunity to update the high flow rating and revise the historical flood peaks.

An FFA has been undertaken for the annual maximum series obtained using the DoR rating, as well as an alternate FFA using the adjusted flood peaks using the rating curve derived using the hydraulic model.

C1.2.2 Annual maximum peak discharges

The 51 annual maximum peak discharges (using the DoR rating) for the October 1968 – September 1969 water year through to the October 2018 - September 2019 water year are shown in Table C.1.

C1.2.3 FFA design discharges using DoR rating

Figure C.1 shows the LP3 distribution fitted to the annual series of recorded peak flows (using the DoR rating) in the Isaac River at Deverill gauge. The 90% confidence limits of the estimate are also shown. To improve the fit of the LP3 curve at higher discharges the lowest 7 annual maximums (flows less than 60 cubic metres per second [m^3/s]) were censored from the main dataset.

Table C.1 - Annual maximum discharges at Isaac River at Deverill stream gauge

Year (Oct-Sep)	Peak flow (m^3/s)	Year (Oct-Sep)	Peak flow (m^3/s)	Year (Oct-Sep)	Peak flow (m^3/s)
1968/69	3	1985/86	142	2002/03	195
1969/70	511	1986/87	184	2003/04	350
1970/71	102	1987/88	2,638	2004/05	20
1971/72	188	1988/89	2,137	2005/06	308
1972/73	233	1989/90	235	2006/07	401
1973/74	1,261	1990/91	2,429	2007/08	2,142
1974/75	424	1991/92	110	2008/09	466
1975/76	533	1992/93	1	2009/10	501
1976/77	156	1993/94	753	2010/11	1,827
1977/78	1,703	1994/95	30	2011/12	1,121
1978/79	2,113	1995/96	236	2012/13	263
1979/80	179	1996/97	1,198	2013/14	1
1980/81	608	1997/98	1,706	2014/15	205
1981/82	83	1998/99	581	2015/16	1,791
1982/83	1,124	1999/00	144	2016/17	1,625
1983/84	307	2000/01	638	2017/18	25
1984/85	137	2001/02	68	2018/19	30

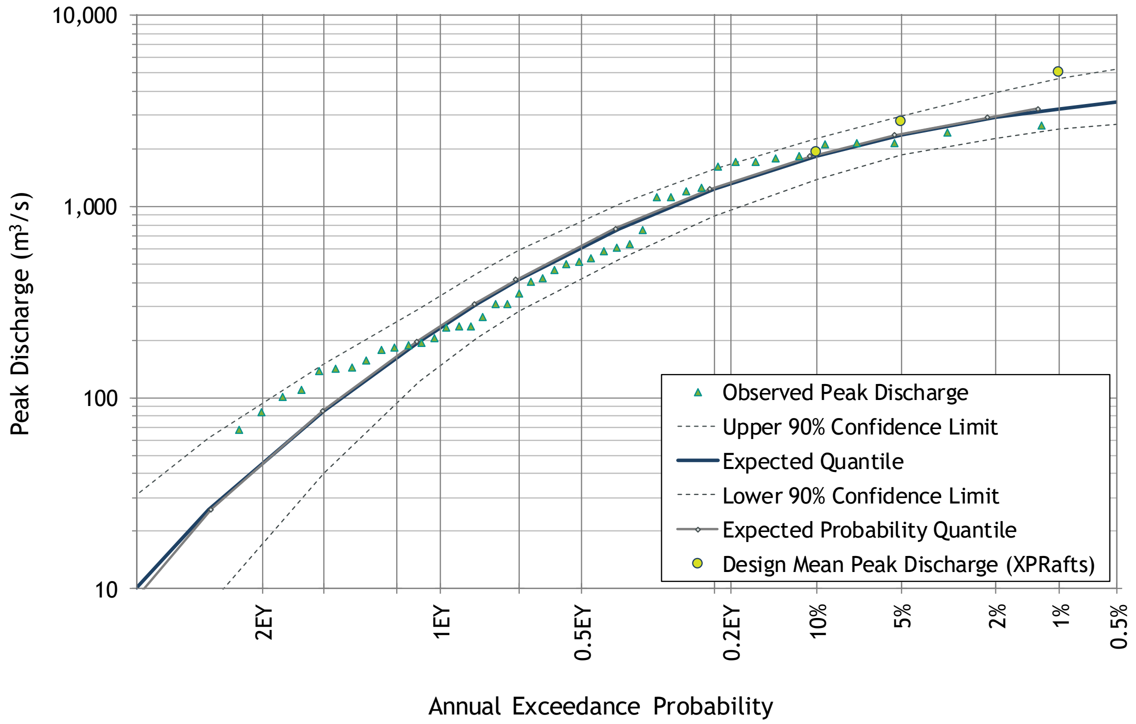


Figure C.1 – LP3 distribution fitted to Isaac River at Deverill annual series, 1968 to 2019

Table C.2 shows the FFA peak discharges for the 10%, 5% and 1% AEP events. It is beyond the limit of extrapolation to use the FFA for design discharges less frequent than this.

Table C.2 - FFA design discharges at Deverill

Design event	Peak discharge (m^3/s)	Lower confidence limit (m^3/s)	Upper confidence limit (m^3/s)
10% AEP (10 Year ARI)	1,827	1,389	2,283
5% AEP (20 Year ARI)	2,353	1,855	2,985
1% AEP (100 Year ARI)	3,250	2,528	4,687

AEP - Annual Exceedance Probability
ARI - Average Recurrence Interval

C1.2.4 Rating curve review

Figure C.2 compares the Deverill discharge rating curve (water surface elevation vs flow relationship) with the rating curve derived using the TUFLOW model. The stream gaugings used to derive the rating are also shown. The following is of note with regards to the rating curve comparison:

- The TUFLOW model matches the in-channel rating curve very well;
- The stream gaugings above 11 m match the DoR rating poorly;
- At a water level of about 11.2 m, the TUFLOW model predicts discharges could vary between 2,200 and 3,000 m^3/s with no change in water level. It matches the gaugings above this level reasonably well.
- A review of the model results shows that the channel banks are perched about 1 to 2 metres (m) above the floodplain. The adjacent floodplain flows independently of the main channel. The channel crest level is about 11.5 m deep at the gauge.

- Above a flow rate of 3,000 m³/s the rating curve rises again as the floodplain flows become fully engaged and the flows drain at the same level across the floodplain.

This suggests that the location of the gauge is poor and the DoR rating above about 10.5m is poor. Given this, there is a high level of uncertainty associated with DoR peak discharges between 2,200 and 3,000 m³/s.

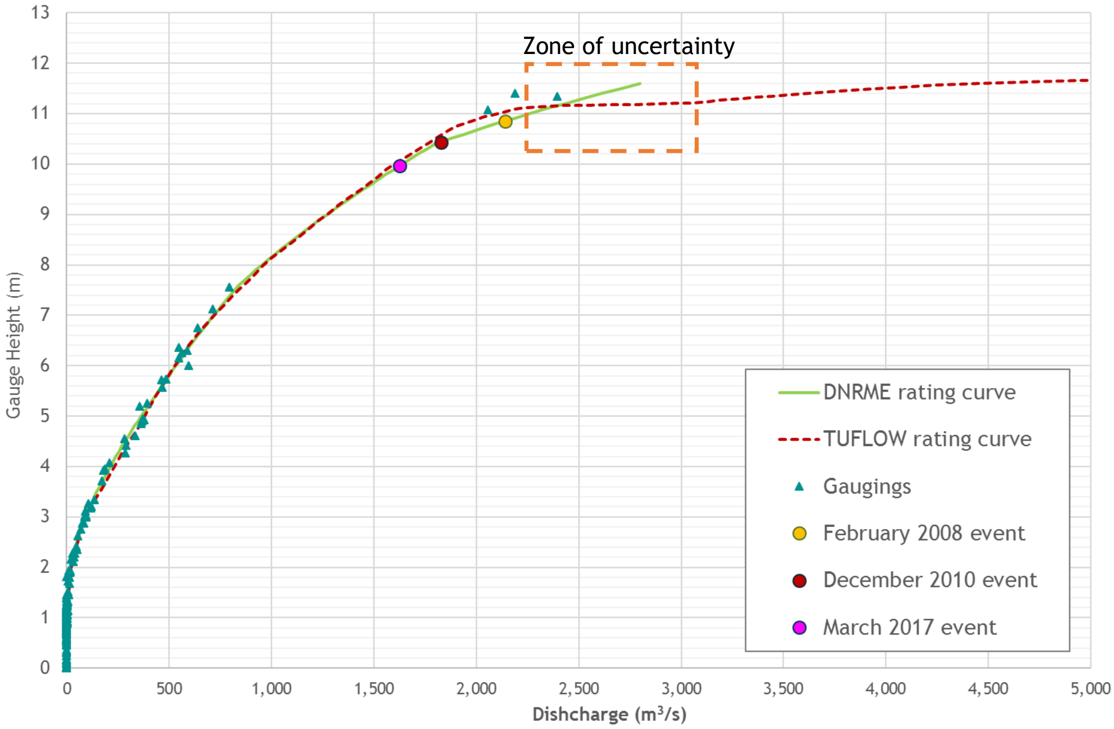


Figure C.2 - Comparison of DoR and modelled rating curves, Isaac River at Deverill

C1.2.5 FFA design discharges using hydraulic model rating

Table C.3 shows the updated nine (9) annual maximum flow rates using the hydraulic model rating. The revised rating has resulted in a significant increase in the flow rate for the two largest events and a slight decrease for next seven largest events. The lower in-channel event peaks were not changed from those given in Table C.1.

Table C.3 – Updated annual maximum flow rates using the TUFLOW rating curve

Year (Oct-Sep)	Recorded water level (mAHD)	Peak flow (m^3/s)		Difference in peak flow (m^3/s)
		Deverill rating curve (DRNME, 2016)	TUFLOW rating curve	
1987/88	11.43	2,638	3,701	+1,062
1990/91	11.20	2,429	3,037	+607
2007/08	10.86	2,142	1,975	-166
1988/89	10.85	2,137	1,971	-166
1978/80	10.82	2,113	1,949	-165
2010/11	10.44	1,827	1,783	-44
2015/16	10.38	1,791	1,761	-31
1997/98	10.17	1,706	1,687	-19
1977/79	10.16	1,703	1,682	-21

Figure C.3 and Table C.4 shows the updated FFA, using the updated annual maximums. The following is of note:

- The estimated 10% AEP (10 Year ARI) design discharge at Deverill is:
  - 1,880 m^3/s for the updated FFA compared to 1,827 m^3/s for the original FFA, an increase of 53 m^3/s; and
  - the 90% confidence interval ranges from 1,360 m^3/s to 2,664 m^3/s;
- The estimated 5% AEP (20 Year ARI) design discharge at Deverill is:
  - 2,699 m^3/s for the updated FFA compared to 2,353 m^3/s for the original FFA, an increase of 346 m^3/s; and
  - the 90% confidence interval ranges from 1,929 m^3/s to 4,058 m^3/s; and
- The estimated 1% AEP (100 Year ARI) design discharge at Deverill is:
  - 4,750 m^3/s for the updated FFA compared to 3,250 m^3/s for the original FFA, an increase of 1,500 m^3/s; and
  - the 90% confidence interval ranges from 3,051 m^3/s to 10,082 m^3/s.

Table C.4 – Updated FFA design discharges at Deverill using the TUFLOW rating curve

Design event	Peak discharge (m^3/s)	Lower confidence limit (m^3/s)	Upper confidence limit (m^3/s)
10% AEP (10 Year ARI)	1,880	1,360	2,664
5% AEP (20 Year ARI)	2,699	1,929	4,058
1% AEP (100 Year ARI)	4,750	3,051	10,082

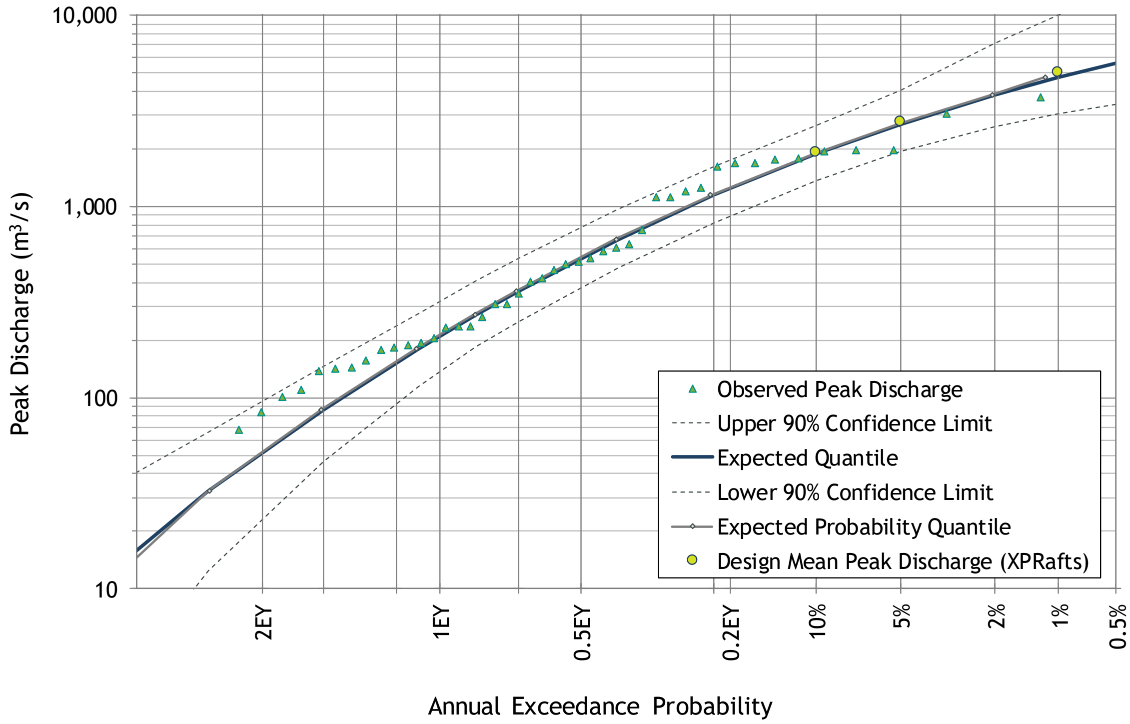


Figure C.3 - LP3 distribution fitted to the updated Isaac River at Deverill annual series, 1968 to 2019

C1.3 XPRAFTS MODELLING

C1.3.1 Spatial configuration

Figure C.4 and Figure C.5 show the XPRafts model configuration used for determining catchment hydrology in the vicinity of the project area.

The Isaac River XPRAFTS Model covers the Isaac River catchment upstream of the Deverill gauging station. The Isaac River XPRAFTS Model includes 104 sub-catchments ranging in size from 0.6 square kilometres (km^2) to 204 km^2. Table C.5 shows the areas of each sub-catchment.

The Ripstone Creek XPRAFTS Model covers the Ripstone Creek catchment upstream of the confluence with Isaac River. The Ripstone Creek XPRAFTS Model includes 33 sub-catchments ranging in size from 1.4 km^2 to 9.3 km^2. Table C.6 shows the areas of each sub-catchment.

C1.3.2 Sub-catchment parameters

Model parameters for each sub-catchment were determined as follows:

- A percentage impervious of zero was adopted for all sub-catchments;
- Catchment slopes were determined based on the available topographic data;
- A sub-catchment storage coefficient multiplication factor 'Bx' of 1.0 was adopted;
- Sub-catchment PERN 'n' values were determined based on the density of vegetation in each sub-catchment. The adopted Isaac River XPRAFTS Model sub-catchment PERN 'n' values range between 0.05 and 0.08 and the adopted Ripstone Creek XPRAFTS Model sub-catchment PERN 'n' is 0.04; and
- The selection of initial and continuing losses for design events is described in Section C1.5.5.

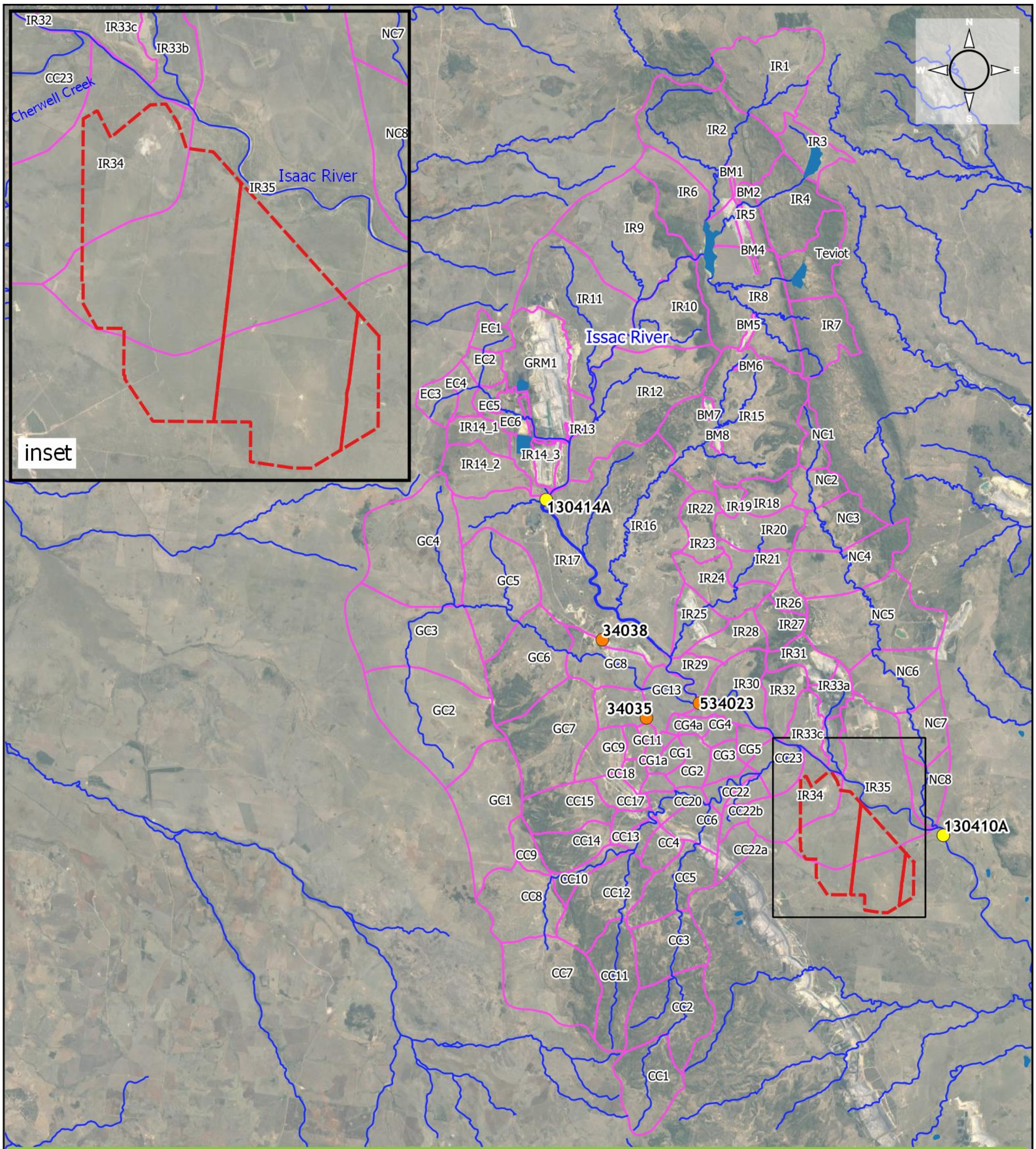
Channel routing was modelled using the Muskingum-Cunge method, based on the channel length and average channel slope for each “link” between sub-catchment node. A channel velocity of 0.5 m/s and a ‘x’ coefficient of 0.25 was adopted for the routing estimation.

Table C.5 -Isaac River XPRAFTS Model sub-catchment areas

ID	Area (km^2)	ID	Area (km^2)	ID	Area (km^2)	ID	Area (km^2)
CC1	49.6	CG1a	4.2	GC10	6.7	IR21	23.1
CC2	63.2	CG1b	2.0	GC11	3.0	IR22	17.4
CC3	45.4	CG2	17.2	GC12	21.6	IR23	7.1
CC4	13.3	CG3	12.7	GC13	25.6	IR24	36.5
CC5	43.4	CG4	8.0	IR1	82.9	IR25	25.1
CC6	21.5	CG4a	2.5	IR2	121.4	IR26	10.8
CC7	78.4	CG4b	6.3	IR3	24.3	IR27	18.3
CC8	55.5	CG5	9.8	IR4	54.4	IR28	24.1
CC9	13.2	EC1	13.2	IR5	25.6	IR29	15.2
CC10	14.2	EC2	13.4	IR6	48.0	IR30	44.4
CC11	51.1	EC3	15.8	IR7	41.3	IR31	21.2
CC12	57.1	EC4	12.1	IR8	25.0	IR32	25.4
CC13	9.1	EC5	8.1	IR9	110.8	IR33a	15.0
CC14	29.1	EC6	14.1	IR10	57.8	IR33b	11.6
CC15	39.6	EC7	2.9	IR11	107.2	IR33c	20.8
CC16	9.1	EC8	0.8	IR12	113.7	IR34	50.1
CC17	14.8	EC9	0.6	IR13	15.9	IR35	135.6
CC18	7.4	GC1	78.7	IR14_1	19.4	NC1	15.2
CC19	5.4	GC2	109.8	IR14_2	38.6	NC2	20.9
CC20	14.0	GC3	104.7	IR14_3	11.1	NC3	37.6
CC21	11.1	GC4	113.7	IR15	162.4	NC4	57.8
CC22	8.3	GC5	78.0	IR16	204.1	NC5	93.3
CC22a	15.5	GC6	72.1	IR17	123.3	NC6	52.3
CC22b	7.2	GC7	80.2	IR18	19.4	NC7	29.4
CC23	23.7	GC8	37.7	IR19	7.9	NC8	24.9
CG1	8.8	GC9	22.2	IR20	34.2	Teviot	40.7

Table C.6 -Ripstone Creek XPRAFTS Model sub-catchment areas

ID	Area (km^2)	ID	Area (km^2)	ID	Area (km^2)	ID	Area (km^2)
RC01	9.3	RC07	4.3	RC15	6.8	RC23	3
RC02	9.1	RC08	3	RC16	4.7	RC24	2.4
RC03a	2.8	RC09	3.4	RC17	7.4	RC25	8.1
RC03b	2.3	RC10	1.4	RC18	3.8	RC26	2.7
RC04	4.5	RC11	5.1	RC19	2.7	RC27	3.4
RC05	8.6	RC12	5.3	RC20	2.5	RC28	5.9
RC06	4.7	RC13	4.6	RC21	4.8	RC29	8.9
RC07	4.3	RC14	1.4	RC22	2	RC30	3.5
						RC31	4.7



Projection: MGA Zone 55 Datum: GDA 94

Legend

- Stream gauge
- Rainfall gauge
- Watercourse
- Waterbody
- XPRafts catchment
- Winchester South MLA

Winchester South Project

XPRafts model configuration

0 10 20 30 km

wrm water + environment

Figure C.4 – XPRafts model sub-catchments for the Isaac River to Deverill

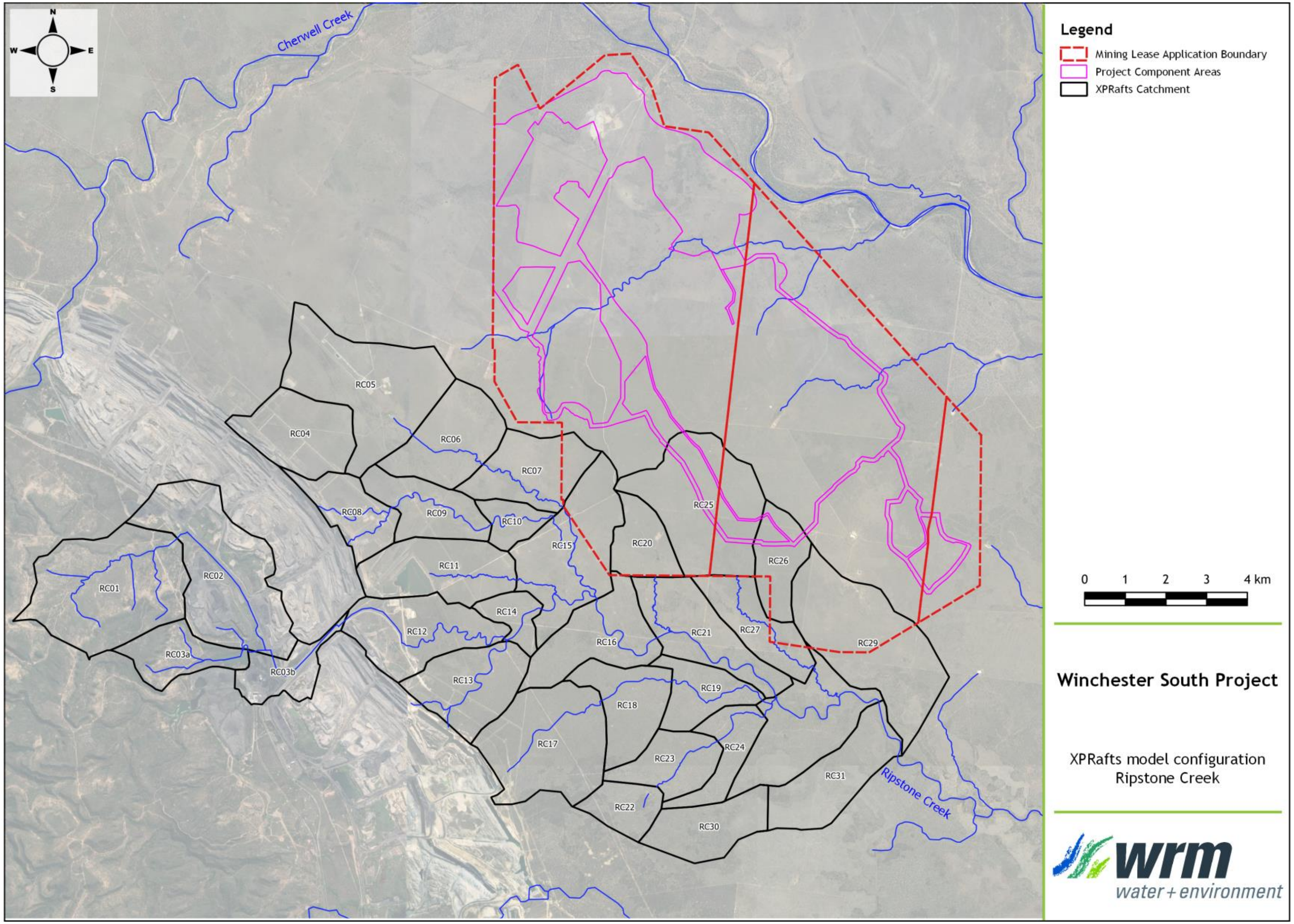


Figure C.5 – XPRafts model sub-catchments for Ripstone Creek to Isaac River

C1.4 ISAAC RIVER XPRAFTS MODEL CALIBRATION

C1.4.1 Overview

The Isaac River XPRAFTS Model was calibrated to discharge hydrographs recorded at the Deverill and Goonyella gauging stations for three historical flood events (2008, 2010 and 2017). The routing parameters and losses were adjusted to match the timing and magnitude of peak discharges at each gauge. A high priority was given to the fit at Deverill, given its proximity to the Project.

C1.4.2 Available data

The available data for the three calibration events is summarised in Table C.7. The rainfall data included daily and sub-daily data and was used to understand the spatial variation in rainfall across the catchment.

Table C.7 - Available rainfall and streamflow data

Station ID	Station name	Data type	Data frequency	Source	Calibration event		
					Feb-08	Dec-10	Mar-17
130410A	Isaac River at Deverill	Rainfall	Sub-daily	DoR	✓	✓	✓
		Discharge	Sub-daily		✓	✓	✓
130414A	Isaac River at Goonyella	Discharge	Sub-daily	DoR	✓	✓	✓
534023	Isaac River Bridge	Rainfall	Sub-daily	BOM	✓	✓	-
34038	Moranbah WTP	Rainfall	Sub-daily	BOM	✓	✓	-
34035	Moranbah Airport	Rainfall	Sub-daily	BOM	-	-	✓

DoR - Department of Resources
BOM - Bureau of Meteorology

The Isaac River XPRAFTS Model was calibrated using sub-daily rainfall data as well as streamflow data recorded at the Deverill and Goonyella gauging stations. Table C.8 shows recorded rainfall and peak discharges for each of the calibration events. Each sub-catchment of the Isaac River XPRAFTS Model was assigned the rainfall from the nearest rainfall station.

Table C.8 - Adopted calibration events, Isaac River catchment

Flood event	Start date	Event duration	Recorded peak discharge (m^3/s)		Total event rainfall (mm)	
		(days)	Goonyella	Deverill	Goonyella	Deverill
February 2008	09/02/2008	9	1,070	2,142	n/a	567
December 2010	18/01/2010	15	910	1,827	n/a	518
March 2017	27/03/2017	7	199	1,624	n/a	168

C1.4.3 Calibration results

The calibration of the Isaac River XPRAFTS Model was achieved by adjusting the catchment and routing parameters and adjusting initial and continuing rainfall losses to obtain the best fit between recorded and predicted discharge hydrographs. The adopted initial and continuing losses for the three events are shown in Table C.9.

Table C.9 – Adopted initial and continuing loss rates, calibration events

Flood event	Initial loss (mm)	Continuing loss (mm)
February 2008	20	4.0
December 2010	8	3.0
March 2017	45	3.0

Table C.10 compares recorded and predicted peak discharges in the Isaac River at the Goonyella and Deverill gauging stations. A discussion of the calibration results is given below.

Table C.10 - Comparison of recorded and modelled peak flood discharges, Isaac River at Goonyella and Deverill gauging stations

Calibration event	Peak discharge at Goonyella (m^3/s)		Difference	Peak discharge at Deverill (m^3/s)		Difference
	Recorded	Modelled		Recorded	Modelled	
February 2008	1,070	1,108	4%	2,142	2,149	0.3%
December 2010	910	868	-5%	1,827	1,854	1.5%
March 2017	199	254	28%	1,624	1,614	-0.6%

February 2008 calibration

Figure C.6 and Figure C.7 show comparisons of recorded and predicted discharge hydrographs at the Goonyella and Deverill gauging stations for the February 2008 event. The model reproduced the timing and shapes of the hydrographs relatively well. However, the model overestimates the peak discharge and flood volumes at both gauges. This is likely due to spatial variation in rainfall that was not covered by the recorded rainfall data.

December 2010 calibration

Figure C.8 and Figure C.9 show comparisons of recorded and predicted discharge hydrographs at the Goonyella and Deverill gauging stations for the December 2010 event. A good calibration was achieved for both gauges, with the XPRafts model satisfactorily reproducing the flood peaks, timing and shapes of the hydrographs.

March 2017 calibration

Figure C.10 and Figure C.11 show comparisons of recorded and predicted discharge hydrographs at the Goonyella and Deverill gauging stations for the March 2017 event. A good calibration was achieved at the Deverill station, with the XPRafts model satisfactorily reproducing the flood peaks, and the timing and shapes of the hydrographs. However, the model moderately overestimates the peak flows at Goonyella.

Three storages at Burton Gorge Dam, Teviot Dam and Lake Elphinstone were also modelled in the 2017 event. The following occurred during the 2017 event:

- Lake Elphinstone is not gauged but was not observed to spill in the 2017 event and did not spill in the XPRafts model;
- Teviot Dam did not record a spill during the event, and no spill occurred in the XPRafts model; and
- Burton Gorge Dam had a spill event, with a recorded peak discharge of about 235 m^3/s at the Burton Gorge Dam gauging station, compared to a peak discharge of about 211 m^3/s in the XPRafts model.

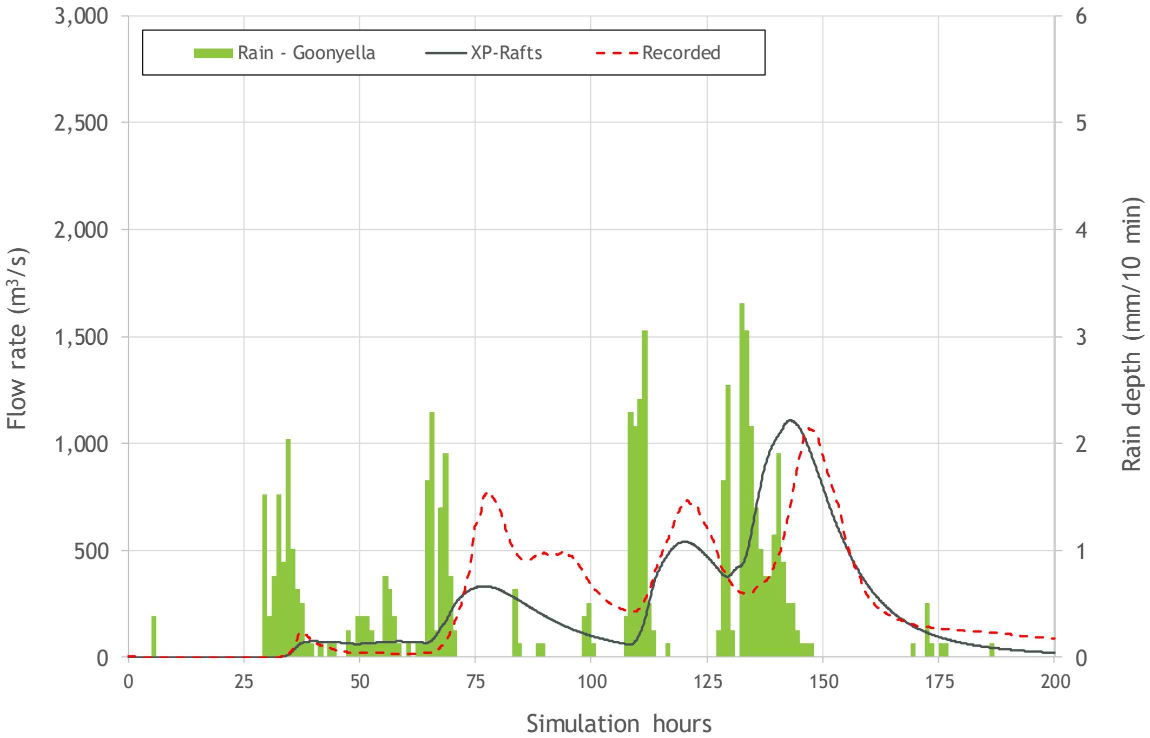


Figure C.6 - Comparison of recorded and modelled discharge hydrographs, February 2008, Isaac River at Goonyella

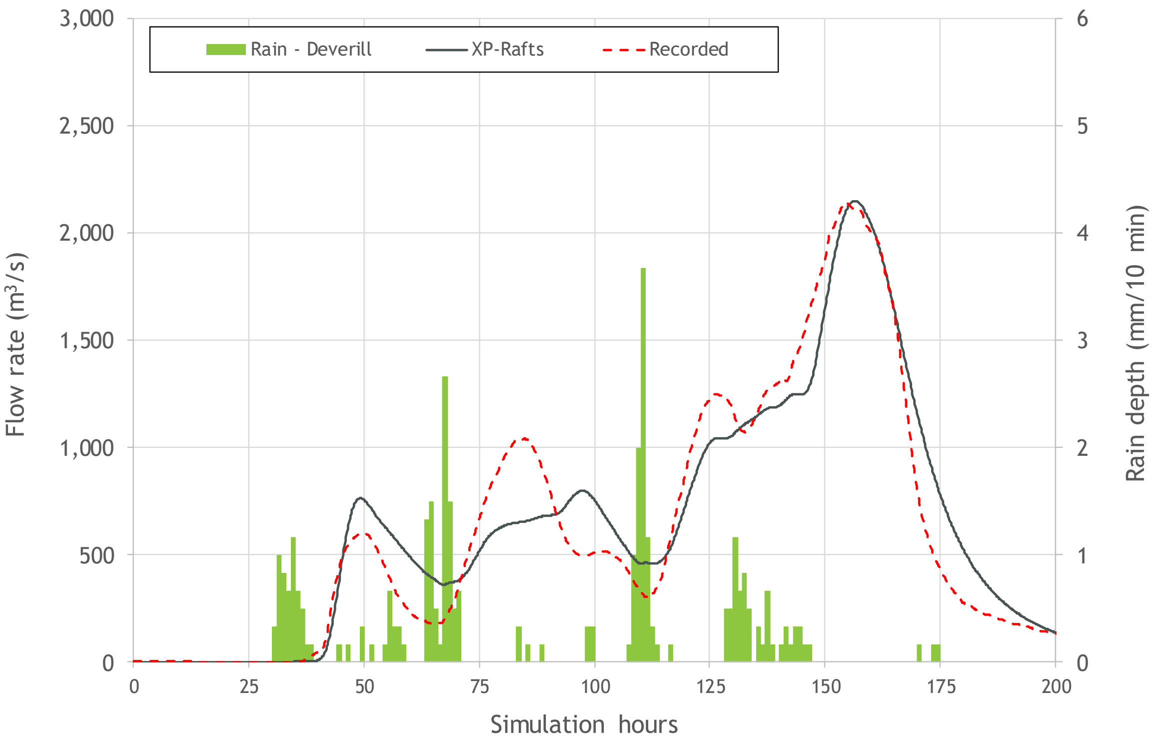


Figure C.7 - Comparison of recorded and modelled discharge hydrographs, February 2008, Isaac River at Deverill

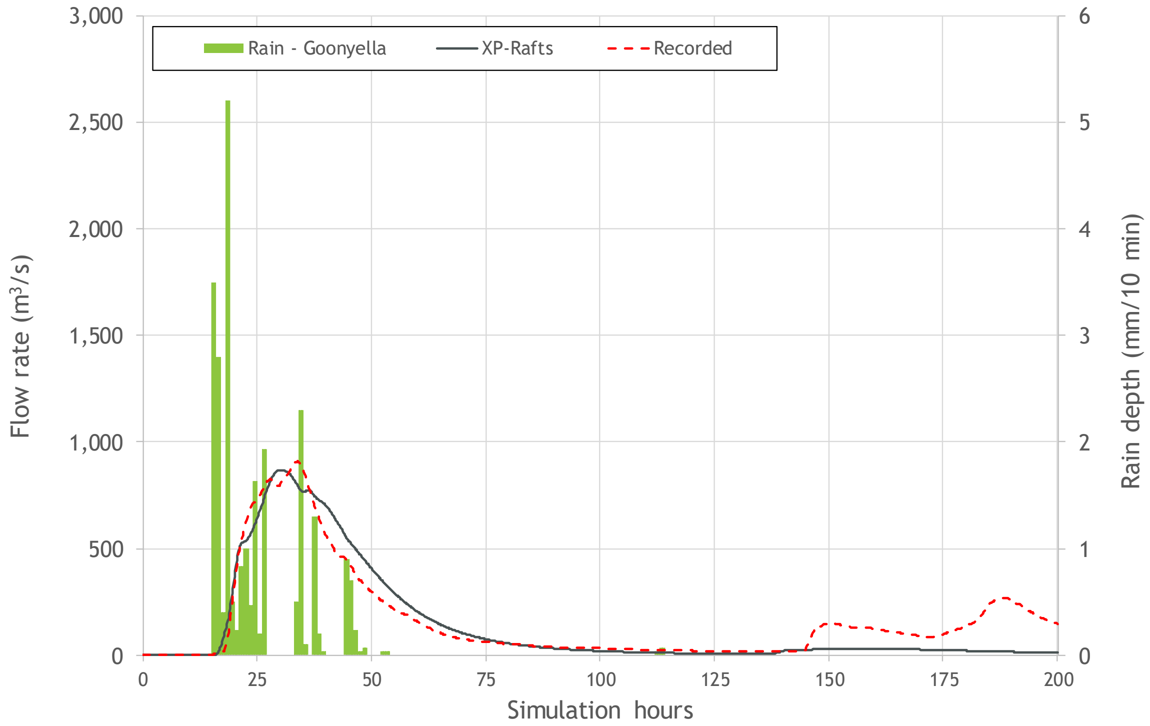


Figure C.8 - Comparison of recorded and modelled discharge hydrographs, December 2010, Isaac River at Goonyella

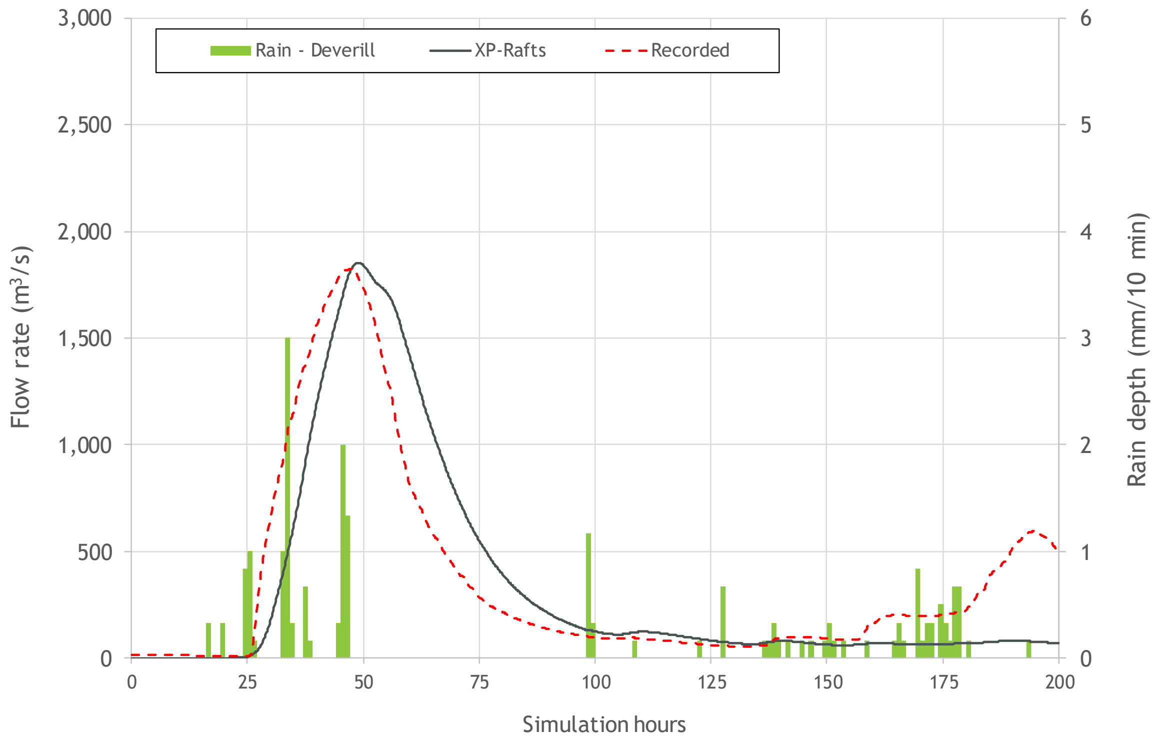


Figure C.9 - Comparison of recorded and modelled discharge hydrographs, December 2010, Isaac River at Deverill

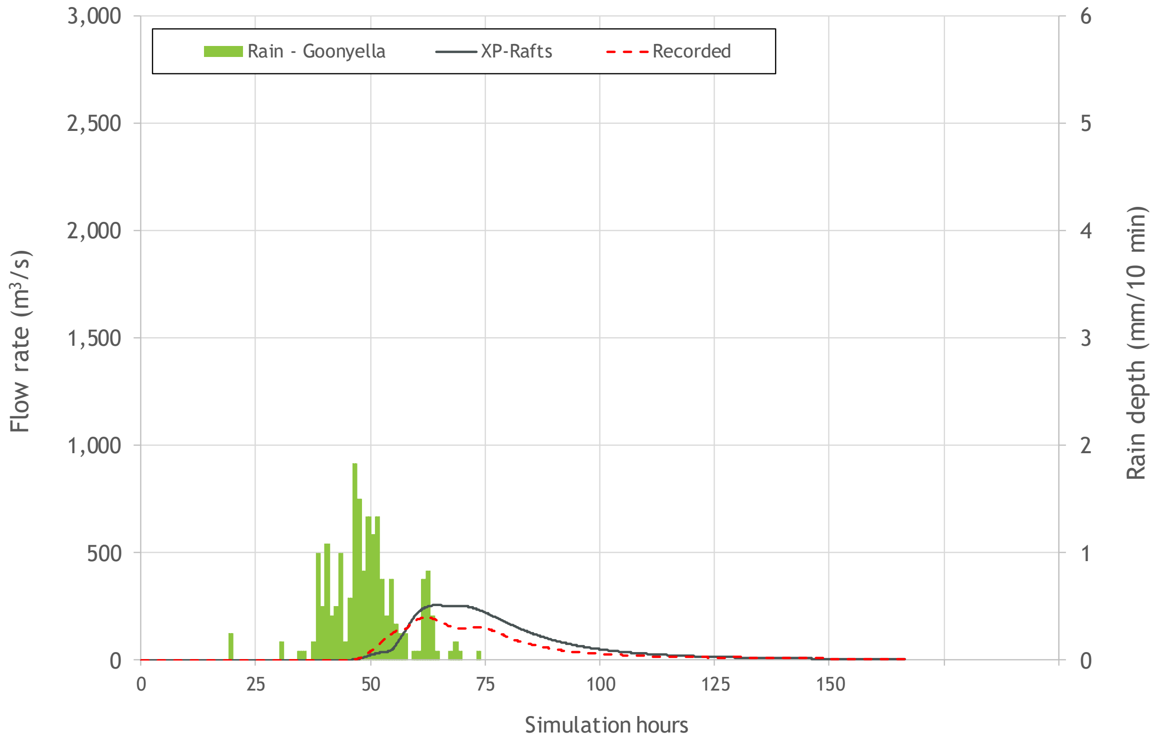


Figure C.10 - Comparison of recorded and modelled discharge hydrographs, March 2017, Isaac River at Goonyella

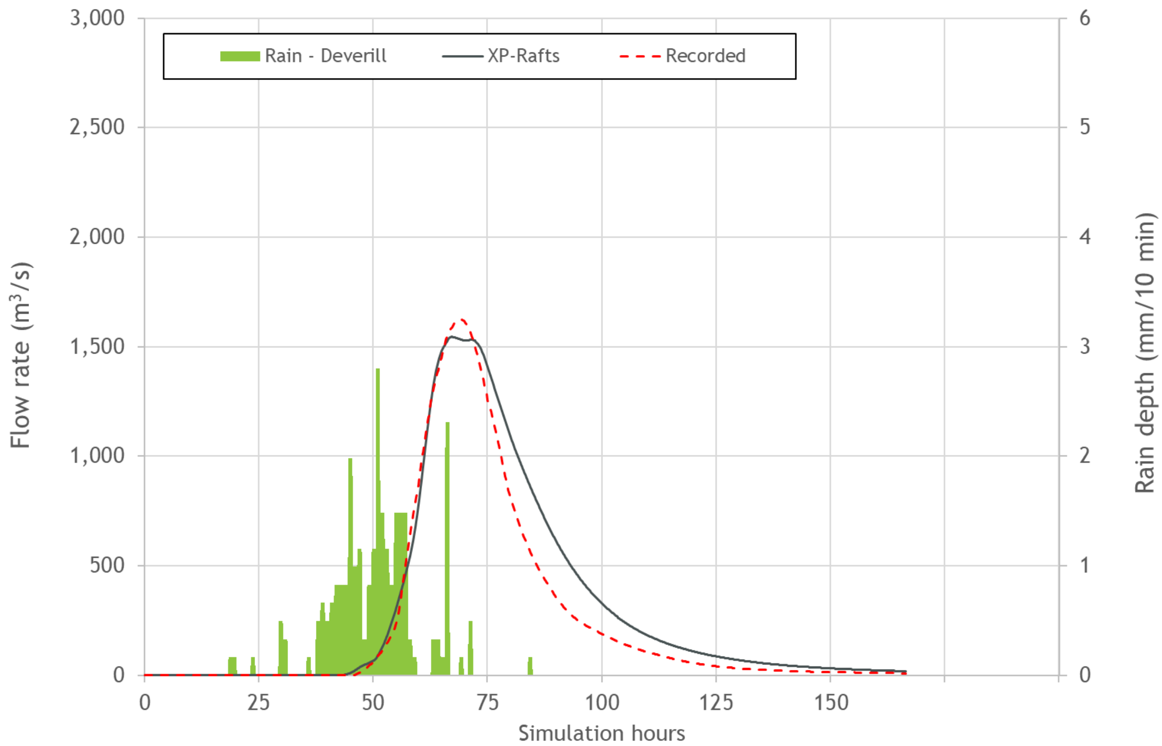


Figure C.11 - Comparison of recorded and modelled discharge hydrographs, March 2017, Isaac River at Deverill

C1.4.4 Summary

Overall, the calibration of the Isaac River XPRAFTS Model is considered acceptable. There is less than 2% difference between the Isaac River XPRAFTS Model predicted peak discharge at the Deverill gauge and the recorded peak discharge for all three calibration events and is considered a good calibration.

C1.5 XPRAFTS DESIGN DISCHARGES

C1.5.1 Overview

The flowing sections describe the derivation of the design rainfall and discharge estimates for the 10%, 5%, 1% and 0.1% AEP events, as well as the probable maximum precipitation (PMP) design event, for a range of storm durations up to 72 hours.

C1.5.2 Design rainfall

Design rainfall depths and intensities for design event up to 0.1% AEP were derived using intensity-frequency duration (IFD) data obtained from the BOM's 2016 Rainfall IFD Data System.

The rainfall depths for the Probable Maximum Precipitation (PMP) design events for durations of 24 hours and longer were estimated using the standard methodology given in the *Guidebook to the Estimation of Probable Maximum Precipitation: Generalised Tropical Storm Method (GTSMR)* (BOM, 2005) based on the Isaac River catchment to the Deverill gauging station. As the Isaac River catchment to Deverill is larger than 1,000 km^2, PMP rainfalls could only be derived for storm durations of 24 hours or longer.

C1.5.3 Spatial and area variability

A comparison of the Isaac River IFDs at the southern, eastern and western catchment boundaries, and at the centroid, revealed on average less than 5% variance in rainfall for 1% AEP event across all durations. The IFDs at the northern catchment boundary were on average within 15% of the IFDs at the centroid of the catchment.

Due to the small variation in design rainfall estimates over majority of the catchment, a uniform spatial rainfall distribution was adopted across the catchment. A uniform spatial distribution was also adopted for the PMP rainfall estimates to maintain consistency.

Areal reduction factors (ARFs) appropriate to the Isaac River catchment to Deverill (Semi-Arid Inland Queensland ARF region) was applied for design events up to 0.1% AEP rainfalls per the recommendation in AR&R (Ball et al., 2019).

No ARF was adopted for PMP rainfalls due to catchment area already being incorporated into the PMP rainfall estimation.

C1.5.4 Temporal patterns

The East Coast North temporal patterns from AR&R Data Hub (Geoscience Australia, 2019) were used for design events up to 1% AEP event. For the 0.1% AEP and PMP events, ARR recommends using the GTSMR (BOM, 2005) temporal patterns for storm durations of 24 hours and longer.

C1.5.5 Design rainfall losses

The initial (IL) and continuing loss (CL) method of accounting for rainfall losses was adopted for this assessment.

The recommended regional loss values for the Isaac River catchment to Deverill from the AR&R Data Hub (Geoscience Australia, 2019) were an initial loss of 45.0 mm (prior to adjustment for preburst rainfall) and a continuing loss of 2.2 millimetre per hour (mm/h).

The adopted design rainfall losses were selected to achieve the best match between the XPRafts design discharges with the design discharges estimated by the FFA at the Deverill gauging station (see Section C1.5.7). The following is of note:

- The initial loss was set to 25 mm for the 10% AEP event and scaled down to 5 mm for the 1% AEP to match the FFA.
- The continuing losses adopted for the calibration of the XPRafts model (3.0 to 4.0 mm/h) were higher than the recommended 2.2 mm/h. A continuing loss of 2.5 mm/hr was adopted for the design events up to 1% AEP in order to reconcile the XPRafts model design discharges with the losses used in the calibration and validated with the FFA results.
- For the 0.1% AEP design event, a conservative 0 mm initial loss was adopted. A continuing loss of 2.0 mm/h was adopted as AR&R recommends continuing loss values should gradually vary from the 1% AEP to the PMP continuing loss.
- For the PMF design event, an initial loss of 0 mm was adopted as per the recommendations from AR&R for arid and semi-arid regions (Ball et al., 2019). The continuing loss for PMP design rainfalls was set to 1.0 mm/h.
- The AR&R recommended continuing losses (1.9 mm/h) was adopted for the Ripstone Creek catchments and validated against RFFE and Rational Method techniques.

Table C.11 summarises the initial and continuing rainfall losses adopted in the XPRafts model. The adopted losses for the 10% to 1% AEP match the losses used in the Goonyella Riverside flood study (WRM, 2019).

Table C.11 - Adopted initial and continuing losses

Source/scenario	Isaac River catchment to Deverill		Ripstone Creek catchments	
	Initial loss (mm)	Continuing loss (mm/hr)	Initial loss (mm)	Continuing loss (mm/hr)
AR&R Data hub	45	2.2	45	1.9
10% AEP	25	2.5	N/A	N/A
5% AEP	10	2.5	N/A	N/A
1% AEP	5	2.5	N/A	N/A
0.1% AEP	0	2.0	0	1.9
PMP	0	1.0	N/A	N/A

N/A - not assessed

C1.5.6 Storages

The three waterbodies upstream of the Project (Lake Elphinstone, Teviot Dam and Burton Gorge Dam) were represented as detention basins in the XPRafts model. For the estimation of design discharges, it was assumed that these storages are at full supply level at the start of each simulation.

C1.5.7 Design discharges

Design discharges were determined using an 'ensemble' of 10 temporal patterns, which produces 10 design hydrographs (and peak discharges) for each duration for each AEP. The temporal pattern which results in a peak discharge closest to, but higher than, the ensemble mean is selected as the representative temporal pattern for that storm duration.

Table C.12 shows the design discharges for the Isaac River at Deverill for the 10%, 5%, 1%, 0.1% and PMF events. Design peak discharges were estimated using the XPRafts model, based on design rainfalls and ARFs obtained for the centroid of the Isaac River catchment to Deverill, and the validated design rainfall losses given in Table C.11.

To illustrate the variation in Isaac River peak discharges from the ensemble of 10 temporal patterns for each storm duration for each event up to 1% AEP, Figure E.1 to Figure E.7 (in Appendix E) provide box and whisker plots (box plots) showing the distribution of peak discharges in the Isaac River to Deverill for the 10% to 1% AEP events. For each duration, the rectangle box represents the 25 percentile and 75 percentile (1st and 3rd quartile, the interquartile range or IQR) bound of the estimate. The horizontal line at the top and bottom (whiskers) represents the upper and lower estimates for 1.5 times of the IQR. The horizontal dashed line within the box is the median value and the horizontal red line represents the mean value. Outliers are represented as grey dots and are defined as values outside 1.5 times the IQR.

Table C.12 – XPRafts design discharges, Isaac River at Deverill

Design event	XPRafts Ensemble mean peak discharge (m^3/s)	XPRafts adopted design peak discharge (m^3/s)[1]	Critical storm duration (hours)	Temporal pattern
10% AEP	1,935	1,936	24	6
5% AEP	2,787	2,886	24	7
1% AEP	5,051	5,068	24	9
0.1% AEP	10,009	10,180	24	2
PMF	36,474	36,474	36	-

NA – not applicable
[1] - Adopted design peak discharge calculated from the temporal pattern which generated a peak discharge closest to, but higher than, the ensemble mean.

Table C.13 shows the adopted Ripstone Creek peak design discharges at key locations in the vicinity of the Project for the 0.1% AEP discharge.

Table C.13 – Adopted Ripstone Creek design discharges, critical storm duration and temporal pattern

Key location	Event	XPRafts adopted design peak discharge (m^3/s)[1]	Critical storm duration (hours)	Temporal pattern
Ripstone Creek at RC31	0.1%	695	6	NA

NA – not applicable
[1]Adopted design peak discharge calculated from the temporal pattern which generated a peak discharge closest to, but higher than, the ensemble mean.

C1.5.8 Comparison to FFA design discharges

Figure C.1 and Figure C.3 shows visual comparisons of the XPRafts design discharges plotted against the FFA curve for the two scenarios. The comparison shows that the FFA in Figure C.3 fits the adjusted annual maximums and the XPRafts discharges better than the FFA in Figure C.2 using the DoR rating. As a result, the adjusted rating has been adopted for comparison to the XPRafts model.

Table C.14 shows the estimated XPRafts model design discharges at the Deverill gauging station and compares to the adjusted FFA discharge estimates. The following is of note:

- The 10% AEP peak discharge is 3% higher than the FFA, but within the 90th percentile confidence limits;
- The 5% AEP peak discharge is 7% higher than the FFA, but within the 90th percentile confidence limits; and

- The 1% AEP peak discharge is 7% higher than the FFA, but within the 90th percentile confidence limits.

The XPRafts model design peak discharges are between 3% to 7% higher than the FFA peak discharges. However, the XPRafts design peak discharges are within the 90th percentile confidence limits for all events. The XPRafts model design discharge estimates are considered reasonable and will be adopted for this study.

Table C.14 - Comparison of FFA and XPRafts design discharges, Isaac River at Deverill

Design event	XPRafts Design Peak Discharge (m^3/s)	FFA Design Peak Discharge (m^3/s)	Difference
10% AEP	1,936	1,880	+3%
5% AEP	2,886	2,699	+7%
1% AEP	5,067	4,750	+7%
0.1% AEP	10,180	-	

C1.5.9 Comparison to RFFE design discharges - Ripstone Creek

There are no recorded continuous streamflow data available for calibration of Ripstone Creek. As a result, the XPRafts design discharges have been verified against RFFE and Rational Method techniques for the 1% AEP design flood event. Only the 1% AEP design flood event was validated against the Rational Method and RFFE, as these methods cannot be used for events greater than 1% AEP.

Table C.15 presents the Ripstone Creek modelled 1% AEP design discharges estimates at RC07 using RFFE, the Rational Method and XPRafts hydrological model.

The table shows that the RFFE estimate is considerably lower than the XPRafts and Rational Method estimates. The XPRafts model discharges compare very well with the Rational Method estimates and are generally within the 95% confidence limit of the RFFE estimate.

Table C.15 - Ripstone Creek XPRAFTS Model design discharge comparison between RFFE, XPRafts and Rational Method

Sub-catchment	Sub-catchment area (ha)	Peak flow (m^3/s)				% Difference between Rational Method and XPRafts
		RFFE	RFFE upper confidence limit (95%)	Rational Method	XPRafts	
RC07 (including RC04, RC05 and RC06)	2,222	39.7	109.0	105.1	93.4	-11.1%

Overall the calibration of the XPRafts hydrological model is considered acceptable.

C1.6 CLIMATE CHANGE ASSESSMENT

The impact of climate change on design discharges was assessed for the 1% and 0.1% AEP Isaac River event. In accordance with AR&R guidelines (Ball et al., 2019), the design rainfall in the XPRafts model was increased by 12%. This was based on a 30 year planning horizon and a high Representative Concentration Pathway producing an estimated temperature increase of between 1.5 and 3.0 degrees Celsius.

Table C.16 compares the Isaac River 1% and 0.1% AEP XPRafts design peak discharges between the base case and the climate change (increases rainfall) case.

Table C.16 – Impact of climate change on Isaac River XPRafts design discharges

Design event	Base Case XPRafts Design Peak Discharge (m^3/s)	Climate Change XPRafts Design Peak Discharge (m^3/s)	Increase in peak flow
1% AEP	5,046	6,040	20%
0.1% AEP	10,180	11,854	16%

C2 Hydraulic model development and calibration

C2.1 OVERVIEW

Due to the flat topography of the Isaac River floodplain and the interaction of overbank flows between the various watercourses in the area of interest, a two-dimensional hydraulic model was used to ensure that the movement of water across the floodplain was adequately simulated. The TUFLOW hydrodynamic model (BMT, 2018a) was used to simulate the flow behaviour of Isaac River, Cherwell Creek and Ripstone Creek in the vicinity of the Project. The two hydraulic models are identified as:

- Isaac River TUFLOW Model – which includes the Isaac River and Cherwell Creek channels and floodplains; and
- Ripstone Creek TUFLOW Model - which includes the Ripstone Creek channel and floodplain.

This section of the report describes the model development, configuration and calibration.

TUFLOW represents hydraulic conditions on a fixed grid by solving the full two-dimensional depth averaged momentum and continuity equations for free surface flow (BMT, 2018b). The model automatically calculates breakout points and flow directions within the study area.

The Isaac River TUFLOW model was calibrated against the recorded flow rate at the Deverill gauging station for the 2017 event as well as the DRNME's rating curve. The calibrated Isaac River TUFLOW Model was used to estimate design peak flood levels, depths, extents and velocities for various events from 10% AEP to the Probable Maximum Flood (PMF). There are no recorded continuous streamflow data available for calibration of the streams within the Ripstone Creek TUFLOW Model.

C2.2 ISAAC RIVER TUFLOW MODEL CONFIGURATION

C2.2.1 Model extent and resolution

Figure C.12 shows the extent and configuration of the Isaac River TUFLOW model. The model was extended sufficiently downstream to allow for a suitable calibration to the Deverill gauging station. The model was configured using HPC-GPU with grid cell size of 10 metres.

The Isaac River TUFLOW Model covers an area of approximately 348 km^2. It extends north-west approximately 6 km upstream of the WSP to include Cherwell Creek, the Aurizon rail bridge and rail embankment, and part of the Project. The model outflow boundary is located 12 km south-southeast of the Deverill gauging station.

C2.2.2 Topographic data

The LiDAR data (captured in 2012) supplied by Whitehaven WS was adopted in the hydraulic model and is supplemented by Geoscience Australia's (2001) Shuttle Radar

Topography Mission (SRTM) Digital Elevation Model for areas outside the LiDAR data coverage. The LiDAR extent is shown in Figure C.13.

C2.2.3 Inflow boundary

Figure C.12 shows the names and locations of 9 inflow boundaries in the Isaac River TUFLOW Model, including the Isaac River, Cherwell Creek and North Creek. The model inflow boundaries were configured using 2D surface area (SA) polygons. Using this approach, flow is initially applied at the lowest spot within each 2D SA polygon. The model was run for the Isaac River critical durations only.

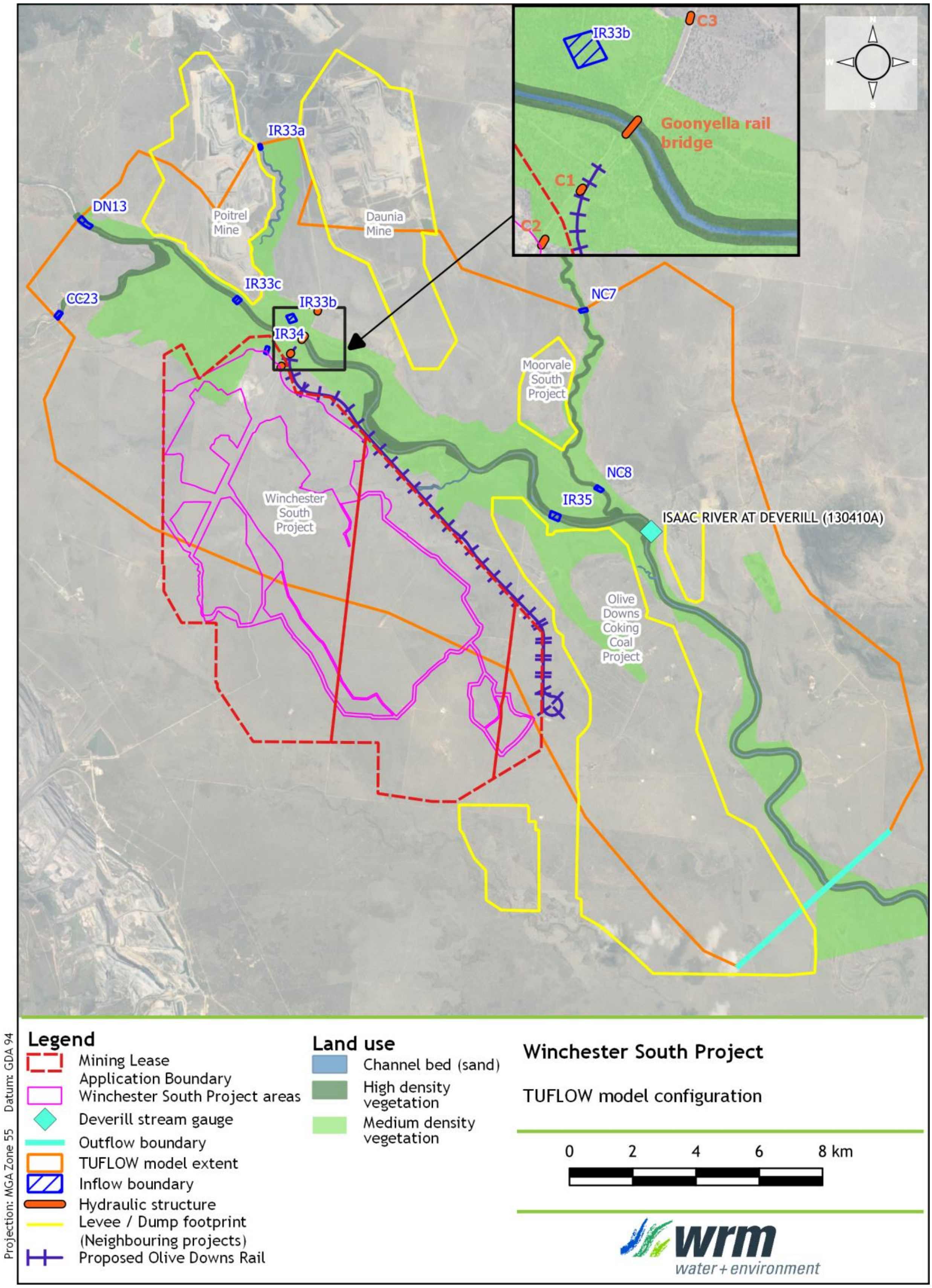


Figure C.12 – Isaac River TUFLOW model configuration

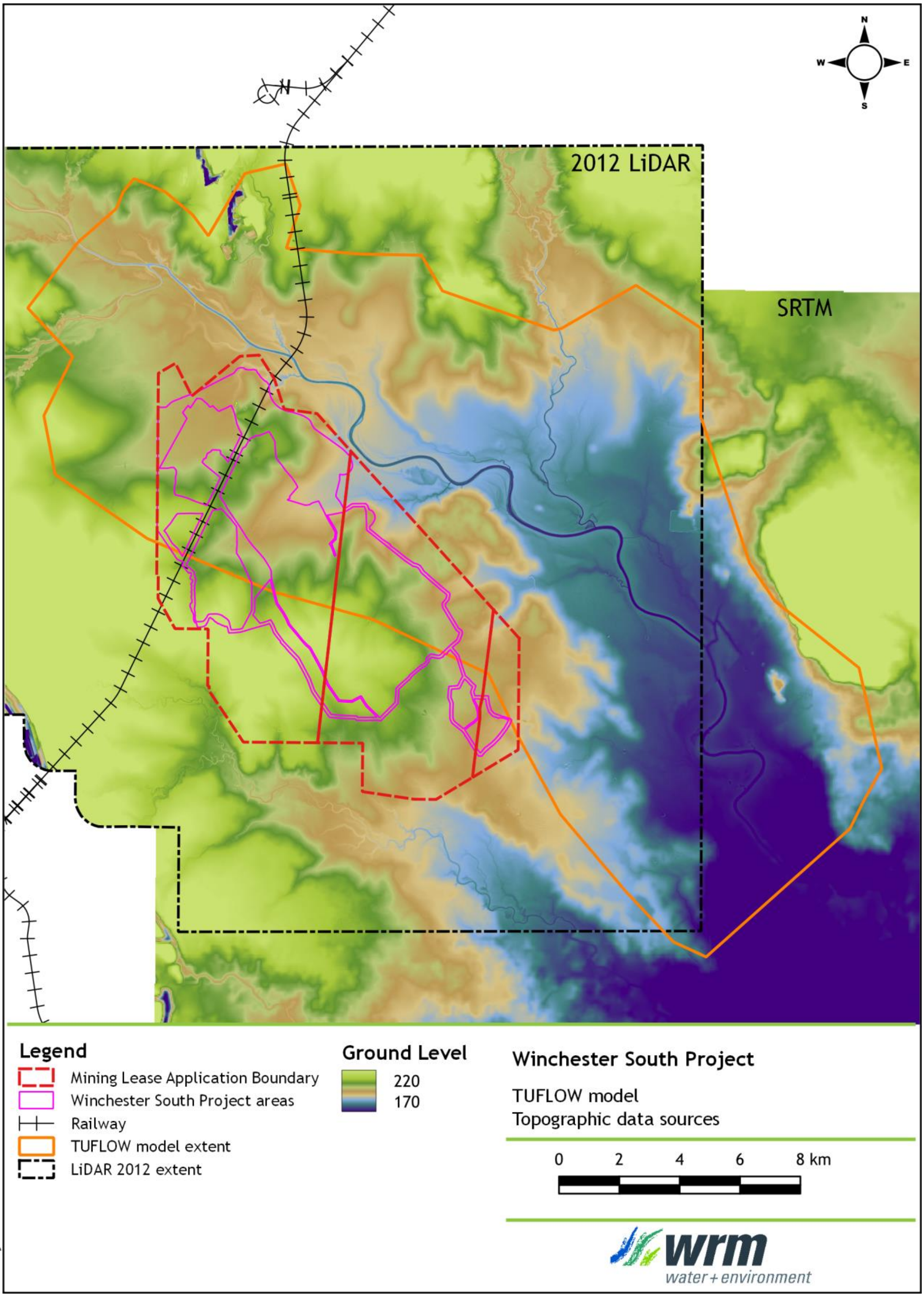


Figure C.13 – Isaac River topographic data sources

C2.2.4 Outflow boundary

The outflow boundary of the hydraulic model is located about 12 km downstream of the Deverill gauging station. A normal depth outflow boundary with a slope of 0.1% was adopted to represent the flood slope. To minimise the impact of tailwater conditions on flooding characteristics at the Project, the model outflow boundary was located as far downstream of Deverill gauging station as the topographic data would allow.

Peak water levels along the Isaac River within the model varies at a flood slope of approximately 0.1%. To assess the sensitivity of peak water levels at the Project to outflow the boundary configuration, peak water levels at the TUFLOW outflow boundary were compared against peak water levels at Deverill gauging station. It was found that peak flood levels at Deverill were between 10.8 m higher for the 10% AEP event and 10.4 m higher for the PMF compared to the peak water levels at the outflow boundary. On this basis, peak water levels at the Project would not be sensitive to the outflow boundary configuration.

C2.2.5 Adopted Manning's 'n' values

The TUFLOW model uses Manning's 'n' values to represent hydraulic resistance of different material types. Figure C.12 shows the adopted land use mapping. The default land use outside of the coloured area is cleared land. The Manning's 'n' values were calibrated to the Deverill stream gauge rating curve. The adopted Manning's 'n' values are given in Table C.17.

Table C.17 – Adopted Manning's 'n' values

Land use	Manning's 'n'
Channel bed (sand)	0.030
Cleared land, grass areas	0.040
Medium density vegetation	0.060
High density vegetation	0.100

C2.2.6 Aurizon Goonyella rail

Figure C.12 shows the locations of four hydraulic structures associated with the Goonyella rail that were modelled using a 2D layered flow constriction. The bridge over the Isaac River was modelled with two different areas of constriction. Each area applied a percentage of constriction, based on the assumed area that was occupied by the bridge structure. The two areas of constriction include:

- The bridge pylons within the water course; and
- The bridge deck (assumed 100% constriction).

The design details for the Goonyella rail bridge deck were provided by Aurizon and the modelling configuration is given in Table C.18.

Culverts C1, C2 and C3 were modelled using a 2D layered flow constriction. The three areas of constriction include:

- The culvert walls (assumed 10% constriction); and
- The rail embankment from the top of the culvert to the top of the embankment (assumed 100% constriction).

The invert levels were estimated from the LiDAR. Table C.19 shows the TUFLOW configuration details for culverts C1, C2 and C3.

Table C.18 – Modelled configuration of the Goonyella rail bridge crossing

Bridge crossing	Deck soffit elevation (mAHD)	Deck depth (m)	Pylon blockage %	Bridge opening width (m)	Bridge length (m)
Goonyella rail bridge	192.1	2.2	5%	150	10

Table C.19 – Modelled configuration of Culverts C1, C2 and C3

Culvert	Invert (mAHD)	Obvert (mAHD)	Blockage %	Embankment depth (m)	Culvert opening width (m)	Culvert Length (m)
C1	189.7	191.5	10%	1.0	30	20
C2	188.0	191.7	10%	0.7	60	20
C3	191.2	192.3	10%	0.7	60	20

C2.3 RIPSTONE CREEK TUFLOW MODEL CONFIGURATION

C2.3.1 Model extent and resolution

Figure C.14 shows the extent and configuration of the Ripstone Creek TUFLOW model. The model was configured using HPC-GPU with grid cell size of 4 metres.

The Ripstone Creek TUFLOW Model covers an area of approximately 24.7 km^2. It extends along the southern edge of the MLA for the Project, until it reaches the approved Olive Downs Project.

C2.3.2 Topographic data

The topographic data used for the Ripstone Creek hydraulic model is the same as that adopted for the Isaac River hydraulic model (see Section C2.3.2).

C2.3.3 Inflow boundary

Figure C.14 shows the names and locations of 21 inflow boundaries in the Ripstone Creek TUFLOW Model. The model inflow boundaries were configured using 2D surface area (SA) polygons. Using this approach, flow is initially applied at the lowest spot within each 2D SA polygon. The model was run for the Ripstone Creek critical durations only.

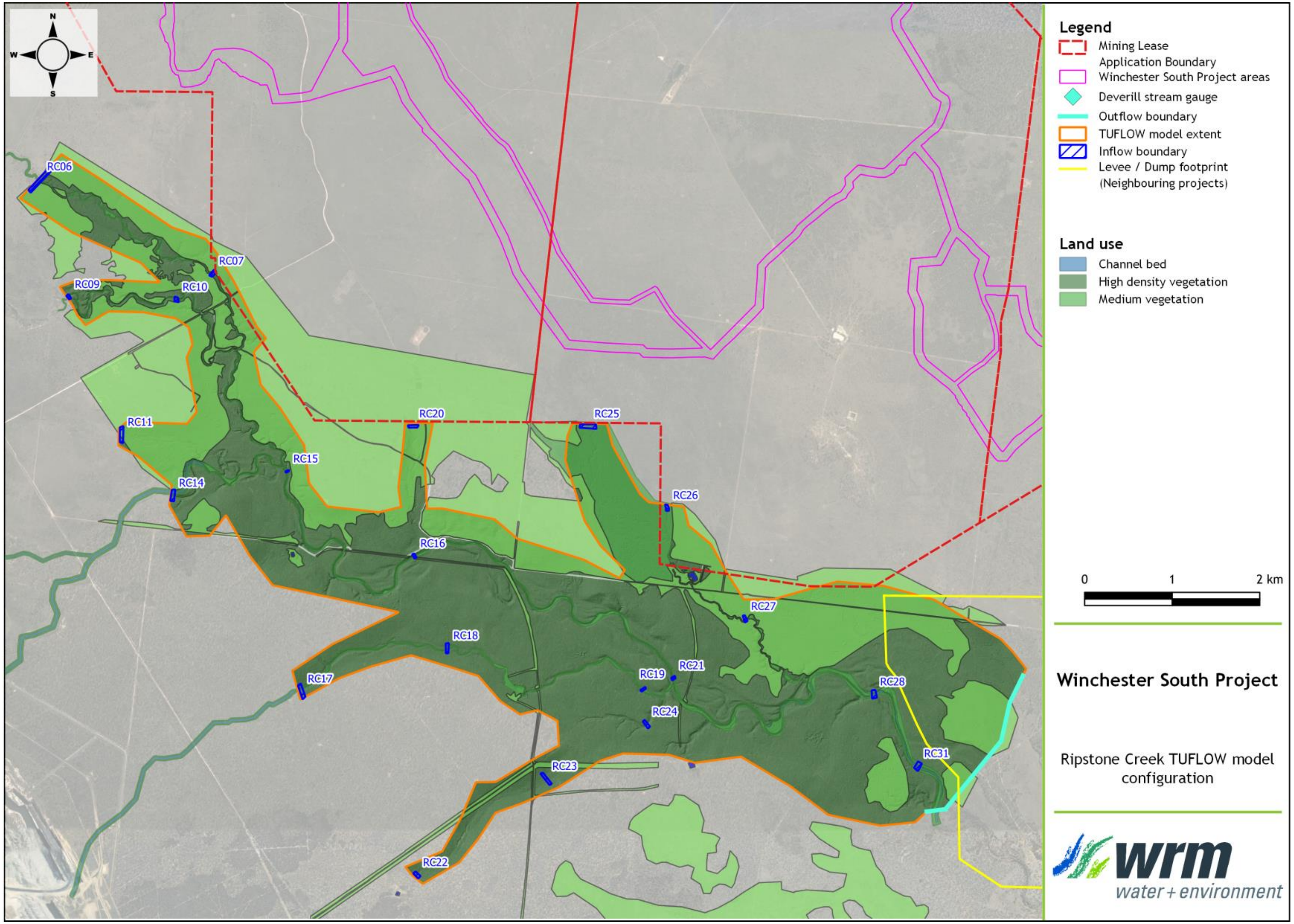


Figure C.14 – Ripstone Creek TUFLOW model configuration

C2.3.4 Outflow boundary

The outflow boundary of the hydraulic model is located about 2.5 km downstream of the MLA for the Project. A normal depth outflow boundary with a slope of 0.2% was adopted to represent the flood slope.

C2.3.5 Adopted Manning's 'n' values

The TUFLOW model uses Manning's 'n' values to represent hydraulic resistance of different material types. Figure C.14 shows the adopted land use mapping. Due to the lack of calibration data for Ripstone Creek, the calibrated Manning's 'n' values used in the Isaac River TUFLOW Model were adopted (see Table C.17). The default land use outside of the coloured area is cleared land.

C2.4 ISAAC RIVER TUFLOW MODEL CALIBRATION

C2.4.1 Overview

The Isaac River TUFLOW Model was calibrated to the recorded water levels and discharges in the Isaac River at the Deverill gauging station for the March 2017 event. The discharge hydrographs obtained from the XPRafts model for the March 2017 event were used as inflows in the TUFLOW model.

The Isaac River TUFLOW Model was calibrated by adjusting the hydraulic model parameters (particularly Manning's 'n' values) until a satisfactory match was achieved between modelled and observed discharge rating curves at Deverill gauging station.

C2.4.2 2017 event calibration

Table C.20 summarises the recorded peak discharge at the Deverill gauging station compared to the peak discharge flow rate estimated by the XPRafts and TUFLOW model for the March 2017 event. Figure C.15 and Figure C.16 shows the recorded and predicted discharge and water levels at Deverill for the March 2017 event. A good calibration was achieved for this event, with the TUFLOW model able to match the peak discharge, water levels, the timing of the peak and the shape of the recorded hydrograph.

Table C.20 - Comparison of recorded and predicted (XPRafts and TUFLOW) peak discharge, March 2017, Isaac River at Deverill

Method	Peak Discharge at Deverill (m^3/s)	Difference
Gauged	1,624	-
XPRafts	1,616	-0.6%
TUFLOW	1,560	-3.9%

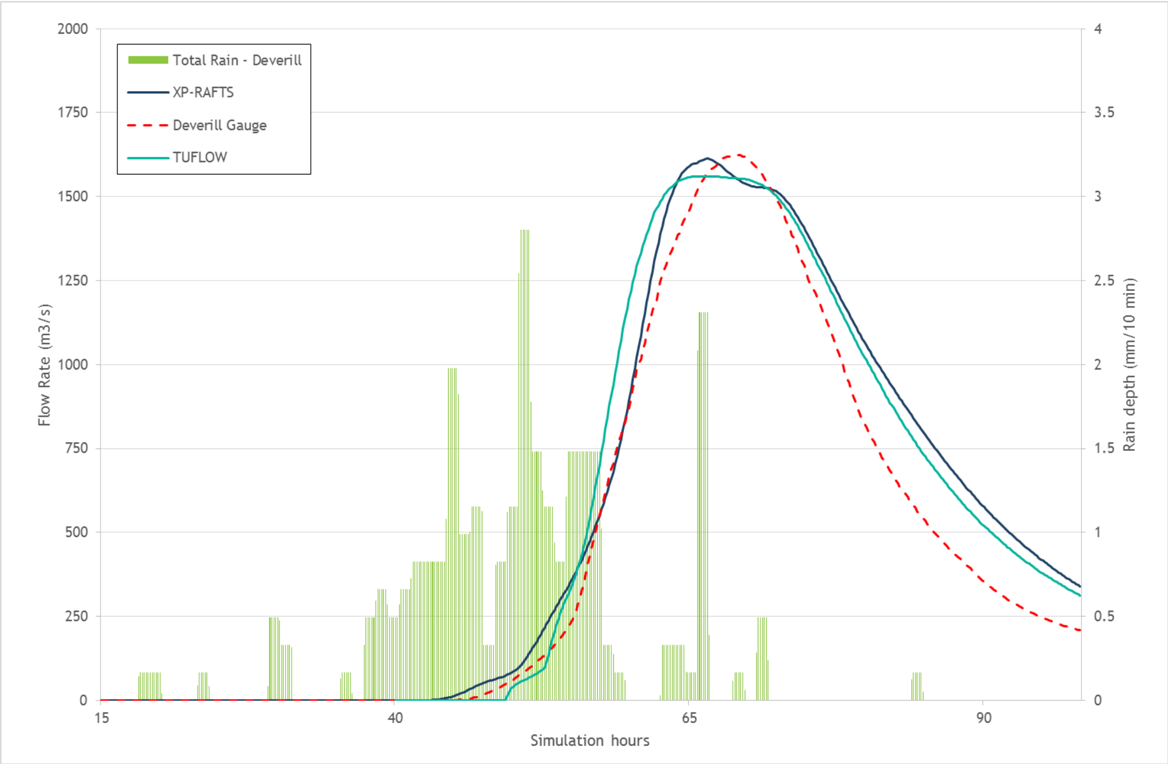


Figure C.15 – Comparison of recorded (gauged flow) and modelled (XPRafts and TUFLOW) discharge hydrographs, March 2017, Isaac River at Deverill

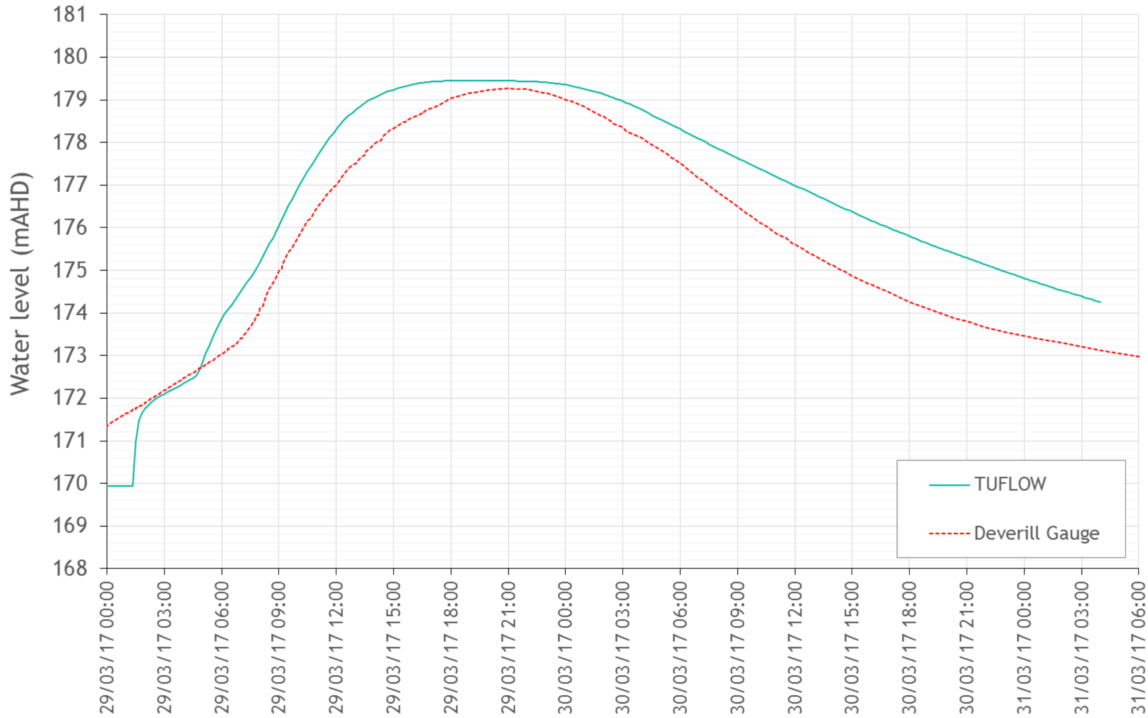


Figure C.16 – Comparison of recorded and modelled water level hydrographs, March 2017, Isaac River at Deverill

Appendix D Isaac River flood maps

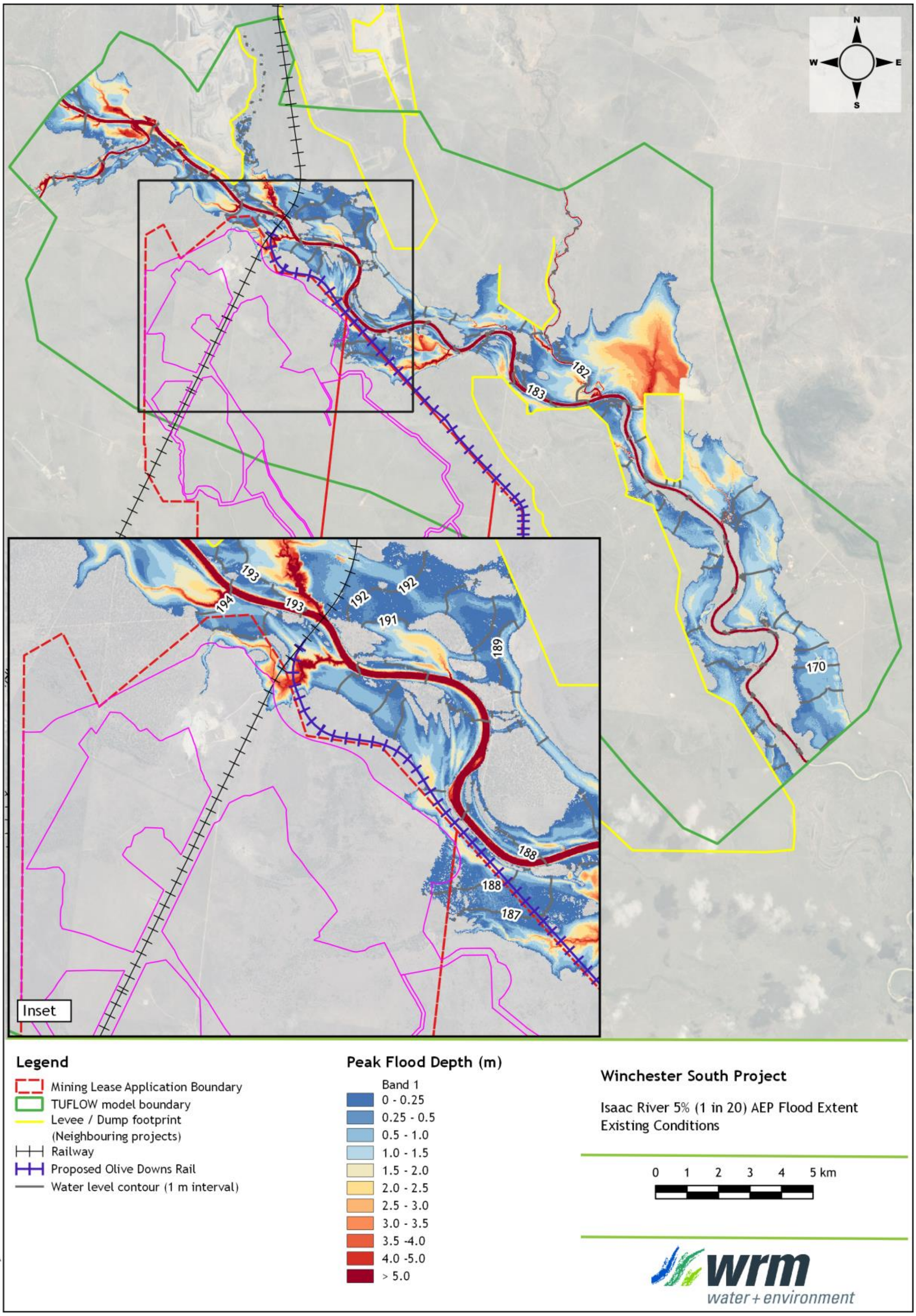


Figure D.1 – 5% AEP depth and flood levels in Isaac River, Existing conditions

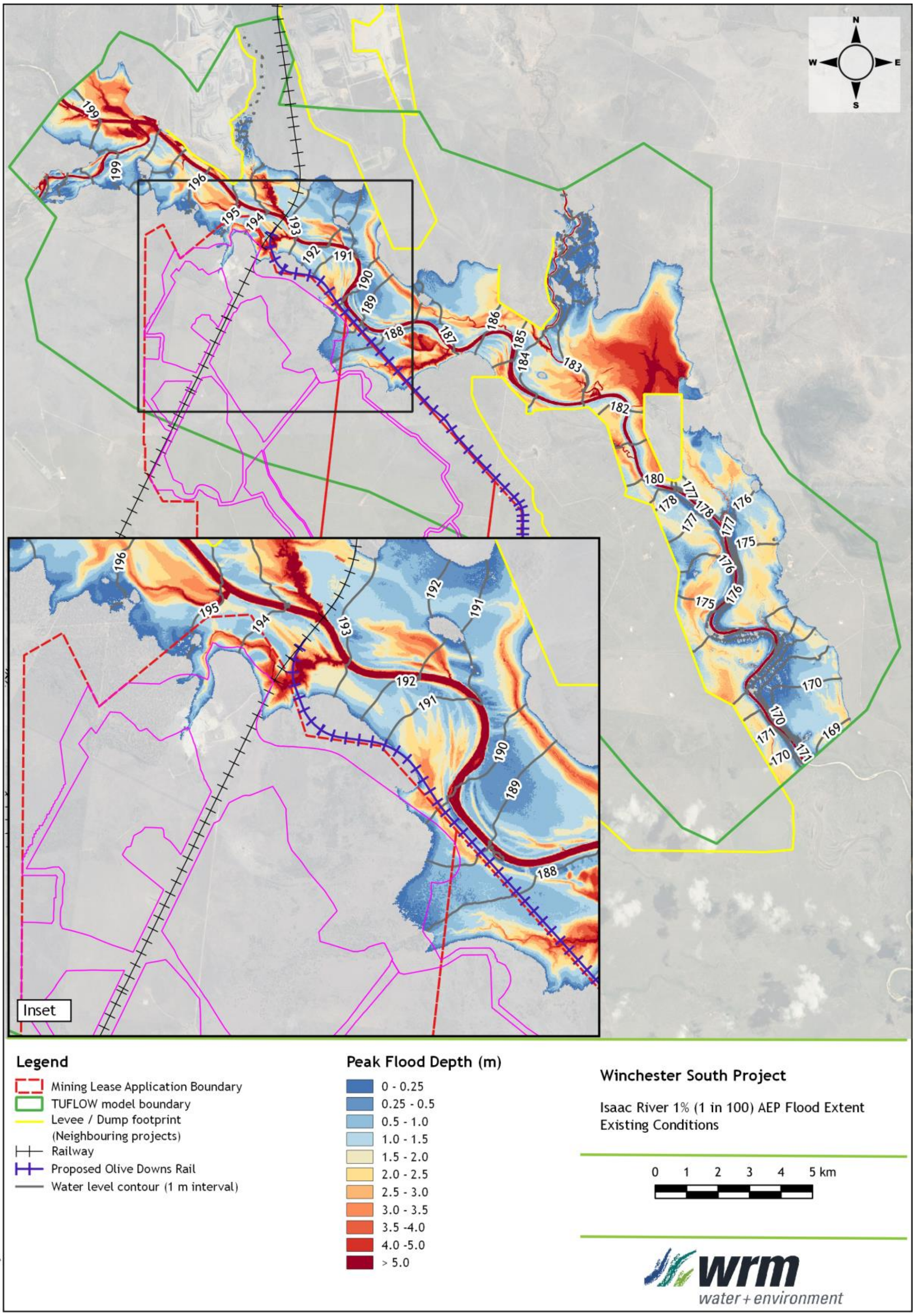
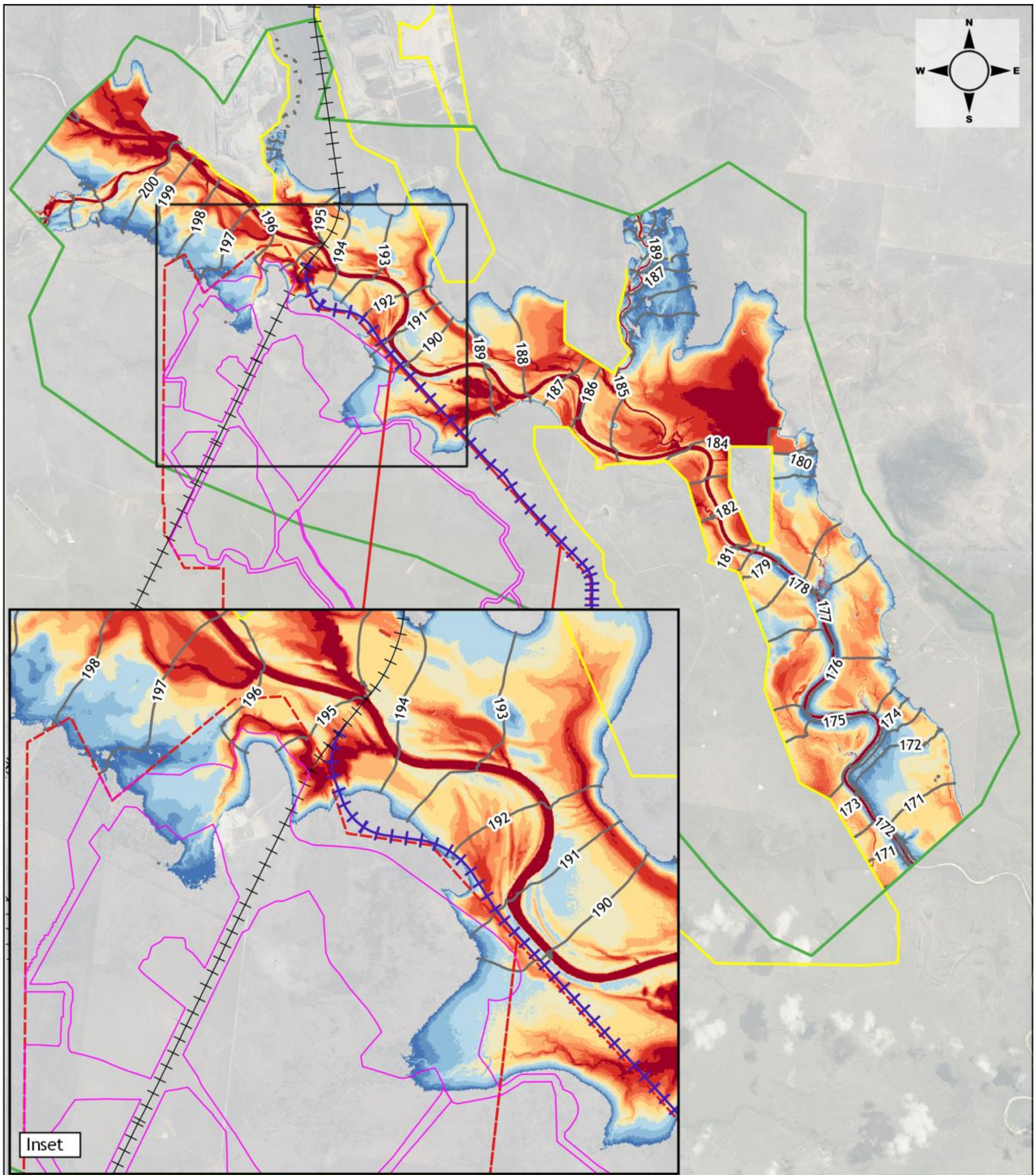


Figure D.2 – 1% AEP depth and flood levels in Isaac River, Existing conditions



Legend
- Mining Lease Application Boundary
- TUFLOW model boundary
- Levee / Dump footprint (Neighbouring projects)
- Railway
- Proposed Olive Downs Rail
- Water level contour (1 m interval)

Peak Flood Depth (m)
- 0 - 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 -4.0
- 4.0 -5.0
- > 5.0

Winchester South Project

Isaac River 0.1% (1 in 1000) AEP Flood Extent Existing Conditions

0 1 2 3 4 5 km

Projection: MGA Zone 55 Datum: GDA 94

wrm water + environment

Figure D.3 – 0.1% AEP depth and flood levels in Isaac River, Existing conditions

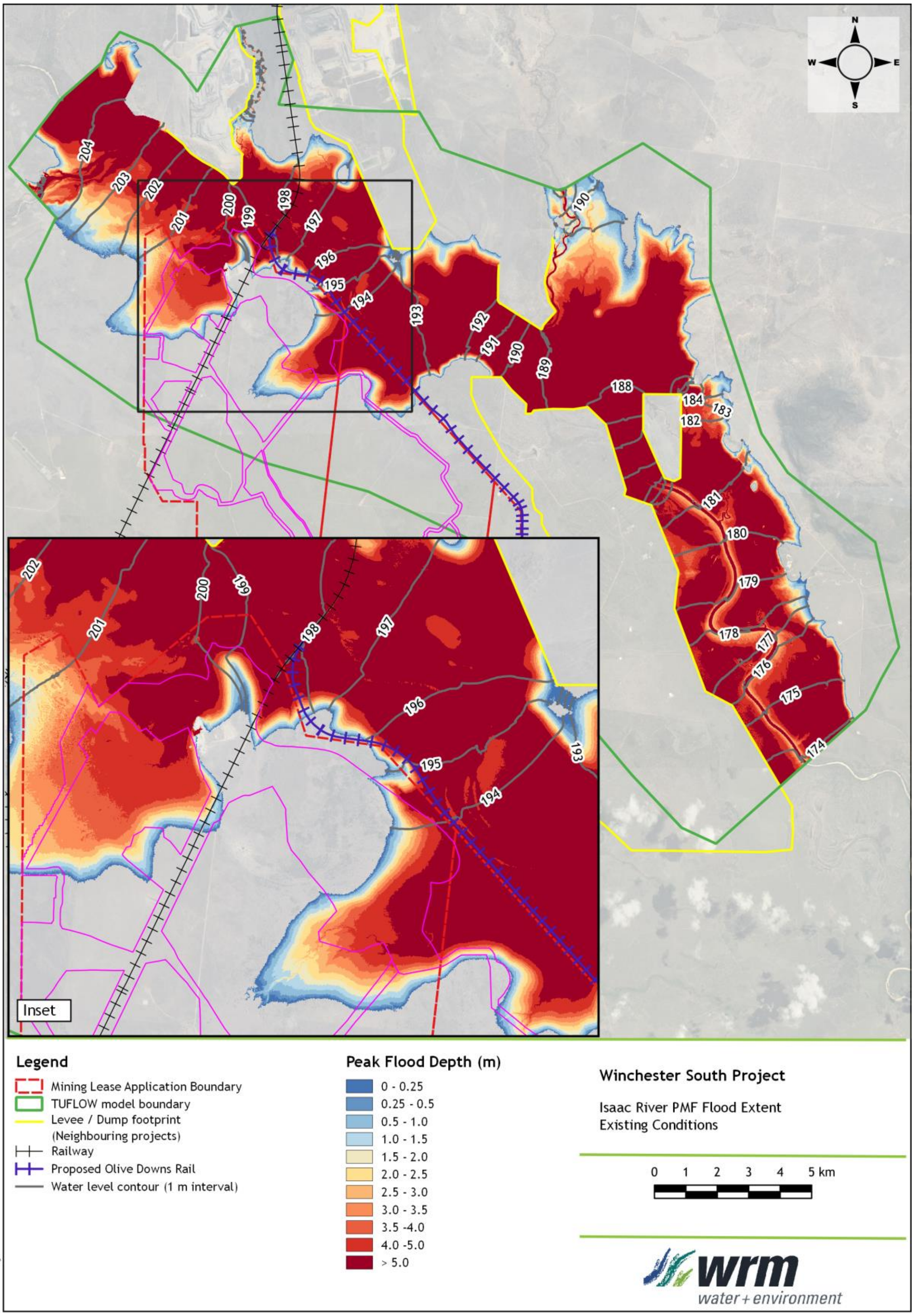


Figure D.4 – PMF depth and flood levels in Isaac River, Existing conditions

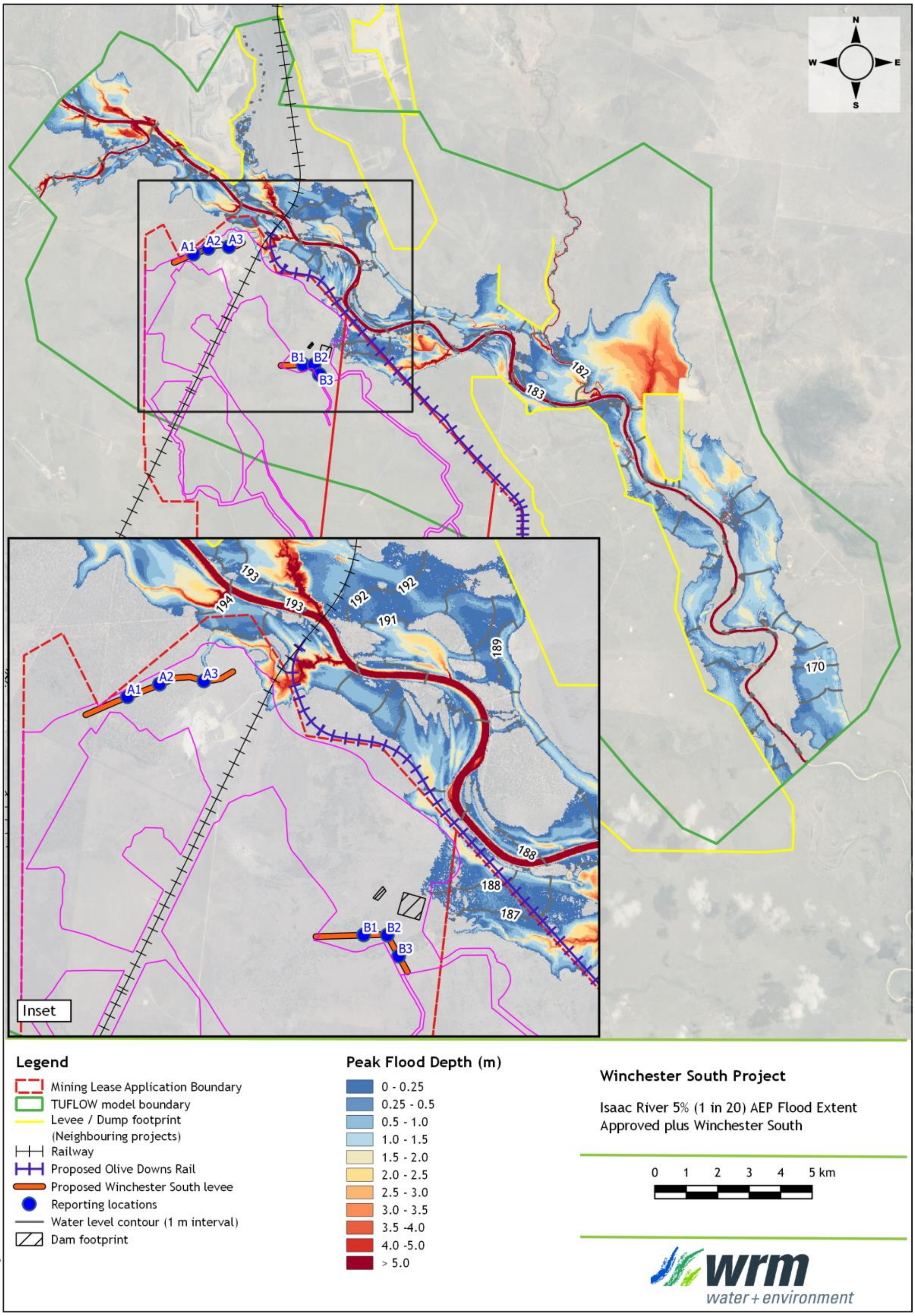


Figure D.5 – 5% AEP depth and flood levels in Isaac River, Proposed conditions

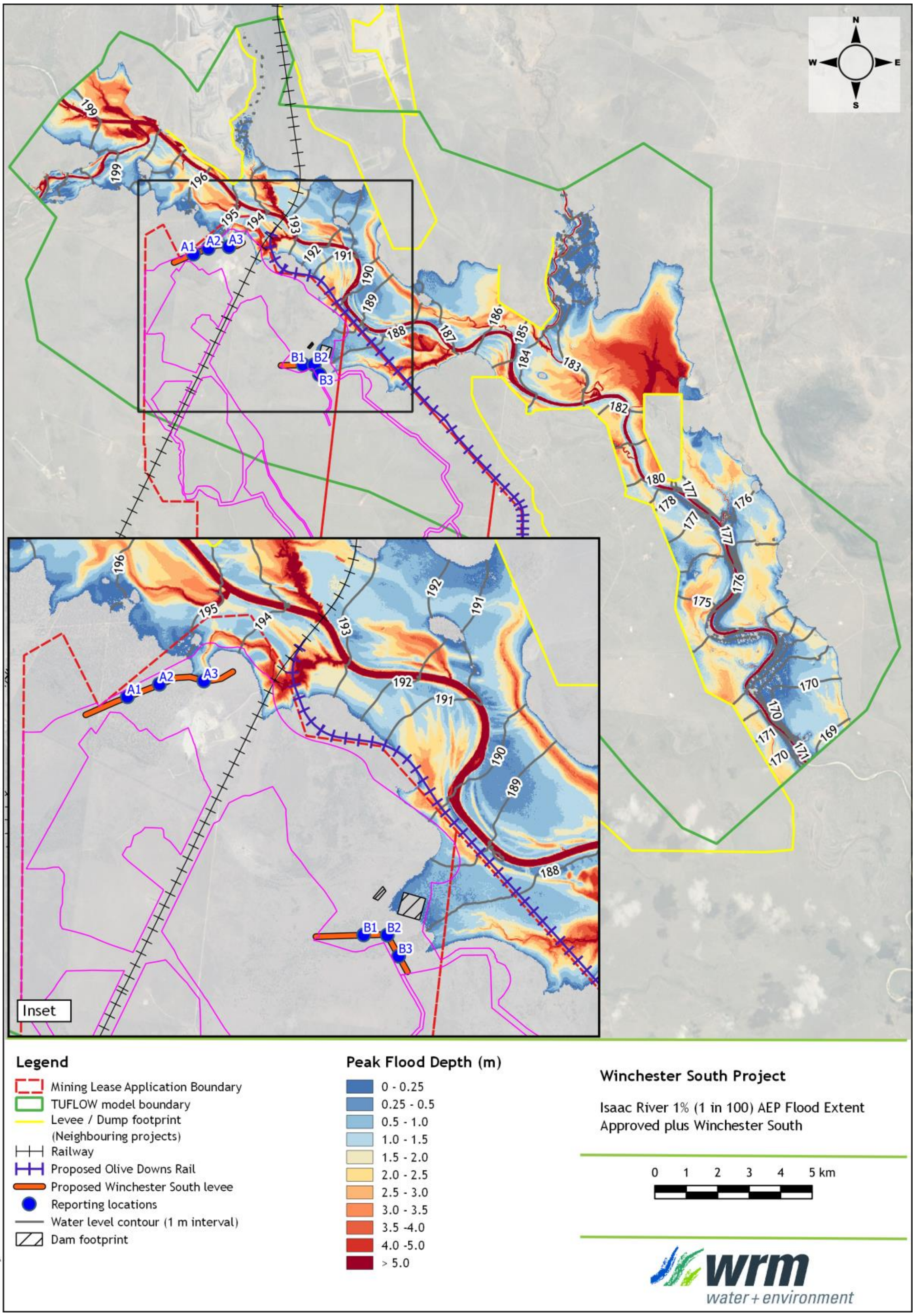


Figure D.6 – 1% AEP depth and flood levels in Isaac River, Proposed conditions

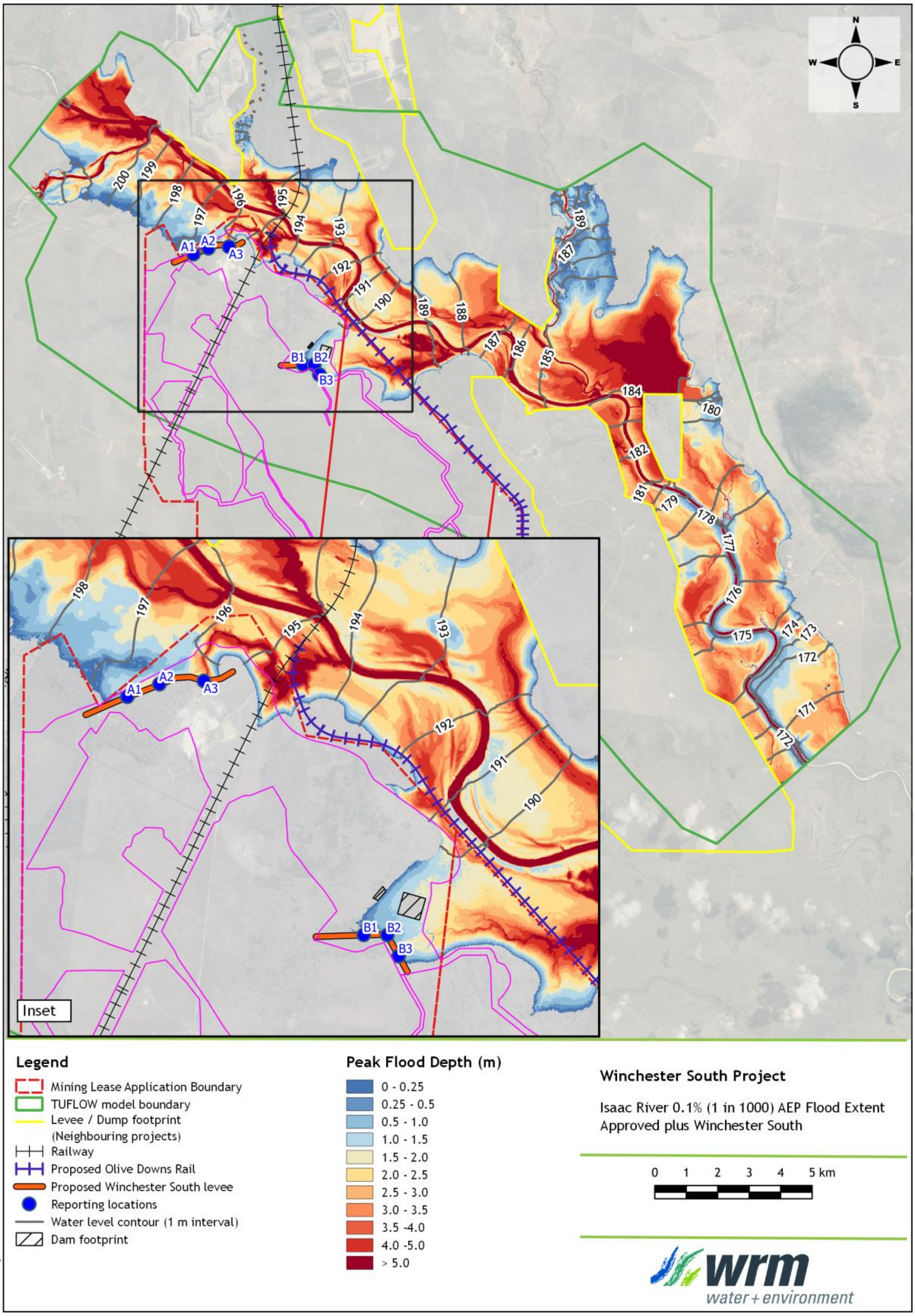


Figure D.7 – 0.1% AEP depth and flood levels in Isaac River, Proposed conditions

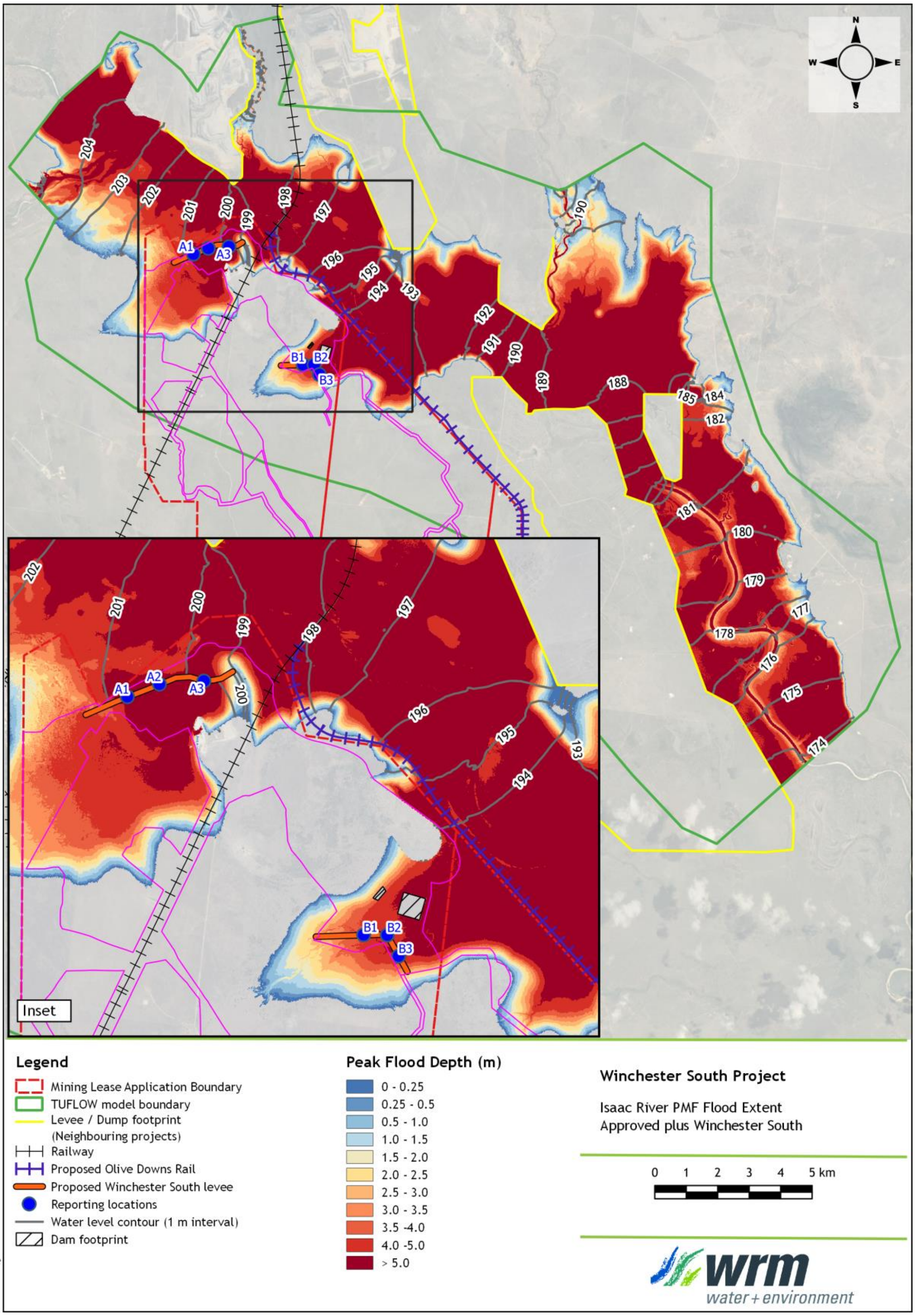


Figure D.8 – PMF depth and flood levels in Isaac River, Proposed conditions

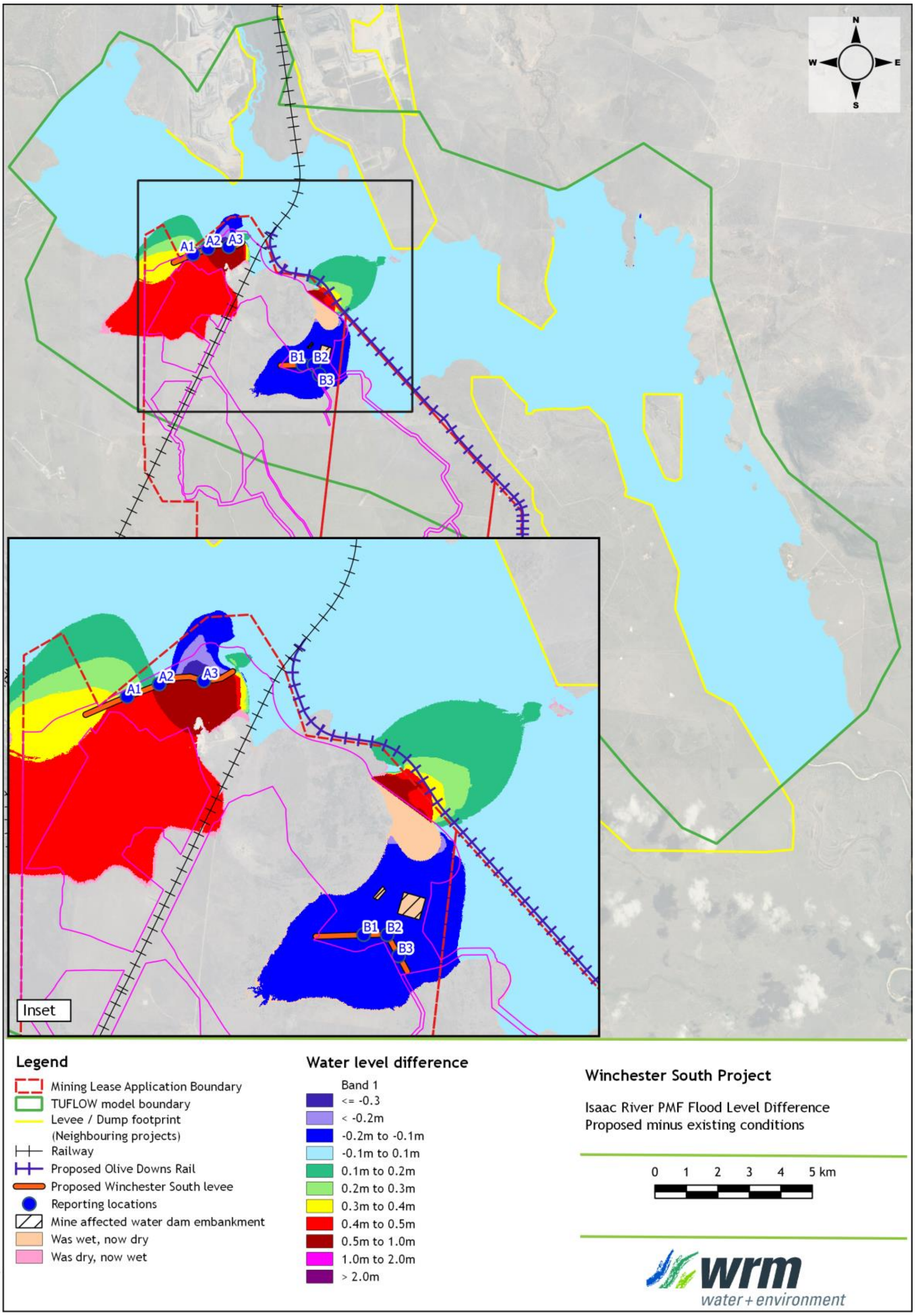


Figure D.9 – Impact on PMF depth and flood levels in Isaac River, Proposed minus Existing conditions

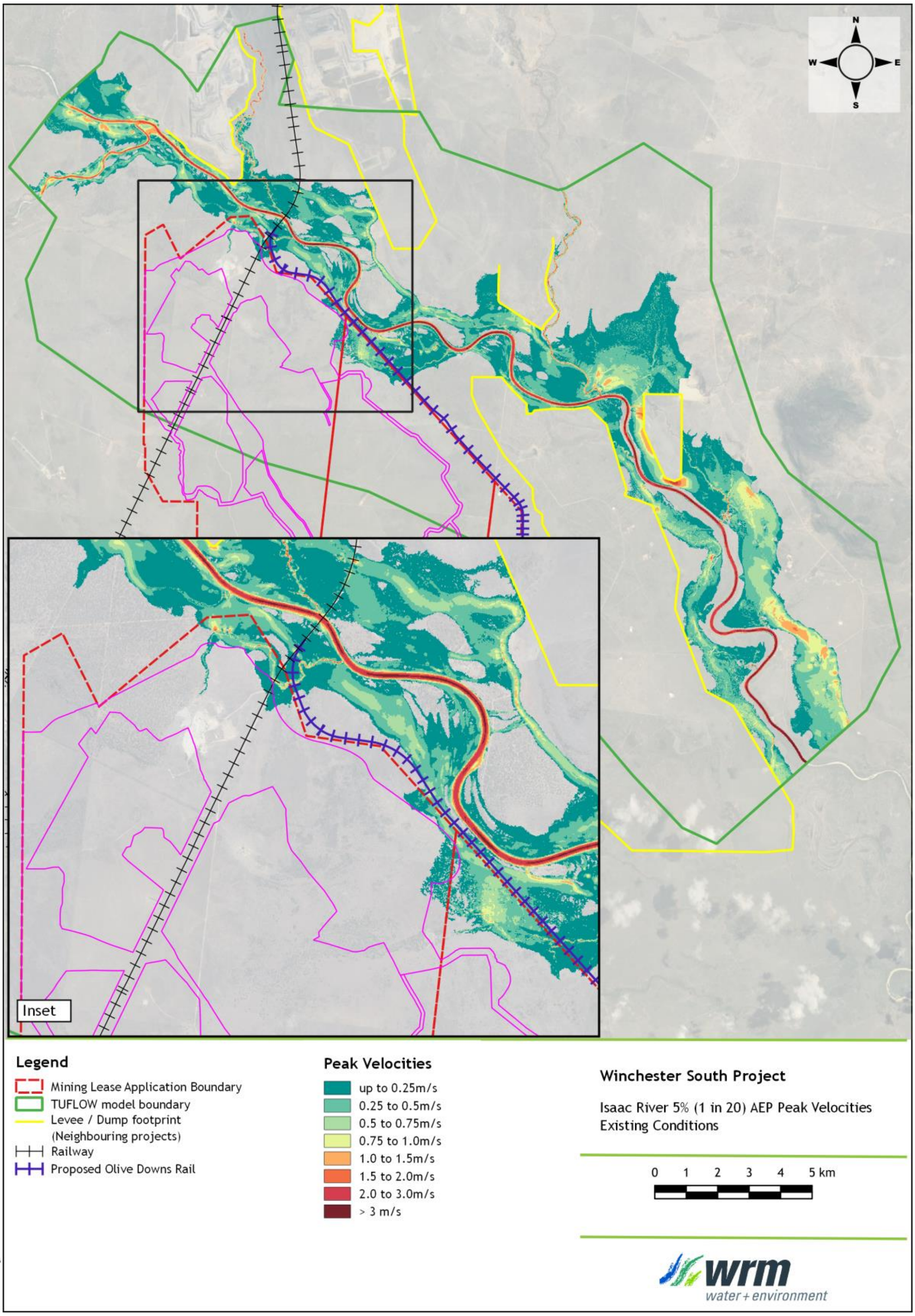


Figure D.10 – 5% AEP velocities in Isaac River, Existing conditions

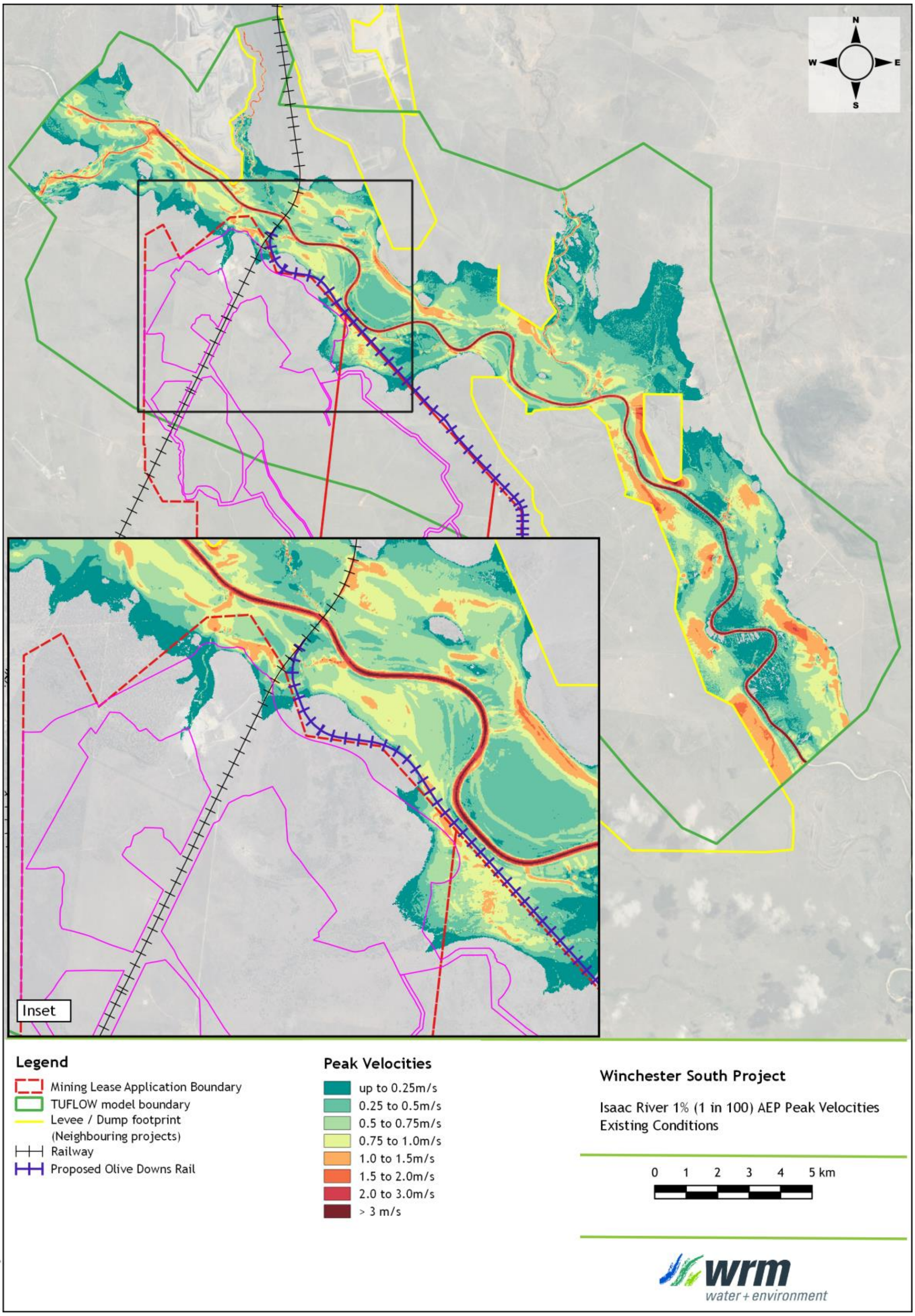


Figure D.11 – 1% AEP velocities in Isaac River, Existing conditions

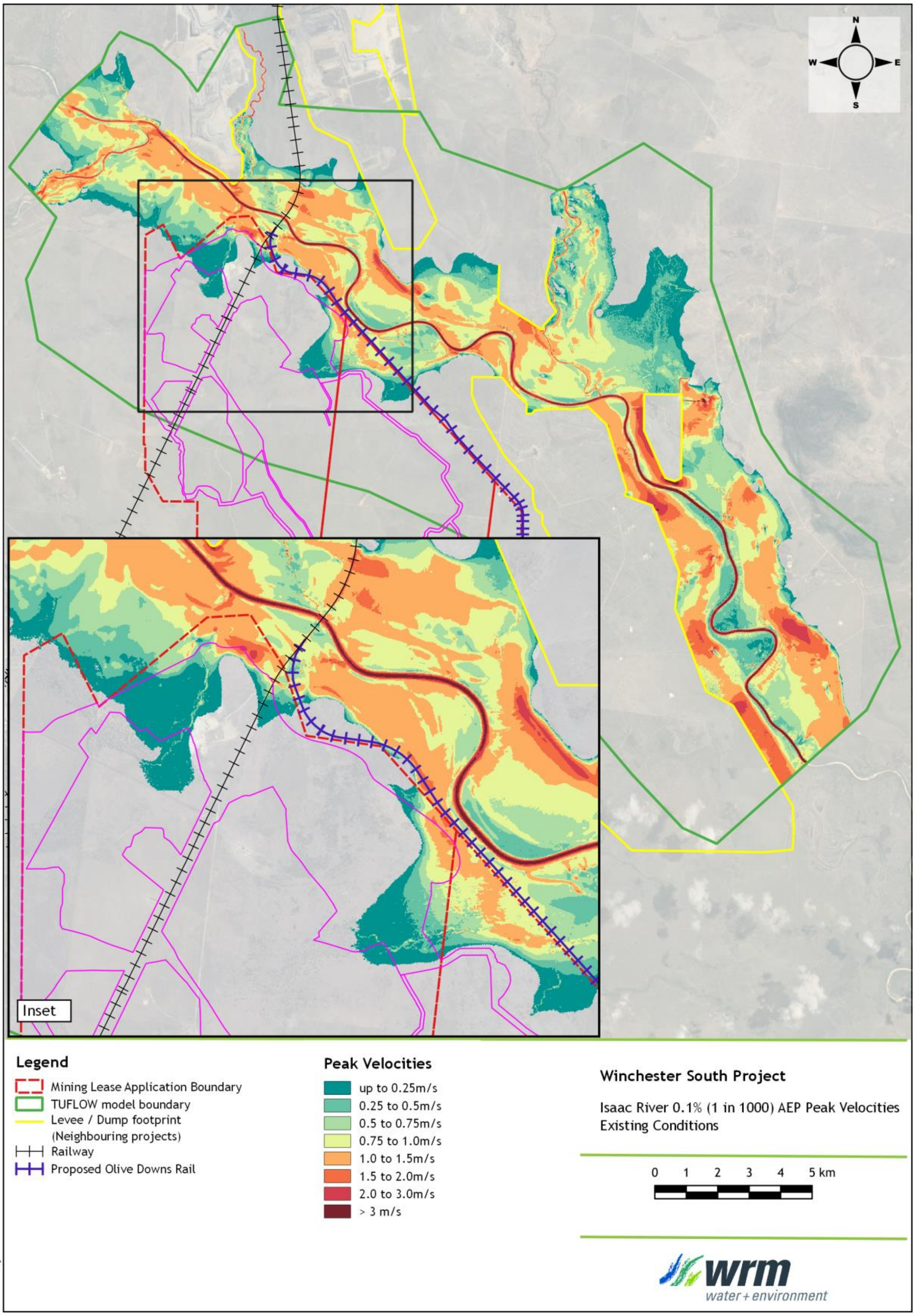


Figure D.12 – 0.1% AEP velocities in Isaac River, Existing conditions

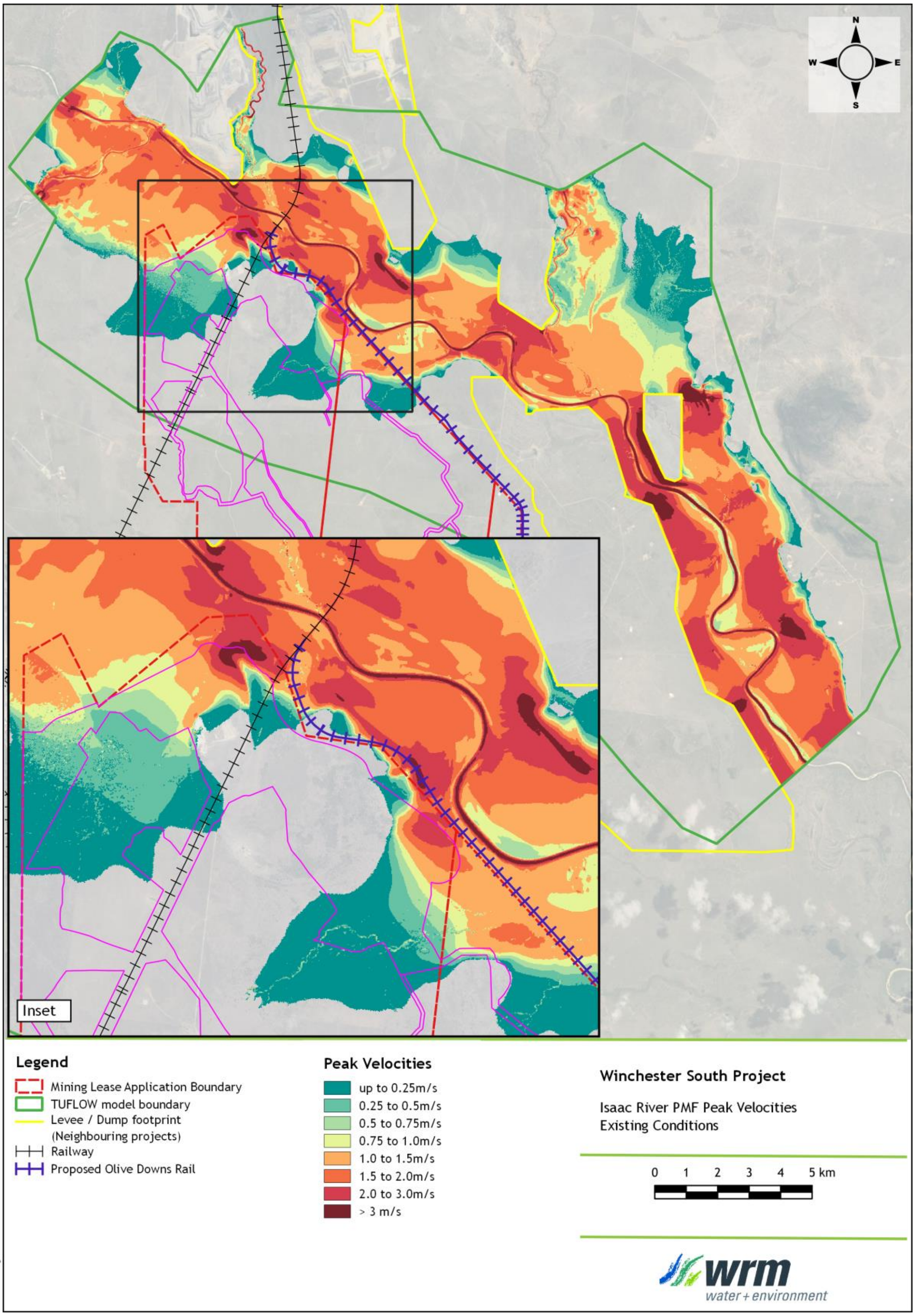


Figure D.13 – PMF velocities in Isaac River, Existing conditions

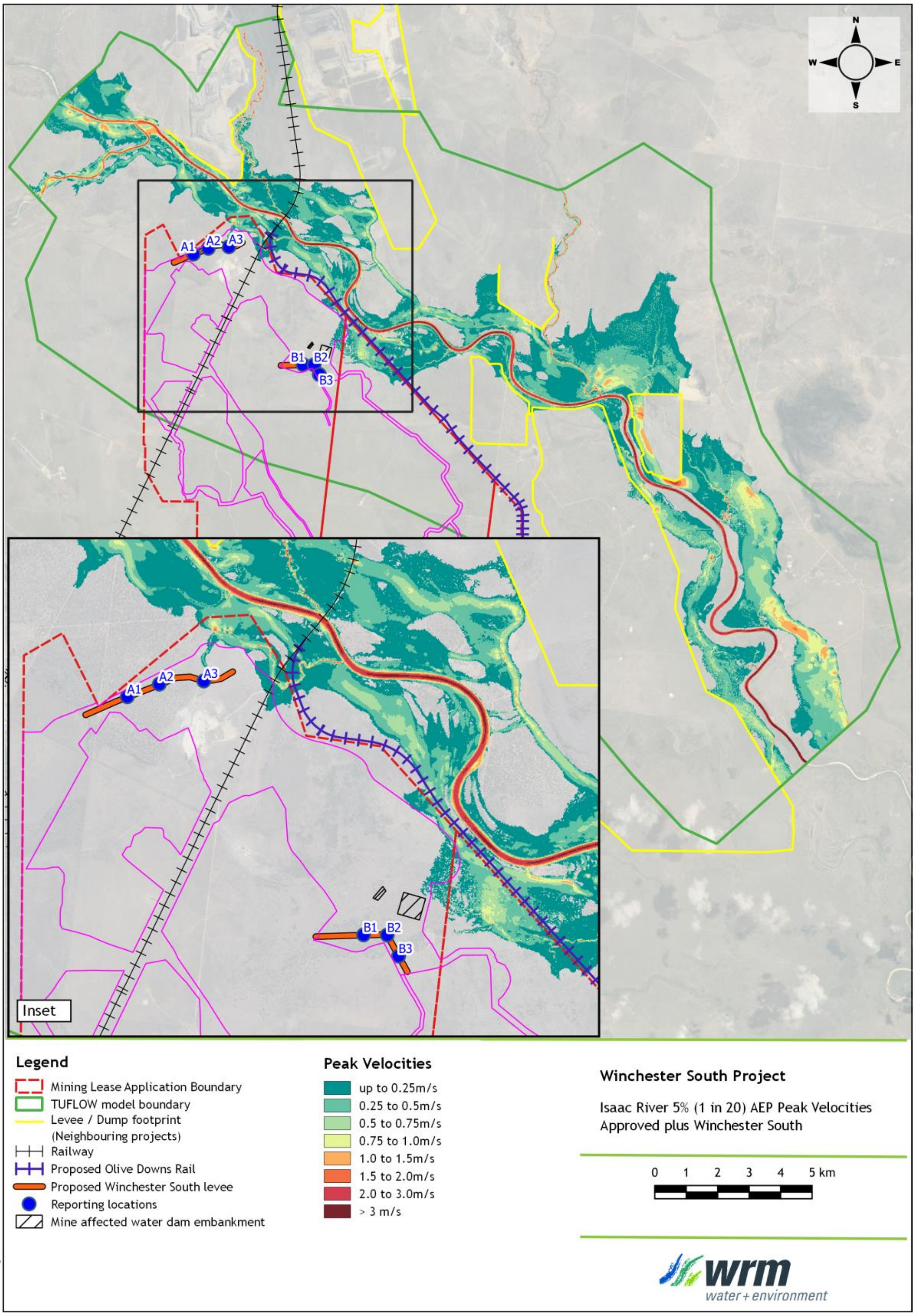


Figure D.14 – 5% AEP velocities in Isaac River, Proposed conditions

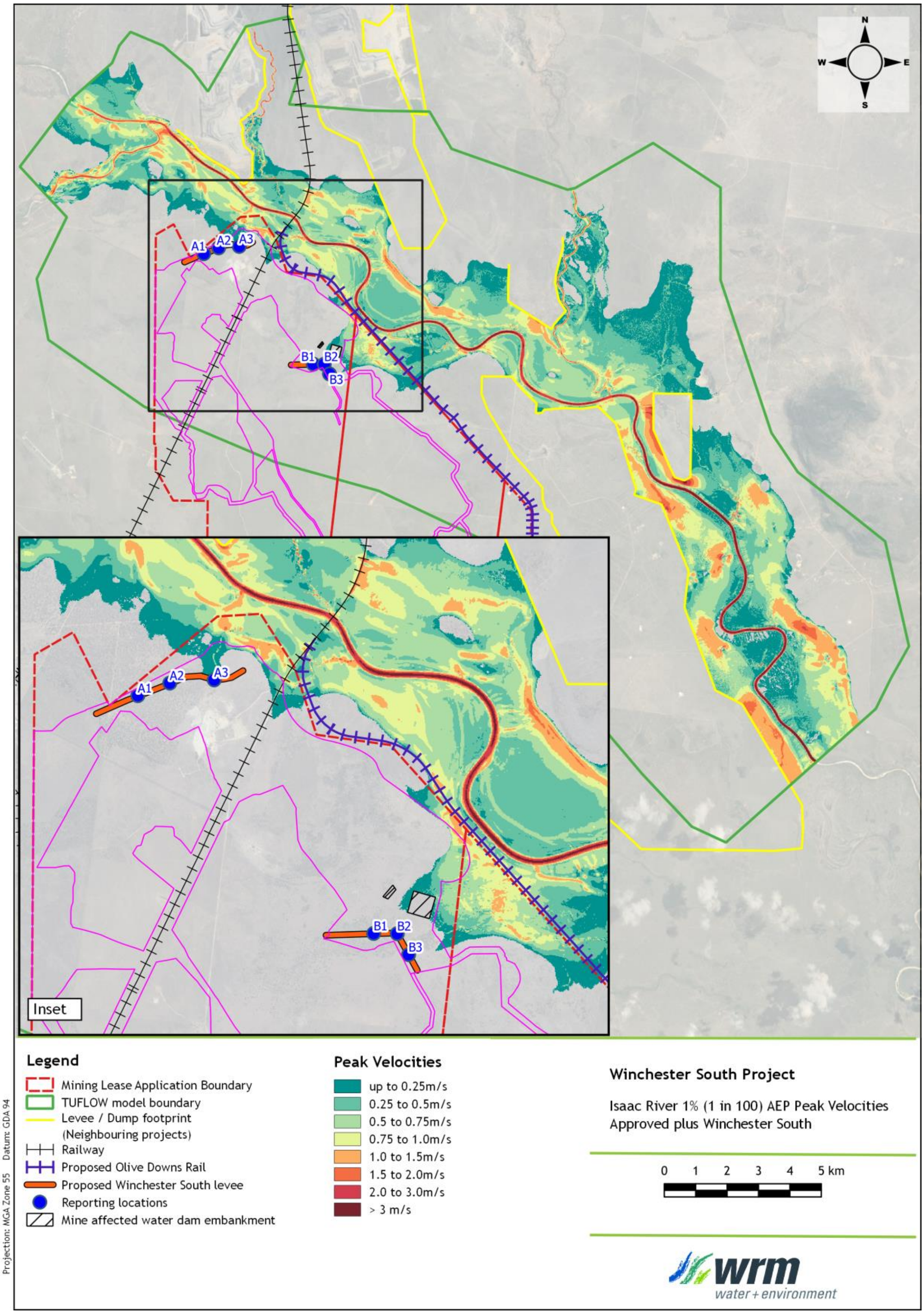


Figure D.15 – 1% AEP velocities in Isaac River, Proposed conditions

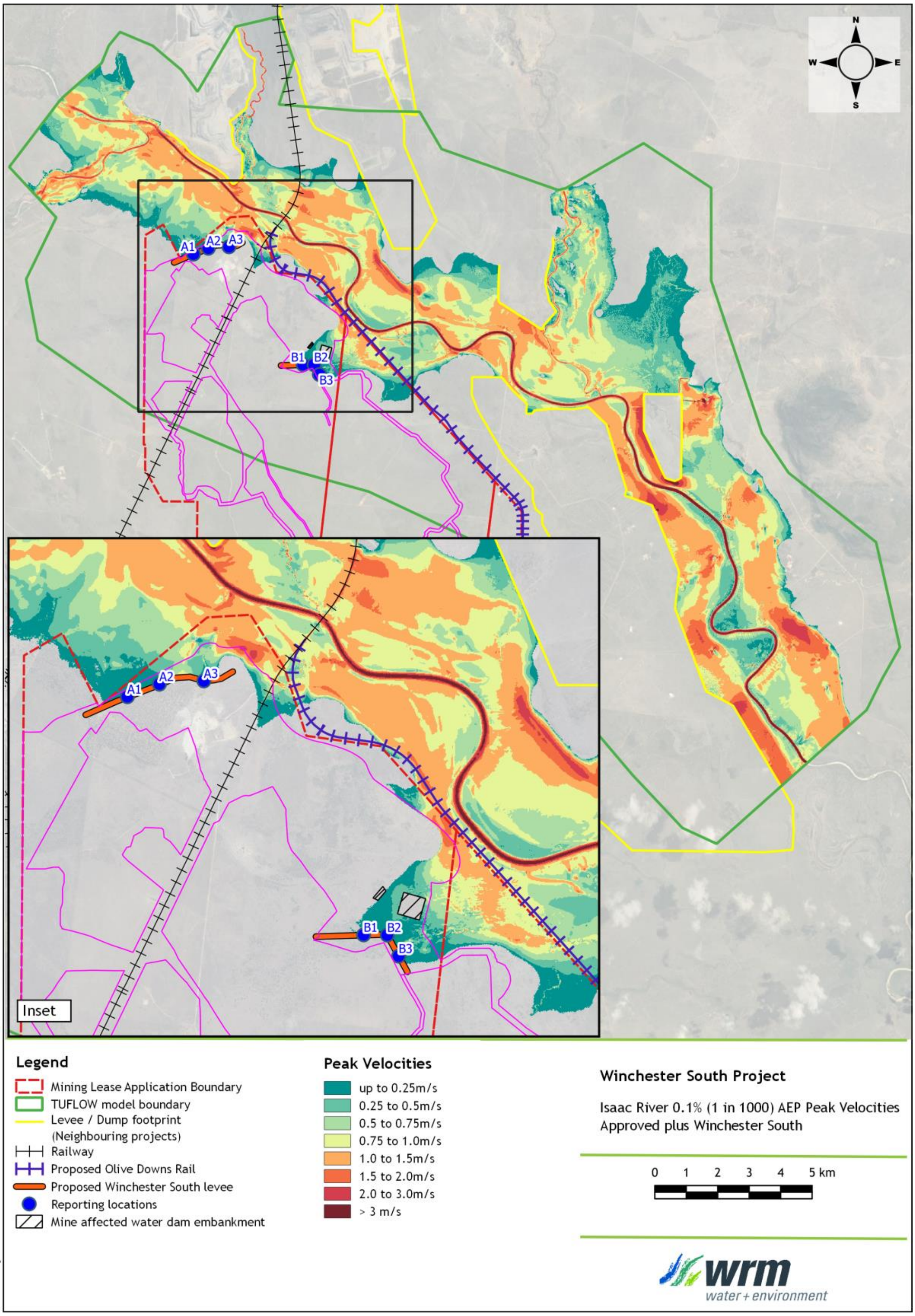


Figure D.16 – 0.1% AEP velocities in Isaac River, Proposed conditions

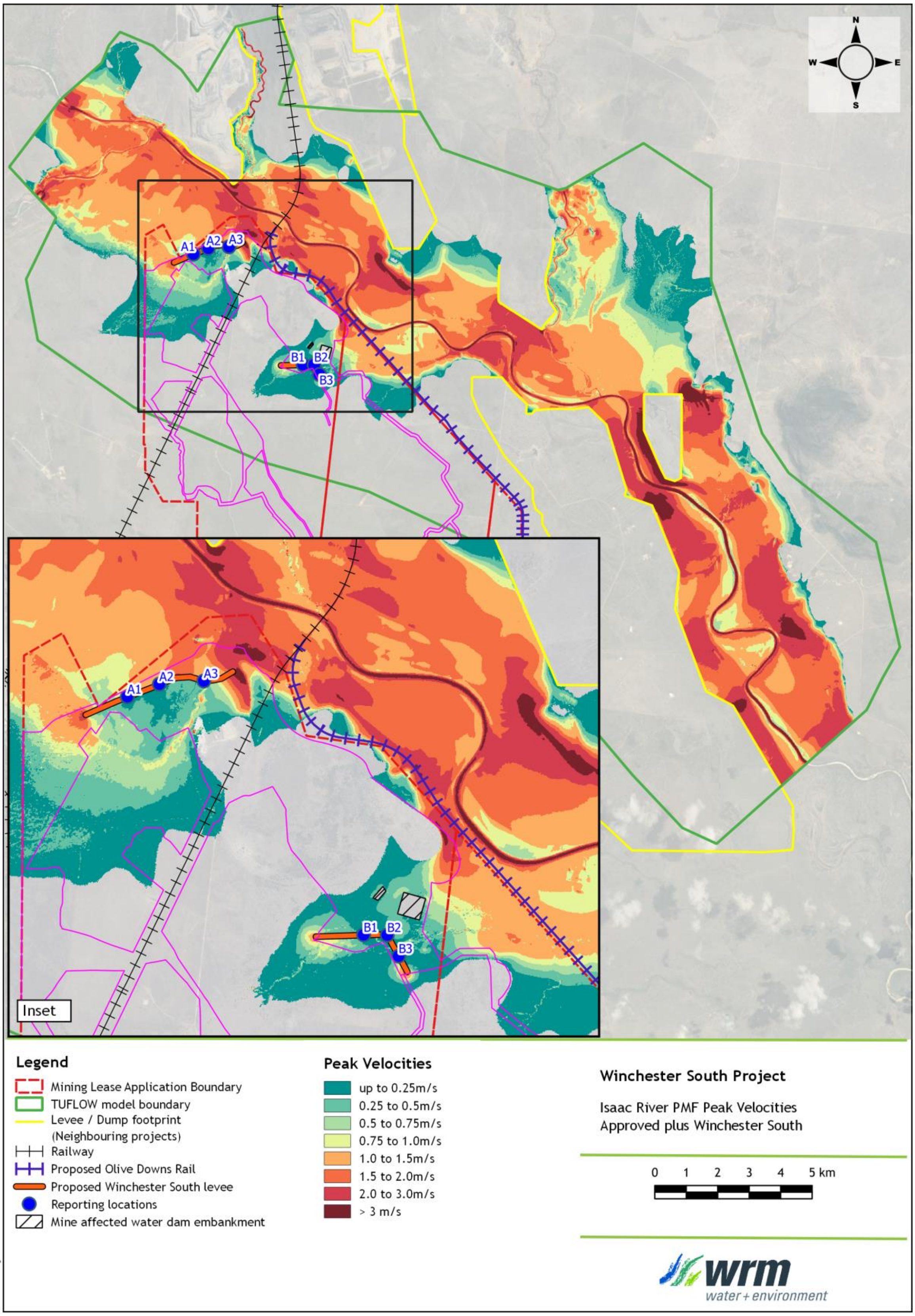


Figure D.17 – PMF velocities in Isaac River, Proposed conditions

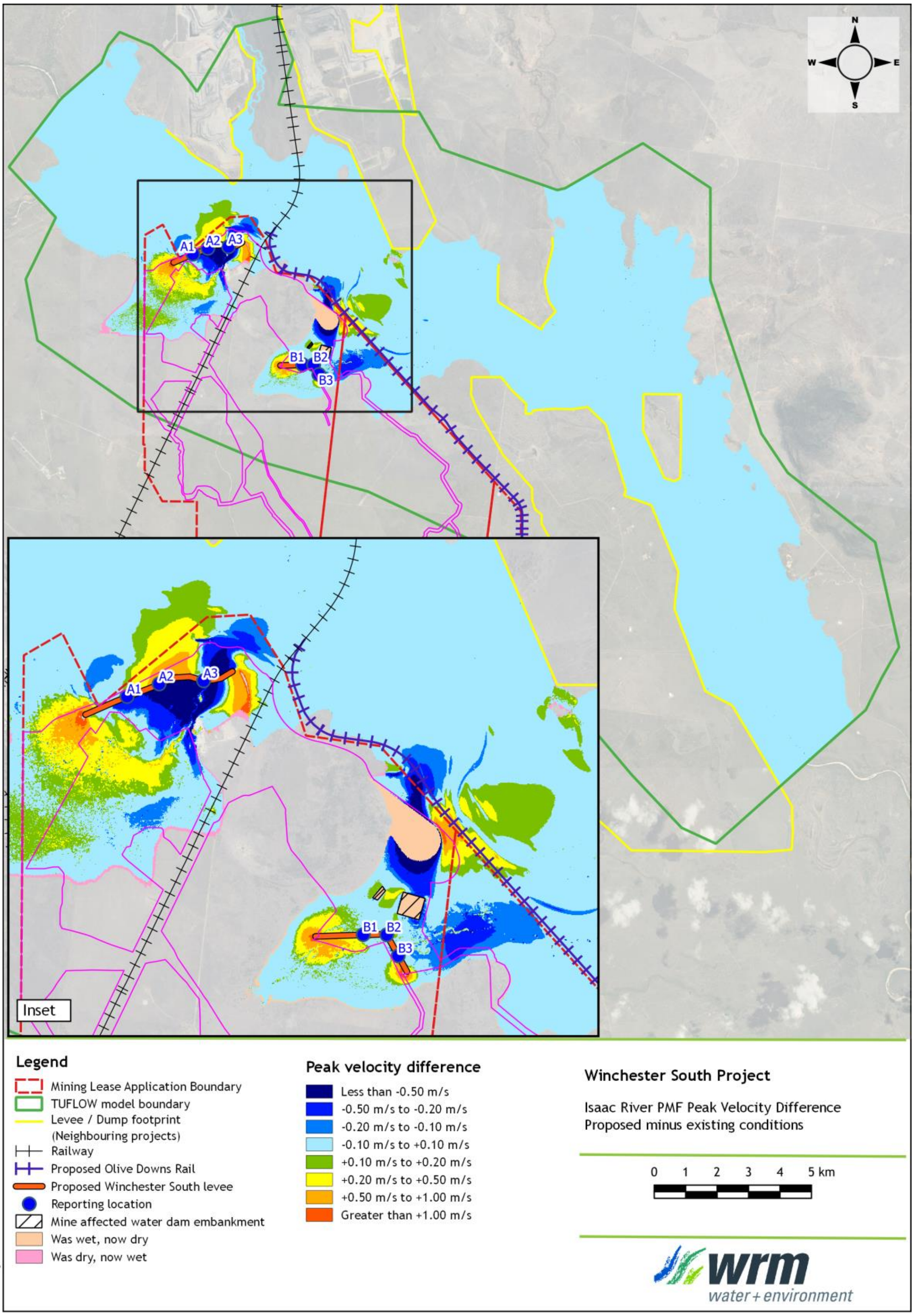


Figure D.18 – Impact on PMF velocities in Isaac River, Proposed minus Existing conditions

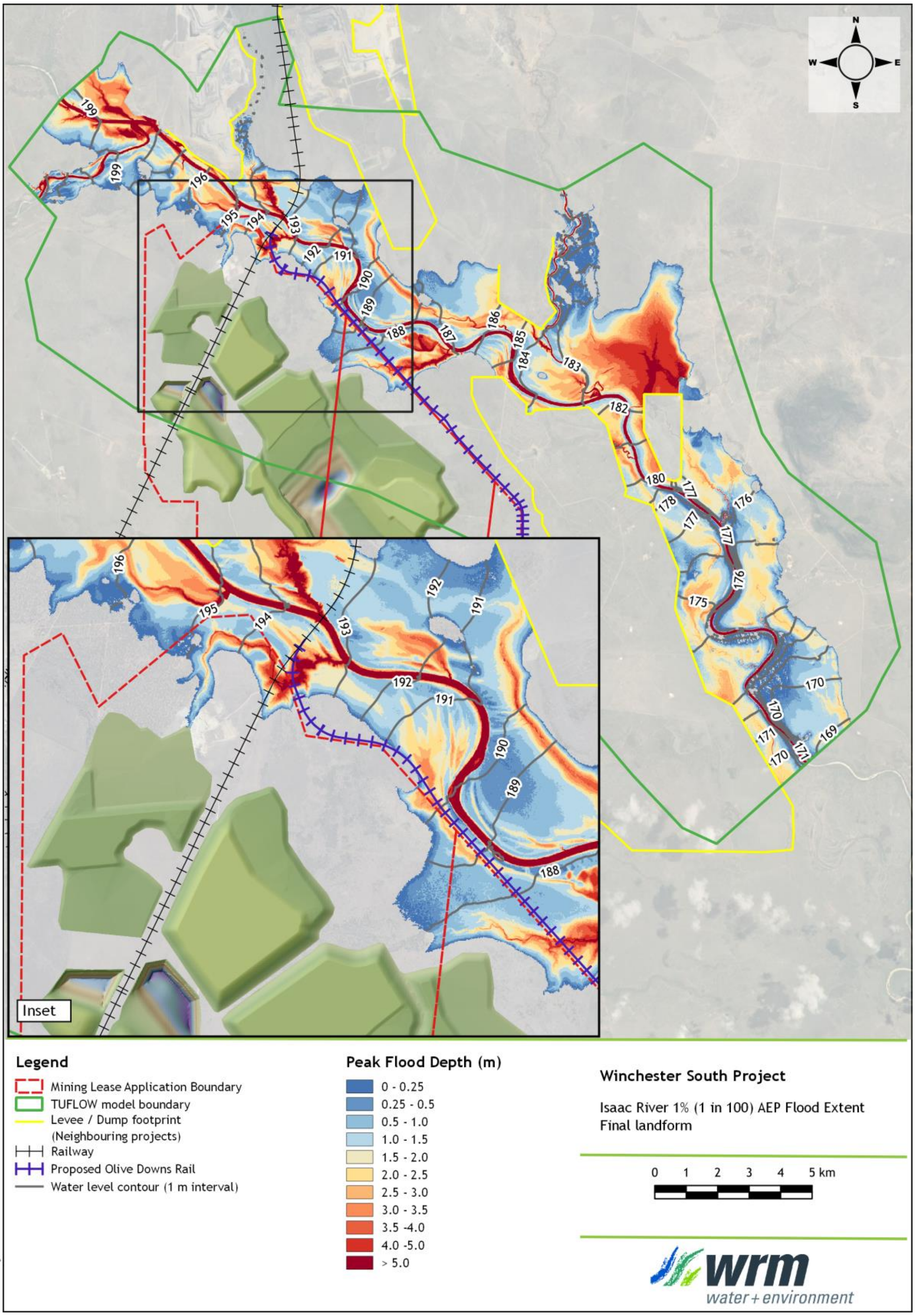


Figure D.19 – 1% AEP depth and flood levels in Isaac River, Post-mining conditions

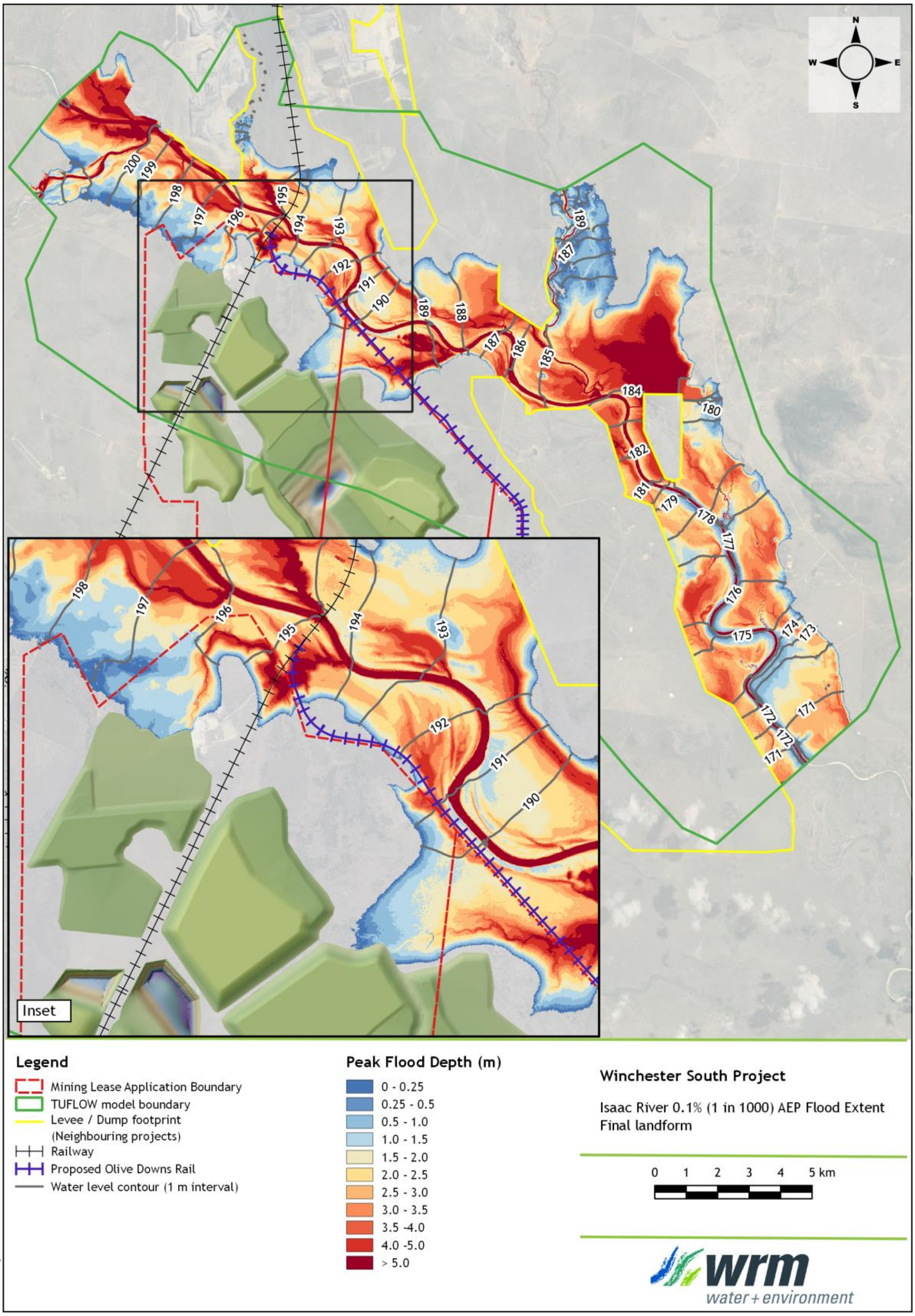


Figure D.20 – 0.1% AEP depth and flood levels in Isaac River, Post-mining conditions

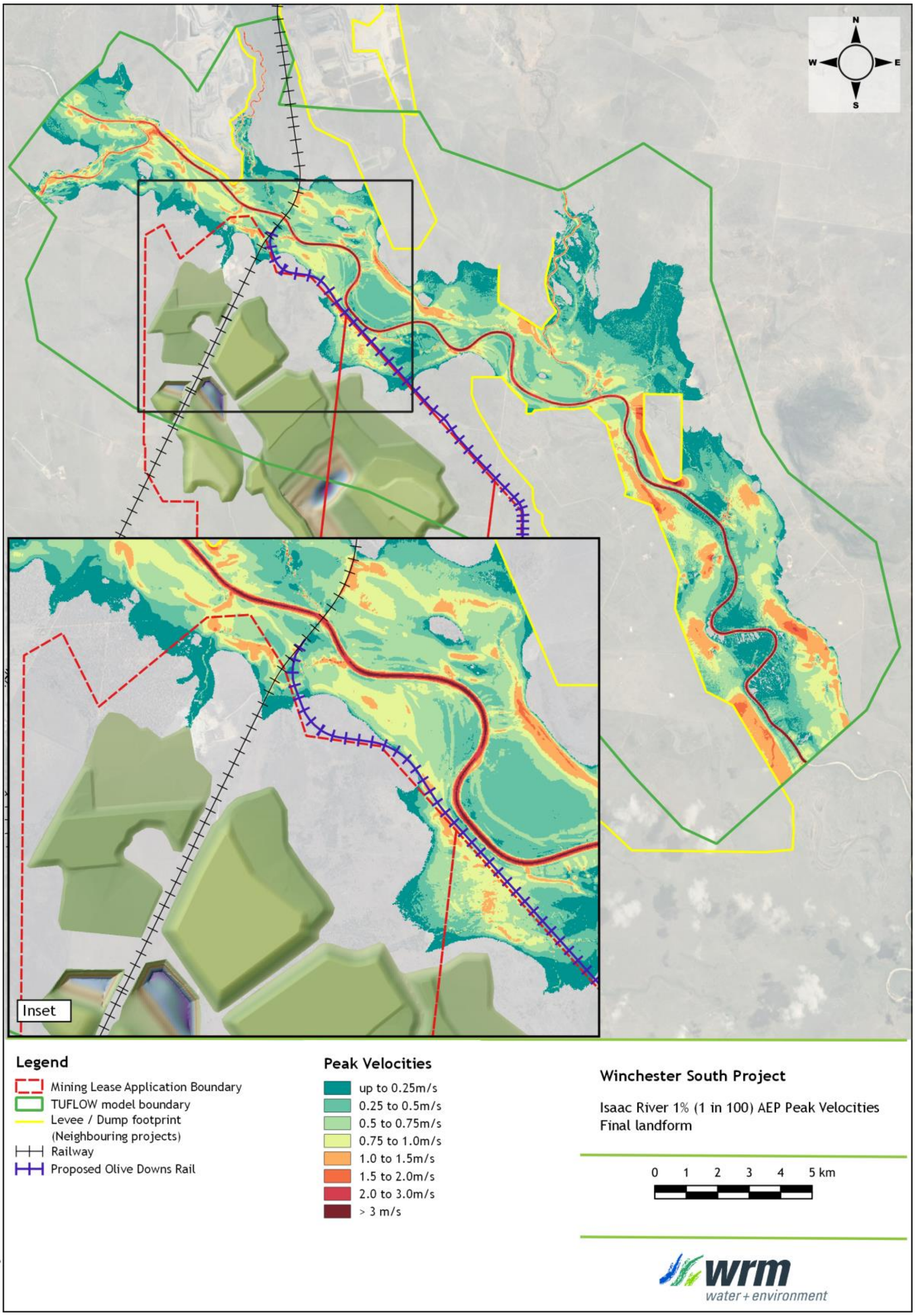


Figure D.21 – 1% AEP velocities in Isaac River, Post-mining conditions

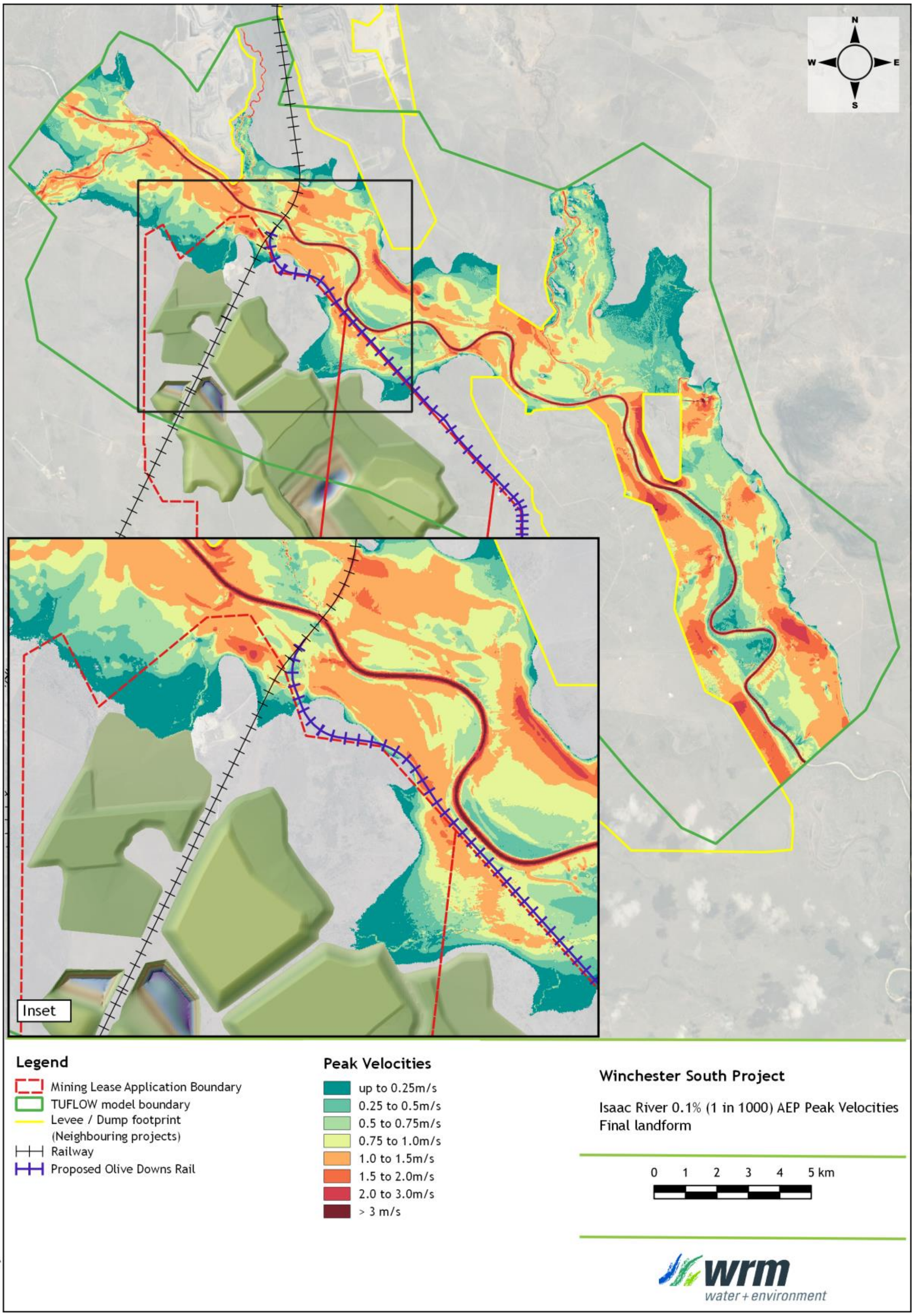


Figure D.22 – 0.1% AEP velocities in Isaac River, Post-mining conditions

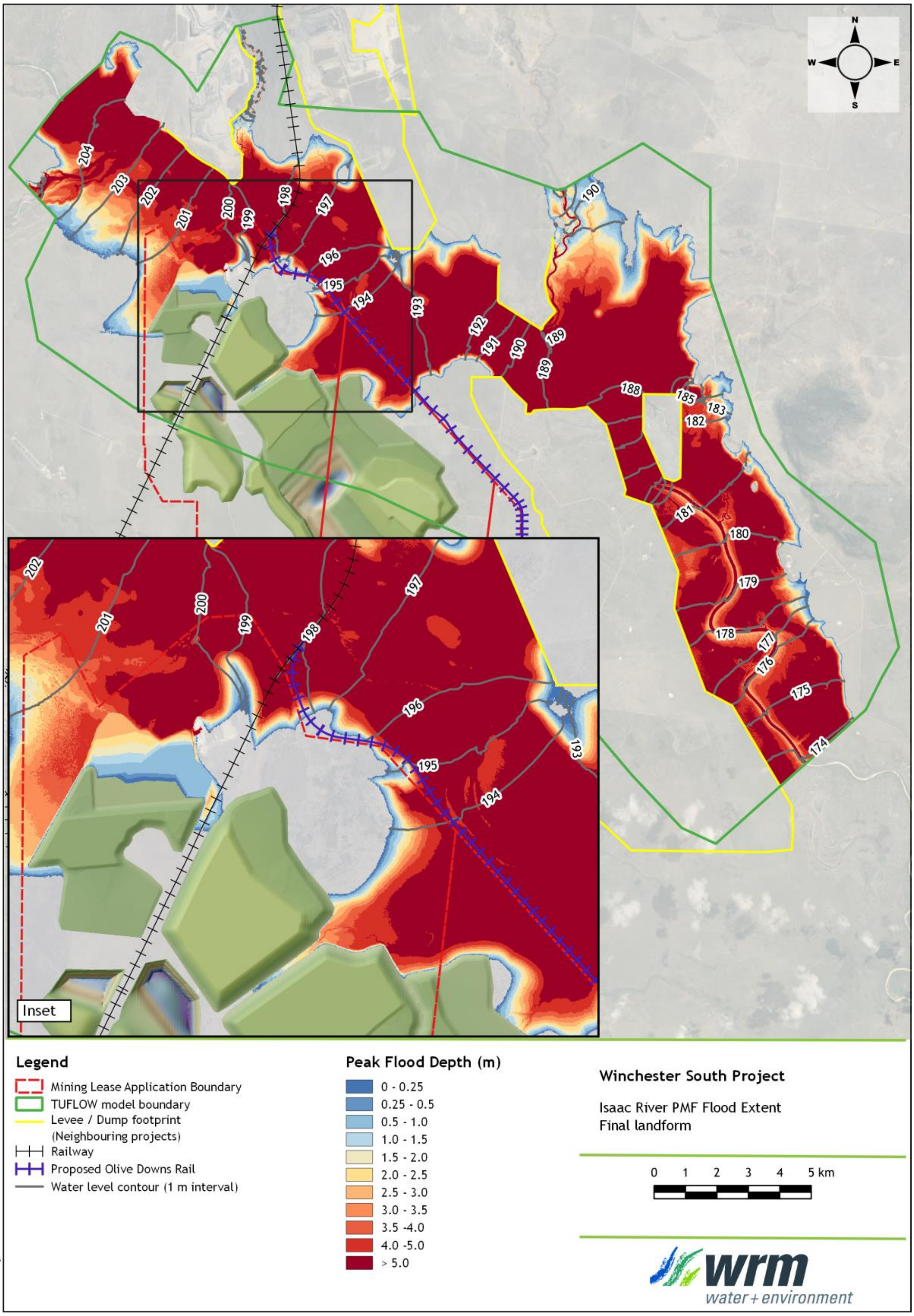


Figure D.23 – PMF depth and flood levels in Isaac River, Post-mining conditions

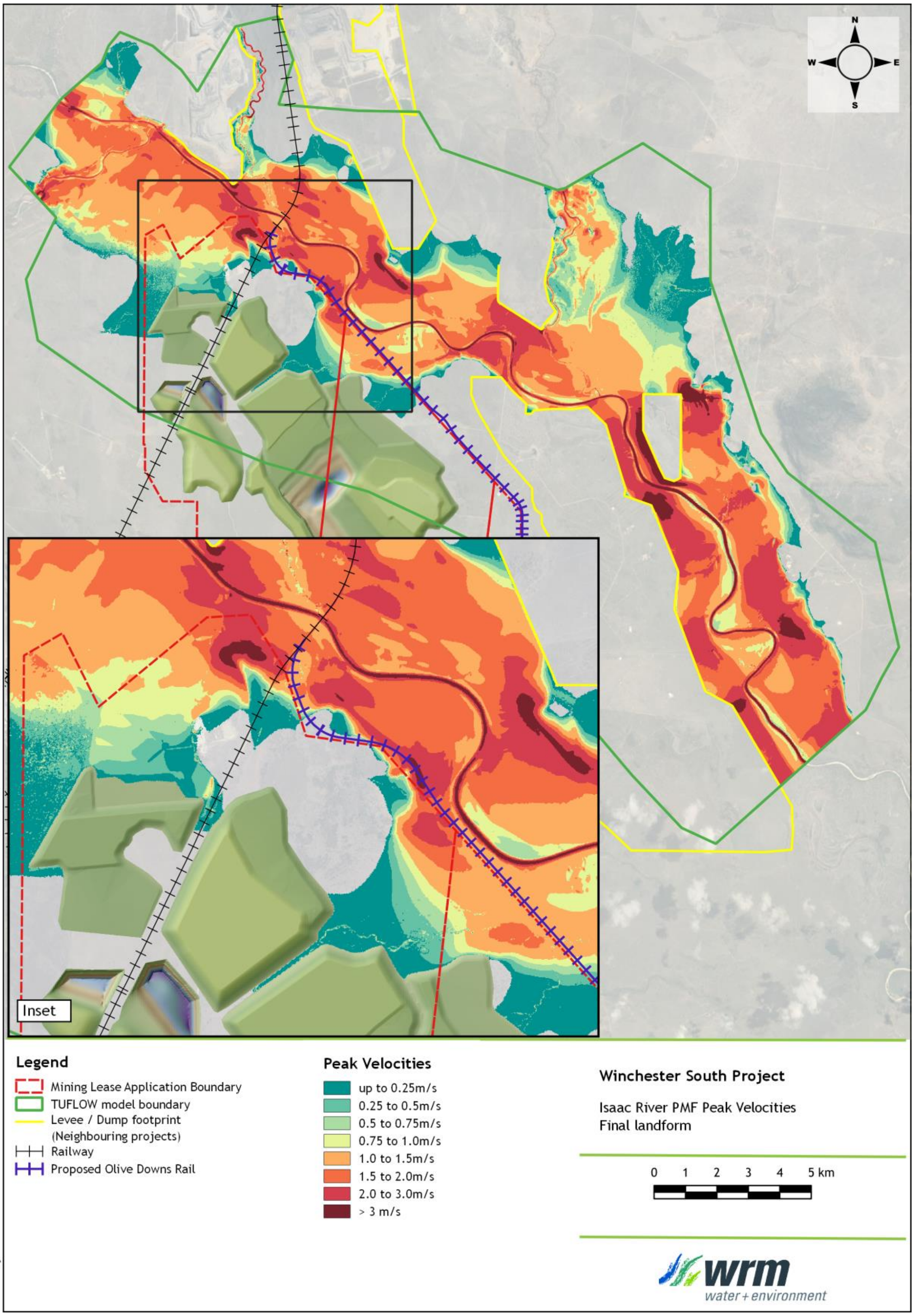


Figure D.24 – PMF velocities in Isaac River, Post-mining conditions

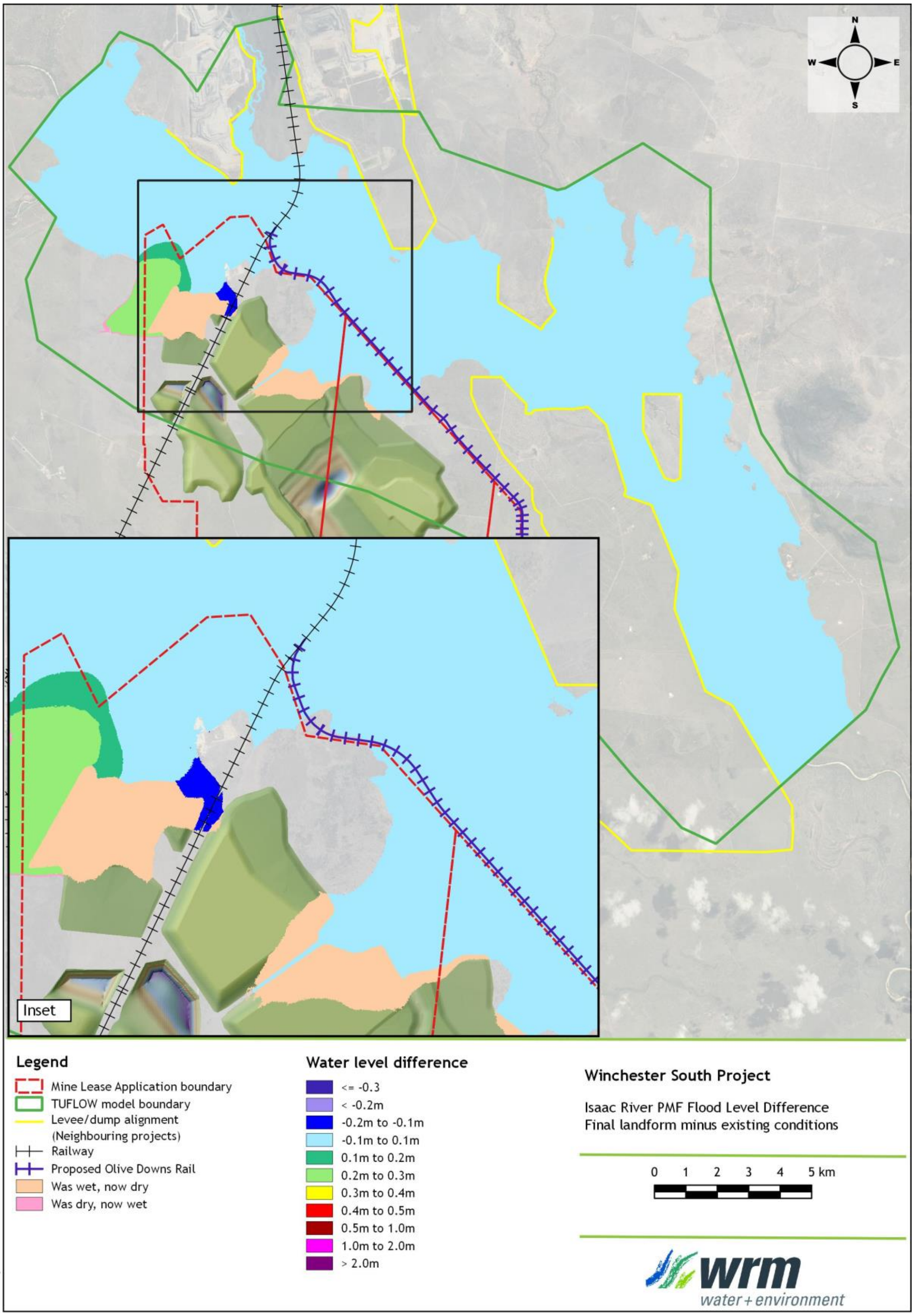


Figure D.25 – PMF change in peak water level, post-mining minus existing conditions

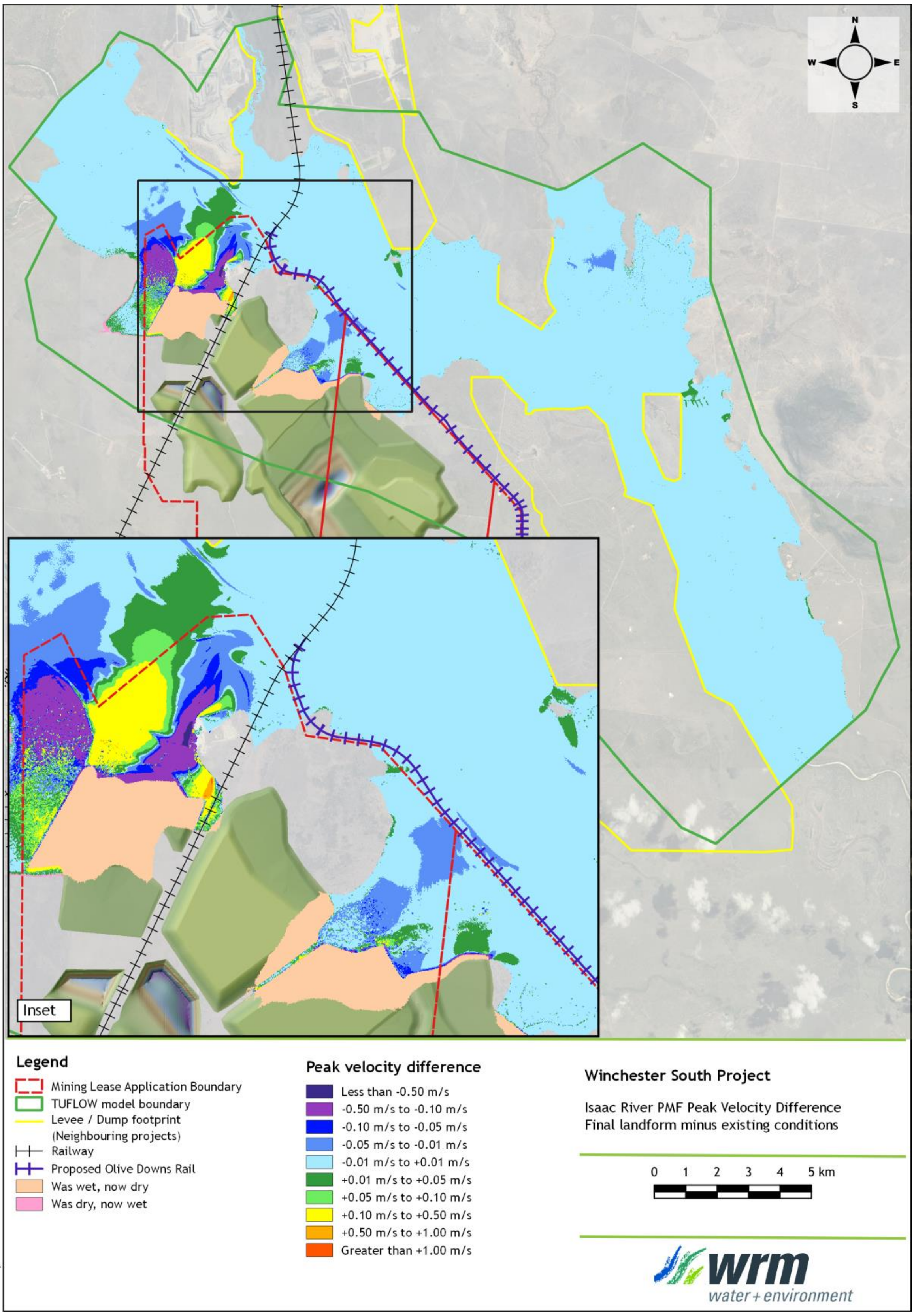


Figure D.26 – PMF change in peak velocity, post-mining minus existing conditions

Appendix E XPRafts design discharge box and whisker plots

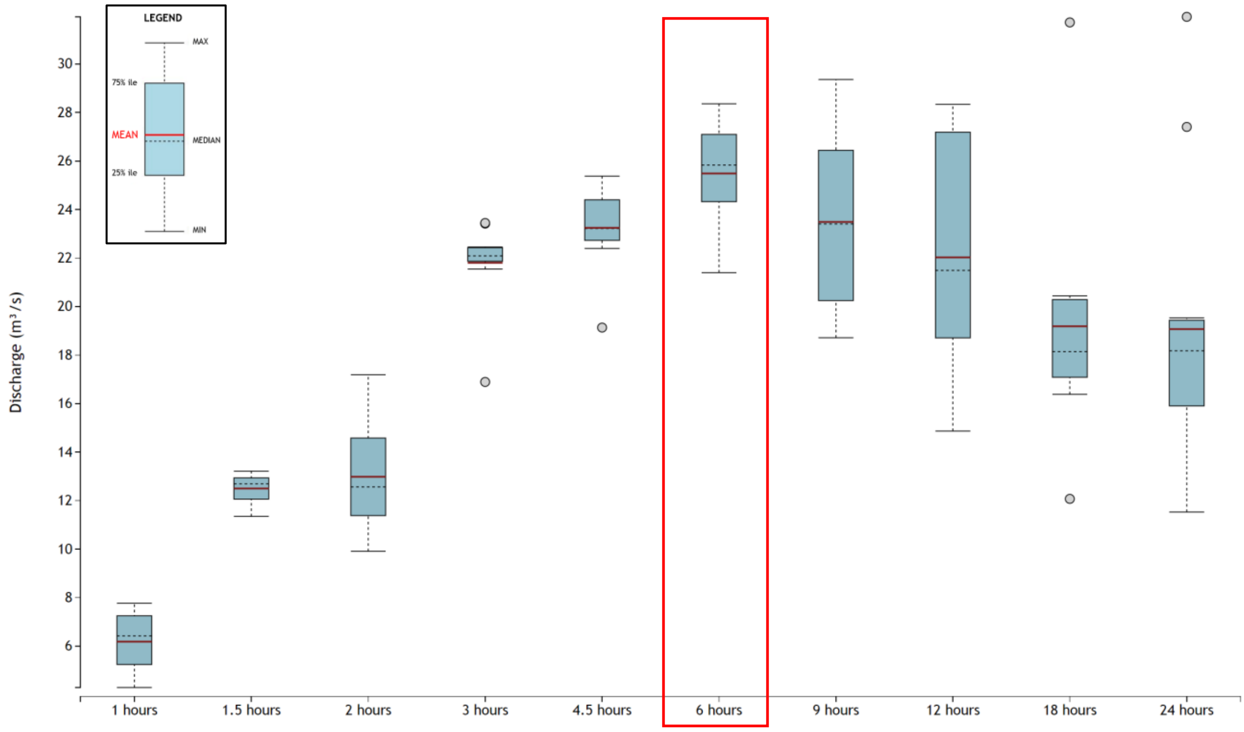


Figure E.1 - Box plots of 10% AEP design discharges at catchment 3, local drainage XPRafts model

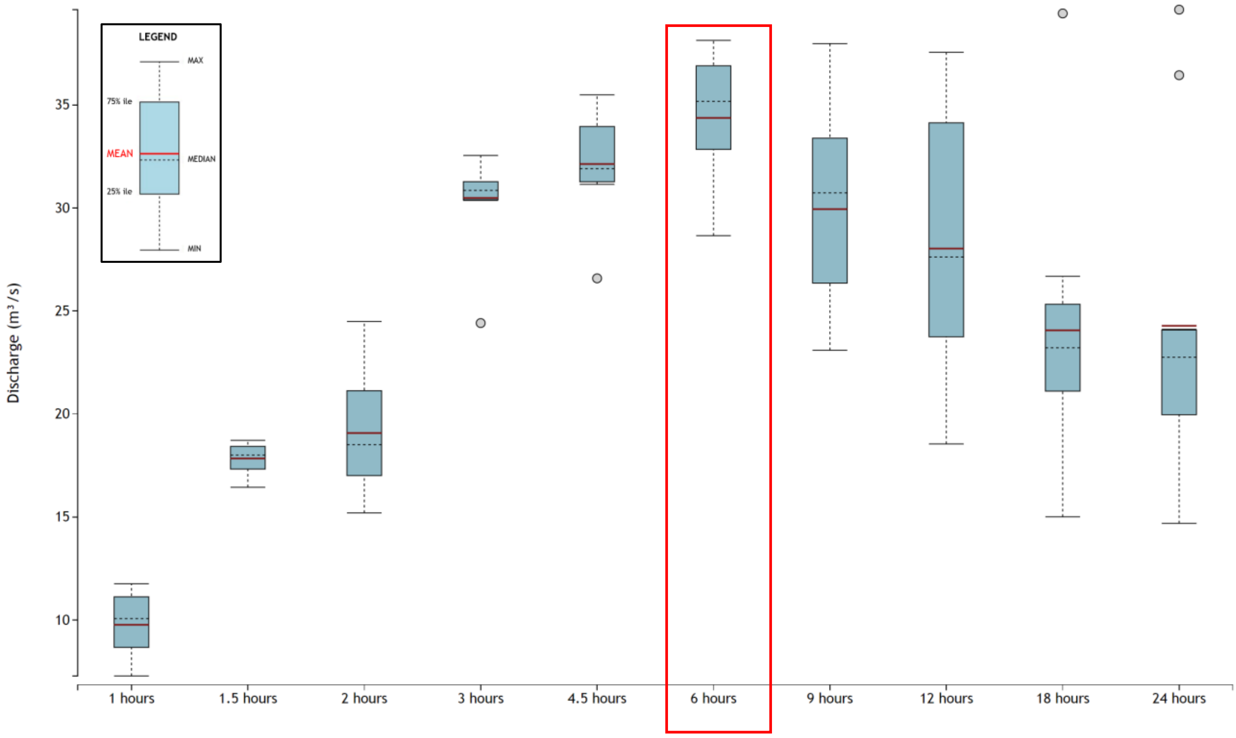


Figure E.2 - Box plots of 5% AEP design discharges at catchment 3, local drainage XPRafts model

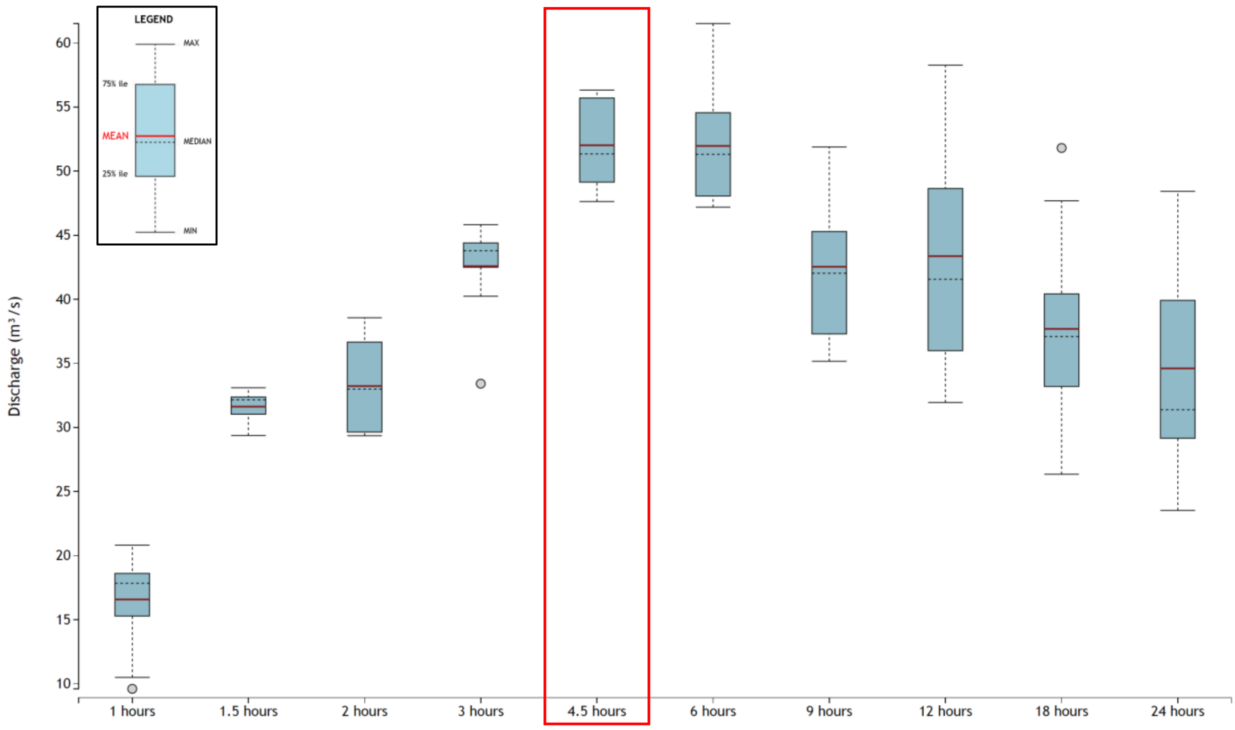


Figure E.3 - Box plots of 1% AEP design discharges at catchment 3, local drainage XPRafts model

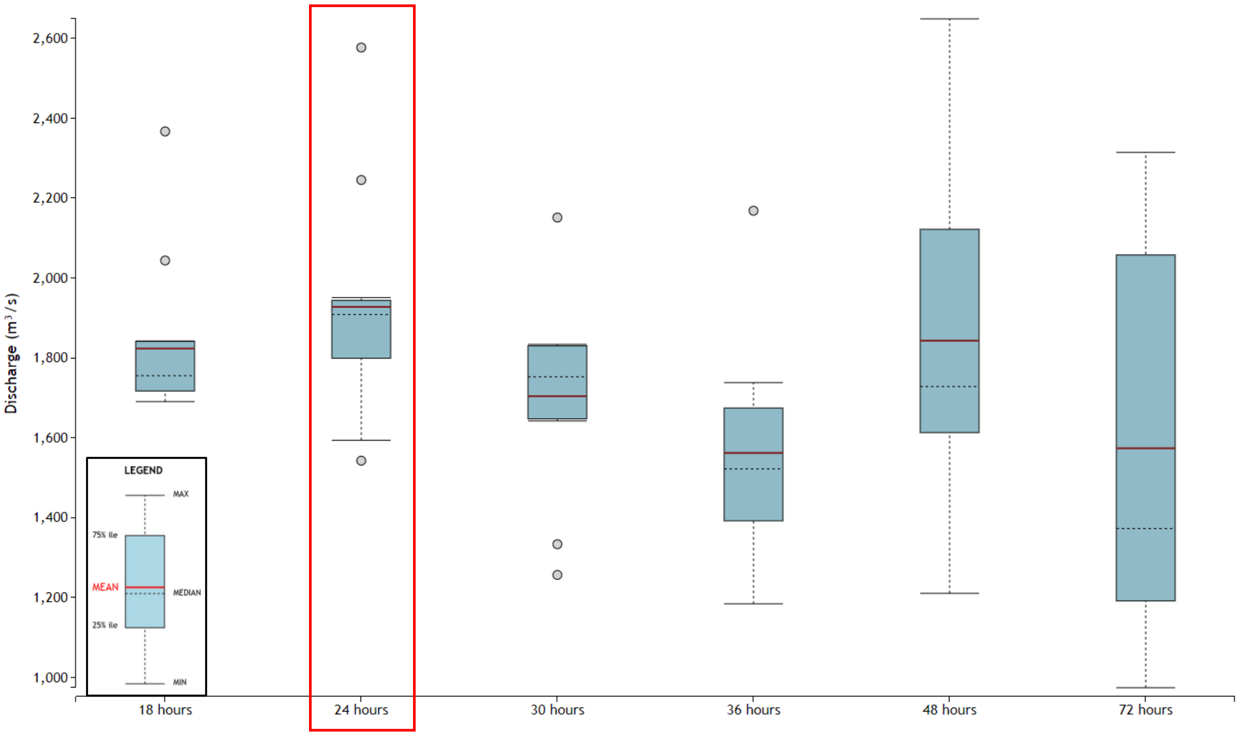


Figure E.4 – Box plots of 10% AEP design discharges at Deverill, Isaac River XPRafts model

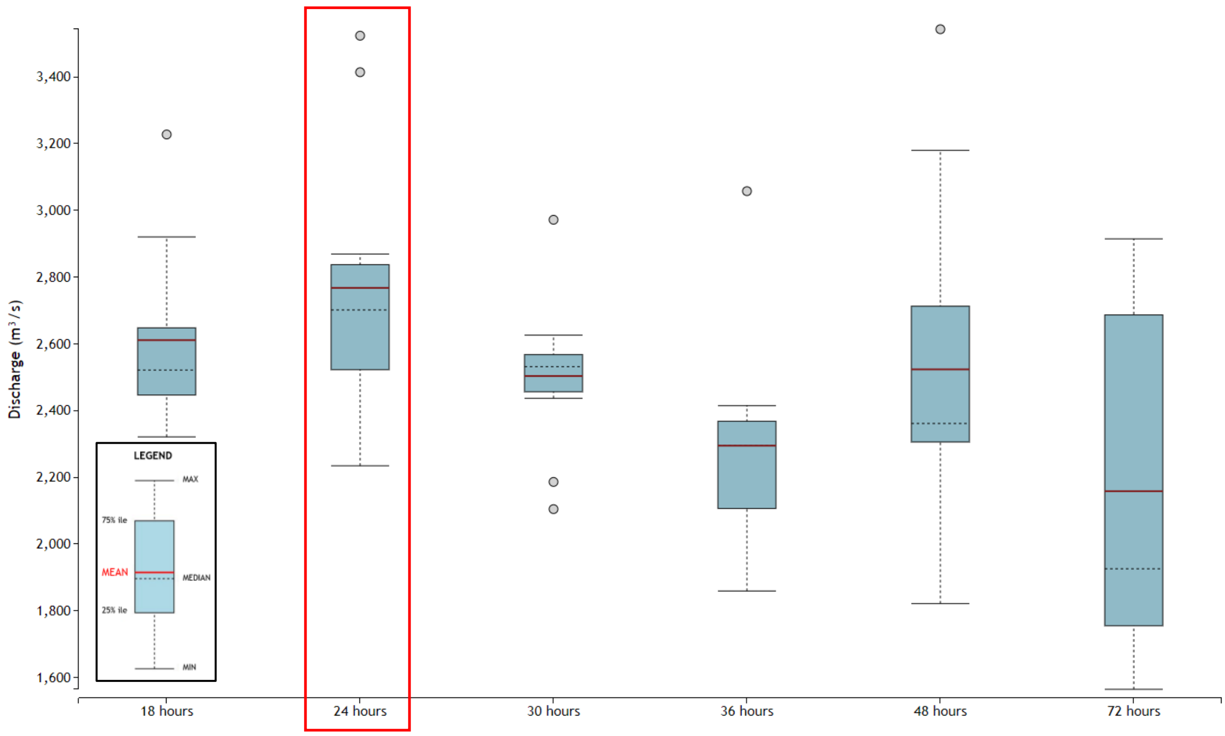


Figure E.5 – Box plots of 5% AEP design discharges at Deverill, Isaac River XPRafts model

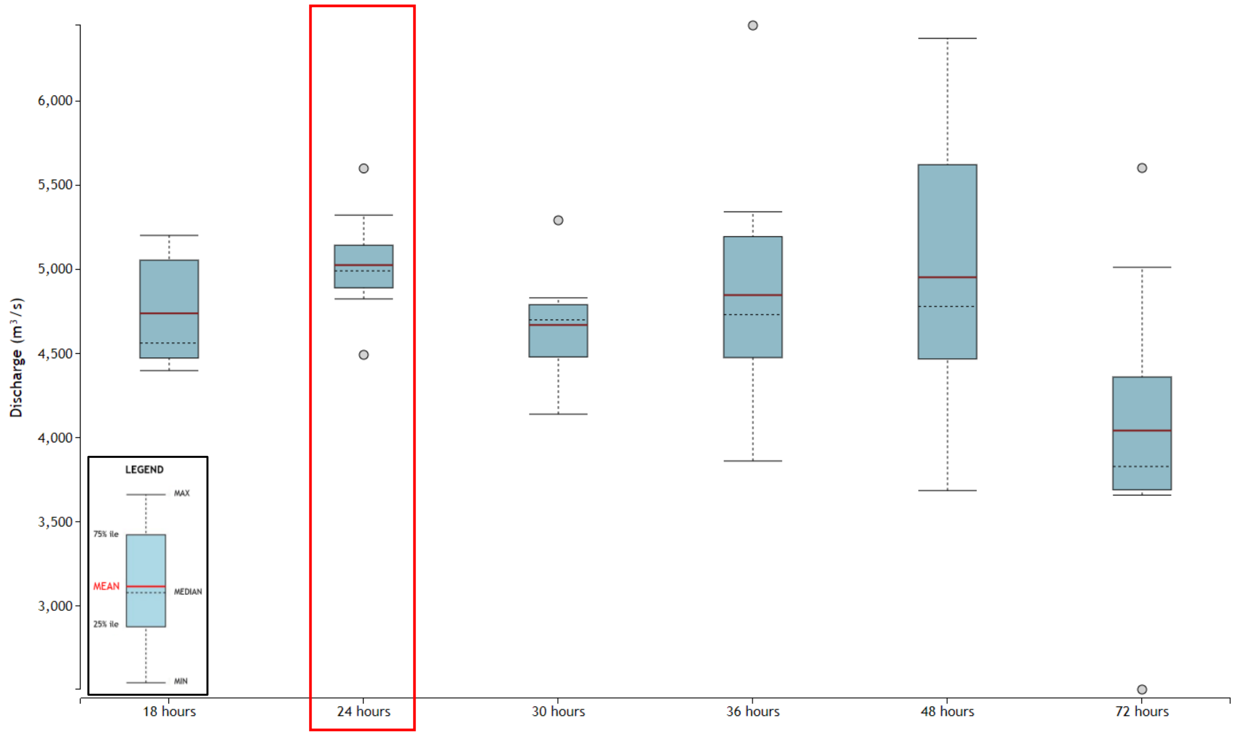


Figure E.6 – Box plots of 1% AEP design discharges at Deverill, Isaac River XPRafts model

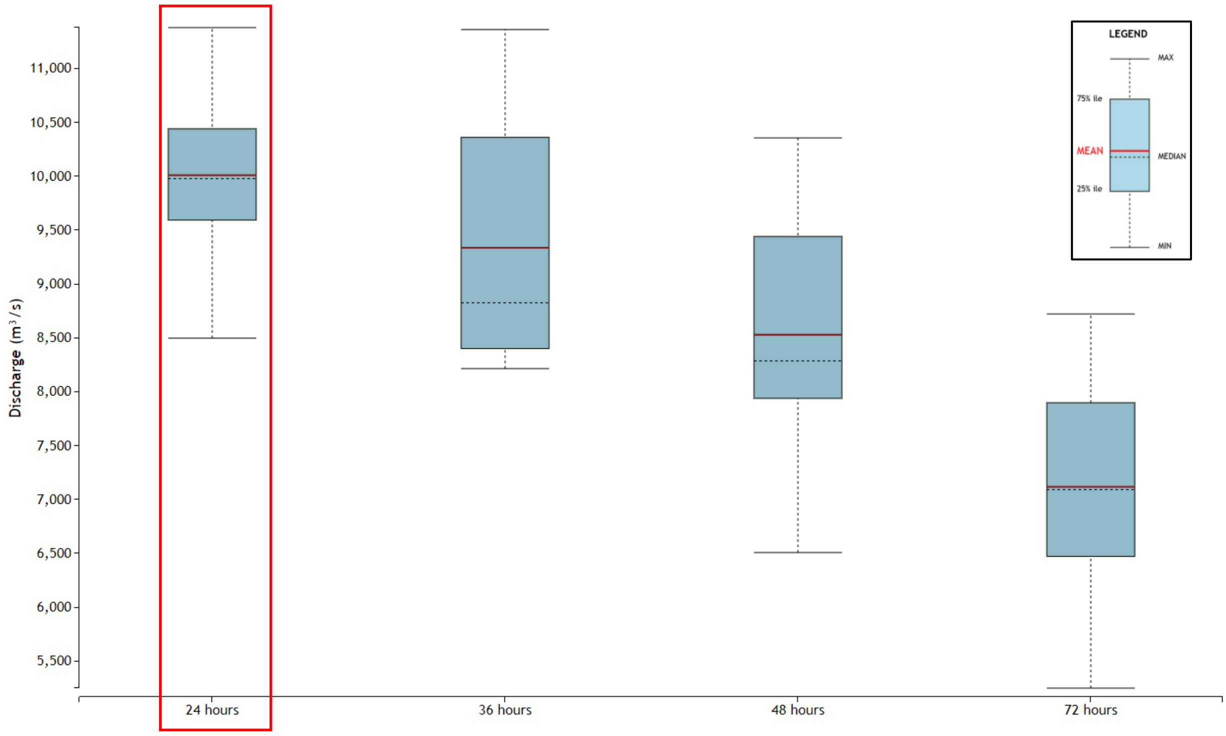


Figure E.7 – Box plots of 0.1% AEP design discharges at Deverill, Isaac River XPRafts model

Appendix F Winchester South Project Technical Study Report - Geomorphology

Winchester South Project

Environmental Impact Statement

Technical Study Report

Geomorphology

Dr Christopher J Gippel

Final

November 2020

FLUVIAL SYSTEMS

Winchester South Project

Geomorphology

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Prepared by:

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November 2020

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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.
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)
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).
Habitat	The place where a species, population or ecological community lives (whether permanently, periodically or occasionally).

Term	Definition
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.
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.
Pool	A deeper section of a stream that retains water.
Proposed development	Underground coal mining and associated activities within the Study Area.
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 watercourse.
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.
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).
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.

Term	Definition
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 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.
Watercourse	Any flowing stream of water, whether natural or artificially regulated (not necessarily permanent) (see also Stream and Waterway).

Acronyms

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

Whitehaven Coal Limited (Whitehaven), proposes to develop the Winchester South Project (the Project), an open cut coal mine and associated infrastructure in an existing mining precinct within the Bowen Basin, located approximately 30 km south east of Moranbah. The Project would include an open cut mine developed within Project Mining Lease Application areas MLA 700049, MLA 700050 and MLA 700051 and also includes development and operation of an infrastructure corridor within MLA 700065 (collectively referred to as the Project MLA areas).

This Geomorphology Technical Report documented the geomorphological character of the 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. The core Project Study Area was the land within the Project MLA areas, although the spatial units of interest were formed by hydrological catchments and sub-catchments that extended upstream and downstream of the boundaries of the Project MLA areas. 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 43 sites within the period 19 – 21 November 2019. Data collected from 5 sites on the Isaac River in 2017 using the same methodology were added to the dataset. 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 using light vehicle to travel between sites, walking from the vehicle to representative locations, and following a sampling protocol. A comprehensive set of variables were 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 Project MLA areas were drained by three small sub-catchments of the Isaac River (labelled A, B and C) that joined the river outside the boundaries of the Project MLA areas. The Isaac River is a Sixth Order river. The watercourses within the Study Area were small and shallow First and Second Order streams. The catchment area of Sub-catchment A upstream of the boundary of the Project MLA was large enough to generate sufficient runoff to form a defined channel, as designated by a mapped blue line and confirmed by field survey. The Surface Water and Flooding Assessment undertaken for the Project included an up-catchment diversion to transfer the flow from this upper catchment area around the proposed Railway Pit and associated waste emplacement.

The surface geology of the Study Area comprised extensive undifferentiated sandy sediments, and Quaternary alluvium. 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, classified as Vertosols / Cracking clay. Thus, the beds and banks of the minor watercourses were mainly formed by fine grained silt/clay material. The terrain within the Study Area was low gradient, being less than 10 degrees and mostly less than 2 degrees, other than on some mined landforms and banks of watercourse.

The Isaac River in the vicinity of the Study Area had a sand bed with a low downstream mean gradient of 0.04 degrees, or 0.07 percent. The channel had almost continuous very steep banks, mostly in the range 25 – 35 degrees. The river channel was laterally unconfined with extensive floodplain connection. These were the characteristics of a Low Sinuosity Sand stream type. The upper and middle sections of the minor watercourses in sub-catchments A, B and C had low downstream gradients less than 0.5 degrees, or 0.9 percent. The channels were generally small, mostly continuous, but in some areas poorly-defined. These watercourses were classified Low Sinuosity Fine Grained stream type. At their downstream extents, these channels incised into the Isaac River floodplain, becoming somewhat wider, deeper and steeper.

Most of the watercourse reaches were in a stable, close to natural or mildly disturbed geomorphic condition. Some watercourses were potentially impacted by factors that reduced their condition, in particular high loads of sand in the bed of the Isaac River, but without historical data concerning condition prior to the land cover and drainage being modified for agricultural and mining use, this remains uncertain. Only two knickpoints, and no zones of major geomorphic instability, were observed over the surveyed area.

The risk of erosion of the channel and floodplain was assessed for Isaac River and Ripstone Creek by considering the potential hydraulic changes due to the Project, modelled as part of the flood study undertaken for the EIS. It was concluded that the risk of significant geomorphic change in the Isaac River and Ripstone Creek due to the proposed mining activity was negligible. A residual area of approximately 14.3 km^2 would continue to drain to the residual voids. The area captured by the voids would represent a small percentage of the total areas of the three main sub-catchments draining within the mining lease area, and this captured area would be distributed between them. The implication of this change for geomorphic forms and processes in the watercourses of the sub-catchments is that they would have slightly lower flows. The reduced flow duration and flow magnitude would tend to result in some vegetation encroachment within the channel, and increased sediment deposition within the channel. Thus, theoretically, these channels would be slightly more stable under the post-mining scenario.

The predicted overall geomorphic impact of the project would be relatively minor. The Project would have negligible impact on the Isaac River; it would reduce the length and catchment area of some small First and Second Order watercourses within three sub-catchments, but these would be largely reinstated in the post-mining landform. Thus, the regional cumulative impacts of the Project on geomorphic characteristics of streams would be negligible.

The focus of geomorphic monitoring would be the undisturbed reaches of minor watercourses downstream of mining operations, extending down to where they meet the Isaac River, as well as the drainage paths from the controlled release points. Monitoring the geomorphology of the Isaac River and Ripstone Creek would be problematic from a scientific perspective and is considered unnecessary. This Geomorphology Technical Report found that physical changes brought about by the Project would have negligible geomorphic impacts on Isaac River and Ripstone Creek, in which case it would not be possible to attribute, with statistical confidence, any geomorphic changes observed on these watercourses to activities associated with the Project.

Geomorphic monitoring should be undertaken using objective, scientifically sound methods, following a BACI (Before/After/Control/Intervention) design. It will be necessary to identify control watercourse reaches that are also monitored, preferably paired reaches of the watercourses found upstream of the Project MLA areas. The degree of change at the control reaches will set the tolerance for change in the impacted watercourses, located downstream of the Project MLA areas. The tolerance for stability of the drainage paths from the controlled release points would be set by the design standards used to construct these components of the water management system. The first survey would be undertaken during the third year after beginning mining operations, or following a flood event exceeding the 5 year average recurrence interval (ARI) event if it occurs in this period. The survey would then be repeated either every 5 years, or after every flood event exceeding the 5 year ARI event. The survey should be done using LiDAR technology. Visual assessment can in some circumstances be used for determining presence or absence of a geomorphic feature (e.g. presence/absence of a channel), but pseudo-quantitative visual assessment of geomorphic variables (e.g. erosion severity, or geomorphic condition score sheets) is not recommended. In general, these methods 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.

1.0 Introduction

1.1 Characteristics of the Winchester South Project

Whitehaven WS Pty Ltd (Whitehaven WS), a wholly owned subsidiary of Whitehaven Coal Limited (Whitehaven), proposes to develop the Winchester South Project (the Project), an open cut coal mine and associated infrastructure within the Bowen Basin, located approximately 30 kilometres (km) south east of Moranbah, within the Isaac Regional Council Local Government Area (LGA) (Figure 1).

The Project involves the development of an open cut coal mine in an existing mining precinct for export of coal products. The Project would include construction and operation of a mine infrastructure area (MIA), including a Coal Handling and Preparation Plant (CHPP), train load-out facility and rail spur, which would be used for the handling, processing and transport of coal. An infrastructure corridor would also form part of the Project, including a raw water supply pipeline connecting to the Eungella pipeline network, an electricity transmission line and a mine access road (Figure 2).

The Project is forecast to extract approximately 15 million tonnes per annum (Mtpa) of run of mine (ROM) coal, with a forecast peak extraction of up to 17 Mtpa, for approximately 30 years. The coal resource would be mined by open cut mining methods, with product coal to be transported by rail to port for export.

This assessment forms part of an Environmental Impact Statement (EIS) which has been prepared in accordance with Part 4 of the State Development and Public Works Organisation Act 1971 (SDPWO Act). This assessment has been prepared to satisfy the requirements of the Terms of reference for an environmental impact statement – Winchester South Project issued by the Coordinator General on 4 September 2019.

The main activities associated with the development of the Project include:

- development and operation of an open cut coal mine within MLA 700049, MLA 700050 and MLA 700051;
- development and operation of an infrastructure corridor within MLA 700065, located outside MDL 183;
- use of open cut mining equipment to extract ROM coal with a current forecast rate of approximately 15 Mtpa (and up to 17 Mtpa);
- a mine life of approximately 30 years;
- placement of waste rock (i.e. overburden and interburden) in out-of-pit waste rock emplacements and within the footprint of the open cut voids;
- construction and operation of the MIA, including a CHPP, ROM pads, workshops, offices, raw and product handling systems, coal processing plant and train load-out facility;
- construction and operation of a Project rail spur and loop to connect the Project to the Norwich Park Branch Railway, including product coal stockpiles for loading of product coal to trains for transport to ports;
- progressive rehabilitation of out-of-pit waste rock emplacement areas;
- progressive backfilling and rehabilitation of the mine voids with waste rock behind the advancing open cut mining operations (i.e. in-pit emplacements);
- installation of a raw water supply pipeline;
- construction of a 132 kilovolt (kV)/22 kV electricity switching/substation and 132 kV ETL to connect to the existing regional power network;
- on-site excavation, if suitable, and/or the use of the existing hard rock quarry for construction activities;
- drilling and blasting of competent overburden/waste rock material;
- construction of a mine access road (including associated railway crossing) from the Eagle Downs Mine Access Road, off Peak Downs Mine Road, to the MIA;
- construction and operation of ancillary infrastructure in support of mining, including electricity supply, consumable storage areas and explosives storage facilities;

- connection to the existing telecommunications network;
- co-disposal of coal rejects from the Project CHPP within the footprint of the open cut voids and/or out-of-pit emplacement areas;
- progressive development and augmentation of sediment dams and storage dams, pumps, pipelines and other water management equipment and structures (including up-catchment diversions, drainage channel realignments and levees);
- progressive construction and use of soil stockpile areas, laydown areas and gravel/borrow areas (e.g. for road base and ballast material);
- progressive development of haul roads, light vehicle roads and services;
- wastewater and sewage treatment by a sewage treatment plant;
- discharge of excess water off-site in accordance with relevant principles and conditions;
- an on-site landfill for the disposal of selected waste streams generated on-site;
- ongoing exploration activities; and
- other associated minor infrastructure, plant and activities.

1.2 Scope and Objectives of this Geomorphology 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.

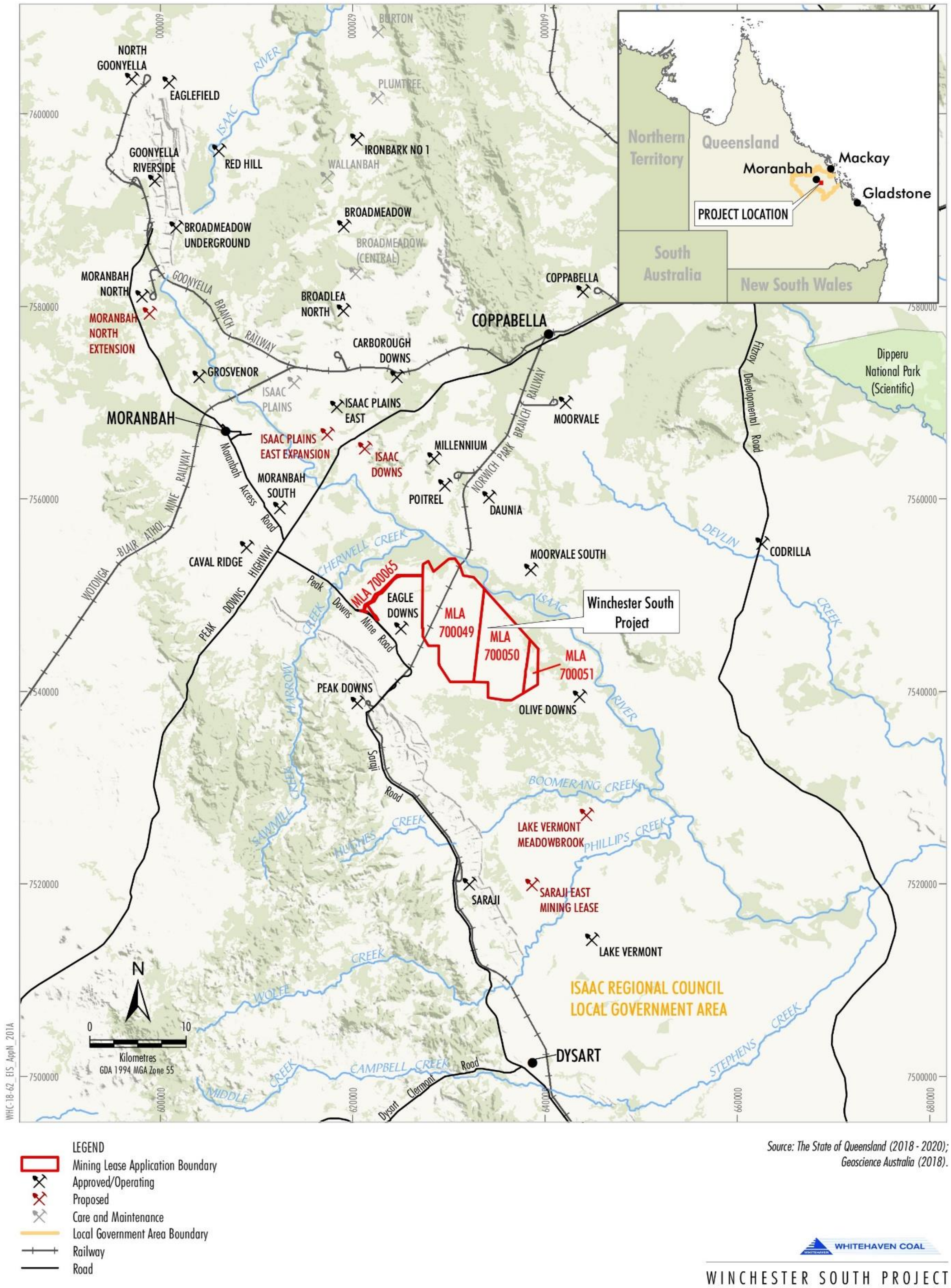

Figure 1. Winchester South Project regional location. Source: Whitehaven WS (2020).

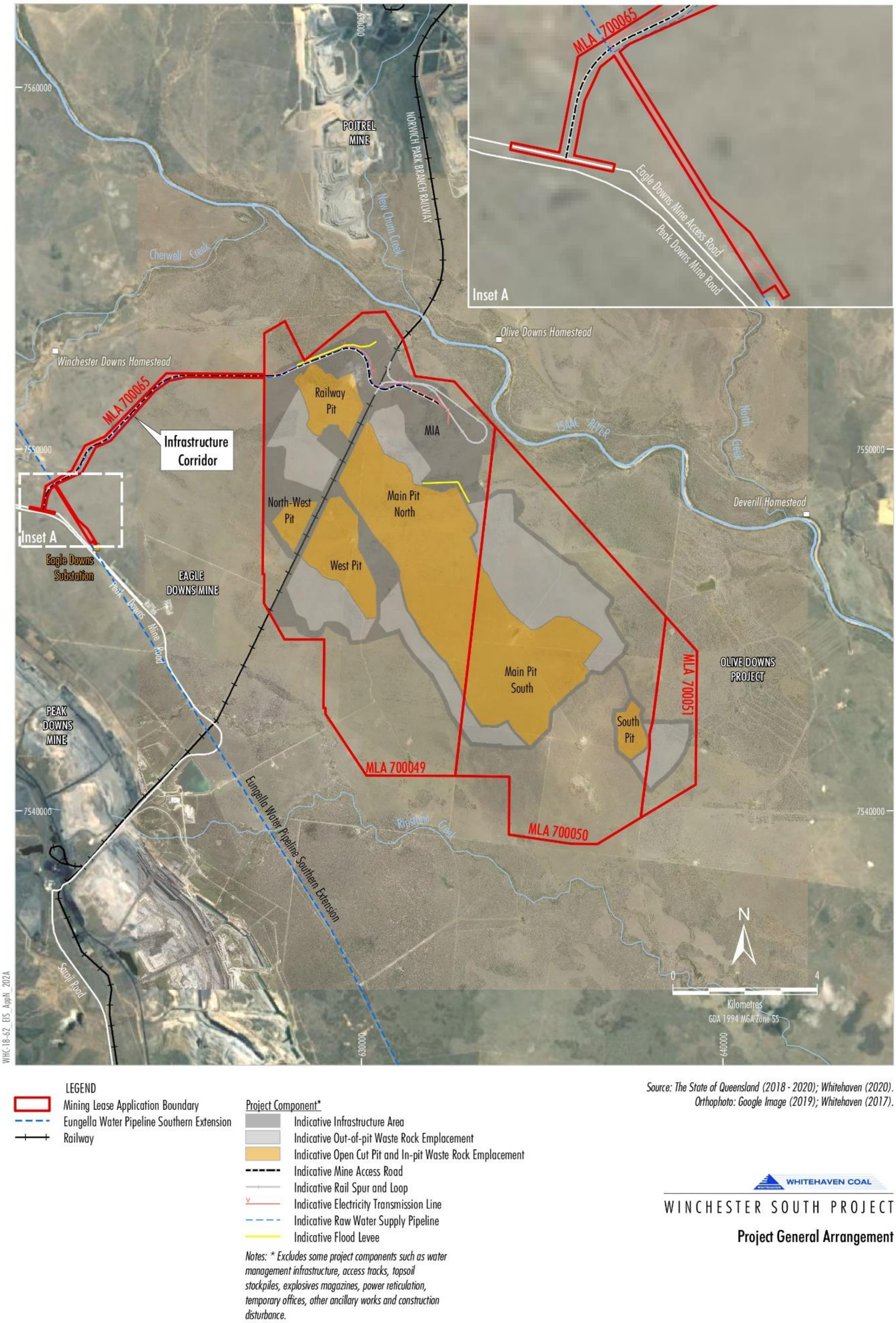

Figure 2. Winchester South Project general arrangement. Source: Whitehaven WS (2020).

1.3 Relevant Policy and Legislative Requirements

This Geomorphology 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, Manufacturing, Infrastructure and Planning, 2019), 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 the terms of reference (Department of State Development, Manufacturing, Infrastructure and Planning, 2019). 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.

The terms of reference (Department of State Development, Manufacturing, Infrastructure and Planning, 2019) set out the scope of project specific matters that should be given detailed treatment in the EIS. Environmental values are specified in the Environmental Protection Act 1994 (EP Act) Part 3, Division 2, Subdivision 1, section 9, the Environmental Protection Regulation 2008 (EP Regulation), environmental protection policies (EPPs) and relevant guidelines. This report addresses environmental objectives of the 'Land' category to be met under the EP Act. The specific environmental objectives are that the:

a) activity is operated in a way that protects the environmental values of land including soils, subsoils, landforms and associated flora and fauna

b) choice of the site, at which the activity is to be carried out, minimises environmental harm on areas of high conservation value and special significance and sensitive land uses at adjacent places

c) location for the activity on a site protects all environmental values relevant to adjacent sensitive use

d) design of the facility permits the operation of the site, at which the activity is to be carried out, in accordance with best practice environmental management.

The terms of reference (Department of State Development, Manufacturing, Infrastructure and Planning, 2019) required that the EIS describe the existing environment, and discuss potential impacts of the proposed land uses taking into consideration the proposed measures that would be used to avoid, minimise or mitigate impacts. Of specific relevance to this report, the impact prediction must address 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 Geomorphology 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	Review of some other geomorphic Investigations in the Fitzroy Basin
Section 3	Methodology – describes the methodology employed for this Geomorphology Technical Report
Section 4	Existing environment – describes the character of the existing geomorphologic environment
Section 5	Impact assessment – describes the potential impacts to geomorphologic character of the environment resulting from the proposed Project
Section 6	Monitoring and Mitigation - provides a summary of environmental mitigation, management and monitoring responsibilities in relation to management of geomorphologic forms and processes
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 (BNCOP), 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 BNCOP 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 BNCOP 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 diversion 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 in stream diversions, and their relevance to natural stream channels impacted by mining has not been established. Also, 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 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 discontinuous, 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. However, the publicly available journal of Ludwig Leichardt, who, upon first sighting the Isaac River on 13 February 1845, described the Isaac River 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 of, 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 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 Olive Downs Project is south of and adjacent to the Project, with the geomorphic assessment for the EIS undertaken by Gippel (2018). A comprehensive set of variables was measured at 43 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 was undertaken using digital elevation data sets with the objective of classifying landforms. Field and desktop data were used to classify streams according to geomorphic type, and geomorphic condition. 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. 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.

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 mostly of fairly short stream reaches 2 to 15 km long, with sampling density in the order of 100s of metres between sites. Variable sampling density would be expected, as the main consideration is that it be adequate to capture the spatial variability in geomorphic character of the streams. Of the above reviewed studies, the most relevant to this report is the assessment of Olive Downs Project. The methodology used in that study was also used to undertake the geomorphic assessment of the Project.

3.0 Methodology

3.1 Study Area

In this Geomorphology Technical Report the core Study Area is the area bounded by MLA 700049, MLA 700050 and MLA 700051, and also includes the footprint of the infrastructure corridor (Figure 2). In this report, this is referred to as the Project MLA areas. With respect to sediment and surface water fluxes, the Project MLA areas, being situated within the Isaac River catchment and containing parts of sub-catchments, is not a closed system, so potential geomorphological impacts of the proposed mining are not necessarily confined within the Project MLA areas. 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 Project MLA areas boundary on the stream was known in the field to within approximately ±100 m; or
- intentional because the stream under survey near the Project MLA areas 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 19 – 21 November 2019. 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 over an area that included the

Study Area. The data were supplied by Whitehaven WS at three resolutions: 5 m, 2 m and 1 m spaced point data that were derived from the LiDAR point cloud data. The 1 m spaced data, dated 2012, were used in this report (Figure 3). 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.

The final landform topography was supplied by Resource Strategies as a digital file of 1 m contours. Except on steep slopes, contour data has lower vertical resolution than LiDAR data, so automatic watershed and drainage line generation applied to contour data would produce more generalised results compared with LiDAR data. Resource Strategies supplied information on Project components as spatial data layers.

Digital aerial photography at 0.5 m pixel resolution, dated June 2017, covering an area that included the Study Area, was supplied by Whitehaven WS (Figure 3).

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.

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 Geomorphology 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 Geomorphology 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.

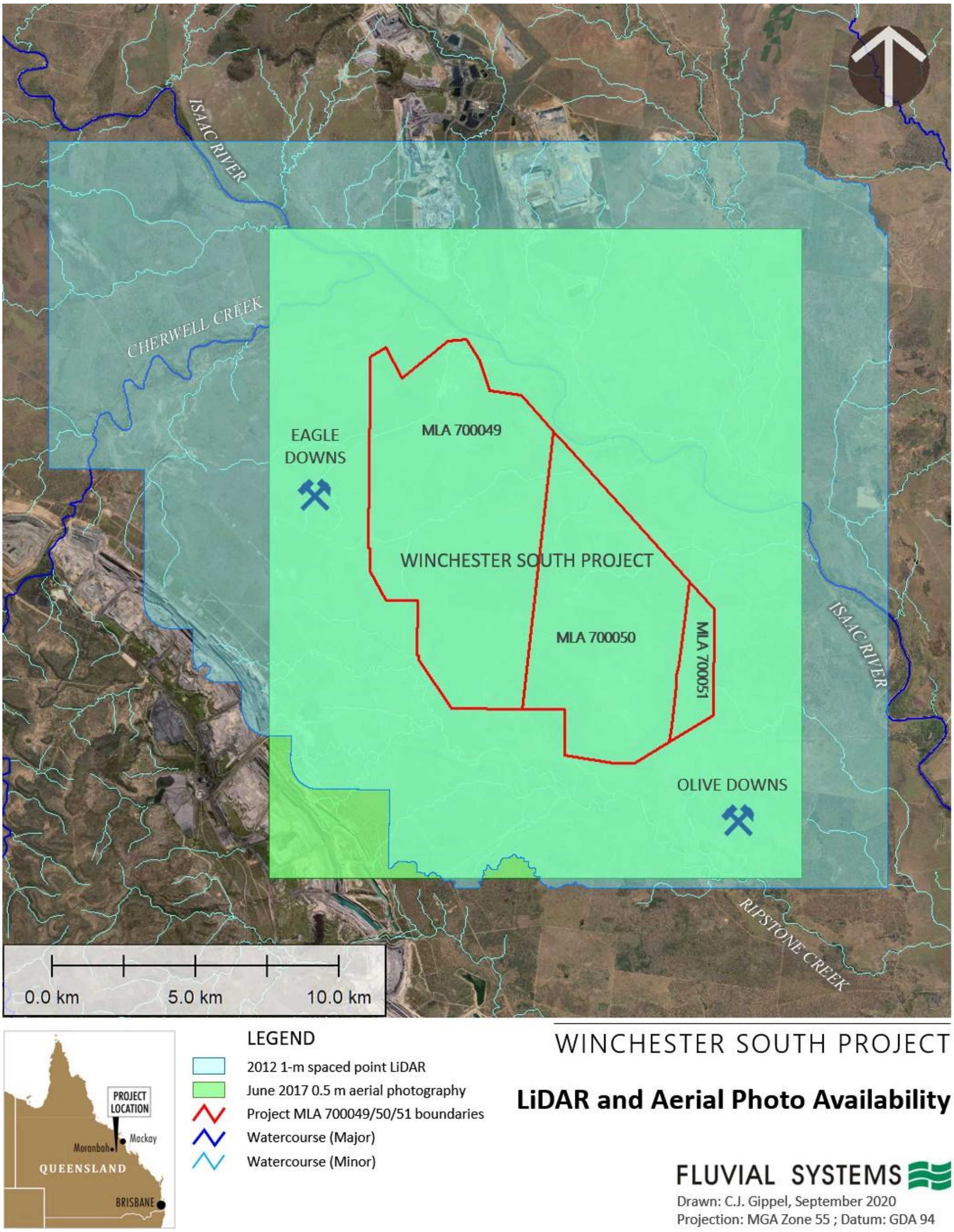

Figure 3. LiDAR data availability for the Study Area.

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, 1978; 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 Geomorphology 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 map was Clermont Sheet SF 55-11, published in 1968. This sheet was downloaded as a non-georeferenced image covering the full map extents. The image was 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; Healey et al., 2012). 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, 2004). 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

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

important role in channel stability/instability, hydraulic habitat creation, and its sensitivity to hydrological conditions, which could potentially be impacted by mining.

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 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 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 19 to 21 November 2019. 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 43 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).

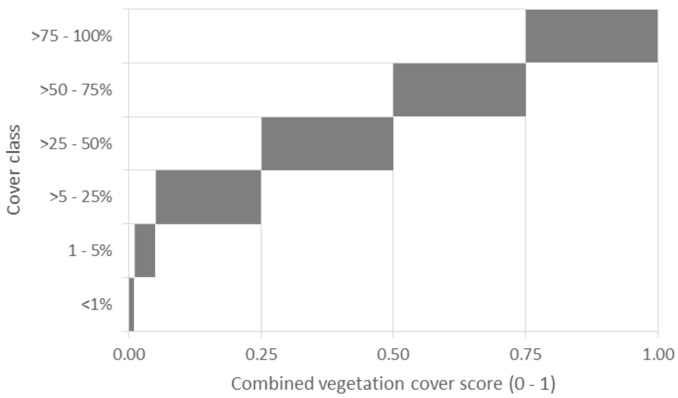

Figure 4. Scale for conversion of combined riparian vegetation cover index score to class.

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 1 × 1 m DEM derived from the supplied point 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 either a 5 × 5 m or a 25 × 25 m DEM derived from the 1 × 1 m DEM was used. The DEMs were resampled using a bilinear interpolation to create a smooth surface between the gridded point data.

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 Boomerang Creek.

3.6.3 Sub-catchment area

Sub-catchment areas were determined for the entire Isaac River catchment upstream of Boomerang 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 20 m, minimum sub-catchment area 2 km^2, and resolution 5 m. 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 Geomorphology Technical Report would require 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 et al., 2002; Brierley and Fryirs, 2005; Fryirs and Brierley, 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.

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 patterns of geomorphic units. • Degraded forms 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 (aggradation)	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 Surface Water and Flooding Assessment undertaken by WRM Water & Environment (2020) for the Project assessed the impacts of the Project on hydraulic conditions in Isaac River and Ripstone Creek. This report used the findings of WRM Water & Environment (2020) to assess the implications of modelled hydraulic changes on Isaac River and Ripstone Creek for potential geomorphic impact. Otherwise, the geomorphic impact assessment considered impacts to the minor watercourses within the Study Area.

The method of assessment of geomorphic risk associated with changed hydraulic conditions used risk categories of maximum permissible velocity and bed shear stress for initiation of fluvial scour of river bank and floodplain soils. The hydraulic thresholds for the risk categories were based on a review of international literature concerning maximum permissible velocity and bed shear stress and Australian Coal Association Research Program (ACARP) design criteria for stream diversion design in the Bowen Basin.

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

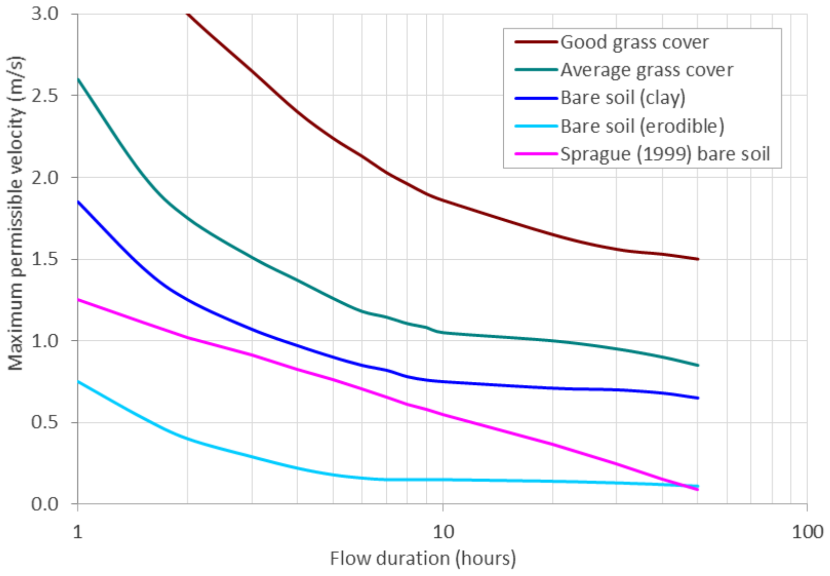

Figure 5. Erosion limits as a function of flow duration. Based on a plots from Fischenich (2001, p. 6) and Sprague (1999).

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 Department of Natural Resources and Mines (2014, p. 33) is reproduced here (Table 10). The reference cited for the critical hydraulic values provided by Department of Natural Resources and Mines (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: Department of Natural Resources and Mines (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 unvegetated 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 Boomerang Creek, a total area of approximately 4,567 km^2 (Figure 6). Within this catchment, land surface elevation ranges from 155 m to 697 mAHD. The Study Area lies within the lowland topographic zone of the catchment, with an elevation range of 182 m to 230 mAHD.

4.1.2 Drainage system

The Isaac River is an Order 6 watercourse at its junction with Boomerang Creek, an Order 5 watercourse (Figure 7). 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, with only 3 Minor watercourses. These three watercourse systems were labelled A, B and C (Figure 8). Within the Project MLA areas, watercourse system A comprises an Order 2 stream; watercourse system B comprises two short Order 1 streams and an Order 2 stream; and watercourse system C comprises a Order 1 stream (Figure 8).

4.1.3 Sub-catchment division

The three watercourse systems within the Project MLA areas were represented by sub-catchments A, B and C (Figure 9). The auto-generated drainage lines within the DEM-derived catchments did not generally follow the mapped watercourses (Figure 9). Part of the Project MLA areas were drained by 2 other sub-catchments that did not have mapped watercourses within this area. An east-draining sub-catchment extended into the south-eastern part of the Project MLA areas, and part of Ripstone Creek catchment extended into southern part of the Project MLA areas (Figure 9).

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 Permian siltstone, sandstone and shale, extensive undifferentiated sandy sediments and soils, and Quaternary alluvium within the lower part of the Isaac River corridor (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. Note that the groundwater assessment for Project used ground survey data to map alluvium boundaries in more detail than provided by the 1:250,000 Geological Series, which presents only a generalised depiction.

4.1.5 Soil classification

The main Australian Soil Classification soil type along the Isaac River corridor is Vertosols (Cracking Clays), with a small area of Chromosols, also know in the Australian Soil Atlas classification as Brown and Black Duplex Soils in the downstream part of sub-catchment A (Figure 12).

The majority of the Study Area has moderately stable surface soils (Figure 13). Erodible non-cohesive soils and dispersive soils occur in fragmented patches around the periphery of the Study Area, with more concentrated areas of erodible soils occurring in the corridor of Isaac River in the upstream of part of the wider Study Area (Figure 13).

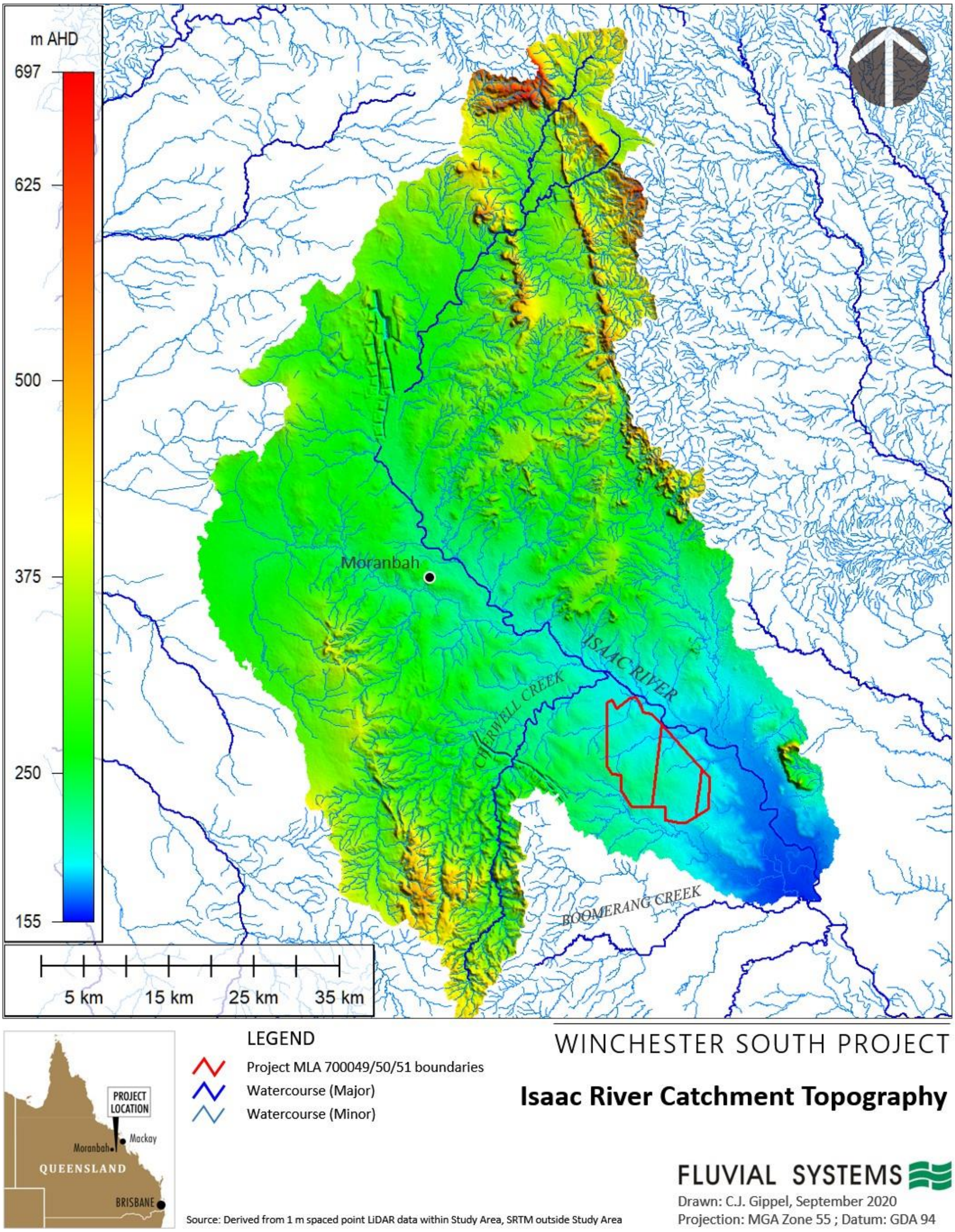

Figure 6. Isaac River catchment to Boomerang Creek junction topography.

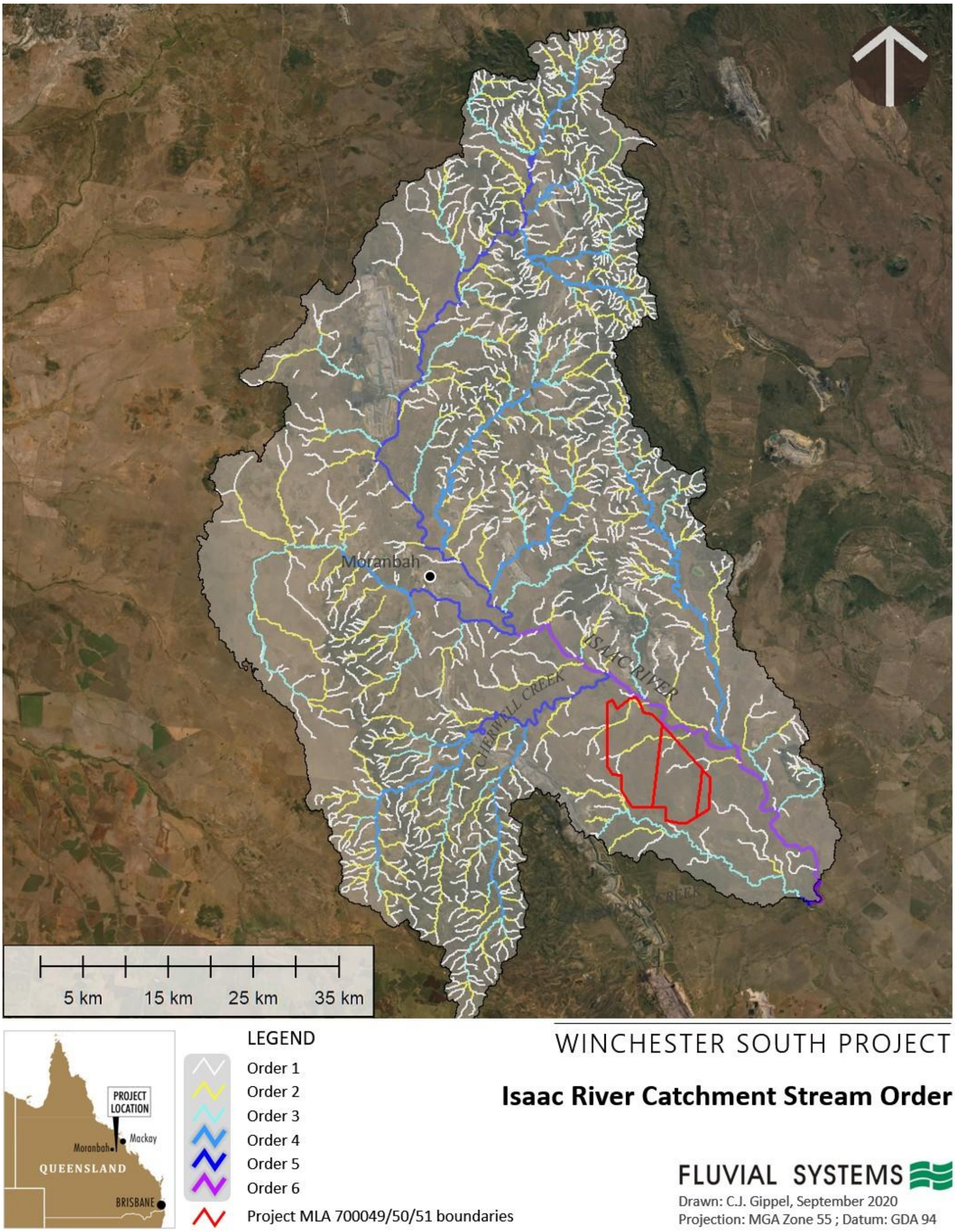

Figure 7. Isaac River catchment to Boomerang Creek junction drainage network classified by Stream Order.

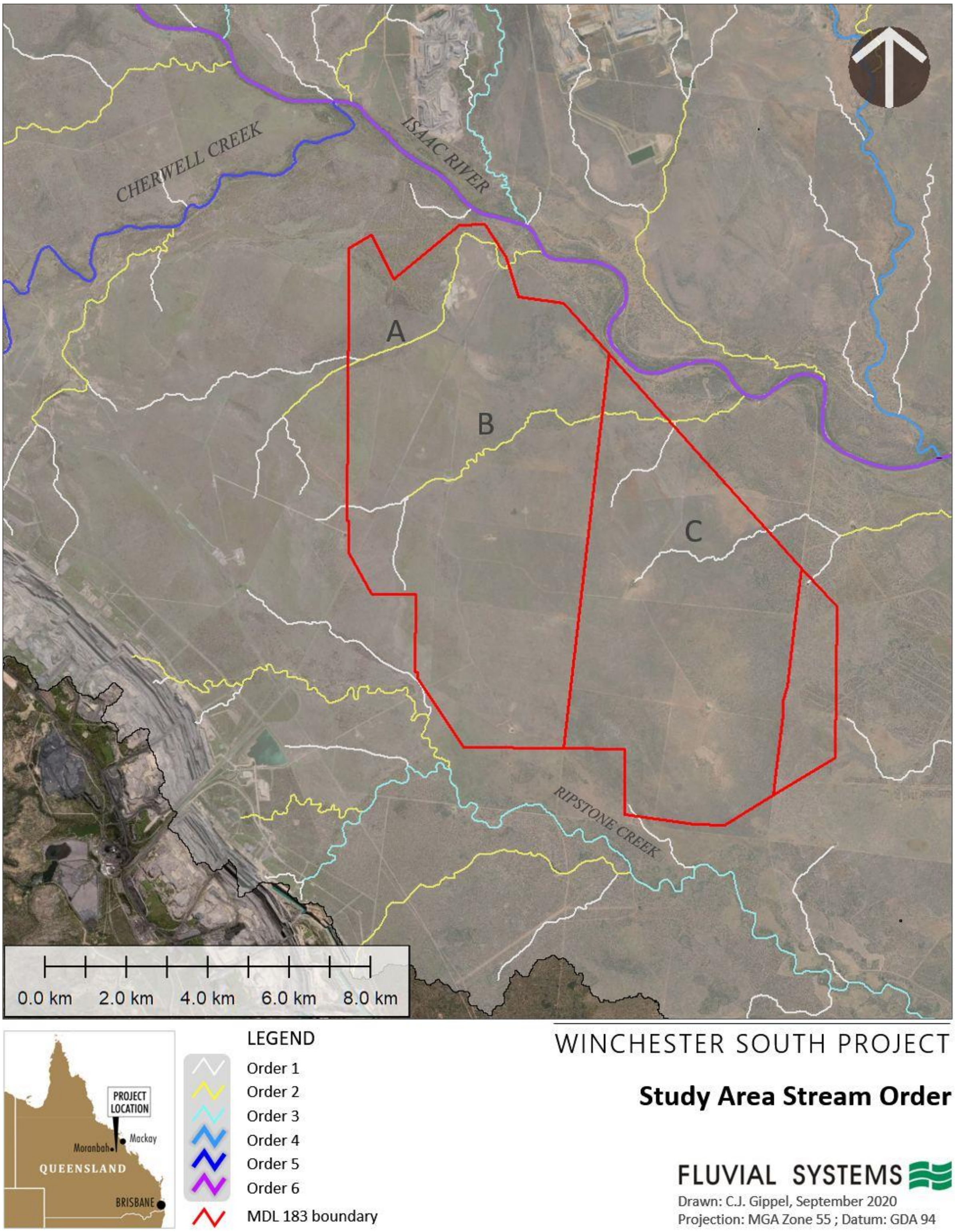

Figure 8. Study Area drainage network classified by Stream Order. The three minor watercourse systems passing through the Project MLA areas were labelled A, B and C.

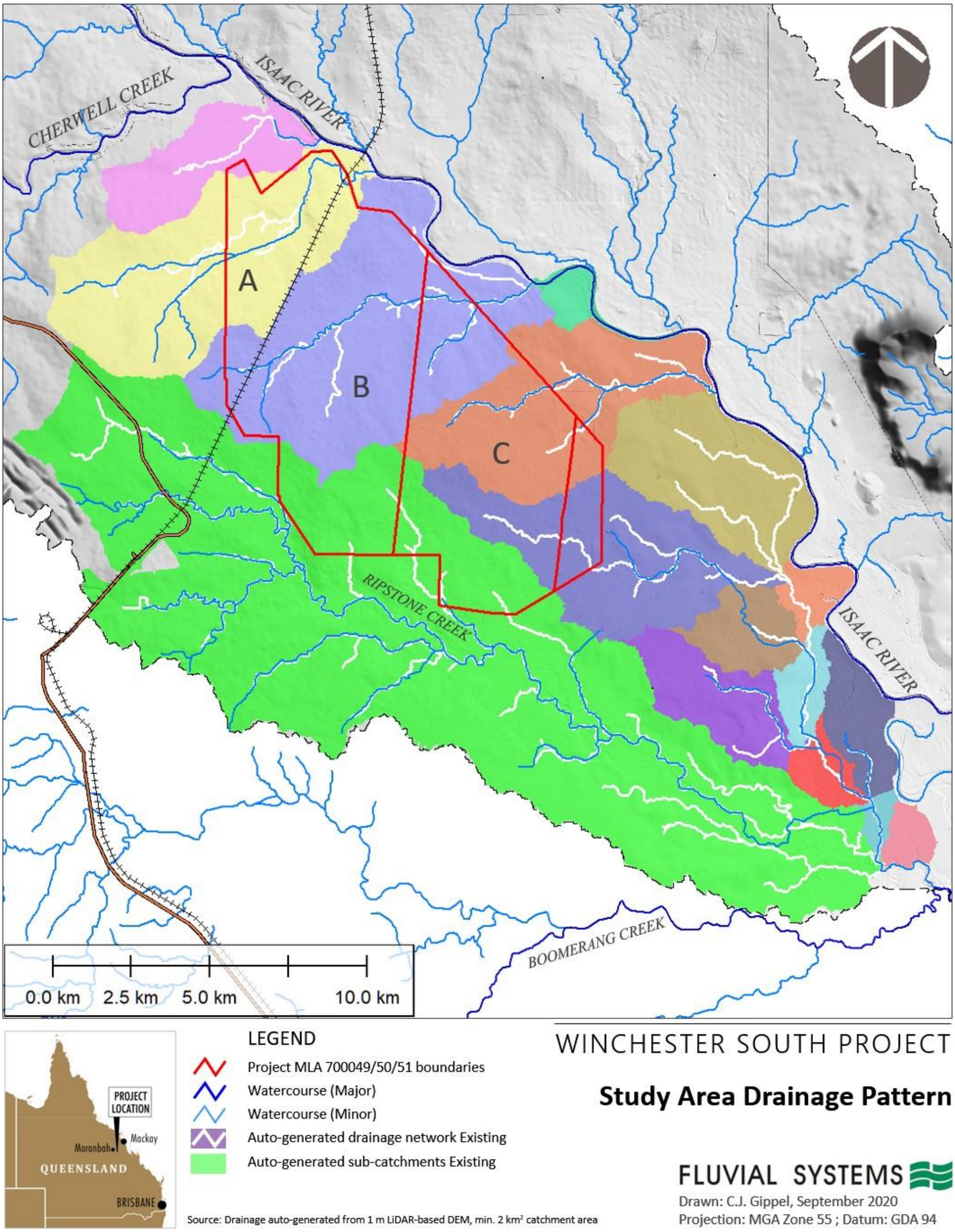

Figure 9. Isaac River sub-catchments draining to, within, and from, the Study Area. The three main sub-catchments draining the Study Area were labelled A, B and C.

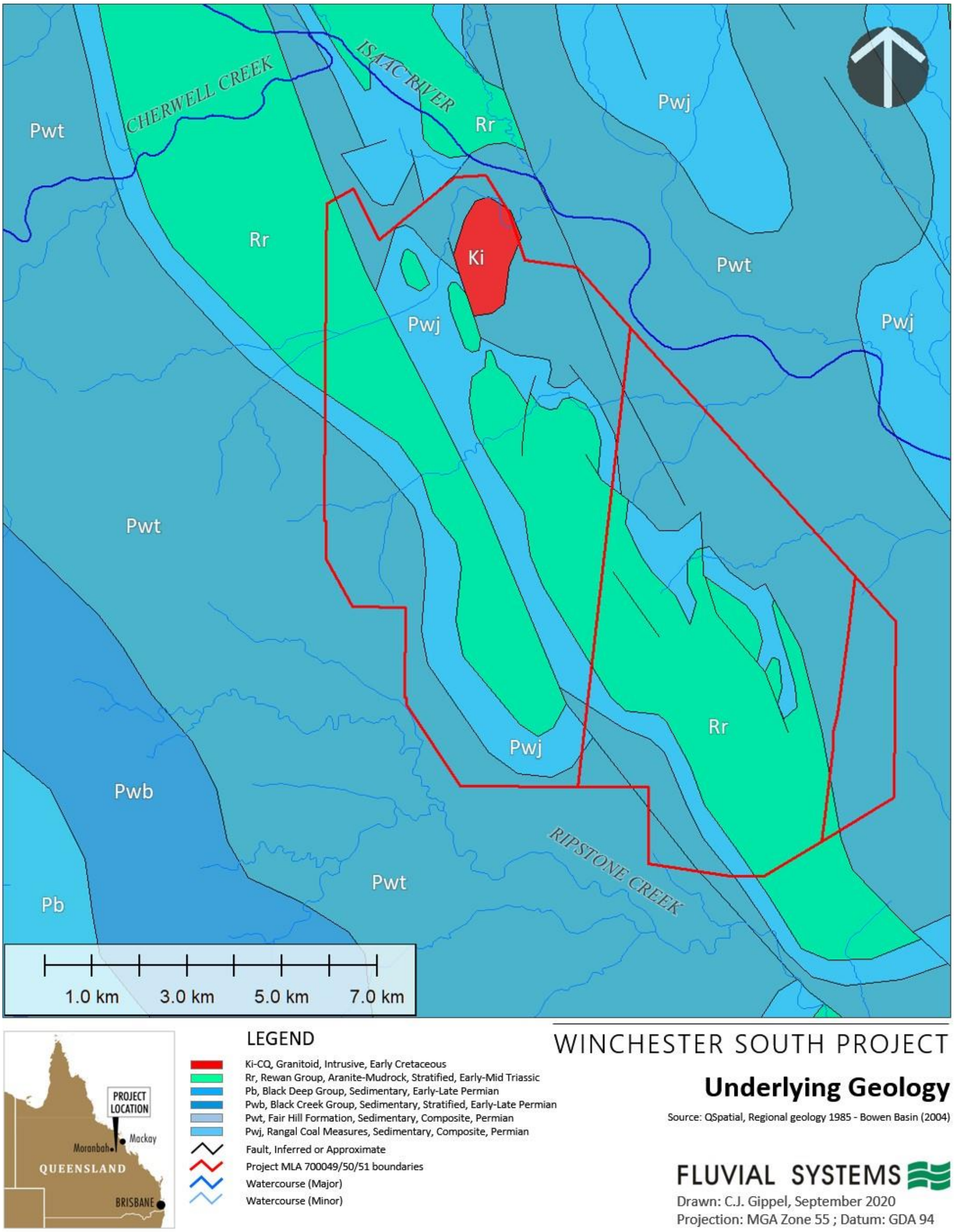

Figure 10. Underlying geology of the Study Area. The mapping does not show the distribution of Quaternary sediments overlying hard rock.

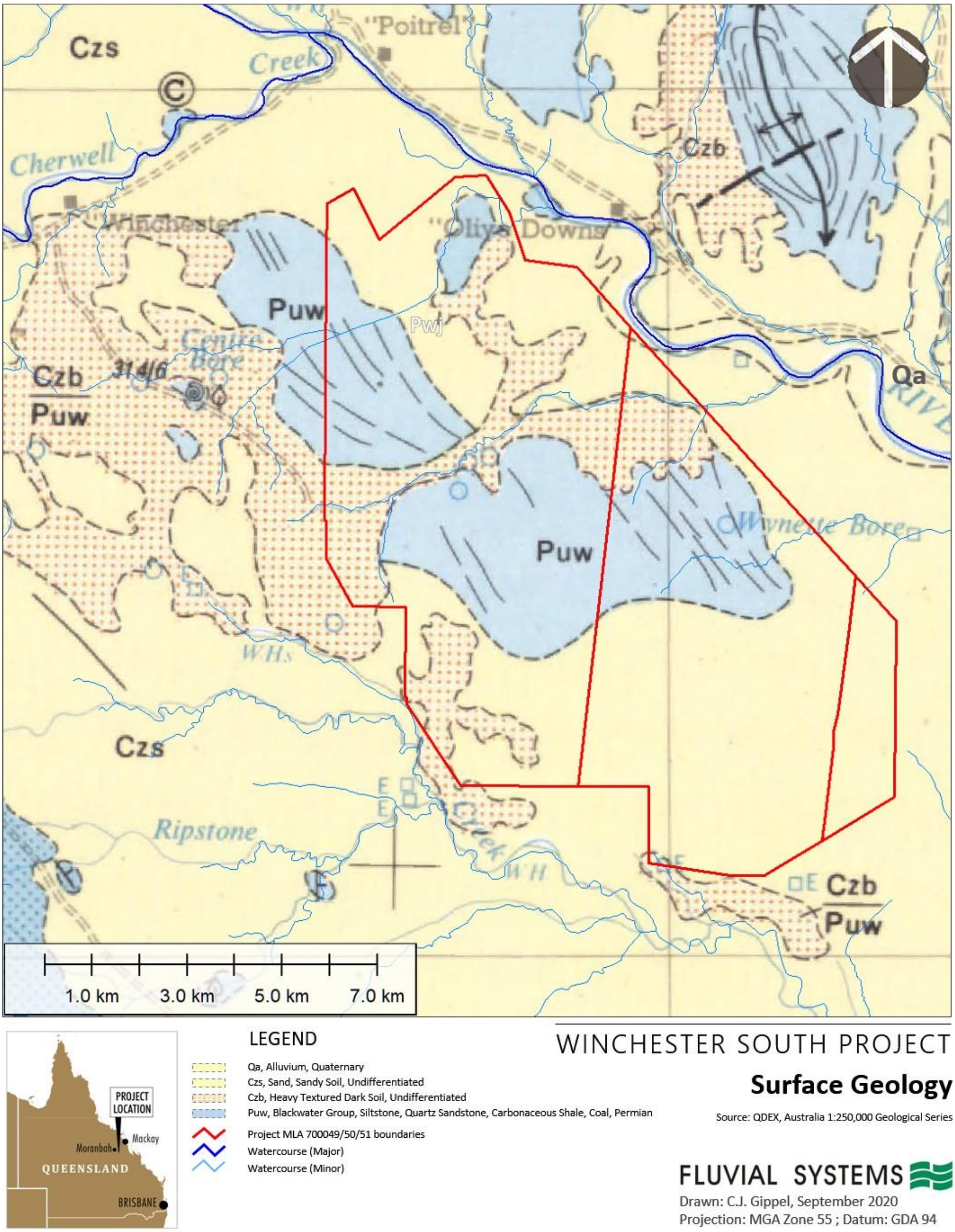

Figure 11. Surface geology of the Study Area. A scanned non-georeferenced source image was rectified and cropped in GIS.

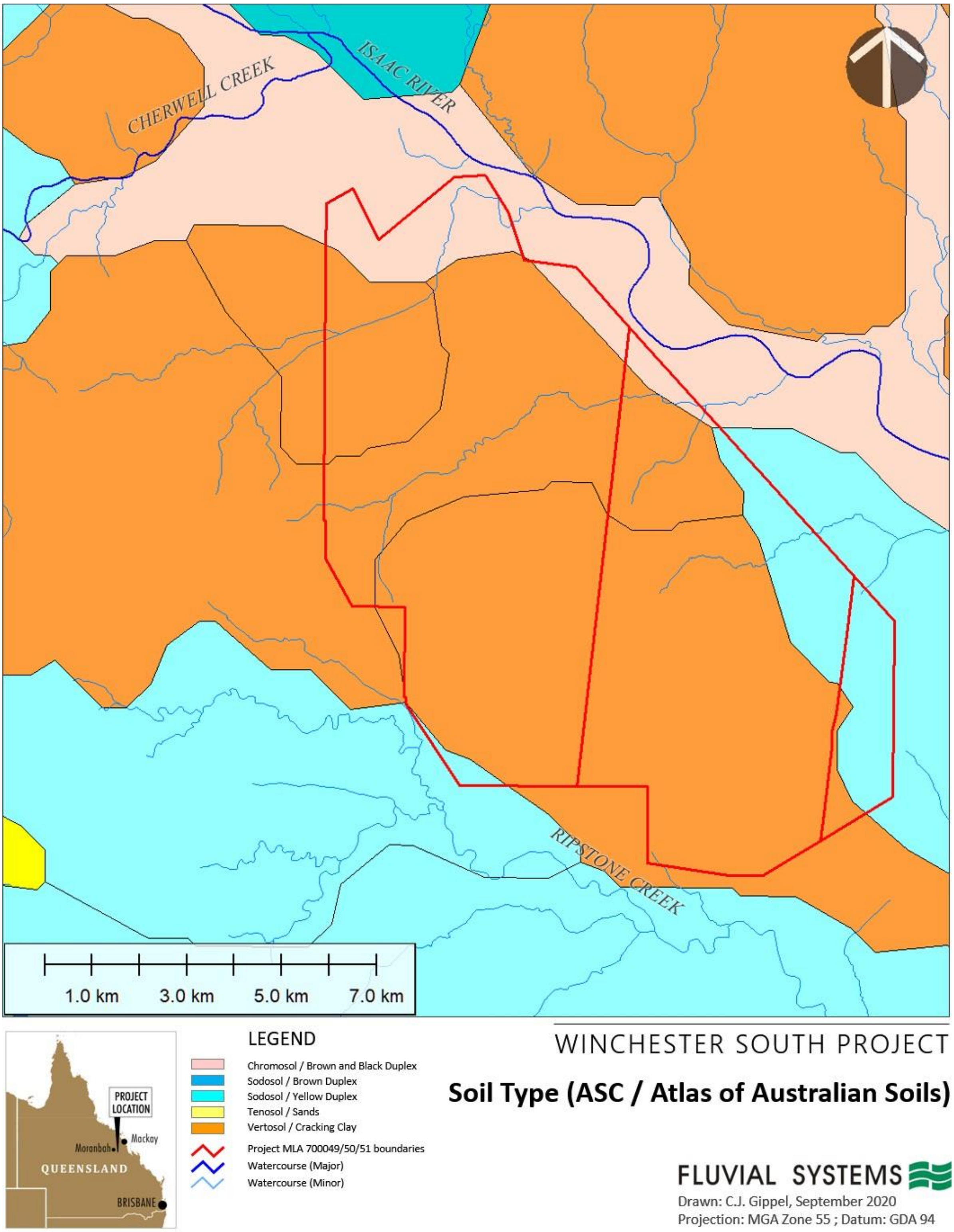

Figure 12. Soil Types in the Study Area.

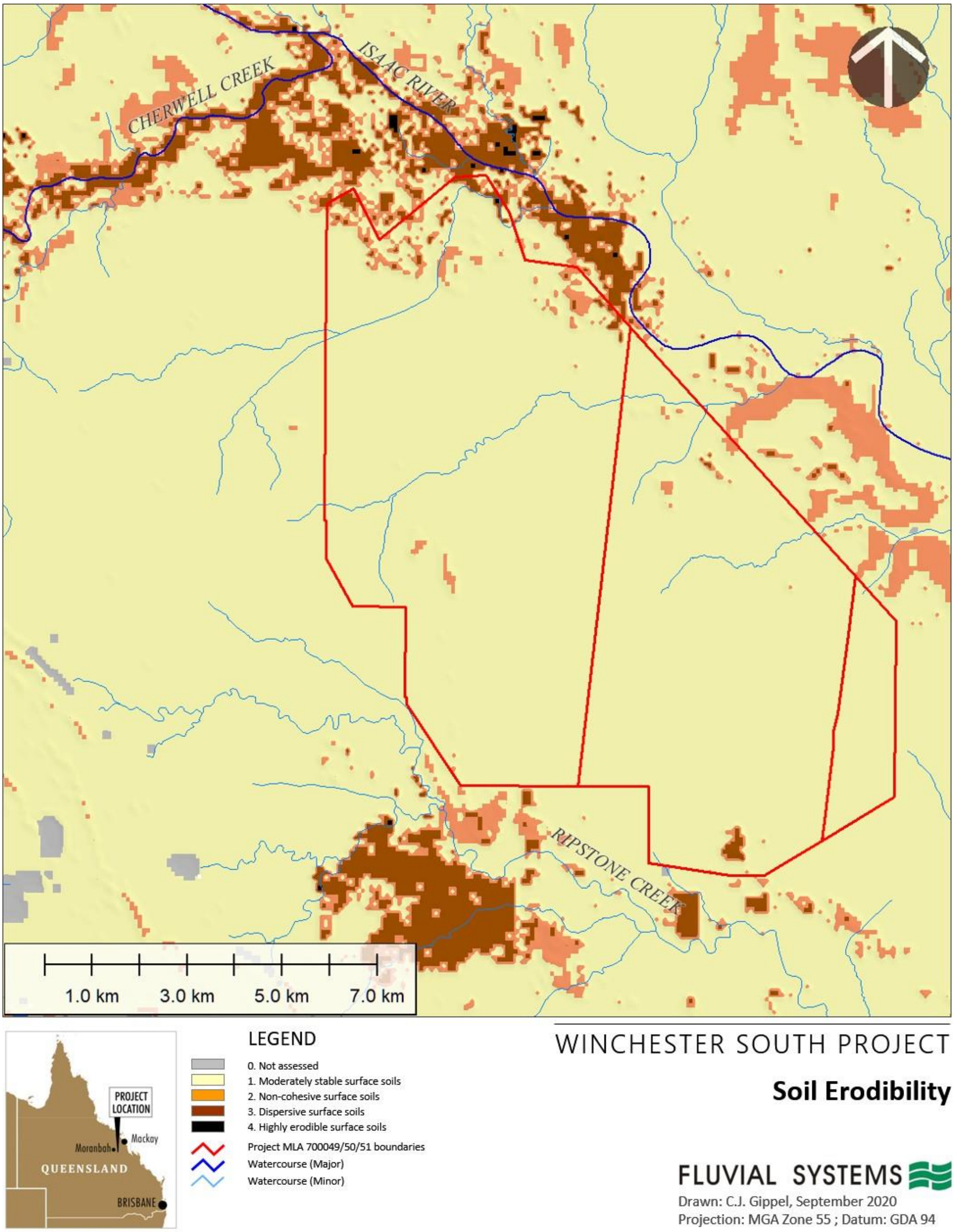

Figure 13. Soil Erodibility in the Study Area.

4.1.6 Land slope

Analysed on the 5 m grid resampled using a bilinear interpolation, the terrain within the Study Area was mostly less than 10 degrees, with the average slope 1.05 degrees (Figure 14). Over the plains of the Study Area, slopes were gentle to flat. The Minor watercourses had banks with very low slopes, mostly in the range 2 – 4 degrees. The channel of the Isaac River had almost continuous very steep banks, mostly in the range 25 – 35 degrees (Figure 14).

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 so the TPI was not used in this assessment. 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. Thus, the landform classes identified by TSC in the Study Area were distinguished only by slope. The 25 × 25 m spatial resolution was too coarse to identify the smaller channels. The Queensland Floodplain Assessment Overlay (QFAO) represents an estimate of areas potentially at threat of inundation by flooding, mapped at 1:100,000 scale. There was no correlation between the TSC boundaries and the QFAO boundary. Overall, the slope and relief of the Study Area were too low for the TSC to be able to distinguish landform boundaries.

Within the terrain of the Study Area, the MRVBF was generally a poor distinguisher of floodplain land (Figure 15). Within the overall gently sloping terrain of the 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). 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. None of TPI, TSC, MRVBF or QFAO correlated with Quaternary alluvium mapped within the lower part of the Isaac River corridor (Figure 11).

Overall, landform classification using automated terrain analysis could not distinguish boundaries of floodplain and hillslope landforms in the Study Area.

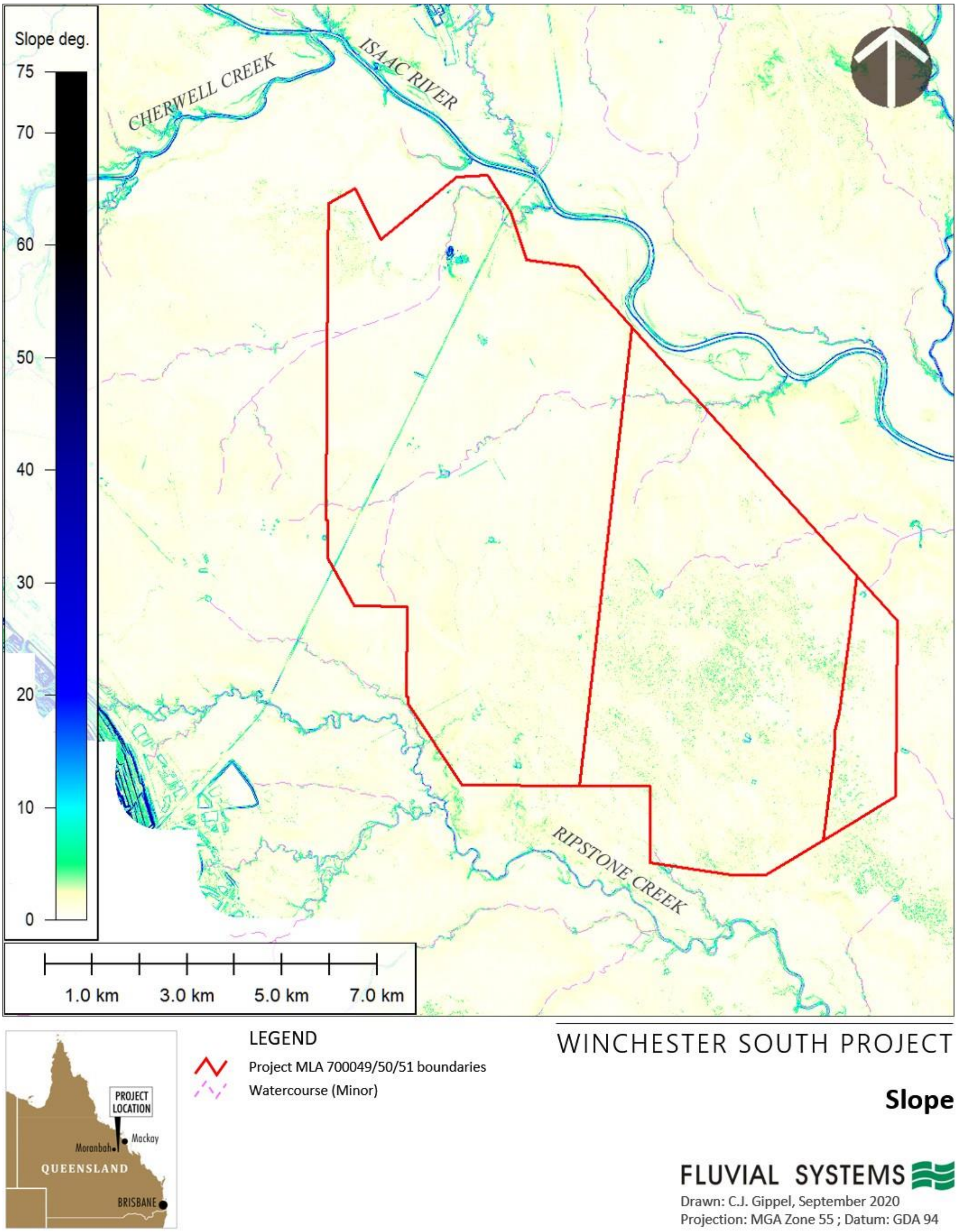

Figure 14. Land slope over the Study Area at 5 × 5 m resolution DEM.

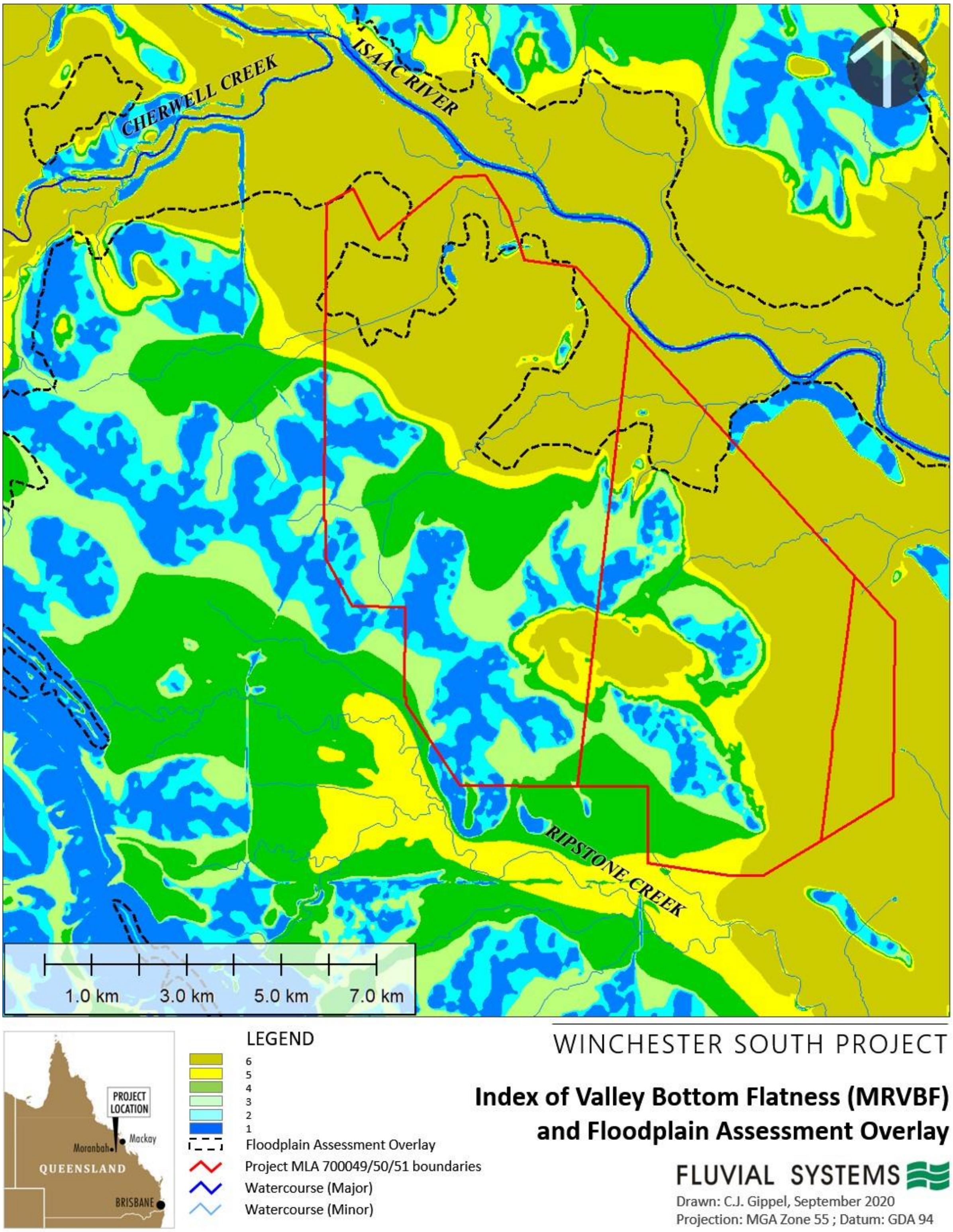

Figure 15. Multispectral index of valley bottom flatness (MRVBF) classification over the Study Area at 25 × 25 m resolution DEM, compared with Queensland Floodplain Assessment Overlay (QFAO).

4.2 Stream reach- and point-scale characteristics

4.2.1 Sampled sites

A total of 43 sites were sampled in the field over the period 18 – 20 November 2019. A further 5 sites previously sampled on the Isaac River on the downstream end of the Study Area on 13 June 2017 (designated I7, I8, I9, I10 and I12) were added to the field data set. The total assessed length of the Isaac River was 21.6 km, measured along the unsmoothed auto-generated thalweg, and 20.4 km measured along a smoothed thalweg. In total, the sample data set comprised 12 sites on Isaac River, 12 sites within sub-catchment A, 11 sites within sub-catchment B, and 13 sites within sub-catchment C (Figure 16). The field procedure aimed to sample the Minor watercourses on the main drainage lines, as identified in the field, although these features were often difficult to distinguish due to the very flat terrain, subtle character of the watercourses, and multiple discontinuous drainage paths. The sampled drainage lines generally corresponded with the auto-generated drainage lines rather than the mapped watercourse lines, although a few observations (A4, A6 and A7) were made where mapped watercourse lines indicated a channel was present but auto-generated network suggested this was unlikely. The Minor watercourses were sampled from their headwaters to their junctions with the Isaac River (Figure 16).

Photographs of each sampled site, looking downstream and upstream, are provided in Figure 17 to Figure 29.

Field collected data for key variables is provided for Isaac River (Table 14 and Table 15), drainage system A (Table 16 and Table 17), drainage system B (Table 18 and Table 19), and drainage system C (Table 20 and Table 21).

4.2.2 Isaac River site characteristics

The field observations suggested that the geomorphic character of the Isaac River was relatively constant throughout the Study Area (Figure 17, Figure 18, Figure 19, Table 14 and Table 15). A series of cross-sections, spaced at 1 km along, and perpendicular to, the river thalweg, were taken from the 1 m LiDAR data, starting at field site I1 and ending at field site I12 (Figure 30, Figure 31 and Figure 32). Bankfull and bank toe levels were interpreted from the cross-sections, and widths calculated at these levels (Figure 33). Channel depth was interpreted as vertical distance from bankfull to bank toe levels. These measured widths and depths were compared with the widths and depths observed in the field (Figure 33). This comparison revealed that the field measurement procedure under-estimated bankfull width by an average of 27.8 m (Table 22), but some difference would be expected as the two methods measured widths at different locations and at a different number of locations. The under-estimation of bankfull level led to underestimation of bankfull depth, by 1.6 m (Table 22). In contrast to bankfull width, field observations tended to over-estimate bed width (Table 22). These differences can be explained by practical difficulties presented by large channels like the Isaac River when using a laser range finder to measure widths and depths. The range finder relies on reflection of the laser beam from a relatively vertical surface. Thus, it has to be aimed slightly above the bank toe and slightly below the bankfull level. Also, vegetation interferes with the signal. Another difficulty in measuring bankfull width in the field is that it relies on visual determination of the top of bank, while maximum curvature can be used to objectively select the position of the top of bank from LiDAR data. These difficulties support the case for undertaking geomorphic monitoring using a method based on repeat LiDAR surveys rather than subjective field observations.

The variability of the channel morphology measured from LiDAR data (Table 22) provides baseline information on the natural range of morphological variability of the Isaac River that would be expected (i.e. the envelope of expected channel dimensions for the unimpacted condition).

The Isaac River was observed to be a low gradient channel, set within a broad floodplain. The sand bed was fairly flat, with shallow pools (<1 m deep) and low amplitude bar forms. The bed material was composed primarily of quartz and feldspathic sand-sized material, but there was a small quantity of mud, gravel and cobbles present in places. The banks were steep and, despite being composed of erodible clayey, silty, sand, 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. 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). Large wood was not present in the channel through the surveyed reach.

4.2.3 Sub-catchment A watercourse site characteristics

The First Order part of sub-catchment A is located upstream of MLA 700049. Near MLA 700049 boundary, sub-catchment A forms a Second Order watercourse. The watercourses of sub-catchment A were low-gradient and continuous, but in the central catchment area some of the observed channels were ill-defined. The beds of the watercourses contained mud, sand and gravels, but mud was the dominant bed material (Table 16). Grass covered a minor proportion of the bed in the upper and middle part of the catchment. Riparian trees were sparse on this creek system (Table 17), and there was little to no large wood in the channels. At the time of the survey, the riparian areas were dry, with limited shrub and ground cover, such that the overall riparian vegetation cover index was low (Table 17). The creek channel widened and deepened significantly, and the bed slope steepened, as it approached the junction with the Isaac River and incised into the river’s floodplain.

4.2.4 Sub-catchment B watercourse site characteristics

Sub-catchment B was almost entirely located within MLA 700049 and MLA 700050. Most of the catchment was drained by a low-gradient, mostly well-defined, Second Order watercourse. The bed material comprised mud, sand and gravels, but mud was the dominant bed material (Table 18, Table 19). Grass covered a minor proportion of the bed in the upper part of the catchment. Riparian trees were sparse on this creek system, although some large wood was found in the watercourse in the lower part of the catchment. At the time of the survey, the riparian areas were dry, with limited shrub and ground cover, such that the overall riparian vegetation cover index was low (Table 19). The creek channel widened and deepened significantly, and the bed slope steepened, as it approached the junction with the Isaac River and incised into the river’s floodplain.

4.2.5 Sub-catchment C watercourse site characteristics

The sub-catchment C First Order watercourse within MLA 700050 was low-gradient, narrow and shallow, and sometimes poorly-defined. Downstream of MLA 700050 and MLA 700051 the drainage formed into a Second Order watercourse. The bed material comprised mud, sand and gravels, but mud was the dominant bed material (Table 20 and Table 21). Riparian trees were virtually non-existent on the First Order watercourse, but some trees were present on the Second Order section (Table 21). Some large wood was found in the watercourse in the lower part of the catchment. At the time of the survey, the riparian areas were dry, with limited shrub and ground cover, such that the overall riparian vegetation cover index was low to moderate (Table 21). The creek channel widened and deepened significantly, and the bed slope steepened, as it approached the junction with the Isaac River and incised into the river’s floodplain.

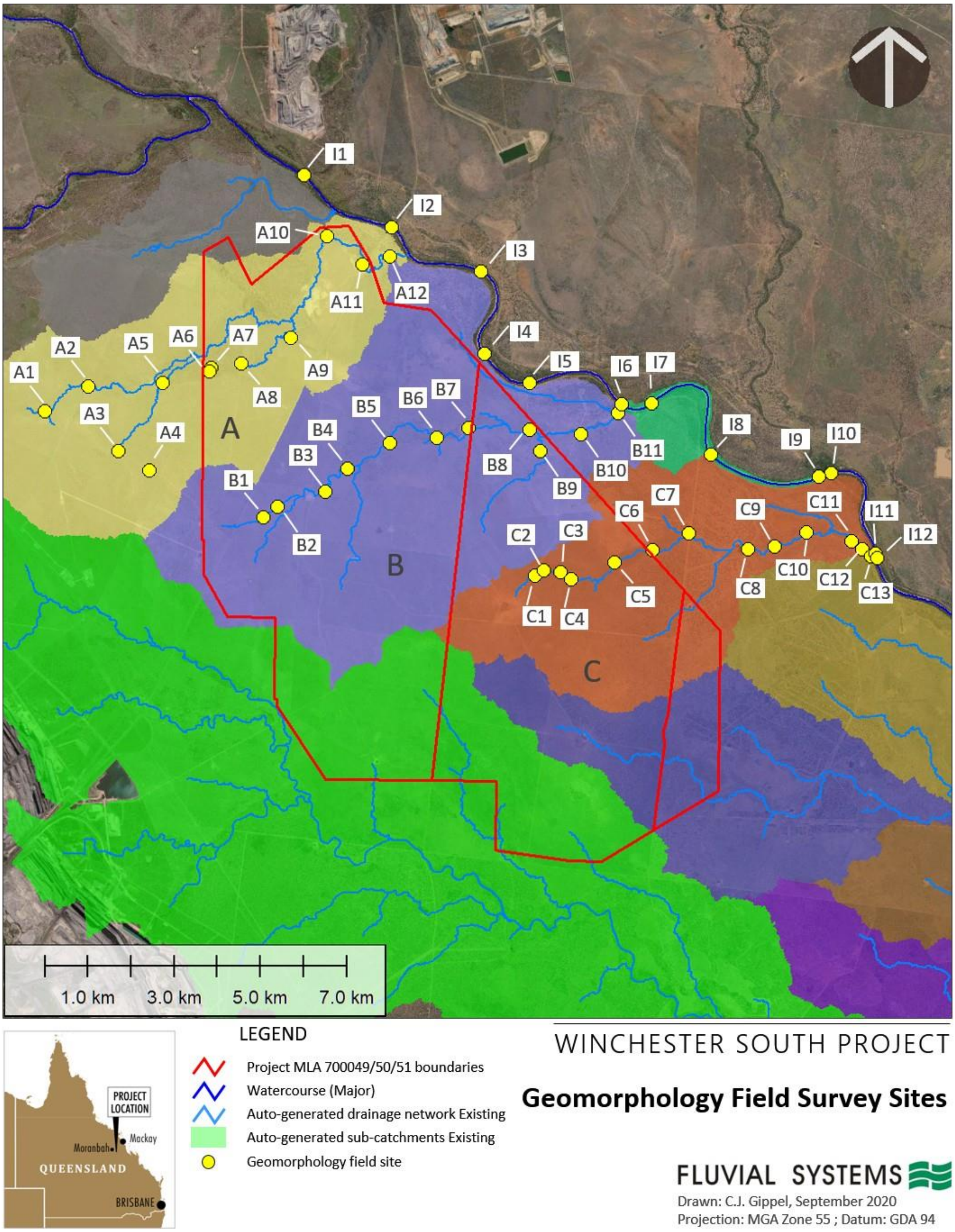

Figure 16. Geomorphology survey sample sites. Data were recorded at 48 observation points.

Figure 17. Sites I1 – I4.

Figure 18. Sites I5 – I8.

Figure 19. Sites I9 – I12.

Figure 20. Sites A1 to A4.

Figure 21. Sites A5 to A8.

Figure 22. Sites A9 – A12.

Figure 23. Sites B1 – B4.

Figure 24. Sites B5 – B8.

Figure 25. Sites B9 – B11.

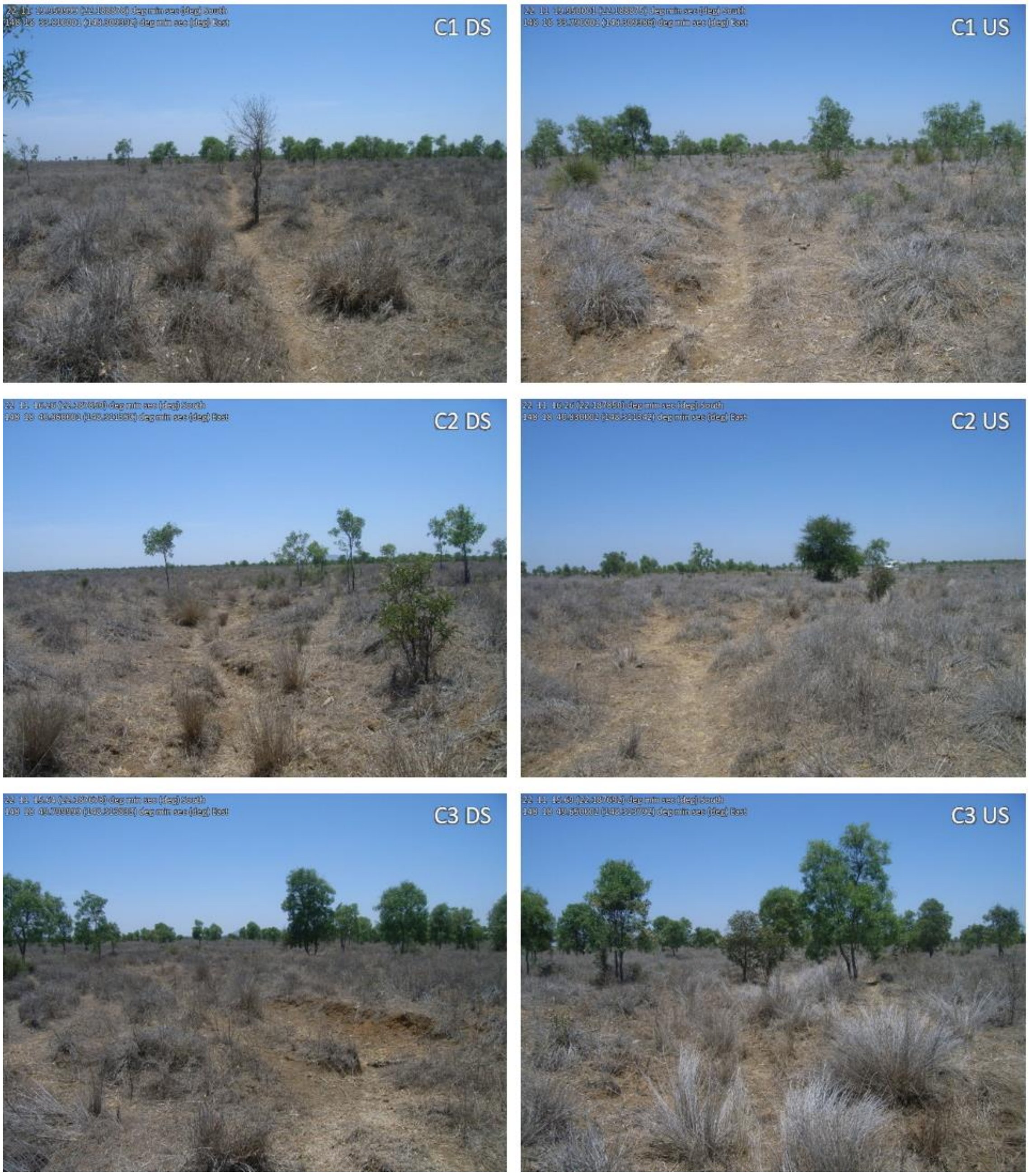

Figure 26. Sites C1 – C3.

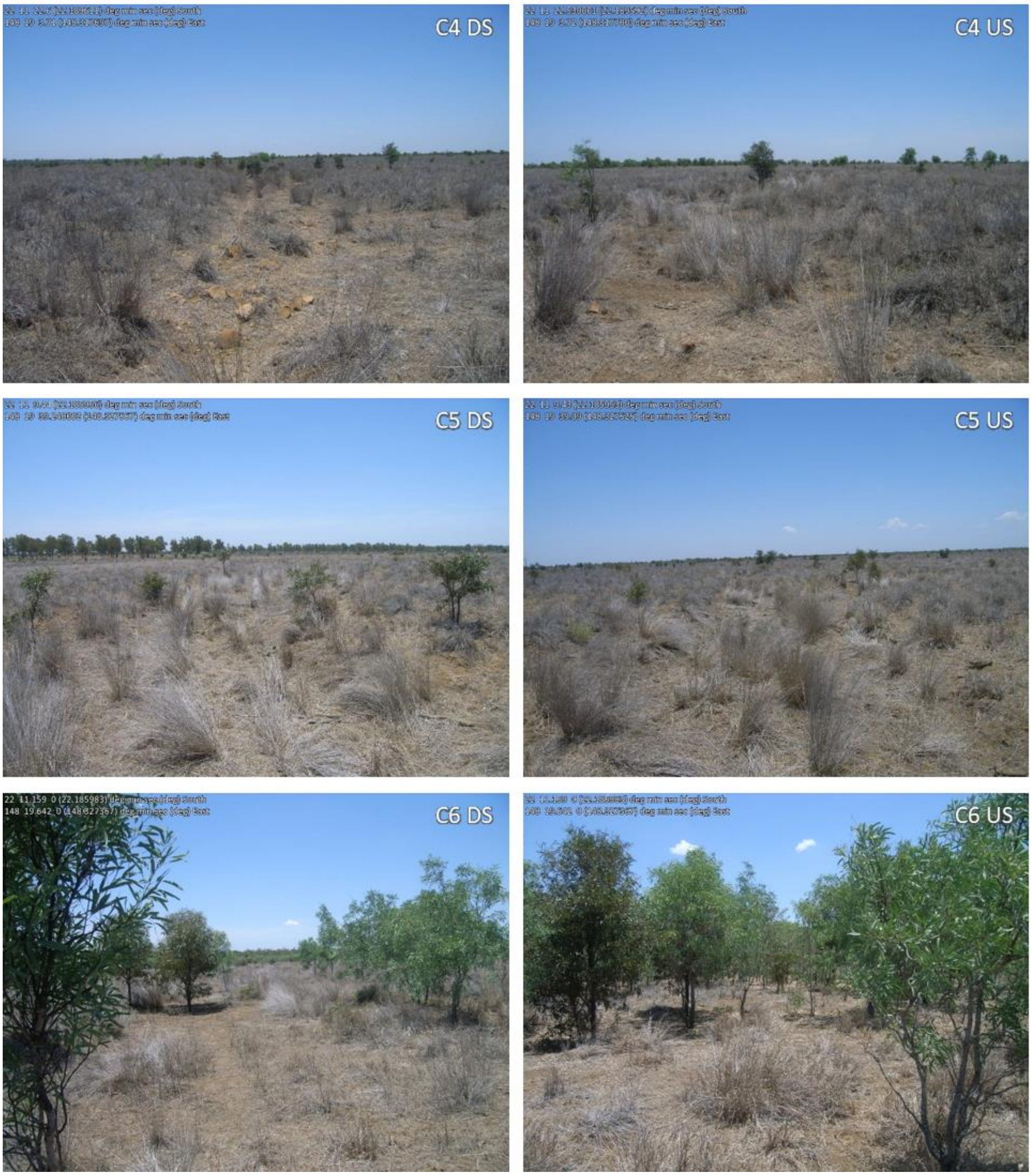

Figure 27. Sites C4 – C6.

Figure 28. Sites C7 – C9.

Figure 29. sites C10 – C13

Table 14. Field data collected for Isaac River sites, location, channel form, bed material and large wood. Partially confined is classified low, moderate or high level of confinement.

Site	Stream	Order	Latitude	Longitude	Longitudinal continuity	X-sec definition	Valley setting	Bed material (present)	Bed material (dominant)	Large wood (pc./100 m)
I1	Isaac	6	-22.105543	148.256806	continuous	strong	Unconfined	sand, gravel, cobble	sand	0
I2	Isaac	6	-22.116185	148.276526	continuous	strong	Unconfined	sand, gravel	sand	0
I3	Isaac	6	-22.125386	148.296821	continuous	strong	Unconfined	sand, gravel	sand	0
I4	Isaac	6	-22.142420	148.297593	continuous	strong	Unconfined	sand, gravel	sand	0
I5	Isaac	6	-22.148555	148.307946	continuous	strong	Unconfined	sand, gravel	sand	0
I6	Isaac	6	-22.152876	148.328553	continuous	strong	Part. confined (low)	sand, gravel	sand	0
I7	Isaac	6	-22.152535	148.335229	continuous	strong	Part. confined (low)	mud, sand, gravel, cobble	sand	0
I8	Isaac	6	-22.163178	148.348664	continuous	strong	Part. confined (low)	mud, sand, gravel, cobble	sand	0
I9	Isaac	6	-22.167631	148.372991	continuous	strong	Unconfined	mud, sand, gravel	sand	0
I10	Isaac	6	-22.166787	148.375641	continuous	strong	Unconfined	mud, sand, gravel	sand	0
I11	Isaac	6	-22.183576	148.385901	continuous	strong	Unconfined	sand	sand	0
I12	Isaac	6	-22.184475	148.386137	continuous	strong	Unconfined	mud, sand, gravel, cobble	sand	0

Table 15. Field data collected for Isaac River sites, channel dimensions, instream bed vegetation structure, riparian vegetation structure. Reach mean slope is DEM-derived and uncertain.

Site	Down-stream chainage (km)	Bed width (m)	Bankfull width (m)	Bankfull depth (m)	Slope (Deg.)	Slope (%)*	Instream bed vegetation presence	Tree/grass bed vegetation cover	Riparian buffer width	Riparian buffer continuity	Riparian tree cover	Riparian vegetation cover index
I1	0	47.4	110.4	7.5	0.027	0.0480	-	-	>50 m	continuous	25 - 50%	25 - 50%
I2	2.441	53.4	74.4	8.4	0.050	0.0869	-	-	>50 m	continuous	25 - 50%	50 - 75%
I3	4.986	63.7	116.9	7.8	0.000	0.0000	-	-	>50 m	continuous	25 - 50%	25 - 50%
I4	7.172	76.5	121.0	8.3	0.083	0.1450	-	-	>50 m	continuous	5 - 25%	25 - 50%
I5	8.519	68.8	118.0	8.7	0.055	0.0315	-	-	>50 m	continuous	25 - 50%	25 - 50%
I6	11.006	81.0	116.0	8.8	0.049	0.0858	-	-	>50 m	continuous	5 - 25%	25 - 50%
I7	11.768	64.4	124.3	6.6	0.000	0.0000	-	-	>50 m	continuous	25 - 50%	50 - 75%
I8	14.677	57.0	119.0	8.4	0.061	0.1060	-	-	>50 m	continuous	25 - 50%	50 - 75%
I9	17.381	59.2	100.7	7.1	0.034	0.0595	-	-	>50 m	continuous	25 - 50%	75 - 100%
I10	17.691	62.0	117.0	6.7	0.034	0.0595	-	-	>50 m	continuous	50 - 75%	75 - 100%
I11	20.283	60.5	109.0	8.0	0.037	0.0642	-	-	>50 m	continuous	5 - 25%	50 - 75%
I12	20.418	56.7	103.8	8.1	0.037	0.0642	-	-	>50 m	continuous	25 - 50%	50 - 75%

* Thalweg slope varied spatially depending on topography of the sand bed. Average slope of smoothed thalweg for entire 20.4 km reach was 0.0668% (0.038 degrees).

Table 16. Field data collected for sub-catchment A sites, location, channel form, bed material and large wood. Partially confined is classified low, moderate or high level of confinement. Isaac fp is Isaac River floodplain.

Site	Stream	Order	Latitude	Longitude	Longitudinal continuity	X-sec definition	Valley setting	Bed material (present)	Bed material (dominant)	Large wood (pc./100 m)
A1	A	1	-22.155291	148.199131	yes	strong	Confined	mud, sand, gravel	mud	0
A2	A	1	-22.150008	148.208809	yes	strong	Part. confined (mod.)	mud, sand, gravel	mud	0
A3	A	1	-22.163408	148.215630	yes	strong	Part. confined (mod.)	mud, sand, gravel, bedrock	mud	0
A4	A	1	-22.167428	148.222531	discontinuous	strong	Confined	mud, sand, gravel	mud	0
A5	A	1	-22.149114	148.225358	yes	weak	Unconfined	mud, sand, gravel	mud	0
A6	A	2	-22.146628	148.236000	discontinuous	Ill-defined	Unconfined	mud, sand, gravel	mud	0
A7	A	1	-22.146003	148.236346	discontinuous	Ill-defined	Unconfined	mud, sand, gravel	mud	0
A8	A	2	-22.144933	148.242988	discontinuous	Ill-defined	Part. confined (mod.)	mud, sand, gravel	mud	0
A9	A	2	-22.139538	148.254193	discontinuous	Ill-defined	Unconfined	mud, sand, gravel	mud	0
A10	A	2	-22.118225	148.262125	yes	strong	Part. confined (high.)	mud, sand, gravel, cobble, boulder	mud	50
A11	A	2	-22.124096	148.270031	yes	strong	Part. confined (high.)	mud, sand, gravel	sand	5
A12	A	2	-22.122240	148.276326	yes	strong	Unconfined (Isaac fp)	mud, sand, gravel	mud	0

Table 17. Field data collected for sub-catchment A, channel dimensions, instream bed vegetation structure, riparian vegetation structure. Reach mean slope is DEM-derived and uncertain. NM = not measurable.

Site	Bed width (m)	Bankfull width (m)	Bankfull depth (m)	Slope (Deg.)	Slope (%)	Instream bed vegetation presence	Tree/grass bed vegetation cover	Riparian buffer width	Riparian buffer continuity	Riparian tree cover	Riparian vegetation cover index
A1	16.0	20.0	0.60	0.354	0.6173	grass	25 – 50%	>50 m	continuous	<1%	5 - 25%
A2	2.2	4.5	0.60	0.157	0.2747	grass	5 – 25%	>50 m	continuous	<1%	5 - 25%
A3	3.3	6.7	1.00	0.399	0.6970	-	-	>50 m	continuous	<1%	5 - 25%
A4	5.4	8.9	1.10	0.340	0.5934	grass	5 – 25%	>50 m	continuous	<1%	5 - 25%
A5	4.6	12.9	1.10	0.111	0.1941	grass	1 – 5%	>50 m	continuous	<1%	5 - 25%
A6	NM	NM	NM	0.089	0.1545	grass	5 – 25%	>50 m	continuous	1 - 5%	25 - 50%
A7	NM	NM	NM	0.071	0.1240	grass	5 – 25%	>50 m	continuous	5 - 25%	25 - 50%
A8	NM	NM	NM	0.089	0.1545	grass	1 – 5%	>50 m	continuous	5 - 25%	25 - 50%
A9	NM	NM	NM	0.048	0.0841	grass	5 – 25%	>50 m	continuous	<1%	5 - 25%
A10	4.2	13.7	1.90	0.051	0.0899	-	-	>50 m	continuous	5 - 25%	25 - 50%
A11	2.4	5.8	0.90	0.264	0.4616	-	-	>50 m	continuous	1 - 5%	5 - 25%
A12	2.5	25.3*	5.0*	0.500	0.8730	-	-	>50 m	continuous	5 - 25%	25 - 50%

* Incised (into Isaac River floodplain) channel dimensions

Table 18. Field data collected for sub-catchment B, location, channel form, bed material and large wood. Partially confined is classified low, moderate or high level of confinement. Isaac fp is Isaac River floodplain.

Site	Stream	Order	Latitude	Longitude	Longitudinal continuity	X-sec definition	Valley setting	Bed material (present)	Bed material (dominant)	Large wood (pc./100 m)
B1	B	1	-22.177065	148.248281	yes	strong	Part. confined (mod.)	mud, sand, gravel, cobble	mud	0
B2	B	2	-22.174891	148.251458	yes	strong	Part. confined (mod.)	mud	mud	0
B3	B	2	-22.171629	148.262096	yes	strong	Part. confined (high)	mud, sand, gravel	mud	0
B4	B	2	-22.166773	148.267190	yes	strong	Part. confined (low)	mud, sand, gravel	mud	0
B5	B	2	-22.161276	148.276535	yes	strong	Part. confined (low)	mud, sand, gravel	mud	15
B6	B	2	-22.160194	148.287061	yes	strong	Part. confined (mod.)	mud, sand, gravel	mud	10
B7	B	2	-22.158075	148.294295	yes	strong	Part. confined (low)	mud, sand, gravel	mud	40
B8	B	2	-22.158376	148.307900	yes	strong	Part. confined (mod.)	mud, sand, gravel	mud	60
B9	B	1	-22.162790	148.310378	yes	strong	Part. confined (mod.)	mud, sand, gravel, cobble	mud	0
B10	B	2	-22.159193	148.319486	yes	strong	Part. confined (mod.)	mud, sand, gravel	sand	25
B11	B	2	-22.154655	148.327838	yes	strong	Unconfined (Isaac fp)	mud, sand, gravel	mud	15

Table 19. Field data collected for sub-catchment B channel dimensions, instream bed vegetation structure, riparian vegetation structure. Reach mean slope is DEM-derived and uncertain.

Site	Bed width (m)	Bankfull width (m)	Bankfull depth (m)	Slope (Deg.)	Slope (%)	Instream bed vegetation presence	Tree/grass bed vegetation cover	Riparian buffer width	Riparian buffer continuity	Riparian tree cover	Riparian vegetation cover index
B1	1.7	5.8	1.20	0.314	0.5479	grass	1 - 5%	>50 m	continuous	<1%	5 - 25%
B2	2.2	5.8	0.50	0.200	0.3490	grass	5 - 25%	>50 m	continuous	<1%	5 - 25%
B3	2.2	5.4	0.80	0.192	0.3358	grass	5 - 25%	>50 m	continuous	<1%	5 - 25%
B4	3.2	9.5	0.85	0.117	0.2038	-	-	>50 m	continuous	<1%	5 - 25%
B5	1.3	3.6	0.55	0.104	0.1807	grass	1 - 5%	>50 m	continuous	5 - 25%	25 - 50%
B6	4.5	9.1	0.60	0.112	0.1958	-	-	>50 m	continuous	5 - 25%	25 - 50%
B7	2.9	8.5	0.45	0.112	0.1958	-	-	>50 m	continuous	5 - 25%	25 - 50%
B8	4.1	7.5	1.60	0.120	0.2088	-	-	>50 m	continuous	25 - 50%	25 - 50%
B9	1.1	2.1	0.40	0.271	0.4734	-	-	>50 m	continuous	<1%	5 - 25%
B10	2.1	4.2	0.75	0.033	0.0592	-	-	>50 m	continuous	<1%	5 - 25%
B11	2.5	23.7*	5.8*	0.346	0.6046	-	-	>50 m	continuous	5 - 25%	25 - 50%

* Incised (into Isaac River floodplain) channel dimensions

Table 20. Field data collected for sub-catchment C sites, location, channel form, bed material and large wood. Partially confined is classified low, moderate or high level of confinement. Isaac fp is Isaac River floodplain.

Site	Stream	Order	Latitude	Longitude	Longitudinal continuity	X-sec definition	Valley setting	Bed material (present)	Bed material (dominant)	Large wood (pc./100 m)
C1	C	1	-22.188893	148.309378	yes	weak	Confined	mud	mud	0
C2	C	1	-22.187824	148.311320	yes	strong	Confined	mud, sand, gravel	mud	0
C3	C	1	-22.188090	148.315260	yes	strong	Confined	mud, sand	mud	0
C4	C	1	-22.189583	148.317664	yes	strong	Part. confined (mod.)	mud, sand, gravel, cobble	mud	0
C5	C	1	-22.185880	148.327318	yes	strong	Part. confined (mod.)	mud	mud	0
C6	C	1	-22.183198	148.335846	yes	weak	Part. confined (mod.)	mud	mud	0
C7	C	1	-22.179710	148.343935	yes	weak	Part. confined (mod.)	mud	mud	0
C8	C	2	-22.182901	148.357155	yes	strong	Part. confined (high)	sand	sand	5
C9	C	2	-22.182371	148.363270	yes	strong	Unconfined (Isaac fp)	mud, sand, gravel	sand	0
C10	C	2	-22.179346	148.370368	yes	strong	Unconfined (Isaac fp)	mud, sand, gravel	mud	15
C11	C	2	-22.181056	148.380493	yes	strong	Unconfined (Isaac fp)	mud, sand, gravel	mud	30
C12	C	2	-22.182721	148.382853	yes	strong	Unconfined (Isaac fp)	mud, sand	mud	40
C13	C	2	-22.184078	148.384806	yes	strong	Unconfined (Isaac fp)	mud, sand, gravel	mud	10

Table 21. Field data collected for sub-catchment C, channel dimensions, instream bed vegetation structure, riparian vegetation structure. Reach mean slope is DEM-derived and uncertain.

Site	Bed width (m)	Bankfull width (m)	Bankfull depth (m)	Slope (Deg.)	Slope (%)	Instream bed vegetation presence	Tree/grass bed vegetation cover	Riparian buffer width	Riparian buffer continuity	Riparian tree cover	Riparian vegetation cover index
C1	0.4	1.0	0.20	0.226	0.3951	-	-	>50 m	continuous	<1%	5 - 25%
C2	0.7	2.1	0.30	0.226	0.3951	-	-	>50 m	continuous	<1%	5 - 25%
C3	0.9	1.7	0.30	0.226	0.3951	-	-	>50 m	continuous	<1%	5 - 25%
C4	0.85	1.6	0.25	0.226	0.3951	-	-	>50 m	continuous	<1%	5 - 25%
C5	2.3	8.0	0.50	0.170	0.2962	-	-	>50 m	continuous	<1%	5 - 25%
C6	5.1	15.0	0.30	0.170	0.2962	-	-	>50 m	continuous	<1%	25 - 50%
C7	1.1	3.1	0.35	0.122	0.2129	-	-	>50 m	continuous	<1%	5 - 25%
C8	2.4	5.5	0.40	0.138	0.2416	-	-	>50 m	continuous	25 - 50%	25 - 50%
C9	2.5	10.1	0.45	0.077	0.1342	-	-	>50 m	continuous	<1%	25 - 50%
C10	2.8	6.1	0.45	0.060	0.1046	-	-	>50 m	continuous	5 - 25%	50 - 75%
C11	4.7	9.2	0.50	0.081	0.1422	-	-	>50 m	continuous	25 - 50%	25 - 50%
C12	5.6	27.0*	4.0*	0.057	0.1000	-	-	>50 m	continuous	25 - 50%	50 - 75%
C13	2.8	50.0*	5.8*	0.057	0.1000	-	-	>50 m	continuous	25 - 50%	25 - 50%

* Incised (into Isaac River floodplain) channel dimensions

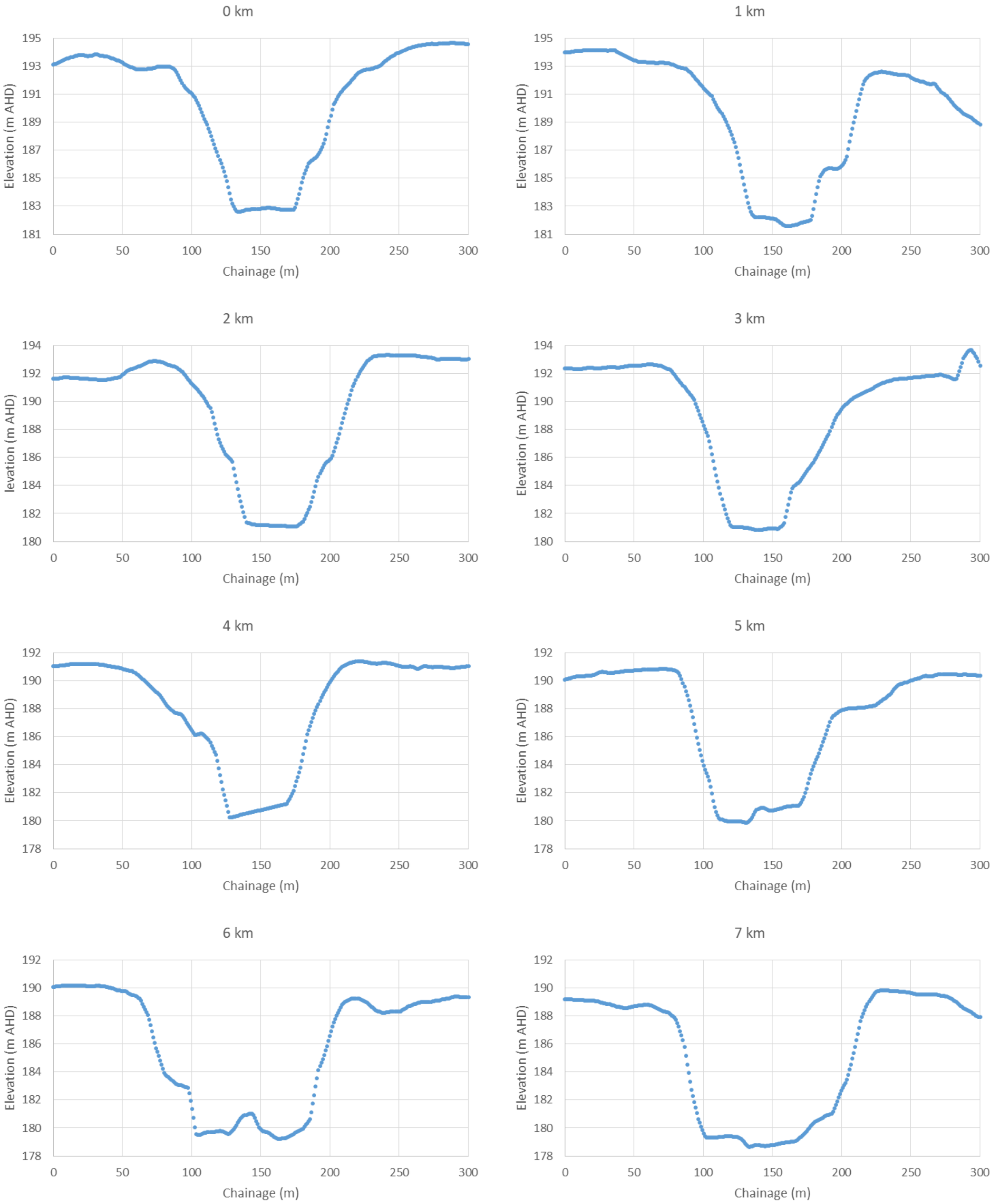

Figure 30. Cross-sections 0 km to 7 km spaced at 1 km intervals along the smoothed thalweg of Isaac River, starting from field observation point I1 (0 km) and ending at field observation point I12 (20.418 km). Chainage direction is left to right looking downstream. Point spacing is 1 m. Data derived from 1 m LiDAR flown in 2012. Consistent scale used for all cross-sections.

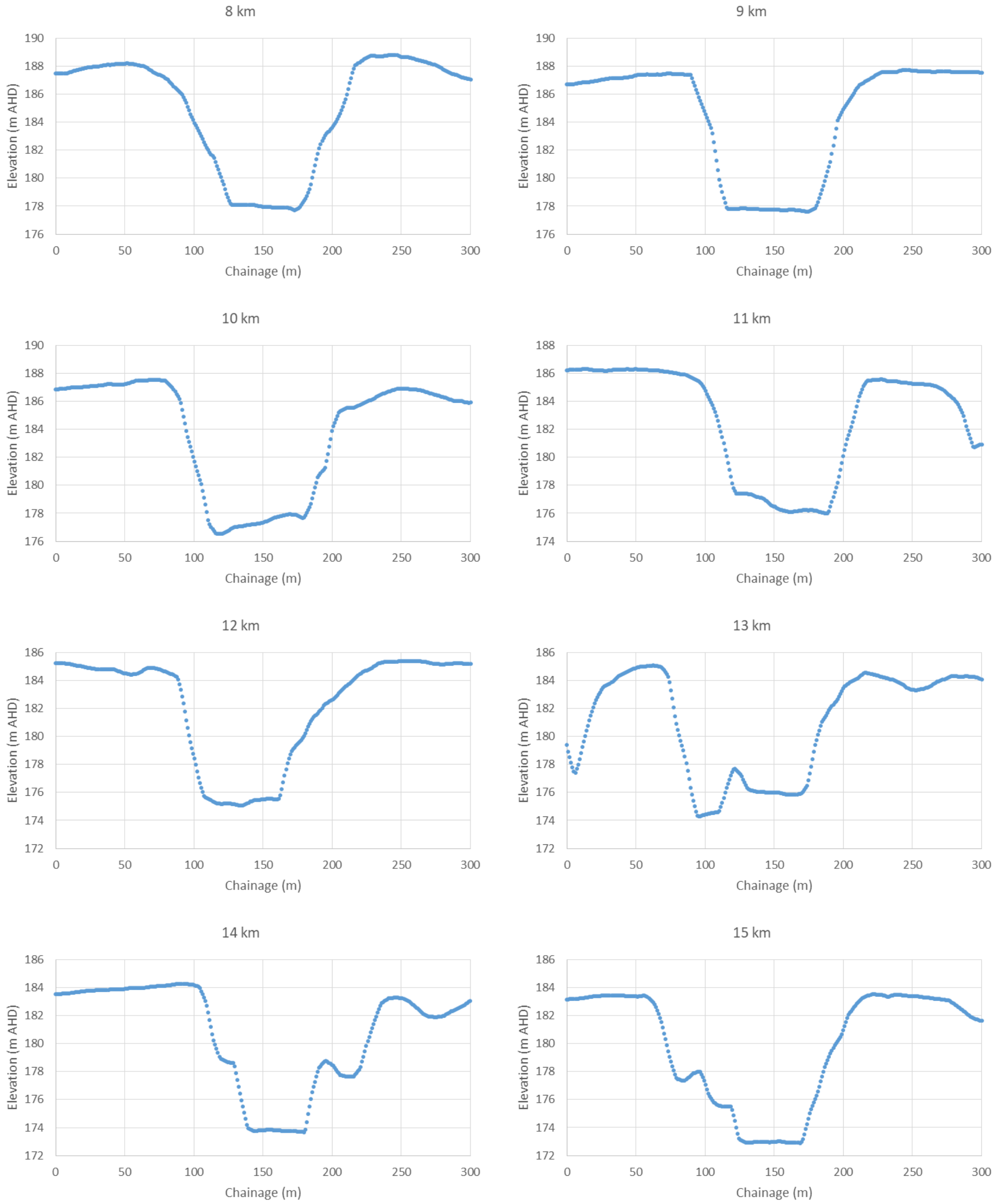

Figure 31. Cross-sections 8 km to 15 km spaced at 1 km intervals along the smoothed thalweg of Isaac River, starting from field observation point I1 (0 km) and ending at field observation point I12 (20.418 km). Chainage direction is left to right looking downstream. Point spacing is 1 m. Data derived from 1 m LiDAR flown in 2012. Consistent scale used for all cross-sections.

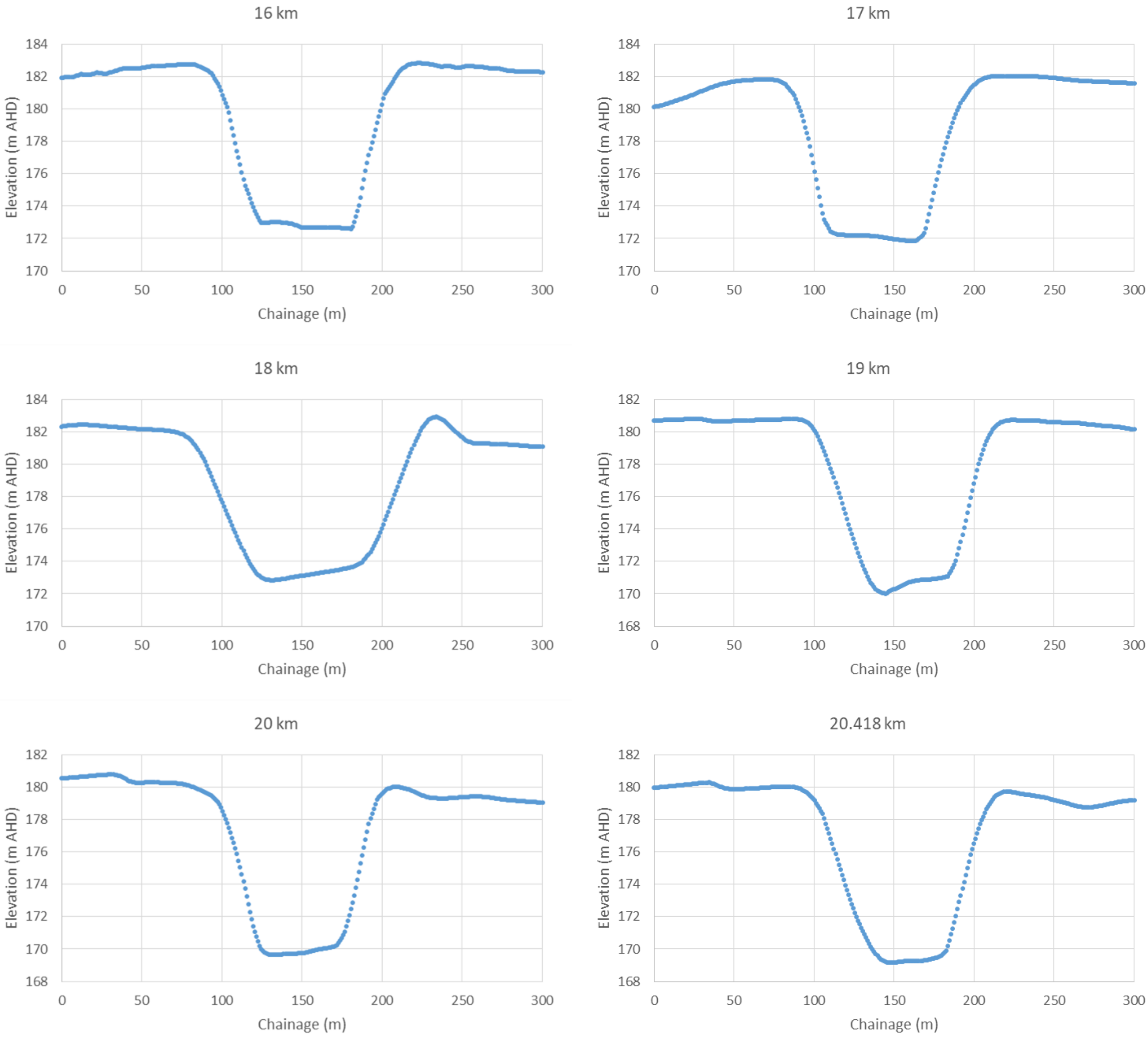

Figure 32. Cross-sections 16 km to 20.418 km spaced at 1 km intervals along the smoothed thalweg of Isaac River, starting from field observation point I1 (0 km) and ending at field observation point I12 (20.418 km). Chainage direction is left to right looking downstream. Point spacing is 1 m. Data derived from 1 m LiDAR flown in 2012. Consistent scale used for all cross-sections. The bed of XS 18 contains a LiDAR artefact (artificially high).

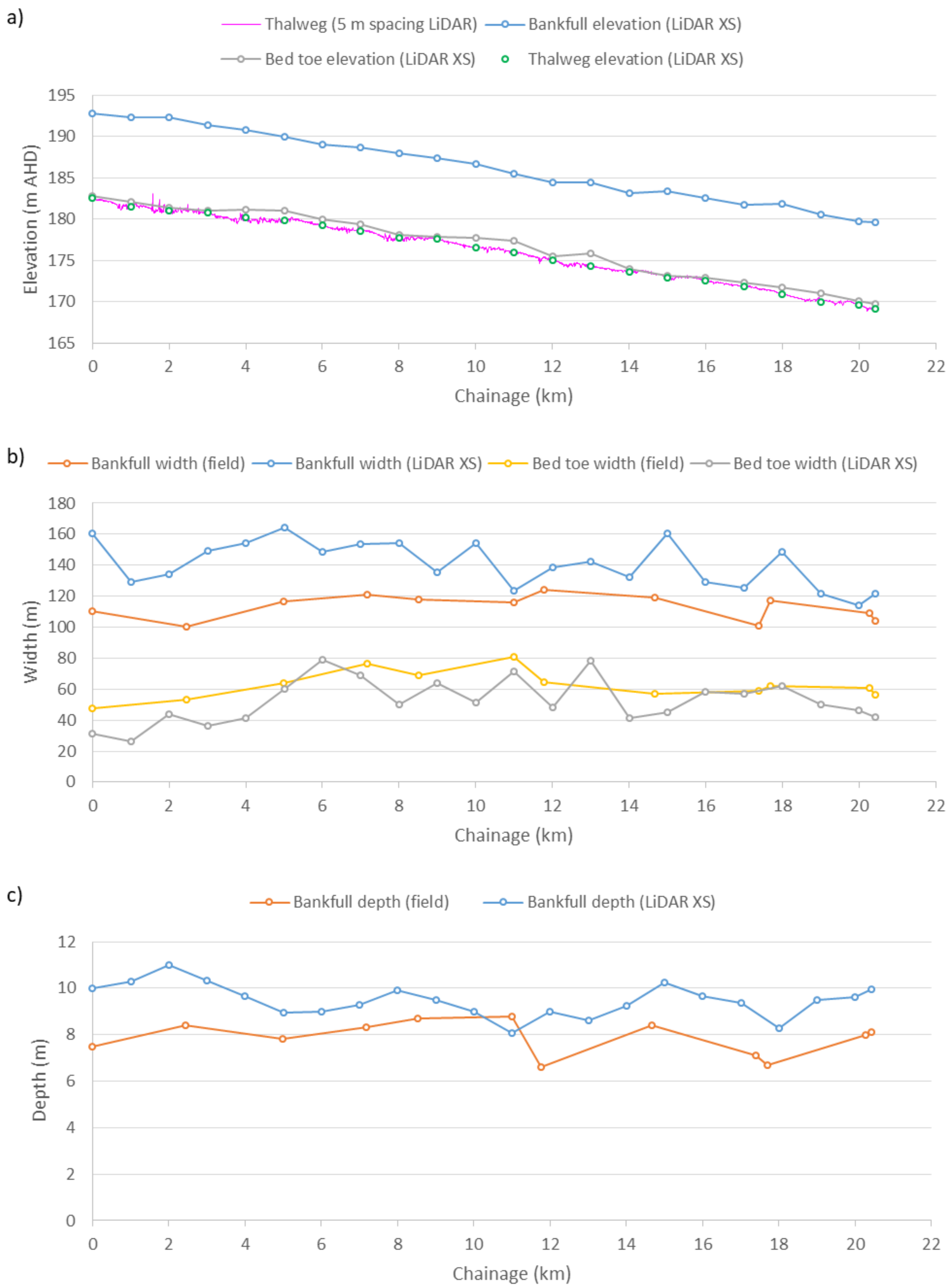

Figure 33. (a) Longitudinal profile of estimated morphological bankfull (top of bank) and bank toe (base of bank) elevations plus thalweg at 1 m spacing, (b) Estimated bankfull width and bed width derived from LiDAR cross-sections compared with field estimates, and (c) Estimated bankfull depth derived from LiDAR cross-sections compared with field estimates. LiDAR taken from cross-sections spaced at 1 km intervals along the smoothed thalweg of Isaac River.

Table 22. Summary statistics of Isaac River width and depth over the Study Area, comparing results of field-based and LiDAR-based methods. N = number of observations.

Methodology	N	Bankfull width (m)		Bankfull depth (m)		Bed toe width (m)	
		Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
LiDAR 1 km spaced cross-sections	22	140.79	14.89	9.47	0.71	52.40	14.38
Field observation using range finder	12	113.04	8.04	7.87	0.74	62.55	9.40

4.2.6 Stream geomorphic type

Stream geomorphic type (equivalent to River Styles®) 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.

Isaac River, being laterally unconfined with extensive floodplain connection, was classified Low Sinuosity Sand type.

The upper and middle sections of the watercourses in sub-catchments A, B and C were low-gradient, generally small, mostly continuous, but in some areas poorly-defined, channels. They were classified Low Sinuosity Fine Grained. At their downstream extents, the channels incised into the Isaac River floodplain. Although the channels became significantly deeper and wider, they retained a fine grained bed and low sinuosity, so the geomorphic type did not change.

4.2.7 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. Longitudinal discontinuities, known as knickpoints, were observed at only two locations. Site A3 had a 1 m knickpoint at a bedrock outcrop (Figure 20), and Site A4 had a 0.45 m knickpoint in uncohesive bed material (Figure 20). Riparian vegetation cover was sparse at nearly all sites, with exotic species present. The poor vegetation cover could have been partly a response to extended dry weather conditions rather than the result of over-grazing.

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 the Isaac River, no evidence was uncovered to suggest that this was unnatural. The sub-surface geology of the wider Study Area is dominated by sandstone, and the surface geology is almost entirely sandy deposits. 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 Coxen's 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*".

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 near 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 areas (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 34). 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 west-northwest 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 its main 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. Bullock team pulling a wagon full of goods, Isaac River, ca. 1878. Source: Trove, National Library of Australia, URL ttp://trove.nla.gov.au/version/167821903 (accessed 4 December, 2017).

4.2.8 Stream geomorphic fragility

The fragility ratings for each geomorphic stream type were taken from Healey et al. (2012, p. 82-84). The Isaac River, being low sinuosity sand type, has a fragility rating of High. In River Styles, a high fragility rating (i.e. sensitive to change to another type if disturbed) is associated with sand bed streams due to the uncohesive nature of the bed materials. Also, it is assumed in River Styles that extensive sand beds indicate that the catchment and river have been impaired by land clearing. Evidence was provided in this report that the sand bed of the Isaac River is likely to be a natural attribute, and it appears to have been in that state since at least the mid-1800s. The watercourses of sub-catchments A, B and C, being low sinuosity fine grained type, have a fragility rating of Low (i.e. not sensitive to change to another type if disturbed).

5.0 Impact assessment

5.1 Operational Phase

The Project would be staged over approximately 30 years. The general arrangement of the Project for Years 2, 5, 9, 19 and 27 are shown in the Main Text of the EIS. Noting that not all Project components are necessarily present at any point in time, the way that the Project components interact with the natural drainage system and topography are depicted in Figure 35.

The Project powerline, pipeline, access road and rail loop do not interact with watercourses. An up catchment diversion, also known as a clean water drainage line, would be constructed in Stage 1 to divert water draining from upper sub-catchment A around Railway Pit and its associated waste emplacement area. Otherwise, open cut mining activities would excise the central part of the drainage system of sub-catchment A and the upper parts of the drainage systems of sub-catchments B and C (Figure 35). The process of removal of parts of natural drainage systems would occur in stages, corresponding with the stages of mining. This process would have the effect of changing the catchment areas of watercourses downstream of the mined area. In general, the periodic changes in catchment area would be small and involve a reduction in area, so erosion of the downstream watercourses would not be expected.

A number of water storages would be constructed in the MIA, and the water management system would also include three controlled water release points. Controlled releases of mine affected water would occur if required via Mine Water Dam (MWD), CC Dam and Railway Pit (Stage 2 to Stage 4 only) into the Isaac River (Figure 35). The release point dams are proposed to be turkey's nest type dams around 5 m deep. The maximum distance between the controlled release points and the Isaac River is around 2 km. WRM Water & Environment (2020) proposed mine affected water release limits that apply during flow events. Water balance modelling by WRM Water & Environment (2020) indicated that controlled releases would only be required for very wet (1 percentile) climatic conditions. The modelling indicated that the dams would not have any uncontrolled spillway discharges to the Isaac River for any climatic conditions assessed over the life of the Project. Details of the water management system can be found in WRM Water & Environment (2020). Releases from Railway Pit would be made directly into an existing, established watercourse. It is possible that a release event could result in erosion of the established watercourse that would otherwise not have occurred, depending on the flow in the watercourse at the time. Releases from MWD and CC Dam would travel about 380 m and 1200 m, respectively, before reaching an existing, established watercourse. A release event from CC Dam and/or MWD could result in scour of a channel between the release point and the established watercourse, but this could be avoided by construction of a stable channel. It is possible that a release event from CC Dam and/or MWD could result in erosion of the established watercourse that would otherwise not have occurred, depending on the flow in the watercourse at the time.

Two temporary levees would prevent floodwaters from the Isaac River from entering the pit areas (Figure 35). They would be regulated structures designed with a crest level above the 0.1% AEP design event plus freeboard. The levees could potentially impact the flood hydraulics of the Isaac River. WRM Water & Environment (2020) used a calibrated Isaac River hydraulic model to estimate design peak flood levels, depths, extents and velocities along the Isaac River and its tributaries for various events from 5% AEP design event to the Probable Maximum Flood (PMF) for existing and proposed conditions. The proposed temporary levees for the Project would not interact with peak water levels up to and including 5% AEP design event. Flood impacts would only occur for the 1% AEP event and higher. WRM Water & Environment (2020) found that the changes to water levels and velocity due to the Project would be largely limited within the Project MLA areas, with a minor excursion (360 m) to the north of the northern temporary levee. As there would be no changes to flood levels or velocity at any key infrastructure (e.g. residences, roads, rail), WRM Water & Environment (2020) concluded that the Project would not result in any flooding impacts to key infrastructure.

From the perspective of geomorphic impacts, on the basis of the WRM Water & Environment (2020) flood model results, this report found that the Project would have no impact on the Isaac River and floodplain up to and including 5% AEP design event, which covers the range of events normally considered important for channel formation. Under the 1% AEP event and higher, the increase in velocity would be localised, of very limited extent, and mostly involve a change of less than 1 m/s. Overall, the geomorphic impact of the Project on the Isaac River and floodplain would be negligible. For Ripstone Creek, modelling by WRM Water & Environment (2020) found that the 0.1% AEP peak flood extent would not interact with the Project. Therefore, the Project would have no geomorphic impacts on Ripstone Creek.

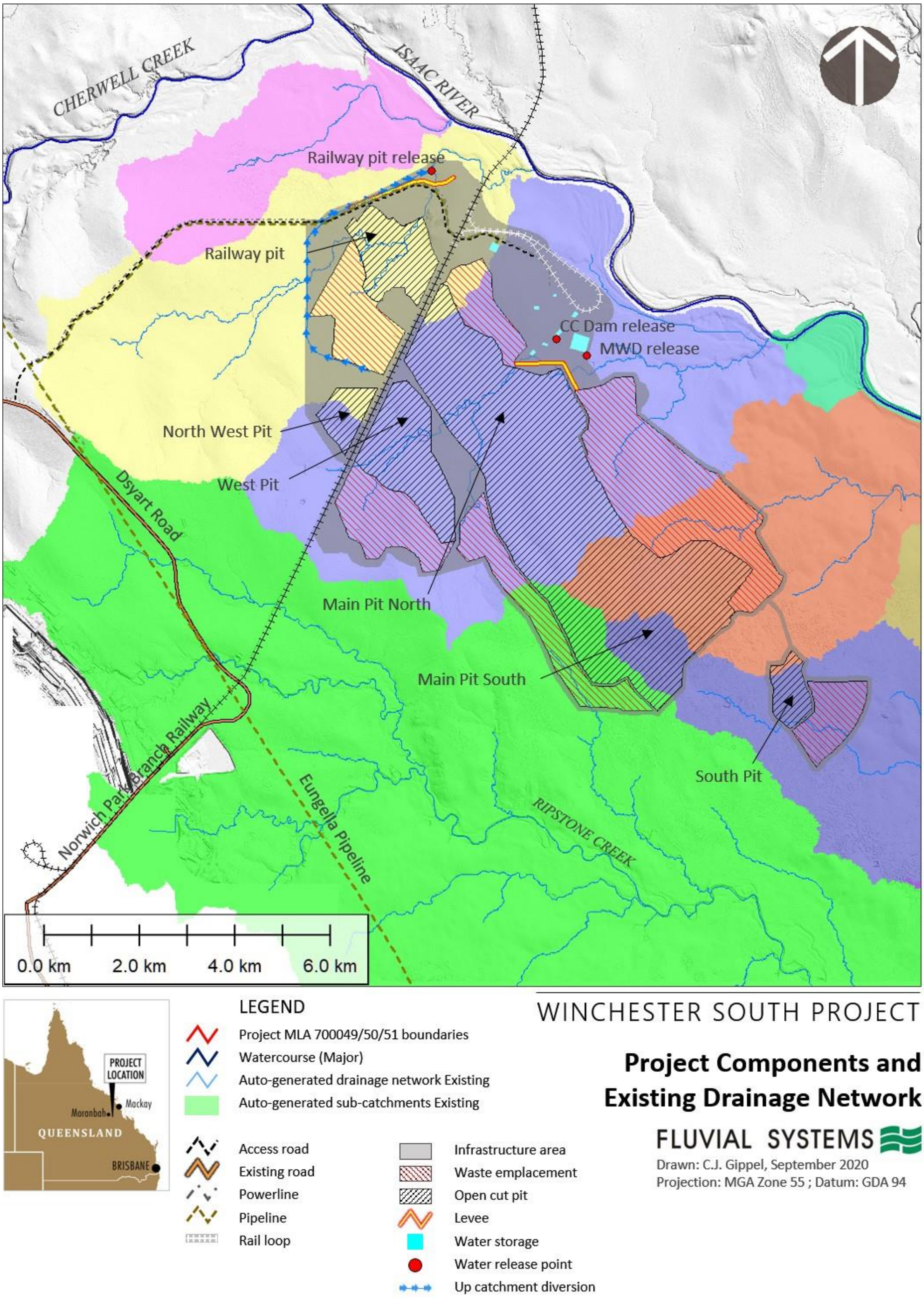

Figure 35. The interaction of Project components with the existing natural drainage system.

5.2 Post-mining

The temporary flood levees for protection from the Isaac River floodplain would be removed and returned to pre-mining conditions as part of the final landform. Permanent drainage of waste rock emplacement areas would be installed to minimise capture of surface runoff into the residual voids (Figure 36). The majority of the disturbed area would be rehabilitated and allowed to drain back to the Isaac River and Ripstone Creek (Figure 36).WRM Water & Environment (2020) estimated that a residual area of approximately 14.3 km^2 would continue to drain to the residual voids (Figure 36).

Terrain analysis was used to calculate the areas of sub-catchments that were within or partially within the Project MLA areas for both the existing and the final landforms. These sub-catchments included sub-catchments A, B and C, the sub-catchment located to the south of sub-catchment C and draining to the south east (labelled Eastern sub-catchment), and Ripstone Creek. Note that in this report the existing catchment area of Ripstone Creek was estimated to be 180.05 km^2, while WRM Water & Environment (2020) estimated a total catchment area of 286 km^2. This difference is explained by WRM Water & Environment (2020) including an area within Ripstone Creek catchment that this report assigned to Boomerang Creek catchment. This relates to the procedure used to delineate catchments, in particular the quality and resolution of the topographic data, and the resolution used in the catchment delineation process. In this region, some areas of the terrain are very low slope with indistinct flow paths, and the alignments of some watercourses have been altered in association with mining, both of which can lead to terrain analysis delineating different catchment areas depending on the resolution of topographic data used in the terrain analysis. In this case, the difference in area of Ripstone Creek has no impact on the conclusions, as the objective related to the change in catchment area as a result of the Project, not the accuracy of the absolute catchment area.

The differences in area of sub-catchments between the existing and post-mining scenarios were a relatively small percentage of their total areas (Table 23). Note that the sum of the differences was 14.0 km^2, which is 0.3 km^2 smaller than the residual area draining to the residual voids. This is explained by small differences in delineation of the catchment area boundaries arising from the final landform DEM being lower resolution (derived from contours) than the existing DEM, and small computational differences that can be considered within the accuracy of the method. The differences in catchment area were negative, except in the case of Eastern sub-catchment, which increased by only 0.16 km^2 (Table 23). This means that the area captured by the voids would be distributed between them. The implication of this change for geomorphic forms and processes in the watercourses of the sub-catchments is that they would have slightly lower flows, and thus, theoretically, be slightly more stable under the post-mining scenario. The reduced flow duration and flow magnitude would tend to result in some vegetation encroachment within the channel, and increased sediment deposition within the channel.

The predicted overall geomorphic impact of the Project would be relatively minor. The Project would have negligible impact on the Isaac River; it would reduce the length of some small First and Second Order watercourses, but these would be reinstated to some extent in the post-mining landform. Thus, the regional cumulative impacts of the Project on geomorphic characteristics of streams would be negligible.

Table 23. Areas of sub-catchments that were within or partially with the Project MLA areas for both the existing and the final landforms.

Scenario	Sub-catchment area (km^2)				
	A	**B**	**C**	**Eastern**	**Ripstone Ck**
Existing	41.43	54.76	31.40	30.24	180.05
Post-mining	41.08	48.99	26.24	30.40	177.18
Difference	-0.35	-5.77	-5.16	0.16	-2.87

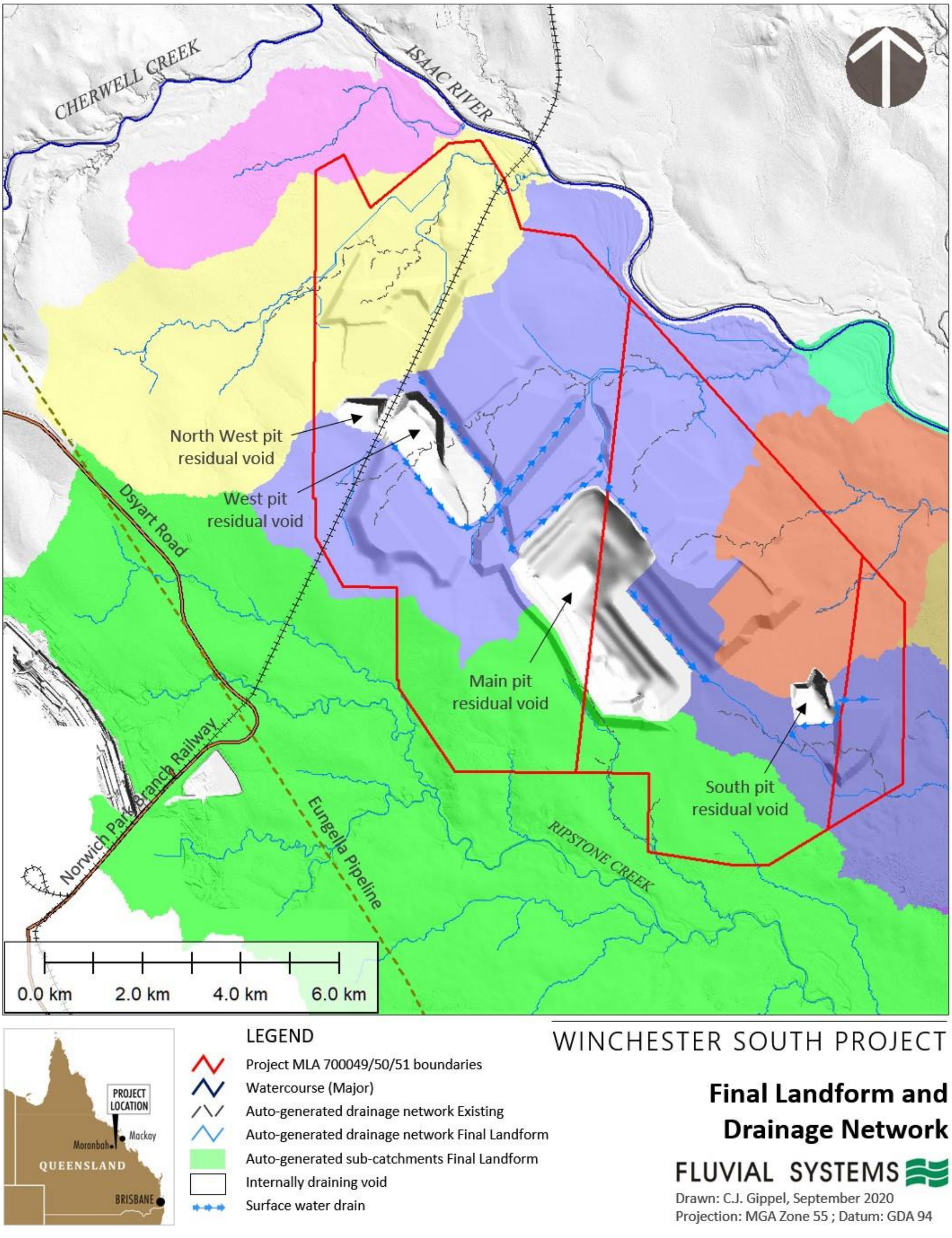

Figure 36. The Final Landform sub-catchments and drainage network. Existing drainage network shown for comparison.

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 repeat topographic survey of minor watercourses downstream of mined areas, including the drainage paths from the CC Dam and MWD controlled release points (note: this excludes the Isaac River and Ripstone Creek, as well as the release point from Railway pit, which is directly to an existing watercourse).

The first survey would be undertaken during the third year after beginning mining operations, or following a flood event exceeding the 5 year ARI event if it occurs in this period. The survey would then be repeated every 5 years, or after every flood event exceeding the 5 year ARI event. The first survey of the drainage lines downstream of the CC Dam and MWD controlled release points would be undertaken during the third year after beginning mining operations. The survey of these drainage lines would be repeated every 5 years. The other monitoring to be undertaken on the drainage lines downstream of the CC Dam and MWD controlled release points is a rapid inspection during and immediately after releases are made. The purpose of this is to determine whether or not a channel has scoured into the land surface; if so, a topographic survey should be undertaken. The suggested trigger for a topographic survey is observation of a channel exceeding 0.2 m deep for a length of 10 metres or more, or initiation of a knickpoint higher than 0.3 m.

The topographic survey of watercourses should be done using LiDAR technology, flown when flow in watercourses is low or stopped. The relatively short lengths of drainage lines downstream of the controlled release points can be surveyed using standard ground survey methods that include cross-sections every 100 metres, plus additional cross-sections at the eroded areas, and thalweg long profiles.

It will be necessary to identify control watercourse reaches that are also monitored, preferably paired reaches of the watercourses found upstream of the Project MLA areas. The monitoring principle is to characterise the degree of change at the control reaches of the watercourses and use this to set the tolerance for change in the intervention reach of the watercourses, located downstream of the Project MLA areas. The tolerance for stability of the drainage paths from the controlled release points would be set by the design standards used to construct these components of the water management system (or as suggested above).

The focus of geomorphic monitoring would be the undisturbed reaches of minor watercourses downstream of mining operations, extending down to where they meet the Isaac River. At any survey time, the spatial extent of the survey would include those minor watercourses downstream of the area being actively mined, and those downstream of areas that had been mined, plus their respective control reaches.

After a survey, a monitoring report would 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.

Monitoring the geomorphology of the Isaac River and Ripstone Creek would be problematic from a scientific perspective and is considered unnecessary. This Geomorphology Technical Report found that physical changes brought about by the Project would have negligible geomorphic impacts on Isaac River and Ripstone Creek, in which case it would not be possible to attribute, with statistical confidence, any geomorphic changes observed on the these watercourses to activities associated with the Project.

Visual assessment can in some circumstances be used for determining presence or absence of a geomorphic feature (e.g. presence/absence of a channel, as suggested above for downstream of release points), but pseudo-quantitative visual assessment of geomorphic variables (e.g. erosion severity, or geomorphic condition score sheets) is not recommended. In general, these methods 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. An unexpectedly large change in channel morphology is one that lies outside the natural range, as characterised by the statistically defined degree of change observed at the control sites (excluding outliers). The most appropriate response would need to be assessed at the time and would range from do nothing (self-healing), to assisted recovery (e.g. plant vegetation and soft engineering such as coir matting and stakes), to hard-engineering (e.g. rock rip-rap). If a channel is observed to have scoured into the land surface downstream of a release point, it should be immediately stabilised and rehabilitated.

7.0 Conclusion

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 or mildly disturbed geomorphic condition. The Isaac River was potentially impacted by factors that reduced its 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. The journal of explorer Ludwig Leichardt from his 1844/45 expedition through the area, plus a photograph of the river taken in 1878, held by the National Library of Australia, provided qualitative information which suggested that the river naturally had a sand bed, and the river morphological type has not changed over historical time. Only two knickpoints, and no zones of major geomorphic instability, were observed over the surveyed area.

The predicted overall geomorphic impact of the project would be relatively minor. The Project would have negligible impact on the Isaac River; it would reduce the length and catchment area of some small First and Second Order watercourses within three sub-catchments, but these would be largely reinstated in the post-mining landform. Thus, the regional cumulative impacts of the Project on geomorphic characteristics of streams would be negligible.

The focus of this monitoring effort would be on the undisturbed reaches of minor watercourses downstream of mining operations to where they meet the Isaac River. There is no need to monitor the geomorphology of the Isaac River. The Project would have negligible impacts on the Isaac River, in which case it would be impossible to attribute any geomorphic changes observed on the Isaac River to activities associated with the Project. 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. A BACI 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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