

Sediment Overview Report

Buller Plateaux Continuation Project

20 July 2026

J-NZ0480-002-R-FINAL

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Document Number: J-NZ0480-002-R-FINAL

Document Date: 20 July 2026

Prepared for:

Bathurst Resources Limited



Prepared by:

Mine Waste Management Limited



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REVISION	DATE	AUTHOR	RECORD OF REVIEW
J-NZ0480-002-R-FINAL	20-07-2026	SH	PW

EXECUTIVE SUMMARY

Bathurst Resources Limited (BRL) is seeking to obtain authorisation through the Fast-track Approvals Act 2024 (FTAA) to progress development and mining of the coal resources across the wider Buller Plateaux. This project is referred to as the Buller Plateaux Continuation Project (BPCP or the Project).

The purpose of the BPCP is to re-consent the existing infrastructure and mining operations associated with the existing Stockton Mine and provide access to additional coal mining areas across the Buller Plateaux, as the coal resource in the current Stockton Mine is close to depletion, and further coal resources for blending are required. There are five key Project sub-areas:

- Stockton mining area (Stockton)
- Mount Frederick South (MFS)
- Escarpment Extended (ESE)
- Upper Waimangaroa Haul Road (UWHR)
- Cypress mining area (Cypress)

Mine Waste Management Limited (MWM) has developed this Sediment Overview Report to summarise the erosion and sediment related studies to support BRL with the assessment of environmental effects (AEE) for its proposed mining activities at MFS, ESE, and the UWHR. Stockton and Cypress sub-areas are addressed in GHD (2026) and are not discussed in this report.

Report Objectives

The studies presented in this report, together with other studies (e.g., BRL, 2026e) have been used to support the development of the Water Infrastructure Design for the BPCP, which was developed by BRL, and is provided as a separate document (BRL, 2026c) to ensure the effects of elevated total suspended solids (TSS) on the receiving environment are minimised.

The objectives of this overview report are to:

- Summarise previous studies that have assessed TSS for mining projects on the Buller Plateaux.
- Describe source terms used for the water and load balance model (WLBM) resulting from the studies
- Understand potential TSS effects on the downstream receiving environment.
- Identify engineering controls for the BPCP to mitigate potential effects of TSS.
- Support the development of management plans to ensure the recommendations identified by the various studies, presented in this overview report, are undertaken.

Key Findings

The two key issues relating to mine-impacted water (MIW) that need to be managed are:

- Elevated TSS.

- Acid and metalliferous drainage (AMD) which is typically low pH and elevated acidity, sulfate (SO_4), and certain potential constituents of concern (PCOC) such as aluminium (Al), iron (Fe), and lesser amounts of trace metals that include cadmium (Cd), cobalt (Co), copper (Cu), manganese (Mn), nickel (Ni), and zinc (Zn).

This report addresses TSS only. Details relating to the potential effects of AMD and its management are provided in the AMD Overview Report (MWM, 2026f), the AMD Engineered Landform (ELF) Management Plan (BRL, 2026a) and the AMD Water Management Plan (BRL, 2026b).

However, suspended solids can also be generated by the treatment of AMD impacted waters that generate iron (Fe) and aluminium (Al) hydroxide precipitates. Such precipitates can also contribute to the measured TSS and have similar effects to TSS generated from suspended sediment.

Studies indicate that the environmental risks associated with TSS at the MFS, ESE, and UWHR can be successfully managed if the appropriate management processes are utilised, appropriate engineering controls are implemented, and performance monitoring is undertaken to support adaptive management principles if there is variation from the expected case.

Recommendations are provided to ensure that risks and uncertainty relating to TSS are managed.

Management Approach

To mitigate the risks associated with elevated TSS at the MFS, ESE, and the UWHR sub-areas, a hierarchy of controls (Management Steps) has been developed:

1. Determine the closure objectives for the mine.
2. Understand the source hazards.
3. Prevent/minimise erosion of soils resulting in generation of TSS.
4. Control and treatment of TSS-impacted waters.
5. Complete an assessment of the potential effects.
6. Monitor performance.

Study Summary

Studies have been completed to address these management steps (as shown in Table E1). These studies have been used to develop erosion and sediment management processes. The following documents have been developed to guide the management of risks for elevated TSS in receiving waterways caused by BPCP activities at the MFS, ESE, and the UWHR sub-areas so that they can be managed in an appropriate manner:

- AMD ELF Management Plan (BRL, 2026a).
- AMD Water Management Plan (BRL, 2026b).
- Water Infrastructure Design (BRL, 2026c).
- Mine Closure Concept Strategy (BRL, 2026d).

- Erosion and Sediment Control Plan for Land Disturbance Activities (BRL, 2026e).
- Water Treatment Report: MFS and ESE (MWM, 2026c).
- AMD Sludge Management (MWM, 2026g).

Report Structure

This report summarises the studies that have been undertaken by MWM, which include the following reports, as shown in Table E1.

Table E1: TSS Study Summary

REPORT NAME	REPORT NUMBER	REFERENCE	APPENDIX
Source Hazard Studies			
Previous TSS Studies	J-NZ0433-014-M-FINAL	MWM, 2026a	Appendix A
MGIU ¹ TSS Review	J-NZ0433-013-M-FINAL	MWM, 2026b	Appendix B
Assessment of Effects			
Construction Phase Report	J-NZ0453-007-R-FINAL	MWM, 2026h	*
ESE Water Load Balance Model Report	J-NZ0433-003-R-FINAL	MWM, 2026d	*
MFS Water Load Balance Model Report	J-NZ0377-003-R-FINAL	MWM, 2026e	*

* These reports have not been provided in this document. They are provided in the AMD Overview Report (MWM, 2026f).

1. MGIU = Stockton Water Quality Monitoring Location: Mangatini (sump) Inlet Untreated, where MIW is treated by CaO to neutralise AMD.

Recommendations

Recommendations to manage the potential effects of TSS for the MFS, ESE, and the UWHR sub-areas to ensure operational and closure objectives for water quality are met as provided in this report (see Section 8).

Management Plans

This work has identified that a management plan is needed to manage the risks associated with TSS. This is provided for in:

- AMD Water Management Plan (BRL, 2026b)
- Water Infrastructure Design (BRL, 2026c).
- Erosion and Sediment Control Plan for Land Disturbance Activities (BRL, 2026e).

Review

This report has been peer reviewed by Dr James Pope of Strata Geoscience Limited (Pope, 2026). The review is provided as part of the substantive FTAA application.

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1 INTRODUCTION

Bathurst Resources Limited (BRL) is seeking to obtain authorisation through the Fast-track Approvals Act 2024 (FTAA) to progress development and mining of the coal resources across the wider Buller Plateaux. This project is referred to as the Buller Plateaux Continuation Project (BPCP or the Project).

The purpose of the BPCP is to re-consent the existing infrastructure and mining operations associated with the existing Stockton Mine and provide access to additional coal mining areas across the Buller Plateaux, as the coal resource in the current Stockton Mine is close to depletion, and further coal resources for blending are required. There are five key Project sub-areas:

- Stockton mining area (Stockton)
- Mount Frederick South (MFS)
- Escarpment Extended (ESE)
- Upper Waimangaroa Haul Road (UWHR)
- Cypress mining area (Cypress)

Mine Waste Management Limited (MWM) has developed this Sediment Overview Report to summarise the erosion and sediment related studies to support BRL with the assessment of environmental effects (AEE) for its proposed mining activities at the MFS, ESE, and the UWHR sub areas. Assessment relating to the Stockton and Cypress sub-areas is addressed in GHD (2026), however local experience from Stockton has been drawn upon to support this assessment for ESE, MFS, and UWHR.

1.1 Purpose

The purpose of this report is to provide a concise summary of all technical studies relating to suspended sediment (measured as total suspended solids [TSS]) completed for the BPCP and explain how the potential risks associated with TSS were assessed and how they will be managed to achieve operational and closure water quality objectives (Hickey, 2026).

This report addresses TSS only. Details relating to the potential effects of AMD and its management are provided in the AMD Overview Report (MWM, 2026f), the AMD Engineered Landform (ELF) Management Plan (BRL, 2026a) and the AMD Water Management Plan (BRL, 2026b).

1.2 Study Objectives

The studies presented in this report, together with other studies (e.g., BRL, 2026e), have been used to support the development of the water and load balance models (WLBMs) for the ESE and MFS sub-areas, the Water Infrastructure Design, and the AMD Water Management Plan for the BPCP.

The WLBMs were developed to understand effects of elevated TSS on the receiving environment and how they can be minimised. The AMD Water Management Plan, Water Infrastructure Design Plan, and Erosion and Sediment Control Plan for Land-Disturbance Activities were developed by BRL, and are provided as separate documents (BRL, 2026b,c,e), to ensure the effects of elevated TSS on the receiving environment are minimised.

The objectives of this Sediment Overview Report are to:

- Summarise previous studies that have assessed TSS for mining projects on the Buller Plateaux.
- Describe source terms used for the WLBM resulting from the studies.
- Understand potential TSS effects on the downstream receiving environment.
- Identify engineering controls for the BPCP to mitigate potential effects of TSS.
- Support the development of management plans to ensure the recommendations identified by the various studies, presented in this overview report, are undertaken.

1.3 Abbreviations

A list of abbreviations is provided to enable clear communication of commonly used terminology.

Table 1: Abbreviations

ABBREVIATION	DEFINITION
AEE	Assessment of environmental effects
AMD	Acid and metalliferous drainage (sometimes called acid mine drainage)
AMD ELFMP	AMD Engineered landform management plan
AMD WMP	AMD Water Management Plan
BCM	Brunner Coal Measures
bcm	Bank cubic metres
BPCP	Buller Plateaux Continuation Project
BRL	Bathurst Resources Limited
CHPP	Coal handling and processing plant
CWD	Clean water drain
Cypress	Cypress mining area
EFA	Engineered fill area (for haul road construction)
ELF	Engineered landform
ESE	Escarpment Extended
FTAA	Fast-track Approvals Act 2024
HAF	High acid forming
KMS	Kaiata Mudstone
MFS	Mt Frederick South
MIW	Mine-impacted water (includes AMD and TSS effects)
MWM	Mine Waste Management Limited
NAF	Non-acid forming

ABBREVIATION	DEFINITION
PAF	Potentially acid forming
PCOC	Potential constituents of concern
SPR	Source-Pathway-Receptor Analysis
Stockton	Stockton mining area (also referred to as STO)
TSS	Total suspended solids
UWHR	Upper Waimangaroa Haul Road
WLBM	Water and load balance model
WMG	Water Management Group
WTP	Water treatment plant

1.4 Project Background

The BPCP covers areas on both the Stockton Plateau and the Denniston Plateau (collectively referred to as the Buller Plateaux). The purpose of the BPCP is to reconsult the existing infrastructure and mining operations associated with the Stockton Mine and provide access to additional coal mining areas across the Buller Plateaux, as the coal resource in the current Stockton operations are close to depletion, and further coal resources for blending are required.

1.4.1 Location and Project Area

The Buller Plateaux is located approximately 15 km northeast of Westport on the West Coast of the South Island. The proposed land use consent boundary for the BPCP in relation to Westport is shown by the magenta outline in Figure 1.

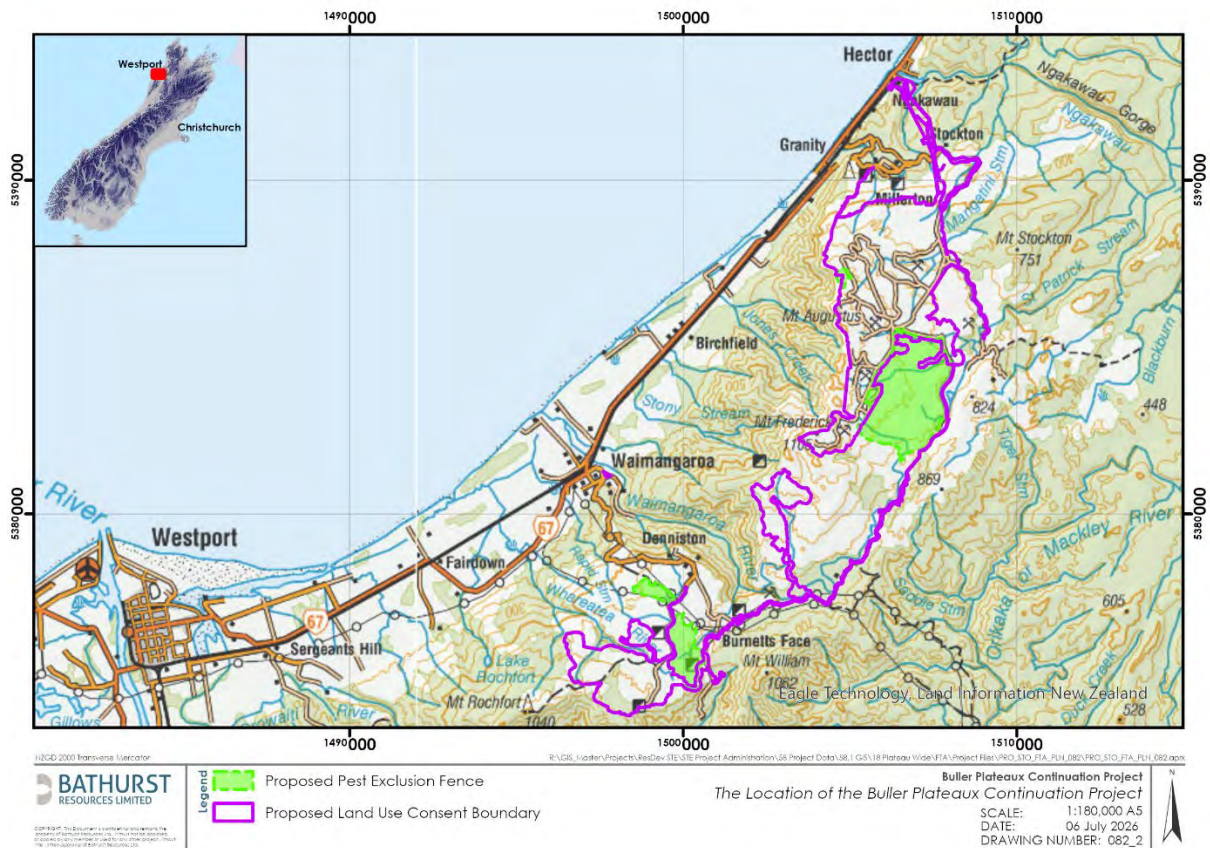


Figure 1: Local context of the BPCP

1.4.2 Project Sub-area Overview

The BPCP comprises five Project sub-areas as explained in Section 1 and as shown in Figure 2, however this report focuses on the MFS, ESE, and UWHR sub-areas. Each sub-area has defined project scopes and site-specific geoenvironmental hazards including:

- **MFS:** A new opencast mining area with initial mining through existing historical underground workings, and extension into unmined areas to the northwest along with the extension of the UWHR road into the MFS mine area. Coal will be transported to Stockton via the UWHR
- **ESE:** Mining is a combination of an existing pit (Escarpment), mining through existing historical underground workings (Whareatea, Escarpment), and an extension into unworked areas (West Whareatea). Coal will be transported to Stockton via the UWHR.
- **UWHR:** Road connecting Stockton with MFS and the ESE operations. The UWHR is a combination of upgrades to existing roads and the development of a new section through the Waimangaroa Valley. This will be used for transport of coal from the MFS and ESE sub-areas to Stockton.

Each Project sub-area includes a “buffer area”, which is included within the proposed land use consent area. The buffer area encircles the planned disturbance footprints to provide some operational flexibility.

The existing and proposed disturbance areas for the Stockton, ESE, MFS, and UWHR Project sub-areas are detailed in Table 2.

Table 2: BPCP sub-areas (ha)

AREA	STO #	UWHR	MFS	ESE
Total consenting footprint	1814	89	216	540
Existing Disturbance (includes up to 31 March 2027)	1319	15	6	40
Proposed Disturbance Areas	29	37	170	442
Buffer Areas *	466	37	40	59

** While Bathurst does not intend to disturb the buffer areas, consent is being sought to do so for contingencies or where further detailed designs are yet to be completed.*

Data updated 13 July 2026.

Stockton. Provided for comparative reference purposes.

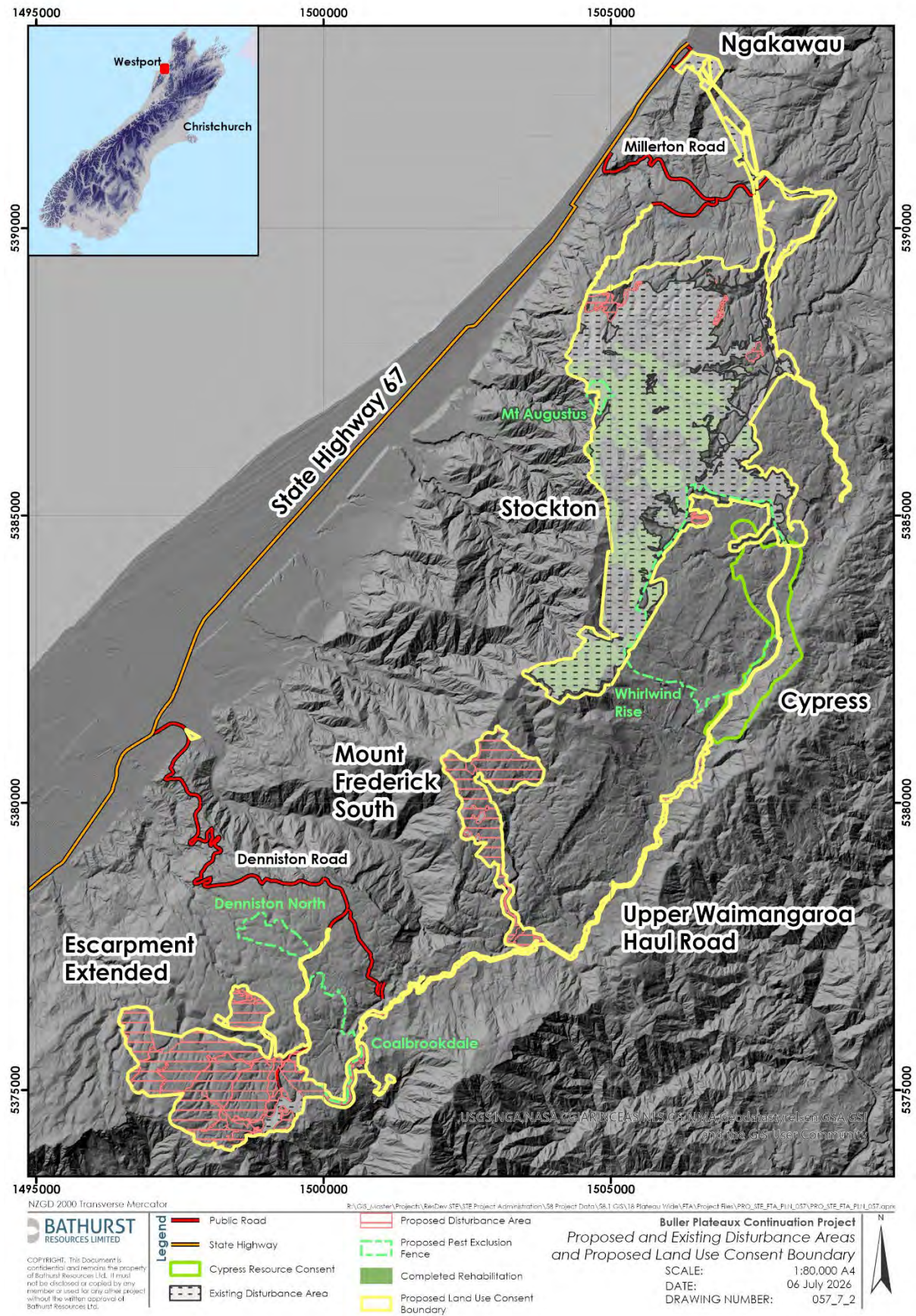


Figure 2: Location map for the BPCP sub-areas.

1.4.2.1 Stockton Sub-area

BRL propose to mine additional areas in the north of the Stockton Mine, continue using the existing infrastructure and facilities, develop new water management infrastructure in the north of the Stockton Mine, carry out further quarrying activities in the A Drive Borrow Pit to provide aggregate for the construction of haul roads including the proposed UWHR, and develop three additional Coal Fines Storage Facilities.

All coal mined in the ESE and MFS sub-areas will be transported to Stockton via the UWHR for processing, blending or washing as required at the Stockton coal handling and processing plant (CHPP) or clean coal handling facilities, and then transported via the existing aerial ropeway to the Ngakawau Rail Loadout.

1.4.2.2 Escarpment Extended Sub-area

Coal will be mined by conventional truck and shovel operation. Coal won from the ESE mine will be stockpiled at the ESE Coal Storage Pad and will then be transported to Stockton via the UWHR.

Ancillary infrastructure will be in place to support the mine, such as a water treatment plant (WTP), workshop, office, warehouse, tyre handling facility, coal haulage infrastructure area, bulk explosives plant and magazine, and fuel storage facilities.

Access to this area is currently provided via the existing public road network on the Denniston Road, but it will be connected to the Stockton Project sub-area by the proposed UWHR.

1.4.2.3 Mount Frederick South Sub-area

MFS will be mined in two pits: West Pit and East Pit (as shown in Figure 2). MFS is considered a direct replacement coal resource for the current Millerton mining area at Stockton. Coal within this targeted resource is a key component of the future export market blend requirements following the forecasted depletion of the Stockton coal resources. This area will be accessed off the proposed UWHR, with a haul road being constructed off the UWHR to reach up into the MFS mine area.

MFS will also be mined by conventional truck and shovel operation, where coal will be stockpiled at the MFS coal stockpile area (coal transfer pad), and transported to Stockton via the UWHR.

MFS will be supported by Stockton and ESE for infrastructure and facilities, where workshops, vehicle washes, explosive magazines, tyre facilities and coal processing will be located at Stockton or ESE. The mine will be limited to infrastructure and facilities such as offices, crib rooms, a coal stockpile area and water treatment plant.

1.4.2.4 Upper Waimangaroa Haul Road Sub-area

The haul road will link the ESE and MFS sub-areas with Stockton and Cypress. The UWHR is considered to be an essential link between the various mine areas to prevent the need for heavy machinery and trucks to utilise the public road network and make coal cartage economically viable.

The haul road alignment from Denniston to Cypress is 11.5 km long and 8.6 m wide. Where possible, the selected alignment leverages existing access roads and previously cleared areas to minimise the disturbance footprint.

1.5 Climate

The Denniston Plateau, located on the West Coast of New Zealand's South Island, experiences a temperate maritime climate characterised by high annual average rainfall, cool temperatures, and frequent cloud cover. Annual precipitation often exceeds 5,000 mm, due to prevailing westerly winds that bring moisture-laden air from the Tasman Sea. Temperatures on the plateau are moderate, with colder and damp winters and mild summers. The combination of high rainfall, geology, and moderated temperatures creates the unique ecological and hydrological characteristics of the Denniston Plateau.

Rainfall and potential evaporation (PE) representative of the Lake Brazil Meteorological Station are summarised on a monthly basis in Figure 3 from the period 25 January 2013 through 31 December 2023 (~11 years). PE was calculated based on the Penman method (Penman, 1948) using daily data from Lake Brazil Meteorological Station and estimates of solar radiation based on the position of the projects on the surface of the earth. An energy deficit¹ is apparent for all months, with PE calculated as approximately 15% of mean annual rainfall (5,414 mm/yr for the 11-year period). The median rainfall intensity was relatively high at ~1 mm/hr ($\sim 3 \times 10^{-7}$ m/sec), with 90% of the rainfall amount occurring at intensities greater than 1 mm/hr. The numerical simulation models in this assessment used a daily time step.

The lowest monthly rainfall over the 11-year dataset was ~100 mm (December 2021) while the highest was 1390 mm (January 2022). Monthly PE only exceeded monthly rainfall on two occasions out of 132 months on record, or ~1.5% (January 2013 and December 2021).

Lake Brazil climate data is representative of the ESE sub-area. For the MFS sub-area, PE will likely be similar, but rainfall is expected to be higher given the higher elevation of the MFS sub-area compared to Lake Brazil and is estimated to be 10% to 15% higher on average based on a rainfall-elevation relationship developed by Chater (2024).

Climate change for the West Coast region is anticipated to increase annual rainfall by between 4% to 8% by 2101–10 for Representative Concentration Pathways (RCP) 2.6 and RCP 8.5, respectively (MfE, 2018). Mean annual daily temperature changes ranged between 0.7 °C and 3.7 °C, which translate to an increase in PE by 2% to 10% (similar magnitude to rainfall increases).

¹ The term energy deficit used here refers to the difference between rainfall and potential evaporation. In other words, rainfall is higher than evaporation on an annual and monthly basis.

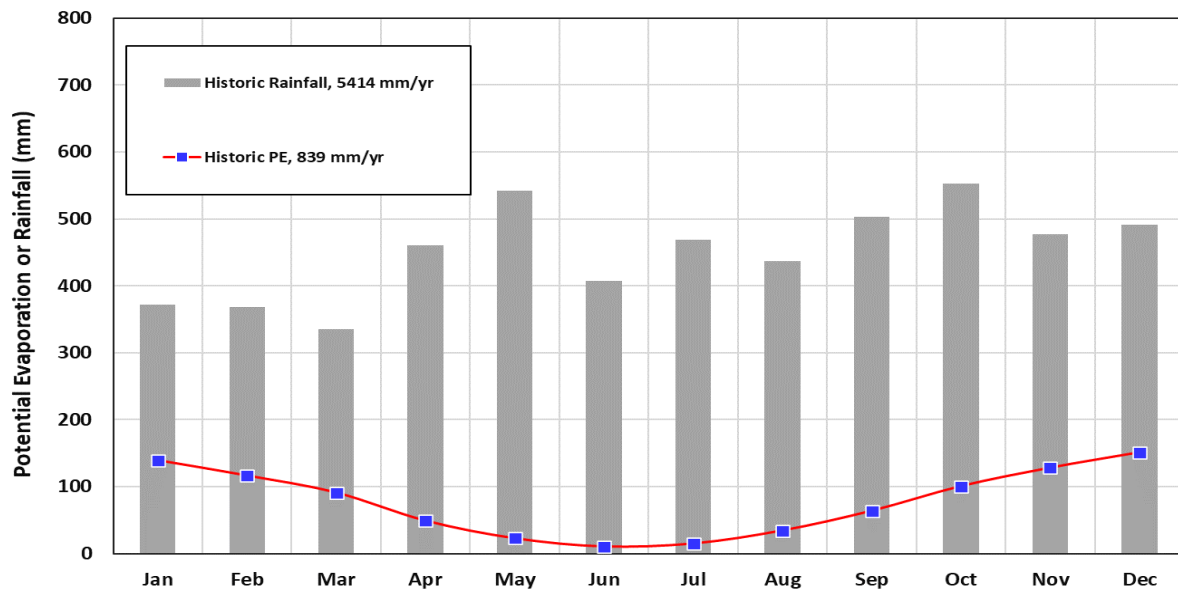


Figure 3: Lake Brazil monthly rainfall and PE.

Note: PE represents potential evaporation.

1.6 Project Site and Schedule Overview

Indicative BPCP timelines are reflected in Figure 4. There are four distinct project phases that are defined by the way mine-impacted waters (MIW) elevated in TSS and AMD are managed:

- **Construction Phase:** defined by the commencement of earthworks on site up until the permanent active WTPs and associated ponds are established. This will require routing of water and minor water management / treatment using a small portable water treatment plant(s) to neutralise acidity using either $\text{Ca}(\text{OH})_2$ (hydrated lime/calcium hydroxide²) or NaOH (caustic); and the addition of flocculants as required to treat TSS.
- **Operational Phase:** Water Management and active water treatment using CaO (burnt lime/calcium oxide), flocculants, and metal-chelating agents with AMD sludge being separated from treated discharge water by lamella clarifiers and mechanical sludge dewatering using pressure filtration (plate and frame filters (Process Flow, 2026)) with AMD sludge disposal to ELF. Some passive treatment commences for ELF that are completed.
- **Active Closure Phase:** Active water treatment continues with a gradual transition to passive treatment of ELF basal seepage. AMD sludge disposal will either be onsite at an appropriate location, disposal at Stockton, or by other approved methods that may be developed over the Operational Phase of the BPCP.
- **Post Closure Phase:** defined by the decommissioning of the WTPs with water treatment being completed by gravity fed passive treatment systems. The preferred current technology being an MSR. AMD sludge disposal will either be onsite at an appropriate location, disposal at Stockton, or by other approved methods that may be developed over the Operational Phase of the BPCP. Back-up options include disposal to approved offsite landfills.

² Noting studies are underway into the use of MgO as a neutralising agent.

The transition from active treatment to passive treatment is expected to occur over ~20 years, following closure and final rehabilitation of ELFs. The location of the MFS and ESE Project sub-areas, in the context of the BPCP, is presented in Figure 1.

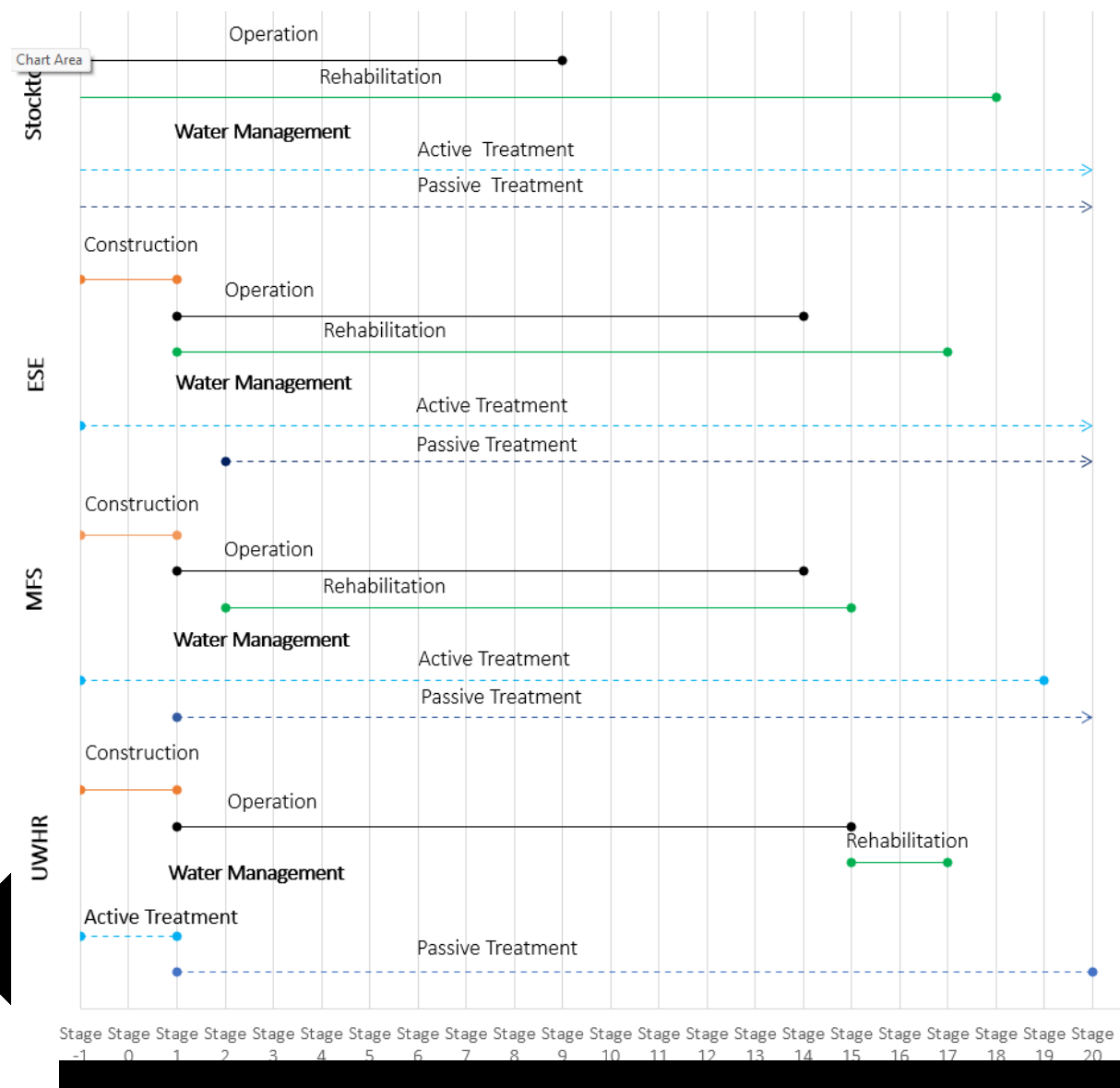


Figure 4: Environmental timelines (by stage and by indicative year).

1.7 Material Quantities

BRL propose to mine approximately 20 million tonnes of coking coal for the export market, utilising the existing workforce and infrastructure facilities at Stockton (Figure 5).

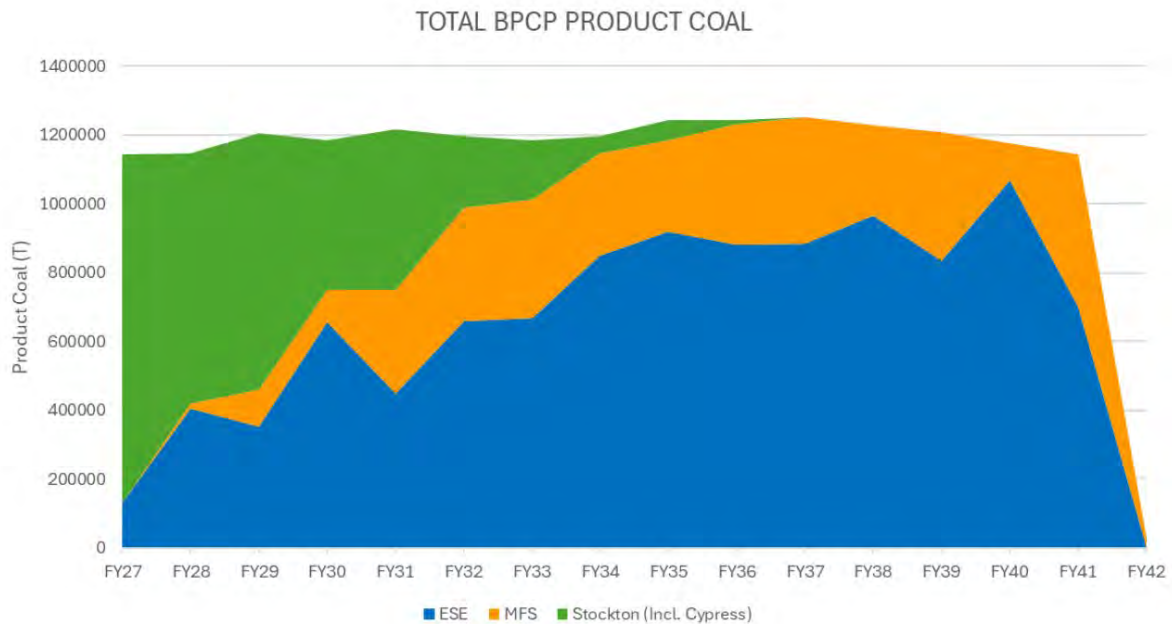


Figure 5: Proposed coal production

Source: BPCP FTAA Application AEE

1.8 Mine Schedule

Material schedules for the BPCP, with the specific sub-area AMD classification criteria, include non-acid forming (NAF), low risk for AMD (Low Risk), and high acid forming (HAF).

1.8.1

Table 3: ESE overburden quantities. Overburden materials are classified by AMD risk, with moderate quantities of HAF (16%), NAF (29%), and Low Risk (55%). The transport and placement of these disturbed materials have the potential to affect local waterways.

Table 3: ESE overburden quantities

INDICATOR YEAR	STAGE	NAF	LOW RISK	PAF	HAF	TOTAL OVERBURDEN ¹
2022	Stage -1	83,800	23,000	503,500	48,900	659,100
2022	Stage 0	260,800	407,100	2,412,800	1,267,500	4,348,100 ³
	Stage 1	820,400	679,500	3,888,400	2,041,700	7,429,800
	Stage 2	610,200	294,000	4,935,700	1,763,300	7,603,100
	Stage 3	1,591,700	694,800	5,957,300	1,560,500	9,804,100
	Stage 4	2,421,200	482,500	4,202,500	2,819,600	9,925,600
	Stage 5	3,779,500	378,400	2,958,200	2,822,500	9,938,500
	Stage 6	3,536,300	481,300	5,185,800	636,600	9,839,800
	Stage 7	3,123,300	1,798,600	3,105,600	1,886,100	9,913,400

INDICATIVE YEAR	PROJECT STAGE	NAF	LOW RISK	PAF	HAF	TOTAL OVERBURDEN ¹
	Stage 8	2,670,100	2,446,800	3,882,200	803,700	9,802,600
	Stage 9	3,862,300	1,615,500	3,250,200	1,195,200	9,923,000
	Stage 10	4,403,500	1,131,400	3,013,400	983,700	9,531,900
	Stage 11	3,126,900	514,100	4,659,400	1,044,300	9,344,600
	Stage 12	1,862,300	432,800	5,619,400	1,062,500	9,030,200
	Stage 13	3,260,800	540,200	-	962,600	8,803,800
	Stage 14	1,418,800	27,600	-	19,400	2,185,800
Grand Total ¹		36,828,900	11,990,000	18,990,000	10,000,000	128,185,500

All results in bcm (bank cubic meters)

1. Total overburden and grand totals are calculated using rounded figures. Therefore, the totals may not equal the sum of the rounded figures shown.
2. Green cells represent the Construction Phase.
3. The ESE active Operational Phase starts at Stage 1.

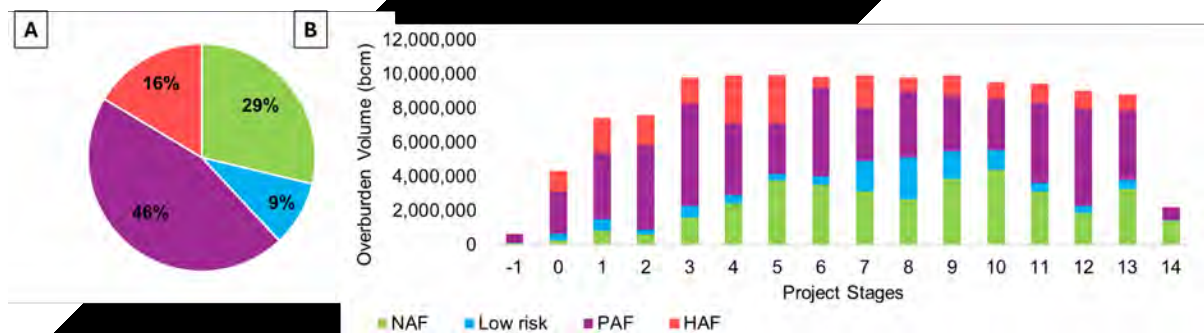


Figure 7: AMD classification by mine development stage

Figure 7: AMD classification by mine development stage (Stage -1 – Stage 14).

Figure 7: AMD classification by mine development stage and proportional composition by mine development stage.

Figure 7: AMD classification by mine development stage

The MFS is provided in (Table 4 and Figure 7). Overall, forecasted overburden consists of 46% low-risk material (NAF and Low Risk) and 18% high-risk material (PAF and HAF). The excavation, transport, and placement of these disturbed materials have the potential to generate AMD that could affect local waterways.

Table 4: MFS overburden quantities

INDICATIVE YEAR	PROJECT STAGE	NAF	LOW RISK	PAF	HAF	TOTAL OVERBURDEN ¹
	Stage -1	-	365,500	30,100	-	395,600
	Stage 0	599,300	210,800	414,100	169,900	1,394,100
	Stage 1	724,100	87,000	38,100	1,700	850,700
	Stage 2	529,300	80,200	17,000	300	626,600
	Stage 3	149,100	154,700	150,300	5,700	459,700

INDICATIVE YEAR	PROJECT STAGE	NAF	LOW RISK	PAF	HAF	TOTAL OVERBURDEN ¹
	Stage 4	413,400	107,800	39,800	500	561,400
	Stage 5	130,800	64,100	61,700	-	256,600
	Stage 6	1,023,500	55,600	25,200	5,700	1,109,800
	Stage 7	1,108,300	143,500	198,800	9,300	1,459,700
	Stage 8	771,900	239,200	45,000	1,500	1,512,400
	Stage 9	1,845,900	108,200	-	4,500	2,113,100
	Stage 10	980,000	216,100	-	900	1,422,200
	Stage 11	367,700	12,000	-	-	871,900
	Stage 12	1,809,000	-	-	-	2,333,600
	Stage 13	405,000	-	-	-	777,300
	Stage 14	85,000	-	-	1,500	65,400
Grand Total ¹					465,900	16,212,100

All results measured in bcm (bank cubic metres).

1. Total overburden and granitic material volumes may not equal the sum of the rounded figures shown.
2. Green cells represent NAF material.



Figure 1.8.2: Summary of overburden volumes and proportional composition by mine development stage

(A) Summary of overburden volume by classification (Stage -1 – Stage 14).

(B) Total overburden volumes and proportional composition by mine development stage.

1.8.3 UWHR Construction Materials

UWHR bulk fill requirements have been determined by BRL and are summarised in this section.

The bulk fill strategy for the construction of the UWHR relies exclusively on competent rock sources recovered from cut operations within Brunner Coal Measures (BCM) and imported granite from the A-Drive Borrow Pit and aggregate source from within the ESE Pit, which is classified as NAF.

No Kaiata Mudstone (KMS) or colluvial materials will be used in the construction of the UWHR road due to their poor geotechnical performance. The total excavated BCM volumes available for reuse have been quantified by road section (Table 5), along with the total volume of BCM unsuitable for placement, due to geochemical or lithological constraints. Unsuitable road fill material will be transported to either the ESE sub-area or Stockton for disposal within an ELF.

Table 5: UWHR material balances (8.6 m pavement width)

ROAD SEC	CATCHMENT	BCM DESIGN CUT TO FILL	UNSUITABLE FOR CONSTRUCTION*			
			ESE PAF ELF	ESE NAF ELF	PAF - STOCKTON	NAF - STOCKTON
		(m ³)	(m ³)	(m ³)	(m ³)	(m ³)
E2C	Burnett's	14,049	-	-	-	-
C2B	Burnett's	26,455	-	-	-	-
B2B	Burnett's	3,528	-	-	-	-
B2B	Gomorra Ck	7,928	3,374	-	-	-
B2B	Upper Waimangaroa	-	322	932	-	-
B2F	Upper Waimangaroa	24,368	-	7,358	-	-
F2C	Upper Waimangaroa	-	-	-	3,266	4,894
Total	-	76,327	3,696	8,290	3,266	4,894

*Fill North of ford and south of Cypress Mine, A mixture of colluvium and basement, which may include Kaiata Mudstone (NAF or PAF) – percentage uncertain. BCM = Brunner Coal Measures, ESE = Escarpment Extended

1.9 BPCP General Effects on Water Quality

The key issues relating to water quality for the BPCP that need to be managed are:

- Elevated TSS.
- AMD which is typically low pH and elevated acidity, sulfate (SO₄), and certain potential constituents of concern (PCOC) such as aluminium (Al), iron (Fe), and lesser amounts of trace metals that include cadmium (Cd), cobalt (Co), copper (Cu), manganese (Mn), nickel (Ni), and zinc (Zn).

1.10 TSS Management Overview

To mitigate the risks associated with TSS, BRL has developed the following controls to manage potential effects:

- Determine the closure objectives for the mine.
- Understand the source hazards.
- Prevent, control, and treat TSS.
- Complete an assessment of the potential effects.
- Monitor performance.

The following section describes these management steps in further detail.

2 POTENTIAL EFFECTS

TSS is a term used to quantify the amount of total suspended solids in water. TSS, in terms of mining related runoff, is typically generated by construction activities, overburden removal, mining, and overburden disposal. During these activities, when areas are stripped of vegetation or any current stabilisation methods are removed, soil and rock have the potential to be eroded and for sediment to be mobilised and be transported via surface water runoff.

Suspended solids can also be generated by the treatment of AMD impacted waters that generate iron (Fe) and aluminium (Al) hydroxide precipitates (i.e., flocs). Such flocs can also contribute to the measured TSS and have similar effects to TSS generated from sediment.

2.1 TSS Sources

Sources of TSS, as noted above, will originate from the following activities:

- Soil/vegetation stripping: Part of overburden removal process and construction activities which removes the stabilised vegetated surface, exposing underlying soils to erosion.
- Overburden removal: Part of the mining and construction process which involves fragmentation (often via blasting), and excavation of materials above the coal seam/final construction surface. As part of this activity, surfaces are left exposed allowing for erosion to occur.
- Disposal of overburden: Part of the mining and construction process, which involves disposal of overburden onto ELF's or using suitable fill material for construction of roads and ancillary areas, some of these being engineered fill areas (EFAs). During these activities there is a period where surfaces are left exposed to erosion.
- Partially rehabilitated surfaces: Occurs after mining and construction has been completed within an area and surfaces are rehabilitated with soil and are planted/revegetated. These areas continue to be susceptible to erosion until surfaces are suitably stabilised.
- Neutralisation of AMD impacted waters that generate Al- and Fe- hydroxide precipitates.

2.2 Potential Effects

Sediment (i.e., TSS) has the potential to be mobilised from the BPCP mining areas and be transported into downstream waterways through poor erosion and sediment management practices. This is primarily due to erosion of unstabilised surfaces through rainfall and surface water flows. Should there be inadequate sedimentation controls to treat this water, the suspended solids are then likely to enter natural waterways.

These suspended solids may negatively impact the downstream waterways by:

- Abrasion of surfaces and benthic communities.
- Increased turbidity, contributing to reduced light penetration and affecting photosynthesis of aquatic plants and behavioural (and potentially ecotoxic) impacts on aquatic fauna.
- Sedimentation of particles, resulting in smothering and damage to vegetation and aquatic habitats.

- Contaminants being introduced through transportation as sediment (e.g., AMD generating materials).
- Reduced visual clarity, resulting in reduced amenity downstream.

Ultimately, ecology within the waterways will be at risk of being negatively impacted by an increase in TSS, and these effects may not be isolated to the area of the source.

Management processes and engineering controls can reduce the potential for erosion to occur and its subsequent mobilisation. Often additional passive treatment is required, which includes sedimentation (i.e., settlement and sediment capture), and active treatment systems. Active treatment of MIW using a WTP is proposed for MFS and ESE during the Operational Phase and the Active Treatment Phase, where TSS not captured by pits sumps is treated. In the closure phases (Active and Post closure phases), rehabilitation and sedimentation systems will be used to manage sediment generation.

Further details on management methods are provided in the AMD Water Management Plan (BRL, 2026b), Water Infrastructure Design (BRL, 2026c), and Erosion and Sediment Control Plan for Land Disturbance Activities (BRL, 2026e).

2.3 Water Quality Objectives

This section discusses water quality monitoring locations and water quality objectives.

2.3.1 Water Quality Monitoring Locations

Three types of monitoring locations have been proposed as shown in Table 6.

Table 6: Water quality monitoring site explanation

MONITORING TYPE	EXPLANATION
Performance	to ensure compliance (and betterment) water quality is on track and will be achieved and provide data for adaptive management purposes.
Compliance	to ensure the Project is achieving its approved water quality objectives.
Reference	to provide reference data to understand climatic variables (e.g., El Niño Southern Oscillation) within unimpacted local catchments.

2.3.2 Water Quality Monitoring Objectives

Water quality guidelines for turbidity have been defined by Hickey (2026) for the MFS, ESE, and the UWHR (noting a relationship between TSS and turbidity used for WLBM is described in Section 6.1 of this report). The site-specific guidelines include:

- Acute guidelines – addressing short-term, high turbidity, events.
- Chronic guidelines – addressing long term water quality, such as WTP discharges.

These guidelines are described in Table 7.

Table 7: Summary of site-specific turbidity guideline values.

CLASSIFICATION / NOMINAL PROTECTION LEVEL	SHORT-TERM (ACUTE) TURBIDITY (NTU) MAXIMUM/LIMIT, EXPOSURE PERIOD	LONG-TERM (CHRONIC) TURBIDITY (NTU) MEDIAN/95TH PERCENTILE/EXPOSURE REPORTING PERIOD
Ecological – continuous	550 max / 100, 7-d rolling median	+5 NTU median above background / +20 NTU 95th percentile / annual
Ecological – discrete	550 max	As above
Aesthetic	n/a	+50% change from background for median; >1.6 m median clarity (bathing)/annual
Performance	n/a	25 NTU 15-sample rolling median ^{1, 2}

Source: Hickey (2026).

1. Site specific turbidity guidelines apply to site MM1 as compliance criteria (see Figure 19).
2. As noted by Hickey (2026): “Proposed limit for “Performance” assumed to be based on weekly or monthly discrete sampling (see Appendix E). Key sites could be assessed based on continuous or discrete monitoring. Trend assessments for Performance sites may be based on annual or 6-yearly monitoring data depending on significance of site”. In this regard, to understand performance at sites V37_F and V37_G a 30 rolling TSS median was chosen to provide context (see Figure 15 and Figure 17).

Table 8 describes the proposed frequency that will occur at the proposed ESE and MFS compliance monitoring sites. Compliance monitoring locations for the UWHR are covered by MFS sites (2W and 17W). Performance monitoring sites are proposed for ESE at sites V37_F and V37_G.

Table 8: Proposed compliance monitoring types and frequencies for turbidity.

MONITORING SITE NAME	MONITORING FREQUENCY
ESE	
MM1	Discrete
W07	Continuous/discrete
KEL	Continuous/discrete
V62	Continuous/discrete
MFS	
SW01	Continuous/discrete
SW03	Continuous/discrete
2W (Smokestack)	Continuous/discrete
17W	Continuous/discrete

Source: Hickey (2026)

3 SOURCE HAZARD CHARACTERISATION

This section assesses the TSS source hazards that could affect water quality at the MFS, ESE, and the UWHR.

3.1 Introduction

Understanding the potential effects of TSS due to the disturbance activities is a key step to determine what engineering controls are required for MFS, ESE, and the UWHR. Identification of potential effects are obtained from analogue site data and site water balance modelling.

Two reports have been completed to understand the TSS source hazards for the BPCP including:

- Previous TSS Studies (MWM, 2026a).
- MGIU³ TSS Review (MWM, 2026b).

These reports are discussed in Section 3.2 and Section 3.3 respectively.

3.2 Previous TSS Studies

The previous TSS studies memorandum by MWM (2026a), is provided as Appendix A.

3.2.1 Memorandum Objective

The objective of this memorandum was to review previous literature related to TSS studies associated with the ongoing Stockton mining activities and data provided for the consent application of the existing Escarpment Mine as part of developing TSS source terms for the WLBMs. These studies are listed in Table 9 and have been undertaken over a period of ~20 years.

Table 9: Previous TSS Studies

AUTHOR	DATE	REPORT
Cochrane	2006	Consultancy Project Preliminary Report 1: Erosion and Runoff Modelling of Waste Rock Capping Slopes at the Stockton Mine.
Cochrane et al.	2007	Soil Armouring, Sediment Yield, and Acid Rock Drainage from Steep Slopes Under High Intensity Rainfall in the West Coast of New Zealand.
Shadbolt and Weber	2007	Performance of Erosion Control Products at Stockton Opencast Mine.
Elder et al.	2011	Addressing the Environmental Effects of Mining on the Ngakawau River.
Bonisch	2011	Sediment Runoff from Stockton Mine Landforms.
URS	2011	Stockton Sedimentation Pond Sizing Method Review.
Golder	2012	Escarpment Mine Project: Mine Water Management Model, Escarpment Mining Area, Denniston Sector, Buller Coalfield, New Zealand.
Golder	2013	Sediment and Erosion Control Plan: Escarpment Mine Project.
WMG	2014	Escarpment Mine Project: Assessment of Revised Water Management Approach.

³ Mangatini (sump) Inlet Untreated

3.2.2 Key Findings

A significant amount of research on TSS has been undertaken over the last ~20 years at Stockton Mine and surrounding areas demonstrating the potential effects of TSS loads on waterways are well understood.

The data presented in the memorandum indicated that active mining, backfill areas, and unrehabilitated ELFs exhibit higher TSS levels than rehabilitated areas. Areas such as those stabilised with vegetation direct transfer, hydro-seeding, and straw mulching report lower levels of TSS.

The review confirmed the main source hazards for TSS and management opportunities. However, there was insufficient data available to determine source terms for modelling (pre-management and post-management) for the following reasons:

- Sampling and rainfall periods associated with each dataset did not align between different reports.
- The methods used to obtain TSS data are not consistent, and in some cases, it was unclear as to how figures have been established or derived.
- It was assumed that some data have been utilised in the other reports, therefore resulting in repetition of the same data.
- Some data have been taken without description of site conditions, as opposed to being drawn from ongoing field trials or long-term data collection programmes.

Therefore, use of empirical data for use as a source term for the water and load balance model is recommended. This is discussed in MWM (2026b). These monitoring results provide an integrated measure of catchment performance and are used to calibrate and validate source term estimates. This ensures that future water and load balance modelling is based on observed site conditions rather than solely on literature-derived values.

3.3 MGIU TSS Review

The MGIU TSS review memorandum by MWM (2026b), is provided as Appendix B. For context, MGIU refers to a water stream that is high in sediment called “Mangatini (sump) inlet untreated”. This water has high TSS and turbidity with a reliable monitoring database.

3.3.1 Memorandum Objectives

The objectives of the memorandum were to:

- Provide sump inflow TSS source terms for surface waters from disturbed areas (using Stockton Mine analogue data), which would be used to represent TSS of pit sump inflows and sump bypass flows in WLBM for MFS and ESE.
- Estimate sump sedimentation rates to allow sediment removal to be modelled through pit sumps and water treatment sumps and thus estimate TSS of sump spill water and inflows to the MFS and ESE WTP.

3.3.2 Key Findings

TSS data of site MGIU from 2011 to 2012 was identified as being the most suitable analogue site for establishing a source term for a large, disturbed active mining area. It was noted that the catchment had less vegetation during 2011-2012, and observed less upstream sedimentation, compared to later years. Hence this was selected as the most reasonable dataset to develop a source term for the WLBm.

The MGIU TSS dataset from 2011-2012 was characterised using a frequency distribution and then adjusted to form a daily average TSS distribution (for use in the WLBm).

The dataset was converted from instantaneous to daily average by applying a factor that was derived from the ratio of instantaneous- to 24-hour average- turbidity sensor data. The resulting daily average TSS was then aligned with a frequency distribution of Stockton Meteorological Station daily rainfall data to provide a look-up table for use in the WLBm (see Table 10). This simplified approach (in the absence of comparable daily TSS and rainfall data) assumes that high daily rainfall produces high TSS, while low daily rainfall produces low TSS, under all conditions.

Table 10: Resulting sump inflow TSS source term, using conversion results from instantaneous to daily average.

PERCENTILE	INSTANTANEOUS TSS (mg/L)	CONVERSION FACTOR	RESULTING DAILY AVERAGE TSS (mg/L)	DAILY RAINFALL (mm)
100	14,996	3.32	4,518	457.6
99	6,218	1.65	3,757	148.6
95	1,880	1.11	1,688	72.6
90	947	0.92	1,035	48.4
85	606	0.82	735	35.4
80	428	0.80	535	25.2
75	324	0.80	405	18.6
70	242	0.80	302	12.9
65	178	0.80	222	9.0
60	123	0.80	154	5.9
55	94	0.80	117	3.4
50	79	0.80	99	2.0
45	59	0.80	73	1.0
40	44	0.80	55	0.4
35	34	0.80	43	0.2
30	27	0.80	34	0.1
25	21	0.80	26	0.1
20	16	0.80	20	0.1
15	12	0.80	15	0.1
10	9	0.80	11	0.1
5	5	0.80	7	0.1
0	3	0.80	3	0

As MGIU is located downstream of small sedimentation sumps with unquantified TSS capture rates, it represents the result of partial sedimentation. It may be that bypass water and water reporting to pit

sumps resemble sources that have undergone partial upstream sedimentation, and therefore the use of MGIU data as a source term can be more easily justified.

Given MGIU is a combination of many upstream sources such as overburden, coal and soil, MGIU is most appropriate as a collective source term for TSS for pit sumps and bypass channel flows in the absence of individual source terms.

An estimation of pond sedimentation efficiency was completed from the observed change in TSS before and after installation of the Mangatini Quarry Sump (a large sedimentation structure directly upstream of MGIU, installed in 2013). It was found that there was a potential reduction of up to 79% of TSS, as presented in Table 11. This reduction figure would then reduce to no observed sediment removal during what has been assumed as low flow periods. This approach assumes that both TSS datasets observe an upward trend of TSS relative to flow, as described above where a high daily rainfall produces high TSS, while low daily rainfall produces low TSS, under all conditions

Table 11: TSS load change before and after installation of the Mangatini Quarry Sump.

	2011 AND 2012	NOV 2014 TO OCT 15	
PERCENTILE	INSTANT. TSS (mg/L)	INSTANT. TSS (mg/L)	DIFFERENCE IN SEDIMENT LOAD
100	14,996	3,727	75%
99	6,218	1,310	79%
95	1,880	453	76%
90	947	314	67%
85	606	206	66%
80	428	151	65%
75	324	112	65%
70	242	73	70%
65	178	63	65%
60	123	46	62%
55	94	33	65%
50	79	29	63%
45	59	25	57%
40	44	21	53%
35	34	15	56%
30	27	13	53%
25	21	10	54%
20	16	9	45%
15	12	8	39%
10	9	6	28%
5	5	6	-7%
0	3	4	-72%

These data have been used in the WLBM to develop source terms for:

- TSS of mine impacted areas, prior to management through a sedimentation process
- TSS after mine impacted waters passes through a sediment pond.

3.3.3 Recommendations

Source Terms

TSS source terms should be validated during the Construction Phase and during the first two years of the Operational Phase. These activities will benefit development of future iterations of WLBM as BPCP works progress and aid in validating the source terms presented in this memo.

Suggested TSS sampling locations, under a range of rainfall and runoff conditions, should include:

- Overburden placement areas (Kaiata Mudstone and Brunner Coal Measures).
- Coal pits.
- Coal handling and processing areas and coal stockpile areas.
- Overburden stripping areas (identifying the rock type).
- Soil stripping areas (making note of subsurface material).
- Soil placement areas.
- Partially rehabilitated areas.
- Fully rehabilitated areas.
- Haul roads.
- Hard stand areas.

This will be achieved by:

- Sensor placement within TSS impacted water channels, pre-sedimentation, for continuous measurement of TSS or turbidity.
- Manual/automatic sampling of TSS impacted water channels, pre-sedimentation, for formation of a dataset and calibration of available sensor data.

Sediment Retention Ponds

It will be beneficial to validate BPCP sediment retention pond efficiencies at the start of the Operational Phase of the BPCP to:

- Validate TSS removal rates and the predicted pond sedimentation rates.
- Validate TSS of surge pond spill waters and outflows to the WTP.

This can be achieved by:

- Sensors and/or manual/automatic sampling located at the inlet and outlet of various sumps/ponds.
- Development of a database of sediment removal efficiencies for various BPCP sumps/ ponds over the operational range of flow rates.

Management

During the Operations Phase, sediment control structures similar to those placed upstream of MGIU should be installed to achieve comparable TSS results at pit sump inlets (these will be designed as per BRL (2026c)).

Adaptive management is required using performance monitoring to ensure the same level of TSS removal is achieved as used in the WLBM. If TSS removal is not appropriate, then other management controls may be required (e.g., coagulant and flocculant dosing of TSS impacted waters).

4 PREVENTION, CONTROL AND TREATMENT OF TSS

This section reviews the management of waters elevated in TSS due to mining activities associated with the BPCP.

4.1 Prevention and Control

Management of TSS requires appropriate controls to prevent erosion and minimise the impact mobilised sediment may have on the environment. These controls include:

- Sediment and erosion control planning.
- Minimising the footprint of disturbance at any one time.
- Management of surface waters through diverting of clean water and appropriate design of stormwater infrastructure.
- Implementation of erosion control methodologies, ensuring rapid stabilisation of disturbed areas.
- Management of mining activities to reduce their ability to exacerbate high TSS.

Furthermore, adaptive management will be implemented to identify variance from expected outcomes through ongoing monitoring, ensuring action is taken where outcomes deviate from the expected outcomes.

Management documents have been developed for the BPCP (not discussed in this report) and include:

- ELF⁴ Management Plan (BRL, 2026a)
- AMD Water Management Plan (BRL, 2026b)
- Water Infrastructure Design (BRL, 2026c)
- Mine Closure Concept Strategy (BRL, 2026d).
- Erosion and Sediment Control Plan for Land Disturbance Activities (BRL, 2026e)
- Water Treatment Report: MFS and ESE (MWM, 2026c)

4.2 Treatment

TSS impacted waters may require passive and / or active treatment. Source control engineering options can reduce the quantity of TSS however treatment is also required at MFS, ESE, and UWHR due to the significant amounts of rainfall and water movement. Treatment can be split into passive and active treatment technologies.

4.2.1 *Passive Treatment – Sedimentation Ponds*

Passive sediment treatment systems will include sedimentation structures such as silt fences, check dams, soak pits, and, in most cases, sedimentation ponds. These systems rely on slowing down surface runoff flows for sedimentation to occur (i.e., dropping out sediment particles).

⁴ Engineered Landform

Typically, small disturbance catchments will be managed through use of silt fences, while larger areas will incorporate progressive sedimentation through use of check dams and a final large sedimentation pond prior to release of water into the natural catchment. In both cases, the techniques utilise time to settle out TSS, by reducing short circuiting and sizing the structures relative to upstream catchments. Further attributes to achieve best practices and maximum sediment removal involve decant structures, incorporating forebays, designing allowance for sediment accumulation, and following shape constraints. Where constituents of the TSS may be too fine for standard ponds, flocculants may be used in conjunction with the sedimentation ponds to improve water quality.

These systems, including maintenance of the structures, are described in the Water Infrastructure Design Plan (BRL, 2026c), the AMD Water Management Plan (BRL, 2026b) and Erosion and Sediment Control Plan for Land Disturbance Activities (BRL, 2026e).

4.2.2 Active Water Treatment - WTP

Active treatment, to be carried out within the ESE and MFS sub-areas, involves the application of a variety of chemicals to treat AMD and remove suspended solids, as well as mechanical methods such as lamella clarifiers to achieve the desired water quality. Due to the limited capacity of these treatment plants, water is typically stored within surge ponds where it is pumped to the WTP over an extended period of time relative to the capacity of the plant. This allows for maximum treatment to be achieved, provided, sufficient storage capacity is available in the surge pond.

Two new active WTPs are proposed for the BPCP within the ESE and MFS sub-areas:

- Figure 8 provides the ESE water treatment plant process schematic.
- Figure 9 provides the MFS water treatment plant process schematic.
- Figure 10 provides the ESE water treatment plant location.
- Figure 11 provides the MFS water treatment plant location.

These plants are designed to treat mine impacted water (AMD and TSS). Further details on the active WTPs proposed for the BPCP are provided in:

- Water Treatment Report: MFS and ESE (MWM, 2026c); and
- Process Flow (2026).

The WTPs include the following treatment processes:

- WTP Surge Ponds (the "Stockpile Surge Pond" at MFS and the Ex-Pit Seal Pit at ESE) – receiving water from the run-off, seepage areas, and from pumping from the pit sumps.
- Powdered CaO silos and mixing tanks to generate a neutralising slurry for MIW water from the surge ponds.
- Pontoon mounted pumps to transfer water from the surge ponds to the acidity neutralisation tank.
- pH controlled CaO slurry dosing of AMD in the acidity neutralisation tank.
- Flocculant and metal-chelating agent dosing to CaO neutralised water prior to transfer to the Lamella Clarifiers.

- Separation of suspended and precipitated solids in the Lamella Clarifier with partial sludge return to the Lamella Clarifier in-flow (i.e., High Density Sludge (HDS) loop).
- Lamella Clarifier sludge is thickened with flocculant and pumped to a pressure filter for dewatering to create a "filter cake". Dewatered filter cake is discharged to a bunker for loadout and trucking to disposal areas.
- Sulfuric acid (i.e., pH) trimming of the Lamella Clarifier thickener overflow (treated supernatant) where required to remove additional metals and meet pH compliance limits.
- Treated supernatant will report to a polishing pond after the pH correction before discharge to the receiving environment.
- Under high rainfall conditions, mine pit surge sumps and WTP surge ponds surge sump capacities are expected to exceed design flows, leading to untreated discharge ~5% of the time. This is discussed in more detail in the WLBM reports MWM (2026d,e).

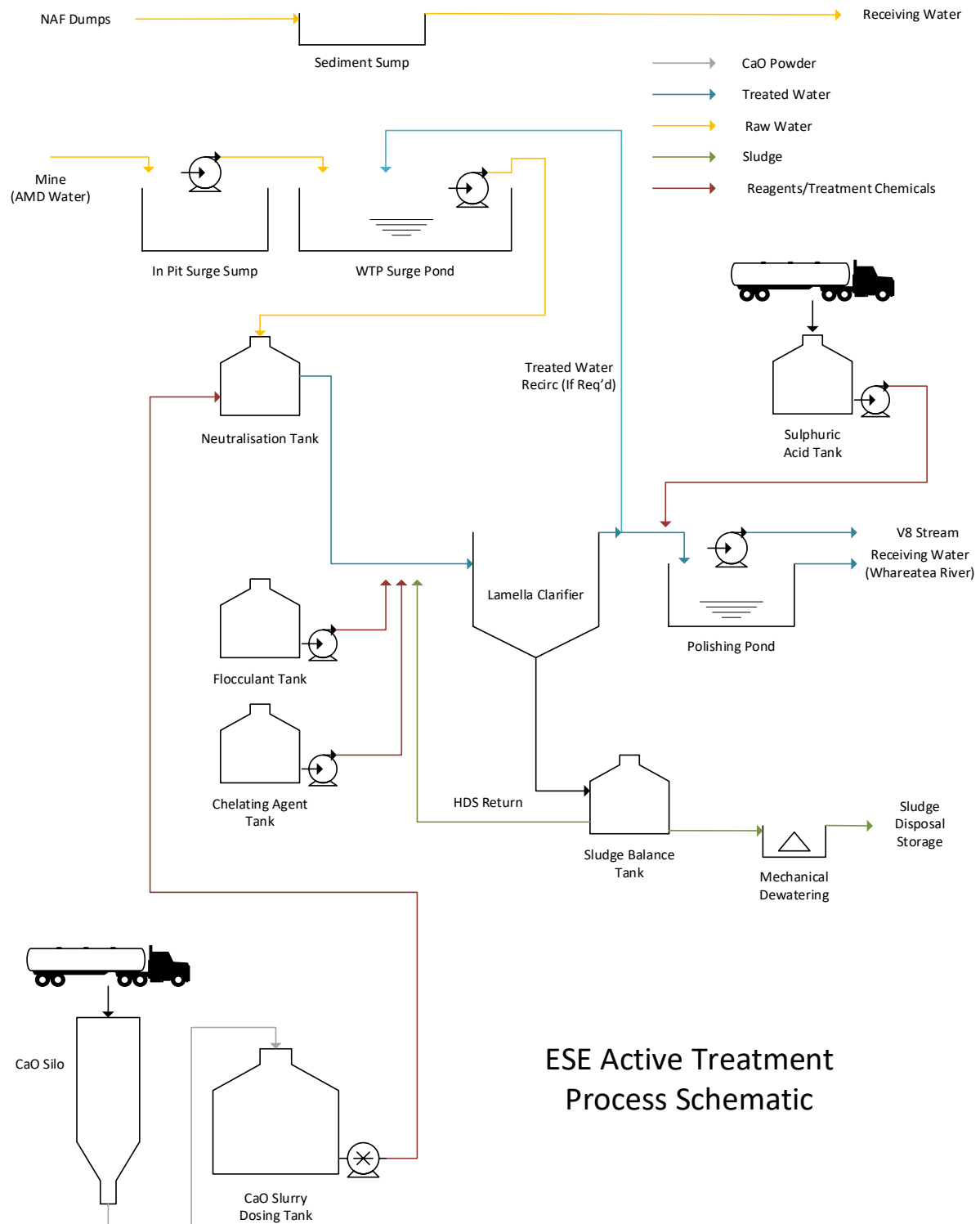
The WLBM for ESE and MFS have determined the following TSS loads will report to the WTP over the Project life (Table 12). TSS loads generated during the Construction Phase of the BPCP at MFS and ESE as shown by green cells in Table 12, are discussed in Section 5.

Table 12: TSS quantities (dry weight) reporting to the ESE and MFS WTPs

YEAR	ESE TSS (Dry Tonnes)	MFS TSS (Dry Tonnes)
2027	186	128
2028	1,226	452
2029	1,499	276
2030	1,662	333
2031	2,041	345
2032	1,825	405
2033	2,042	466
2034	2,197	524
2035	2,351	719
2036	2,419	727
2037	1,778	833
2038	1,949	866
2039	1,845	773
2040	1,878	743
2041	1,975	869
2042	1,688	821
2043	1,703	391
2044	1,176	29
2045	1,152	14
2046	99	14
2047	99	-
2048	99	-
2049	99	-

YEAR	ESE TSS (Dry Tonnes)	MFS TSS (Dry Tonnes)
2050	99	-
2051	99	-
2052	100	-
2053	100	-
2054	100	-
2055	100	-
2056	100	-
2057	100	-
Total	33,786	9,730

Green cells indicate the Construction Phase of the Project, prior to treatment via the WTP. This phase is not covered by the WLBM.



ESE Active Treatment Process Schematic

Figure 8: ESE water treatment plant process schematic

Source: Process Flow (2026).

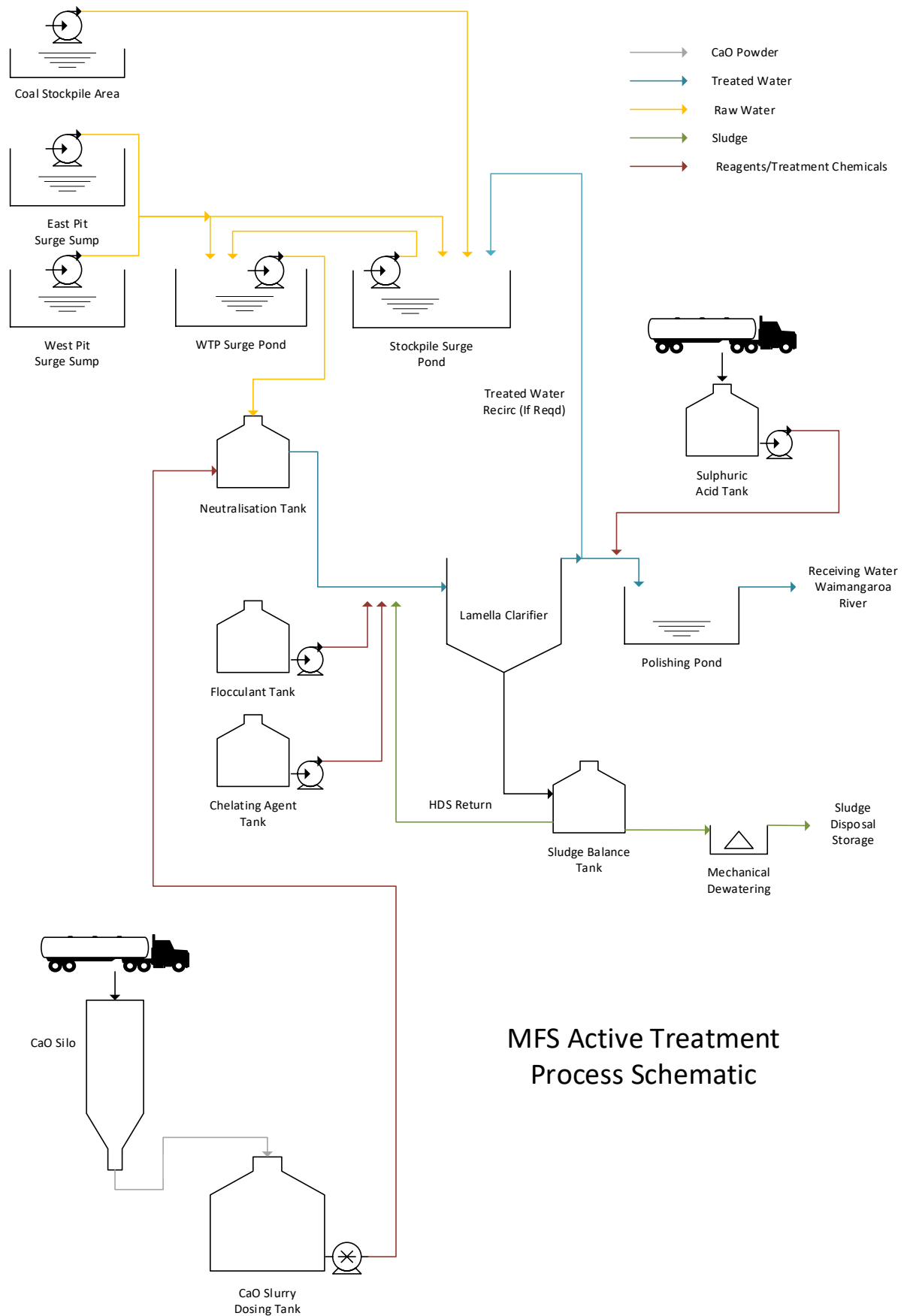


Figure 9: MFS water treatment plant process schematic.

Source: Process Flow (2026).

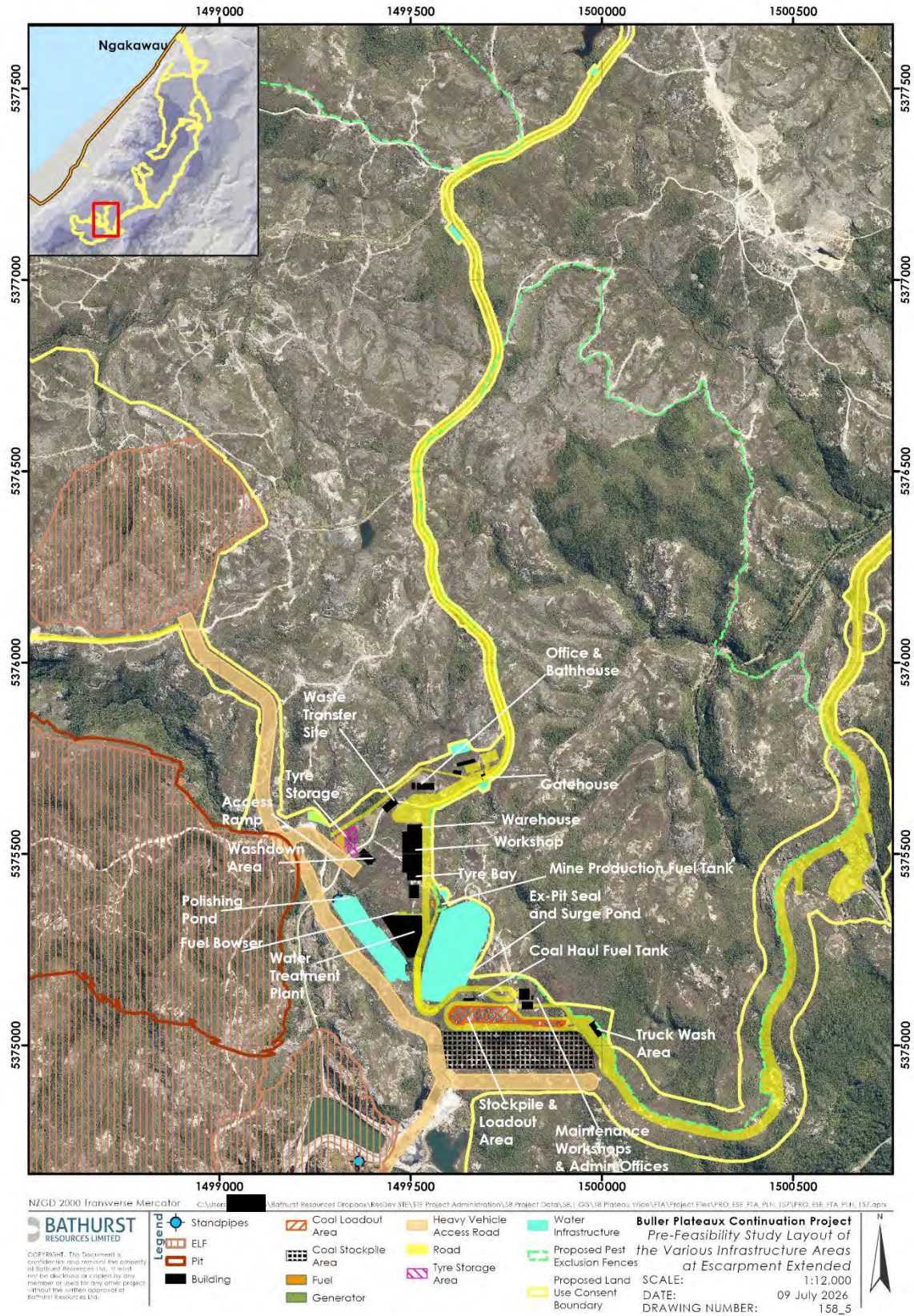


Figure 10: ESE sub-area water treatment plant location



5 CONSTRUCTION PHASE

5.1 Introduction

The information provided in this section of this report is obtained from:

- The Construction Phase Report (MWM, 2026h)
- Water Treatment Report: MFS and ESE (MWM, 2026c)
- AMD Sludge Management (MWM, 2026g)

5.2 Report Purpose

This report provides an assessment of effects and identifies management strategies to address the management of AMD and TSS associated with the Construction Phase of the BPCP that is two years duration and includes:

- Road Construction (UWHR and the MFS Access Road).
- Break-in activities at MFS and ESE.

The proposed management activities associated with the Construction Phase relate to the BPCP time-period when the proposed WTPs and associated WTP ponds have not been fully constructed at MFS and ESE (noting these will be under construction during this time).

The objectives of this report, based on a traditional Source-Pathway-Receptor (SPR) risk assessment process, are to:

- Identify the potential source hazards for elevated TSS and AMD within these areas.
- Identify potential receptors (i.e., waterways) that could be affected by TSS and AMD, given pathways exist from the source hazards to the receptor during the Construction Phase.
- Explain how related risks will be minimised and what mitigation methods will be utilised.
- Explain what performance monitoring will be undertaken.

This summary discusses TSS hazards and how those hazards will be managed for the Construction Phase of the BPCP. AMD hazards associated with the Construction Phase are covered in the AMD Overview Report (MWM, 2026f).

5.3 Source Hazards

Sediment and elevated TSS in waterways are expected to be generated during the Construction Phase due to ground disturbance. TSS management is required for disturbed surfaces, namely:

- Cut surfaces.
- Rock fill surfaces.
- Roadway surfaces.
- Infrastructure areas (e.g., WTP, coal storage pads, etc).
- Partially rehabilitated surfaces.

- ELFs and soil stockpiles.
- Water management infrastructure.

Construction of the UWHR, the MFS Access Road, and infrastructure pads within the MFS and ESE sub-areas during the Construction Phase of the BPCP is expected to generate sediment during construction of these mine domains. The Construction Phase is expected to take two years and will consist of cutting into in-situ ground and backfilling low points with blasted rock to generate a final road surface and/or infrastructure area. As vegetation is removed the exposed surface will be prone to erosion.

5.4 Management

The management of TSS associated with the construction of these facilities during the Construction Phase is discussed in:

- AMD Water Management Plan (BRL, 2026b)
- Water Infrastructure Design Plan (BRL, 2026c)
- Erosion and Sediment Control Plan for Land Disturbance Activities (BRL, 2026e)

5.4.1 Construction Phase Water Management

Treatment of MIW is expected during the Construction Phase, prior to the completion of the ESE and MFS WTPs and associated WTP ponds. The following is noted:

- TSS will be the dominant contributor to MIW during the Construction Phase due to lesser effects from ELF AMD impacted seepage at the start of the Project. This will be managed by passive treatment processes (e.g., sediment ponds, check dams, floc blocks (further details in BRL, 2026e)) or, when required, small portable treatment systems will be used (see 5.4.2).
- The expected volume of AMD sludge at ESE is ~10,000 m³ in the first year of construction and for MFS it is 20,000 m³ over the two years (3 wt% solids; MWM, (2026c)).
- ESE: The current Escarpment Mine Pit 3 Pit Lake and other existing water treatment infrastructure (e.g., Lake Brazil) will be used to treat and settle TSS and AMD sludge (i.e., the existing water treatment system that is in place, except for the water treatment plant). Treated waters will be discharged to Cascade Creek Trib (V8). Backfill of mine rock will eventually bury this AMD sludge. Pit 3 has a capacity of ~200,000 m³. The active WTP is expected to be commissioned early in the second year of construction, which will be fed from the Pit 3 Pit Lake until construction of the associated ESE WTP ponds are completed.
- MFS: Temporary water treatment sumps of 10,000 m³ will be built near the MFS Coal Storage Pad and the West Pit Sump for management of construction water. The Coal Storage Pad sump will be buried by rock at the end of the MFS Construction Phase once the MFS WTP is operational, while the sump adjacent to the West Pit Sump will continue to be utilised for management of water within the area. The temporary AMD treatment sumps will be operational until the MFS active WTP is constructed and will manage treatment of any AMD and TSS during the Construction Phase. The active WTP is expected to be commissioned in the second year of construction and will be fed from the temporary treatment sumps until the West Pit Sump

and operation sumps are complete. Treated waters will be discharged to the Waimangaroa River above 2W (Smokestack) and Deep Creek above SW03.

5.4.2 Water Treatment

The primary objective of TSS management during the Construction Phase is to prevent and minimise the discharge of TSS impacted water to receiving environments. This will be achieved through a combination of passive erosion and sediment control processes (e.g., BRL, 2026e), and active TSS treatment systems such as the modular Siltbuster treatment system⁵ when required (e.g., a lamella clarifier).

The Siltbuster system is a mobile water treatment system designed to remove fine TSS from impacted water systems. They are well proven in the mining and civil construction industries for managing TSS impacted water systems and dewatering discharges (Figure 12).

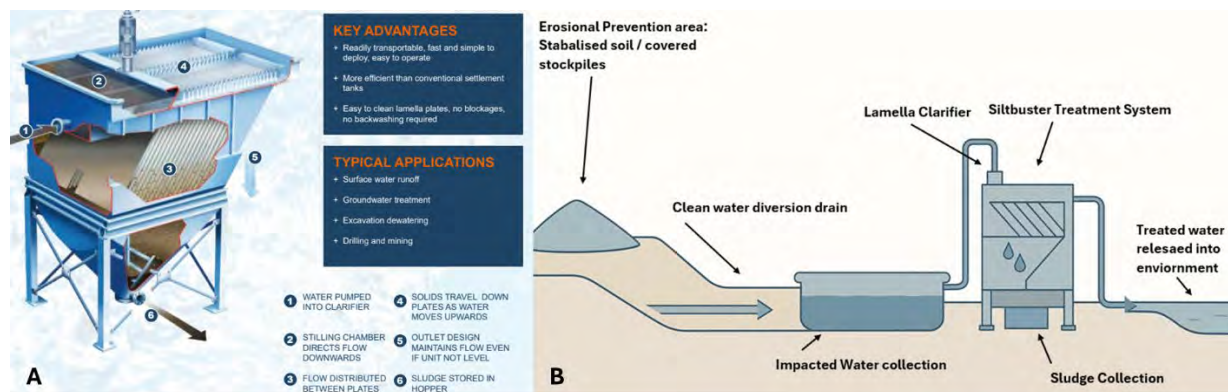


Figure 12: Siltbuster portable water treatment plant.

(A) Typical Lamella Clarifier; (B) Typical schematic of Construction Phase water treatment.

Source: <https://www.siltbuster.co.uk/wp-content/uploads/2020/10/Solutions-for-Suspended-Solids-Removal-1.pdf>

5.5 Monitoring

The following monitoring programme is proposed.

5.5.1 UWHR and MFS Access Road

The construction of the roads could affect local streams with TSS. Compliance monitoring (Figure 13) of any effects on water quality during the Construction Phase will be undertaken at:

- Deep Creek at SW01 and SW03 relating to the construction of the MFS Access Road and initial access to the MFS mining area.
- Waimangaroa River at 2W (Smokestack) relating to the construction of the UWHR.
- Waimangaroa River at 17W to assess effects of MFS and the UWHR.

5.5.2 ESE and MFS Infrastructure Areas

Infrastructure will be constructed within the ESE sub-area, in the vicinity of the existing Escarpment Mine, and within the MFS sub-area, at the base of the MFS Access Road (adjacent to the Waimangaroa

⁵ <https://enviroz.co.nz/solutions/business/siltbuster-hire>

River) and at the south of the West Pit. This infrastructure includes, for instance, buildings, the ex-pit seal (relating to ESE), and the construction of the WTP, surge ponds, polishing ponds, and other water management infrastructure. Mine development will occur at ESE within the second year of construction (e.g., the box cut), while at MFS the West Pit Sump will be under development at this time.

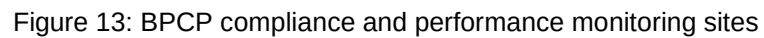
Compliance monitoring (Figure 13) of any effects on water quality during the Construction Phase will be undertaken at:

- Deep Creek at SW01 and SW03, relating to the construction of the MFS Access Road, development of the West Pit Sump, and associated ex-pit ELFs, and the infrastructure pad.
- Waimangaroa River at 2W (Smokestack) relating to the construction of the MFS Coal Storage Pad and WTP infrastructure area.
- Waimangaroa River at 17W to assess all effects of MFS and the UWHR.
- Cascade Creek Trib (V8) at MM1 relating to the proposed ESE mining area during construction.
- Rapid Stream at WO7 relating the proposed ESE mining area during construction.
- Whareatea River at KEL relating the proposed ESE mining area during construction.

5.5.3 Other Performance Monitoring Requirements

Additional performance monitoring (Figure 13) is proposed to ensure any effects on receiving waterways are minimal. This will include:

- Monitoring of sedimentation ponds to ensure TSS is being managed and is in alignment with expectations (BRL, 2026e).
- Monitoring of any portable water treatment activities for TSS to ensure discharge water is suitable for release.
- Monitoring at additional locations along the UWHR route (performance monitoring sites) to inform adaptive management following any localised impacts.
- Monitoring at V37_F and V37_G (within the V37 Stream that drains to the Cascade Creek) relating to the proposed ESE mining area during construction.



5.6 Summary

The following recommendations are provided:

- Develop a suitable water management system for MFS and ESE infrastructure areas to ensure TSS effects are managed.
- Undertake an adaptive management approach for the Construction Phase and ensure performance monitoring is in place.

6 OPERATIONAL AND CLOSURE PHASES

This section discusses the effects of TSS during the Operational and Closure Phases of the BPCP for ESE and MFS sub-areas and describes the sediment management controls that will be in place for the UWHR.

6.1 Introduction

Predicting expected water quality associated with the mining activities is important for understanding potential impacts on the wider receiving environment. This also supports the identification of additional treatment or management controls that may be required to minimise impacts. The modelled data (inputs and outputs) can then be compared to actual data, from the operational phase, to validate the model and identify/understand model improvements to support adaptive management.

MWM (2026d,e) has undertaken WLBMs studies for ESE and MFS to understand the potential concentrations of TSS that may be observed during the operational and closure phases of the BPCP for these sub-areas, whilst Hickey (2026) has identified the required water quality levels (provided as turbidity (NTU) limits), which are summarised below.

The WLBMs utilise TSS as it is a mass-based measurement and can be balanced within the model when mixed with other waters, whereas turbidity cannot. Therefore, a relationship (Equation 1) was used (based on observed water quality data at S16, Stockton Mine (MWM, 2026b)) to convert modelled TSS to NTU to assess the modelled outputs against the proposed protection levels:

$$\text{Equation 1: } NTU = 0.79 \times TSS \text{ (mg/L)}$$

6.2 ESE Water Load Balance Model Report

The ESE WLBMs was developed to forecast changes to flows within waterways, support design of water management infrastructure, and forecast downstream water quality as a result of mining at ESE.

Further details are described below and provided in MWM (2026d).

6.2.1 Key Findings

MWM (2026d) presents a site wide water and load balance model to assess water flows and dissolved solute loads from key mine domains associated with the proposed BPCP. The model for ESE simulates the second year of the Construction Phase, the Operational (mining) Phase, the Active Closure Phase, and the Post Closure Phase (these phases are described in Section 1.6). Two treatment phases are then defined for management of MIW (these define the reporting periods described in the results below):

- Active Treatment Phase where active treatment via the WTP occurs until such time that all MIW may effectively be treated via MSRs. This phase covers the Operational and Active Closure phases.
- Post-Closure Phase, where MIW is passively treated through use of MSRs.

Performance and compliance monitoring locations have been proposed for ESE (see Figure 13). Modelling has then been undertaken to understand potential effects at these locations, and these results have then been assessed against the proposed water quality protection levels.

Performance monitoring sites include:

- V37_F (drain into V37 Creek)
- V37_G (drain into V37 Creek)

Compliance monitoring sites include:

- W07 (Rapid Stream)
- KEL (Whareatea River)
- V62 (V62 Stream)
- MM1 (Cascade Creek Trib (V8))

V37_F, V37_G and MM1 discharge into Cascade Creek (south of the mining operations), W07 is located downstream of the Sullivan NAF ELF (north of the mining operations), KEL is located downstream of the ESE WTP effluent and the Whareatea mining area, and V62 is located downstream of the Conglomerate mining area.

The key findings for the 'base case scenario' water quality model are described in the following sections. TSS exceedance curves present the model results relative to how likely these are to be exceeded (with relation to treatment phase); observations describe all phases unless noted otherwise. TSS compliance plots illustrate the model results as a time series and overlay the proposed compliance limits; here, modelled TSS results were made relevant by converting values to turbidity using Equation 1.

6.2.1.1 Site V37_F

The exceedance probability plot for modelled TSS at V37_F is shown in Figure 14. It is to be noted that:

- Maximum concentrations at V37_F reach approximately 100 mg/L during the active treatment phase (2028-2057).
- The majority of time (more than 90%), concentrations remain below 10 mg/L.
- The median concentration is 2 - 3 mg/L.

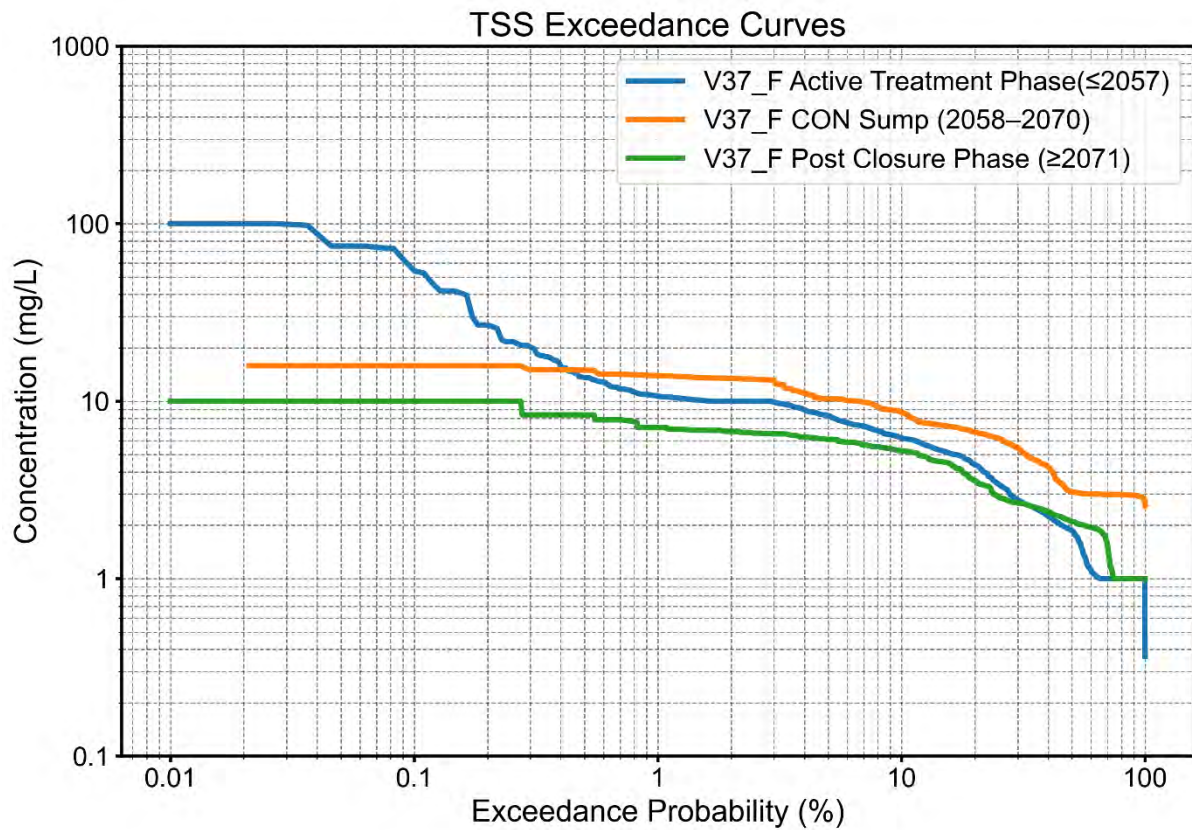


Figure 14: Exceedance probability of daily TSS results at V37_F

Source: MWM (2026d)

A 30-day rolling median plot is shown in Figure 15. No protection levels are proposed for V37_F.

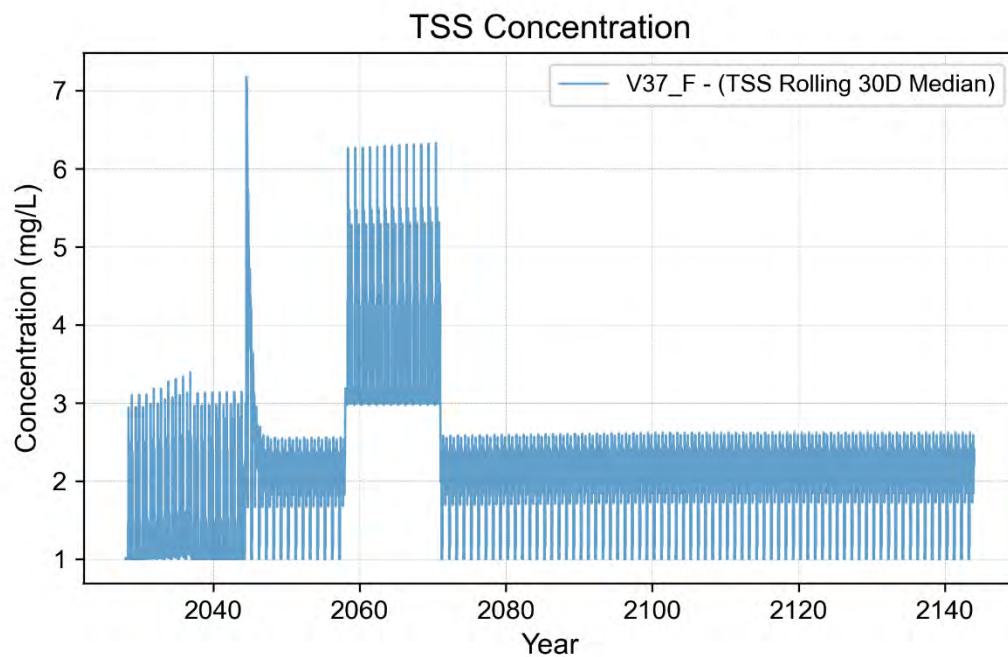


Figure 15: 30-day rolling median TSS model results at V37_F.

Source: MWM (2026d)

6.2.1.2 Site V37_G

The exceedance probability plot for modelled TSS at V37_G is shown in Figure 16. It is noted that:

- Maximum concentrations at V37_G are modelled to be about 20 - 30 mg/L.
- The majority of time (~90%), concentrations remain below 10 mg/L.
- The median concentration is 1 - 2 mg/L.

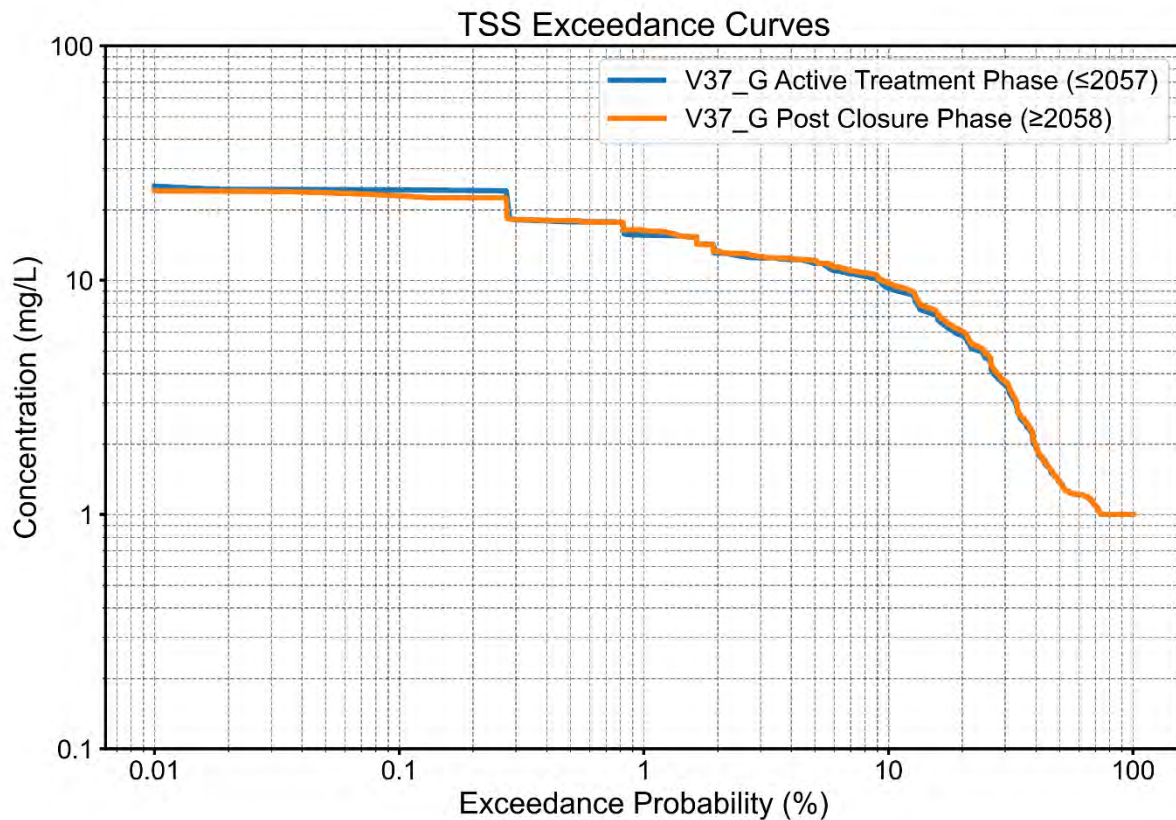


Figure 16: Exceedance probability of daily TSS results at V37_G

Source: MWM (2026d)

A 30-day rolling median plot is shown in Figure 17. No protection levels are proposed for V37_G.

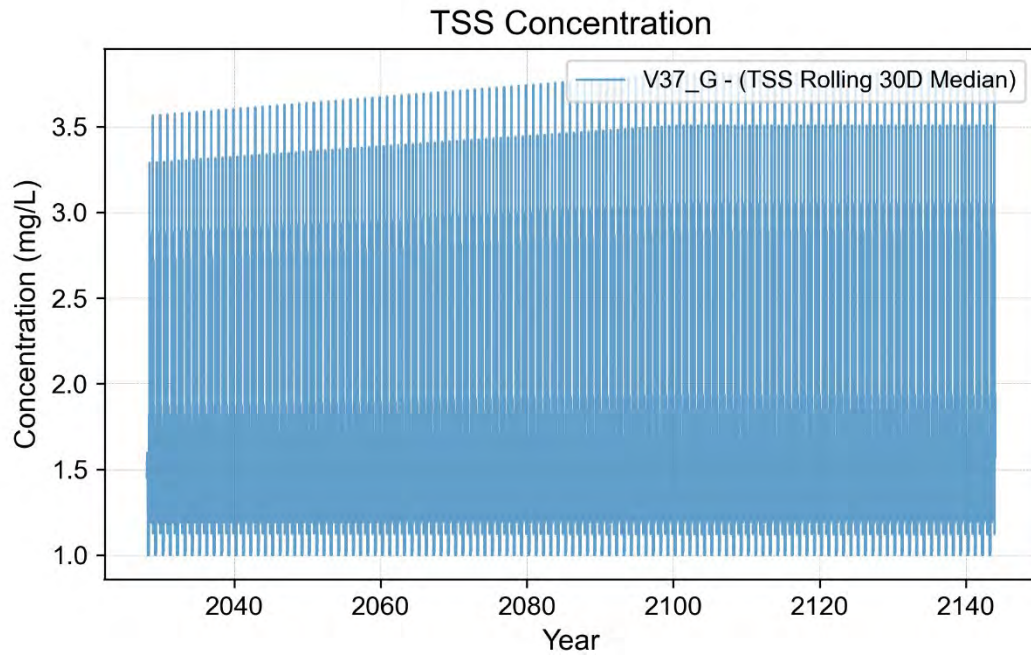


Figure 17: 30-day rolling median TSS model results at V37_G.

Source: MWM (2026d)

6.2.1.3 Site MM1

The exceedance probability plot for modelled TSS at MM1 is shown in Figure 18. It is noted that:

- Maximum concentrations at MM1 are modelled to be about 10 - 20 mg/L.
- The majority of time (more than 90%), concentrations remain below 7 mg/L.
- The median concentration is about 1 - 3 mg/L.

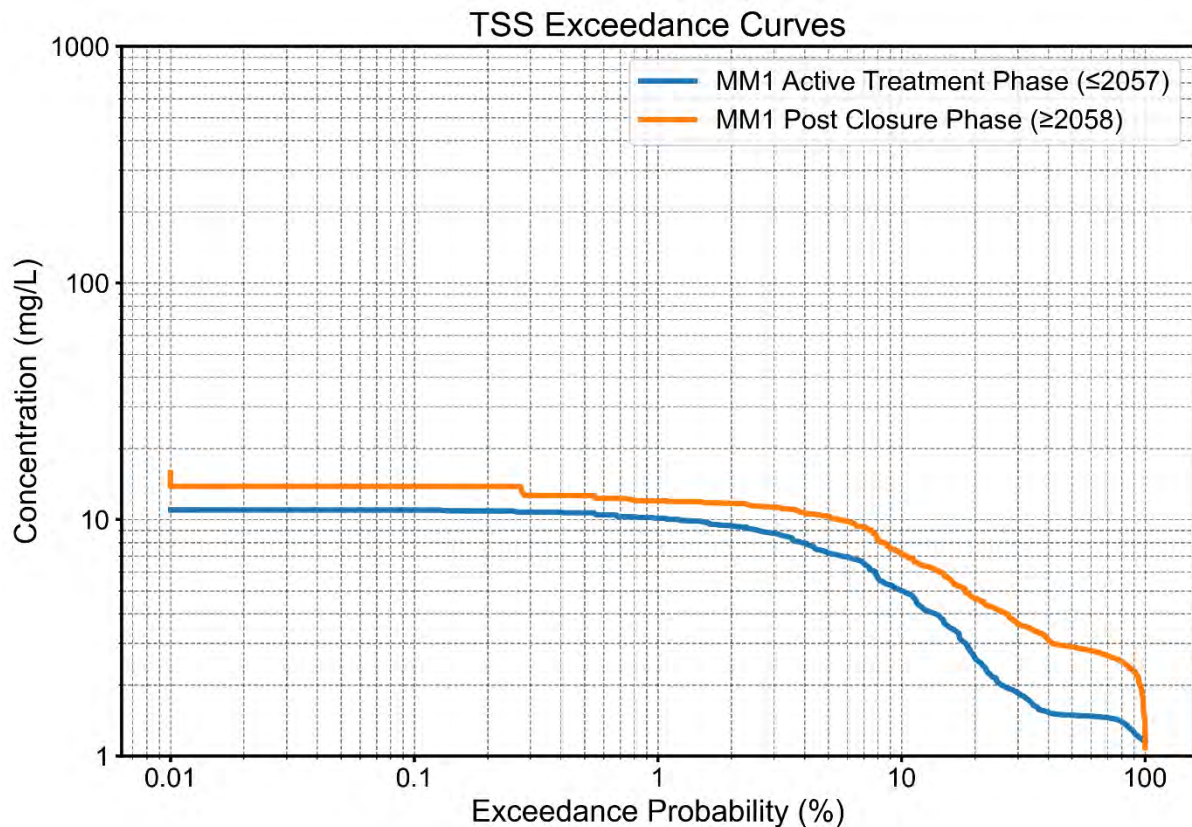


Figure 18: Exceedance probability of daily TSS results at MM1

Source: MWM (2026d)

A 15-day rolling median plot is shown in Figure 19. Screening of model results against the proposed protection levels for turbidity does not suggest exceedance over the proposed exposure periods.

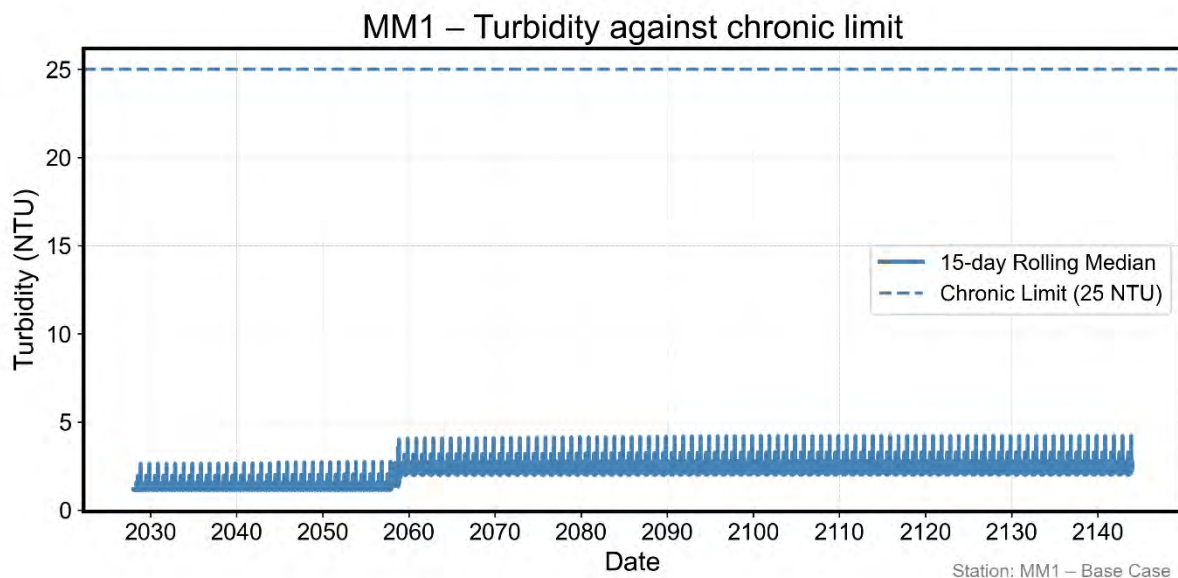


Figure 19: 15-day rolling median NTU model results at MM1, with the 15-sample rolling median limit of 25 NTU.

Source: MWM (2026d)

Water quality protection levels: Hickey (2026)

6.2.1.4 Site W07

The exceedance probability plot for modelled TSS at W07 is shown in Figure 20. It is noted that:

- Maximum concentrations at W07 reach about 40 - 45 mg/L during the active treatment phase (2028-2045).
- The majority of time (more than 90%), concentrations remain below 10 mg/L.
- The median concentration is 1 - 3 mg/L.

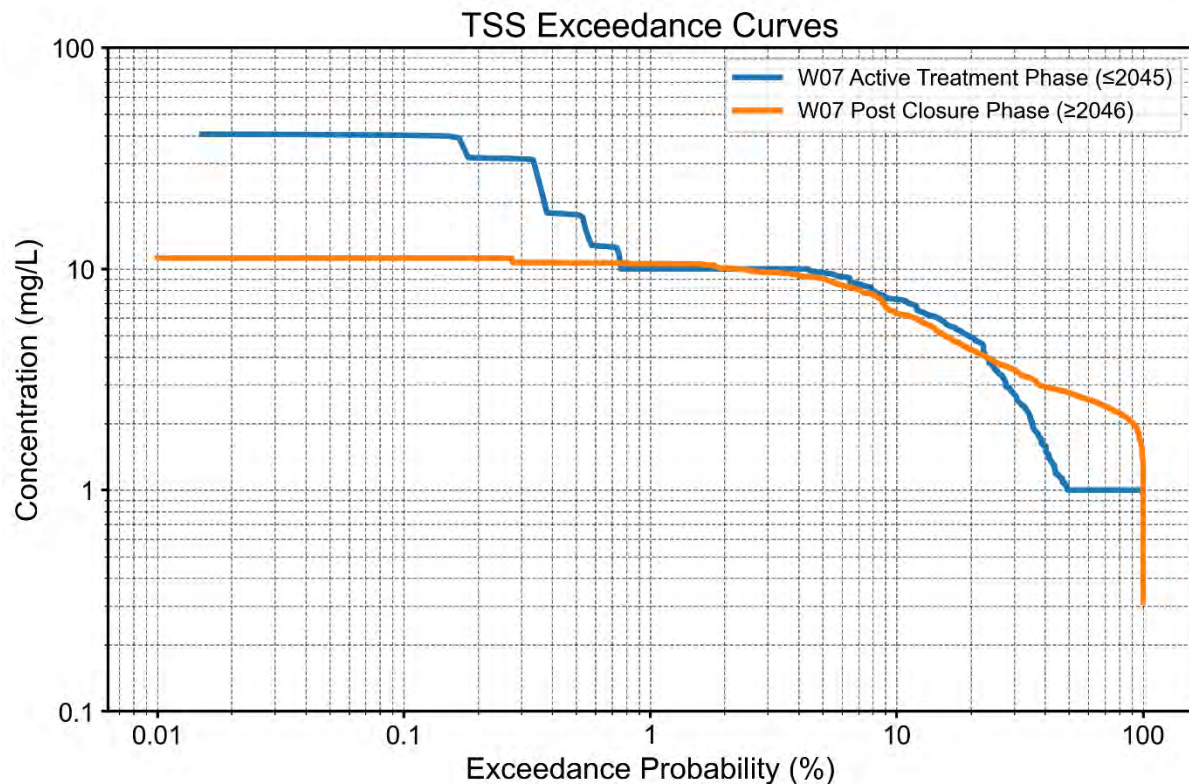


Figure 20: Exceedance probability of daily TSS results at W07

Source: MWM (2026d)

Turbidity compliance plots are presented below as time series, where modelled daily and 7-day rolling median turbidity compared to acute limits is shown in Figure 21, and the annual median and 95th percentile turbidity values compared to chronic limits are shown in Figure 22, relative to the proposed protection levels.

Screening of model results against the proposed protection levels for turbidity does not suggest exceedance over the proposed exposure periods.

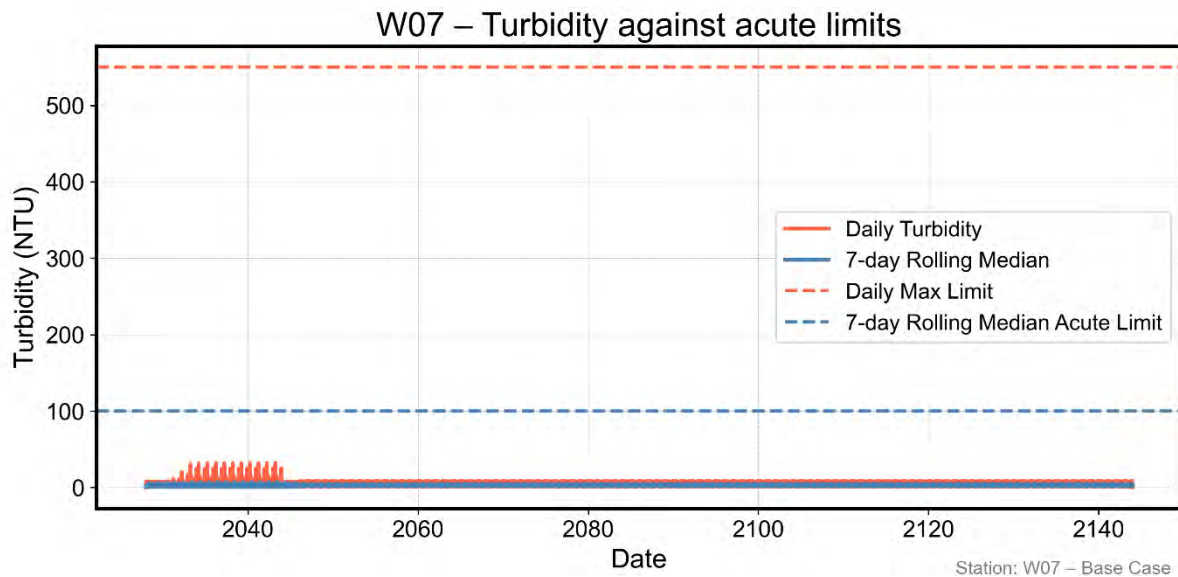


Figure 21: Daily and 7-day rolling median turbidity model results at W07, with the daily (550 NTU) and 7-day rolling median (100 NTU) limits.

Source: MWM (2026d)

Water quality protection levels: Hickey (2026)

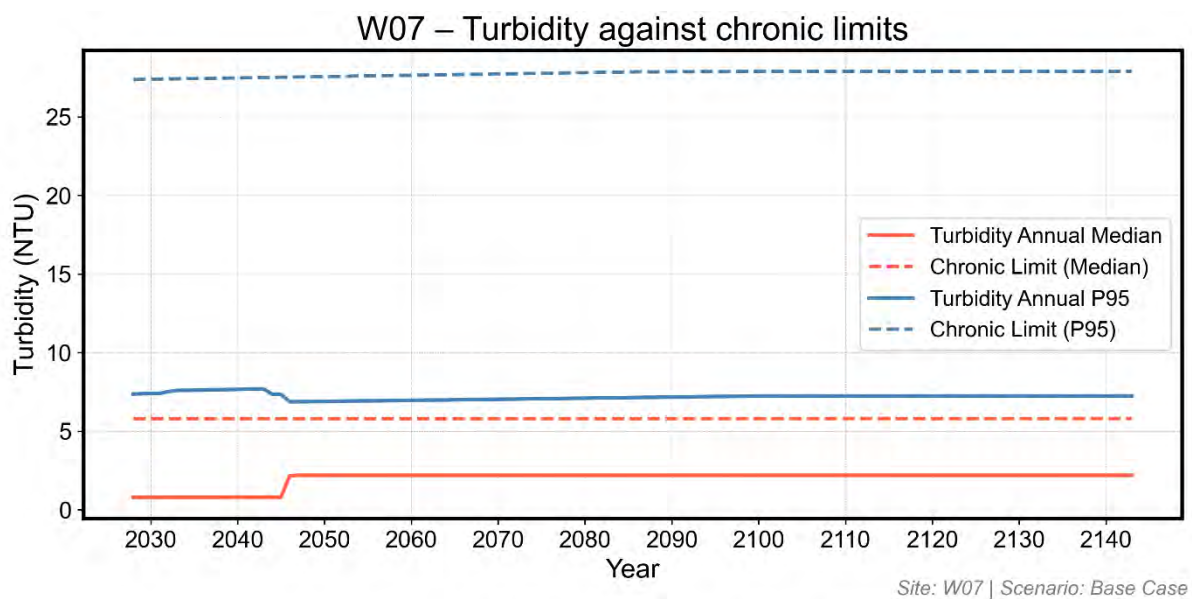


Figure 22: Annual turbidity statistics at W07, with the annual median (baseline + 5 NTU) and annual 95th %ile (baseline + 20 NTU) limits.

Source: MWM (2026d)

Water quality protection levels: Hickey (2026)

6.2.1.5 Site KEL

The exceedance probability plot for modelled TSS at KEL is shown in Figure 23. It is noted that:

- Maximum concentrations at KEL reach approximately 200 mg/L during the active treatment phase (2028-2057).
- The majority of time (more than 90%), concentrations remain below 10 mg/L,
- The median concentration is 1 - 4 mg/L.

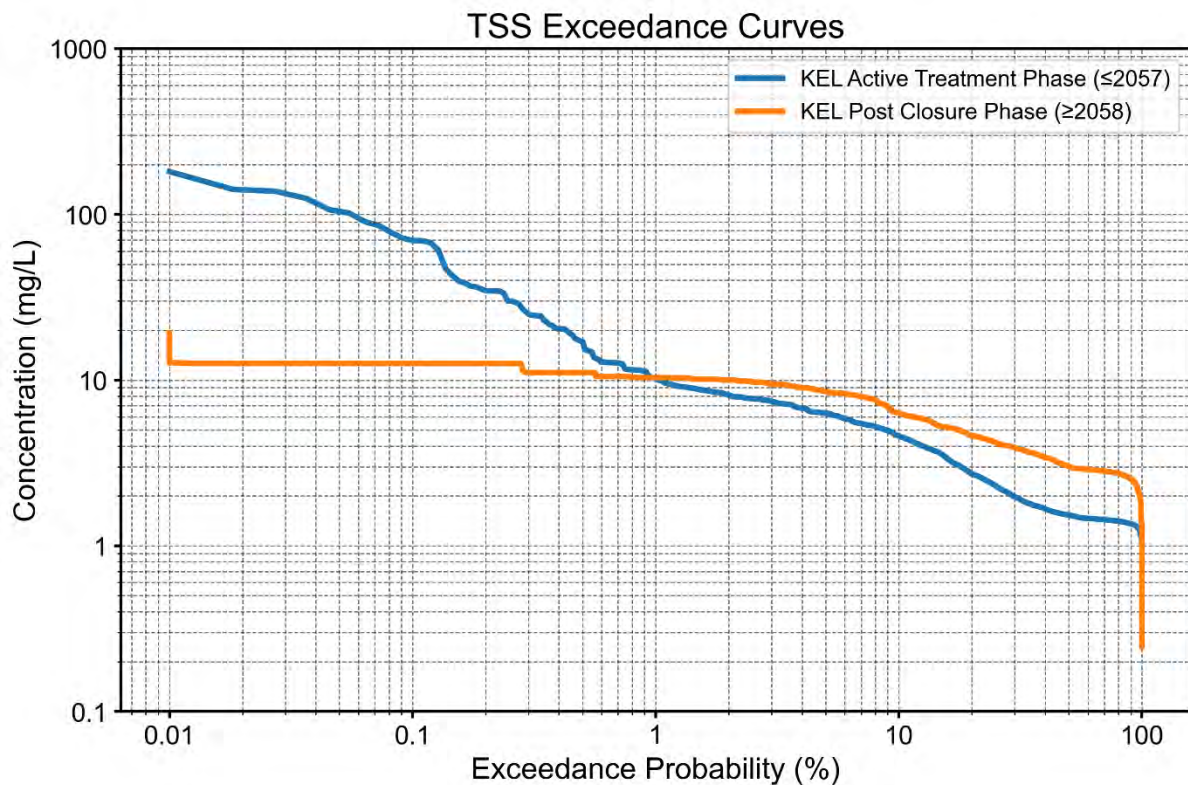


Figure 23: Exceedance probability of daily TSS results at KEL

Source: MWM (2026d)

Turbidity compliance plots are presented below as time series, where modelled daily and 7-day rolling median turbidity compared to acute limits is shown in Figure 24, and the annual median and 95th percentile turbidity values compared to chronic limits are shown in Figure 25, relative to the proposed protection levels.

Screening of model results against the proposed protection levels for turbidity does not suggest exceedance over the proposed exposure periods.

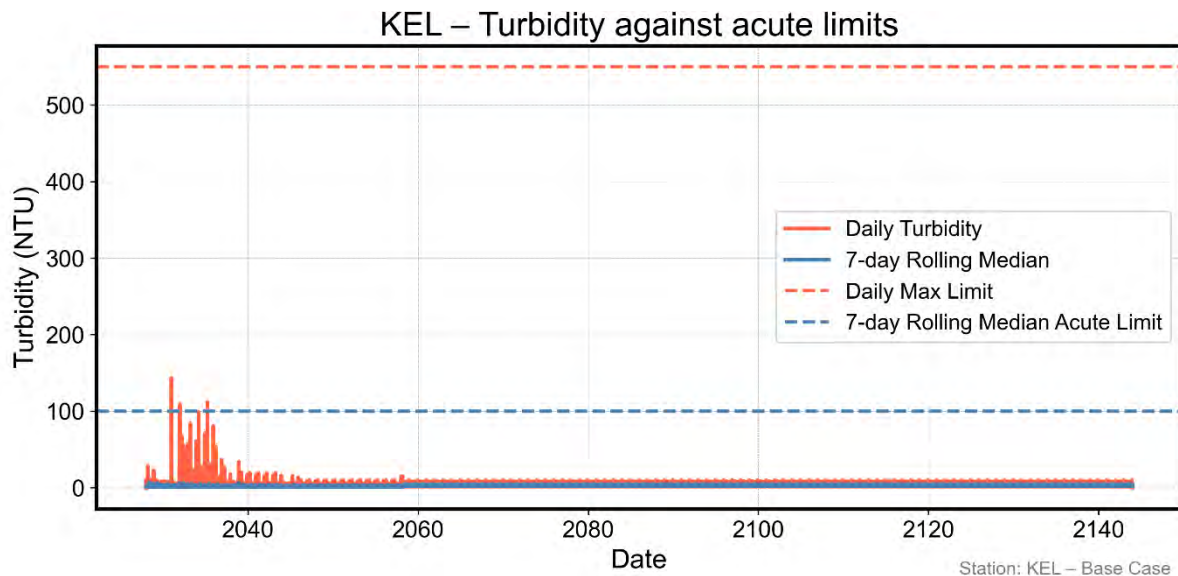


Figure 24: Daily and 7-day rolling median turbidity model results at KEL, with the daily (550 NTU) and 7-day rolling median (100 NTU) limits.

Source: MWM (2026d)

Water quality protection levels: Hickey (2026)

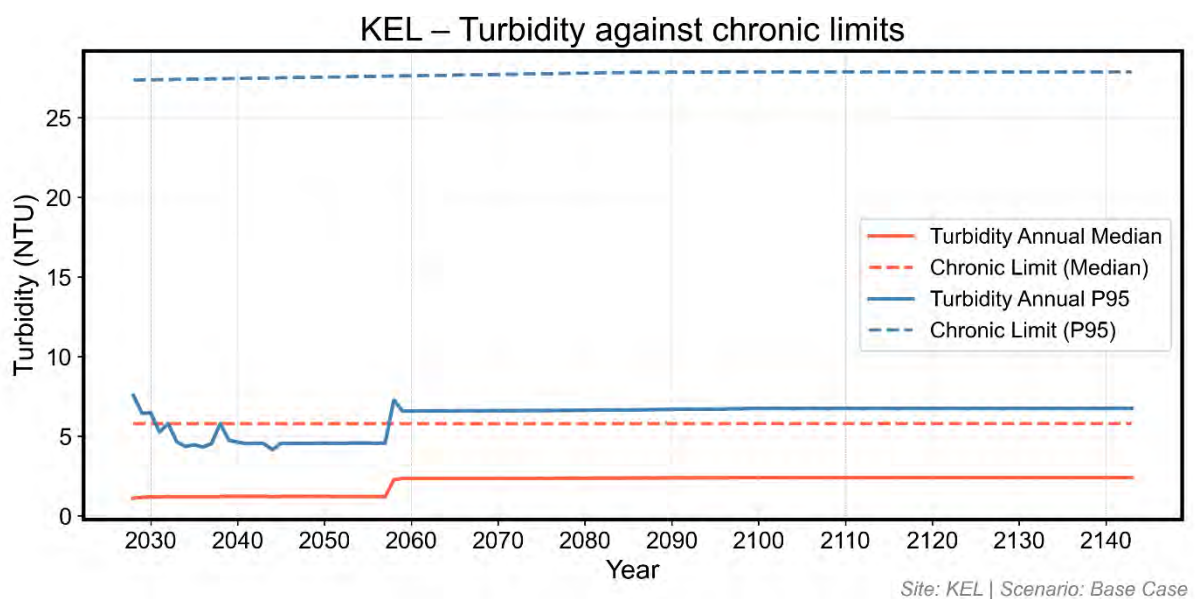


Figure 25: Annual turbidity statistics at KEL, with the annual median (baseline + 5 NTU) and annual 95th %ile (baseline + 20 NTU) limits.

Source: MWM (2026d)

Water quality protection levels: Hickey (2026)

6.2.1.6 Site V62

The exceedance probability plot for modelled TSS at V62 is shown in Figure 26. It is noted that:

- Maximum concentrations at V62 reach about 200 - 250 mg/L during the active treatment phase (2028-2057).
- The majority of time (~90%), concentrations remain below 10 mg/L.
- The median concentration is 1 - 4 mg/L.

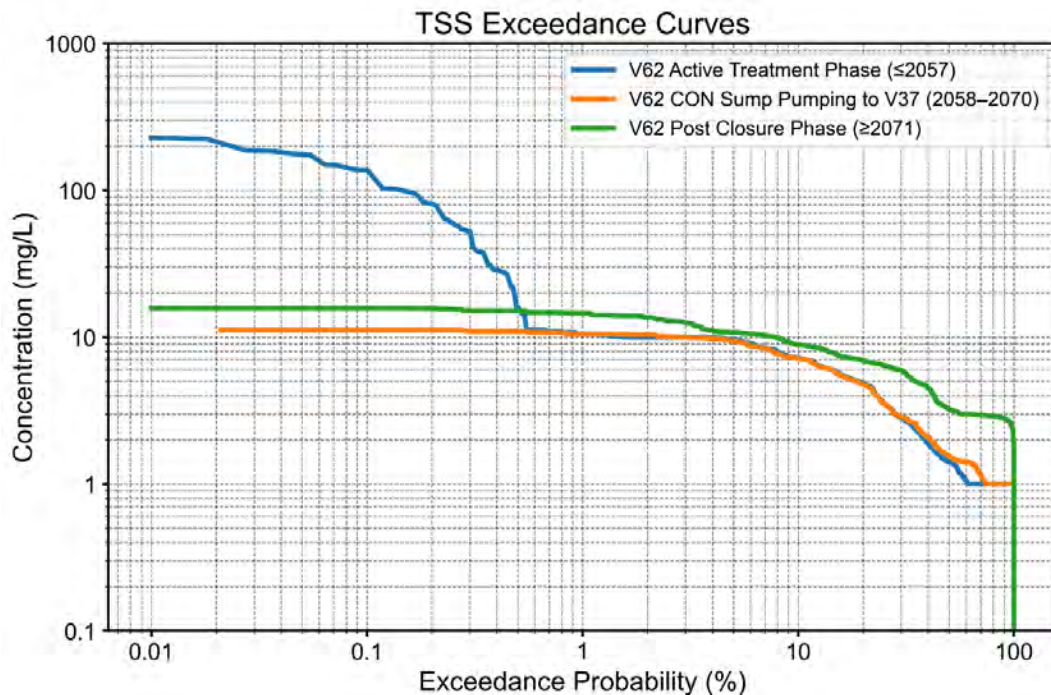


Figure 26: Exceedance probability of daily TSS results at V62

Source: MWM (2026d)

Turbidity compliance plots are presented below as time series, where modelled daily and 7-day rolling median turbidity compared to acute limits is shown in Figure 27, and the annual median and 95th percentile turbidity values compared to chronic limits are shown in Figure 28, relative to the proposed protection levels.

Screening of model results against the proposed protection levels for turbidity does not suggest exceedance over the proposed exposure periods.

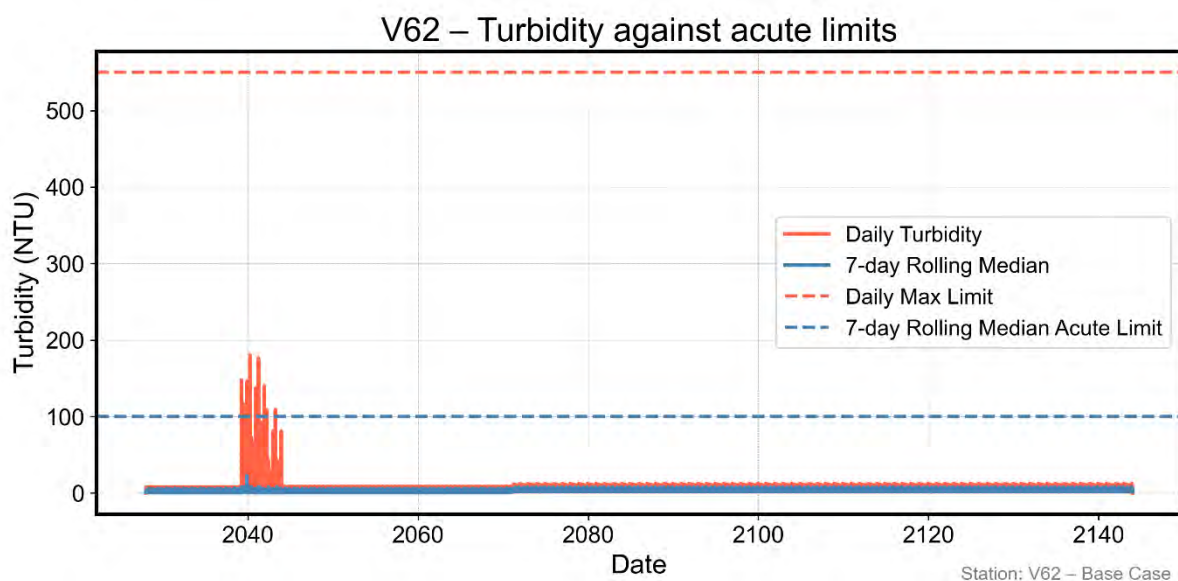


Figure 27: Daily and 7-day rolling median turbidity model results at V62, with the daily (550 NTU) and 7-day rolling median (100 NTU) limit.

Source: MWM (2026d)

Water quality protection levels: Hickey (2026)

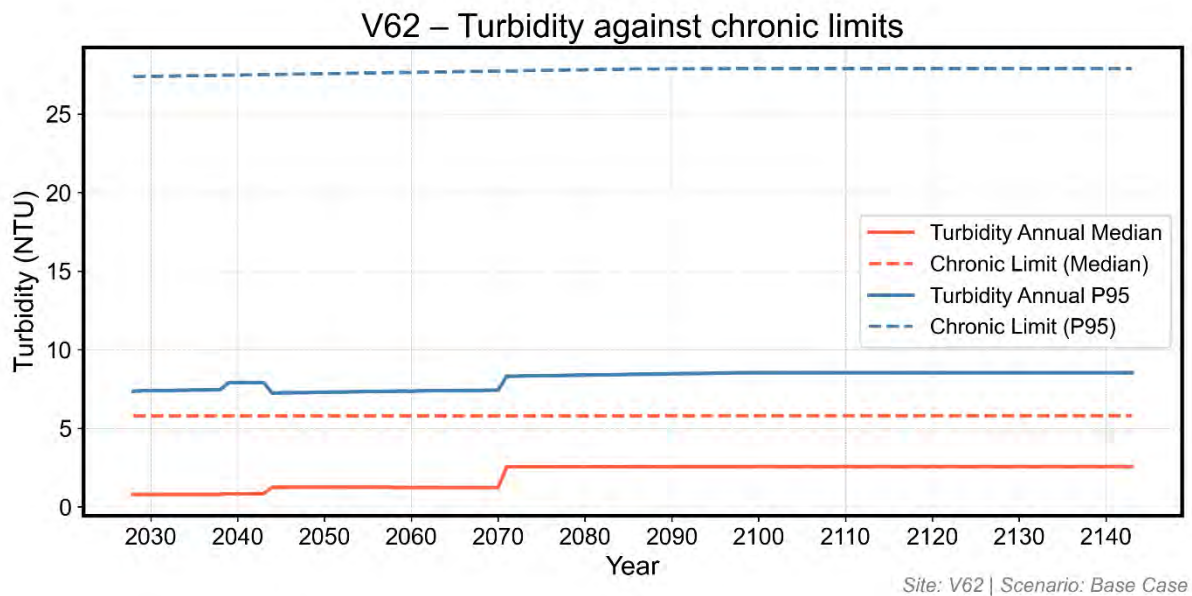


Figure 28: Annual turbidity statistics at V62, with the annual median (baseline + 5 NTU) and annual 95th %ile (baseline + 20 NTU) limits.

Source: MWM (2026d)

Water quality protection levels: Hickey (2026)

6.3 MFS Water Load Balance Model Report

The MFS WLBM was developed to forecast changes to flows within waterways, support design of water management infrastructure, and forecast downstream water quality as a result of mining at MFS. The MFS WLBM includes a proportion of effects from the UWHR where it is located upstream of monitoring site 17W.

Further details are described below and provided in MWM (2026e).

6.3.1 Key Findings

MWM (2026e) presents a site wide water and load balance model to assess water flows and dissolved solute loads from key mine domains associated with the proposed BPCP. The model for MFS simulates the Operational (mining) Phase, Active Closure Phase, and the Post Closure Phase (these are described in Section 1.6). Two treatment phases are then defined for management of MIW (these define the reporting periods described in the results below):

- Active Treatment Phase, where active treatment via the WTP occurs until such time that all MIW may effectively be treated via MSRs. This phase covers the Operational and Active Closure phases.
- Post Closure Phase, where MIW is passively treated through use of MSRs.

Four compliance monitoring locations have been selected for MFS (see Figure 13). Modelling has then been undertaken to understand potential effects at these locations, and these results have then been assessed against the proposed water quality protection levels.

The compliance monitoring sites include:

- SW01 (Deep Creek)

- SW03 (Deep Creek)
- 2W (Smokestack) (Waimangaroa River)
- 17W (Waimangaroa River)

SW01 and SW03 are located downstream of the East and West Pit mining areas respectively, 2W is located downstream of the MFS WTP effluent within the Waimangaroa River, and 17W is located downstream of the confluence of Deep Creek and the Waimangaroa River.

The key findings for the base case scenario are described in the following sections. TSS exceedance curves present the model results relative to how likely these are to be exceeded (in relation to treatment phases); observations describe the Active Treatment Phase (2029 -2046) and Post Closure Phase (after 2046) including presenting all results over the entire simulated time period, unless noted otherwise. TSS compliance plots illustrate the model results as a time series and overlay the proposed compliance limits; here, modelled TSS results were made relevant by converting values to turbidity following Equation 1.

6.3.1.1 Site SW01

The exceedance probability plot for modelled TSS at SW01 is shown in Figure 29. It is to be noted that:

- Maximum concentrations at SW01 reach about 60 - 70 mg/L during the active treatment phase (2029-2046).
- The majority of time (more than 90%), concentrations remain below 10 mg/L.
- The median concentration is about 1 - 3 mg/L.

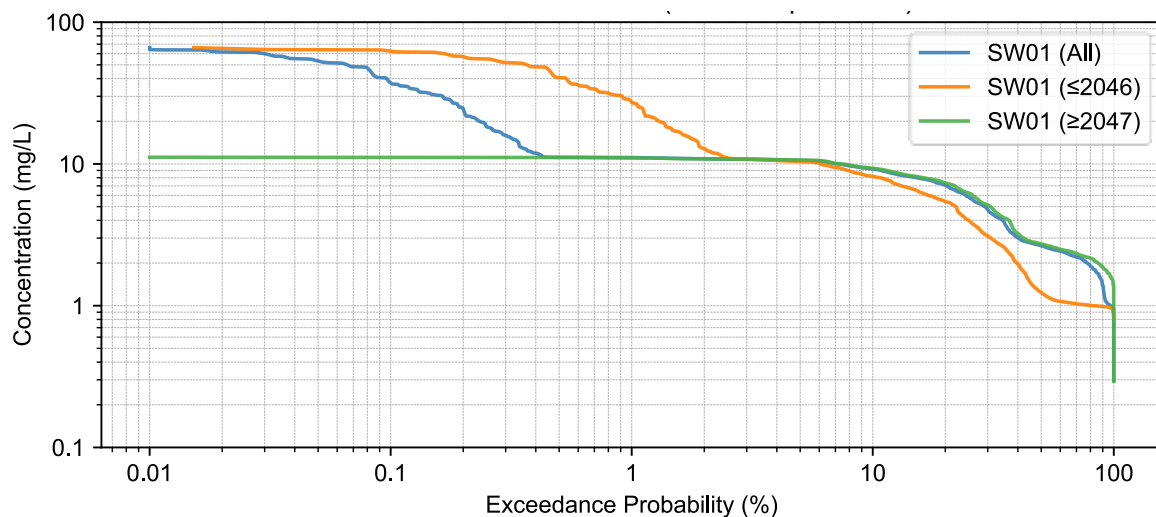


Figure 29: Exceedance probability of daily TSS results at SW01

Source: MWM (2026e)

Turbidity compliance plots are presented below as time series, where modelled daily and 7-day rolling median turbidity is shown in Figure 30, and the annual median and 95th percentile turbidity values are shown in Figure 31, relative to the proposed protection levels.

Screening of model results against the proposed protection levels for turbidity does not suggest exceedance over the proposed exposure periods.

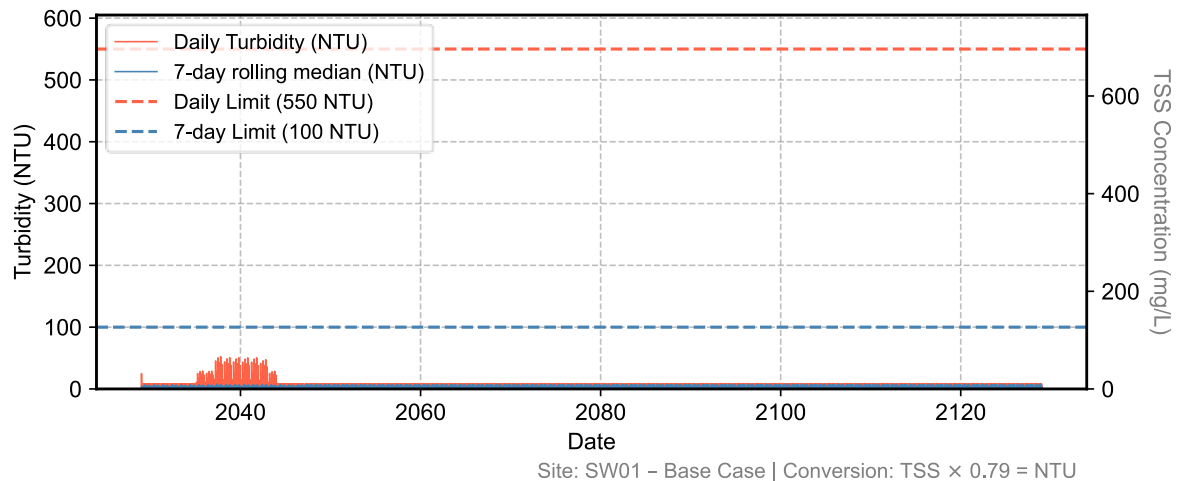


Figure 30: Daily and 7-day rolling median turbidity model results at SW01, with the daily (550 NTU) and 7-day rolling median (100 NTU) limits.

Source: MWM (2026e)

Water quality protection levels: Hickey (2026)

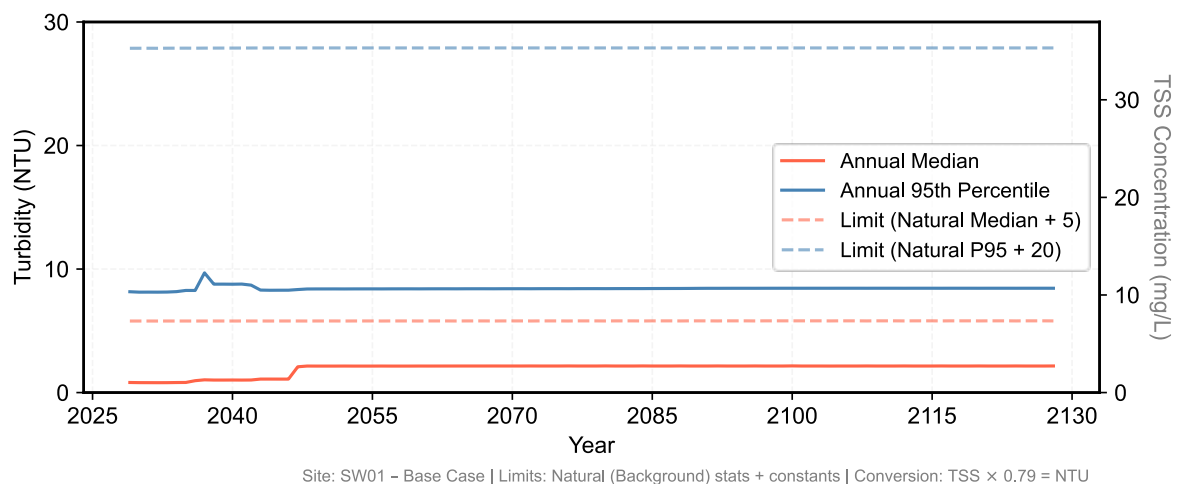


Figure 31: Annual turbidity statistics at SW01, with the annual median (background + 5 NTU) and annual 95th %ile (background + 20 NTU) limits.

Source: MWM (2026e)

Water quality protection levels: Hickey (2026)

6.3.1.2 Site SW03

The exceedance probability plot for modelled TSS at SW03 is shown in Figure 32. It is noted that:

- Maximum concentrations at SW03 reach about 50 - 60 mg/L during the active treatment phase (2029-2046).
- The majority of time (~90%), concentrations remain below 10 mg/L.
- The median concentration is ~3 mg/L.

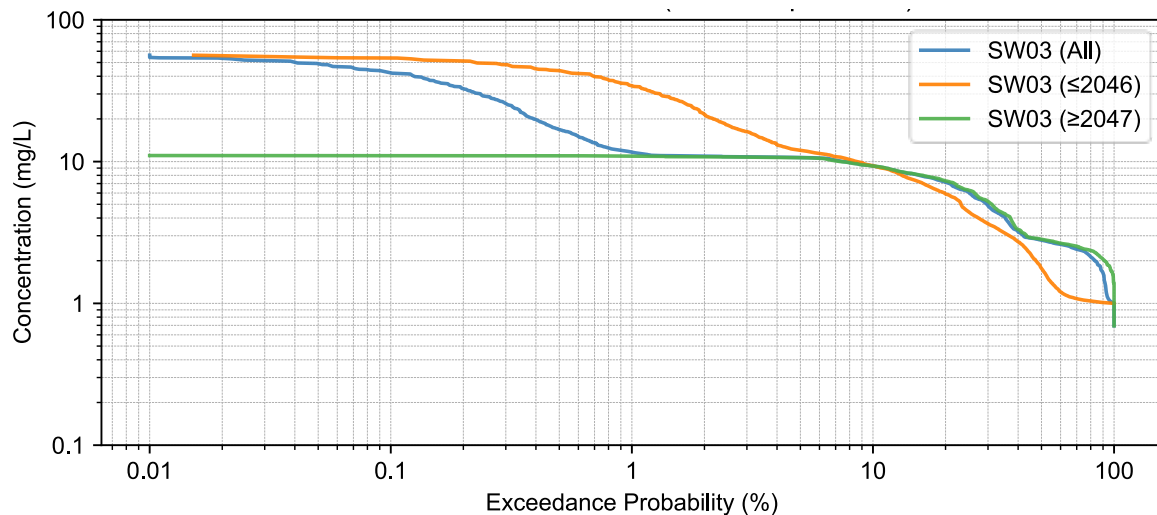


Figure 32: Exceedance probability of daily TSS results at SW03

Source: MWM (2026e)

Turbidity compliance plots are presented below as time series, where modelled daily and 7-day rolling median turbidity is shown in Figure 33, and the annual median and 95th percentile turbidity values are shown in Figure 34, relative to the proposed protection levels.

Screening of model results against the proposed protection levels for turbidity does not suggest exceedance over the proposed exposure periods.

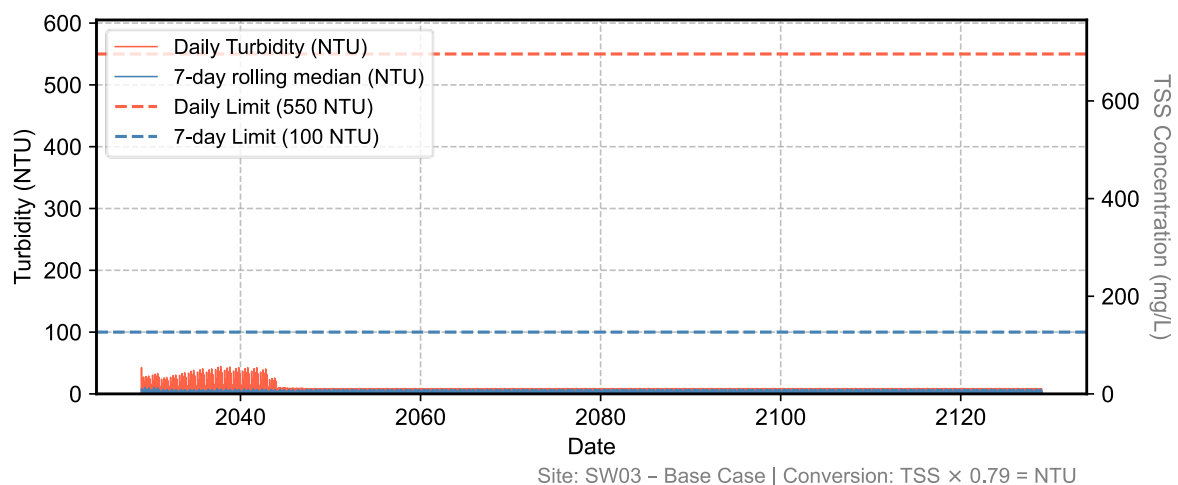


Figure 33: Daily and 7-day rolling median turbidity model results at SW03, with the daily (550 NTU) and 7-day rolling median (100 NTU) limits.

Source: MWM (2026e)

Water quality protection levels: Hickey (2026)

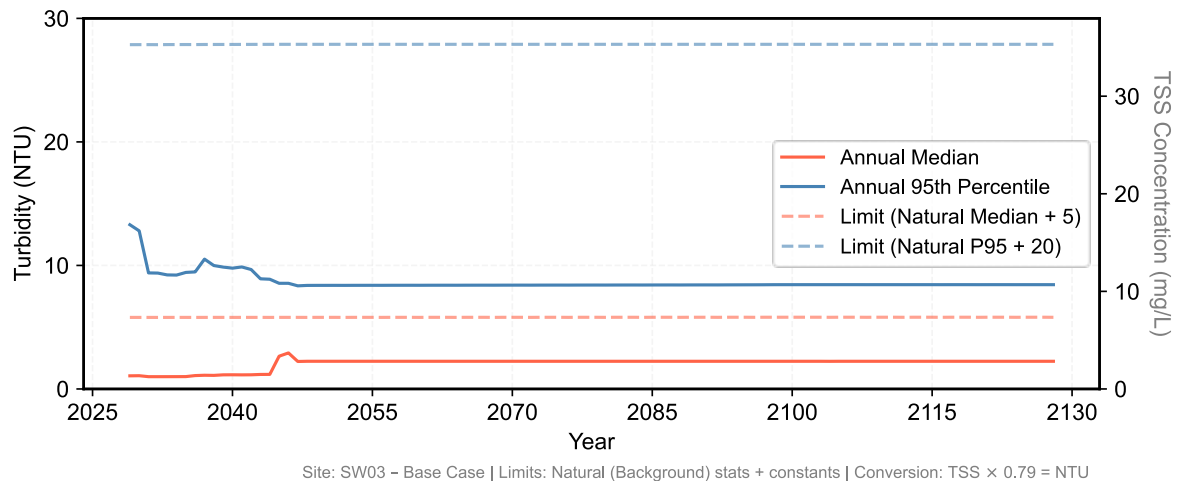


Figure 34: Annual turbidity statistics at SW03, with the annual median (background + 5 NTU) and annual 95th %ile (background + 20 NTU) limits.

Source: MWM (2026e)

Water quality protection levels: Hickey (2026)

6.3.1.3 Site 2W (Smokestack)

The exceedance probability plot for modelled TSS at 2W is shown in Figure 35. It is noted that:

- Maximum concentrations at 2W reach approximately 20 mg/L during the active treatment phase (2029-2046).
- The majority of time (~90%), concentrations remain below 10 mg/L.
- The median concentration is 1 - 2 mg/L.

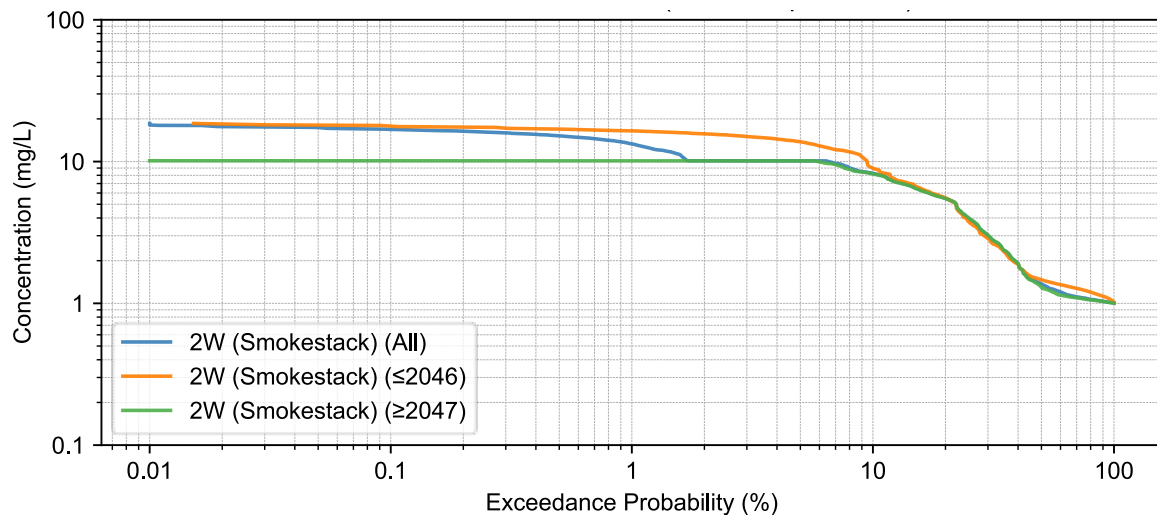


Figure 35: Exceedance probability of daily TSS results at 2W

Source: MWM (2026e)

Turbidity compliance plots are presented below as time series, where modelled daily and 7-day rolling median turbidity is shown in Figure 36, and the annual median and 95th percentile turbidity values are shown in Figure 37, relative to the proposed protection levels.

Screening of model results against the proposed protection levels for turbidity does not suggest exceedance over the proposed exposure periods.

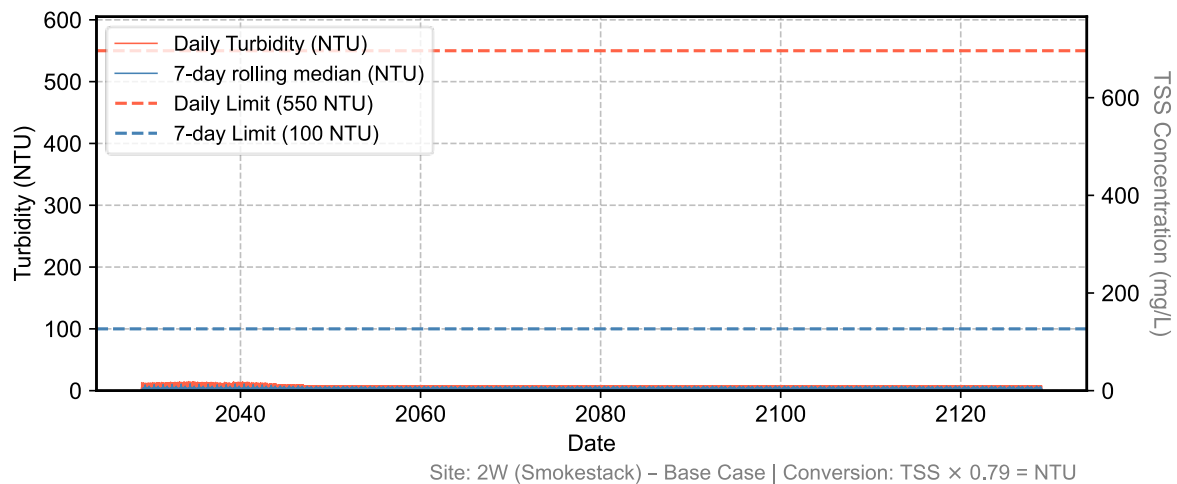


Figure 36: Daily and 7-day rolling median turbidity model results at 2W, with the daily (550 NTU) and 7-day rolling median (100 NTU) limits.

Source: MWM (2026e)

Water quality protection levels: Hickey (2026)

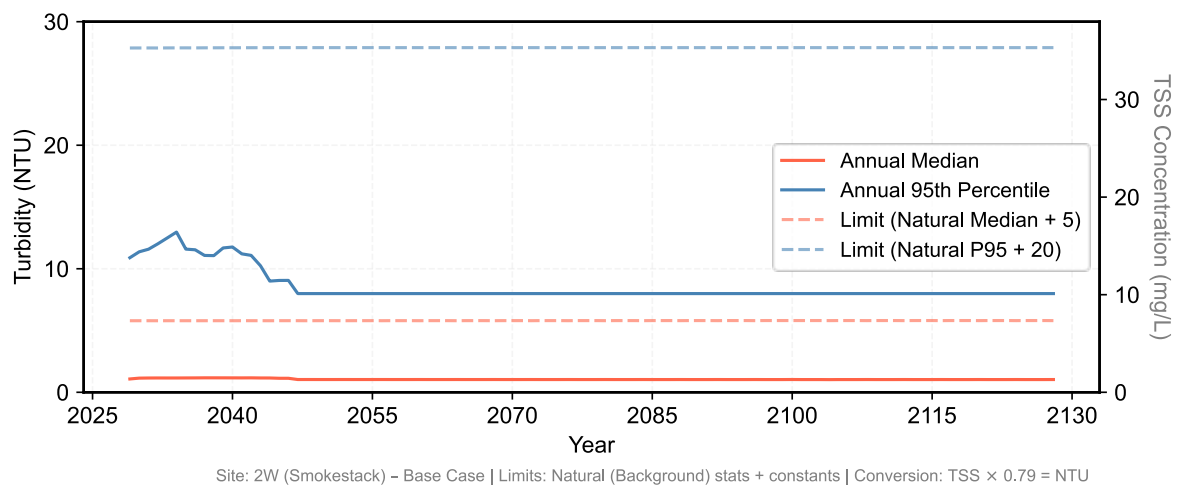


Figure 37: Annual turbidity statistics at 2W, with the annual median (background + 5 NTU) and annual 95th %ile (background + 20 NTU) limits.

Source: MWM (2026e)

Water quality protection levels: Hickey (2026)

6.3.1.4 Site 17W

The exceedance probability plot for modelled TSS at 17W is shown in Figure 38. It is noted that:

- Maximum concentrations at 17W reach about 20 - 25 mg/L during the active treatment phase (2029-2046).
- The majority of time (~90%), concentrations remain below 10 mg/L.
- The median concentration is 1 - 3 mg/L.

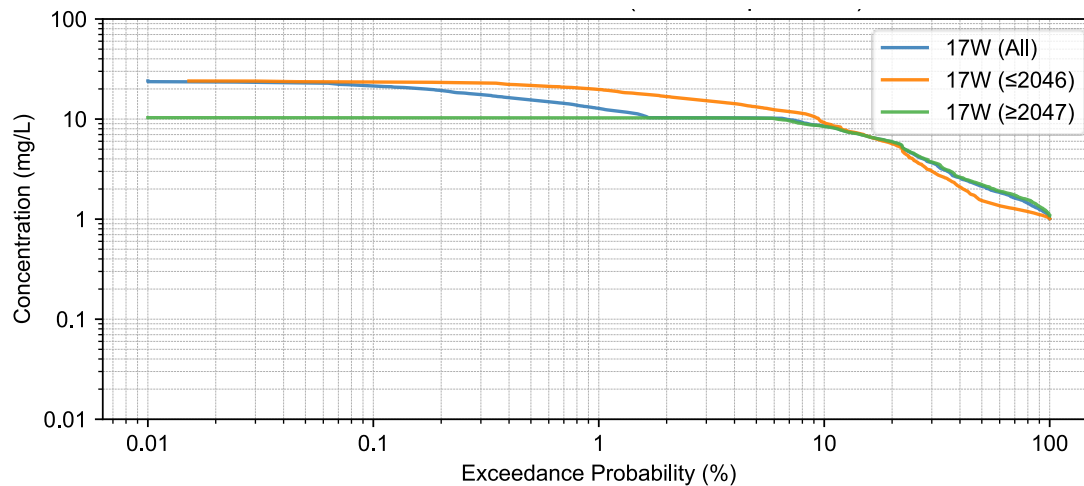


Figure 38: Exceedance probability of daily TSS results at 17W

Source: MWM (2026e)

Turbidity compliance plots are presented below as time series, where modelled daily and 7-day rolling median turbidity is shown in Figure 39, and the annual median and 95th percentile turbidity values are shown in Figure 40, relative to the proposed protection levels.

Screening of model results against the proposed protection levels for turbidity does not suggest exceedance over the proposed exposure periods.

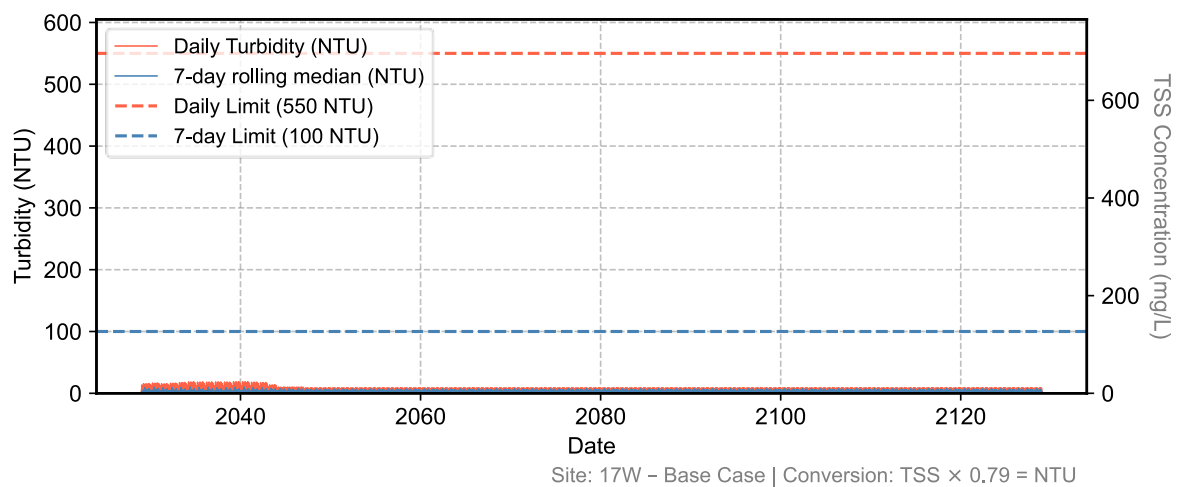


Figure 39: Daily and 7-day rolling median turbidity model results at 17W, with the daily (550 NTU) and 7-day rolling median (100 NTU) limits.

Source: MWM (2026e)

Water quality protection levels: Hickey (2026)

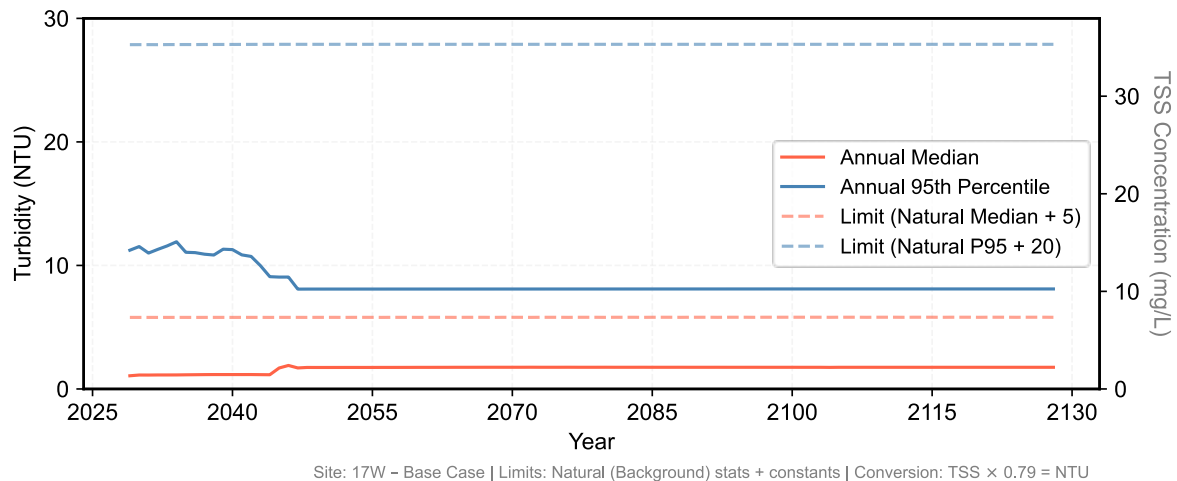


Figure 40: Annual turbidity statistics at 17W, with the annual median (background + 5 NTU) and annual 95th %ile (background + 20 NTU) limits.

Source: MWM (2026e)

Water quality protection levels: Hickey (2026)

6.4 UWHR

The Construction Phase of the UWHR will ensure all controls are in place to manage TSS over the Operational Phase of the haul road (as per BRL, 2026e). This includes:

- Engineered road construction.
- Sediment controls, including use of sediment retention ponds and silt fences.
- Erosion controls, including stabilisation of the road surface with aggregate, and rehabilitation / stabilisation of disturbed areas beyond the roadway and infrastructure areas.
- Continued operation of the clean water drains (CWDs).
- Monitoring and maintenance of all water management infrastructure.

During the Active Closure Phase the UWHR will be rehabilitated, allowing for minimum access for transport of AMD sludge from ESE and MFS sub-areas to Stockton Mine for disposal where required. At Post Closure, the UWHR will allow minimum access to MFS for maintenance of passive treatment systems and allowing for recreational and ongoing Transpower access through to where the Mackley Track diverges from the roadway. North of the Mackley Track divergence, and between Escarpment and Burnett's Face, the UWHR may be completely rehabilitated, have allowance for recreational use, or allow minimum access for transport of AMD sludge during Post Closure to be transported to Stockton.

TSS management after closure would rely on the roadway and infrastructure areas being rehabilitated and the remaining road surfaces being stabilised with aggregate. Sediment retention ponds may be left in place to capture any remaining sediment generation but would not be maintained post closure with the expectation that any further erosion would be short-term and with minimal sediment accumulation. Water infrastructure (e.g., CWDs) may be decommissioned as required.

7 **SUMMARY**

The report provides an overview of the studies that have been completed to assess the potential effects of suspended solids in min impacted waters from the proposed BPCP. This includes:

- Understanding the source hazards for suspended solids.
- The development of source terms for TSS impacted waters.
- Using the source terms within the water and load balance models to understand potential effects for ESE and MFS.
- Using model results to guide decision making processes on how better to manage potential effects and provide design criteria for infrastructure design.

7.1 **Management of Suspended Solids**

Sediment has the potential to be mobilised from the BPCP mining areas to downstream waterways through poor erosion and sediment management practices. Studies indicate that high levels of TSS are generated from mining activities, and, as such, can negatively impact the receiving environment if left unmanaged; therefore, management of impacted waters is required to mitigate the effects.

To mitigate the risks associated with elevated TSS, BRL has developed a hierarchy of controls (Management Steps):

1. Determine the closure objectives for the mine.
2. Understand the source hazards.
3. Prevent, control, and treat TSS.
4. Complete an assessment of the potential effects.
5. Monitor performance.

Studies have been completed to address these management steps (as shown in Table E1). These studies have been used to develop erosion and sediment management processes. The following documents have been developed to guide the management of risks for elevated TSS in receiving waterways caused by the BPCP activities so that they can be managed in an appropriate manner:

- ELF Management Plan (BRL, 2026a)
- AMD Water Management Plan (BRL, 2026b)
- Water Infrastructure Design (BRL, 2026c)
- Mine Closure Concept Strategy (BRL, 2026d).
- Erosion and Sediment Control Plan for Land Disturbance Activities (BRL, 2026e)
- Water Treatment Report: MFS and ESE (MWM, 2026c)

7.2 **Findings**

Studies indicate that the environmental risks associated with TSS at the BPCP can be successfully managed if the proposed management processes are utilised, appropriate engineering controls are

implemented, and performance monitoring is undertaken to support adaptive management principles if there is variation from the expected case.

7.3 Review

This report has been peer reviewed by Dr James Pope of Strata Geoscience Limited (Pope, 2026). The review is provided as part of the substantive FTAA application.

8 RECOMMENDATIONS

The following overarching recommendations are provided for TSS risks based on the work completed by MWM for the BPCP FTAA application.

8.1 Background Water Quality

Understanding background water quality is essential to develop water quality objectives for the Project given that many waterways in the area are degraded by historical mining activities and the discharge of untreated AMD to streams. A significant water quality database is available for the MFS, ESE, and the UWHR sub-areas to provide guidance on PCOC within these sub-areas with data being collected for many decades. For instance:

- Extensive water quality monitoring has been undertaken at the Stockton Mine with records in the Stockton Water Quality Database⁶ commencing in 1987. Such data has application to the wider BPCP as the same lithological materials will be excavated.
- It is noted that observations, interpretations, and about 120,000 samples⁷ from 125 sites over 45 years demonstrate that the Denniston and Stockton catchments are amongst the most well understood catchments in New Zealand.
- The AMD risks are well understood for the Project areas and the materials that will be disturbed by the BPCP activities.

Although background water data is robust, it is recommended it be continually verified through the life of the BPCP to validate the proposed management processes.

Recommendation #1	Expanded knowledge base	Continue water quality monitoring at compliance, performance, and reference monitoring sites over the construction, operational, and closure phases of the project.
Recommendation #2	Validate baseline water quality	Undertake continuous monitoring data (flow, EC, pH, and turbidity) to provide time-based data to fully characterise the relationships between flow and physicochemistry at compliance monitoring locations (e.g., 2W: Smokestack) prior to construction commencing and then continuing throughout life of mine phases.
Recommendation #3	Validate baseline water quality	Validate the TSS and turbidity equation (Equation 1) with field and laboratory data during the Operational Phase of the BPCP.

⁶ As provided by BRL

⁷ As sourced from the BRL water quality database, including sonde measurements.

Recommendation #4	Validate baseline water quality	Validate and refine flow weighted water quality source terms (mg/L) to improve estimates of closure water quality.
Recommendation #5	Baseline water quality	Validate mine impacted water storage and WTP capacity required to manage extreme rainfall events or wet years.
Recommendation #6	Baseline water quality	Update the water and load balance models with new baseline data to validate management and monitoring measures prior to each stage commencing.

An essential part of demonstrating that TSS management is appropriate during the Post Closure Phase is a suitable monitoring programme that shows that suspended sediment loads/concentrations has been achieved over an appropriate timeframe. Any long-term Post Closure Phase monitoring programme should acknowledge that with increasing confidence in data trends (over time) that there should be a decreasing monitoring intensity.

Recommendation #7	Adapt Monitoring Frequency	Undertake a SQEP ⁸ review of the water quality data and incorporate TSS monitoring type and frequency changes into the following management plans/documents: • AMD ELF Management Plan. • AMD Water Management Plan. • Water Infrastructure Design. • Mine Closure Concept Strategy. • Erosion and Sediment Control Plan for Land Disturbance Activities.
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Data from MGIU have been used in the WLBM to develop source terms for:

- TSS of mine impacted areas, prior to management through a sedimentation process
- TSS after mine impacted waters passes through a sediment pond.

Recommendation #8	Water Quality Source Terms	Validate TSS observations through the use of continuous performance monitoring to ensure the same level of effectiveness is achieved.
Recommendation #9	Water Quality Source Terms	Implement performance monitoring for water flows into the pit sumps and after passage through the pit sumps to meet water quality objectives.

⁸ Suitably Qualified and Experienced Person

8.2 Construction Phase

During the construction of the UWHR and the MFS Access Road, and the MFS and ESE infrastructure areas, the activities will be managed to minimise effects using management processes provided by BRL (2026c) and BRL (2026e). Performance monitoring is required to ensure effects are minimised.

Recommendation #10	Operational Pit Sump TSS Efficacy	During the Construction Phase, install sediment controls similar to those observed upstream of MGIU to achieve comparable TSS results at pit sump inlets (which are documented in BRL (2026e) for the BPCP).
Recommendation #11	Performance Monitoring UWHR and MFS	Undertake the following performance monitoring: • Sedimentation ponds to ensure TSS is being managed and is in alignment with expectations (BRL, 2026e). • Portable water treatment activities for TSS to ensure effluent is suitable for discharge.

A WLBM has not been completed for the Construction Phase (although Stage 0 of ESE is included within the ESE WLBM). The analyses provided in the Water Treatment Report (MWM, 2026c) and the Construction Phase Report (MWM, 2026h) provide supporting data for the minor effects.

Recommendation #12	Construction Phase	Update the water and load balance model prior to the commencement of the Construction Phase for ESE and MFS to ensure effects are understood and water treatment infrastructure is appropriate.
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Portable water management plants are proposed for the Construction Phase. Detailed design is required when finalising the mine plans for ESE and MFS.

Recommendation #13	Construction Phase	Develop a suitable water management system for MFS and ESE infrastructure areas to ensure TSS effects are managed and include as part of the detailed design stage.
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8.3 Operational and Closure Phases

During the Operational and Closure phase of the MFS, ESE, and the UWHR sub-areas, the activities will be managed to minimise effects using management processes provided by BRL (2026c), BRL (2026e) and MWM (2026c). Performance monitoring is required to ensure effects are minimised and enable updating of WLBM to calibrate them.

Recommendation #14	Operational and Post Closure phases	Undertake Performance monitoring including: • Sedimentation ponds to ensure TSS is being managed and is in alignment with expectations of the WLBMs. • WTP effluent for TSS to ensure effluent is suitable for discharge and is in alignment with WTP design expectations. • MSR influent and effluent for TSS to ensure it is suitable for the operation of the MSR and effluent is suitable for discharge.
Recommendation #15	Operational and Post Closure phases	• Review performance monitoring data and implement required adaptive management measures from performance monitoring data into the following plans: - o AMD ELF Management Plan. - o AMD Water Management Plan. - o Water Infrastructure Design. - o Mine Closure Concept Strategy. - o Erosion and Sediment Control Plan for Land Disturbance Activities.
A WLBM has been completed, however, it is identified that further scenarios would be beneficial to understand if additional storage and WTP capacity is required to manage wet years.		
Recommendation #16	Active Treatment Phase	• Update the WLBM prior to each life of mine phase to include additional performance monitoring data as available to calibrate the model and to improve confidence in model results for closure.
Recommendation #17	Performance Monitoring UWHR and MFS	Review performance monitoring data and implement required adaptive management measures for performance monitoring data into the following plans/documents: • AMD ELF Management Plan. • AMD Water Management Plan. • Water Infrastructure Design. • Mine Closure Concept Strategy. • Erosion and Sediment Control Plan for Land Disturbance Activities.

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Process Flow, 2026. Active Water Treatment Plant Basis of Design – Buller Plateaux Continuation Project. Document Number PFL-2408-PRJ-BOD-00001.

10 LIMITATIONS

Attention is drawn to the document “Limitations”, which is included in Appendix C of this report. The statements presented in this document are intended to provide advice on what the realistic expectations of this report should be, and to present recommendations on how to minimise the risks associated with this project. The document is not intended to reduce the level of responsibility accepted by Mine Waste Management, but rather to ensure that all parties who may rely on this report are aware of the responsibilities each assumes in doing so.

APPENDIX A PREVIOUS TSS STUDIES

MEMORANDUM

Recipient: [REDACTED] – Bathurst Resources Limited

From: [REDACTED]

Date: 20 July 2026

Cc: [REDACTED]

Document Number: J-NZ0433-014-M-FINAL

Document Title: Previous TSS Studies

This memorandum reviews hydrological literature related to Total Suspended Solids (TSS) within Stockton Mine waterways, and at the existing Escarpment Mine and aims to develop source terms for water and load balance models for the proposed Escarpment Extended and Mount Frederick South sub-areas.

INTRODUCTION

Bathurst Resources Limited (BRL) is seeking to obtain authorisation, through the Fast-track Approvals Act, to progress development and mining of the coal resources across the wider Buller Plateaux. The project is known as the Buller Plateaux Continuation Project (BPCP or Project).

The purpose of the BPCP is to re-consent the existing infrastructure and mining operations associated with the existing Stockton Mine and provide access to additional coal mining areas across the Buller Plateaux, as the coal resource in the current Stockton Mine is close to depletion, and further coal resources for blending are required. There are five key Project sub-areas:

- Stockton mining area (Stockton)
- Mount Frederick South (MFS)
- Escarpment Extended (ESE)
- Upper Waimangaroa Haul Road (UWHR)
- Cypress mining area (Cypress)

Mine Waste Management Limited (MWM) have developed this memo to support BRL with the assessment of environmental effects (AEE) for its proposed mining activities. This memorandum relates specifically to the assessment of TSS for the Project.

Stockton Coal Mine experiences high rainfall due to its location and local orographic effects. As a result, annual precipitation increases from 3000 mm at the coast to 6000 mm at Stockton. Frequent extreme rainfall events exceeding 200 mm/day can occur in any season (Elder et al., 2011).

Rainfall can be highly variable throughout the year, with monthly rainfall ranging from 104 mm to 1,612 mm being observed at Stockton Met. On average, March receives the least rainfall (353 mm), with December receiving the most (632 mm). January to April is described as the drier period while September to December is described as the wet period (Chater, 2024).

WATER QUALITY LIMITS

The water quality consent (RC10193) for the existing Escarpment Mine is used to define water quality reference values for determining whether potential constituents of concern (PCOC) are elevated (Table 1). While the water quality consent conditions were developed in 2013 for the downstream monitoring site, WM-2, they provide a useful reference for indicating if a PCOC is elevated.

Table 1: Receiving waters median concentration compliance limits at monitoring site W-M2

PARAMETER	REFERENCE VALUES	
pH (pH Units)	4.5 - 6.5	
MEDIAN CONCENTRATIONS		
Total Suspended Solids (mg/L)	15	
Turbidity (NTU)	15	
Iron + Manganese (mg/L)	1.1	
Aluminium (mg/L)	0.5	
MEDIAN pH	pH > 5.5	pH < 5.5
Cadmium (mg/L)	0.0003	0.0012
Chromium (mg/L)	0.05	0.2
Cobalt (mg/L)	0.044	0.18
Copper (mg/L)	0.002	0.0013
Lead (mg/L)	0.0065	0.026
Nickel (mg/L)	0.017	0.068
Zinc (mg/L)	0.012	0.054

Limits for nickel and zinc are based on a median water hardness of 50 mg CaCO₃/L.

LAND SURFACE ERODIBILITY

Rainfall can create the conditions for the mobilisation of soils and has the potential to generate high levels of TSS in the waterways. Landforms and surfaces across Stockton exhibit differing levels of erosion and sediment loss. The following landforms / surfaces are considered within the literature review and are briefly described:

- Active mining areas – overburden stripping areas, unrehabilitated engineered landforms (ELFs), and exposed coal areas are vulnerable to high TSS concentrations in runoff due to the lack of protective cover and significant surface disturbance (e.g., blasting and material disturbance).
- Rehabilitated areas – includes land that has been rehabilitated through vegetation direct transfer (VDT), hydro-seeding, straw mulching, and plantings. Such areas all report lower TSS levels, indicating the success of these erosion control measures in reducing sediment loss and improving water quality.
- Haul roads and hardstands – these areas experience variable sediment runoff, with compacted surfaces generating less TSS compared to loose unrehabilitated soil areas.

LITERATURE REVIEW

WMG (2014) provide water quality data for various mine surfaces, showing that active mining areas, coal floors, and highwalls contribute significantly to TSS due to direct exposure to erosive processes, while rehabilitated ELF's have lower sediment transport rates. Shadbolt and Weber (2007) and Elder et al. (2011) describe two erosion studies completed at Stockton Mine over the course of a year.

Shadbolt and Weber (2007) describe a field trial in which erosion gutters were established at the base of six test plots. Five of the plots had different erosion reduction methods placed over the soil while a sixth (bare soil) was used as a control (C). The erosion reduction methods included:

- Hydro-seeding applied at a high rate (35 kg grass seed/ha)
- Hydro-seeding applied at a medium rate (13 kg grass seed/ha)
- Straw mulch applied at a medium rate (3.5 t wheat straw/ha)
- Straw mulch applied at a high rate (5 t wheat straw/ha)
- Polyvinyl alcohol-based binding agent, Binder8 (B8)

The trial was designed to direct surface water runoff into sediment and water catch troughs, which passed the water runoff through a coarse mesh and a splitter, to separate one tenth of the runoff into a collection drum. The catch-troughs allowed sediment accumulation, however, TSS results were obtained from water samples taken from the collection drums. For 25 weeks, weekly samples were obtained; sporadic samples were then taken for the remainder of the 52-week trial.

The trial illustrated the benefits of straw and hydroseeding to reduce erosion, where straw demonstrated low TSS over the entirety of the trial and hydroseeding demonstrated improvement after grass strike was established. It was also noted that soil armouring by larger particles reduced the erosion rate of the control plot over time as the fines were washed away. The binding agent B8, produced poor results.

Average TSS data obtained from each study plot was as follows:

- Hydroseeding: 2,787 - 3,489 mg/L.
- Exposed soil: 3,710 mg/L.
- Soil stabilised with straw mulch: 249 - 328 mg/L.
- Binding agent: 10,279 mg/L.

These results are illustrated in Figure 1.

Elder et al. (2011) describes Bonisch and Rossiter (2011) field sampling data which identifies significant sediment generation from active coal pits and overburden areas. The sampling data is summarised as follows:

- 854 mg/L for old overburden dump.
- 49,260 mg/L for active overburden dump.
- 22,348 mg/L for active coal pit.
- 61 mg/L for VDT.

- 31 mg/L for hydro-seeded slopes.
- 74 mg/L for straw mulched slopes.

These results are illustrated in Figure 2.

It should be noted that another active overburden dump and coal pit were sampled at a similar time and indicated results of 9,715 mg/L and 5,368 mg/L respectively (Bonisch and Rossiter, 2011). The above results illustrate the range of erosion possible from overburden dumps and active pits and the potential range of TSS that may be generated as a result.

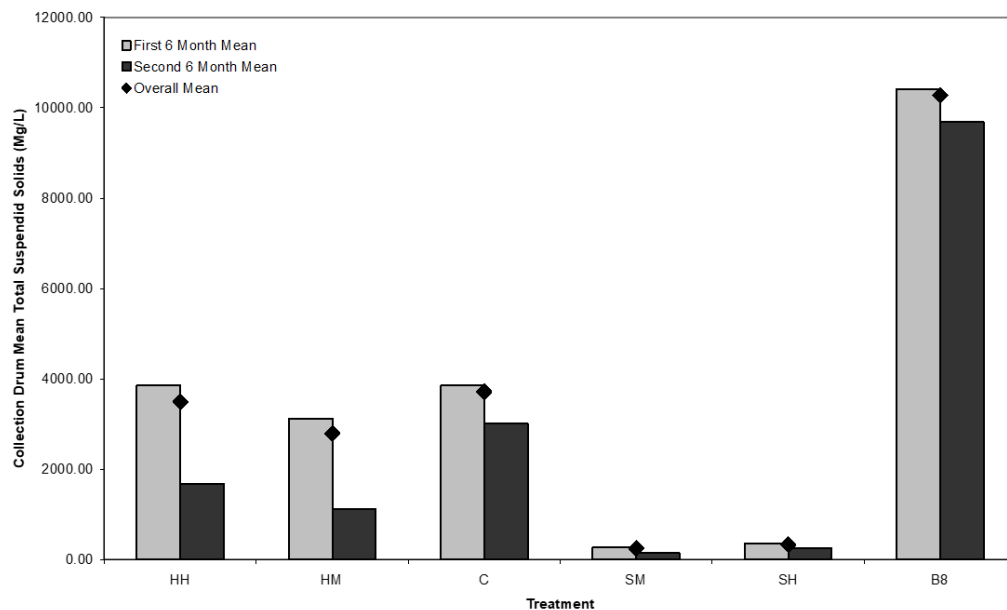


Figure 1: Mean TSS (mg/L) for all trial plots divided into 6 monthly intervals.

Source: Shadbolt and Weber (2007)

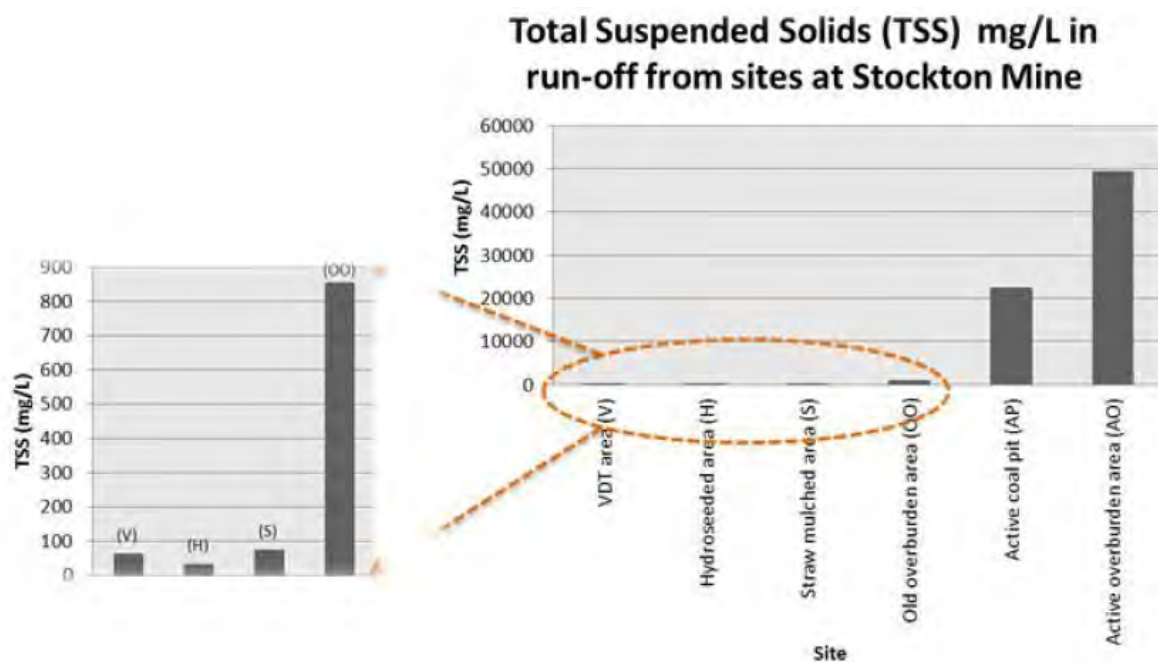


Figure 2: TSS (mg/L) in water run-off from sites under different treatments.

Source: Elder et al. (2011)

For the consent application of the existing Escarpment Mine, Golder (2013) compared the results from Elder et al. (2011), with figures calculated using the Modified Universal Soil Loss Equation (MUSLE). It can be seen (Table 2), that modelled peak erosion rates are greater than observed TSS, whereas mean modelled TSS are mostly lower than observed (apart from re-vegetated ELFs).

Table 2: Expected average TSS (mg/L) for mine-influenced water.

	YIELD (tonnes)	AVERAGE TSS (mg/L)	PEAK TSS (mg /L)	STOCKTON (PIZEY et al. 2012) (mg /L)
PIT	26.05	10,000	45,000	22,348
Elf- Uncovered Runoff	14.4	18,500	82,000	49,260
Elf- Covered and Revegetated Runoff	0.697	330	1,500	31-74
Hardstand	1.95	800	3,400	N/A
Road	3.12	1,200	5,400	N/A

Source: Golder (2013).

Elder et al. (2011) referenced as Pizey et al. (2012) - Noting this was the same paper but presented at two different conferences.

URS (2011) compare historic TSS estimates for Stockton Mine (Beca, 2005) with estimated TSS concentrations based on data from Mangatini Sump (from a Lower St Pats Reservoir capacity assessment study) (see Table 3). It is suspected that the URS estimates were then used in subsequent reports such as Golder (2012) and WMG (2014). The URS (2011) estimates were generated for the use in water balance models run using a daily time step, whilst the Beca (2005) estimates were based on a 1-hour storm of approximately 8 mm. URS (2011) comment that these estimates are subject to a high level of uncertainty due to methods used and the limited datasets available.

Table 3: Comparison of TSS (mg/L) concentration estimates from previous literature.

MINE AREA	90TH PERCENTILE TSS CONCENTRATION	
	URS ESTIMATE (mg/L)	Beca ESTIMATE (mg/L)
Active Pit	2,500	6,300
Active Backfill	5,000	31,000
Haul Road	1875	6,850
Old Backfill/Partial Rehabilitation	250	390
Rehabilitated Backfill	12	190

Source: URS (2011)

A soil armouring study by Cochrane et al. (2007) reports on experimental steep slope erosion, demonstrating that fine soil particles are quickly eroded and leave behind a coarse surface layer that protects against further sediment loss. This process is known as soil armouring and was observed to reduce erosion rates by over 75% in high-rainfall environments (Cochrane et al., 2007); this can be observed in the Elder et al. (2011) data of active and older overburden areas.

SOURCE TERMS

TSS concentrations vary across different mining landforms due to spatial variability in soil, rainfall intensity, slope and landform stability. Soil stripping zones, coal floors, and highwalls, also exhibit temporally variable erosion rates, making estimation of TSS values more qualitative than definitive (given the range of conditions under which observations are made). This section reviews the characteristics of the different types of land surface associated with mining activities.

Active Mining Areas

Active mining areas experience high levels of erosion and subsequent sediment runoff due to the surface disturbances from excavation and machine movements. Table 4 presents the TSS concentration from the runoff of active mining areas during different rainfall intensities, as stated from previous literature.

Table 4: Literature values of TSS (mg/L) in response to rainfall on active mining areas.

LANDFORM/SURFACE TYPE	TSS (mg/L)	RAINFALL	SOURCE
Active Mining Areas	49,260	80 mm/day	Elder et al. (2011)
Active Coal Pit	22,348	80 mm/day	Elder et al. (2011)
Active Coal Pit	2,500	*	URS New Zealand Limited (2011)
Active Coal Pit	6,300	8 mm/hr #	Beca (2005) ¹
Pit	2500	800 mm/day	WMG (2014)

* Figure represents the 90th %ile TSS concentration for use in daily timestep modelling; rainfall based on daily average

Figure represents the 90th %ile TSS concentration based on a 1-hour target storm (approx. 8 mm/hr)

1. Report uncited – data obtained from URS (2011)

Unrehabilitated ELF's

Unrehabilitated ELF's are susceptible to erosion and sediment loss and will therefore potentially contribute to the TSS in runoff. Table 5 presents the TSS and corresponding rainfall data for unrehabilitated ELF's from previous literature.

Table 5: Literature values of TSS (mg/L) in response to rainfall on unrehabilitated ELF's.

LANDFORM/SURFACE TYPE	TSS (mg/L)	RAINFALL	SOURCE
Active Overburden Dump	49,260	80 mm/day	Elder et al. (2011)
Old Unrehabilitated ELF	854	80 mm/day	Elder et al. (2011)
Active Backfill	5,000	*	URS New Zealand Limited (2011)
Old Backfill	250	*	URS New Zealand Limited (2011)
Active Backfill	31,000	8 mm/hr #	Beca (2005) ¹
Old Backfill	390	8 mm/hr #	Beca (2005) ¹
ELF – Uncovered Runoff	5,000	800 mm/day	WMG (2014)

ELF – Uncovered Seepage	20	800 mm/day	WMG (2014)
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* Figure represents the 90th %ile TSS concentration for use in daily timestep modelling; rainfall based on daily average

Figure represents the 90th %ile TSS concentration based on a 1-hour target storm (approx. 8 mm/hr)

1. Report uncited – data obtained from URS (2011)

Hardstand / Haul Roads (NAF and PAF)

Hardstand and haul roads are vital transportation routes for mining activities. However, these areas can be prone to erosion, especially during rainfall events. Resulting TSS levels in runoff tend to vary depending on the road type and road use. Table 6 presents key TSS data related to the mine-site hardstands and haul roads, derived from previous literature.

Table 6: Literature values of TSS (mg/L) in response to rainfall on hard stands and haul roads.

LANDFORM/SURFACE TYPE	TSS (mg/L)	RAINFALL	SOURCE
Haul Road	1,875	*	URS New Zealand Limited (2011)
Haul Road	6,850	8 mm/hr #	Beca (2005) ¹
Road	1,875	800 mm/day	WMG (2014)

* Figure represents the 90th %ile TSS concentration for use in daily timestep modelling; rainfall based on daily average

Figure represents the 90th %ile TSS concentration based on a 1-hour target storm (approx. 8 mm/hr)

1. Report uncited – data obtained from URS (2011)

Exposed Soil

In the absence of vegetation, exposed soils (including areas stripped of vegetation ahead of mining) are at risk of erosion during rainfall events that generate runoff. Mobilisation of fine soil particles from these areas will lead to an increase in TSS in rainfall runoff.

Field observations at Stockton indicate that up to 50 mm of soil loss can occur from engineered landforms (after topsoil spreading during the rehabilitation process) prior to soil armouring occurring (Elder et al. 2011). Table 7 through Table 10 describe experimental results (Cochrane et al., 2007) and modelled results (Cochrane, 2006) that relate soil erosion rates to different rainfall intensity on topsoil.

Table 7 describes results from the laboratory experiment which observed the effect of simulated rainfall over different material capping systems. Three small plots (900 mm by 600 mm in area), each had 210 mm depth of soil as the upper layer and were irrigated with different rainfall intensities. Soil loss was measured and reported as a yield relative to each simulated rainfall intensity (which represented storms with different annual recurrence intervals). Resulting runoff ratios ranged from 0.5 to 0.9 depending on rainfall intensity and resulted in soil loss of up to 1.4 kg/m² for the highest rainfall intensity.

Table 7: Observed inter-rill erosion for experimental topsoil erosion plots.

RAINFALL INTENSITY (mm/hr)	AVERAGE RECURRENCE INTERVAL (Years)	SOIL LOSS (kg/m ²)	RUNOFF RATIO
22	0.2	0.05 to 0.09	0.5 to 0.7
45	1	0.37 to 0.46	0.7 to 0.8
68	25	1.00 to 1.40	0.8 to 0.9

Source: Cochrane (2006)

Table 8 describes results from the Water Erosion Prediction Project model (WEPP) using the same inputs as the laboratory setup described above (and illustrated in Table 7). The observed results were used to calibrate and validate the model for the observed laboratory conditions.

Table 8: Modelled soil loss from topsoil erosion plots described in Table 7.

RAINFALL INTENSITY (mm/hr)	AVERAGE RECURRENCE INTERVAL (Years)	SOIL LOSS (kg/m ²)	RUNOFF RATIO
22	0.2	0.064	13.69/22 = 0.6
45	1	0.408	36.59/45 = 0.8
68	25	1.103	59.57/68 = 0.88

Source: Cochrane (2006)

Table 9 and Table 10 present results from the calibrated WEPP model when it is parameterised for a 20 m (horizontally measured) surface with a 20% slope. Table 9 presents simulation results with no vegetation on the surface which indicated a resulting average annual soil loss of up to 144 kg/m². Table 10 describes model results for vegetation grown on the soil surface over the course of the simulation period (1 year) and indicates an average annual soil loss of just 46 kg/m².

Table 9: Average potential soil loss over 1 year.

	LOW RAINFALL INTENSITY	HIGH RAINFALL INTENSITY	UNITS
Average Annual Precipitation	5,057	5,057	mm
Average Annual Runoff	3,032	3,208	mm
Average Annual Soil Loss	70	144	kg/m ²
Average Annual Sediment Yield	696	1,436	t/ha

Source: Cochrane (2006)

In summary, Cochrane (2006) notes that erosion rates reduce to 1 mm a year once vegetation is established and armouring has established. The experimental and modelling results indicated that soil loss increases with rainfall intensity, ranging from 0.05 to 1.40 kg/m² with higher rainfall recurrence intervals leading to a higher runoff ratio. Vegetation cover was seen to reduce soil loss and sediment yield, with losses under high rainfall decreasing from 144 to 46 kg/m².

Table 10: Impact of vegetation on soil loss

	LOW RAINFALL INTENSITY	HIGH RAINFALL INTENSITY	UNITS
Average Annual Precipitation	5,057	5,057	mm
Average Annual Runoff	2,399	2,741	mm
Average Annual Soil Loss	29	46	kg/m ²
Average Annual Sediment Yield	294	460	t/ha

Source: Cochrane (2006)

The experimental and modelled losses described by Cochrane et al. (2007) and Cochrane (2006) can be used to estimate TSS into receiving waters, however, unlike the Shadbolt and Weber (2007) data (Table 11), transported sediment that has accumulated at the base of the slope (and thus is not

transported into waterways), is not explicitly described and therefore can't be subtracted from sediment load that would be transported. This could result in over-estimation of TSS from the predicted soil erosion rates which do not reflect deposition of suspended sediment after initial erosion. Table 11 presents TSS data related to exposed soil, derived from previous literature.

Table 11: Literature values of TSS (mg/L) in response to rainfall on exposed soil

LANDFORM/SURFACE TYPE	TSS (mg/L)	RAINFALL	SOURCE
Soil Placement, No Vegetation, 18° Batter Slopes	3,710	Data based on weekly/sporadic samples over the course of year	Shadbolt and Weber (2007)
Soil Stockpile Orica Road	4,753	80 mm/day*	Bonisch (2011)

* Figure changed to be correlate with Elder et al. (2011) documentation (sampling taken within the same period).

Rehabilitated ELFs

Rehabilitated ELFs, which undergo vegetation restoration, report lower TSS levels due to the protective cover provided by vegetation and soil armouring. Table 12 summarises the range of TSS values measured from re-vegetated mine site slopes and surfaces found in previous reporting and literature.

Table 12: Literature values of TSS (mg/L) in response to rainfall on rehabilitated ELFs

LANDFORM/SURFACE TYPE	TSS (mg/L)	RAINFALL	SOURCE
Vegetation Direct Transfer (VDT)	61	80 mm/day	Elder et al. (2011)
Hydro-seeded slope	31	80 mm/day	Elder et al. (2011)
Straw mulched slope	74	80 mm/day	Elder et al. (2011)
Hydroseeding Applied onto Soil, 18° Batter Slopes	2,787 - 3,489	Data based on weekly/sporadic samples over the course of year	Shadbolt and Weber (2007)
Straw Mulch Applied onto Soil, 18° Batter Slopes	249 - 328	Data based on weekly/sporadic samples over the course of year	Shadbolt and Weber (2007)
Binding Agent Applied onto Soil, 18° Batter Slopes	10,279	Data based on weekly/sporadic samples over the course of year	Shadbolt and Weber (2007)
Rehabilitated Backfill	12	*	URS New Zealand Limited (2011)
Rehabilitated Backfill	190	8 mm/hr #	Beca (2005) ¹
Partial Rehabilitation	250	*	URS New Zealand Limited (2011)
Partial Rehabilitation	390	8 mm/hr #	Beca (2005) ¹
ELF Covered and Revegetated Runoff	250	800 mm/day	WMG (2014)
ELF Covered and Revegetated Seepage	5	800 mm/day	WMG (2014)
Rehabbed Forest Runoff	12	800 mm/day	WMG (2014)
Rehabbed Pakihi Runoff	12	800 mm/day	WMG (2014)

* Figure represents the 90th %ile TSS concentration for use in daily timestep modelling; rainfall based on daily average

Figure represents the 90th %ile TSS concentration based on a 1-hour target storm (approx. 8 mm/hr)

1. Report uncited – data obtained from URS (2011)

Highwalls

Exposed highwalls have steep slopes and bare surfaces and are susceptible to erosion during rainfall. The lack of vegetation cover allows for rapid water runoff, which transports sediment into surrounding waterways, increasing TSS levels. The level of erosion will depend on the highwall material and if rehabilitation can be achieved. There were limited literature values available that pertained specifically to highwall areas.

SUMMARY

The data presented in this memo indicates that rehabilitation and erosion control methods employed on mine sites reduce TSS concentrations. Active mining and backfill areas, and unrehabilitated ELFs exhibit higher TSS levels than rehabilitated areas (such as those stabilised with VDT, hydro-seeding, and straw mulching report lower levels). This emphasises the importance of effective land rehabilitation in reducing environmental impacts from rainfall-induced erosion in mining areas.

The reviewed literature, whilst providing data that will be of interest, is however, unable to draw any robust conclusions for the following reasons:

- Sampling and rainfall periods associated with each dataset do not align between different reports.
- The methods used to obtain TSS data are not universal, and in some cases, it is unclear as to how figures have been established or derived.
- It is our assumption the URS (2011) data have been utilised in the Golder (2013) and WMG (2014) reports, therefore resulting in repetition of some data.
- Some data have been taken without description of site conditions, as opposed to being drawn from ongoing field trials or long-term data collection programmes.

Therefore, use of empirical data for use as a source term for the water and load balance model is recommended. This is discussed in MWM (2026). These monitoring results provide an integrated measure of catchment performance and are used to calibrate and validate source term estimates. This ensures that future water and load balance modelling is based on observed site conditions rather than solely on literature-derived values.

It is noted that some reported erosion values are high. These have been checked for calculation errors, and where verification has been possible, results have been found to be consistent with the source data.

CLOSING REMARKS

Please do not hesitate to contact Paul Weber at [REDACTED] or [REDACTED] should you wish to discuss this matter in greater detail.

Attachments:	Attachment A - Sediment Runoff from Stockton Mine Landforms (Bonisch, 2011)
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	Attachment B - Consultancy Project Preliminary Report 1: Erosion and Runoff Modelling of Waste Rock Capping Slopes at the Stockton Mine (Solid Energy) (Cochrane, 2006)
	Attachment C - Soil Armouring, Sediment Yield, and Acid Rock Drainage from Steep Slopes Under High Intensity Rainfall in the West Coast of New Zealand. (Cochrane et al., 2007)
	Attachment D - Addressing the Environmental Effects of Mining on the Ngakawau River (Elder et al., 2011).
	Attachment E - Escarpment Mine Project: Mine Water Management Model, Escarpment Mining Area, Denniston Sector, Buller Coalfield, New Zealand (Golder Associates, 2012).
	Attachment F - Sediment and Erosion Control Plan: Escarpment Mine Project (Golder Associates, 2013).
	Attachment G – Performance of Erosion Control Products at Stockton Opencast Mine (Shadbolt and Weber, 2007).
	Attachment H – Stockton Sedimentation Pond Sizing Method Review (URS New Zealand Limited, 2011)
	Attachment I - Escarpment Mine Project: Assessment of Revised Water Management Approach (WMG, 2014).

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**ATTACHMENT A - SEDIMENT RUNOFF FROM STOCKTON MINE LANDFORMS
(BONISCH, 2011)**

Sediment Runoff from Stockton Mine Landforms

12th of May 2011

Rainfall Stockton Met - 12:00pm 11/5/2011 till 12:00pm 12/5/2011 = 41.8mm over 24 hours (medium rain event). Refer back page for hourly rainfall breakdown.

Results refer to back page from both the 4/4/11 and 12/5/11.

MF14 Coal Pit (active)

8:20am. Active coal pit at the top of Mt Fred, 10-15 degree slope on pit floor, covering 80 metres squared.



A10 Coal Pit (Active)

9:20am. Active coal pit, 10-12 degree slope on coal floor, covering 90 metres squared.



Hook Dump (Active tip head)

9:30am. Active tip head for overburden from Davies Block, Millerton and 4West. Sample taken from the bottom of three lifts/stages. Face is 10 metres in length. 37 degree slope.



Ross Dump (active tip head)

9:00am – Active tip head for overburden from AN11. Sampled at the bottom of lifts/stages. 37 degree slope with a 15 metre in length face.



MF16 Dump (old tip head)

8:28am – Old tip head with overburden from Mt Fred. 1.5-2 years old. 30-37 degree slope. Length of slope 15 metres. Sample at bottom of slope.



MF16 Hydroseeding

8:33am – Hydroseeding at MF16 exposed rock face. 30-40 degree angle of slope. 30+ metres in length. Sampled at bottom.



VDT Campbell Dump

10:04 – VDT from Millerton placed on 18-22 degree slope, 30+ metres in length of slope. 2-3 months since placed on slope.



Haul Road (2-5 Haul Road)

10:15am – Sample taken on the side of road where runoff from the surface was clearly visible. Road is used by light and heavy vehicles.



MGUT (Mangatini intake before lime dosing)

10:25am. The Mangatini intake captures water from 4 West, Rockies, Webb and Webb East, Augustus, Campbells and Managtini block.



Sample Bottle Clarity



MF16 Dump, Hook Dump, Ross Dump



A10 Coal Pit, MF14 Coal Pit



MF16 Hydroseeding, VDT Campbells



Haul Road, Managtini Intake Untreated

Sediment Runoff Locations



Results

Date 12/5/2011

SITE	Sample No	Date/Time	pH pH Units	NTU	TSS mg/L
VDT campbells	W11-3018	12/05/2011 10:04	4.1	2.2	<2.5
MF14 coalpit active	W11-3019	12/05/2011 8:20	4.4	745	2162
MF16 old overburden	W11-3020	12/05/2011 8:28	4.3	1340	1128
MF16 Hydroseeding	W11-3021	12/05/2011 8:33	5.0	1.3	<2.5
Ross dump active over/b	W11-3022	12/05/2011 9:00	3.5	372	1609
Hook dump active over/b	W11-3023	12/05/2011 9:30	2.2	4311	3713
A10 coal pit active	W11-3024	12/05/2011 9:20	3.5	2596	3067
Haul Rd	W11-3025	12/05/2011 10:15	6.3	5350	9153
MGUT	W11-3026	12/05/2011 10:25	2.8	1635	1359

Date 4/4/2011

SITE	Sample No	Date/Time	pH pH Units	NTU	TSS mg/L
VDT campbells	W11-2101	4/04/2011	3.8	7.5	61
Hope Dump Rehab (A10) Strawmulch	W11-2102	4/04/2011	3.8	30	73.8
MF14 coalpit active	W11-2103	4/04/2011	4.4	2240	5368
MF16 old overburden	W11-2104	4/04/2011	4.3	950	854
MF16 Hydroseeding	W11-2105	4/04/2011	5.0	16	31
Ross dump active over/b	W11-2106	4/04/2011	5.0	34700	49260
Hook dump active over/b	W11-2107	4/04/2011	3.1	4700	9715
A10 coal pit active	W11-2108	4/04/2011	4.0	3800	22348
Soil stockpile orica Rd	W11-2109	4/04/2011	4.9	2020	4753

Rainfall Data (mm/hr)

Time	Hourly Rainfall
3/04/2011 16:00	1.4
3/04/2011 17:00	2.6
3/04/2011 18:00	8.6
3/04/2011 19:00	4.4
3/04/2011 20:00	0.8
3/04/2011 21:00	2.6
3/04/2011 22:00	3.2
3/04/2011 23:00	0.2
4/04/2011 0:00	0.4
4/04/2011 1:00	6.2
4/04/2011 2:00	0
4/04/2011 3:00	1.4
4/04/2011 4:00	0
4/04/2011 5:00	0
4/04/2011 6:00	0
4/04/2011 7:00	1
4/04/2011 8:00	0
4/04/2011 9:00	0
4/04/2011 10:00	0
4/04/2011 11:00	2.2
4/04/2011 12:00	9.8
4/04/2011 13:00	12
4/04/2011 14:00	6.8
4/04/2011 15:00	9.4
4/04/2011 16:00	3.2
4/04/2011 17:00	3.2

Time	Hourly Rainfall
11/05/2011 12:00	0
11/05/2011 13:00	0
11/05/2011 14:00	0
11/05/2011 15:00	0
11/05/2011 16:00	0
11/05/2011 17:00	0.6
11/05/2011 18:00	0.6
11/05/2011 19:00	0.8
11/05/2011 20:00	5.2
11/05/2011 21:00	5.6
11/05/2011 22:00	0
11/05/2011 23:00	0.4
12/05/2011 0:00	1.4
12/05/2011 1:00	0.6
12/05/2011 2:00	2.8
12/05/2011 3:00	0.2
12/05/2011 4:00	9
12/05/2011 5:00	0.4
12/05/2011 6:00	0
12/05/2011 7:00	1.8
12/05/2011 8:00	8.2
12/05/2011 9:00	1.8
12/05/2011 10:00	0
12/05/2011 11:00	0
12/05/2011 12:00	2.4

**ATTACHMENT B - CONSULTANCY PROJECT PRELIMINARY REPORT 1: EROSION AND
RUNOFF MODELLING OF WASTE ROCK CAPPING SLOPES AT THE STOCKTON MINE
(COCHRANE, 2006)**

Consultancy Project Preliminary Report 1 (Nov 2, 2006):
Erosion and runoff modelling of waste rock capping slopes at the
Stockton mine (Solid Energy)

Natural Resources Engineering
Dept. of Civil Engineering
University of Canterbury

Introduction:

Runoff and soil loss was simulated with the WEPP (water erosion prediction project) model for the following conditions:

- Slope lengths: 10, 15, 20, 25, and 50 meters
- Soil type: 1 topsoil (the one currently being used in UoC experiments)
- Slope gradients: 15, 18, 20, 22, 25, and 30 %
- Climate: 0.2, 1, 25, and 100 year storm events as well as continuous climate as extrapolated from data provided by SE
- Plant cover: Simulation of soil loss and runoff will be conducted over bare soil conditions and under simulated plant growth.

The WEPP (water erosion prediction project) model simulates interrill and rill erosion from hillslopes. Rill and interrill erosion are the primary forms of erosion occurring on restored slopes at Stockton. Interrill and rill erosion are defined as:

Interrill erosion (sometimes referred to as sheet erosion): Raindrops striking exposed soil detach the soil particles and splash them into the air and into shallow overland flows. Raindrops striking these shallow flows enhance the flows' turbulence and help to transport more of the detached sediment to a nearby rill or flow concentration.

Rill erosion (concentrated flow erosion): Rill erosion is the removal of soil by concentrated water running through little streamlets, or headcuts. Detachment in a rill occurs if the sediment in the flow is below the amount the load can transport and if the flow exceeds the soil's resistance to detachment. As detachment continues or flow increases, rills will become wider and deeper.

Limitations:

- This analysis was based on 1 topsoil type found at Stockton.
- Calibration of the model was done using interrill erosion estimates from a series of laboratory studies under simulated rainfall of 22, 45, 68 and 80 mm/hr.
- Model calibration for all slopes and slope lengths was based on laboratory plot experiments done only at an 18 degree slope angle.
- Experiments on rill erodibility have not been conducted and therefore rill erodibility estimates for the model have been based on the topsoil physical properties.
- The WEPP model does not automatically account for changes in soil structure (armouring). The reduction of long term soil loss due to armouring has been estimated based on results from the laboratory experiments.

Calibration and parameterization of the model:

The WEPP model was calibrated using data obtained from laboratory erosion experiments under simulated rainfall for a sample of Stockton topsoil at a slope of 18 degrees. Information from soil analysis and experiments was used to define parameters for the model (Appendix A). The model was run and compared with measured results (Table 1 and 2). Calibration and verification of the model with actual measured erosion data was successful.

Table 1. Observed interrill erosion immediately after topsoil application (summary of results from Gareth Jack 2006*):

Rainfall intensity (1 hour)	Average recurrence interval (years)	Soil loss (kg/m ²)	Runoff ratio
22 mm/hr	0.2	0.05 to 0.09	0.5 to 0.7
45 mm/hr	1	0.37 to 0.46	0.7 to 0.8
68 mm/hr	25	1.00 to 1.40	0.8 to 0.9

* 90 cm by 60 cm surface under simulated rainfall

Table 2. Calibration and verification of results using WEPP for 90cm by 60 cm plot.

Rainfall intensity (1 hour)	Average recurrence interval (years)	Soil loss (kg/m ²)	Runoff ratio
22 mm/hr	0.2	0.064	13.69/22 = 0.6
45 mm/hr	1	0.408	36.59/45 = 0.8
68 mm/hr	25	1.103	59.57/68 = 0.88

The interrill soil erodibility factor (K_i) for the topsoil (freshly applied) was determined to be approximately: $1.2\text{e}+006 \text{ kg}\cdot\text{s}/\text{m}^4$ (This value was derived from the experimental results). Infiltration and permeability values were obtained from field and laboratory studies.

Climatic data was obtained from solid energy. Intensity and average storm recurrence intervals were obtained from the analysis of the climatic data conducted by Beca.

Modelling Results

The quantity of soil loss (erosion) is a function of soil, topography, climate, vegetative cover, and conservation practices. For this modelling exercise we quantitatively compare results from the interactions of these factors:

Soil type: 1 type of topsoil from Stockton

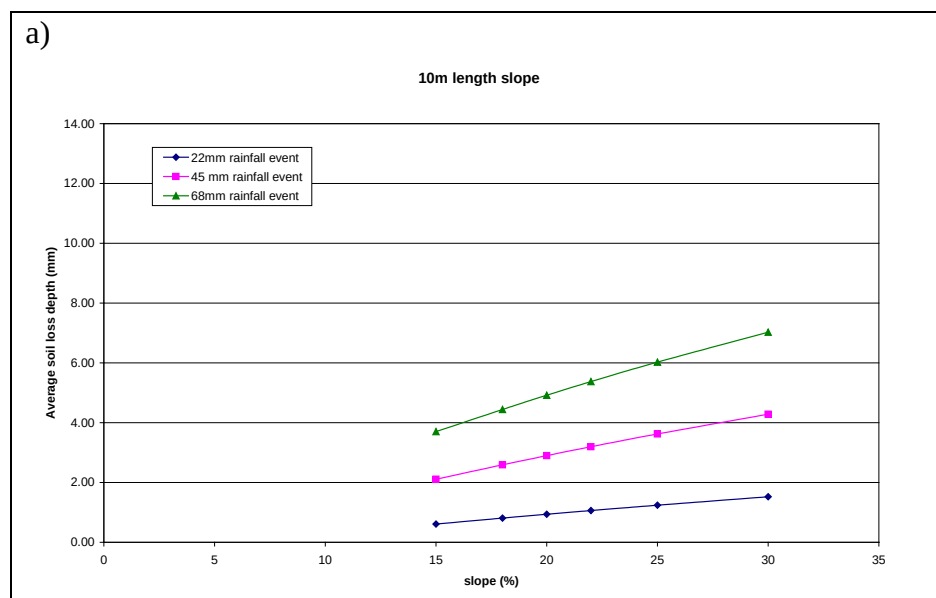
Rainfall intensity: 22, 45, 68 mm/hr (representing an average storm recurrence interval of 0.2, 1, and 25 year). The model has been set up to run other rainfall events as well as to simulate erosion from a series of long term continuous climate inputs.

Slope gradients: 15, 18, 20, 22, 25, 30 % slopes

Slope lengths: 10, 15, 20, 25, and 50 m

Q. How much erosion do we expect from slopes at Stockton at different slopes and lengths?

A. Figure 1 shows the potential soil loss in millimetres (mm) of depth of freshly applied topsoil as a function of gradient, slope lengths, and rainfall intensities. Results clearly show the interactions between slope and slope length under the 0.2, 1, and 25 year storms. These results can help in the selection and design of ideal slope gradients and lengths. Figure 2 shows the potential soil loss as a function of slope length for a 20% slope gradient. Results in kg/m^2 are presented in the attached spreadsheet. However, it is important to note that these results are based on soil loss from freshly applied topsoil. The phenomenon of armouring and its potential impact on long term erosion will be discussed further in this report.



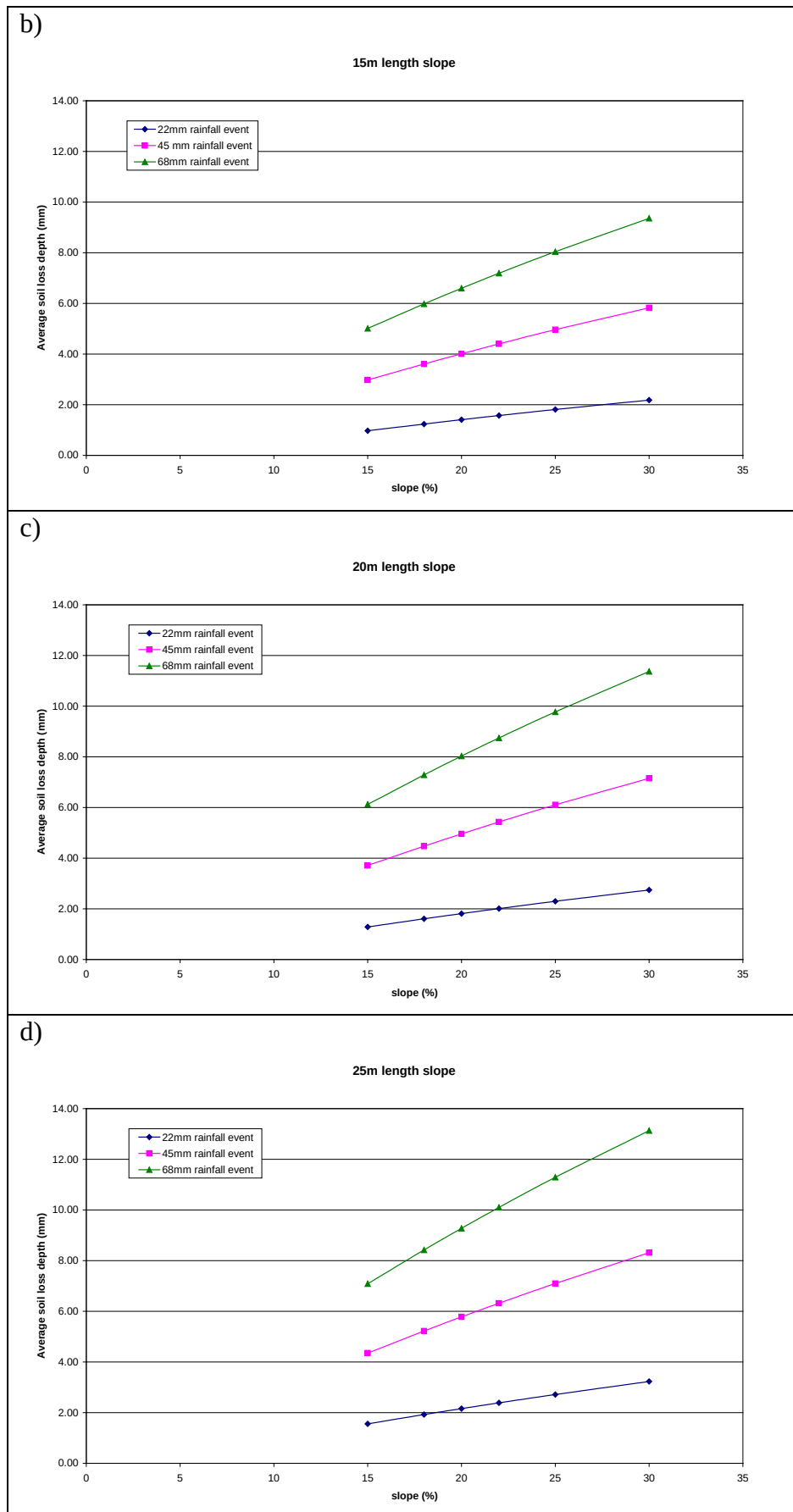


Figure 1. Soil loss as a function of slope and rainfall intensity for a) 10 m, b) 15 m, c) 20 m, and d) 25 m length slope.

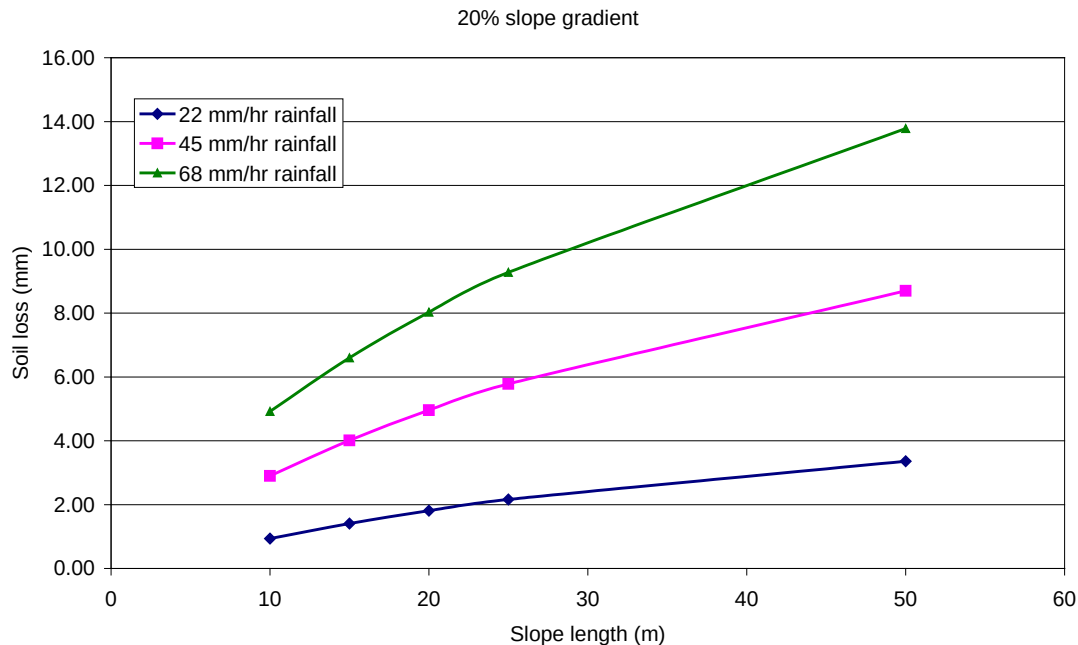


Figure 2. Soil loss (mm) as a function of slope length and rainfall intensity.

Q. How do the capping layers impact erosion?

A. Experimental results (Gareth Jack, 2006) suggest that the capping layers impact the infiltration rate of water. The smaller the infiltration, the greater the runoff and therefore higher soil loss is expected. For the modelling results presented here an average infiltration (permeability) has been used. However, specific modelling of erosion based on the properties of each capping layer (Granite, Silt Pond fines, and Granite/Ash, or others) can be done by altering the effective infiltration rate.

Q. How much and where do we loose soil along a slope profile?

A. Soil loss is greater towards the foot of the slope because runoff concentrates downslope creating greater shear stresses and inducing rill erosion. Modelling results of soil loss along a 20% slope profile (20m slope length) are shown in Figure 3 for an average low intensity and high intensity yearly simulation (5057 mm of rainfall). Although the overall results show that the average soil loss along the profile is 54 and 111 mm respectively, greater depths of soil loss are found toward the foot of the slope. In order to minimize or avoid damage to the capping layers it is important to reduce the slope length, slope gradient, or modify the shape of the constructed slope. However, it is also important to note that this simulation assumes no “armouring” occurs.

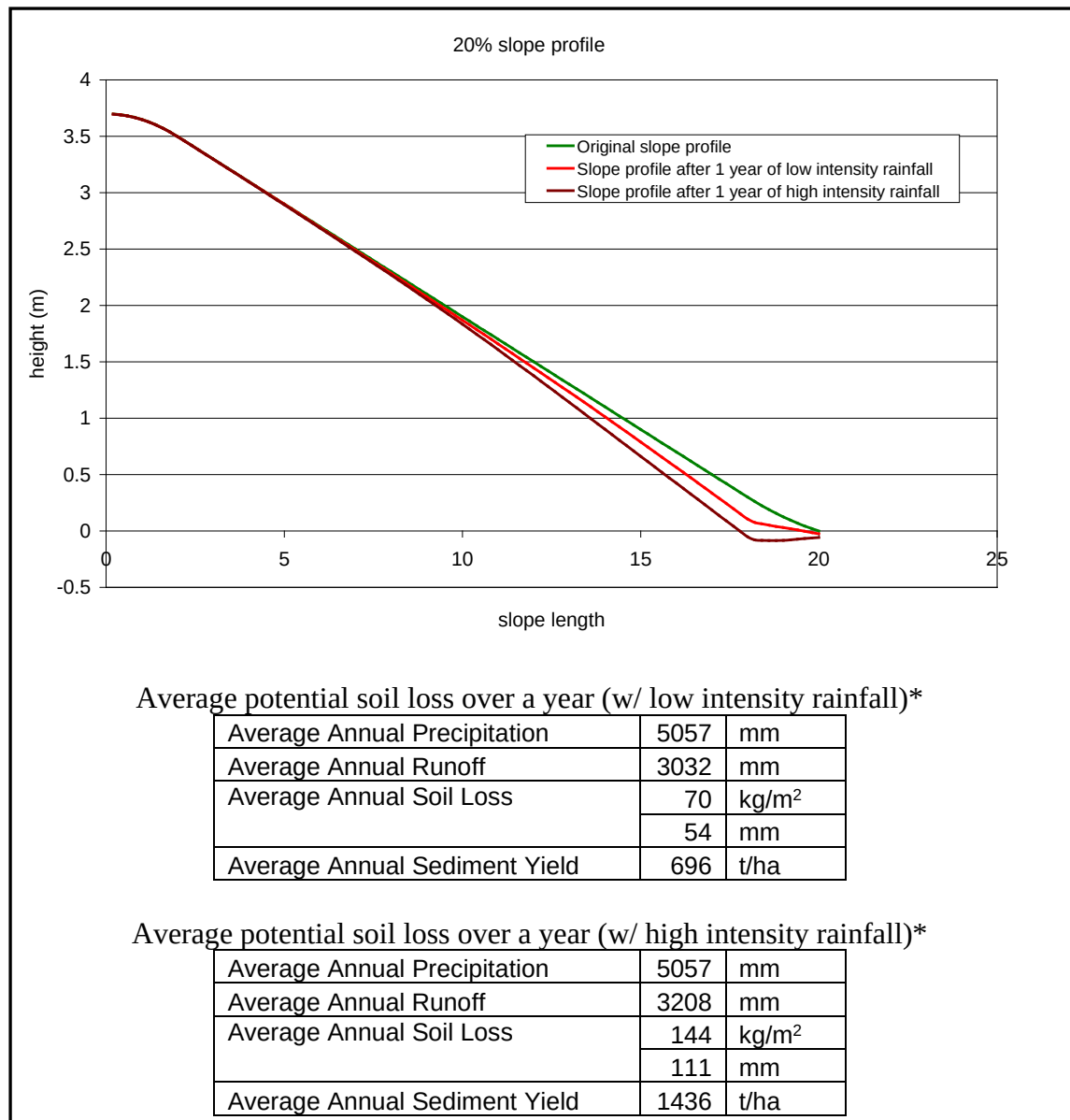


Figure 3. Slope profile soil loss after 1 year of high and low intensity rainfall (based on actual daily rainfall data from Stockton).

Q. Does armouring reduce soil loss over time?

A. Yes, experimental results show that armouring reduces the erodibility of the soil after a given number of storms. Initial estimates show that for interrill erosion at 18 degree slopes, at least 20mm of soil is lost before significant armouring occurs. It is estimated that under natural conditions it would take 3 to 6 months for the soil to armour itself and keep erosion rates below an average of 1 to 5 mm a year (further experimentation is needed to confirm this).

The factors that affect armouring (degree and time) are:

- Rainfall intensity and periods between rainfalls
- Slope angle / length
- Quantity of rocks/gravel in soil.

It is yet to be determined if armouring minimizes rilling or if rilling speeds up the armouring process.

Q. How much will vegetation cover reduce erosion?

A. Vegetation cover will significantly reduce erosion. Plant growth was modelled over a year (Figure 4) and soil loss over the year was simulated for conditions of high and low rainfall intensities (for a 20% and 20m slope). Results are shown in Figure 5. Once vegetation is established and armouring has set in, erosion is estimated to be reduced to below 1mm a year for 20% and 20m long slopes.

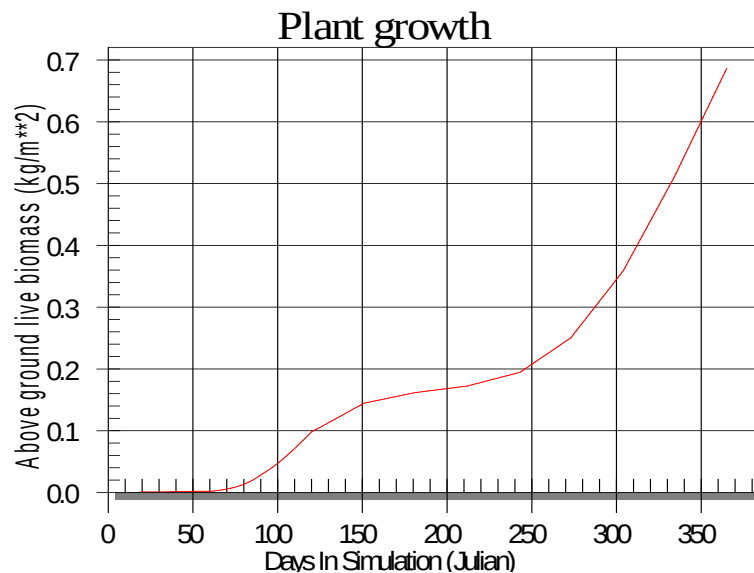


Figure 4. Simulated plant growth over a year.

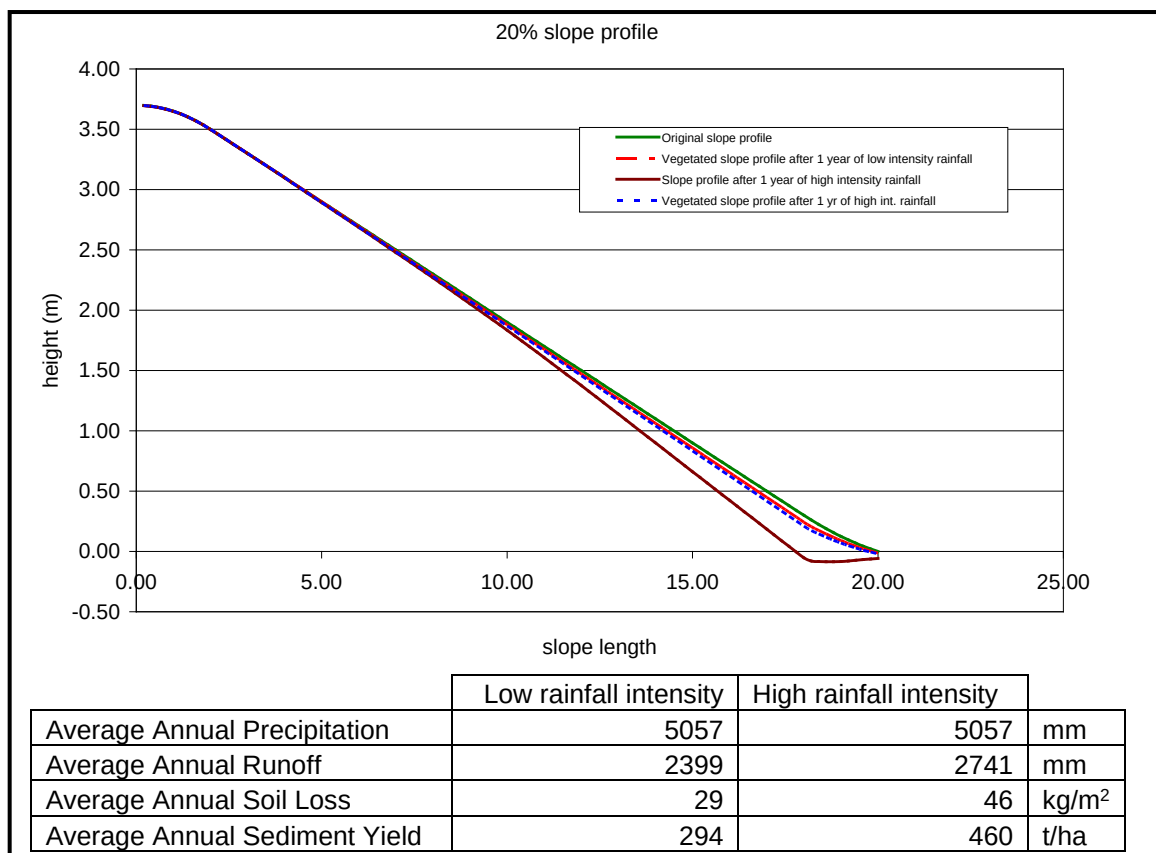


Figure 5. Impact of vegetation on soil loss.

Recommendations:

Further research is needed to study the armouring phenomenon. Extension of the experiments conducted in the laboratory will help improve erosion estimates at different slopes and soil types (rock contents, capping materials, and infiltration characteristics). Experiments of armouring under concentrated flows (rills) are necessary to establish long term erosion estimates. Comparisons of laboratory results to field experiments are also necessary.

Improvement of long term modelling of erosion will require:

1. Hourly (or 15 min) rainfall data to derive rainfall intensity values (daily values are not sufficient to do this) – erosion estimates are dependent on rainfall intensity.
2. Other climatic factors are needed for long term plant growth, runoff, and erosion modelling (these include solar radiation, wind speed, temperatures – daily values are sufficient for these)
3. incorporation of the armouring phenomenon in the modelling (variable soil erodibility).
4. further laboratory and field test verification and calibration.

Appendix A.

Defining soils in WEPP: Soils in the WEPP program are defined by the following parameters.

Cation Exchange Capacity (CEC)

Cation Exchange Capacity is the quantity of cations adsorbed on soil particles per unit of mass of the soil under chemically neutral conditions (milliequivalents/100 grams of soil). CEC is used in the parameter estimation equations for hydraulic conductivity.

Range: 1 to 150

Standard soil tests usually provide a value for CEC of the soil. If you do not have a measured value for CEC of your soil, the tables provide suggested values for various soil types.

Rock (%)

In the WEPP model, rock fragments are assumed to reduce the cross sectional area of the soil profile, and therefore reduce soil hydraulic conductivity, soil porosity, and volumetric water contents (thetfc and thetdr):

$$K_s = K_s * (1 - r_{fg})$$

$$por = por * (1 - r_{fg})$$

$$thet_{fc} = thet_{fc} * (1 - r_{fg})$$

$$thet_{dr} = thet_{dr} * (1 - r_{fg})$$

Soil Texture

The soil texture class for the top soil layer. This name is for information only. No variable within the model is set based on soil texture name.

Albedo

Albedo is the percent of the solar radiation which is reflected back to the atmosphere. This parameter is used to estimate the net radiation reaching the soil surface.

Possible Values: 0 to 100 (%)

Suggested Values for bare, dry soil: 5 to 20 (%).

The WEPP input parameter value is for a bare dry soil surface. The model will adjust the albedo for the effect of soil moisture, vegetation, residue cover and snow.

Initial Saturation Level

The definition of SAT is the percent of the porosity filled by water at the beginning of the simulation.

The continuous simulation option of the WEPP model operates for a minimum of one year with a starting date of January 1. Therefore, "initial" soil water content refers to the soil water content on January 1 of the first simulation year.

Recommended value for SAT is 70%, which is about 33 kPa (field capacity) for most soils.

Range: 0 to 100 (%)

The SAT parameter is used to indicate the soil water content of each soil layer. The soil water content of the top soil layer is changed daily depending on the infiltration of the rainfall, irrigation water and/or snow melt and, soil evaporation and percolation to the lower layer.

The soil water content of the lower soil layers are subject to change due to the percolation, plant transpiration, and/or flow to the drainage tiles.

Recommended value for SAT is 70%, which is about 33kPa (field capacity) for most soils.

Interrill Erodibility

Baseline interrill erodibility parameter ($\text{kg}\cdot\text{s}/\text{m}^{**4}$), expressed in scientific notation. Interrill erodibility reflects the susceptibility of the soil to detachment by raindrop impact and shallow flows.

The following sets of equations may be used to estimate this erodibility parameter.

For soils with 30% or more sand:

$$K_i = 2728000 + 192100 \cdot \text{VFS}$$

where VFS is percent very fine sand in the surface soil. VFS must not exceed 40%. If your value for VFS is greater than 40%, use 40% in the equation.

For soils containing less than 30% sand:

$$K_i = 6054000 - 55130 \cdot \text{CLAY}$$

where CLAY is percent clay in the surface soil. CLAY must not exceed 40%. If your value of CLAY is greater than 40%, use 40% in the equation.

Experimental K_i values are usually between 2,000,000 and 11,000,000 $\text{kg}\cdot\text{s}/\text{m}^{**4}$.

Another option to entering a value for interrill erodibility is to have the model calculate it based on other soil and input parameters. To do so, click on the appropriate Have Model Calculate check box for this parameter.

Rill Erodibility

Baseline rill erodibility parameter (s/m).

Rill erodibility reflects the susceptibility of the soil to shear detachment by water flowing in rills.

Equations may be used to estimate this erodibility parameter.

For surface soils containing 30% or more sand, the equation for K_r is

$$K_r = .00197 + .00030 \text{ VFS} + .03863 e^{-1.84 \text{ ORGMAT}}$$

VFS is percent very fine sand in the surface soil. VFS must not exceed 40%. If your value for VFS is greater than 40%, use 40% in the equation.

ORGMAT is percent organic matter in the surface soil. In the development of these equations, ORGMAT was assumed to be 1.724 times the organic carbon content. If ORGMAT is less than 0.35, use 0.35 in the equations.

For soils containing less than 30% sand, the equation for K_r is

$$K_r = .0069 + .134 e^{-.20 \text{ CLAY}}$$

If CLAY is less than 10%, use 10% in the equation for K_r for soils containing less than 30% sand.

Another option to entering a value for rill erodibility is to have the model calculate it based on other soil and input parameters. To do so, click on the appropriate Have Model Calculate check box for this parameter.

Critical Shear

Baseline critical flow hydraulic shear (N/m^2).

Critical shear is a threshold value, under which rill detachment does not occur.

For soils containing 30% or more sand, the equation is:

$$\text{TAUc} = 2.67 + 0.065 \cdot \text{CLAY} - 0.058 \cdot \text{VFS}$$

where VFS is percent very fine sand in the surface soil, and CLAY is percent clay in the surface soil. Neither VFS nor CLAY can exceed 40%. If either value is greater than 40%, use 40% for that variable in this equation.

For soils with less than 30% sand:

$$\text{TAUc} = 3.5$$

Experimental cropland TAUc values are usually between 1 and 6 N/m^2 , while experimental rangeland TAUc values are usually between 1.5 and 6.0 N/m^2 .

Another option to entering a value for critical shear is to have the model calculate it based on other soil and input parameters. To do so, click on the appropriate Have Model Calculate check box for this parameter.

Effective Hydraulic Conductivity

The key parameter for WEPP in terms of infiltration is the Green and Ampt effective conductivity parameter (K_e). This parameter is related to the saturated conductivity of the soil, but it is important to note that it is not the same as or equal in value to the saturated conductivity of the soil. The second soil-related parameter in the Green and Ampt model is the wetting front matric potential term. That term is calculated

internal to WEPP as a function of soil type, soil moisture content, and soil bulk density: it is not an input variable.

The effective conductivity (av_{ke}) value for the soil may be input on Line 4i of the soil input file, immediately after the inputs for soil erodibility. If the user does not know the effective conductivity of the soil, he/she may insert a zero (0.0) and the WEPP model will calculate a value based on the equations presented here for the time-variable case (see Equation 1 below).

The model will run in 2 modes by either: A) using a "baseline" effective conductivity (K_b) which the model automatically adjusts within the continuous simulation calculations as a function of soil management and plant characteristics, or B) using a constant input value of K_e . The soil file contains a flag (0 or 1) which the model uses to distinguish between these two modes. A value of 1 indicates that the model is expecting the user to input a K_b value which is a function of soil only, and which will be internally adjusted to account for management practices. A value of 0 indicates the model is expecting the user to input a value of K_e which will not be internally adjusted and must therefore be representative of both the soil and the management practice being modeled. It is essential that the flag be set consistently with the input value of effective conductivity for the upper soil layer.

Another option to entering a value for effective hydraulic conductivity is to have the model calculate it based on other soil and input parameters. To do so, click on the appropriate Have Model Calculate check box for this parameter.

Soil Layer (Read Only)

The number of soil layers depends on the variability of the soil water and physical properties of the soil horizons. Up to 8 input soil layers can be defined by the user. If the soil physical properties, such as texture, are not greatly different between two soil layers, it is recommended that only one soil layer be input. The WEPP model internally redefines soil layers (adds layers and resizes layers) into increments appropriate for infiltration and percolation computations.

Depth (mm)

The bottom depth of each soil layer from the soil surface is determined using this soil layer thickness parameter.

Range: 10 to 1200 (mm)

Sand (%)

Enter the percentage of sand content in the soil layer.

In WEPP, the sand content is used to estimate soil parameters such as soil bulk density, porosity, water retention curve, and effective hydraulic conductivity.

Range: 0 to (100 - %CLAY)

NOTE: The interface computes an acceptable input value for the SAND content based upon the current value of CLAY in the next input field, and it does not allow entry of a SAND content value that would make the total sum of SAND + CLAY exceed

100 %. If you have problems entering a high value of SAND content, first go to the CLAY entry field and enter the correct low value for CLAY content.

Clay (%)

Enter the percentage of clay content in the soil layer.

In WEPP, the clay content is used to estimate soil parameters such as soil bulk density, porosity, water retention curve, and effective hydraulic conductivity.

Range: 0 to (100 - %SAND)

NOTE: The interface computes an acceptable input value for the CLAY content based upon the current value of SAND in the previous input field, and it does not allow entry of a CLAY content value that would make the total sum of SAND + CLAY exceed 100 %. If you have problems entering a high value of CLAY content, first go to the SAND entry field and enter the correct low value for SAND content.

Organic Matter

Organic matter is an important part of a soil. Organic content in the soil modifies the soil's physical properties. Organic matter is mostly responsible for the increase of soil porosity, improvement of water and air relations, and reduction of erosion by wind and water.

In WEPP, organic matter is used to calculate soil bulk density, porosity, water retention curve, and erodibility parameters.

Typical values of soil organic matter depend on management practices and vary between 1 and 5 % on most typical soils. Standard soil tests usually report the value for soil organic matter.

Cation Exchange Capacity (CEC)

Cation Exchange Capacity is the quantity of cations adsorbed on soil particles per unit of mass of the soil under chemically neutral conditions (milliequivalents/100 grams of soil). CEC is used in the parameter estimation equations for hydraulic conductivity.

Range: 1 to 150

Standard soil tests usually provide a value for CEC of the soil. If you do not have a measured value for CEC of your soil, tables provide suggested values for various soil types.

Rock (%)

In the WEPP model, rock fragments are assumed to reduce the cross sectional area of the soil profile, and therefore reduce soil hydraulic conductivity, soil porosity, and volumetric water contents (thetfc and thetdr):

$$K_s = K_s * (1 - rfg)$$

$$por = por * (1 - rfg)$$

$$thetfc = thetfc * (1 - rfg)$$

$$thetdr = thetdr * (1 - rfg)$$

Use Restricting Layer

This is a new option for 2006 version soil files. If the check-box is checked a restricting layer can be set at the bottom of the soil profile. If the “User Defined” entry is selected the Ksat value for the layer can be entered, all other restricting layers have predefined Ksat values. The general type of bedrock are those given by Domenico and Schwartz(1997), representing the most commonly occurring sedimentary and crystalline rocks. For these rocks the vertical Ksat values range from 3×10^{-14} m/s for unfractured igneous and metamorphic rocks to 3×10^{-2} m/s for gravel.

KSat

This is the saturated hydraulic conductivity of the restricting layer if present. If a restricting layer is picked from the list then the Ksat value associated with that rock is used. If the “User Defined” entry is selected from the restricting layer selection box then a Ksat value can be entered.

Anisotropy Ratio

This is used to describe the relative predominance of lateral versus vertical flow. When information about the anisotropy ratio is available the user directly specifies the value. When a value is not known the default value of 25 can be entered. Domenico and Schwartz (1997) suggest a range of 1-1,000 for most geologic materials. Internal to the WEPP model the value of Ksat in the horizontal direction for each soil layer will in turn be altered by multiplying the Ksat values by the anisotropy ratio. Currently, a single anisotropy ratio is assigned for all soil layers.

**ATTACHMENT C - SOIL ARMOURING, SEDIMENT YIELD, AND ACID ROCK DRAINAGE FROM
STEEP SLOPES UNDER HIGH INTENSITY RAINFALL IN THE WEST COAST OF NEW ZEALAND
(COCHRANE et al., 2007)**



American Society of
Agricultural and Biological Engineers

An ASABE Meeting Presentation

Paper Number: 07xxxx

Soil armouring, sediment yield, and acid rock drainage from steep slopes under high intensity rainfall in the West Coast of New Zealand

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Written for presentation at the
2007 ASABE Annual International Meeting
Sponsored by ASABE
Minneapolis Convention Center
Minneapolis, Minnesota
17 - 20 June 2007

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Abstract. The loss of valuable topsoil due to erosion and the environmental impacts of acid rock drainage are two major concerns in the process of restoring landscapes in open cast coal mines in New Zealand's rainy West Coast region. To minimize acid drainage, waste rock material is covered with an engineered subsoil capping layer which reduces infiltration and is designed to minimize oxygen exposure of the underlying potentially acid forming waste rock. Topsoil, a valuable commodity at West Coast coal mining sites, is then used as a protective cover for the capping layer and as a medium for vegetation growth. The performance of a crushed granite material, a mixture of fly ash and granite, and silt pond sediments as capping materials to reduce infiltration and oxygen ingress were evaluated in the laboratory. The mixture of fly ash and granite were found to perform the best. Furthermore, a series of laboratory rainfall simulation experiments were conducted to quantify the sediment yield from rainfall events with intensities ranging from 22 to 80 mm/h at slopes of 18 degrees. The combination of high concentrations of gravel and rocks in the topsoil and the high intensity rainfall resulted in a rapid soil armouring process. Fine soil particles were quickly eroded leaving a coarse surface layer of rocks and gravel which offered enhanced erosion protection. Results showed over 75% reduction in erosion between highly armoured soils and freshly applied soil on steep hillslopes. Future modeling of armouring and soil loss at different slopes angles and lengths will help improve the design and management of restored landforms.

Keywords. erosion, armouring, mining, sediment yield, acid rock drainage

Introduction

Two major environmental concerns associated with coal mining are soil erosion of bare steep slopes and acid rock drainage. This is especially of concern in the West Coast Buller Coal field of New Zealand where annual rainfall exceeds 5000 mm and the topography is steep and rugged. As restoration efforts at mine sites in the region are currently underway, specific problems related to the minimization of acid generation and the quantification of erosion from restored slopes needed to be investigated.

Soil erosion of bare steep slopes

New Zealand has geologically young and vulnerable soils. In large surface mining operations such as the coal mines in the West Coast Buller Coal field of New Zealand, topsoil is a limited commodity and a valuable resource. Topsoil is used for restoring vegetation and for providing an adequate cover to protect the capping material used to cover potentially acid generating rock waste underneath. Excess topsoil loss due to erosion is not only detrimental to the environment, but is also an economic liability that can hinder the overall restoration effort. Significant effort is required to capture lost topsoil and prevent it from entering waterways.

To help in the design of engineered slopes and to mitigate environmental and economic losses during the mine restoration process, it is necessary to quantify the potential rate of soil erosion. Although under more normal circumstances the application of an erosion model such as RUSLE (Toy et al., 1999) or WEPP (Flanagan and Nearing, 1995) would have been adequate to estimate erosion rates, initial field observations had revealed the occurrence of significant soil armouring. During the soil armouring process fine soil particles are eroded quickly, leaving a coarse surface layer of rock and gravel. This coarse layer provides protection to the underlying soil, reducing further erosion. In other words, soil armouring effectively decreases sediment transport with time by preferentially stripping away fine particles (Sharmeen and Willgoose, 2006). Soil armouring is a process which is not readily simulated by WEPP or RUSLE unless changes in erodibility or rock cover are quantified. Furthermore, although a specific erosion and armouring model called ARMOUR (Willgoose and Sharmeen, 2006) has been recently developed; it has only been applied to a couple of mine sites in Australia and would need significant calibration with measured data. Given the unique combination of steep slopes, high rainfall and a soil whose erodibility properties change over time due to armouring; initial quantification of erosion rates and armouring potential had to be done by physical experiments.

Acid rock drainage

Acid rock drainage (ARD) is difficult to treat once it is created, and therefore preventing the acid forming at the source is a more effective method of control. Acid drainage is formed when pyrite rich overburden rock (waste rock from coal mining operations) is exposed to oxygen and water. The resulting water is usually high in acidity and dissolved metals which can adversely impact surrounding ecosystems and waterways. ARD affects aquatic living systems in numerous ways that can be loosely categorized as chemical, physical, biological, and ecological (Gray, 1997). The overall effect on the system is the reduction in stability through the simplification of the food chain due to elimination of species and habitat. Most vegetation can not tolerate the low pH that ARD introduces to waterways. Hydrogen ions cause inactivation of enzyme systems, restricting respiration and root uptake of minerals and water (Williamson et al., 1982).

To reduce acid generation, a wet capping system is being implemented for restoration of mine sites in the West Coast region. This system consists of covering the waste rock with a layer

(0.5 to 1m) of compacted capping material and then covering the capping layer with topsoil. This system relies on the saturation of the capping layer, with the saturated capping layer having a much higher ratio of water-filled pores to air filled pores. Oxygen travels 10,000 times faster through air-filled pores than water-filled pores (Kim and Benson, 1999). The wet capping system is ideal for the region as it takes advantage of the high rainfall to help keep the capping layer saturated. It is therefore necessary that the capping layer have a high water holding capacity and low permeability. It is also necessary that the capping material be sourced at the site, because it is economically restrictive to transport large quantities of capping material from other locations. Research was therefore needed to test the efficiency of potential capping materials at reducing infiltration and oxygen ingress. Materials that were readily available and selected as potential capping material were a weathered granite subsoil material, sediment deposited in silt ponds at mine sites, and a mixture of fly ash and the granite subsoil.

Materials and Methods

A series of controlled laboratory experiments were conducted to accurately quantify soil armouring, sediment yield, and capping material efficiency. Laboratory experiments enabled precise measurements of runoff, sediment yield, pH, infiltration, oxygen ingress, and other parameters under controlled simulated rainfall. This paper specifically reports on results from these controlled experiments.

Quantifying soil armouring, sediment yield and capping material efficiency in a controlled laboratory setup

The laboratory setup consisted of having three large containers (Figure 1) at an 18 degree angle under simulated rainfall (Jack, 2006). Simulated rainfall was designed to mimic actual events on-site based on measured rainfall records for the last 75 years. Each container had a depth of 665 mm, a length of 900mm and a width of 600mm. A filter layer of gravel was placed at the bottom of the containers which was connected to a series of infiltration tubes used to collect the infiltrate. Each bin contained three layers (Figure 2): the topsoil on the top, the waste rock at the bottom, and a different type of capping layer in each of the three containers (bins):

- Bin 1: Granite capping layer
- Bin 2: Sediment pond fines capping layer
- Bin 3: Granite/fly ash capping layer

Topsoil, waste rock, and capping materials were sourced directly from an active mine site and layered as shown in Figure 2. Fly ash, a waste product from coal combustion, was sourced from nearby industry. Fly ash and Granite and were mixed at a ratio of 1:5. All capping layers were compacted under the same compacting force and pressure to match field conditions. The 18 degree slope is a standard restoration slope angle at the West Coast coal mine site.

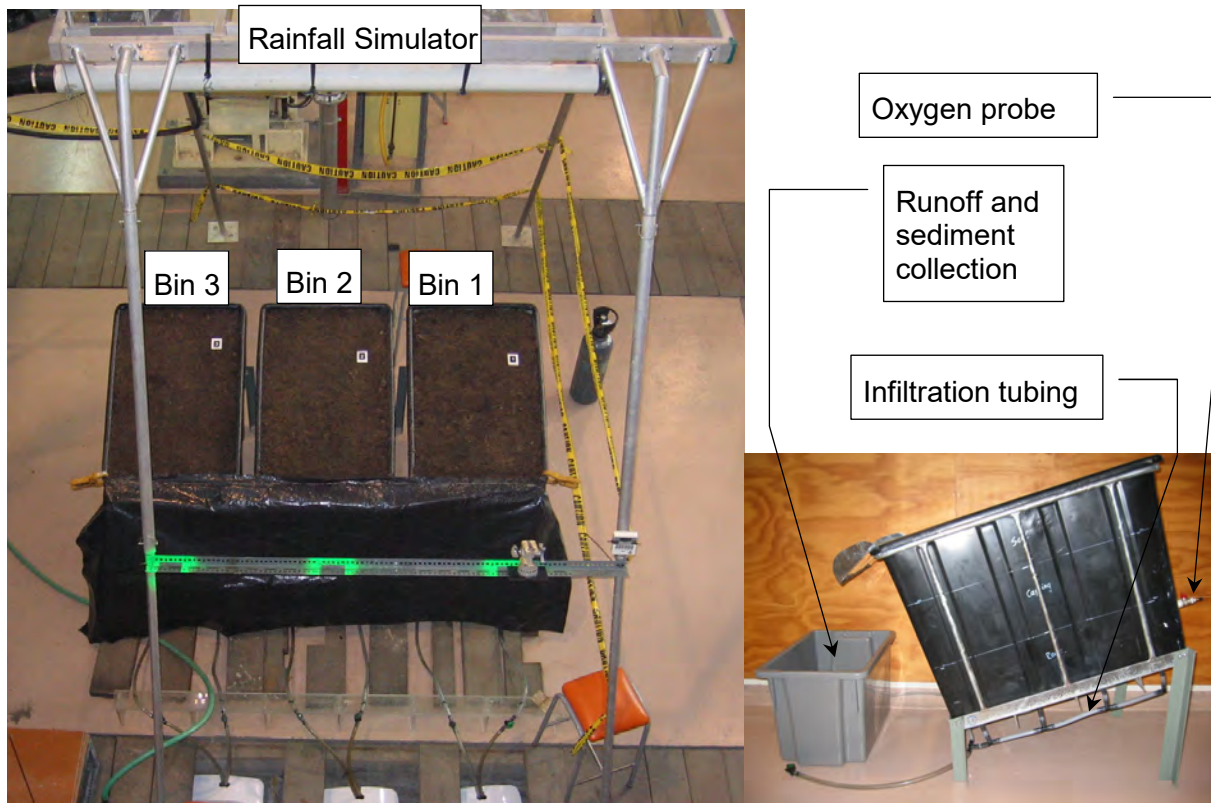


Figure 1. Experimental setup of 3 bins under a rainfall simulator.

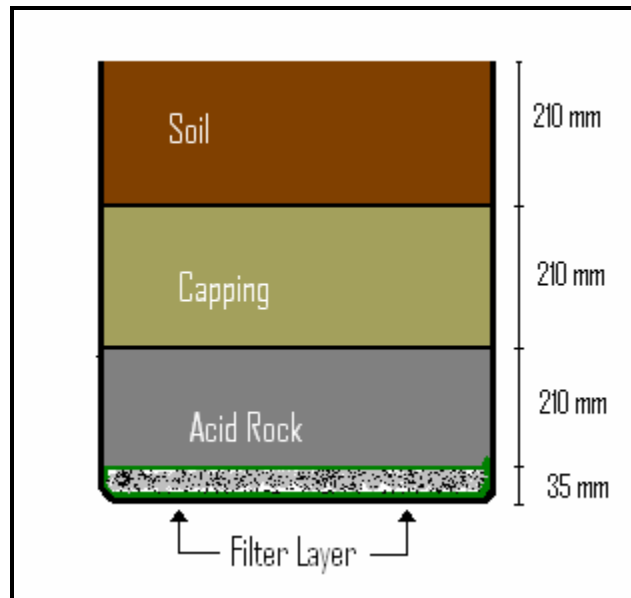


Figure 2. Experiment container depth and topsoil, capping material, and acid rock layering.

Experiments and measurements

Three main sets of experiments were conducted on the three bins:

1. Four consecutive 1 hour experiment simulations at 22 mm/hr intensity rainfall followed by a final storm event at 80 mm/hr intensity
2. Four consecutive 1 hour experiment simulations at 45 mm/hr intensity rainfall followed by a final storm event at 80 mm/hr intensity
3. Four consecutive 1 hour experiment simulations at 66 mm/hr intensity rainfall followed by a final storm event at 80 mm/hr intensity

After the last experiment set, another storm event at the intensity of 80 mm/hr was run followed by another two one-hour runs at 22 mm/hr. The purpose of this experiment was to quantify the reduction of erosion after the soil has been significantly armoured.

For each experiment, water and sediment runoff was collected. The coarse particles (particles greater than 212 μm) were separated from the fine particles (particles finer than 212 μm) using an appropriate sieve. All the coarse particles were captured in the sieve, and the rest of water and fine sediments were collected in a subbin. The coarse particles were transferred from the sieve to a beaker with the aid of deionised water and dried at 105°C in the oven. A representative sample of suspended fine sediments was collected from the subbin which was thoroughly stirred so the particles were suspended. Samples were dried in containers to quantify concentration of fine sediments. The pH of runoff was also recorded.

The volume of infiltration substrate was weighed and the pH recorded after each run. Samples of the leachates were sent to a certified laboratory (Hills Laboratory New Zealand) to be tested for acidity and dissolved metals (including dissolved aluminium (Al), dissolved iron (Fe), dissolved nickel (Ni), and dissolved zinc (Zn)).

Oxygen penetration into the waste rock was measured by taking gas samples from the waste rock layer. The gas samples were extracted using a self-pumping gas analyser from an oxygen probe placed in the waste rock layer (Figure 2). A return hose was added to the experimental bins to ensure that the extraction of gas samples did not create a negative pressure in the experimental profile therefore preventing drawing oxygen down through the capping rock layer. The oxygen probe fitting was also used to flood the waste rock with nitrogen prior to the experiment beginning. This enabled the monitoring of oxygen ingress throughout the experiment.

Limitations of laboratory simulations

Simulation in the laboratory offer many significant advantages, however, some limitations are worth noting particularly due to laboratory space availability and experimental container size. Since the simulations are conducted on a relatively small surface, only interrill (overland) erosion processes are observed. Soil armouring and sediment loss from concentrated flows (rills) were not studied. Large rocks, greater than 150 mm, often found in the granite capping material and the waste rock at the mine sites were excluded from the laboratory experiments. It is also important to note that the depth of the capping layer simulated in the laboratory studies is less than half of the actual depth used in field conditions.

Results and Discussion

Topsoil, capping material and waste rock properties

The topsoil used was classified as a Denniston series soil according to New Zealand soil surveys. Particle size distribution of the topsoil as well as the other subsoil materials is presented in Figure 3. The topsoil and subsoils contain large percentage of stones and gravels due to the excavation process and grabbing of underlying rock during soil extraction. It is important to note that less than 10% of acid waste rock material passed through the 19 mm sieve. Silt pond sediment had the highest percentage of finer particles as this sediment comes from silt ponds that collect eroded topsoil sediment. The particle size distribution of Granite alone show that only 1% of particles are smaller than 150 Gm. With the addition of fly ash, the percentage of particles finer than 150 Gm in the Granite/ash material increases to 21%.

Porosity and average particle density of the silt pond sediment, topsoil and granite material used for the laboratory simulations are shown in Table 1. The density of topsoil is significantly lower than the density of the other materials because organic matter and/or small quantities of coal were found in the topsoil.

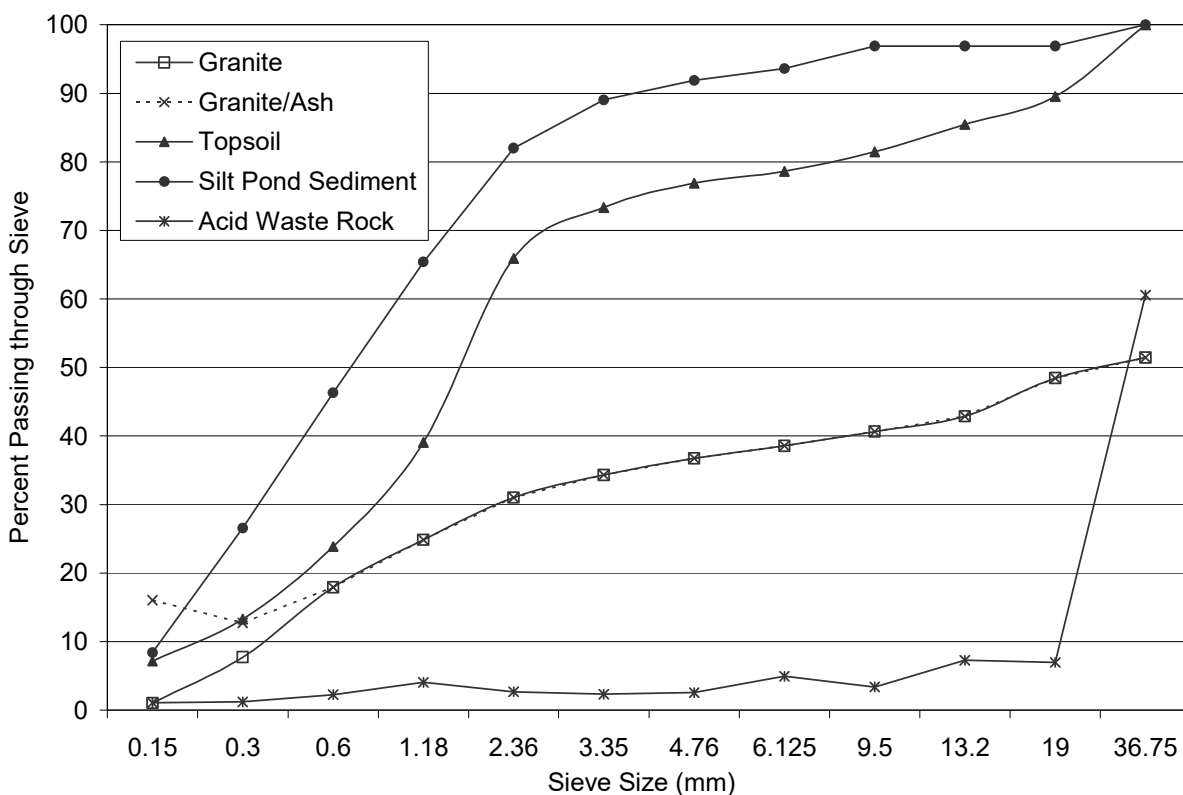


Figure 3. Particle size distribution of topsoil and subsoils used in the experiments.

Table 1. Sediment particle densities and porosities.

Soil or capping material	Porosity	Density (g/cm ³)
Silt pond sediment	0.275	2.55
Topsoil	0.336	2.23
Granite material	0.316	2.63

Soil armouring and sediment yields

The armouring phenomenon was qualitatively observed and quantified during the experiments. Figure 4 illustrates the observed surface change that occurs due to the armouring process. The depth of the armouring is dependent on gravel size. For the series of laboratory experiments conducted it was usually less than 1 cm on average (Figure 4c). About 2.5 mm of soil were lost to produce the armouring between Figure 4a and 4b.

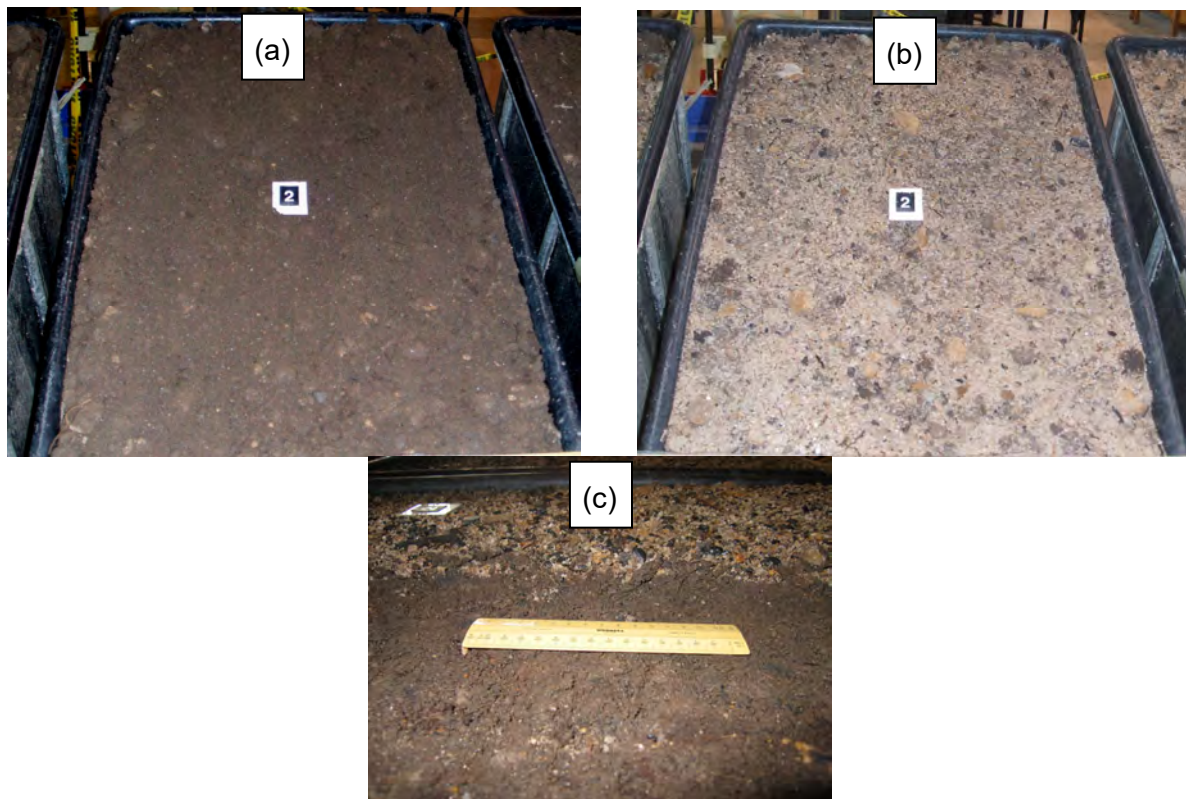


Figure 4. Photographs of the surface of experiment bin 2 showing (a) freshly applied soil, (b) heavily armoured soil after simulations, and c) the armouring layer.

Sediment yield measurements from the experiments clearly showed the effects of armouring. Figure 5 shows that after 4 hours of 22 mm/hr rainfall, a subsequent 80mm/hr rainfall event produces 32 g/mm of runoff. However after 4 hours of 66 mm/hr rainfall events a subsequent 80 mm/hr rainfall event only produces 23 g/mm runoff. In other words there is a reduction of over 30 % in erosion due to the armouring process that occurs. This armouring process is driven by the removal of fine sediments which leaves a layer of coarser material that is less

prone to erosion. The degree of armouring for the tested topsoil type is high due to the large particle size distribution of the topsoil.

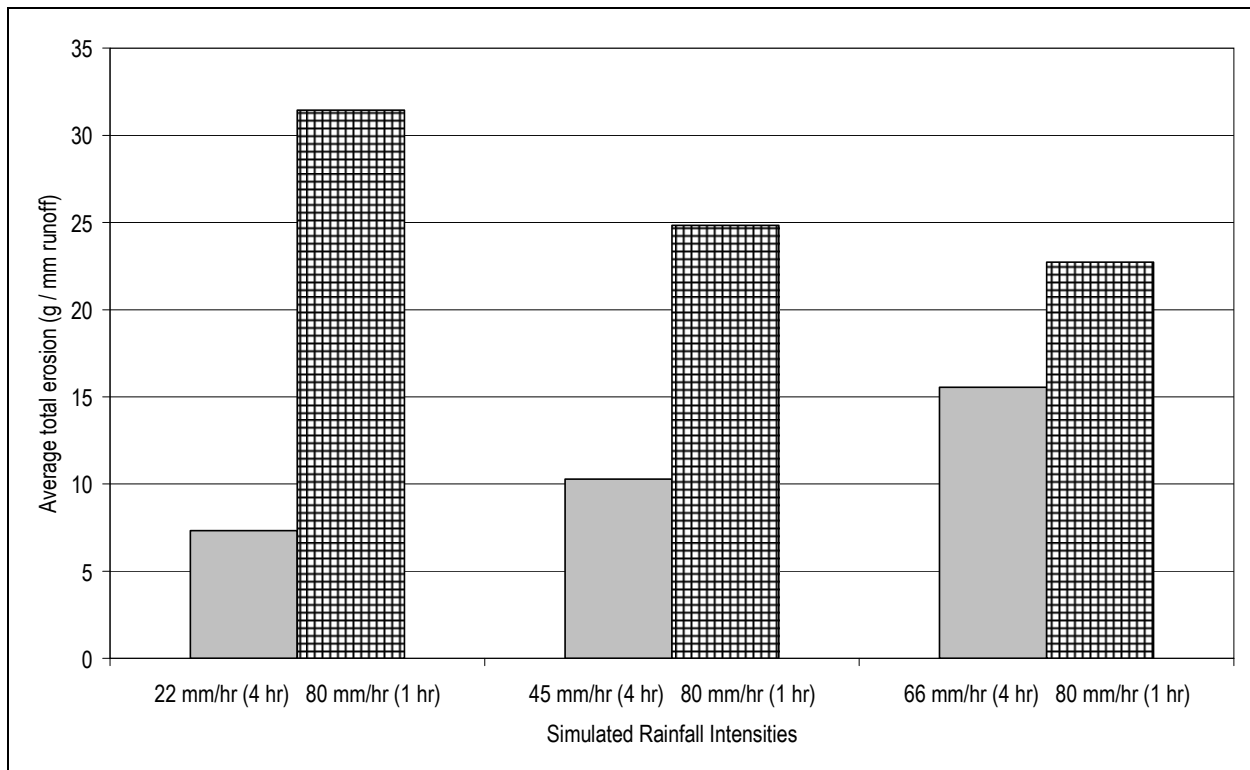


Figure 5. Total soil loss under showing effect of armouring at the 80mm/hr storm event after four hours of consecutive 22, 45, and 66 mm/hr rainfall events

Another example of the degree of armouring is shown in Figure 6. The experiments show erosion rates of freshly applied topsoil under 22mm/hr rainfall. Heavy armouring of this freshly applied soil was achieved by simulating four one hour 66 mm/hr storm events followed by two one hour 80 mm/hr storms. The armoured soil was finally submitted to two 22 mm/hr storm events and these sediment yields were compared to sediment yields from 22 mm/hr events on freshly applied soil. Results plotted in Figure 6 show a reduction of over 75% in total erosion rates after heavy armouring. The reduction in the erosion of finer sediments (less than 212 μ m diameters) is greater than the reduction in erosion rates of coarse sediments (greater than 212 μ m diameters). A one hour 22 mm/hr rainfall event represents a 0.2 year average storm return interval for the West Coast coal mines.

It is very clear that if armouring rates are not taken into account, erosion modeling would over5 predict sediment yields from hillslopes. By establishing the rate of armouring occurring and the reduction in erodibility, it is now possible to adjust models such as WEPP to accurately reflect erosion rates in the field.

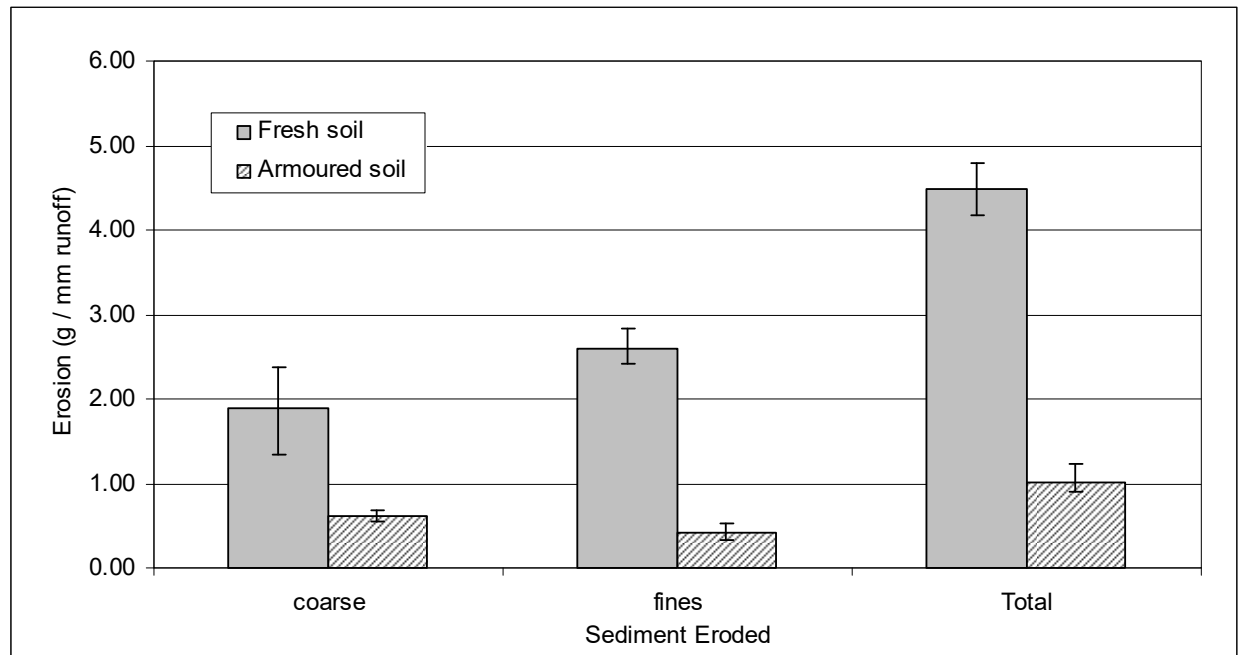


Figure 6. Observed armoring effect on soil erosion under 22 mm/hr rainfall (coarse sediment implies sediment with particle sizes greater than 212 Gm). Error bars show range of experimental results.

Capping material efficiency

The efficiency of the capping material can be quantified by the ability of the material to retain water and to reduce infiltration. The efficiency of the capping material can also be quantified indirectly by the quality of the infiltrated water. To compare infiltration rates between capping materials in the laboratory, the granite material was compacted to match field measurements as closely as possible. The other materials were then compacted using the same force and pressure as was applied to the granite material. A 10cm head of standing water was then applied to each bin and infiltration of this water was recorded over time. Infiltration results showed that both the silt pond sediment and the granite/ash mixture had lower infiltration rates than the granite material alone (Figure 7). Silt pond sediment had a particle size distribution that was finer than granite material and therefore it was expected that the infiltration through this material be lower. The mixture of ash with granite increased the quantity of fine particles in the capping material. This increase in fine material significantly increases the ability of the material to retain moisture and reduces the infiltration rate. Laboratory results of infiltration were also compared to field measurements (Table 2). Difference in results between laboratory and field conditions is mainly due to the difference in thickness of the laboratory simulated capping material (210 mm) versus actual field conditions (500 to 1000 mm).

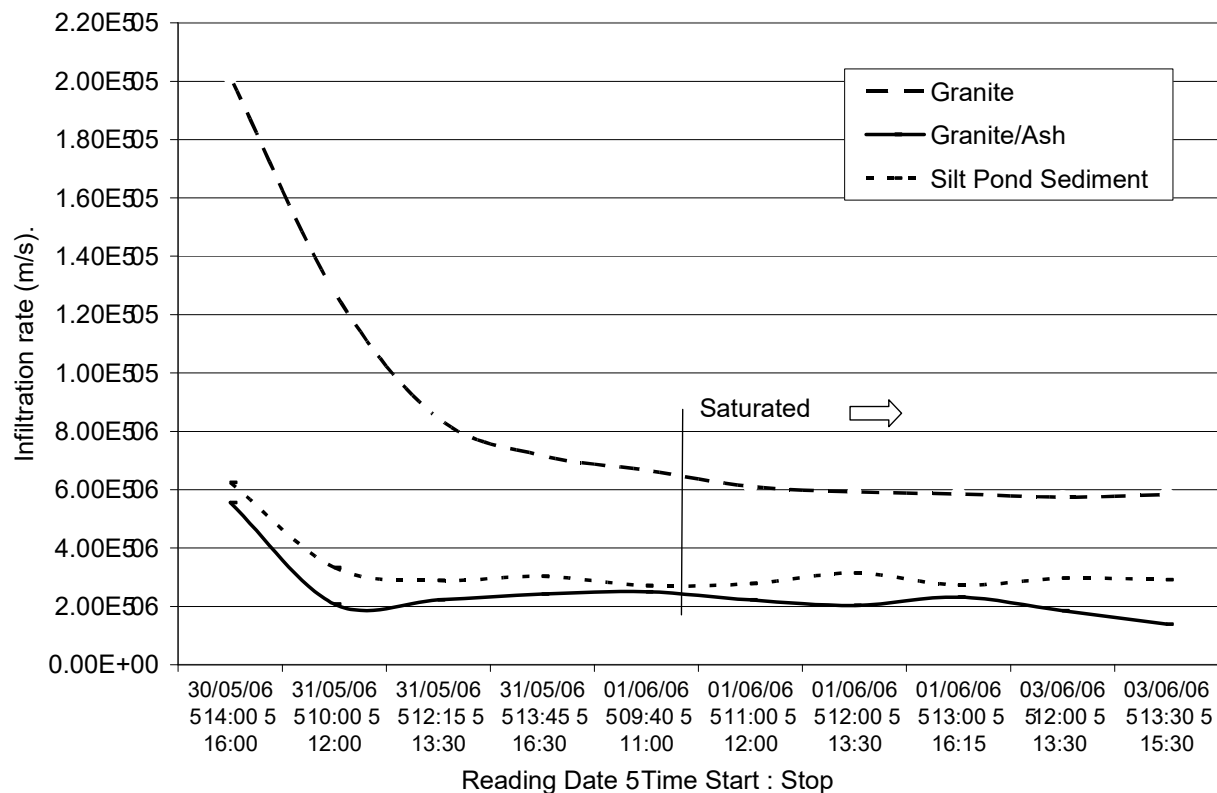


Figure 7. Capping material infiltration rate as it approaches saturated state.

Table 2. Comparison of laboratory measured infiltration with field observations from Connor (2005).

Capping material	Average saturated infiltration measured in the laboratory (m/s)	Field Observed Infiltration (m/s)	
		Min.	Max
Granite	6.02E+06	1.00E+07	1.00E+06
Silt pond sediment	2.87E+06	1.70E+07	2.30E+07
Granite/Ash	2.05E+06	N/A	N/A

Note: Laboratory capping material depth was 0.21 m
Field capping material depth (0.55±0.0 m)

Although infiltration tests showed that both silt pond sediment and granite/ash mixture seemed to be appropriate materials for the capping layer, the measurement of the quality of the infiltrate showed that silt pond sediment should not be considered an ideal capping material. Samples of water infiltrate were analyzed in a certified laboratory and results are presented in Tables 3 and 4. Although care was taken to ensure consistency while placing the waste rock layer in each bin, some variation in water quality results can be explained by variability of the waste rock material found in each bin. However, infiltrate water quality results clearly show that silt pond sediment had high levels of dissolved metals and high acidity.

Silt pond fines were harvested from sedimentation ponds at the mine site. These sediments contain a high proportion of fine material which is more likely to be contaminated with high

acidity and metal concentrations. It is also likely that ARD (acid rock drainage) is leaching into these ponds, further contaminating the sediments. The acidity and dissolved metals present in these sediments are then transferred to the infiltrate as water is conveyed through the experimental capping layer and profile. The poor performance of silt pond sediment is due to the contamination prior to placement as a capping material, with pH levels of the material close to 3. Therefore the use of this material as a capping layer has less benefit than granite/fly ash mixture with regards to leachate quality.

Fly ash displayed an acid neutralizing capacity of 10.1 (g/100g dry weight, CaCO_3 equivalent) compared to 50.01 for silt pond sediment and 50.03 for granite material. The acid neutralizing capacity of the ash in the granite/ash capping layer mixture may reduce the acidity of the infiltrate. The granite/ash mix also provided the greatest seal against oxygen ingress and by proxy, oxidation of pyrite in the waste rock.

Table 3. Dissolved metal concentrations in infiltrated water passing through the three capping materials (granite, silt pond sediment, and granite/ash).

Capping material	Dissolved Iron (g/m ³)	Dissolved Aluminum (g/m ³)	Dissolved Nickel (g/m ³)	Dissolved Zinc (g/m ³)
Granite	0.03	0.016	0.0070	0.081
Silt pond sediment	7.58	270.000	0.7020	4.120
Granite/Ash	0.04	13.900	0.0619	0.749

Table 4. Acidity of infiltrated water passing through the three capping materials (granite, silt pond sediment, and granite/ash).

Capping material	Acidity (g/m ³ as CaCO_3)
Granite	<1
Silt pond sediment	260
Granite/Ash	<1

Conclusions

Results from the laboratory experiment confirm that the ash/granite capping material provides superior protection from oxygen ingress and lower water infiltration properties, when compared to the traditional granite capping material. This capping material is currently being trialed in the field. Silt pond sediments are an effective barrier to oxygen ingress, but leachate quality is poor compared to granite and the granite/ash mixture. However, compared to leachate quality from the potentially acid forming rocks which have acidity as high as 1000 to 3000 mg/L, the benefits may be reasonable.

Experiments show that a rapid armouring of the topsoil occurs. The rate of armouring is dependent on the intensity of rainfall with higher rainfall intensities leading to quicker armouring. Results show that erosion is reduced by over 75% on heavily armoured topsoil as compared to freshly applied soil under a 22 mm/hr rainfall. The heavy armouring was achieved after a various high rainfall intensity events and an approximate 2.5 mm soil depth loss over the entire surface. Calculations are on their way to estimate rate of armouring given the intensity and distribution of rainfall in the West Coast mine sites. Further laboratory experiments on the

armouring phenomenon are required to quantify sediment yields when concentrated flows occur.

On site field experiments to study erosion and acid rock drainage are being conducted and are expected to further validate these laboratory experiments. Modeling efforts are currently on the way to modify WEPP to account for the physical changes in soil surface erodibility.

Understanding the armouring phenomenon will permit more accurate long term predictions of erosion from steep slopes and thus help improve the design and management of these.

Although this study was conducted under unique climatic and soil types specific to the West Coast of New Zealand, the armouring effect occurs in a wide range of conditions around the world and needs to be accounted for when predicting erosion.

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**ATTACHMENT D - ADDRESSING THE ENVIRONMENTAL EFFECTS OF MINING ON THE
NGAKAWAU RIVER (ELDER, et al., 2011)**

Addressing the environmental effects of mining on the Ngakawau River

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Solid Energy New Zealand Ltd

ABSTRACT

On 17 May 2005 Solid Energy committed to a five-year programme to improve the water quality of the Ngakawau River. Following extensive stakeholder consultation, Solid Energy committed to agreed water-quality targets of pH ≥ 4.7 (99% of the time); Al < 1 mg/L (99% of the time); NTU to be no greater than 25 NTU (based on a 30-day rolling median); and clarity to be > 54 cm (NIWA Clarity Tube) $> 90\%$ of the time during base flow conditions (base flow is typically observed 70 to 75% of the time).

Significant management systems were developed and infrastructure constructed to achieve these targets including site-wide sedimentation ponds, the Stockton Black Water Treatment Plant; the Mangatini Limestone Dosing Plant; and the Mangatini Sump (900,000 m³).

For the period January 2011 to September 2011 the target for pH was achieved 97.3% of the time, Al 98.3% of the time, NTU 100% of the time and clarity 89.8%, assuming base flow occurs for 70% of the time. Significant progress has been achieved compare to pre 2005 standards and noteworthy results include the return of *galaxias inanga* (whitebait) in the Ngakawau River. Further work is required to achieve the agreed targets and Solid Energy has plans to mitigate other sources of acid mine drainage and turbidity to the Ngakawau River.

KEYWORDS

Stockton Coal Mine, acid mine drainage, water treatment, erosion, TSS

1 INTRODUCTION

The Stockton opencast coal mine (Figure 1), located on the West Coast of the South Island 35km north of Westport, is owned by Solid Energy New Zealand Ltd and is operated by the Stockton Alliance, a partnership between Solid Energy and Downer EDI Mining New Zealand Ltd. It is the largest opencast mine in New Zealand with an active mining area of ~930 ha; ~180ha of which is rehabilitated. Stockton mine has sufficient economically recoverable resources to continue producing for at least another 20 years and delivers high-quality steelmaking coal for export.

The mine is located on the coastal Stockton Plateau, at 700 to 1100 m above sea level, at the top of a steep scarp that rises almost directly from the coast, < 4 km away. Orographic rainfall occurs as prevailing westerly winds that bring moisture-laden air from the Tasman Sea to the mountains. Annual precipitation at the coast is ~3000 mm/year, increasing to ~6000 mm/year at the mine; frequent rain events with daily rainfall exceeding 200 mm can occur at any time throughout the year; and mean annual temperature is ~9°C (Davies et al., 2011). The amount and intensity of rainfall at the mine has significant implications for erosion control of 930ha of disturbed ground and the management of entrained suspended solids within waterways.

Coal on the Stockton Plateau is present within the Eocene estuarine Brunner Coal Measures (BCM) as thick seams of bituminous coal. These coal measures are overlain by marine sediments, mainly mudstones, with some marginal-marine sandstones near the contact with the coal measures. Pyrite is abundant (up to 5 wt%) in the upper portions of the coal measures and the lower parts of the overlying marine sediments (Hughes et al., 2006; Weber et al., 2006; Weisener and Weber, 2010; Pope et al., 2010). Interaction between rainfall, oxygen, and pyritic waste rock results in acid mine drainage or AMD (Alarcon Leon and Anstiss, 2002; Black et al., 2005;

McCauley et al., 2010; Pope et al., 2010). AMD at Stockton contains abundant dissolved Al and Fe, and elevated concentrations of trace metals compared to natural drainages (Alarcon Leon and Anstiss, 2002; Black et al., 2005; de Joux and Moore, 2005).

Several catchments are affected by AMD and elevated total suspended solids (TSS) derived from the Stockton Coal Mine (Figure 1) and earlier mining by Solid Energy's predecessor and a number of private mines. Solid Energy has recognised these adverse effects and the concerns of the local stakeholders. The Mangatini Stream, a significant tributary of the Ngakawau River, was identified as the main source of poor water quality within the Ngakawau catchment and an action plan was established to rectify the issues. Following extensive research into possible solutions and stakeholder consultation (Ngakawau Riverwatch, Buller District Council, West Coast Regional Council, and the Department of Conservation), Solid Energy committed to agreed water-quality targets for the Ngakawau River of:

- pH $\geq$ 4.7 (99% of the time);
- Al < 1mg/L (99% of the time);
- NTU $\leq$ 25 NTU based on a 30-day rolling median; and
- Clarity to be >54 cm (NIWA Clarity Tube) > 90% of the time during base flow conditions (base flow is typically observed 70-75% of the time).

To achieve these by the target date of June 2010 significant management systems were developed and infrastructure constructed over the five-year period. Root-cause management systems were put in place to reduce requirements for water treatment, including preventative measures such as staff education and environmental awareness, capping of acid-forming rock to reduce AMD generation, erosion control to reduce sediment loss and revegetation using direct transplants and seedlings to stabilise batter slopes. On the treatment side downstream water treatment technologies were installed, including site-wide sedimentation ponds to capture sediment and coal at the point of generation; the Stockton Black Water Treatment Plant to remove coal fines, sediment, and correct pH; the Mangatini ultrafine limestone dosing plant to increase pH and remove dissolved metals (including aluminium); and the Mangatini Sump to capture AMD sludge, unreacted limestone, and sediment.

This paper presents and discusses the work to date and reviews performance against the agreed targets. Further specific details are available as referenced.

2 METHODOLOGY

2.1 INTRODUCTION

Solid Energy has engaged SGS New Zealand Ltd to undertake the majority of water sampling, in-situ analysis (as required), and laboratory testing as required in accordance with the Australian/New Zealand Standard for Water Quality - Sampling (AS/NZS 5667.1:1998). A number of the water samples are sub-contracted to R J Hill Laboratory in Hamilton.

2.2 ANALYSIS

Water samples were analysed in the field for dissolved oxygen (DO) in accordance with the 4500-OG Dissolved Oxygen Membrane Electrode Method, while the pH, EC, and temperature were determined using a TPS WP 81 pH, Cond, Salinity meter using a TPS pH and conductivity probe, pH electrode double junction with porous Teflon BNC Plug. The meter was calibrated at pH 4 and 7 using TPS or BDH branded buffers weekly.

Acidity (mg L⁻¹ CaCO₃) was measured by back-titration of a 50 mL aliquot to pH 4, 5, and 7 with 0.1 M NaOH; acidity was then calculated as per the American Public Health Association (APHA 2005). An unacidified sample was filtered through a 0.45 µm membrane filter to remove suspended particulate matter and then sent to R J Hill Laboratory for various parameters. Metals were typically analysed by ICP-MS using the APHA 3125 B 21st ed. 2005 standard method. Ammoniacal nitrogen was determined by phenol/hypochlorite colorimetry using a discrete analyser APHA 4500-NH₃ F (modified from manual analysis) 21st ed. 2005; CBOD₅ (chemical biological oxygen demand) was determined by the APHA 5 Day BOD Test, 5210 B, 21st edition 2005).

Figure 1. Catchments affected by mining (Mangatini Stream, St Patrick Stream, and Mine Creek) that drain the Stockton coal mine. S14, S14b, S16, and NR are standard compliance water-monitoring sites.



Total suspended solids or TSS was determined by gravimetric analysis of a known representative aliquot of water following filtration and oven drying. Clarity was determined using a NIWA Water Clarity Tube (1000mm long, 44mm internal diameter clear acrylic tube with an adjustable black disk).

Turbidity (NTU) is measured by a HACH 2100N turbidity meter. The unit of measure is NTU (Nephelometric Turbidity Unit). This analysis is undertaken in accordance with Standard Methods APHA 1989 method 2130 B and turbidity is determined by referencing the light scattering properties of a formazin polymer (standard) to the sample being analyzed.

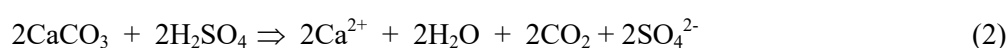
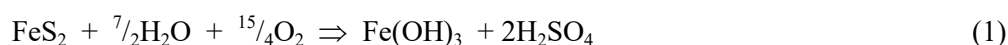
Automatic flow meters have been installed at NR, S14, S14b, and S16. Seeps are measure by small Sensus flow meters.

An important aspect of acid-base-accounting to determine AMD potential is total sulfur determination. This was undertaken by both SGS and Amdel Laboratories and total S was also determined by LECO analysis (Crock et al., 1999) whereby the sample is combusted in an O₂ atmosphere at 1370 °C (V₂O₅ catalyst) to oxidise sulfide and SO₄ to SO₂ and then the S content is measured by a calibrated solid state infrared detector

3 ACID MINE DRAINAGE

3.1 INTRODUCTION TO AMD

Acid mine drainage (AMD) is the result of sulfide mineral oxidation in the presence of oxygen and water (*e.g.*, Equation 1). Pyrite is the most common sulfide mineral in coal measures and four moles of acid are generated for every mole of pyrite oxidised. The acidity generated by pyrite oxidation can be neutralised by materials such as limestone (*e.g.*, CaCO₃). Two moles of CaCO₃ are required to neutralise the acidity generated by the oxidation of one mole of pyrite (Equation 2).



The potential for a rock to produced acidity (the maximum potential acidity) can thus be determined by the amount of sulfur present (Equation 3), although there are several assumptions and not all the sulfur may be pyritic (see Weber, 2003)

$$\text{MPA (kg H}_2\text{SO}_4\text{/t)} = \text{wt\% S} \times 30.6 \quad (3)$$

Where 30.6 is the conversion factor and is determined by:

$$CF(\text{for pyrite}) = \left[\frac{2 \text{ mole H}_2\text{SO}_4 \times 98.076}{2 \text{ mole S} \times 32.06} \right] \times 10 = 30.6 \quad (4)$$

Rocks can contain both pyrite and carbonate, which means that although pyrite may be present, if the carbonate content is sufficient, AMD may not occur. In this regard the Net Acid Production Potential of a rock can be determined by the maximum potential acidity less the acid neutralisation capacity (Equation 5):

$$\text{NAPP (kg H}_2\text{SO}_4\text{/t)} = \text{MPA} - \text{ANC} \quad (5)$$

Where the ANC is determined by acid digest of the sample followed by back-titration with base to determine the amount of acid consumed (*e.g.*, IWRI and EGi, 2002; Weber et al., 2004)

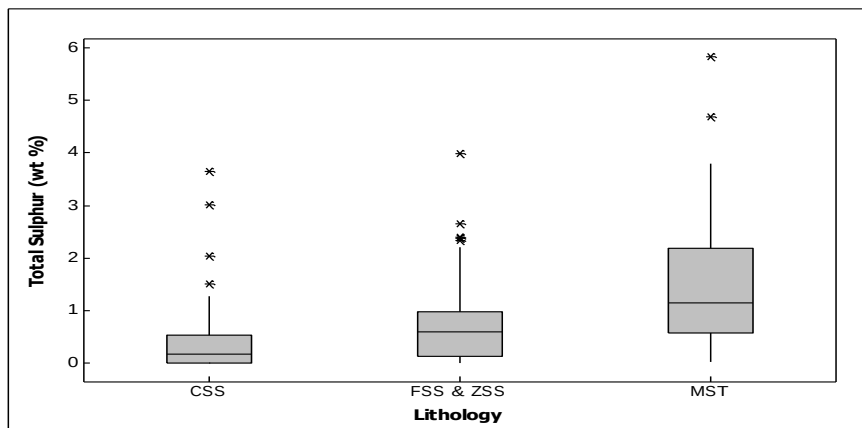
The Brunner Coal Measures (BCM) are often deficient in carbonate minerals, and have very unreactive aluminosilicate minerals (K-feldspar, kaolinite, muscovite) that provide little silicate neutralisation such that the oxidation of pyrite typically leads to the formation of AMD. However, the sulfur content and thus pyrite content of rock varies significantly on a geographic basis and lithologically within the Stockton coal mining area. This is related to the palaeo-environmental setting. Estuarine coal measures tend to have higher pyrite content, whereas fluvial environments are lower in pyrite (see Pope et al., 2010).

Coarse grained sandstones tend to be low in pyrite and thus low acid-forming (LAF) likely due to either deposition in a fluvial (low S) environment or low organic matter availability to convert SO_4^{2-} to H_2S (and thence pyrite). Mudstones and similar lithologies such as carbonaceous mudstones and siltstones tend to be elevated in pyrite which is linked to deposition in a low energy estuarine environment with good sources of Fe, SO_4^{2-} , and organic matter. This lithological variation in sulfur at Stockton coal mine is shown in Figure 2. At the southern end of the mine site within the Mt Frederick mining block the palaeo-environment was fluvial and thus even mudstones can be LAF. This is clearly identified in the tiphead sampling programme dataset where samples are collected daily from active tipheads and analysed for total S (Figure 3).

For AMD management (prevention and treatment) at Stockton the data shown in Figure 3 therefore indicates that the greatest effort to minimise pyrite oxidation and treat AMD formation should be within the northern mining blocks, *i.e.*, the Mangatini Catchment, which will thus provide the greatest water quality improvements in the Ngakawau River where targets have been agreed. This is validated by stream drainage chemistry that indicates seeps discharging from the Mt Frederick mining block to the south have higher pH's and lower acidities (*e.g.*, Herbert Stream seep pH 2.9 – 3.2 and an acidity of 60 -110 mg/L) compared to northern areas that can have pH < 2.0 and acidities > 5000 mg/L (*e.g.*, Collis Seep) (Weber et al., 2008). Similar trends have been identified by McCauley et al. (2010).

Although Mangatini Stream has been identified as the priority catchment for mitigating the effects on the Ngakawau River, Solid Energy has embarked on plans to treat all waterways affected by AMD including Mine Creek, Ford Creek, Fly Creek, and St Patrick Stream.

Figure 2. Total Sulphur of the Brunner Coal Measures (northern sites – does not include Mt Frederick mining block). CSS = coarse sandstones (104 samples), FSS & ZSS = Fine sandstones and siltstones (145 samples), MST = mudstones (76 samples). The upper whisker shows the highest data value within the upper limit. The top of the box is the third quartile. The median is the middle of the data and this is shown by the line within the box. The bottom of the box is the first quartile. The lower whisker extends to the lowest value within the lower limit. The Asterisk's represent outliers.



As shown in Equation 1 the oxidation of pyrite releases Fe, SO₄, acidity, and produces low pH in drainage waters. Low pH leads to the dissolution of metals from the surrounding rock. For example, at pH values < 4.5, Al is partially leached from aluminosilicate minerals. The end result is elevated metals (Fe, Al, trace metals) and high acidity in streams draining the Stockton Plateau that have been affected by historical and current mining operations. It was estimated that the Mangatini Stream discharged 756 tonnes of Al, 300 tonnes of Fe, and ~6,200 tonnes of acidity (CaCO₃ equivalent) per year (PCE, 2006,) prior to Solid Energy embarking on its 5 year programme to improve water quality in the Mangatini Stream and thus the Ngakawau River. Further details relating to the Mangatini stream geochemistry is available (Davies et al., 2011).

3.2 AMD MINIMISATION

3.2.1 INTRODUCTION

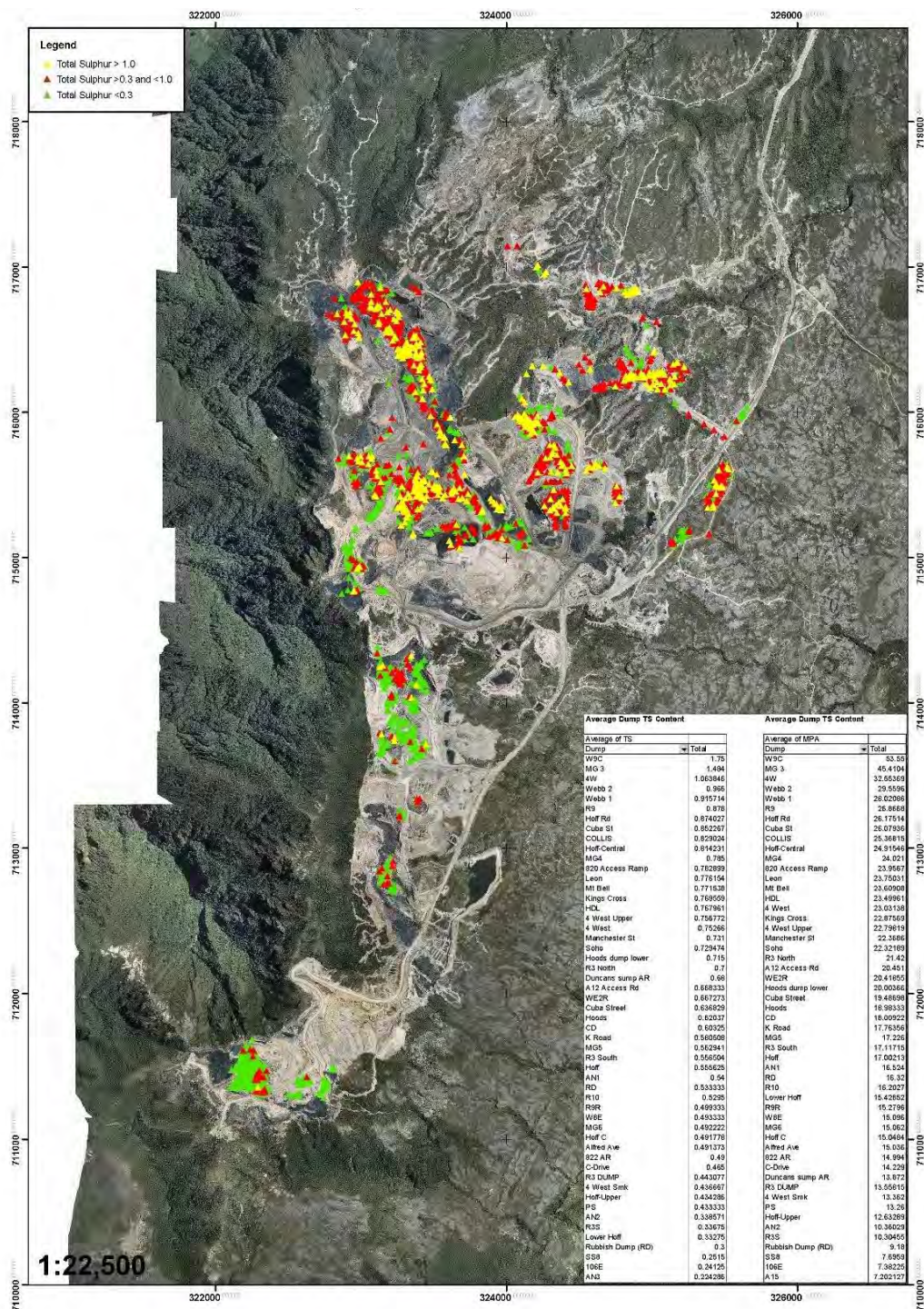
An integral part of the AMD management plan at Stockton is the separation of the overburden rock and the subsequent overburden dumps into their propensity to generate AMD. This is undertaken at the exploration stage whereby drill core is sampled and analysed for total S (to determine MPA) and thence the NAPP determined, with the assumption that ANC is zero for the BCM (see Weber et al 2006). Within the Kaiata mudstone the NAG (Net Acid Generation) test is used (IWRI and EGi, 2002; Weber et al., 2004) as carbonates are also present and need to be accounted for.

For the BCM the non-acid-forming (NAF), low acid-forming (LAF) and potentially acid-forming (PAF) rocks are separated, often based on lithology (Table 1). Conglomerates and granite beneath the BCM are NAF; coarse grained quartz sandstones are often LAF and both are a valuable construction material for roadways and for capping PAF rock within engineered landforms. As shown in Figure 2 the mudstones are typically PAF or high PAF.

Table 1. AMD characterization for the Brunner Coal Measures, Stockton Coal mine.

AMD Classification	NAPP (kg H ₂ SO ₄ /t)
Non-Acid Forming (NAF)	<0
Low Acid Forming (LAF)	0 - 5
Potentially Acid Forming (moderate) (PAF)	5 - 30
Potentially Acid Forming (high) (PAF)	> 30

Figure 3. Total S content for rock samples collected daily from active tipheads. Data up to 2007.



Calculations based on Equation 1, using 10 mg/L oxygen in rainwater indicates that with 5m of rainfall per year at Stockton and an infiltration rate of 0.3 this equates to 25g H₂SO₄ per m² per year or 250kg H₂SO₄ per Ha per year and 250 tonnes for 1000ha currently disturbed per year, which is minor compared to the current acid load of ~6,200 tpa for the Mangatini Stream alone. Thus encapsulation of PAF rock by NAF rock and engineered covers must limit the amount of oxygen that can reach the sulfide rich rock and hence the amount of acidity generated (e.g., Equation 1) rather than water exclusion. The following section looks at ways to minimise AMD formation by oxygen exclusion.

3.2.2 ENGINEERED LANDFORMS

A general requirement for the management of overburden is the need to minimize the time between blasting of the PAF rock and placement within an engineered landform, which minimizes the amount and duration of

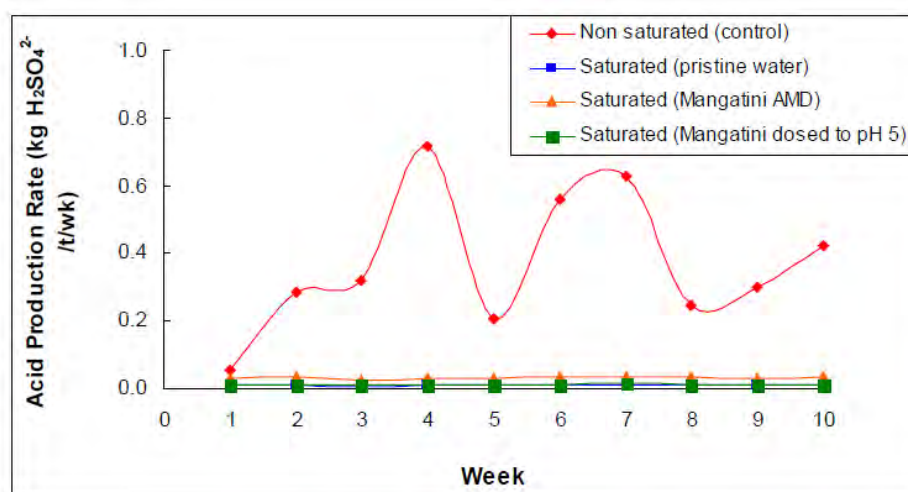
interaction of the PAF rock with oxygen and water. Overburden rock is then carted to the engineered landform and whenever possible the dumps are constructed by end-tipping where the height of the lift is limited to 5m or less. Heavy traffic thence compacts this lift. End tipping can create fines and coarse rock separation and a chimney effect whereby oxygen flows down the coarse layers enabling deep penetration into the core of the engineered landform (Figure 4). Limiting end-tip height reduces the depth of oxygen penetration. Trials on site have demonstrated that 5m lifts can reduce dissolved aluminium in drainage waters by 10-30% and reduce acidity by 10-15% (pers. comm. Phil Lindsay).

Figure 4. Autopsy of a waste dump constructed by end-tipping. Note the pathways for oxygen ingress (coarse material). Figure courtesy of Environmental Geochemistry International Pty



Previous work (see Hughes et al., 2007 for details and methodology) has demonstrated that permanent saturation of PAF rock with rainwater, or even AMD effectively shuts down acid generation by preventing oxygen reacting with the sulfides present in the submerged waste rock (Figure 5). This has important design ramifications for engineered landforms in that many are constructed in old pits and this can provide 2-5% acid reduction by submerging the basal parts of the engineered landform. At Stockton's Cypress resource area, currently in development the plan is to back-fill the pits and bury 10 million BCM beneath the water table.

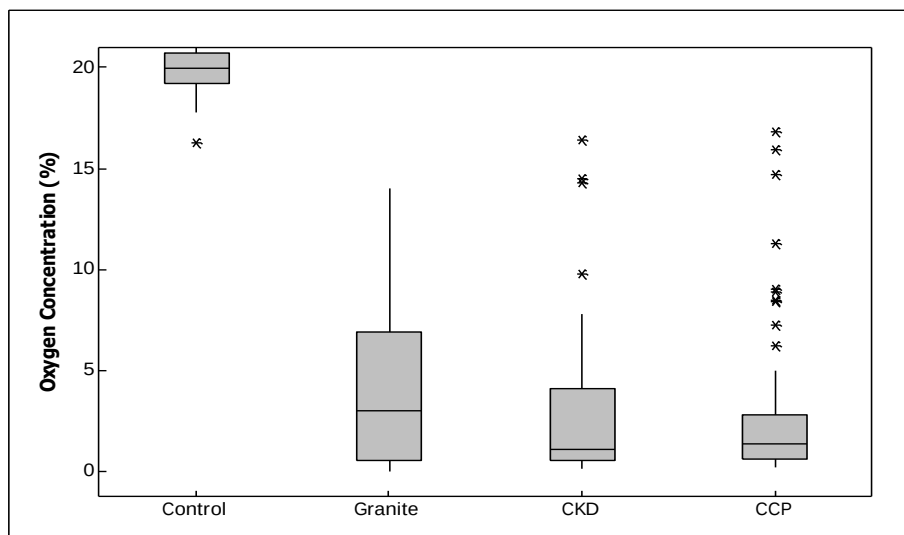
Figure 5. Acid generation for BCM PAF rock laboratory columns submerged under water. (see Hughes et al., 2008 for further details).



After reshaping of the engineered landform it is compacted with several bulldozer passes and then 500mm of weathered granite (>5 wt% fines < 63 μ m) is compacted above the PAF rock as a low permeability cap. Where LAF is available a layer of this rock is wrapped over the PAF core. The granite cap is compacted to a permeability of < 1×10^{-6} m/s as measured by the double ring infiltrometer and is designed to be saturated to reduce oxygen ingress. 400mm of topsoil is then placed over the surface of the granite to act as a growing medium, which is then replanted.

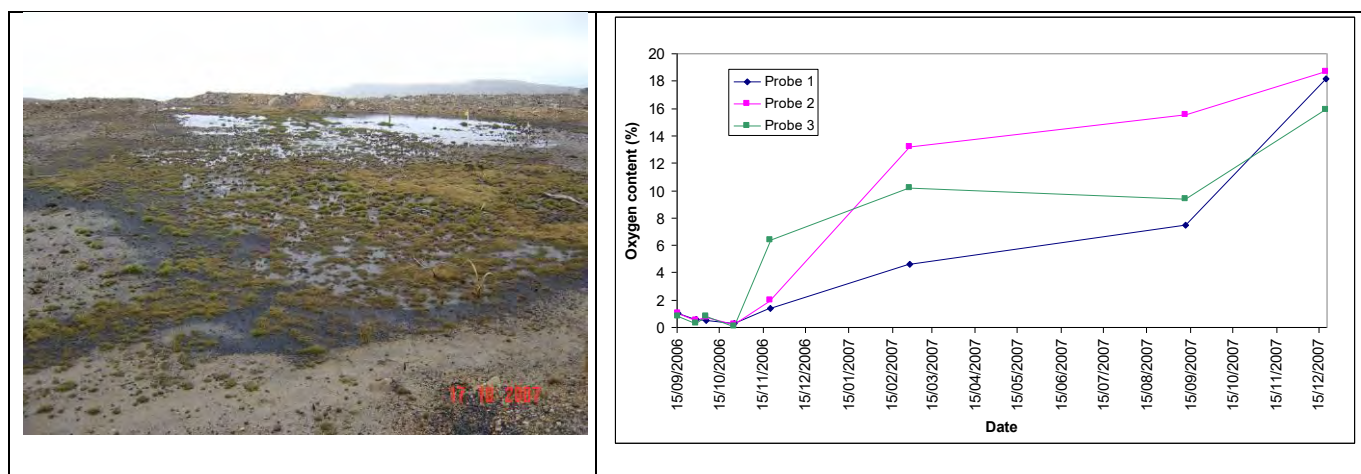
Other options for engineered caps have been developed, including alkaline covers using coal ash and cement kiln dust (CKD) having ANC values of 100 – 700 kg CaCO₃ respectively that both exclude oxygen and release alkalinity to the underlying PAF rock (Weber et al., 2008). Results demonstrating oxygen ingress are shown in Figure 6. These opportunities are limited by product availability and flat dump surfaces as, on dump slopes, the CKD and coal ash could produce slip planes.

Figure 6. Oxygen Concentration measured beneath various capping materials. The granite oxygen probes were located at WE8 overburden area and C drive; CKD caps, CCP (coal ash) caps, and the control were from the Egypt trial pads.



Mining guidelines developed at Stockton recommend that dumps are capped within 2 months to minimise oxidation. However, because this is often impractical, and interim solutions have been developed. Silt pond fines (SPF) disposal requires significant effort and it was believed that this material could be used as a capping material. A 40m by 20m trial site was selected on the flat C-drive overburden area and was bunded 300mm high to which SPF were added. Oxygen probes (2m depth) were inserted to measure oxygen content. They are essentially a PVC pipe designed to extract oxygen from a certain depth and remain sealed by a ball valve hooked up to an air hose fitting).

Figure 7. Silt pond fines trial site and oxygen content monitoring results. Atmospheric oxygen content = 20.6%.



Results shown in Figure 7 indicate that the saturated cap worked exceptionally well for the first three months and then failed. This is associated with the silt pond fines drying out. Thus they are not a long-term capping solution as the pond will require continual topping up every few month with additional SPF. Nevertheless they still have potential as a short term solution for AMD control prior to final capping and also the management of SPF.

3.3 AMD TREATMENT

Although prevention technologies for AMD will reduce acid loads within the engineered landforms, some treatment is still needed. It is anticipated that treatment will be required at Stockton for at least 100 years as disturbed overburden and the inherent pyrite continues to oxidise. Research into treatment processes that could treat this long-term liability commenced in 2005.

3.3.1 LIMESTONE NEUTRALISATION OF THE MANGATINI STREAM

A cost analysis indicated that the cheapest long term solution for the treatment of AMD was limestone (provided reasonable dissolution efficiencies could be obtained). A pilot-scale plant that could dose ultra-fine limestone (UFL) into the Mangatini Stream was constructed in 2006 and was run as batch trials. Several different limestones were tested and reactivity was variable due to ANC content and crystal structure of the limestone. It was demonstrated that UFL (90% < 100 μm) from Murchison Lime Quarry was reasonably efficient (50-70%) when at least 60 minutes rapid in-stream mixing was available (~400m stream length) and could raise the pH to > 6, which was sufficient to achieve water quality targets in regards to dissolved aluminium and pH.

Monitoring data obtained from downstream pH and turbidity loggers picked up pulses of neutralised water moving downstream. The pH profile at monitoring site S14B in the Mangatini Stream (4.1 km downstream of the dosing station) and site NR in the Ngakawau River (9.4 km downstream of the dosing station) is shown in Figure 8. Compared to the Mangatini Stream, there was a smaller pH increase in the Ngakawau River, which is expected considering the greater flow rate of the Ngakawau River, and thus dilution of the lower volume, higher pH Mangatini Stream.

Figure 8. pH Levels in the Mangatini Stream and Ngakawau River after UFL dosing.

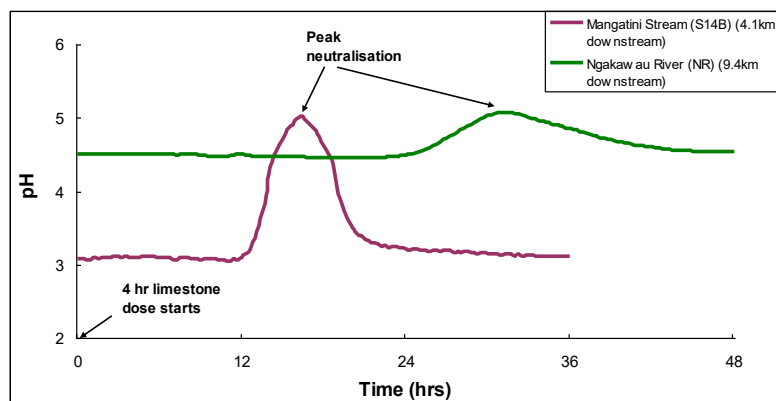


Figure 9. pH, dissolved Al, and dissolved Fe levels at site S14A (400m downstream of the dosing plant) after limestone dosing.

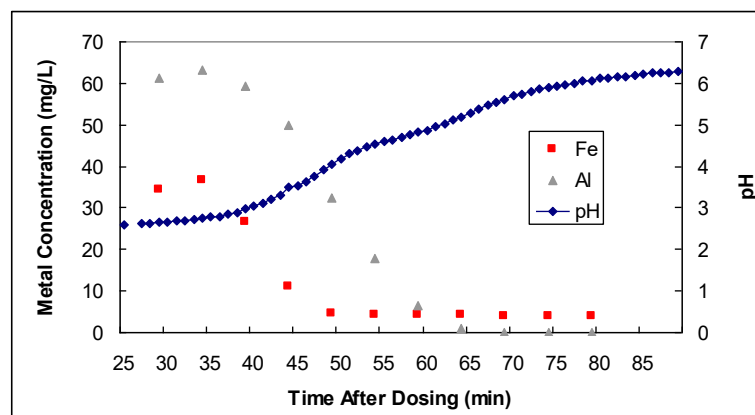


Figure 9 shows the pH, Fe, and Al concentrations in the Mangatini Stream recorded at a site 500 m downstream of the limestone dosing plant. From these results it can be observed that pH levels started to increase 30 minutes after dosing started and increased to pH 6.3 after 90 minutes. The precipitation and removal of dissolved Fe between pH 2.8 – 3.3 and dissolved Al between pH 4.3 – 5.0 buffered the rate at which pH increased due to

the associated lewis acidity. Most of the dissolved Fe and Al was removed from the stream at approximately pH 3.5 and pH 5.0 respectively. Thus these results confirmed that at base flow conditions using 1.5 tonnes of fine limestone (90% < 100 microns) the fine limestone could be effectively used to raise the pH of the Mangatini Stream and reduce the aluminium load to levels that met with the Solid Energy's commitment to water quality in the Ngakawau River. This provided the science and confidence to construct a full scale plant.

From 2007 a temporary limestone dosing plant has been operating at Mumm's bridge dosing directly to the Mangatini Stream (see Weber et al., 2008 for details) with significant improvements in water quality (Fe, Al, pH) although clarity has been poor due to direct dosing of the limestone to the stream and the formation of Fe and Al hydroxide precipitates. This has been partially resolved by dosing of limestone into the Mangatini Stream above the Mangatini Sump, although further optimization is required.

The final stages of project involves a dosing plant that will be constructed in the upper catchment of the Mangatini stream in early 2012. This plant will have the capacity to dose both UFL and $\text{Ca}(\text{OH})_2$ and will be fully automated to receive tanker deliveries of product and dose to the sump based on inflow pH meters calibrated against flow rate.

3.3.2 PASSIVE TREATMENT

Passive treatment is a system that uses a leach bed or reactor using limestone, organic material, or a combination of the two to treat AMD. A number of papers have been published on passive systems for Stockton (e.g., Weber et al., 2008; McCauley et al., 2009, 2010; Crombie et al., 2011). Passive treatment has limited treatment capacity (<40 L/sec in general). Crombie et al. (2011) identified the best place for a passive system using waste mussel shell is for low volume water discharging from AMD seeps where TSS is low to prevent clogging up of the passive treatment system.

An operating full scale passive system has been installed to treat the Manchester Seep (0.04 – 0.6 L/sec; pH 2.8; acidity ~400 mg/L CaCO_3). During high rainfall events the overflow (> 0.6L/sec) discharges via a spillway. The system has been operating for approximately 2 years with significant results (Table 2). pH has increased from 2.8 to 7, acidity has been removed, and all metals have been reduced to very low levels. Based on these results more of these passive systems re-using a waste product are planned for areas that cannot be treated by UFL dosing where the flow and water quality are appropriate.

Table 2. Influent and effluent water analysis for the mussel shell passive treatment system.

	Al (mg L ⁻¹)	Fe (mg L ⁻¹)	Ni (mg L ⁻¹)	Zn (mg L ⁻¹)	pH	EC ($\mu\text{S cm}^{-1}$)	Acidity (mg L ⁻¹ CaCO_3)	DO (mg L ⁻¹)	Ammoniacal Nitrogen (mg L ⁻¹)
Influent									
Min	<0.003	0.81	0.10	0.5	2.1	332	240	2.1	0.037
Mean	51	29	0.27	1.18	2.8	1246	422	8.5	0.15
Median	54	23	0.24	1.0	2.9	1311	430	9.4	0.12
Max	80	140	0.5	2.2	4.0	1621	790	10.2	0.32
Effluent									
Min	<0.003	<0.02	<0.0005	<0.001	6.2	943	0	0.5	0.06
Mean	0.013	0.17	0.028	0.008	6.9	1445	0.3	2.8	7.81
Median	0.004	0.04	0.0062	0.004	7.0	1463	0	2.4	3.9
Max	0.21	0.92	0.038	0.045	8.6	2110	9.9	6.1	46

4 EROSION

4.1 INTRODUCTION

With up to 6000mm of rainfall per year and 930 ha of disturbed or recently rehabilitated ground at Stockton the management of erosion and the subsequent suspended sediment in waterways is a challenge. Typically during rain events soil armouring processes occur whereby fine soil particles are eroded quickly, leaving a coarse surface layer of rock and gravel. This coarse layer provides protection to the underlying soil, reducing further erosion. However, field observations have indicated that up to 50mm of soil can be lost from engineered landforms following topsoil respreading prior to the effect of armouring occurring. This equates to 500m³ per Ha of sediment that is lost from slopes. Better management solutions were required to minimise fines loss and

the following section looks at the activities undertaken at Stockton to minimise sediment loss that thence generates elevated TSS within waterways.

4.2 EROSION MINIMISATION

4.2.1 INTRODUCTION

The most effective means of minimising erosion is to minimise the amount of area disturbed within a mining block and the first step of this is accurate delineation of the mining area. All clean water is diverted, where possible, away from the mining block to minimize scouring and sediment entrainment. The following activities look to minimize the subsequent loss of sediment from the mining block and from the rehabilitated landform.

During the design and construction of engineered landforms consideration should be given to final slope gradient. The lower the angle of the slope the less erosion prone it will be. This, however, is often counterproductive as greater area is required for the dump and thus the disturbed area foot print is larger. Hence a balance must be struck. Design of engineered landforms should also look at maximum slope length between benches, diversion of drains away from slopes to remove high energy point sources of water-flow, and the ability to start progressive rehabilitation. One of the most important aspects of erosion management is monitoring, review, and maintenance of erosion control systems and structures.

4.2.2 SLOPE STABILISATION

Successful rehabilitation of engineered landforms (ELFs) at Stockton Mine relies on the retention of remaining soil once it is re-applied at the completion of the mining process. The soil is important as a growing medium and also as a cover to the underlying granite cap that has been constructed to reduce oxygen ingress into the underlying PAF rock. Following placement of the soil the area is planted out with native seedlings (25 different species) at a rate of 5,000 – 15,000 stems per ha as a standard approach (Rodgers et al., 2011). However, prior to canopy closure this leaves a significant area of ground without any vegetative cover and the potential for significant erosion.

Researchers have shown the effectiveness of straw mulch to control erosion (*e.g.*, Meyer et al., 1970; Jennings and Jarrett, 1985; Benik et al., 2003; Shadbolt and Weber, 2007). Hydro-seeding, like straw mulching, had also been used for erosion control (*e.g.*, Albaladejo Montoro et al., 1999). Six plots (each ~ 217m²) were established in May 2006 on the Collis Dump with 5m long erosion gutters placed at the base of the plot to capture sediment runoff (Figure 10). Straw and hydro-seed was applied to the plots:

- Plot 1 – Hydro-seeding; paper 1t/ha, Browntop 5kg/ha, Yorkshire Fog 5kg/ha, Tama Ryegrass 25kg/ha, DAP 400kg/ha, **(HH – hydro-seeding high rate)**
- Plot 2 – Hydro-seeding; paper 1t/ha, Browntop 2.5kg/ha, Yorkshire Fog 2.5kg/ha, Tama Ryegrass 8kg/ha, DAP 400kg/ha, **(HM – hydro-seeding medium rate)**
- Plot 3 - Control plot; bare soil **(C)**
- Plot 4 - Straw mulching; wheat straw 3.5t/ha **(SM – straw medium rate)**
- Plot 5 - Straw mulching; wheat straw 5t/ha **(SH – straw high rate)**

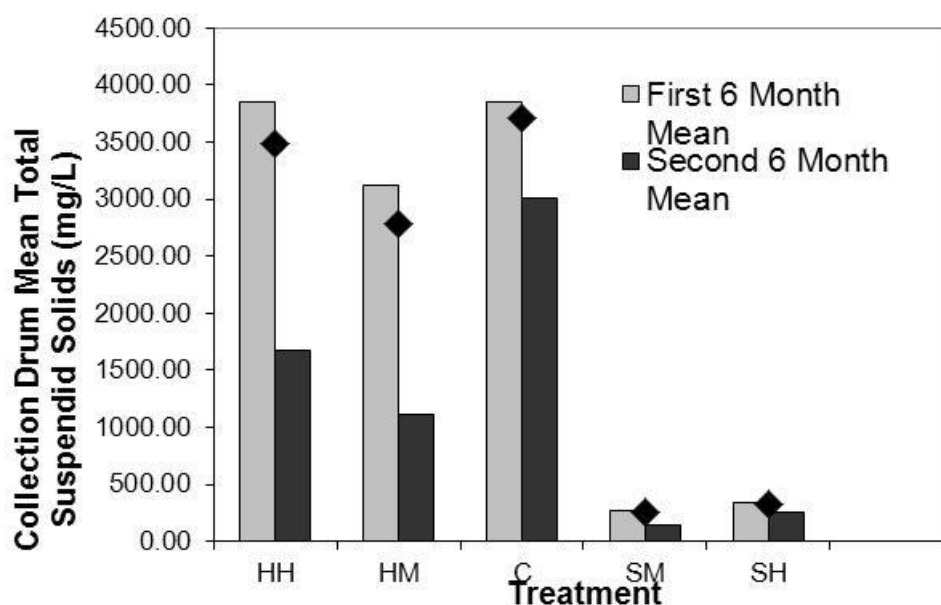
Results (Figure 11) demonstrated that straw was the most successful method to mitigate erosion. The ability for hydro-seed to work was initially compromised by poor winter growth but sediment loss was significantly reduced once the grass had established in the second 6 month period. After one year the straw had started to break down and was no longer as efficient at retaining sediment whereas the grass established by hydro-seeding had greater longevity.

As a result of this research Solid Energy has implemented a procedure whereby straw is applied (4 tonnes/ha) as soon as practical to areas rehabilitated with respread soil and hydro-seed is also applied before seedlings are transplanted.

Figure 10. Erosion control gutter used to measure sediment loss from trial plots. Further details of the design, methodology, and results are available (Shadbolt and Weber, 2007).



Figure 11. TSS (mg/L) for all trial plots divided into 6 monthly intervals



4.2.3 VEGETATION DIRECT TRANSFER (VDT)

Vegetation Direct Transfer (VDT), also called ‘habitat-’ or ‘community-translocation’ is a method whereby intact mats or sods of vegetation and the attached soils are removed and relocated to sites which have been prepared for rehabilitation (Figure 12). VDT minimises structural damage, enabling the salvage, relocation and reuse of the biotic layers (i.e. vegetation, topsoil, intact root structures, plant litter, seed and seedling banks, microbial and mycorrhizal root associations, and invertebrates) in a way that preserves the potential for natural regeneration (Rodgers et al., 2011). VDT has been developed at Stockton Mine since 1998 and has become the preferred rehabilitation method for rehabilitating high-value, low-stature ecosystems.

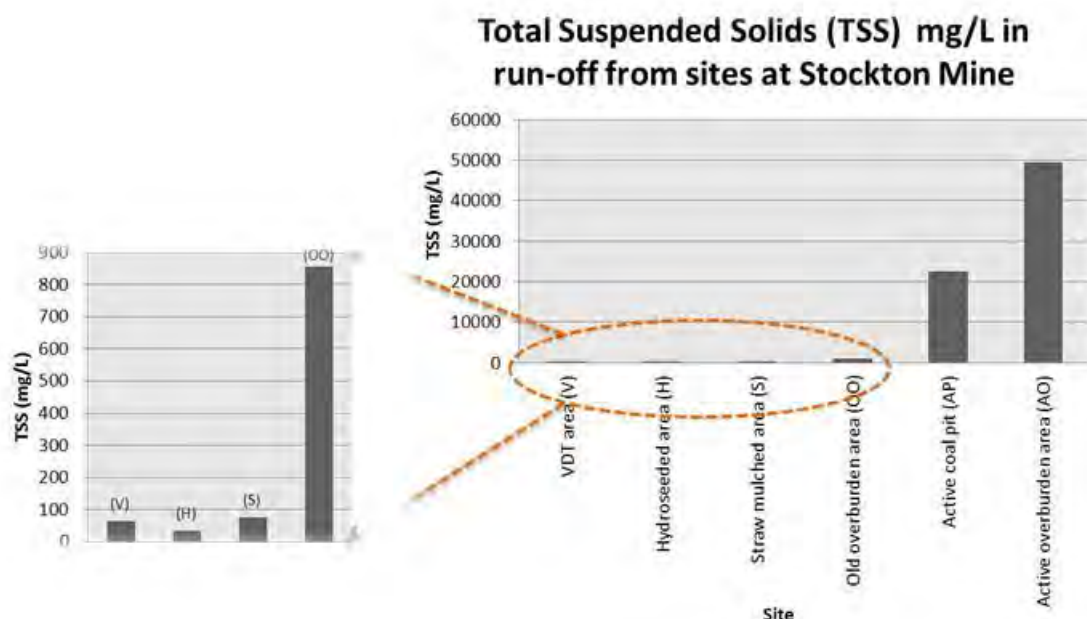
Figure 12: VDT bucket salvaging thin sods from pavement. The bucket has a cutting front edge and flat base



A field study carried out in May 2011 demonstrated the greater effectiveness of rehabilitation, including VDT, in limiting sediment run-off (Figure 13). The study was carried out during a moderate rainfall event (80mm in 24 hour period), with water samples collected from rehabilitated slopes with three different rehabilitation treatments (VDT, hydro-seeding, straw mulching), and from three non-rehabilitated areas (old overburden area, active overburden area, active coal pit). The grab samples were analysed for total suspended solids (mg/L) and visual clarity (Bonisch and Rossiter, 2011).

All three rehabilitated slopes generated run-off with high clarity and comparatively low TSS: (61 mg/L for VDT; 31 mg/L for hydro-seeded slope; 74 mg/L for straw mulched slope). By comparison, the non-rehabilitated slopes had poor visual clarity and very high TSS: (854 mg/L for old overburden dump; 49,260 mg/L for active overburden dump; 22,348 mg/L for active coal pit) (Figure 13).

Figure 13. Total suspended solids (mg/L) in water run-off from sites under different treatments.



Thus VDT also provides an immediate ground cover which reduces TSS in run-off to levels comparable with hydro-seeding and straw mulching. The direct costs of VDT are highly variable (~\$40,000 – \$200,000 per ha) and are greatly influenced by the capital cost of machinery used to transport the VDT, the distance and elevation

between VDT source and destination (rehabilitation) areas, and the proportion of down-time the fleet spends not transporting or loading sods. However, in comparison with traditional soil spreading and planting techniques, VDT is overall less expensive when considering the 'life-cycle' costs involved in conventional rehabilitation, which include erosion control (such as hydro-seeding and/or straw-mulching and/or silt fences to retard sediment mobilisation), weed monitoring and control and on-going management. VDT also reduces the time required to achieve closure criteria (such as vascular plant cover and height and species assemblages). Further information on VDT is available (Rodgers et al., 2011)

4.2.4 SEDIMENT CONTROL

As a first line of defence against the transport of sediment from active mining areas into waterways the site uses silt fences to trap water and entrained sediment. The fences are installed prior to mining in the area (Figure 14). The fences are reinforced with wire to support, intensive, overland flow and sediment loads. Site personnel undertake checks of these fences as part of a monthly maintenance programme and after each significant rainfall event (i.e. >50mm in any 24 hour period). Erosion Control Tubes (ECT) or strawbales are also used and enable rapid filtration of water unlike silt fences that are designed to stop water flow.

Road side check dams (Figure 15) are installed on roads with a life of > 3 months and their purpose is to reduce the velocity of concentrated flows, thus providing some sediment control from roadside runoff and reducing the effects of scouring on the drain (and hence more sediment generation). The distance between check dams is based on the gradient of the slope:

- Gradient steeper than 10%: check dam separation to be no more than 30m
- Gradient flatter than 10%: check dam separation to be no more than 45m

Figure 14. Silt fence installed prior to mining.



Figure 15. Roadside check dams at Stockton Mine.



4.3 TREATMENT

4.3.1 SEDIMENT PONDS

As shown in Figure 13 the greatest sources of sediment from the mine site are active pits and overburden areas. Because only 180 ha of the 930ha disturbed by mining is rehabilitated there is a significant amount of sediment created. The first line of treatment is sedimentation ponds.

In-pit sediment sumps or dams are an essential water management tool for Stockton. They provide primary settlement of medium-coarse sediment in medium and high flows and significant settlement of fine sediments in low flow situations. Typically the structures are 2.5m in depth (and no more than 3m) and are designed to have a length to breadth ratio of greater than two to be most effective at settling sediments than an impoundment with irregular shape and/or a length to breadth ratio of less than two where short circuiting can occur.

Discharge from the sediment sumps is either by a spillway or floating decant. Sumps are sized based on the upstream catchment and the following general rules apply:

1. Sumps without a floating decant require a surface area of 500m² per ha of catchment
2. Sumps with a floating decant require a surface area of 200m² per a of catchment

Sumps are inspected weekly and any maintenance or sediment removal is scheduled with operations as a priority. The sediment excavated from the sediment ponds is carted to a nearby fines disposal area that prevents the fines from being remobilized. Other options for reuse of this material have been discussed in Section 3.2.2.

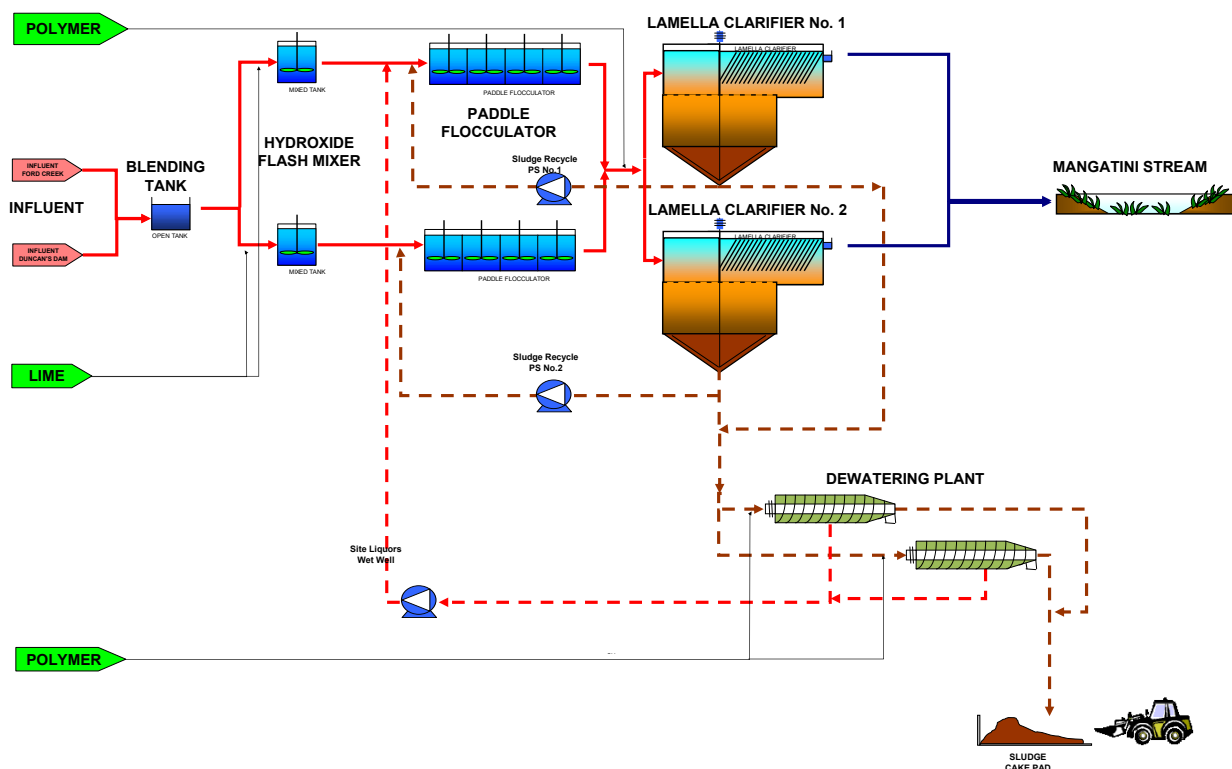
4.4 STOCKTON BLACK WATER TREATMENT PLANT

Part of the water management approach at Stockton is to separate black-water (containing coal fines from mining pits, ROM pad, and processing site) and brown-water (containing general mining sediment other than coal) at the source of generation and transport them to the treatment plant. The reason for this is that the removal of fine suspended coal is inherently more difficult. This is a function of the lower specific gravity of coal compared to mineral sediment, which results in differential settling rates that result in a higher concentration of coal fines remaining in suspension (Kingett Mitchell, 2005).

The standard process of sedimentation ponds thus does not achieve the desired water quality for black-water and a black water treatment plant was designed and constructed. The final stages of this plant were completed in 2010. The Stockton Black Water Treatment Plant (BWTP) is an example of a classical active mine water treatment process, which involves, neutralization of the acidity, flocculation of the precipitates and sediment, consolidation of the sludge, and discharge of clean water. A conceptual design is provided in Figure 16; and Figure 17 provides a view of the as-built plant.

In the initial stages of treatment the acidity (H^+ , Lewis acidity associated with dissolved Fe and Al) is neutralized by $Ca(OH)_2$ in the flash mixer. $Ca(OH)_2$ is used due to its almost instantaneous neutralization capacity, unlike ultrafine limestone that requires up to one hour of turbulent mixing. A precipitate is formed composed of $Fe(OH)_3$ and $Al(OH)_3$ together with gypsum and any suspended sediment in the flocculator (flocculant is added). Separation of the clean water from the floc occurs in the lamella thickeners and the sludge underflow is sent to centrifuges for further dewatering.

Figure 17. Schematic flow diagram for the Stockton Black water Treatment Plant. From Ellis (2008).



Due to the increase in pH and the addition of flocculant a significant component of the dissolved Fe and Al in solution is precipitated together with suspended sediment and coal fines. Results (Table 3) indicate that the BWTP is effectively removing ~99% of the dissolved aluminium and iron respectively and reducing turbidity by ~84%.

Figure 18. The Stockton Black water Treatment Plant. Photo from Ellis (2008) prior to the installation of the centrifuges.



Table 3. Relative improvement in mine water composition following treatment by the Stockton BWTP.

	Units	Mean Influent	Mean Effluent	Percentage Reduction
pH	-	3.4	6.4	-
Turbidity	NTU	19.4	3.19	84 %
Suspended Solids	g/m ³	19.7	8.18	59 %
Dissolved Aluminium	g/m ³	29.8	0.13	99.6 %
Dissolved Iron	g/m ³	15.8	0.07	99.5 %

4.5 THE MANGATINI SUMP

The Mangatini Sump is another significant component of the Stockton Water Management Project aimed at achieving community water quality targets. It has been designed to capture and remove sediment by gravity settlement derived from upstream mining areas and also precipitate AMD sludge created by the upstream neutralisation of acidity. In the near term the sump is intended to provide sediment storage for 10 to 15 years of the mine when sediment rates (TSS) will remain high due to mine disturbance. In the long term, the sump is intended to provide AMD sludge storage capacity from ongoing AMD treatment for up to 100 years. Eventually it is anticipated that the sump will be drained, capped, and integrated into the final rehabilitation plan of the mine.

The sump was excavated entirely below coal floor following mining of the MG05, MG06 and MG07 mine blocks. The total excavation volume from coal floor to the sump bottom (RL 567 m) is approximately 1.8 million BCM, which makes it one of the largest sediment control structure in New Zealand. The total water storage capacity for the normal operating level (RL 593.5 m) is about 900,000 m³ of which approximately 443,000 m³ is live storage. Flows of up to ~15 m³/sec are diverted from the Mangatini Stream into the sump via a low diversion structure located on the Mangatini Stream. A floating decant structure decants treated water from the surface of the Mangatini Sump and conveys it through a tunnel back to the Mangatini Stream.

Figure 19. Aerial view of the Mangatini Sump.



Figure 20. Influent via the Mangatini Stream into the Mangatini Sump. Note limestone dosing turbidity



5 RESULTS – IMPROVEMENTS IN WATER QUALITY

The following figures demonstrate the improvements to water quality in the Ngakawau River since limestone dosing started in early 2007. As can be seen significant reductions in the acid load have decreased dissolved aluminium and increased pH. Improvements towards targets for clarity and turbidity (Figures 23, 24) has not been as good as the limestone remained in the stream together with precipitates. However, clarity is significantly improved after June 2010 following commissioning of the Mangatini Sump.

Figure 21. pH results (daily) for the Ngakawau River.

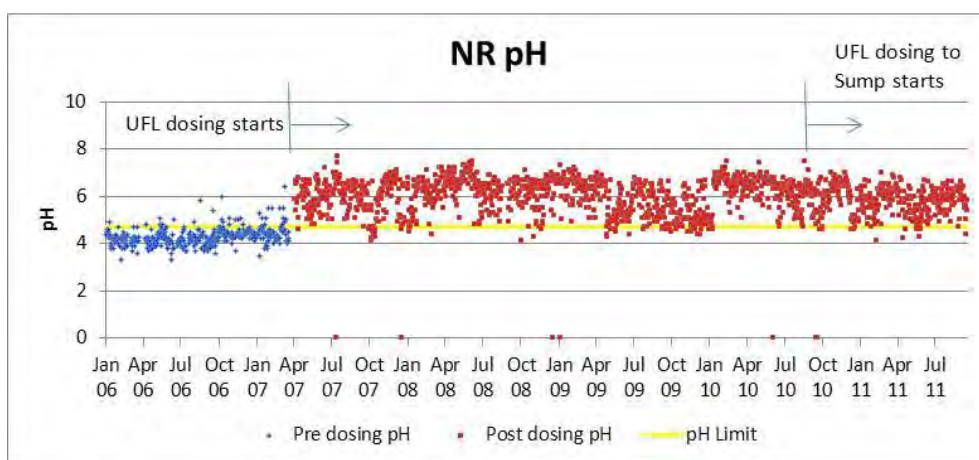


Figure 22. Dissolved aluminium results (daily) for the Ngakawau River.

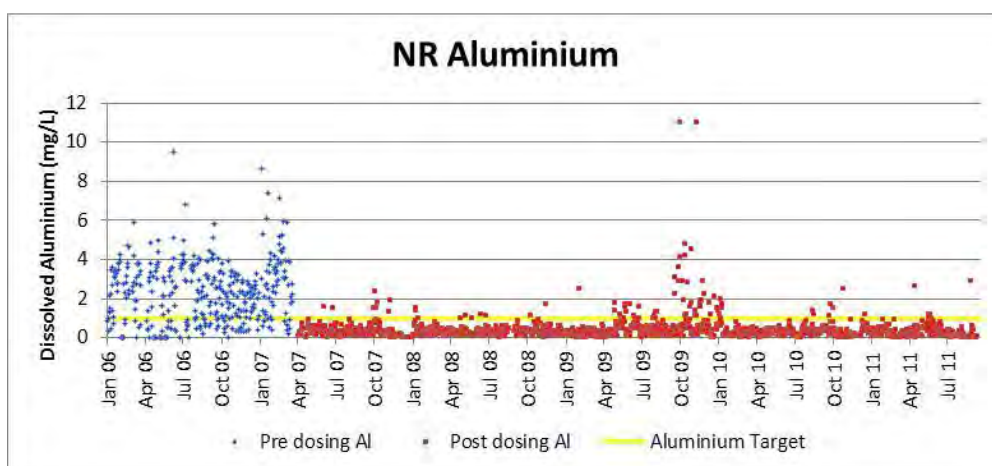


Figure 23. Clarity (cm) results (daily) for the Ngakawau River.

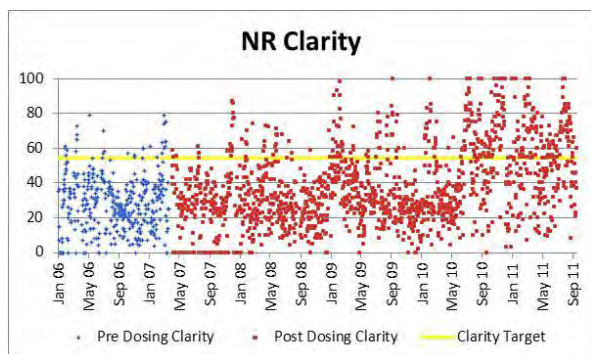
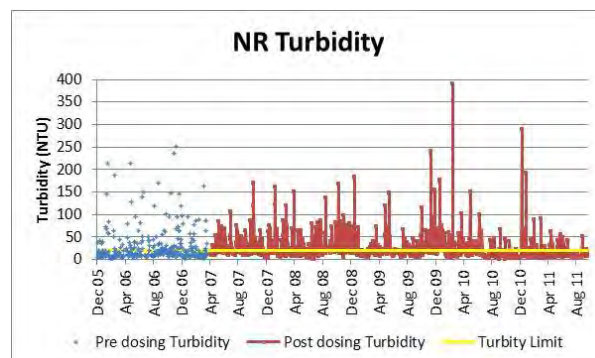


Figure 24. Turbidity for the Ngakawau River.



Analysis of the above results for site NR in the Ngakawau River indicate that between 6 April 2007 and 21 September 2011 the pH was ≥ 4.7 , 96.7% of the time; and dissolved aluminium was < 1 mg/L, 94.6% of the time, which was close to targets. From January 2011 to September 2011 the pH was ≥ 4.7 , 97.3% of the time and aluminium was < 1 mg/L, 98.3% of the time. These results demonstrate that Solid Energy is close to its agreed stakeholder targets and effectively managing the effects of AMD on the Mangatini catchment.

In regards to sediment load (turbidity) and water clarity, which is a function of erosion products, ultrafine limestone dosing, and AMD precipitates, significant improvements have occurred over the last six years, particularly in the last twelve months following commissioning of the Mangatini Sump and upstream UFL dosing. Between 6 April 2007 and 21 September 2011 the target in regards to turbidity was 96.1% (25 NTU, 30 day rolling median); and in regards to clarity was 41.3% (>54 cm during base flow). Subsequent to further process improvements (completion of the Mangatini Sump and upstream limestone dosing above the sump) results for the period January 2011 to September 2011 have increased to 100% of the time for turbidity (25 NTU, 30 day rolling median) and clarity has increased to 89.8% (>54 cm during base flow assuming base flow is 70% of the time).

6 DISCUSSION AND CONCLUSIONS

As this paper has demonstrated Solid Energy has undertaken a significant amount of work to manage sediment and mitigate the effects of acid forming overburden over the last six years. The capital costs for the Mangatini Sump, BWTP, associated water management infrastructure (e.g., A Drive Dam, Ford Creek Dam, Duncan's Sump), and the temporary limestone dosing plant is close to \$45M. Further capital commitments are planned in the future such as the long-term (100 year) Limestone Dosing Plant (\$4M) to be built above the Mangatini Sump. The long term limestone dosing plant above the Mangatini sump is expected to improve water quality further.

The results presented have shown a significant improvement in water quality in regards to acid load (pH) and dissolved aluminium and confirm that tackling the Mangatini Stream first was the best option for significant improvements in water quality in the Ngakawau River. Further work is required to reduce suspended solids to improve water clarity. This includes other streams that impacted the quality of water in the Ngakawau River (Mine Creek, Ford Creek, Fly Creek, and St Patrick Stream) and this work will be undertaken in the next few years.

Acid Mine Drainage (AMD) is a significant environmental liability at the Stockton Coal Mine located on the West Coast of New Zealand. This liability is the product of historical and current coal mining and the associated oxidation of pyrite. Management and treatment of the effects of AMD will last at least 100 years. Management of sediment and TSS will be intensive in the short term but post closure following rehabilitation and canopy closure this will reduce and eventually the adverse effects will be negligible.

Significant progress has been achieved to date and further improvements are planned. It is anticipated that with the improvements to stream health there will be an increase in biodiversity. Noteworthy results to date include the return of *galaxiids* inanga (whitebait) in the Ngakawau River (with some good catches being recorded).

ACKNOWLEDGEMENTS

The authors would like to thank the numerous individuals working within Solid Energy who have contributed to this project including staff members, contractors, and consultants.

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**ATTACHMENT E - ESCARPMENT MINE PROJECT: MINE WATER MANAGEMENT MODEL,
ESCARPMENT MINING AREA, DENNISTON SECTOR, BULLER COALFIELD, NEW ZEALAND
(GOLDER ASSOCIATES, 2012)**



August 2012, Updated October 2012

ESCARPMENT MINE PROJECT

Mine Water Management Model, Escarpment Mining Area, Denniston Sector, Buller Coalfield, New Zealand

Submitted to:
Buller Coal Limited
Po Box 290
Westport



REPORT

Report Number. 1078101422_002_R_Rev3_
401-062

Distribution:





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APPENDICES

APPENDIX A

Report Limitations

APPENDIX B

Progressive Mine Plan Catchment Area

APPENDIX C

Natural Catchment Run-off Water Quality Assessment



1.0 INTRODUCTION

Buller Coal Ltd (BCL) is currently seeking resource consents and Department of Conservation (DOC) access agreements associated with the development of a mining licence for the Escarpment Mine Project (EMP) part of the Buller Coalfield on the Denniston Plateau, New Zealand (Figure 1).

The proposed open cast mine (EMP) covers 157 hectares (ha) and will contain the following principal components:

- An open cast pit,
- An engineered land form (ELF) for the disposal of overburden material,
- Coal preparation plant (CPP) facilities,
- Infrastructure for mine water management.

On 2 September 2010 BCL applied to the West Coast Regional Council (WCRC) and the Buller District Council (BDC) for land use, water take and discharge consents associated with the EMP. In mid 2011, Hearing Commissioners were selected and a joint Council hearing was held. In a decision dated 26 August 2011 the Hearing Commissioners granted BCL various resource consents for the development of the EMP (WCRC 2012). The decision was subsequently appealed to the Environment Court and a hearing is scheduled for later this year (2012).

To support the consenting process and particularly the Environment Court hearing, BCL requires an assessment of the potential effects the proposed mine may have on surface water quantity and quality. BCL has retained Golder Associates (NZ) Limited (Golder) to develop a revised water management model which can be used by BCL's ecological consultants to evaluate such effects. To complete the assessment, Golder has developed a site-wide water management model for the EMP using the GoldSim software package. This report¹ documents the model approach, model inputs, scenarios modelled, model calibration and model predictions.

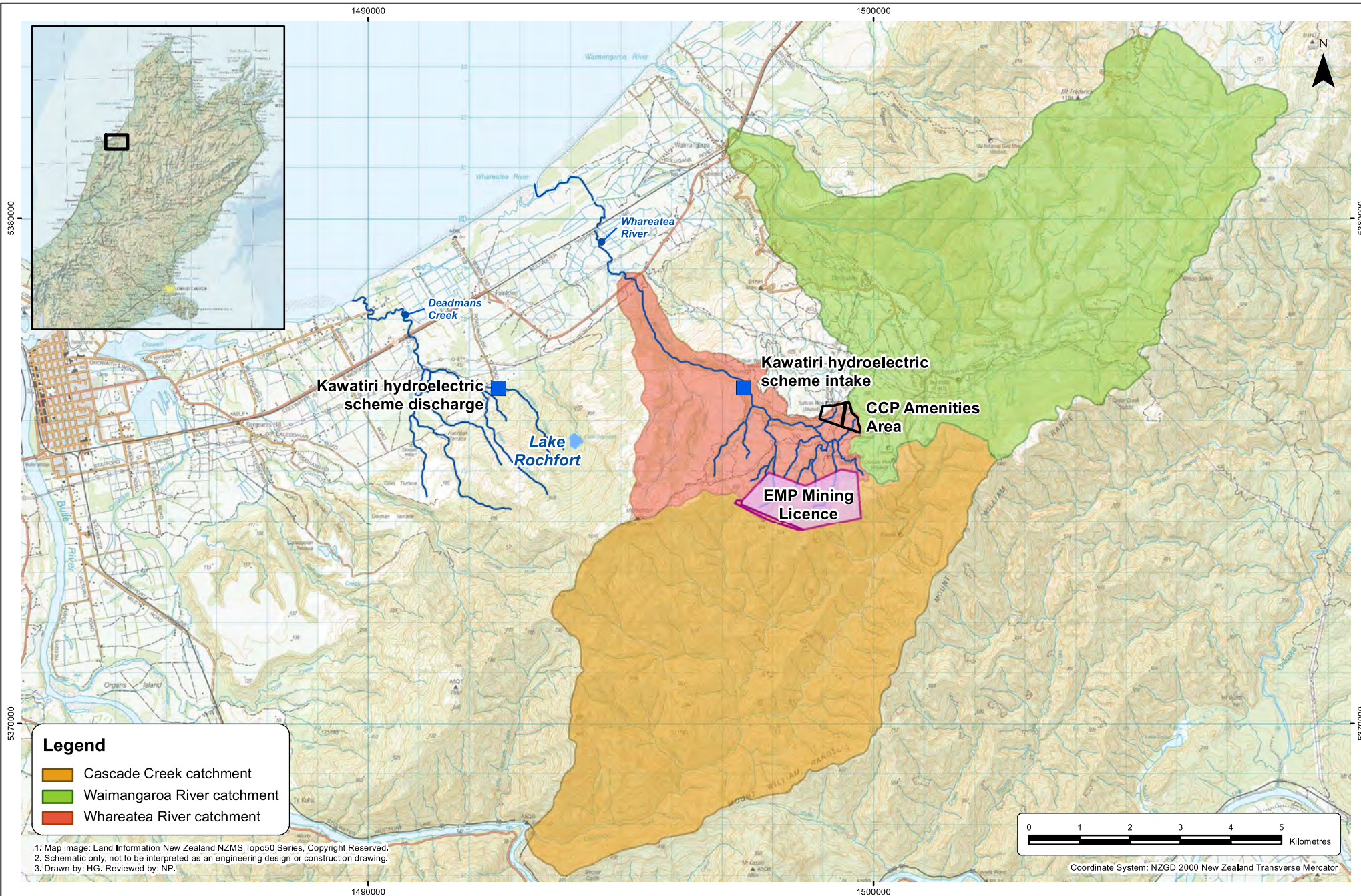
2.0 BACKGROUND

In May 2011, Golder prepared an initial mine water management model for the EMP (Golder 2011a). Since then, changes to the mine plan have been sufficient to warrant re-evaluation of catchment areas. Additionally the conceptual design of the final ELF has been further developed, additional flow and water quality data made available and a review of water quality parameters to be modelled has been undertaken. The initial mine water management model was updated and enhanced to cater for the above changes. The specific objectives of the model update were to:

- Address changes to the mine plan since the original model was developed,
- Add water quality parameters to the model (increasing the parameter list to approximately 20),
- Modify assumptions where additional information is available to reduce model uncertainty,
- Re-structure the model from a conceptual model for consenting purposes to a more detailed model which is to be used to assist design and management of the water management infrastructure.

This updated model will form the basis for an updated water management plan.

¹ This report is subject to the limitation in Appendix A.





On 13 June 2012 Golder provided BCL with a letter which provided a preliminary summary of the model objectives and predictions. The letter was provided to BCL to enable preparation of evidence for the Environment Court hearing to proceed in parallel with completion of this model report. This report builds on and replaces the information provided in the 13 June 2012 letter.

This report documents the current mine water management model for the EMP as at 13 June 2012. It should be noted that at the time of writing this report BCL had not assessed the 13 June 2012 model and had not confirmed that it represents their proposed plans for the EMP.

3.0 MODEL OBJECTIVES

The three main objectives of the EMP mine water management modelling are:

- 1) To provide a representative water balance for the site that enables the relative size and performance criteria for mine water infrastructure objects to be assessed under various mine development scenarios. The model should provide a tool to support conceptual water management system design and evaluation. Within this report the model has been used to, on a conceptual basis, optimise the size of the pit sump, mine influenced water (MIW) surge sump, MIW water treatment plant (MIW-WTP) and the surface water - water treatment plant (SW-WTP) which is a settling basin associated with the CPP on a yearly basis through the life of the mine.
- 2) Following input from BCL regarding preferred risk strategy and taking into account the corresponding levels of conservatism, the model could be used to support the detailed design of water management infrastructure.
- 3) To assess compliance with key water quality parameters within the mine site and at key locations in the receiving environment downstream. The Hearing Commissioners decision dated 26 August 2011 contained consent conditions which stipulate compliance limits (Section 6.4.5) with which operations must abide (WCRC 2011). In evidence to be presented to the Environment Court, it is expected that BCL will propose revised consent conditions setting out compliance limits for contaminants. These will be measured at monitoring points downstream of the mine permit area consistent with those outlined in the Hearing Commissioners decision dated 26 August 2011.
- 4) While the mine occupies a relatively small part of the overall Whareatea River catchment, it has the potential to alter the flow regimes in the upper sub-catchments. Overall flow regime changes are expected to be temporary but this conclusion requires a supporting assessment which the model provides. Specific objectives relative to changes in downstream receiving water bodies include:
 - An evaluation of the effect of the pre-mine infrastructure development on downstream water quality.
 - An evaluation of the effect of mine operations and closure conditions on water quality and flows in downstream surface water bodies (streams and rivers).

4.0 MODELLING APPROACH

Golder used the GoldSim model platform (GoldSim v10.50 (SP1)) to develop a mine water management model for the EMP site. The EMP GoldSim model estimates flow and water quality at various key locations on a daily basis. The model uses a combination of:

- Local climate and flow data.



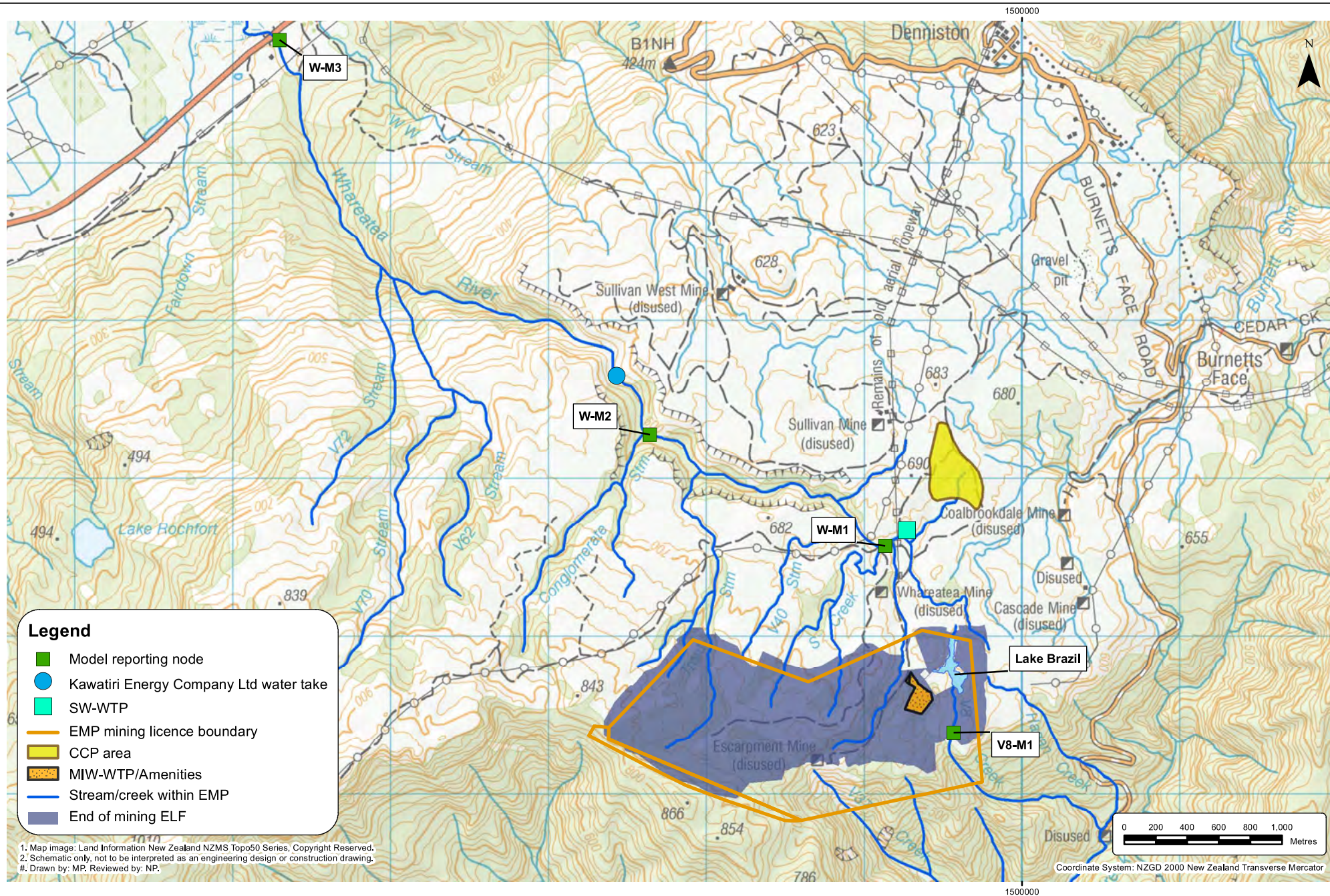
- A rainfall runoff model (the Australian Water Balance Model (AWBM)) for defining run-off from natural and rehabilitated catchments.
- The rational method for defining run-off from mine affected catchments.
- Estimated contaminant load concentrations.
- Site layouts, drainage systems and proposed surface water usage provided by BCL.
- Available water quality data.
- Treatment efficiencies provided by BCL and their technical advisors for the site's mine water treatment facilities.
- The results of technical assessments of groundwater seepage and ELF design.

From these data the model generates contaminant loads and uses mass-balance calculations to provide flow and water quality projections for numerous locations within the boundary of the proposed mining lease and in receiving waters at specified compliance points. The EMP GoldSim model was set up to have a degree of flexibility in case additional features were required and the model can easily be adapted. To meet the project objectives and as directed by BCL, this report focuses on the following parameters and key model nodes:

- Water quality and quantity at:
 - W-M1, W-M2, and W-M3 (existing monitoring points located on the Whareatea River which are shown in Envirolink 2012a and on Figure 2). W-M1 is on the upper Whareatea River above the S Creek confluence. W-M2 is on the upper Whareatea River above the Conglomerate Creek confluence. W-M3 is on the lower Whareatea River at the State Highway Bridge. W-M2 represents the current compliance monitoring location in the Hearing Commissioners decision dated 26 August 2011 (WCRC 2011).
- Water quality at:
 - MIW-WTP influent².
 - MIW-WTP effluent.
- Water quantity at:
 - MIW surge sump volumes and spill events.
 - Pit sump volumes and overflow events.
 - SW-WTP spill events.

EMP GoldSim model includes 19 water quality chemical parameters, five of which are hardness dependent and the model predicts concentrations both with and without a hardness adjustment. In preparation for the Environment Court Appeal BCL requested that Dr Christopher Hickey, Principal Scientist with the National Institute of Water and Atmospheric Research (NIWA), review the list of chemical parameters of potential concern in the downstream receiving environment. BCL requested Golder to increase the parameter list within the surface water model, as required. Dr Mark Ellis of Ellmock Consulting Limited developed an initial list of 19 parameters (Ellmock 2012a) by screening available data from the Whareatea River (Envirolink 2012a) and lysimeter data provided by CRL Energy Limited (CRL 2011). To maintain the rigorous appeal schedule Golder used the preliminary list to expand the model. Chris Hickey reviewed the preliminary list and included 11 of the 19 chemical parameters, plus turbidity, in his proposed compliance limits for the Whareatea River (Hickey 2012). In addition Golder elected to also model calcium and magnesium for the purpose of evaluating the likely hardness at the model reporting nodes.

² The MIW-WTP influent water quality is equivalent to the MIW surge sump water quality.





Arsenic was also included as it is a publicly sensitive parameter. Turbidity was not modelled as it could be approximated from total suspended solids (TSS). Therefore, this report focuses on the following 15 chemical and physical parameters:

■ Aluminium	■ Cobalt	■ Manganese
■ Arsenic	■ Copper ⁴	■ Nickel ⁴
■ Cadmium ³	■ Iron	■ pH
■ Calcium	■ Lead	■ TSS
■ Chromium ⁴	■ Magnesium	■ Zinc ⁴

5.0 INITIAL ASSUMPTIONS

5.1 Introduction

A range of assumptions with regard to input parameters and outcome projections have been incorporated into the model. Most of these assumptions relate to either climate patterns or water quality values and are discussed below.

5.2 Climate Variability

The EMP GoldSim model uses long term rainfall and evaporation records and a key assumption is that future climatic conditions are likely to be similar to historic records. Because of climatic fluctuations, the above assumption is only valid if long climatic records are used.

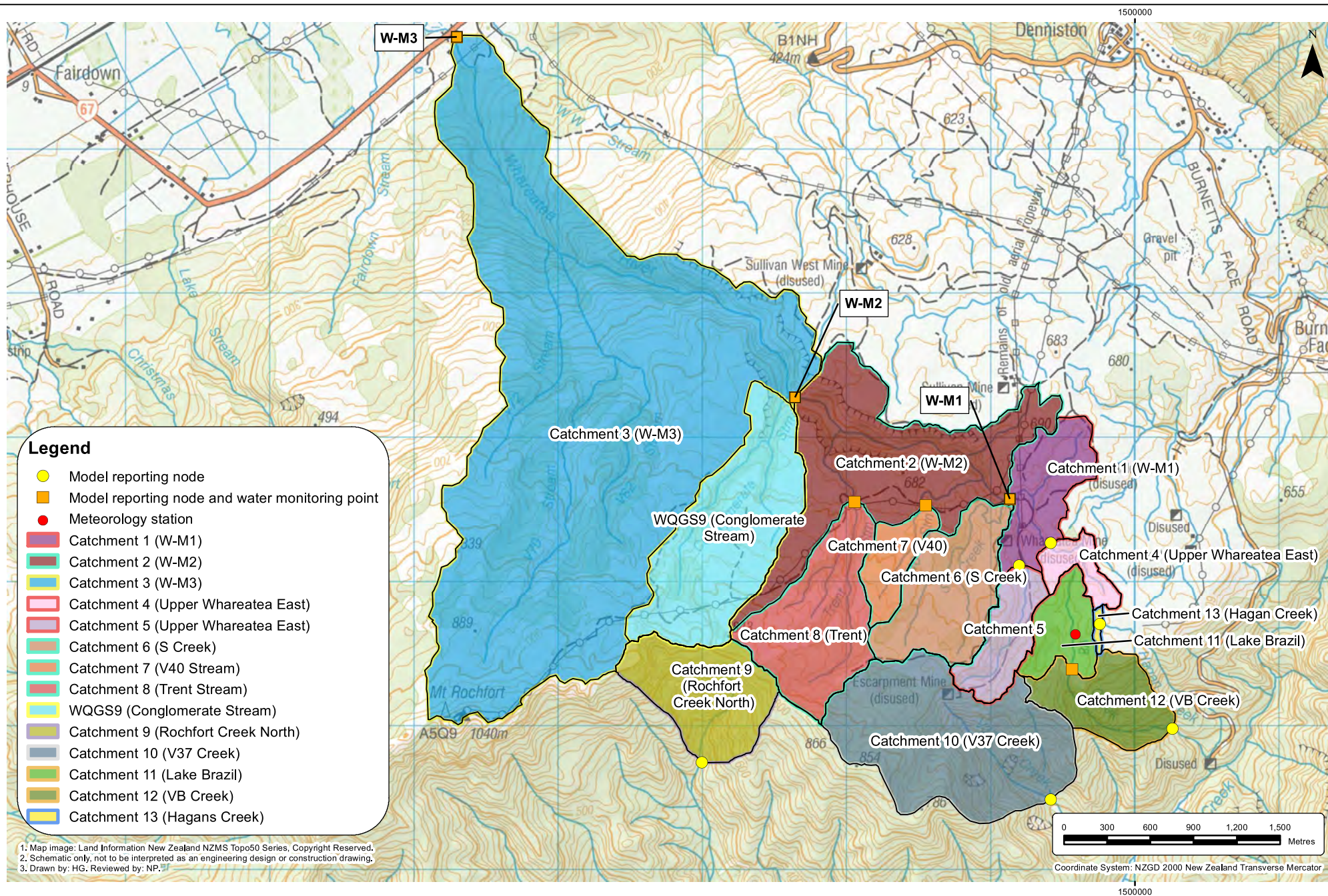
On a seasonal and year-to-year basis, New Zealand's climatic variability is strongly affected by the El Niño/La Niña Southern Oscillation (ENSO) (Nicholls 1992, Salinger et al. 1996, Hay et al. 1993). Recently, scientists have identified a longer interdecadal variability in climate associated with the Interdecadal Pacific Oscillation (IPO) (Salinger & Mullan 1999, Salinger et al. 2001, Folland et al. 2002). Distinct shifts in climate in 1977 and possibly again in 1998 have been identified with wetter phases between 1951 and 1976 and post 1998 and a drier phase from 1977 to 1997. Such variability reinforces the need to use as long a climatic record as possible when developing water management models. For the EMP GoldSim model, climatic data from 2 March 1945 to 12 April 2012 (approximately 67 years) (Golder 2012a) has been used, which should ensure that extreme climatic conditions observed historically are suitably considered.

BCL have indicated that the EMP has an operational life of approximately five years, followed by a site rehabilitation period. While the EMP GoldSim model does not specifically include allowances for future climate change, it is considered reasonable to assume that climate extremes occurring over the next 10 years are unlikely to exceed the extremes experienced over the last 67 years.

5.3 Flow Variability

Daily flow records for the EMP site are required to develop runoff coefficients within the AWBM and are a key calibration record for the EMP GoldSim model. Envirolink have measured flow at various locations within and downstream of the EMP since 7 November 2010 (Envirolink, 2012a). Water monitoring points are shown on Figure 3. Flow data up to 11 April 2012 were provided to Golder by Envirolink (Envirolink 2012c). These data have been analysed and used in the EMP GoldSim model. Golder has assumed the flow data provided by Envirolink is accurate and no checking of the data has been undertaken.

³ The chemical parameter is hardness dependant and reported results have been adjusted to a hardness of 50 g/m³ of CaCO₃.





While the length of the monitored period is limited and there are a number of gaps in the monitored data, the continuous nature of the dataset is useful for comparing with simulated daily flows. Envirolink have indicated that the low flow end of the rating curve for the various flow sites is well defined. However, the high flow end is not well defined due to the short duration of flood events, making flood gaugings difficult to obtain (per coms Brenda Clapp of Envirolink 1 May 2012) (Envirolink 2012d). Flow will also be subject to the climatic variability (ENSO and IPO) discussed above. The short nature of the measured flow record means that it is unlikely to capture the full variability associated with the ENSO and the IPO.

The available flow data reflect pre-mining conditions. Runoff coefficients under operational and post-closure conditions have been estimated based on experience from existing mine sites (namely the various mines on the Stockton Plateau). Golder recommends that the EMP GoldSim model be validated as flow data become available from catchments affected by mining operations.

5.4 Water Quality

It has been assumed that all contaminants are transported in the surface water systems without attenuation, except what may be provided through dilution or via direct treatment (i.e., settlement of TSS within the silt ponds etc.). This assumption fundamentally affects the EMP GoldSim model outcomes and how these outcomes are to be understood. In the case of the major ions, this assumption is generally expected to be correct. However, most metals/metalloids are subject to geochemical reactions leading to adsorption, desorption, precipitation or dissolution, depending on factors such as the changing pH conditions, redox conditions or available organic carbon in the surface water system. The water quality projections documented in this report are generally believed to be conservative with respect to dissolved metals/metalloids but further geochemical testing and more detailed modelling would be required to substantiate this assumption.

While the absolute values generated from EMP GoldSim model projections for a given scenario should be viewed with caution, the model's strength lies in its capacity to qualitatively compare different scenarios and to reliably evaluate relative changes. Golder understands that Dr Hickey will discuss and interpret the EMP GoldSim models' water quality outputs based on an assessment of background water quality and the potential for chemical contaminants to result in toxicity-related adverse effects in relation to the EMP as summarised in Hickey (2012).

Envirolink have measured turbidity, conductivity and pH continuously⁴ at various locations within and downstream of the EMP since November 2010 (Envirolink 2012a). Of the continuously monitored water quality parameters only pH is simulated directly in the mine water management model⁵. Since November 2011 Envirolink have also taken numerous discrete water quality samples at various locations within and downstream of the EMP which have been tested for a variety of chemical parameters (Envirolink 2012a). The discrete sampling approach and consequent small⁶ data set for the other water quality parameters, limits their usefulness for calibration. The EMP is located in small headwater catchments of the Whareatea River, which experience rapid runoff due to the high rainfall they receive, their small area and their steep terrain. The rainfall response times for the catchments are short, with freshes and floods tending to peak within hours rather than days. Water quality is expected to be related to flow conditions, this is particularly the case for turbidity and TSS concentrations which will tend to peak during freshes and flood events. The discrete water quality sampling approach is unlikely to pick up peak instantaneous concentrations. Nonetheless, the data have still been used to develop model water quality inputs for undisturbed site conditions because they provide the best indication available for pre-existing water quality. If the water quality dataset were able to be compared to larger data sets from similar sites, confidence in the observed range of results could be increased. However, at the time of model development no additional data were available.

⁴ Continuous monitoring refers to readings at approximately 15 minute intervals.

⁵ TSS is simulated in the mine water model and is related to turbidity.

⁶ The number of discrete samples varies from site to site. The available water quality data up to 23 February 2012 indicates there was a maximum of 30 discrete samples from any of the sites.



Calibrating the EMP GoldSim model using the available dataset allowed the model to be adjusted to account for the variation in water quality coming from different catchments along the Whareatea River. The variation in water quality observed is likely related to variation in surface water flows affecting degrees of dilution of oxidised metals/metalloids from exposed bedrock, discharges from underground workings which also carry dissolved metals/metalloids, variation in geologic formations which form the source of the leached metals/metalloids and changing land use. As previously noted, the highest concentrations in the surface water bodies may not have been represented in the water quality data set from Envirolink. To increase the conservatism in the EMP GoldSim model the water quality inputs to the model represent the high end of the measured values rather than median values.

The available water quality data represent pre-mining conditions. Water quality inputs during mine operations have been estimated by Dr James Pope of CRL (Pope 2012a), and in the case of TSS by Dr Mark Ellis of Ellmock Consulting Limited (Ellmock) (Ellmock 2012). To incorporate uncertainties in mine water quality, optimistic (lower contaminant loads), typical (expected contaminant loads) and extreme (maximum expected contaminant loads) water quality inputs have been used to envelope potential outcomes.

Golder recommends that the EMP GoldSim model be validated as new water quality data become available, particularly water quality data from catchments affected by mining operations.

ANZECC (2000) describes a method for adjusting trigger values for cadmium, copper, chromium (III), lead, nickel and zinc that are hardness dependent, i.e., the toxicity of those metals decreases as hardness increases. For the purposes of comparing modelled results for metals to hardness-based compliance limits, the results on a daily time step basis were normalised to a hardness of 50 g/m³ of CaCO₃ using the available hardness for each time step. This hardness value was selected by Hickey (2012) because it approximated the median hardness observed in the Whareatea River at W-M2 for many of the model runs. Further discussion on hardness is provided in Section 6.4.5.

6.0 MODEL DEVELOPMENT PROCESS

Generic model development included several steps, undertaken in the following order:

- Define the purpose of the model and the required model projections (Sections 0 and 4.0 above).
- Define the stages of mine development that require model projections (Section 6.1 below).
- Create the conceptual model (Section 6.1 below), including defining the:
 - Model limits,
 - Mine-site features (pits, covered and uncovered ELF, rehabilitated areas, haul roads and, amenities areas, treatment plant and sedimentation ponds),
 - Catchments and water quality classifications,
 - Receiving environment waterways,
 - Discharge locations,
 - Receiving environment water quality and quantity projection points.
- Define the model inputs for each stage of mining (Section 6.4 below), including:
 - Catchment areas,
 - Rainfall and evaporation (Golder 2012a),
 - Groundwater seepage rates,
 - Water quality for groundwater seepage inputs,



- Runoff water quality for each catchment classification,
- Pumping rates ,
- Storage volumes for pits, pit sumps, MIW surge sump, freshwater and recycle dam and SW-WTP (sedimentation ponds),
- Sedimentation pond and water treatment plant assumptions, including treatment efficiencies.
- Construct the numerical model. Flexibility was built into the model to allow all model input parameters to be easily altered. Several redundant features were included in case additions were required to accommodate future mine plan changes.
- Calibrate model by adjusting model input parameters until simulation results acceptably match measured pre-mine data (Section 7.0 below).
- Carry out predictive analyses and document results (Section 9.0 below).

6.1 Mine Development and Model Scenarios

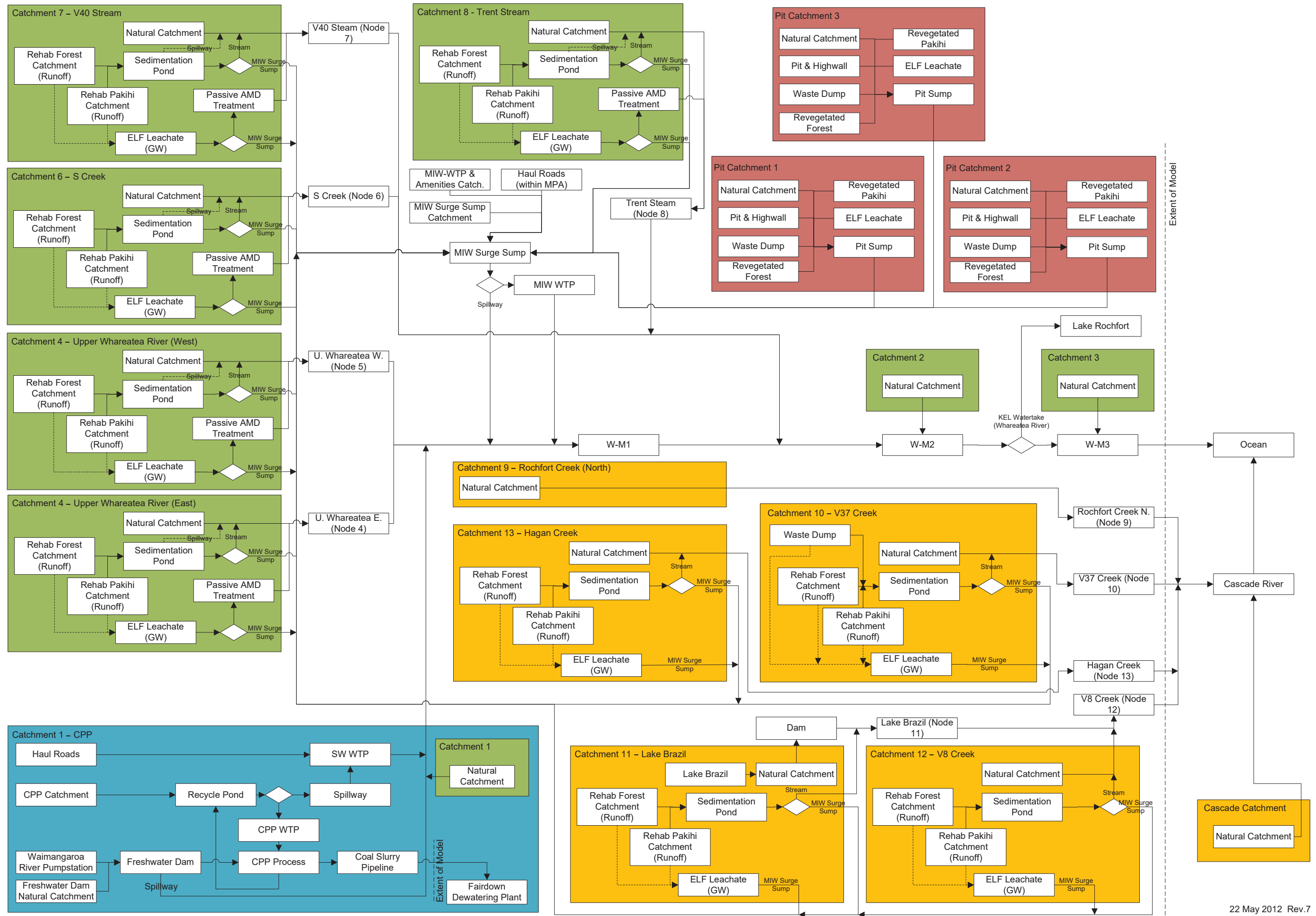
BCL indicated that the water quality and quantity predictions were required for the following ten land use scenarios (McCracken 2012):

- Pre-mining, undisturbed (pre-existing or undisturbed conditions), subsequently called Year 0.
- The operational period of the mine including seven development stages:
 - The infrastructure development stage (representing the maximum disturbance period during pre-mining construction of infrastructure (including coal preparation plant (CPP), freshwater and recycle dams, haul road, MIW surge sump, MIW-WTP, SW-WTP, amenities area and run of mine (ROM) pad). This scenario was subsequently called Year 0.5.
 - Years 1, 1.5, 2, 3, 4 and 5 of mining.
- Post-closure (rehabilitated conditions following mining), subsequently called post-mine. Two post-mine scenarios were considered one involving active management (continued operation of the MIW-WTP and SW-WTP) and one involving passive management.

Staged mine plans were provided by BCL (2012) for the seven mine development scenarios are contained in Appendix B. The infrastructure development Year 0.5 mine plan is shown in Figure B1. Similarly the mine plans for years 1, 1.5, 2, 3, 4, 5 and post-mine are shown in Figures B2 to B7. Year 1.5 represents a half-way point between Year 1 and 2. Major conceptual erosion and sediment control structures for mine years 0.5, 1, 1.5, 2, 3, 4, 5 and post-mine are shown in Figures 17, 18, 19, 20, 21, 22, 23 and 25 of Golder (2012b), the engineered landform design philosophy report, respectively.

The EMP water management model has been set up to allow other land use scenarios such as revised mining schedules or the various stages of closure and rehabilitation to be easily assessed if required.

A flow diagram which illustrates the input parameters and how they are linked within the EMP GoldSim model is provided in Figure 4.



1. Schematic only, not to be interpreted as an engineering design or construction drawing
3. DRAWN BY: SG REVIEWED BY: NP



A key objective of the modelling was to generate projections for water quantity and quality changes at key locations due to the BCL's proposed development of the EMP. This is achieved by comparing the projections for the various proposed mining scenario with those for the current pre-mine scenario. The pre-mine situation provides the baseline against which overall change associated with the proposed mining can be assessed, and was included to assist with overall calibration of the EMP GoldSim model.

6.2 Model Area

The EMP is located in the small headwater catchments of the Whareatea River particularly the sub-catchments of Trent Stream, V40 Stream and S Creek (Figure 2). Much of the area covered by the EMP has previously been subject to underground mining and there are numerous existing mine adits some of which discharge to the catchment of Cascade Creek a tributary of the Buller River. The EMP GoldSim model does not fully model flows in the Cascade Creek catchment but it does consider some of the mine related flows into the catchment and specifically seepage flows from the existing mine adits particularly the Escarpment Mine adit. Catchments or sub-catchments of the Rochfort Creek North, V37 Creek, VB Creek and Hagen Creek (all of which are upper sub-catchments of Cascade Creek), are considered in the model.

6.3 Model Time Step

The Hearing Commissioners decision dated 26 August 2011 required a combination of continuous, weekly and monthly compliance monitoring. For practical reasons management of the proposed water management system at the mine is likely to be on a daily basis. The long term rainfall record developed for the EMP is based on daily rainfall measurements at the Downertown rainfall station (Golder 2012a). The limited water quality data that is available for the EMP is mainly based on grab samples which are collected at approximately weekly intervals.

The EMP is located in small headwater catchments of the Whareatea River, which experience rapid runoff due to the high rainfall they receive, their small area and steep terrain. The rainfall response times for the catchments are short, with freshes and floods tending to peak within hours rather than days. Water quality is expected to be related to flow conditions, this is particularly the case for turbidity TSS concentrations which will tend to peak during freshes and flood events. To assess turbidity and TSS concentrations the time-step of the model should be consistent with the flow fluctuations. A daily time step has been used for the EMP GoldSim model, with outputs based on average daily values. The model cannot generate accurate projections for the peak instantaneous flow rates required for certain mine infrastructure (e.g., the maximum flow rates required for pump sizing). Similarly the model may miss some instantaneous concentration peaks due to the daily time step that has been used.

To be hydrologically consistent, all output data are assessed and reported in New Zealand hydrological years from 1 July through to the following 30 June.

6.4 Model Input Parameters

6.4.1 Climate and hydrology

The climatic and hydrological data which was utilised in the GoldSim modelling is summarised below. A full description of the derivation of the data can be found in the EMP rainfall and evaporation assessment (Golder 2012a).

There is a lack of good climatic data from the Denniston Plateau, which makes it difficult to predict climatic conditions at the proposed EMP site. Long term synthetic daily rainfall and evaporation records for the EMP site were developed for the period 2 March 1945 to 25 April 2012. The rainfall record was generated from:



- Approximately 16 months of daily rainfall data recorded at V8-M1, within the proposed EMP site, supplied by Envirolink
- Daily rainfall recorded at M1-R2 (Downertown (Bathhouse) on the Stockton Plateau) supplied by Envirolink
- A correlation equation between daily rainfall at M1-R2 and V8-M1, provided by Envirolink (2012a).

Golder has assumed the rainfall data provided by Envirolink is accurate and no checking of the data has been undertaken. The long term synthetic daily rainfall record for the EMP site indicates an average hydrological year (1 July to following 30 June) rainfall of approximately 7,420 mm ranging from a high of approximately 10,170 mm, during the 1967-1968 hydrological year, to a low of approximately 4,950 mm, during the 2009-2010 hydrological year. The long term synthetic record shows a slight seasonal pattern in monthly rainfall, with the spring months of September to November generally receiving the highest rainfall. The late summer autumn months of February to April tend to be the driest. Extreme rainfall events can occur throughout the year and maximum monthly rainfall has exceeded 1,100 mm in all calendar months.

Daily evaporation at the EMP site is required to develop runoff coefficients within the AWBM and to assess evaporation from the surface of water reservoirs or ponds at the site. A long term synthetic Penman potential evapotranspiration (PET) record was developed for the EMP site using the synthetic daily Penman PET data from the NIWA virtual climate station 19209. This virtual climate station is located in the upper Trent Stream catchment within the proposed EMP. The daily evaporation record developed for the EMP site indicates an average hydrological year (1 July to following 30 June) evaporation of approximately 560 mm ranging from a high of approximately 730 mm, during the 2009-2010 hydrological year, to a low of approximately 435 mm, during the 1986-1987 hydrological year. The long term synthetic record shows a strong seasonal pattern for evaporation. The summer months of November to February generally have the highest evaporation while the winter months of May to July tend to have the lowest evaporation.

Envirolink have measured flow at various locations within and downstream of the EMP. Flow data up to 27 April 2012 was provided by Envirolink to Golder and has been analysed and used in the water management modelling. Golder has assumed the flow data provided by Envirolink is accurate and no checking of the data has been undertaken.

6.4.2 Catchment areas and landuse

The mine affected catchment areas were determined from mine plans provided by BCL (see catchment areas identified in Appendix B). Staged mine plans were provided for years 0.5, 1, 1.5, 2, 3, 4, 5 and for the final landform at mine closure (post-mine). BCL also provided the location of key infrastructure (haul roads, surge sumps, mine-influenced water treatment plant (MIW-WTP) and amenities area. The conceptual ELF design includes covering the waste rock with a 1 m thick low permeability layer (LPL) and an overlying protective layer which is 1 to 5 m thick depending on the revegetation plan. The relatively flat areas of the final landform will be revegetated with pakihi and the sloped areas with scrub or forest. These areas have been considered separate catchment types due to the variation in groundwater infiltration and runoff. Newly revegetated rehabilitated areas are considered to have a different effect on runoff and produce different water quality than more mature rehabilitated areas and therefore considered different catchment types. Toward the end of the modelling process BCL indicated that rock fields would also be included in the rehabilitation plans and areas of potential rock fields were identified (Kingsbury 2012). Rock fields make up part of the current pre-mine landuse and runoff from them will be included in the AWBM runoff coefficients for the pre-mine natural catchments. Unfortunately it was too late in the modelling process to include the potential rock fields in the 13 June 2012 model. However, as runoff from the rehabilitated areas is estimated using the AWBM runoff coefficients for the pre-mine natural catchments the inclusion of rock fields would not change the models runoff predictions. Overall the mine affected catchments are separated in to the following ten categories:

- Haul road,



- MIW-WTP and amenities area,
- CPP – coal processing plant,
- Pit,
- Uncovered ELF or waste dump (areas with no low permeability layer (LPL) or protective layer,)
- Revegetated ELF- pakihi (flat areas with recently completed final cover including LPL and a 1 m protective layer),
- Revegetated ELF – scrub/forested (sloped areas with recently completed final cover including LPL and a 5 m protective layer),
- Rehabilitated ELF – pakihi (flat areas with well developed final cover),
- Rehabilitated ELF – scrub/forested (flat areas with well developed final cover),
- Clean catchments - natural catchment which has been temporarily redirected to the mine water management system or another nearby natural catchment.

As the mine progresses certain natural catchments are intercepted and temporarily redirected to the mine water management system. These areas are designated as “clean catchments”. The final landform has a different contour pattern from the natural pre-mine topography and therefore the catchment areas for Trent Stream, V40 and S Creek and the Upper Whareatea West have been recalculated.

Catchment areas were delineated by Golder using the Geographical Information System (GIS) tool ArcGIS. Pre-mine catchment areas used in the GoldSim EMP model are shown in Figure 2. The staged mine plans for operations years and the post-mine catchment areas used in the GoldSim EMP model are shown in the figures provided in Appendix B. The areas are tabulated in Table 1 (natural catchments) and Table 2 (mine affected catchments).

6.4.3 Runoff and the Australian water balance model (AWBM)

Runoff in the EMP GoldSim model is calculated in two ways, depending on the catchment type. Mine site catchments are calculated using a look-up table with runoff coefficients for various rainfall depths. This approach allows modification of coefficients during the calibration process to match observed water volumes stored in pits and silt dams. Mine affected catchments were separated into the following six categories: the pit, waste dumps (i.e., uncovered ELF), the coal processing plant (CPP), haul roads, and two categories associated with the covered ELF. The two covered ELF situations represent when the ELF has been covered with a low permeability layer (LPL) and revegetated with either forest (on the sloping areas) or pakihi (on the flat areas). Surface runoff from mine affected catchments was derived using the rational method using the following surface runoff coefficients (Table 3).

Runoff from both natural catchments and rehabilitated mine catchments was calculated using the AWBM. The AWBM was developed in the early 1990s (Broughton 1993) and has been used extensively throughout Australia and increasingly in New Zealand to estimate runoff from ungauged catchments. The AWBM generates runoff projections, by developing a relationship between rainfall, evapotranspiration and runoff and then applying that relationship to the long term (2 March 1945 to 25 April 2012) synthetic daily rainfall and evaporation time series generated for the EMP site. The relationship takes into account soil and groundwater storage and release, antecedent wetness, infiltration, vegetation and evapotranspiration (Broughton 2005). This relationship can be effectively developed through calibration of the model, using available rainfall, evapotranspiration and runoff data for catchments in the area. The AWBM uses a series of coefficients which are calibrated using the Rainfall Runoff Library (RRL) software developed by the eWater Cooperative Research Centre (eWater CRC).



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Table 1: Catchment areas – natural catchments.

Catchment	Area (ha) ⁽¹⁾								
	Pre-mine	Year 0.5 ⁽²⁾	Year 1 ⁽³⁾	Year 1.5 ⁽³⁾	Year 2 ⁽³⁾	Year 3 ⁽³⁾	Year 4 ⁽³⁾	Year 5 ⁽⁴⁾	Post mine
Whareatea									
West Upper Whareatea	30.6	24.0	8.0	8.0	8.0	8.0	7.9	4.8	4.8
East Upper Whareatea	14.8	14.7	14.7	14.7	14.7	14.7	14.7	11.1	11.2
Upper Whareatea above W-M1	42.9	42.9	42.9	42.9	42.9	42.9	42.9	42.9	42.9
Mid Whareatea above W-M2	141	141	141	141	141	141	141	141	141
Lower Whareatea above W-M3	730	730	730	730	730	730	730	730	730
Trent Stream	78.0	75.6	54.2	33.2	33.2	33.2	33.3	33.2	33.2
V40 Stream	22.3	21.7	21.7	21.7	21.4	21.1	21.1	21.1	21.7
S Creek	65.4	60.4	60.4	65.3	62.0	50.8	41.8	41.7	41.7
Hagan Creek (in Cascade Creek catchment)	1.7	1.7	1.7	1.7	1.7	1.7	1.2	0.0	0.0
Natural – Sedimentation Ponds	0	0	0	0	0	7.6	7.9	7.9	7.9
Trent – Rehab Forest	0	0	0	0	13.7	23.3	23.7	23.8	23.8
V40 – Rehab Forest	0	0	0	0	0	0	1.8	1.8	1.8
S Creek – Rehab Forest	0	0	0	0	0	0	18.0	17.9	17.9
West Upper Whareatea – Rehab Forest	0	0	0	0	0	0	0	19.3	19.3
East Upper Whareatea – Rehab Forest	0	0	0	0	0	0	0	5.0	5.0
Hagan – Rehab Forest	0	0	0	0	0	0	0	2.3	2.3
Trent – Rehab Pakihi	0	0	0	0	8.8	25.6	27.2	27.6	27.5
S Creek – Rehab Pakihi	0	0	0	0	0	0	11.2	11.0	10.9
West Upper Whareatea – Rehab Pakihi	0	0	0	0	0	0	0	35.6	35.6
Cascade									
Rocheft Creek	62.3	62.3	62.3	62.3	62.3	62.3	62.3	62.3	62.3
V37	136	136	135	140	139	113	104	104	104
V8	42.5	42.5	42.5	42.5	42.5	42.5	36.1	36.1	36.1
Lake Brazil	26.2	22.5	22.7	22.7	22.7	22.7	10.8	0.8	0.8
V37 – Rehab Forest	0	0	0	0	0	0	0	4.8	4.8
V8 – Rehab Forest	0	0	0	0	0	0	0	3.6	3.6
Underground Mine Workings	30	0	0	0	0	0	0	0	0
Total Natural Catchments	1,424	1,375	1,337	1,326	1,344	1,340	1,337	1,390	1,390

Notes: (1) Areas less than 100 ha have been rounded to the nearest 0.1 ha. Areas greater than 100 ha have been rounded to the nearest ha.

(2) Year 0.5 represents the situation at the end of infrastructure development.

(3) Represents the situation at the end of the periods mentioned.

(4) Year 5 represents the situation at the end of active mining.



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Table 2: Catchment areas- mine affected catchments.

Catchment	Area (ha) ⁽¹⁾								
	Pre-mine	Year 0.5 ⁽²⁾	Year 1 ⁽³⁾	Year 1.5 ⁽³⁾	Year 2 ⁽³⁾	Year 3 ⁽³⁾	Year 4 ⁽³⁾	Year 5 ⁽⁴⁾	Post mine
Pit 1 (Western Pit Sump)									
Natural	0	0	0.7	5.7	1.1	0	0	0	0
ELF2a	0	0	2.0	3.2	0	8.7	10.9	0	0
ELF2b	0	0	1.0	4.6	0	0.4	3.7	0	0
Pit & Highwall	0	0	9.6	9.3	8.4	10.9	0	0	0
Waste Dump	0	0	8.6	11.5	8.5	4.1	0	0	0
Pit 2 (Eastern Waste Dump)									
Natural	0	0	4.0	4.0	4.0	4.06	1.7	0	0
Waste Dump	0	2.9	12.1	12.1	13.9	13.9	14.9	0	0
Pit 3 (Eastern Brazil Block Pit Sump)									
ELF2a	0	0	0	0	0	0	3.6	0	0
ELF2b	0	0	0	0	0	0	3.5	0	0
Pit & Highwall	0	0	0	0	0	0	3.9	0	0
Waste Dump	0	0	0	0	0	0	6.0	0	0
Mine Influenced Water									
MIW Sump Catchment	0	1.5	1.5	1.5	1.5	1.5	1.6	1.6	1.6
MIW Haul Road	0	11.6	11.0	10.1	8.2	5.5	3.5	1.4	0
MIW WTP Amenities	0	2.3	2.3	2.3	2.3	2.3	2.2	1.4	0
Waste Dump V37	0	0	3.6	3.6	1.9	1.9	1.7	0	0
CPP									
Catchment	0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Site Catchment	0	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8
Recycle Pond – Natural	0	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Recycle Pond – Haul Road	0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
CPP - Haul Road Treatment Pond	0	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Natural - Haul Road Treatment Pond	0	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3
Freshwater Dam Surface	0	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Freshwater Dam Catchment	0	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
Total mine affected catchments	0.0	46.1	84.2	95.7	77.6	81.1	85.0	32.2	29.4
Total area⁽⁵⁾	1,424	1,421	1,421	1,422	1,421	1,422	1,422	1,422	1422

Notes: (1) Areas less than 100 ha have been rounded to the nearest 0.1 ha. Areas greater than 100 ha have been rounded to the nearest ha.
(2) Year 0.5 represents the situation at the end of infrastructure development.
(3) Represents the situation at the end of the periods mentioned.
(4) Year 5 represents the situation at the end of active mining.
(5) Total area equals mine affected catchments plus natural catchments from Table 1.



Table 3: Surface runoff coefficients for mine affected areas.

Daily rainfall ⁽¹⁾ (mm)	Surface runoff coefficients					
	Pit	Waste dump ⁽²⁾ (uncovered ELF)	CPP	Haul roads	LPL with revegetated forest ⁽²⁾	LPL with revegetated pakihi ⁽²⁾
0	1	0	0	0	0	0
5		0.5	0.5	0.5	0.5	0.5
10		1	1	1	1	1
20	1					
50	1					
80	1	1	1	1	1	1
800 ⁽³⁾	1	1	1	1	1	1

Notes: (1) The GoldSim Model linearly interpolates between daily rainfall values.

(2) Runoff coefficients for the ELF were adjusted and refined during the calibration process which is described in Section 7.4

(3) The long term rainfall record for the site indicates a maximum daily precipitation of approximately 770 mm.

For the purposes of this project, the AWBM runoff model was developed and calibrated for both runoff from existing pre-mine areas and outflow from the Escarpment Mine adit. Site climatic data and the flow record from the monitoring sites on the Whareatea River at M-W1, M-W2 and M-W3 and from the Escarpment Mine adit were used to calibrate the AWBM model. Calibration and verification of both the overall EMP GoldSim model and the AWBM runoff model are described in Section 7.0.

6.4.4 Groundwater

The EMP GoldSim model is focused to report on surface water quality and quantity. Groundwater inputs to the model are required where groundwater interacts with surface water. The AWBM includes consideration of base flow, which is the surface expression of groundwater movement. As such, the EMP GoldSim model does not need a specific input for groundwater seepage from either natural catchments or former mine catchments within the EMP.

The EMP mine plan includes control of groundwater seepage from mine areas. Off-site migration of groundwater will be mitigated through the sealing of adits and capture of seepage flow by interceptor drains which will be directed to the surge sump. Groundwater flows and water quality during mine operations is estimated within the EMP GoldSim model as a component of the MIW-WTP influent. In the post-closure scenario the model reports groundwater seepage flow and water quality discharging from the ELF separate from the influence of other surface water discharges. The EMP water management model requires specific consideration of groundwater seepage for the following two situations that occur in mine affected catchments:

- Pit inflows
- Seepage from the ELF under various conditions (construction through to fully rehabilitated)

Simplistic two-dimensional steady state groundwater models developed for the site were used to estimate seepage rates which were applied to the EMP GoldSim model as a constant daily rate (Golder 2012c). The groundwater flow rates outlined in Table 4 were incorporated into the EMP GoldSim model.



Table 4: Groundwater seepage rates used in the RGP water management model.

Catchment type	Seepage rate over contributing catchment ⁽¹⁾ (mm/day)
Inflow to the proposed pit	0
From hardstand catchments	0
ELF – uncovered ¹	12
ELF – revegetated forest ²	1.87
ELF – revegetated pakihi ³	4
ELF – rehabilitated forest ²	1.87
ELF – rehabilitated pakihi ³	4

Notes: (1) Assumes approximately 65% of average annual combined rainfall and evaporation (18.7 mm) calculated from Table 1 of Golder (2012c) would infiltrate into the relatively porous and uncompacted fill areas..

(2) Source: An average of the maximum and minimum estimated infiltration rates listed in Table 7 in Golder (2012c).

(3) The maximum infiltration rate estimated for the areas of ELF cover prepared to support pakihi vegetation listed in Table 7 of Golder (2012c).

6.4.5 Water quality

Modelled water quality parameters

The initial May 2011 mine water management model for the EMP (Golder 2011a) modelled seven chemical parameters (aluminium, iron, nickel, zinc, manganese, TSS and pH (as H⁺)). Following input from Chris Hickey of NIWA (Hickey 2012) Golder included the following 14 chemical and physical parameters in the updated EMP GoldSim model. The parameters modelled include calcium and magnesium which are used to calculate hardness for each time-step. Five of the parameters are hardness dependent and the model predicts mean daily concentrations both with and without a hardness adjustment.

- | | |
|--|--------------------------------------|
| ■ Aluminium | ■ Iron |
| ■ Arsenic | ■ Lead |
| ■ Cadmium with hardness adjustment | ■ Magnesium |
| ■ Cadmium without hardness adjustment | ■ Manganese |
| ■ Calcium | ■ Nickel with hardness adjustment |
| ■ Chromium with hardness adjustment | ■ Nickel without hardness adjustment |
| ■ Chromium without hardness adjustment | ■ pH |
| ■ Cobalt | ■ Total Suspended Solids (TSS) |
| ■ Copper with hardness adjustment | ■ Zinc with hardness adjustment |
| ■ Copper without hardness adjustment | ■ Zinc without hardness adjustment |

Compliance limits

Water quality compliance limits were established in the 26 August 2011 consent decision document (as summarised in Table 5). The primary downstream compliance monitoring point for the EMP is at W-M2 on the Whareatea River. Subsequent to the assessment of water quality parameters relevant to the EMP, discussed above, Hickey provided proposed indicative compliance limits at W-M2 as presented in his evidence for the Environment Court Hearing (Hickey 2012) and as summarised in Table 6. As an initial assessment of modelled water quality, predicted concentrations at W-M2 are compared to these two sets of consent limits (see Section 9.4),



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Table 5: Receiving waters compliance limits at monitoring site W-M2 on the Whareatea River (from August 2011 Consent Decision).

Parameter ^(1,2)	Shall not fall outside range	Median (rolling) concentrations	95 th percentile concentrations	Combined maximum concentrations
pH (unitless)	4.5 – 7.2			
Total suspended solids		15	30	
Turbidity (NTU)		15	30	
Iron		1.0	2.0	2.5 ⁽³⁾
Aluminium		0.5	2.0	
Manganese		-	1.2	
Nickel ⁽⁴⁾		-	0.05 – 0.15	
Zinc ⁽⁴⁾		0.1	0.20	

Notes: (1) All units are g/m³ except pH and turbidity.

(2) All metal concentrations are dissolved metal concentrations.

(3) Total combined dissolved concentration for Fe, Al, Mn, Ni, and Zn shall not exceed 2.5 g/m³.

(4) The current consent does not indicate the hardness used to develop the consent limit for hardness dependant metals.

Table 6: Proposed indicative receiving waters compliance limits at monitoring site W-M2 (Hickey 2012).

Parameter	Compliance limits			
pH (unitless)	Shall not fall outside a range of 4.5 – 6.5.			
	Median concentrations		95 th percentile concentrations	
Total suspended solids	15		30	
Turbidity (NTU)	15		30	
Iron	1.0		2.0	
Aluminium	0.5		1.0	
Manganese	0.1		0.2	
pH	pH >5.5	pH <5.5	pH >5.5	pH <5.5
Cadmium	0.0003	0.0012	0.0011	0.004
Chromium	0.050	0.20	1.0	4.0
Cobalt	0.044	0.18	0.17	0.63
Copper	0.0020	0.0013	0.007	0.004
Lead	0.0065	0.026	0.030	0.14
Nickel	0.017	0.068	0.26	1.0
Zinc	0.012	0.054	0.067	0.29

Notes: (1) All units are g/m³ except pH and turbidity.

(2) All compliance limits are based on dissolved metal concentrations.

(3) Limits for cadmium, chromium, lead, nickel and zinc are based on a median water hardness of 50 g CaCO₃/m³.

(4) pH dependant limits based on biotic ligand model predictions

(5) Chromium limit is based on Cr (III) and uses USEPA criteria values.

(6) Total suspended solids and turbidity to be based on percentile monitoring for 6 monthly period.



Hardness adjustment within the model

Ecological risk-based freshwater quality trigger values for certain metals (cadmium, copper, chromium (III), nickel and zinc) are hardness based because toxicity tends to decrease as hardness increases. ANZECC (2000) specifies a method for hardness adjustment, which is based on an exponential factor that varies from metal to metal. The metals considered in the model that are hardness dependant are cadmium, chromium, copper, nickel and zinc. As stated previously, proposed consent compliance limits were developed for these parameters based on a hardness of 50 g/m^3 of CaCO_3 because it approximated the median hardness observed at W-M2 for many of the model runs (Hickey 2012). Figure 5 shows the exceedance plot of predicted typical hardness in the Whareatea River at W-M2 for the period 1 May 1945 to 1 April 2012 under landuse scenario Year 3. For the purposes of comparing modelled results for hardness dependent metals to a hardness-based compliance limit, the results on a daily time step basis were normalised to a hardness of 50 g/m^3 of CaCO_3 using the available hardness for each time step.

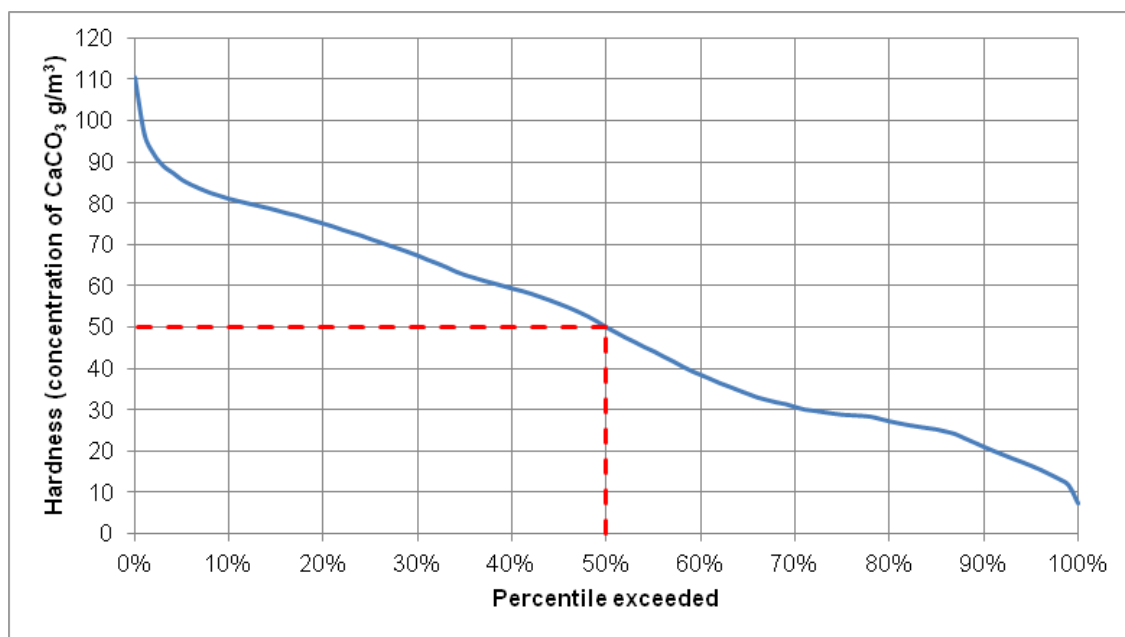


Figure 5: Simulated typical hardness as concentration of CaCO_3 in the Whareatea River at W-M2 for the period 1 May 1945 to 1 April 2012 under landuse scenario Year 3.

pH modelling within the EMP GoldSim model

The EMP GoldSim model was not designed to take into account chemical changes. However, pH was modelled using a mass balance to help assess potential for chemical changes in the downstream systems. When developing pH inputs for the model, measured pH values were converted from pH to moles of hydronium (H_3O^+) through to g/m^3 hydronium as H^+ ($1 \text{ M } \text{H}_3\text{O}^+ = 1.008 \text{ g/m}^3 \text{ H}^+$). However, pOH was not considered, so the model was biased towards acidic pH values, and it was not possible to model pH values ($\text{pH} > 7$), nor was buffering capacity (total alkalinity or acidity) considered. For example, mixing an unbuffered solution of water at pH 6 with an equal amount of water at pH 8 should produce water at pH 7. However, when only pH is considered, and not pOH, the calculated pH value for the mixed solution is 6.3. This model limitation meant pH was underestimated (i.e. predicted values were biased towards low pH values) as pH approached 7. However, this bias decreased with decreasing pH (and correspondingly smaller OH^- concentrations). As all the input pH values for the EMP GoldSim model were < 7 , the inherent bias was not considered large enough to invalidate the model's pH predictions. It is noted though, that actual pH values may be greater (less acidic) than predicted by the model.



Natural catchment water quality input parameters

As stated previously, Envirolink have measured turbidity, conductivity and pH continuously⁷ at various locations within and downstream of the EMP since November 2010 (Envirolink 2012a). Of the continuously monitored water quality parameters, only pH is simulated directly in the mine water management model⁸. Since November 2011 Envirolink have also taken numerous discrete water quality samples at various locations within and downstream of the EMP which have been tested for a variety of chemical parameters (Envirolink 2012a). Analysis of the water quality data collected by Envirolink indicated that a number of the chemical parameters are likely to be flow related.

Golder in association with Ellmock used the available water quality data up to 23 February 2012 collected by Envirolink to develop initial model water quality inputs for the existing natural catchments. During development of the initial water quality inputs it was assumed that the water quality from all natural catchments was the same. Later, during calibration the inputs were adjusted to approximate observed variations between catchments. Table 7 and Table 8 outline the flow dependent and non flow dependent natural catchment water quality inputs that were incorporated into the EMP GoldSim model.

Table 7: Flow dependent natural catchment water quality input parameters(1).

Flow yield ⁽²⁾ (L/s/ha)	Concentrations (g/m ³ unless stated)							
	Aluminium	H ⁺ ion for pH ⁽⁴⁾	Iron	Manganese	TSS	Calcium	Magnesium	Zinc
0	0.15	0.032	0.15	0.025	3	0.8	0.9	0.02
0.01	0.15	0.032	0.15	0.025	3	0.8	0.9	0.02
0.07	0.25		0.31					
0.1		0.016		0.025		0.8		
0.2	0.25							
0.3			0.31				0.9	
1					7			0.02
100	0	0.016	0	0.001	10	0.001	0.001	0.001
1E+13 ⁽³⁾	0	0.016	0	0.001	10	0.001	0.001	0.001

- Notes:**
- (1) The parameters were adjusted and refined during the calibration process which is described in Section 0.
 - (2) The GoldSim model linearly interpolates between daily rainfall or flow yield values.
 - (3) An arbitrary large number which is never exceeded in the model. The long term rainfall record for the site indicates a maximum daily precipitation of approximately 760 mm which if it all runs off equates to a maximum yield of approximately 88 L/s/ha.
 - (4) Unit less GoldSim coefficient, not a measurement of concentration

Table 8: Non flow dependent natural catchment water quality input concentrations.

Chemical parameter	Concentration (g/m ³)
Arsenic	0.01
Cadmium	0.0005
Copper	0.001
Lead	0.003
Nickel	0.001
Cobalt	0.0015
Chromium	0.001

⁷ Continuous monitoring refers to readings at approximately 15 minute intervals.

⁸ TSS is simulated in the mine water model and is related to turbidity.



Mine affected catchments water quality input parameters

To assess the acid mine drainage (AMD) potential at the EMP, BCL commissioned CRL to develop a program of laboratory and field leach testing to determine the maximum acid release, trace element release or acid neutralising capacity of the rocks likely to be disturbed at the EMP (CRL 2011, CRL 2012a). This testing has been ongoing over the past 16 months and continues (Pope 2012).

Leach columns were constructed using different mixtures of rock considered representative of the EMP including rock types that are primarily potentially acid forming (PAF), a mixture of rocks that are likely to be non-acid forming (NAF) and PAF, and rocks likely to be NAF. These results, in combination with geochemical data from the region in available literature and the experience of CRL, were used to estimate mine drainage and runoff chemistry.

Recommended inputs for the selected model water quality parameters (except TSS) for catchments potentially affected by mine drainage chemistry were provided by CRL (2012b) and incorporated into the EMP GoldSim model as non-flow dependant variables. These inputs are summarised in Table 9 and include the following catchments:

- Pit runoff,
- Uncovered ELF runoff,
- Uncovered ELF seepage,
- Covered revegetated ELF runoff,
- Covered revegetated ELF seepage,
- Rehabilitated Covered ELF scrub/forest runoff,
- Rehabilitated Covered ELF pakihi runoff,
- Rehabilitated Covered ELF seepage.

As indicated in Table 9, the chemistry of leach test data and data published for mines in similar rock types were used by CRL to identify model inputs for three situations which represent a range of possible mine drainage chemistry which may result from mine operations.

All three situations consider the presence or absences of a cap or cover to minimise acid formation in the rocks beneath and with runoff from capped or uncapped ELF based on alkaline leachate in the column trials (Pope 2012). The three situations have been described in Pope (2012) as follows:

- 1) Situation 1. Optimistic approach to mine drainage chemistry. Covering and capping of PAF rocks by suitable material occurs in a manner that minimises acid reactions and rocks are managed so that lag periods also minimise acid formation.
- 2) Situation 2. Capping and covering of rocks occurs but cannot be scheduled to prevent acid forming reactions. Uncovered rocks produce acid. This situation has been considered 'typical' or average conditions.
- 3) Situation 3. All rocks that are not covered produce maximum acid. Acid composition is based on field column leach testing data and mine drainage chemistry from similar sites. This represents the likely extreme case of AMD discharges.



EMP - MINE WATER MODEL

Table 9: Non flow dependent mine affected catchment water quality input parameters.

Parameter	Concentrations (g/m ³) for various water sources																													
	Pit ⁽¹⁾			ELF- Uncovered runoff ⁽²⁾			ELF- Uncovered seepage ⁽³⁾			ELF- Covered and revegetated runoff ⁽⁴⁾			ELF- Covered and revegetated Seepage ⁽⁵⁾			ELF- Rehabilitated Forest runoff ⁽⁶⁾			ELF- Rehabilitated Pakihi runoff ⁽⁶⁾			ELF- Rehabilitated Seepage ⁽⁷⁾			Hardstand ⁽⁸⁾			Road and coal processing plant ⁽⁸⁾		
	Optimistic	Typical	Extreme	Optimistic	Typical	Extreme	Optimistic	Typical	Extreme	Optimistic	Typical	Extreme	Optimistic	Typical	Extreme	Optimistic	Typical	Extreme	Optimistic	Typical	Extreme	Optimistic	Typical	Extreme	Optimistic	Typical	Extreme	Optimistic	Typical	Extreme
Aluminium	4	5	70	4	70	70	4	5	70	0.03	0.03	0.03	5	5	70	0.03	0.03	0.03	0.03	0.03	0.03	70	70	70	0.02	0.02	0.02	0.02	0.02	0.02
Arsenic	0	0	0.02	0	0.02	0.02	0	0	0.02	0	0	0	0	0	0.02	0	0	0	0	0	0	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Cadmium	0.002	0.002	0.003	0.002	0.003	0.003	0.002	0.002	0.003	0.0007	0.0007	0.0007	0.002	0.002	0.003	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.003	0.003	0.003	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Copper	0.22	0.22	0.4	0.22	0.4	0.4	0.22	0.22	0.4	0.003	0.003	0.003	0.22	0.22	0.4	0.003	0.003	0.003	0.003	0.003	0.003	0.4	0.4	0.4	0.002	0.002	0.002	0.002	0.002	0.002
Iron	1	6	70	1	70	70	1	6	70	0.01	0.01	0.01	6	6	70	0.01	0.01	0.01	0.01	0.01	0.01	70	70	70	0	0	0	0	0	0
Lead	0.02	0.03	0.12	0.02	0.12	0.12	0.02	0.03	0.12	0.0007	0.0007	0.0007	0.03	0.03	0.12	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.12	0.12	0.12	0.001	0.001	0.001	0.001	0.001	0.001
Manganese	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.3	0.3	0.3	0.7	0.7	0.7	0.3	0.3	0.3	0.3	0.3	0.3	0.7	0.7	0.7	0.16	0.16	0.16	0.16	0.16	0.16
Nickel	0.32	1.2	0.7	0.32	0.7	0.7	0.32	1.2	1.2	0.05	0.05	0.05	1.2	1.2	0.7	0.05	0.05	0.05	0.05	0.05	0.05	0.7	0.7	0.7	0.03	0.03	0.03	0.03	0.03	0.03
Zinc	2.6	2.6	3	2.6	3	3	2.6	2.6	3	0.1	0.1	0.1	2.6	2.6	3	0.1	0.1	0.1	0.1	0.1	0.1	3	3	3	0.06	0.06	0.06	0.06	0.06	0.06
H ion for pH	10 ⁻³	10 ^{-2.8}	10 ^{-2.5}	10 ⁻³	10 ^{-2.5}	10 ^{-2.5}	10 ⁻³	10 ^{-2.8}	10 ^{-2.5}	10 ⁻⁴	10 ⁻⁴	10 ⁻⁴	10 ^{-2.8}	10 ^{-2.8}	10 ^{-2.5}	10 ⁻⁴	10 ⁻⁴	10 ⁻⁴	10 ⁻⁴	10 ⁻⁴	10 ⁻⁴	10 ^{-2.5}	10 ^{-2.5}	10 ^{-2.5}	10 ^{-5.1}	10 ^{-5.1}	10 ^{-5.1}	10 ^{-5.1}	10 ^{-5.1}	10 ^{-5.1}
Calicum	15	15	45	15	45	45	15	15	45	3	3	3	15	15	45	3	3	3	3	3	3	45	45	45	1.92	1.92	1.92	1.92	1.92	1.92
Magnesium	6	6	15	6	15	15	6	6	15	1	1	1	6	6	15	1	1	1	1	1	1	15	15	15	0.92	0.92	0.92	0.92	0.92	0.92
Cobolt	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.25	0.013	0.013	0.013	0.15	0.15	0.15	0.013	0.013	0.013	0.013	0.013	0.013	0.15	0.15	0.15	0.01	0.01	0.01	0.01	0.01	0.01
Chromium	0.002	0.003	0.7	0.002	0.7	0.7	0.002	0.003	0.7	0	0	0	0.003	0.003	0.7	0	0	0	0	0	0	0.7	0.7	0.7	0.002	0.002	0.002	0.002	0.002	0.002

Note: (1) From CRL (2012b), based on values defined as Highwall Runoff (surface).
(2) From CRL (2012b), based on values defined as Uncovered ELF Runoff – Year 0.5.
(3) From CRL (2012b), based on values defined as Uncovered ELF ARD Leachate – Year 0.5.
(4) From CRL (2012b), based on values defined as Covered ELF Runoff (surface).
(5) From CRL (2012b), based on values defined as Covered ELF ARD Leachate Year 0.5 (value provided for optimistic scenario was also used for typical scenario in the absence of provided data).
(6) From CRL (2012b), based on values defined as Covered ELF Runoff (surface) after rehabilitation. Values same as Covered ELF ARD Leachate Year 0.5.
(7) From CRL (2012b), based on values defined as Covered ELF ARD Leachate Year 5.
(8) The water quality parameters for runoff from the Hardstand , Road, and Coal Processing Plant were developed by Golder and Ellmock and are based on experience from existing mine sites and the assumption that the areas consist of NAF material.

Table 10: Mine affected catchment TSS water quality input parameters⁽¹⁾.

Daily Rainfall ⁽²⁾ (mm)	TSS concentrations (g/m ³) for various water sources								
	Pit ⁽⁴⁾	ELF- Uncovered runoff ⁽⁴⁾	ELF- Uncovered seepage ⁽⁴⁾	ELF- Covered and revegetated runoff ⁽⁴⁾	ELF- Covered and revegetated seepage ⁽⁴⁾	ELF- Rehabilitated Forest runoff ⁽⁴⁾	ELF- Rehabilitated Pakihi runoff ⁽⁴⁾	ELF- Rehabilitated Seepage ⁽⁴⁾	Road and coal processing plant ⁽⁴⁾
0	50	100	10	5	3	3	3	100	40
21.6	50	100	10	5	3	3	3	100	40
95.1	2,500	5,000	20	250	5	12	12	5,000	1,875
800 ⁽³⁾	2,500	5,000	20	250	5	12	12	5,000	1,875

Note: (1) The parameters were adjusted and refined during the calibration process which is described in Section 6.
(2) The GoldSim model linearly interpolates between daily rainfall or flow yield values.
(3) The long term rainfall record for the site indices a maximum daily precipitation of approximately 760 mm.
(4) The TSS water quality parameters were developed by Golder and Ellmock and are based on experience from existing mine sites and the existing monitoring data from the EMP supplied by Envirolink (2012c)

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Recommended inputs for water quality parameters for ancillary mine influenced catchments (haul roads and amenity areas) were provided by Ellmock and incorporated into the EMP GoldSim model as non-flow dependant variables.

These inputs are summarised in Table 10 and include the following catchments:

- Haul Road runoff,
- Runoff from hard standing areas around the CPP, MIW-WTP and the amenities area.

TSS concentrations from mine affected catchments were provided by Ellmock and incorporated into the EMP GoldSim model as flow dependant variables (Table 10).

Golder recommends that the EMP GoldSim model be validated as new water quality data become available, particularly water quality data from catchments affected by mining operations.

6.4.6 Water treatment efficiencies

BCL have commissioned Ellmock to assist with design of the proposed water treatment facilities at the EMP. Ellmock provided metal/metalloid treatment efficiencies and changes in pH for the proposed MIW-WTP based on bench scale treatment trials (Ellmock 2012b) and treatment experience of the Solid Energy New Zealand Limited Stockton project (SENZ 2010). Ellmock also provided mine-influenced water treatment efficiencies for TSS based on settling column trials which included trialling of various coagulates and flocculant mixes (Ellmock 2011). The testing demonstrated that reduction of TSS to 10 g/m³ was achievable using coagulating and/or flocculating agents available in New Zealand assuming a sediment pond retention time of at least 1 to 2 hours.

A passive treatment system scenario was included which showed reduction of contaminants based on preliminary suggestions by CRL (May 2012). Conservatively low removal rates were assumed in the absence of more detailed passive treatment assessment or site-specific treatability testing at a bench top, field trial or pilot scale level. The water treatment efficiencies which were incorporated into the EMP GoldSim model are summarised in Table 11. Removal efficiencies for settlement of suspended sediment in the various proposed sediment ponds on the EMP site are summarised in Table 12.

6.4.7 Mine infrastructure components

BCL staff and Ellmock provided sizes and capacities for the various mine infrastructure components which were incorporated in to the EMP GoldSim model and are presented in Table 13 for items whose capacity and size does not vary and Table 14 for the MIW Surge Sump and MIW-WTP the location of which are shown in the Figures in Appendix B.

Figure 6 shows the preliminary layout for the CPP area including the freshwater and recycle dams. The location of the SW-WTP and Lake Brazil are shown in Figure 2. Golder in association with Ellmock used the EMP GoldSim model to trial various sizes/capacities of some of the water infrastructure. The sizes/capacities presented in Table 13 and Table 14 represent the finalised sizes/capacities selected. Further description of the sizing process is provided in Section 9.2.



EMP - MINE WATER MANAGEMENT MODEL

Table 11: Assumed treatment efficiencies for the Mine Influenced Water – Water Treatment Plant, the Surface Water – Water Treatment Plant and the Passive Treatment System.

Chemical	Treatment efficiency ^(1,2)		
	Mine Influenced Water – Water Treatment Plant	Surface Water – Water Treatment Plant	Passive Treatment System ⁽⁴⁾
Aluminium ^(2,3)	99.4 %	0 % i.e., not removed	80 %
Arsenic	0 % i.e., not removed	0 % i.e., not removed	0 % i.e., not removed
Cadmium	89.1 %	0 % i.e., not removed	20 %
Copper	99.8 %	0 % i.e., not removed	20 %
Iron	99.5 %	0 % i.e., not removed	80 %
Lead	96.1 %	0 % i.e., not removed	20 %
Manganese	62.3 %	0 % i.e., not removed	20 %
Nickel	98.1 %	0 % i.e., not removed	20 %
Zinc	99.0 %	0 % i.e., not removed	20 %
pH (as H ⁺)	Varies with the pH of inflow as follows:		0 % i.e., no change
	Inflow pH	Treatment efficiency ⁽¹⁾	
	<=6.5	0 % i.e., no change	
	>6.5	Varies, is % required to reduce to a pH of 6.5	
Total Suspended Sediment TSS	Varies with the TSS concentration of inflow as follows:		98 %
	Inflow TSS concentration	Treatment efficiency ⁽¹⁾	
	<=10 g/m ³	0 % i.e., not removed	
	>10 g/m ³	Varies and is % required to reduce to a TSS of 10 g/m ³	
Calcium	Varies with Flow and pH (see Section 6.4.5)		0 % i.e., not removed
Magnesium	Varies with Flow and pH (see Section 6.4.5)		0 % i.e., not removed
Cobalt	99.1 %	0 % i.e., not removed	20 %
Chromium	89.7 %	0 % i.e., not removed	20 %

Note: 1) Treatment efficiency equates to removal rate i.e., a treatment efficiency of 75 % means that 75 % of the material is removed i.e., the discharge concentration is 25 % of the inflow concentration.

2) Ellmuck (2012b, c)

3) SENZ (2010)

4) CRL (2012b)

Table 12: Assumed removal efficiencies for TSS settlement in the various sediment ponds.

Inflow TSS concentration (g/m ³) ⁽¹⁾	TSS removal rate (%)
< 480 g/m ³	70 %
>= 480 g/m ³	Varies and is % required to reduce to a TSS of 480 g/m ³

Note: (1) Golder 2011b, Table 2. Based on column settling test for untreated surface water after 1 hour of settling. Assumes the retention time in the sedimentation pond will not be less than 1hr.



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Table 13: Input factors for mine water management flows.

Item		Units	Value ⁽¹⁾
Recycle Pond associated with the CCP ⁽³⁾	Area	ha	0.9
	Initial Volume	m ³	10,000
	Minimum Volume	m ³	50
	Maximum Volume	m ³	48,000
	Pump Rate ⁽⁵⁾	m ³ /hr	350
SW—WTP associated with CPP	Area	ha	0.6
	Capacity	m ³ /day	12,096 ⁽²⁾
Lake Brazil ⁽³⁾	Area	ha	1
	Initial Volume	m ³	43,155
	Minimum Volume	m ³	43,155
	Maximum Volume	m ³	355,860
Freshwater Dam associated with CPP ⁽⁴⁾	Initial Volume	m ³	20,000
	Minimum Volume	m ³	152,000
	Maximum Volume	m ³	20,000
	Dam Fill Level	m ³	72,000
Pit 1 - Western Pit Sump, Pit 2 - Eastern Pit Sump and Pit 3 - Eastern Brazil Block Pit Sump	Maximum Sump Volume	m ³	15,000
	Pump Rate	l/s	800
	Pit Volume ⁽⁵⁾	m ³	400,000
Catchment Sedimentation Pond Treatment Capacity	Trent Stream Sediment Pond	m ³ /day	86,400
	V40 stream Sediment Pond	m ³ /day	86,400
	S Creek Sediment Pond	m ³ /day	86,400
	West Upper Whareatea Sediment Pond	m ³ /day	86,400
	East Upper Whareatea Sediment Pond	m ³ /day	86,400
	V37 Sediment Pond	m ³ /day	86,400
	Lake Brazil Sediment Pond	m ³ /day	86,400
	V8 Sediment Pond	m ³ /day	86,400
Other Infrastructure	Flow Rate to Coal Slurry Pipeline ⁽⁶⁾	m ³ /hr	370 ⁽⁸⁾
	Process water Required ⁽⁶⁾	m ³ /hr	
	KEL maximum water take ⁽⁷⁾	m ³ /day	103,680

Notes: (1) All pump rates and volumes were obtained during discussions with BCL staff or their technical advisors. Surface areas were delineated by Golder using ArcGIS from site maps and aerial photos. Areas are rounded to the nearest 0.1 of a hectare.

(2) Size optimised by Golder and Ellmook using EMP GoldSim model.

(3) Lake Brazil was included in the model as a potential water storage / treatment facility but was excluded from the final water management infrastructure.

(4) Golder 2010 dam break analysis for the freshwater and recycle ponds.

(5) Rodgers 2012.

(6) RSPL 2010.

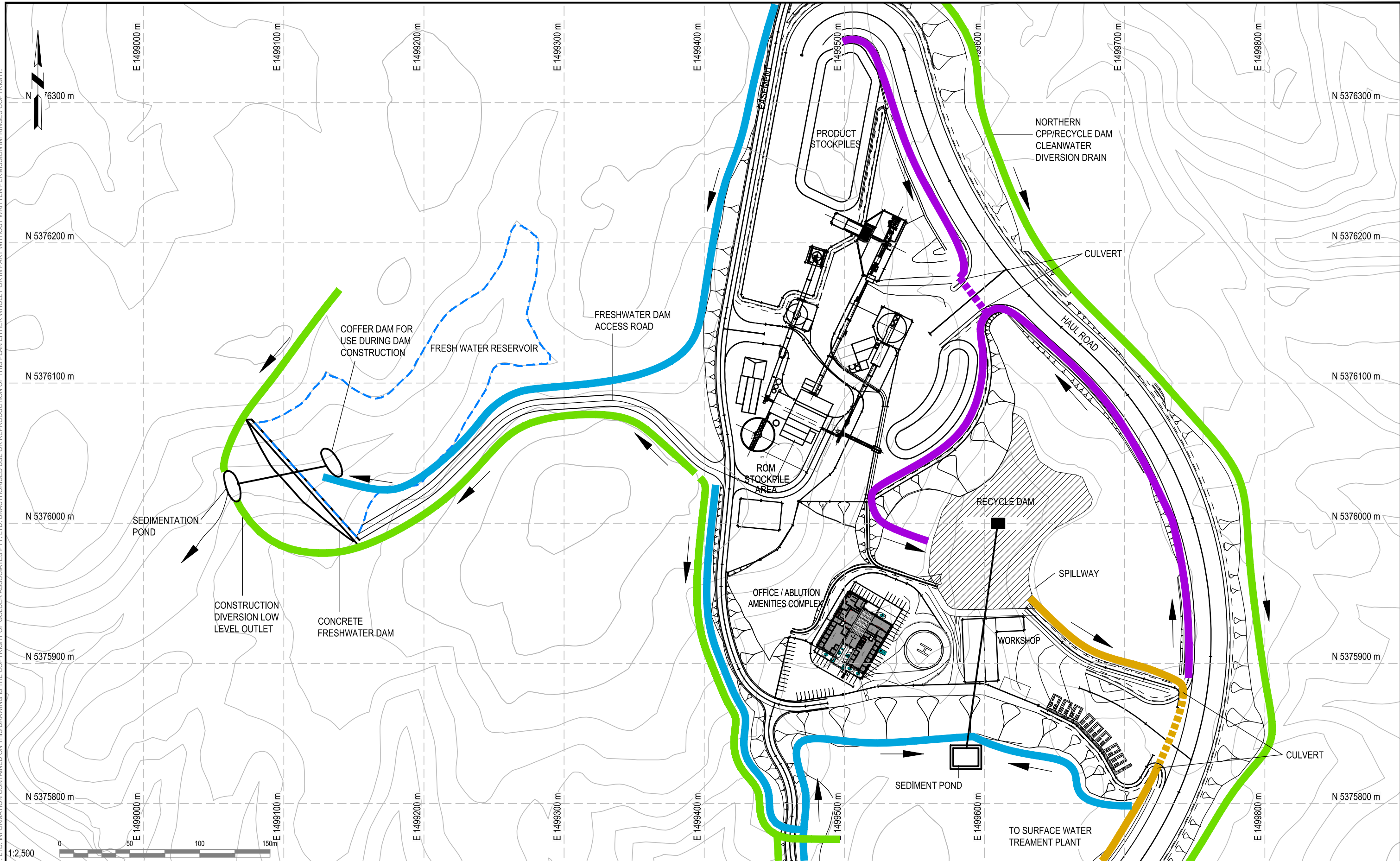
(7) Kawatiri Energy Limited's (KEL) resource consent (RC03332).

(8) For the infrastructure development scenario (Year 0.5) and the post-mine scenario; the flow rate to the coal slurry pipeline and the process water requirement is assumed to be 0 m³/day, i.e. both are not operational.

Table 14: Mine Influenced Water: Surge Sump volume and Water Treatment Plant capacity.

Item	Mine Development Stage or Model Scenario									
	Pre-mine	0.5 year	1 year	1.5 year	2 year	3 year	4 year	5 year	Post-mine	
									Active	Passive
MIW-Surge Sump Volume (m ³)	0	200,000	200,000	200,000	200,000	200,000	100,000	100,000	10,000	1,000
MIW-WTP capacity (l/s)	0	0	175	175	350	350	350	350	75	0

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New Zealand Transverse Mercator 2000 (NZGD2000)
grid coordinates
Source: Bathurst Resources Ltd Escarpment Project
Crown Mineral Permits Relative to Project Infrastructure
Drawn: [REDACTED]

LEGEND

- CLEAN WATER DIVERSION DRAINS
- MINE INFLUENCED WATER INTERCEPTION DRAINS
- HAUL ROAD AND CONSTRUCTION WATER INTERCEPTOR DRAIN
- RECYCLE DAM SPILL DRAIN

TITLE

PRELIMINARY CPP LAYOUT

PROJECT

AUG 2012
1078101422

6



6.4.8 Affects of lime dosing on water quality downstream of MIW-WTP

In the proposed water treatment method for the EMP, lime is added to raise the pH of mine influenced waters before flocculants are added to remove suspended material.

As shown in Table 15, the lime used “Taylor’s Lime” is principally composed of calcium hydroxide, but the lime also contains magnesium. Calcium (Ca) and magnesium (Mg) are the primary contributors to water hardness. Therefore, calcium and magnesium in the added lime must be considered when determining final concentration of effluent water from the MIW-WTP.

To determine if calcium and magnesium inputs from lime could be considered on a mass balance basis, a geochemical thermodynamic equilibrium model was created using PHREEQC⁹.

Table 15: Principal components of Taylor’s Lime.

Constituent	Element formula ⁽¹⁾	% wt. ⁽¹⁾	Moles per g lime ⁽²⁾	Moles in 1 % slurry (M) ⁽²⁾
Calcium	Ca(OH) ₂	93 %	1.26E-02	1.26E-01
Silicon	SiO ₂	0.06 %	9.99E-06	9.99E-05
Aluminium	Al ₂ O ₃	0.06 %	8.01E-06	8.01E-05
Iron	Fe ₂ O ₃	0.13 %	1.25E-05	1.25E-04
Magnesium	MgO	0.27 %	6.70E-05	6.70E-04
Sulfur	SO ₃	0.03 %	3.75E-06	3.75E-05
Potassium	K ₂ O	0.01 %	1.82E-06	1.82E-05
Sodium	Na ₂ O	0.11 %	2.82E-05	2.82E-04
Manganese	Mn ₂ O ₃	0.11 %	1.07E-05	1.07E-04

Notes: (1) As stated on Taylor’s Lime factsheet.

(2) Key constituent only

The model analysed data in three stages. First, a 1 % solution of lime slurry was charge balanced by pH. This resultant pH of a 1 % slurry at equilibrium was approximately 13 pH units. The equilibrated slurry was then mixed with a solution of mine water based on quality data from Escarpment Lysimeters 7 & 8 (see Ellmuck 2012). Insufficient data were available to predict solution buffering, so an arbitrary mix of 10:1,000 slurry to mine water was assumed. Finally this mixed water was equilibrated to commonly occurring precipitates in mine-waters. The final pH of the mixed solution at equilibrium was 8.2 pH units.

Based on analysis using PHREEQC, a 1 % slurry of Taylor’s Lime at equilibrium (pH ~13) will be over-saturated with respect to certain calcium and magnesium minerals, including brucite (Mg(OH)₂), chrysotile (Mg₃Si₂O₅) and portlandite (Ca(OH)₂).

At lower pH values (≤8.3) the only mineral over-saturated with respect to calcium or magnesium is magnesioferrite (Fe₂MgO₄). However, the slow precipitation kinetics of this mineral means the precipitation of magnesium as this mineral is unlikely during water treatment. Therefore, given the target treatment pH is 6.5, it can be considered that, so long as the lime slurry used is well-mixed before application, the mass of calcium and magnesium added to the downstream effluent is likely to be equal to the mass of calcium and magnesium added via the slurry.

As a mass balance model can be assumed, the following equations apply when determining the addition of calcium and magnesium from lime during the treatment process.

⁹ PHREEQC is a computer programme based on an ion-association aqueous model used for geochemical equilibria calculations.



$$Ca \text{ in effluent (g/m}^3\text{)} = \frac{0.503 * S_a * S_v + I_{Ca} * I_v}{S_v + I_v}$$

$$Mg \text{ in effluent (g/m}^3\text{)} = \frac{0.01628 * S_a * S_v + I_{Mg} * I_v}{S_v + I_v}$$

Where: S_a = Concentration of slurry (g/m³)

S_v = Slurry volume added as treatment (m³)

I_{Ca} = Calcium concentration in influent (g/m³)

I_{Mg} = Calcium concentration in influent (g/m³)

I_v = Volume of influent (m³)

The above equations were incorporated in to the EMP GoldSim model with the calculation completed on a daily basis.

6.5 EMP GoldSim Model Details

The EMP GoldSim model was set up so that all balances and calibration graphs are generated within the model. All the input data that the model requires have been incorporated into the model and there is no importing of data. Similarly all output graphs from the scenario runs are generated within the EMP GoldSim model. Detailed analysis of the time series output (including determining percentiles etc) is not possible within GoldSim. Actual time series results from the scenario runs were exported from the EMP GoldSim model to various excel spreadsheets for processing of the results to determine percentiles.

The EMP GoldSim model has been set up with a dashboard to simplify calibration and running of the model. The initial dashboard was used to assist with calibration. A "Player" version of the EMP GoldSim model is to be provided to BCL, the dashboard for which will provide sufficient functionality to run mine water management scenarios without enabling accidental modification of the overall calibration or model setup. The items covered by the respective dashboards are outlined in Table 16.

Table 16: EMP GoldSim model dashboard functionality.

Item	Golder calibration EMP GoldSim model dashboard	BCL player EMP GoldSim model dashboard
Natural catchment areas	✓	✓
Mine affected catchment areas	✓	✓
Groundwater seepage rate	✓	
Runoff coefficients	✓	
Water quality parameters	✓	
Climate data	✓	
Water treatment infrastructure sizes	✓	✓
Water treatment infrastructure efficiency	✓	✓



7.0 MODEL CALIBRATION

7.1 Introduction

The EMP GoldSim model provides projections for water quantity and quality at various key locations. The EMP GoldSim model requires calibration for both variables. The following four step process was completed to calibrate the model:

- 1) The EMP GoldSim model estimates the runoff from natural catchments and rehabilitated mine catchments using the AWBM. The AWBM uses a series of coefficients which were initially calibrated using the Rainfall Runoff Library (RRL) software developed by the eWater Cooperative Research Centre (eWater CRC). The AWBM coefficients were included into the EMP GoldSim model. Output runoff from the pre-mine scenario of the GoldSim model was compared with measured flow data and the AWBM coefficients within the EMP Goldsim model were manually refined to ensure the model replicated measured stream flows, particularly flow fluctuations, low flows and high flow events.
- 2) The EMP GoldSim model simulates the concentrations of various contaminants at key locations using estimated catchment concentrations and mass balance calculations. The initial water quality input factors used for key contaminants included in the model are presented in Section 6.4.5 above and summarised in Table 7 and Table 8. Predicted water quality from the modelled pre-mine scenario was compared with measured water quality data collected by Envirolink. The input water quality values within the EMP Goldsim model were then manually adjusted to ensure the model reproduced water quality from natural catchments, particularly dissolved metals during low flow events and TSS during both high and low flow events.

As discussed in Section 6.3, the EMP Goldsim model uses a daily time step and the results therefore represent average daily flows and concentrations. The measured water quality data are however from a discrete set of single grab samples taken at one point in time. Surface water flows and contaminant concentrations are likely to fluctuate rapidly within a period of one day. The focus of the calibration was therefore on the general trend and scale of concentrations rather than exact values.

- 3) As the mine is a proposed greenfields development there is no monitored water quality data available which could be used to calibrate the mine affected catchments. This lack of calibration data means that the flow rates and contaminant concentrations predicted for the mine scenarios should be used with care. While the EMP Goldsim model can be used to predict relative changes and differences between the various mining scenarios the lack of calibration data for mine affected catchments means it is not possible to determine the accuracy of the actual predicted values for the mining scenarios. To help overcome this, flow rates and contaminant concentrations at key locations were simulated for the various mining scenarios. The range of flow rates and contaminant concentrations predicted for the mining scenarios were assessed by Golder mine water quality experts to ensure they were consistent with Golder's experience from other similar mine sites. This assessment was qualitative and was aimed at ensuring the predicted values were reasonable. The focus of the qualitative assessment was on the general trends and scale of flows and concentrations rather than exact values.
- 4) Mass and flow balances were completed on the EMP Goldsim model for all nine scenarios. This balance check was undertaken to confirm that the GoldSim model itself balances, both in total and for individual parameters. Particular attention was paid to the water balance for the ELF to ensure that seepage and runoff rates were appropriately predicted.

7.2 AWBM Calibration

Runoff from both natural catchments and rehabilitated mine areas have been modeled using the AWBM. The conceptual logic of the AWBM is presented in Figure 7.

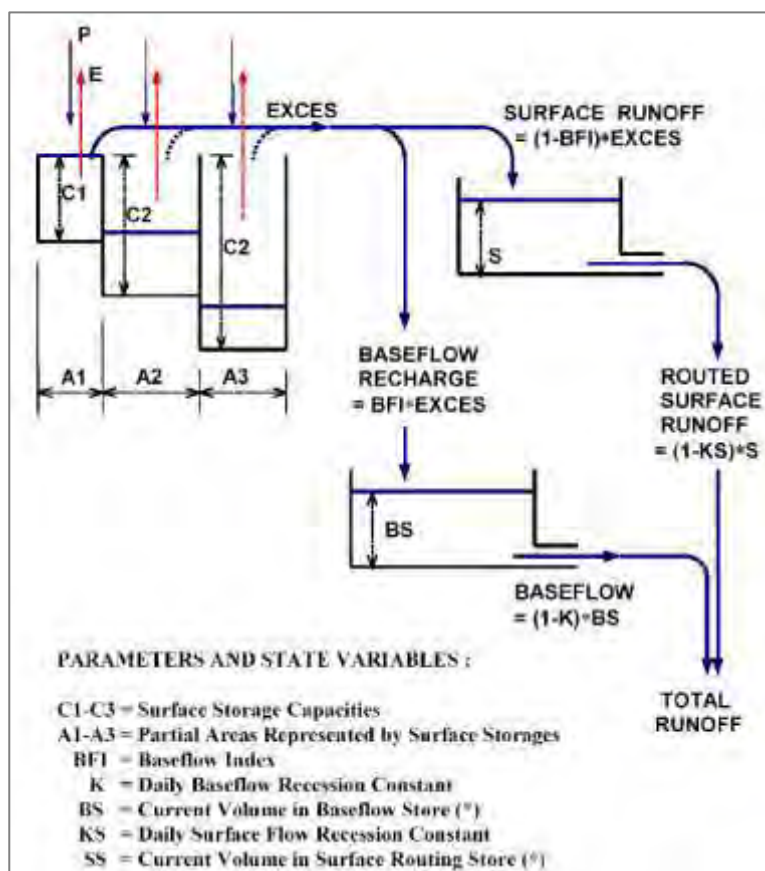


Figure 7: Australian Water Balance Model (from Podger 2004).

To calibrate an AWBM; rainfall, evapotranspiration and runoff data are required. The AWBM has been calibrated using the Rainfall Runoff Library v1.0.5 (RRL) software package. The data used for these calibrations is summarised in Table 17. The RRL has been used to calibrate the AWBM by varying the parameters applied in the AWBM to produce a runoff data set that acceptably matched the flow data supplied by Envirolink.

Table 17: Data used in the EMP AWBM calibrations.

Data type	Dataset	Source	Data period
Rainfall (daily total)	Site rainfall at V8-M1.	Envirolink	7 November 2010 to 11 April 2012
Evapo-transpiration (daily total)	Penman PET at NIWA virtual climate station 19209	NIWA via the Cliflow climate database	7 November 2010 to 11 April 2012
Runoff (average daily flow)	Flow in the Whareatea River at: W-M1 W-M2 W-M3	Envirolink	7 November 2010 to 23 March 2012 8 January 2011 to 23 March 2012 12 March 2011 to 11 April 2012

An AWBM calibration was completed for each of the three flow records outlined in Table 17 above. For each calibration a section of the data was selected for use as warm-up data in the RRL, to allow for the program to



incorporate the rainfall conditions prior to the start of the model and make an estimate of the contents of each of the soil moisture stores (Podger 2004).

The RRL allows a variety of optimisation methods and objective functions to be used for the calibration. A variety of methods were trialed and an acceptable initial calibration was achieved for each of the four calibrations. The warm up period, calibration period, optimisation method, objective functions and results for the four calibrations are summarised in Table 18 and shown in Figures 3 to 6. All three calibrations reproduced the measured fluctuations in flow, but the calibrations for W-M2 and W-M3 understate flows for both high and low flow events (Figures 3 to 5). The calibrated solutions are not unique and quite different parameter values were obtained for the calibrations for sites W-M1, W-M2 and W-M3 on the Whareatea River. The difference in the calibrated parameters between sites W-M1, W-M2 and W-M3 on the Whareatea River may suggest that the hydrology of the reporting catchments varies. Sites W-M1 and W-M2 are located on the Denniston Plateau whereas site W-M3 is located on the coastal fringe although the vast majority of the catchment that reports to M-W3 is located on the Denniston Plateau.

Golder has not undertaken a detailed assessment of the respective catchments but maps and aerial photos of the area suggest that all three catchments have similar landuse, vegetative cover, soil cover, geologies, topography and elevation. The only obvious difference in the three catchments is potential differences in the amount of underground mining that has occurred within each catchment. Underground mine workings can dewater over-lying strata, alter the hydraulic conductivities of the strata, provide areas for groundwater storage, provide conduits for underground flow, alter groundwater catchment boundaries and can alter groundwater chemistry. Such changes to the groundwater system can directly affect surface water flow.

Table 18: AWBM calibrations for EMP.

Parameter			Calibration		
			W-M1	W-M2	W-M3
Catchment area (km ²)			0.9	4.0	11.0
Warm up period			10 Dec 2010 – 27 Dec 2010	8 Jan 2011 – 8 Mar 2011	12 Mar 2011 – 21-Apr 2011
Calibration Period			27 Dec 2010 – 23 Mar 2012	8 Mar 2011 – 23 Mar 2012	21 Apr 2011 – 11 Apr 2012
Optimisation method			Rosenbrock Multi-Start Optimiser	Rosenbrock Multi-Start Optimiser	Rosenbrock Multi-Start Optimiser
Objective Functions	Primary		Nash-Sutcliffe criterion ⁽¹⁾	Nash-Sutcliffe criterion ⁽¹⁾	Nash-Sutcliffe criterion ⁽¹⁾
	Secondary		Flow duration curve	None	None
Nash–Sutcliffe model efficiency coefficient ⁽²⁾			0.923	0.706	0.8086
Calibration Results	Surface store capacities	C1	41.8	0	2.0
		C2	180.8	180.8	10.2
		C3	393.2	0	459.6
	Surface store area split	A1	0.134	0.134	0.134
		A2	0.433	0.433	0.433
		A3	0.433	0.433	0.433
	BFI Base flow index		0.795	1	1
	Ks Surface runoff recession constant		1	0.516	0.745
	Kb Baseflow recession constant		0.392	0	0.083

Notes: (1) The Nash-Sutcliffe criterion is also referred to as the coefficient of efficiency.

(2) Nash–Sutcliffe model efficiency coefficient is used to assess the predictive power of hydrological models. Nash–Sutcliffe efficiencies can range from $-\infty$ to 1, with an efficiency of 1 corresponding to a perfect match of modelled discharge to the observed data. Essentially, the closer the model efficiency is to 1, the more representative the model is.

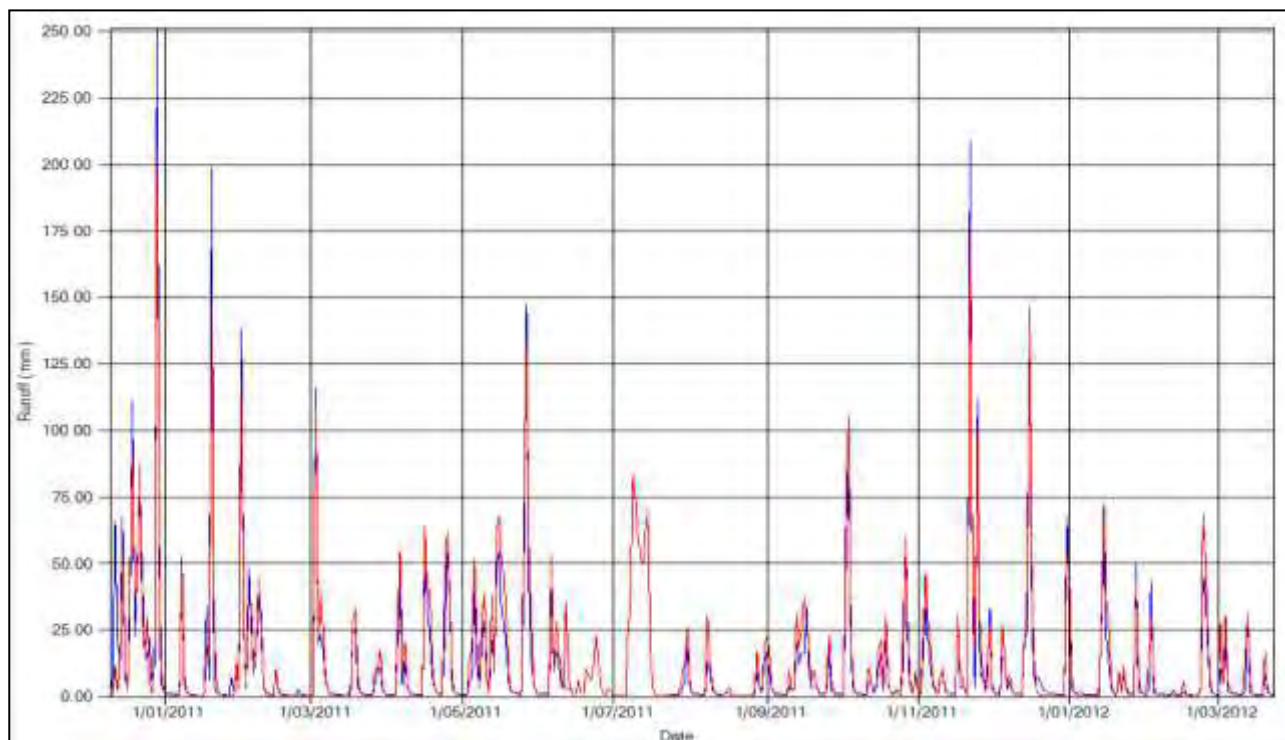


Figure 8: AWBM RRL calibration showing calculated run-off (red) plotted against recorded run-off (blue) from the Whareatea River at W-M1 for the period 10 December 2010 to 23 March 2012.

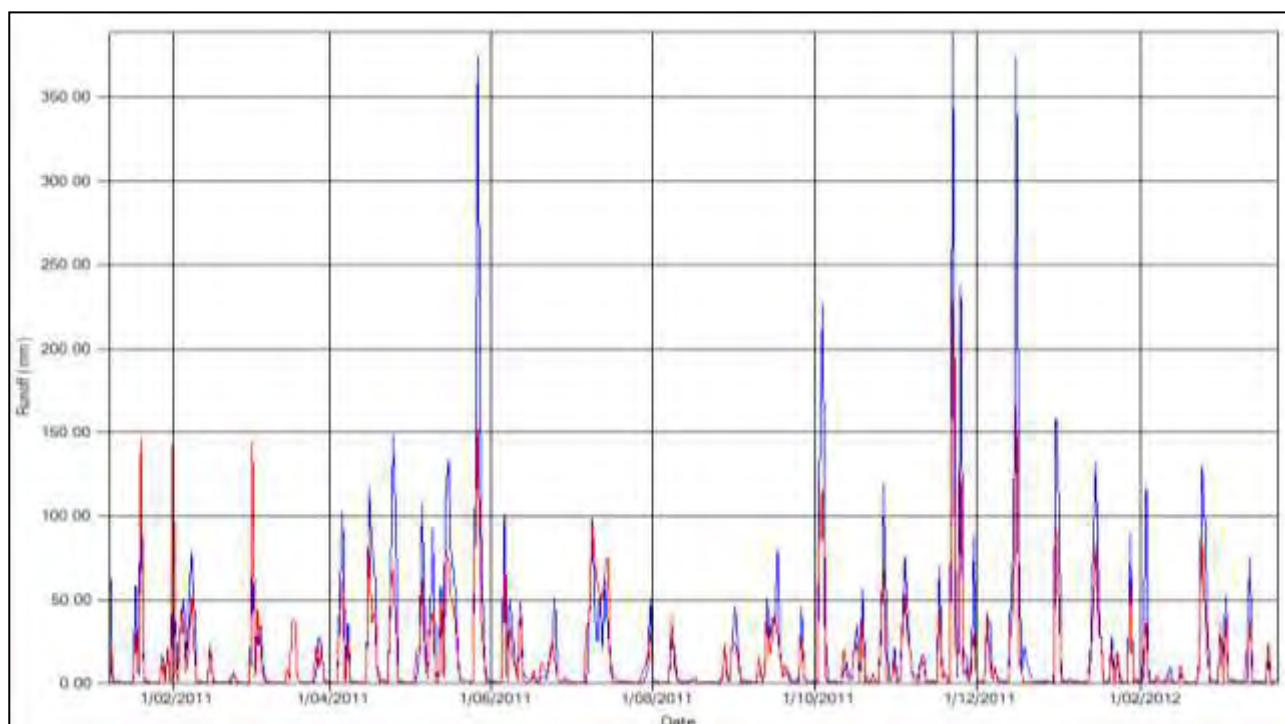


Figure 9: AWBM RRL calibration showing calculated run-off (red) plotted against recorded run-off (blue) from the Whareatea River at W-M2 for the period 8 January 2011 to 23 March 2012.

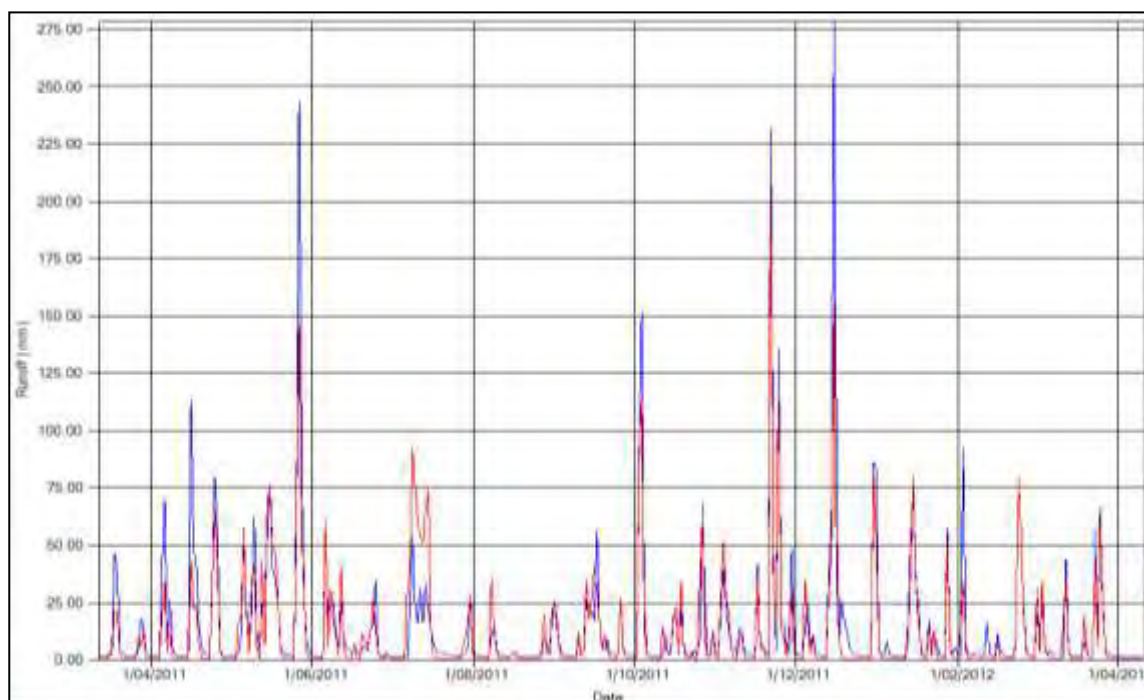


Figure 10: AWBM RRL calibration showing calculated run-off (red) plotted against recorded run-off (blue) from the Whareatea River at W-M3 for the period 12 March 2011 to 11 April 2012.

The AWBM parameters derived from the RRL calibration were then applied as input values to the EMP GoldSim model for the pre-mine scenario. The AWBM parameters used in the EMP GoldSim model were manually adjusted to improve the simulation of runoff from high and low flow events. The RRL calibration for the M-W1 site was applied to all the native catchments in the GoldSim model. The M-W1 calibration was selected due to its higher Nash–Sutcliffe model efficiency coefficient and the fact that the rainfall station at V8-M1 is more representative of the catchment upstream of M-W1 than it is of the catchments upstream of either M-W2 or M-W3.

The manual adjustment of the AWBM parameters in the EMP GoldSim model was initially focused on stream flows in the Whareatea River at M-W1 and then moved downstream to M-W2 and M-W3. The final calibration produced an acceptable simulation for the full range of flows at M-W1 (Figure 11). The AWBM parameters derived from the RRL calibration and the final AWBM parameters are presented in Table 19.

Table 19: AWBM Parameters for EMP.

Parameter ⁽¹⁾		W-M1		W-M2		W-M3	
		Initial RRL calibration	Final GoldSim calibration	Initial RRL calibration	Final GoldSim calibration	Initial RRL calibration	Final GoldSim calibration
Surface store capacities (mm)	C1	41.8	10	0	10	2.0	10
	C2	180.8	50	180.8	50	10.2	50
	C3	393.2	150	0	150	459.6	150
Surface store area split (%)	A1	0.134	0.4	0.134	0.4	0.134	0.4
	A2	0.433	0.3	0.433	0.3	0.433	0.3
	A3	0.433	0.3	0.433	0.3	0.433	0.3
BFI Base flow index		0.795	0.96	1	0.96	1	0.85
Ks Surface runoff recession constant		1	0.92	0.516	0.92	0.745	0.97
Kb Baseflow recession constant		0.392	0.2	0	0.2	0.083	0.35

Note: (1) Units presented in brackets where necessary.

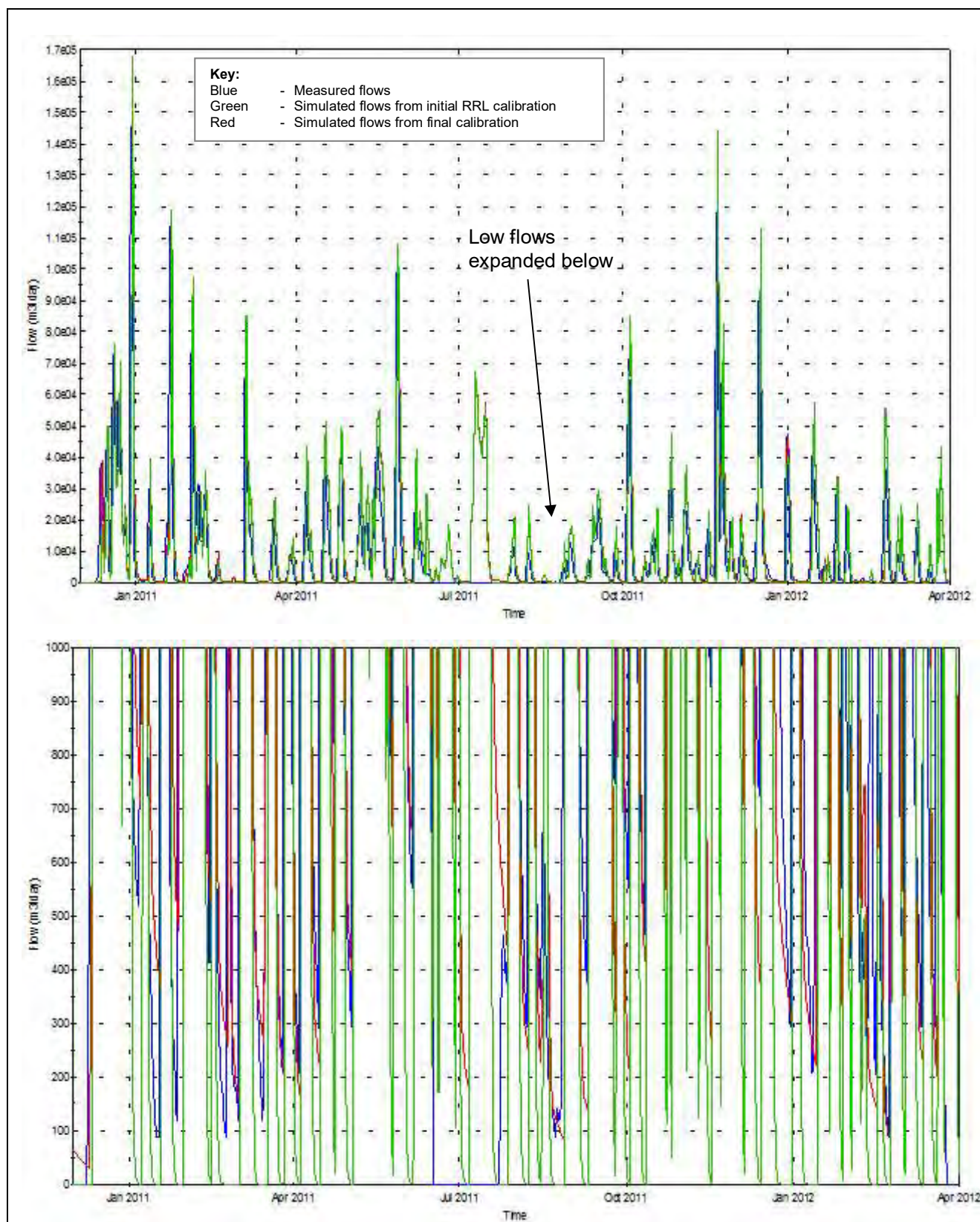


Figure 11: Simulated and measured stream flow in the Whareatea River at W-M1, 1 December 2010 to 1 April 2012.



The final AWBM parameters for the catchment above W-M1 were then applied to the catchment above W-M2. The resulting predicted flows at W-M2 reproduced the measured fluctuations in flow and low flows but tended to underestimate high flows Figure 12. Envirolink have indicated that the high end of the rating curve for the W-M2 site on the Whareatea River is not well defined (per coms Brenda Clapp of Envirolink 1 May 2012) (Envirolink 2012d). Given this and that there are known to be underground workings in the catchments above both W-M1 and W-M2 it was considered appropriate to have the same AWBM parameters for the catchments above W-M1 and W-M2.

The final AWBM parameters for both the W-M1 and W-M2 catchments were then applied to the catchment above W-M3. The resulting predicted flows at W-M3 reproduced the measured fluctuations in flow and high flows but tended to significantly underestimate low flows Figure 13. Low flows are critical when assessing effects of contamination as during low flows there is less dilution and the contamination effects are usually at their highest level. To ensure that the model adequately predicts low flow at W-M3 the AWBM parameters used in the EMP GoldSim model for the W-M3 catchment were manually adjusted to improve the simulation of runoff from low flow events (Figure 13 and Table 19). It is noted that in manually adjusting the parameters it was not possible to get parameters that consistently predicted both high and low flows and the final AWBM parameters tend to under predict high flows. The final AWBM parameters for the W-M3 catchment were slightly different to those used for both the W-M1 and W-M2 catchments with a lower base flow index and a higher baseflow recession constant (Table 19). Such changes are consistent with the W-M3 catchment producing higher baseflow than the W-M1 and W-M2 catchments. It is expected that this higher baseflow from the W-M3 catchment is due to that catchment not being subject to historic underground mining.

7.3 Natural Catchments Water Quality Calibration

The EMP GoldSim model simulates the concentrations of various contaminants at key locations based on estimations of water quality from various sub-catchment types and water sources at the site. The initial concentrations applied to natural catchments in the model were derived from analysis of water quality data from the site provided by Envirolink (2012b).

The contaminant concentrations at W-M1, W-M2 and W-M3 on the Whareatea River predicted by the EMP GoldSim model for the pre-mine scenario were compared with measured water quality data supplied by Envirolink. To overcome the time dependent issues discussed in Section 7.1 the comparison was undertaken on a flow rather than time basis. The comparison indicated that water quality from natural catchments varied between sub-catchments. Where necessary, the initial input water quality values used in the EMP GoldSim model (Table 7 and Table 8) were manually adjusted within pre-defined ranges for reasonable values to reproduce the measured water quality records at W-M1, W-M2 and W-M3 on the Whareatea River.

The calibration between catchments was undertaken in a downstream progression with the catchment above W-M1 calibrated first then the remaining catchment above W-M2 and finally the remaining catchment above W-M3. As the Whareatea River at W-M2 is expected to be the principal compliance monitoring point particular care was taken to ensure that the calibration at W-M2 was as representative as possible.

Particular attention was paid to dissolved metal concentrations during low flow events and both TSS concentrations and pH during both high and low flow events. Simulated and measured water quality results for the Whareatea River at W-M2 for the pre-mine scenario are presented in Figure 14 and Figures C1-C6 in Appendix C. In each case, the outcomes are presented for simulations including the initially applied water quality values and for the final calibrated values.

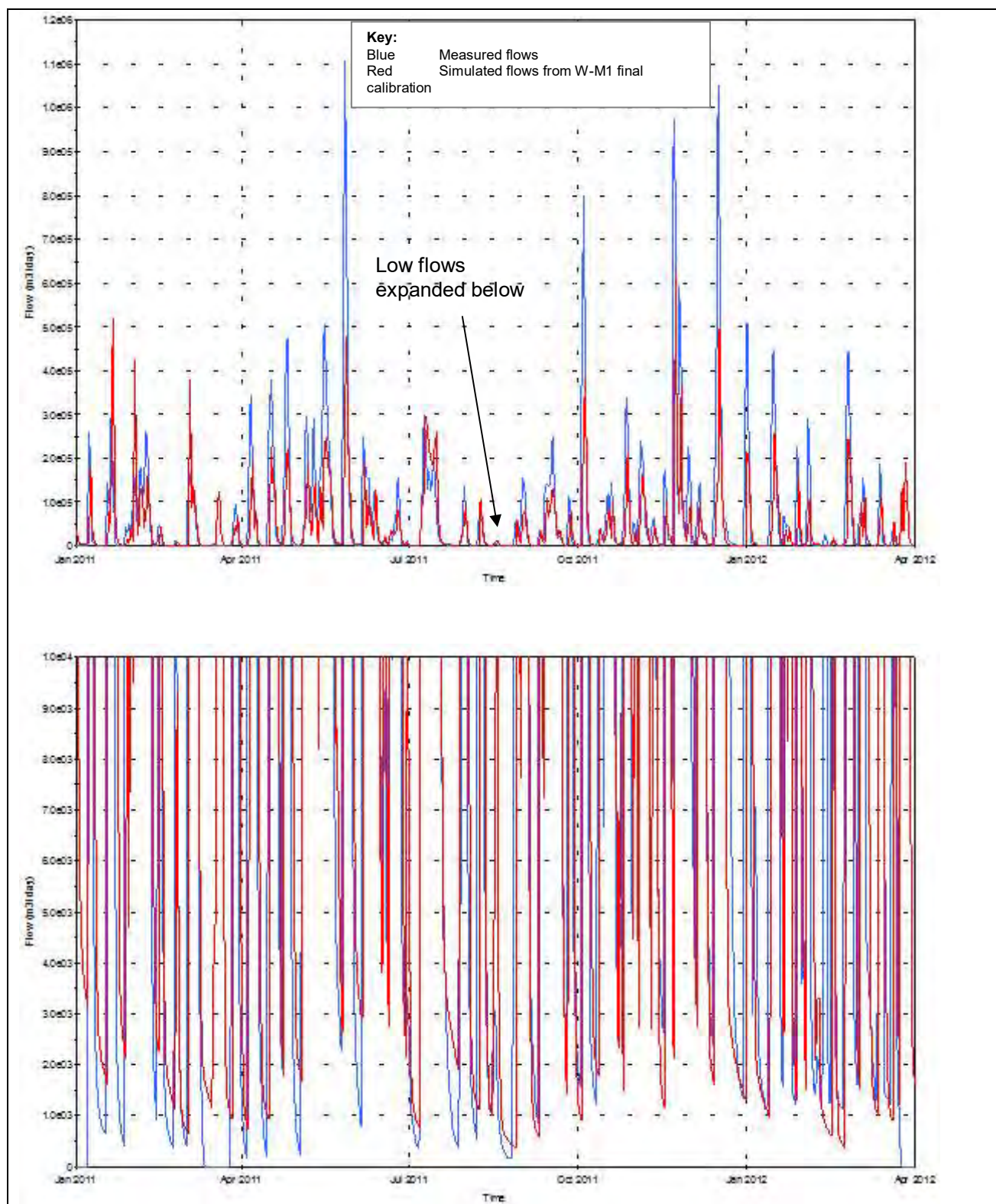


Figure 12: Simulated and measured stream flows for the Whareatea River at W-M2, 1 January 2011 to 1 April 2012.



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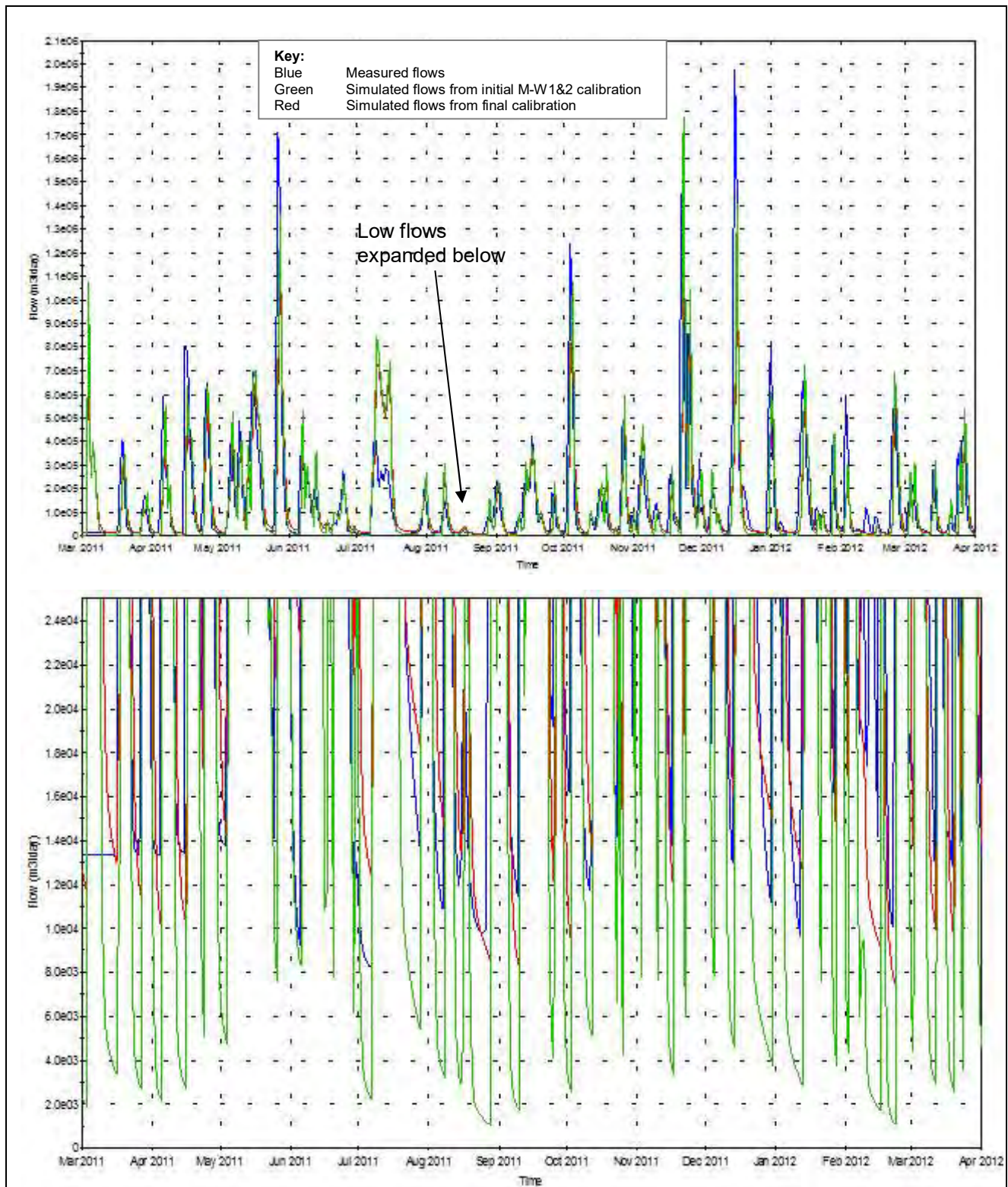


Figure 13: Simulated and measured stream flows for the Whareatea River at W-M3, 1 March 2011 to 1 April 2012.



The initial input parameters for aluminium from natural catchments envelope measured concentrations in the Whareatea River at W-M1 but tend to overestimate concentrations at both W-M2 and W-M2 (Figure 14). The input parameters for the catchments above both W-M2 and W-M3 were reduced slightly to provide a better fit with the monitored data (Figure 14). The initial and final calibrated aluminium input parameters are summarised in Table 20.

A similar process was completed for the other natural catchment water quality input parameters which resulted in the input parameters for iron, manganese, magnesium, zinc, pH and TSS from natural catchments being adjusted. The relevant plots and summary tables for these six parameters are presented in Appendix C. The calibrations for pH and TSS considered both the discrete pH and TSS data and the continuous pH and turbidity data collected by Envirolink. The initial input parameters for arsenic, cadmium, calcium, chromium, cobalt, copper, lead and nickel (Table 7 and Table 8) were found to suitably envelope measured concentrations in the Whareatea River at W-M1, W-M2 and W-M3 and did not require further calibration.

Table 20: Calibration of natural catchment aluminium input parameters.

Flow yield ⁽¹⁾ (L/s/ha)	Aluminium Concentrations (g/m ³)			
	Initial input for all natural catchments	Final input		
		Natural catchment above W-M1	Natural catchment above W-M2	Natural catchment above W-M3
0	0.15	0.15	0.1	0.05
0.01	0.15	0.15	0.1	0.05
0.07	0.25	0.25	0.18	0.2
0.2	0.25	0.25	0.18	0.2
80			0.005	0.05
100	0	0.005		0.05
1E+13 ⁽²⁾	0	0.005	0.005	0.05

Notes: (1) The GoldSim model linearly interpolates between daily rainfall or flow yield values.

(2) An arbitrary large number which is never exceeded in the model. The long term rainfall record for the site indices a maximum daily precipitation of approximately 760 mm which if it all runs off equates to a maximum yield of approximately 88 L/s/ha

Calibrating the model using the available data set allowed the model to be adjusted to account for the variation in water quality coming from different catchments along the Whareatea River. The variation in water quality observed is likely related to discharges from underground workings, variation in geologic formations and changing land use. Although the highest possible concentrations in the surface water bodies may not have been represented in the water quality data set from Envirolink, to increase the conservatism in the model the inputs to the model represent the high end of the measured values rather than the median values.

7.4 ELF Flow Balance

Rainfall on the ELF will either infiltrate into the ELF or runoff. The GoldSim mine water model considers both runoff and seepage from the ELF. As outlined in Table 4 seepage from the ELF varies depending on the stage of the ELF. During initial construction of the ELF before it is covered high seepage rate of 12 mm/day is expected which will decrease as the ELF is progressively covered, revegetated and rehabilitated. Runoff from the ELF is calculated using the rational method with runoff coefficients for various rainfall depths. The initial surface runoff coefficients used in the model are shown in Table 3. To ensure conservation of flow for the ELF a flow balance was undertaken on each of the stages of ELF development (uncovered, revegetated and rehabilitated) and the ELF runoff coefficients for each were adjusted until the cumulative flow balance plots (Figure 15, Figure 16 and Figure 17) for the ELF indicated a good visual match between cumulative inflows and cumulative outflows.



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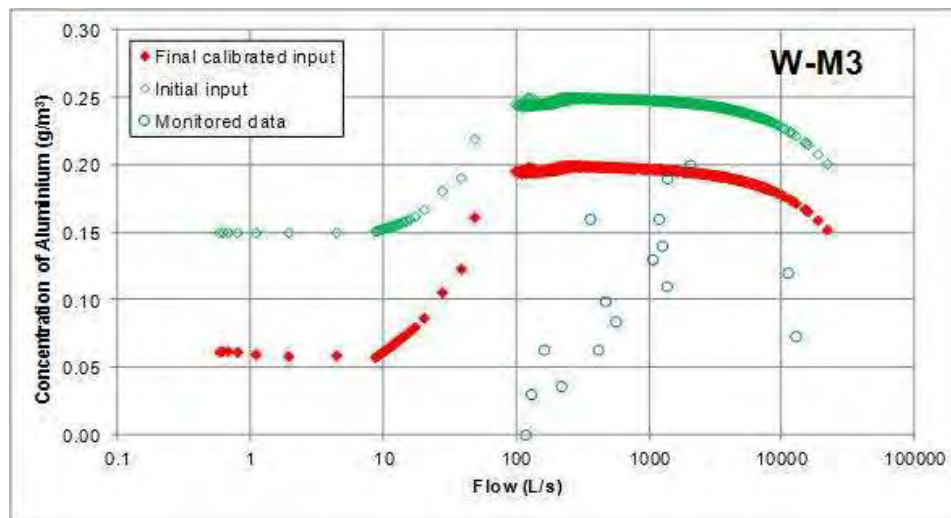
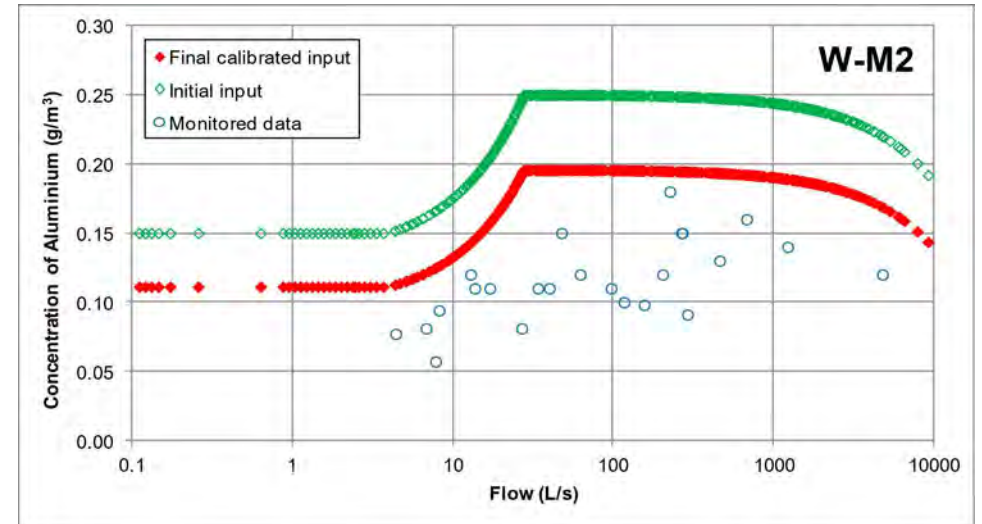
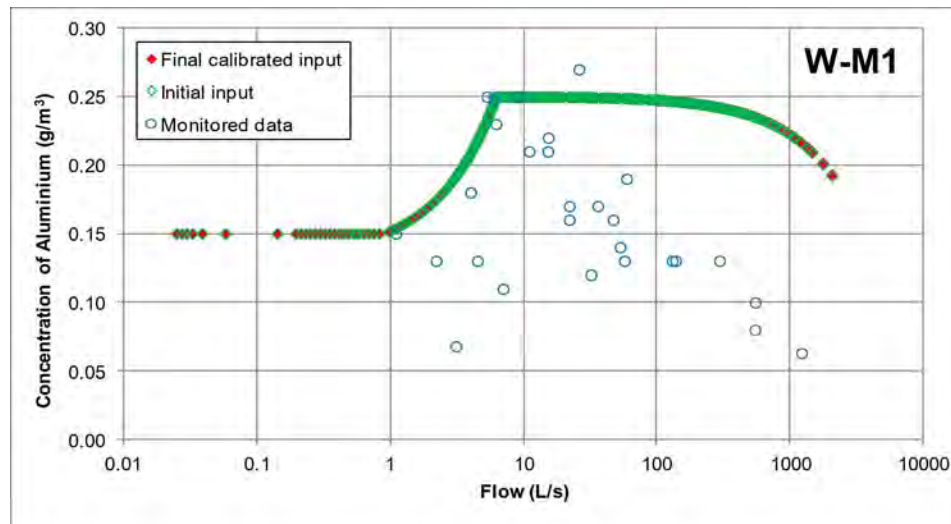


Figure 14: Calibration plots of natural catchment Aluminium input parameters.

Notes: Monitored data from 12 November 2010 to 23 February 2012.
Simulated predictions from 1 November 2010 to 1 April 2012.



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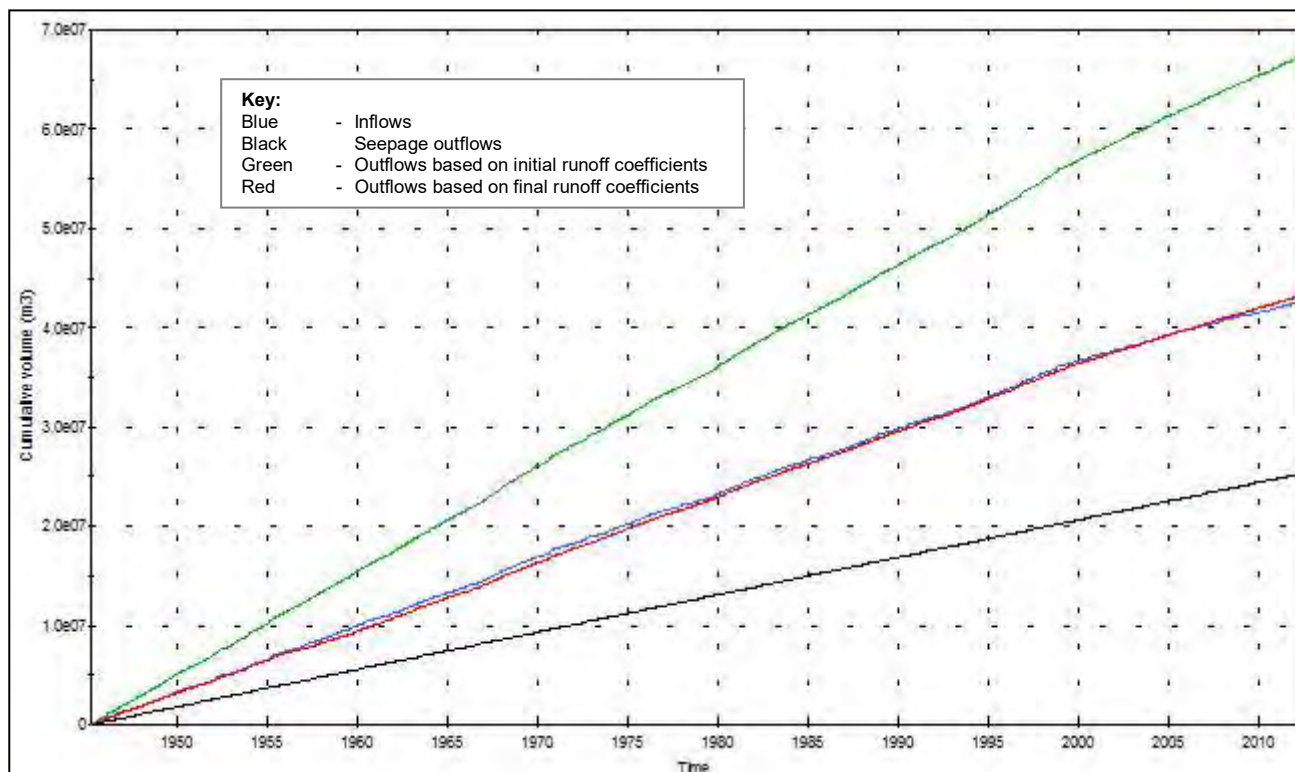


Figure 15: Cumulative flow balance for the simulated uncovered ELF Year 1 for the period 1 April 1945 to 25 April 2012.

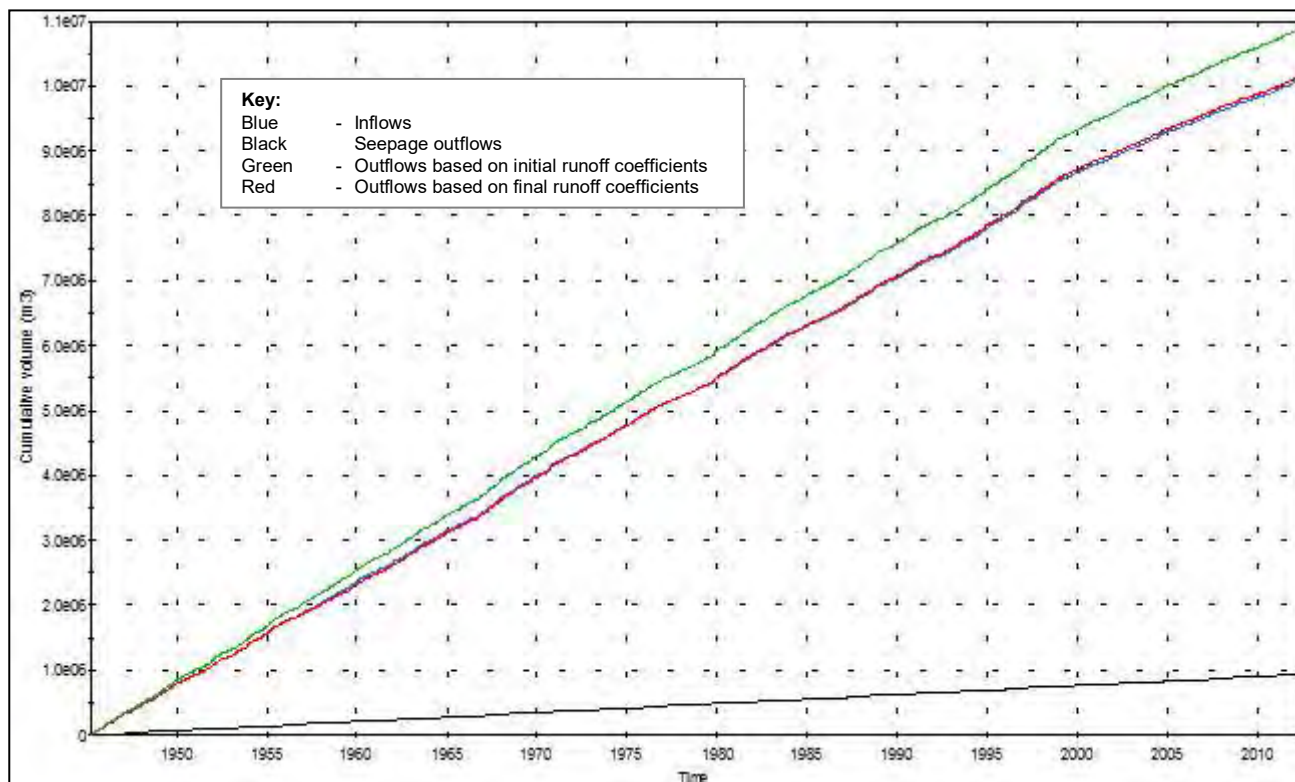


Figure 16: Cumulative flow balance for the simulated covered and revegetated forest ELF Year 1 for the period 1 April 1945 to 25 April 2012.

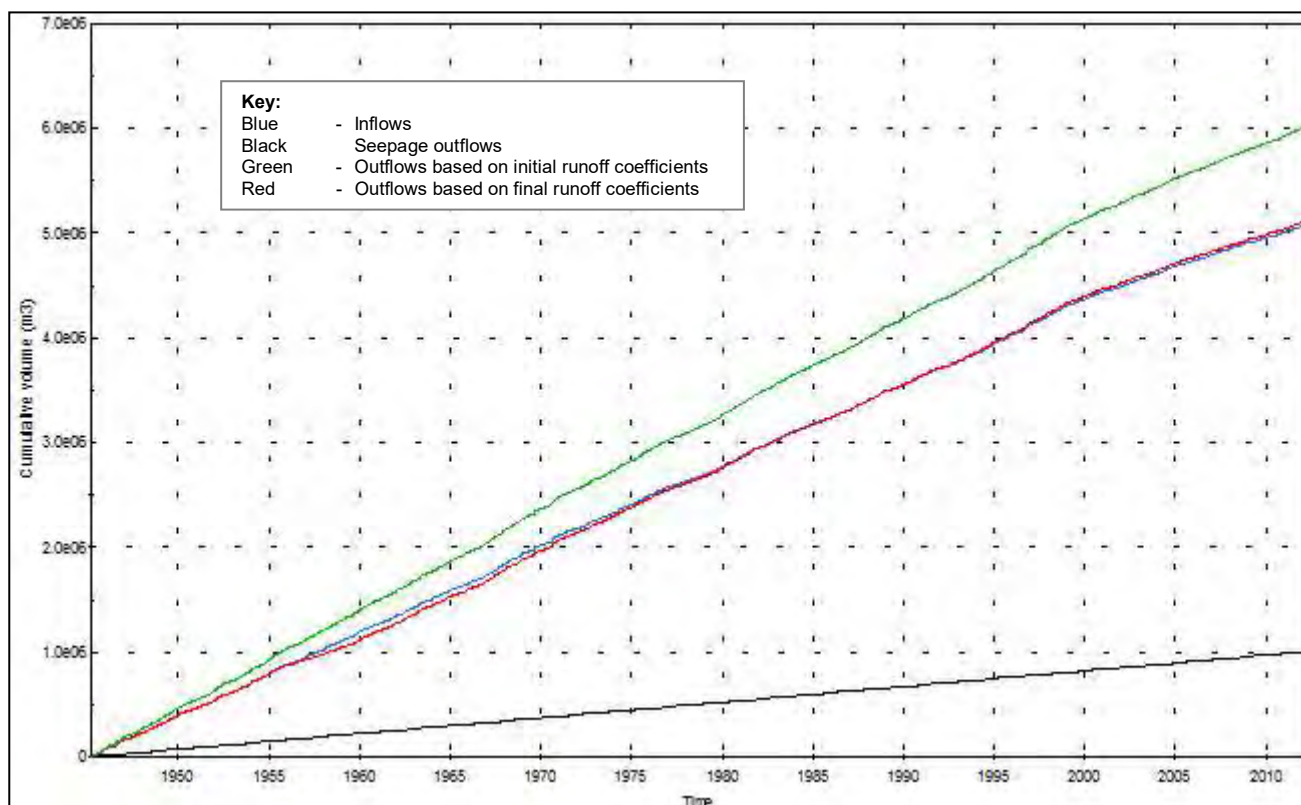


Figure 17: Cumulative flow balance for the simulated covered and revegetated pakihi ELF Year 1 for the period 1 April 1945 to 25 April 2012.

Inflows (rainfall) were compared with outflows (evaporation, surface runoff and ground water seepage). During initial construction of the ELF before it is covered, the ELF will be devoid of vegetation and is expected to be generally highly permeable, with the exception of surfaces compacted by mine traffic. Rainfall which falls on the uncovered ELF is expected to quickly infiltrate the surface and evaporation is expected to be limited. Some pooling of rainfall is expected during heavy rainfall events on areas where compaction by the continuous passage of mine vehicles has reduced infiltration rates. Some evaporation from these pools is expected, however overall evaporation from the uncovered ELF is expected to be low.

The proposed ELF is to be covered by a low permeability layer which will significantly reduce infiltration and seepage. Following covering with the low permeability layer the ELF will be progressively rehabilitated and revegetated. It will take some time for the vegetation to establish fully and evapotranspiration rates will take some time to return to pre-mining levels

The water balance for the uncovered, revegetated forest and revegetated pakihi ELF indicated that the initial runoff coefficients and groundwater seepage rates used in the model were overestimating outflows from the ELF. The runoff coefficients were manually decreased to ensure a suitable balance was achieved. The cumulative water balances for the period 1 April 1945 to 25 April 2012 for the year 1 uncovered ELF, revegetated forest ELF and revegetated pakihi ELF are presented in Figure 15, Figure 16 and Figure 17 respectively the final runoff coefficients for the ELF are summarised in Table 21.



Table 21: Surface runoff coefficients for the ELF used in the EMP water management model.

Daily rainfall ⁽¹⁾ (mm)	Surface runoff coefficients					
	Waste dump (uncovered ELF)		LPL with Re-vegetated Forest		LPL with Revegetated Pakihi	
	Initial	Final	Initial	Final	Initial	Final
0	0	0	0	0	0	0
5	0.5		0.5	0	0.5	0
10	1		1	0.75	1	0.35
12		0				
20		0.2				
80	1	0.52	1	1	1	1
800 ⁽²⁾	1	0.8	1	1	1	1

Notes: 1) The GoldSim model linearly interpolates between daily rainfall values.
2) The long term rainfall record for the site indicates a maximum daily precipitation of approximately 770 mm.

7.5 Model Balances

Flow and mass balance calculations are incorporated into the model. The water and mass are in balance for all nine land use scenarios. The model flow balance and the mass balance (aluminium, iron, copper, chromium, TSS and for pH (as H⁺ ions) for the Pre-mine, Construction, Year 3 and Post-mine scenarios are shown in Table 22. The mass and volume values shown in Table 22 represent the summation of daily balances where the volume and mass retained within storage reservoirs (i.e., the MIW surge sump and the various sediment ponds) is included each day and therefore the values do not represent overall mass or volume that moves through the model.

7.6 Calibration Summary

Overall the model simulates low and medium flows well but tends to understate high flow flood events. The projected concentrations are consistent with the fluctuations and ranges of the measured water quality data. The underestimation of high flows is unlikely to be an issue with respect to water quality compliance as during high flows there will be a considerable dilution effect. The potential for compliance issues is the highest under conditions where the MIW surge sump and/or the sump associated with the SW—WTP spills or under median to low flow periods when mine site discharges form a high proportion of the total flow of water passing the compliance points of W-M1, W-M2 and W-M3 on the Whareatea River.

Water quality and flow projections derived from the model should be considered indicative rather than fully representative on a day to day basis. While the model does not provide information which on its own is suitable for detailed design of the EMP water management infrastructure, the projections are suitable for conceptual design and evaluation of design options. The model is used to assess the performance of the proposed water treatment infrastructure by comparing EMP operational conditions to pre-mining conditions. While the lack of detailed calibration data prevents an assessment of model accuracy for a given mine operation scenario, relative comparisons between scenarios provide useful information for assessing mine impacts and water management options.

Due to the uncertainty described above, the model is not suitable for use in daily operational water management decision making. The model is however suitable for the intended purpose of producing water quality projections for evaluating the performance of conceptual water management layouts, assessing the water treatment requirements, providing a tool to assist with design of the water management infrastructure and for consenting and compliance purposes.



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Table 22: Total water and contaminant mass balance for the EMP mine water management model.

Parameter	Pre-mine Year 0 ⁽¹⁾			Construction Year 0.5 ⁽¹⁾			Year 3 ⁽¹⁾			Post-mine Active ⁽¹⁾		
	Cumulative model inputs	Cumulative model outputs ⁽³⁾ plus storage	Difference ⁽⁴⁾	Cumulative model inputs	Cumulative model outputs ⁽³⁾ plus storage	Difference ⁽⁴⁾	Cumulative model inputs	Cumulative model outputs ⁽³⁾ plus storage	Difference ⁽⁴⁾	Cumulative model inputs	Cumulative model outputs ⁽³⁾ plus storage	Difference ⁽⁴⁾
Volume of water (m ³)	2.16 x 10 ⁸	2.16 x 10 ⁸	0.0 %	2.49 x 10 ¹⁰	2.49 x 10 ¹⁰	0.0 %	2.44 x 10 ¹⁰	2.44 x 10 ¹⁰	0.0 %	2.51 x 10 ¹⁰	2.51 x 10 ¹⁰	0.0 %
Mass of Al ⁽²⁾ (g)	3.33 x 10 ⁹	3.33 x 10 ⁹	0.0 %	2.78 x 10 ¹⁰	2.78 x 10 ¹⁰	0.0 %	2.26 x 10 ¹⁰	2.26 x 10 ¹⁰	0.0 %	1.13 x 10 ¹⁰	1.13 x 10 ¹⁰	0.0 %
Mass of Fe ⁽²⁾ (g)	2.79 x 10 ⁹	2.79 x 10 ⁹	0.0 %	2.87 x 10 ¹⁰	2.87 x 10 ¹⁰	0.0 %	1.92 x 10 ¹⁰	1.92 x 10 ¹⁰	0.0 %	1.03 x 10 ¹⁰	1.03 x 10 ¹⁰	0.0 %
Mass of Cu ⁽²⁾ (g)	8.67 x 10 ⁶	8.67 x 10 ⁶	0.0 %	2.66 x 10 ⁸	2.66 x 10 ⁸	0.0 %	1.69 x 10 ⁸	1.69 x 10 ⁸	0.0 %	5.85 x 10 ⁷	5.85 x 10 ⁷	0.0 %
Mass of Cr ⁽²⁾ (g)	8.59 x 10 ⁶	8.59 x 10 ⁶	0.0 %	2.50 x 10 ⁸	2.50 x 10 ⁸	0.0 %	1.69 x 10 ⁸	1.69 x 10 ⁸	0.0 %	9.72 x 10 ⁷	9.72 x 10 ⁷	0.0 %
Mass of TSS ⁽²⁾ (g)	6.15 x 10 ¹⁰	6.15 x 10 ¹⁰	0.0 %	5.97 x 10 ¹²	5.97 x 10 ¹²	0.0 %	1.48 x 10 ¹²	1.48 x 10 ¹²	0.0 %	4.22 x 10 ¹¹	4.22 x 10 ¹¹	0.0 %
Mass of H ions (pH) ⁽²⁾ (g)	1.34 x 10 ⁸	134 x 10 ⁸	0.0 %	2.04 x 10 ⁹	2.04 x 10 ⁹	0.0 %	1.37 x 10 ⁹	1.37 x 10 ⁹	0.0 %	5.78 x 10 ⁸	5.78 x 10 ⁸	0.0 %

Notes: (1) All balance is over the period 1 April 1945 to 25 April 2012.
(2) All mass balances are for the typical values.
(3) Cumulative model outputs as predicted in the Whareatea River at W-M3.
(4) Difference equals inputs minus outputs as a percentage of inputs.



8.0 MODEL LIMITATIONS

8.1 Introduction

As with all models the accuracy of model predictions is a combination of the following two principal factors which are discussed below.

- 1) The accuracy of the input data.
- 2) The accuracy of the model itself and how representative the model is of the actual system and physical and chemical processes being modelled.

Interpretation of model predictions requires care and needs to fully consider the models limitations. Ideally interpretation of model predictions should be done by people who are fully conversant with both the system being modelled and the model itself and particularly its objectives, structure, inputs and underlying assumptions. The EMP GoldSim model is designed to model a multifaceted system, the process flow diagram (Figure 4) upon which the model is based is complex and the model logic is extensive. Care is required when modifying or running the model and Golder recommends that running of the model and interpretation of model predictions only be undertaken by people who are fully conversant with the model and its underlying assumptions.

8.2 Accuracy of the Model Inputs

8.2.1 Rainfall and evaporation record

As outlined in sections 5.2 and 6.4.1 the EMP GoldSim model uses a synthetic climate record from 2 March 1945 to 12 April 2012 (the derivation of which is summarised in Golder 2012a). There are standard measurement errors associated with all climate measurements and the synthetic climate record will include both measurement errors associated with the actual data used to create the synthetic series and errors associated with the process used to create the synthetic series. Overall both sources of error are expected to be relatively small (i.e. for daily rainfall, measurement error is usually $\pm 0.5\text{mm}$ and the Envirolink relationship used to create the synthetic rainfall series has a sample size of $n=70$ and a strong correlation with $r^2 = 0.92$, (Golder 2012a)) and the overall error in daily values is expected to be small in comparison to the natural fluctuations in the daily values.

The EMP GoldSim model does not include allowances for future climate change rather it assumes that the approximately 67 year record (2 March 1945 to 12 April 2012) will include climate extremes which exceed any that are expected to occur over the next 10 years (i.e., 5 year mine life plus a rehabilitation period). This is considered a reasonable assumption however there is the possibility that an extreme climate event could occur during the mines life that exceeds expectations. Golder 2012a contains an analysis of expected climate change effects on extreme rainfall events which suggests that under average climate change predictions the 100 year annual recurrence interval 24 hour rainfall event at the EMP site is expected to increase by 7 % (from 760 mm to approximately 810 mm) by 2040.

8.2.2 Flow record for model calibration

Envirolink have measured flow at various locations within and downstream of the EMP since 7 November 2010 (Envirolink, 2012a). This flow data has been analysed and used in the EMP GoldSim model. There are errors associated with all flow data which include measurement errors (associated with both the continuous water level (stage) data and the instantaneous flow gauging) and rating errors (associated with converting the measured stage data to flow). Envirolink have indicated that the high flow end of the rating curves for the various flow sites is not well defined due to the short duration of flood events, making flood gaugings difficult to obtain (per coms Brenda Clapp of Envirolink 1 May 2012). Flow will also be subject to the climatic variability. Errors in the order of $\pm 10\%$ are typical for flow data although the overall error in the average daily flow values is expected to be small in comparison to the natural fluctuations in the daily values.



The available flow data reflect pre-mining conditions and runoff from mine influenced catchments have been estimated using runoff coefficients derived from experience from existing mine sites (namely the various mines on the Stockton Plateau). While conservative coefficients have been chosen which are expected to ensure that predicted runoff is conservatively high, errors in the order of $\pm 20\%$ are expected in the predicted daily runoff volumes from mine influenced catchments.

The EMP is located in small headwater catchments of the Whareatea River, which experience rapid runoff with freshes and floods tending to peak within hours rather than days. The EMP GoldSim model is based on a daily timestep and is unlikely to predict peak instantaneous flow rates. Care will be required when using the model to assist with design of mine EMP water management infrastructure as the peak daily flows predicted by the model are likely to underestimate actual peak instantaneous flows.

8.2.3 Water quality data for model calibration

The water quality part of the EMP GoldSim model has been calibrated using a relatively small set of pre-mine water quality monitoring data. The limited size of the calibration data set and the lack of water quality data from mined catchments, reduces confidence in the models water quality predictions. If the available pre-mine water quality data could be compared to larger data sets from similar sites and/or if water quality data (particularly continuous monitoring data) from an existing operational opencast coal mine in a similar location could be obtained then confidence in the models water quality predictions could be increased, but at the time of model development no additional data was available.

To increase the conservatism in the model the water quality inputs for natural catchment used in the model represent the high end of the measured values rather than the median values. To incorporate the uncertainty in water quality from mined catchments, optimistic (lower contaminant loads), typical (expected contaminant loads) and extreme (maximum expected contaminant loads) water quality inputs were incorporated into the model to envelope potential outcomes.

The limit amount of water quality data available for calibration is the biggest limitation to the model and Golder recommends that the model be validated as new water quality data become available, particularly water quality data from catchments affected by mining operations.

8.3 Accuracy of the Model Itself

The EMP GoldSim model is based on a the process flow diagram (Figure 4) which was developed by Ellmuck based on preliminary design level mine plans supplied by BCL. The model logic has been reviewed internally by Golder and was found to be consistent with the process flow diagram (Figure 4). Model balances show that the model itself accurately accounts for both flow and mass (Section 7.5). The model has considerable inbuilt flexibility allowing it to be quickly run for a variety of possible mine infrastructure options provided there are no changes to the process flow diagram. Dashboards within the model allow catchment areas, water treatment infrastructure sizes and efficiencies to be easily changed. Changes to the process flow diagram would require modification of the model logic. The time involved to modify the model logic is dependent on the complexity of the changes and whether or not additional water management infrastructure is proposed.

In regard to water quality the EMP GoldSim model does have a number of important limitation in that the model does not incorporate geochemical reactions, including the attenuation of metals within the system by adsorption or precipitation, or account for desorption of metals already in the stream bed. Furthermore, the model does not relate changes in pH to potential changes in the water chemistry. The EMP GoldSim model estimates the change in mass of contaminants across the surface water system with contaminants assumed to be transported conservatively (i.e., dilution is the only control on concentrations). The modelled water quality results are likely to be conservative and should only be used for preliminary assessment of potential receiving water conditions. Qualitative assessment of geochemical reactions, such as mineral precipitation



or sorption reactions can be done using major ion data and pH. Such an assessment is outside the scope of this assessment.

9.0 RESULTS

9.1 Introduction

Following calibration the EMP GoldSim model was used as a tool to achieve some initial objectives identified by BCL which included:

- Assessment of the relative size and performance of various mine water infrastructure under various mine development scenarios to provide a defensible conceptual approach to mining for the consenting process. This included, on a conceptual basis, optimisation of the size of the pit sump, MIW surge sump, MIW-WTP and the SW-WTP on a yearly basis through the life of the mine.
- Evaluation of short-term flow changes and potential effects within the Whareatea River catchment resulting from the mining activities.
- Demonstration that key water quality parameters associated with activities at the mine site are likely to achieve compliance with proposed consent conditions at key locations in the downstream receiving environment.
- Use of these preliminary model outcomes in the mine water management plan described in evidence prepared by Dr Mark Ellis (Ellis 2012) and assessment of potential downstream aquatic ecological effects described in evidence prepared by Dr Chris Hickey (Hickey 2012) to be presented at the Environment Court Hearing.

This section summarises the conceptual sizing of the various mine water treatment infrastructure and the predicted flow and water quality in the downstream receiving environment. The conclusions regarding the effectiveness of the conceptualised water management plan for the five years of mine operations and post-closure conditions are summarised in Section 10.0.

While the EMP GoldSim model has inherent limitations, it can effectively be used to assist with other aspects of mine management planning which are described in the recommendation section of this report (Section 11.0).

It is important to recognise that the EMP GoldSim model cannot take into account on-site interventions that may be either:

- Outside the options incorporated in the model, or
- Allowed for within the model but applied in response to operational drivers that are not focused on mine water management.

For this reason BCL has a greater capacity to manage water flows and contaminant loads at the site under unusual or extreme conditions than is allowed for in the EMP GoldSim model. This additional water management capacity means the modelled outcomes are not only conservative with respect to contaminant input concentrations but also with respect to site water management procedures.



9.2 Mine Water Management Infrastructure Sizing

9.2.1 Sizing process

The model was used to assist with conceptual sizing of the various mine water treatment infrastructure. This was achieved by setting performance criteria for the treatment system which were based on consideration of operational requirements (i.e., space limitations within the mining licence, proposed mine scheduling etc.) and the compliance limits that were established in the 26 August 2011 consent decision document. The compliance limits outlined in the 26 August 2011 consent decision document have two components that required consideration during the sizing process.

Firstly, the stipulated downstream receiving environment water quality compliance limits which are summarised in Table 5 and which stipulate both median (rolling) and 95th percentile limits for the concentration of various parameters. Secondly condition 154 which states the following:

154. The Consent Holder shall install a MIW surge sump and MIW-WTP capable of holding and treating MIW and will ensure that MIW is not able to bypass the surge sump and treatment system more than 5% of the time (as calculated over a year).

The 26 August 2011 consent decision document indicates that these two compliance considerations were expected to be directly linked. This implies that 5 % of the time the site infrastructure (MIW surge sump and MIW-WTP) will not be able to treat all the MIW and during these periods the anticipated exceedances of the 95th percentile compliance limits would occur. The 5 % of the time that the MIW bypasses the surge sump and treatment system is expected to occur during either extreme rainfall events or after extended wet periods and is likely to co-occur with high flows in the receiving waters which will provide dilution for the MIW that bypasses the surge sump and treatment system.

The model utilises approximately 67 years (2 March 1945 to 12 April 2012) of historic climate data. Initial sizing of the water treatment infrastructure was completed on the basis of ensuring the infrastructure did not spill for more than 5% of the total model run time (i.e., 67 years). Subsequently the performance of the infrastructure was then assessed based on two individual years, 1970-1971 which was a 95th percentile rainfall (wet) year and 2005-2006 which was a 5th percentile rainfall (dry) year.

The following two step approach was adopted for sump and water treatment plant sizing:

- 1) Initially, pit sump volumes and pit pump rates were based on inflows to the sumps and a desire to minimise the period of time when the sumps would flood into the pit and cause disruption to mining.
- 2) The MIW surge sump volume and MIW-WTP capacity were then determined on the basis of limiting spillage from the MIW sump to no more than 5 % of the time, which is consistent with the 95% compliance level established in the 26 August 2011 consent decision.

In sizing the MIW surge sump volume and MIW-WTP capacity it is acknowledged that there are a large number of combinations that would achieve the above objectives. Golder trialled various combinations, with the selected sizes based on the following:

- 1) Ensuring desired performance goal is achieved.
- 2) Where possible, the sizes are consistent with those indicated at the 2011 Council hearing.
- 3) Sizes that are considered both feasible and practical in terms of construction and fit with BCLs development plans and proposed site layouts.

The results of the sizing process for the pit sumps are summarised in Section 9.2.3 while Section 9.2.4 discusses sizing of the MIW surge sump and the MIW-WTP.



9.2.2 Effect of proposed Kawatiri Hydro-electric Scheme

Prior to sizing the sump and water treatment plant, the flow effects of the proposed Kawatiri hydro-electric scheme were investigated. The proposed scheme will draw water from below the W-M2 flow monitoring site on the Whareatea River. This removal of water reduces downstream flows but tends to improve downstream water quality by increasing the dilution effect provided by the natural catchment that contributes to the Whareatea River below the hydro-electric take. The hydro-electric take has its largest effect during mid-range flows and can significantly reduce downstream flows. Figure 1 attached shows simulated flow in the Whareatea River above and below the hydro-electric take. All subsequent modelled scenarios have been completed on the basis that the proposed Kawatiri hydro-electric scheme is operating.

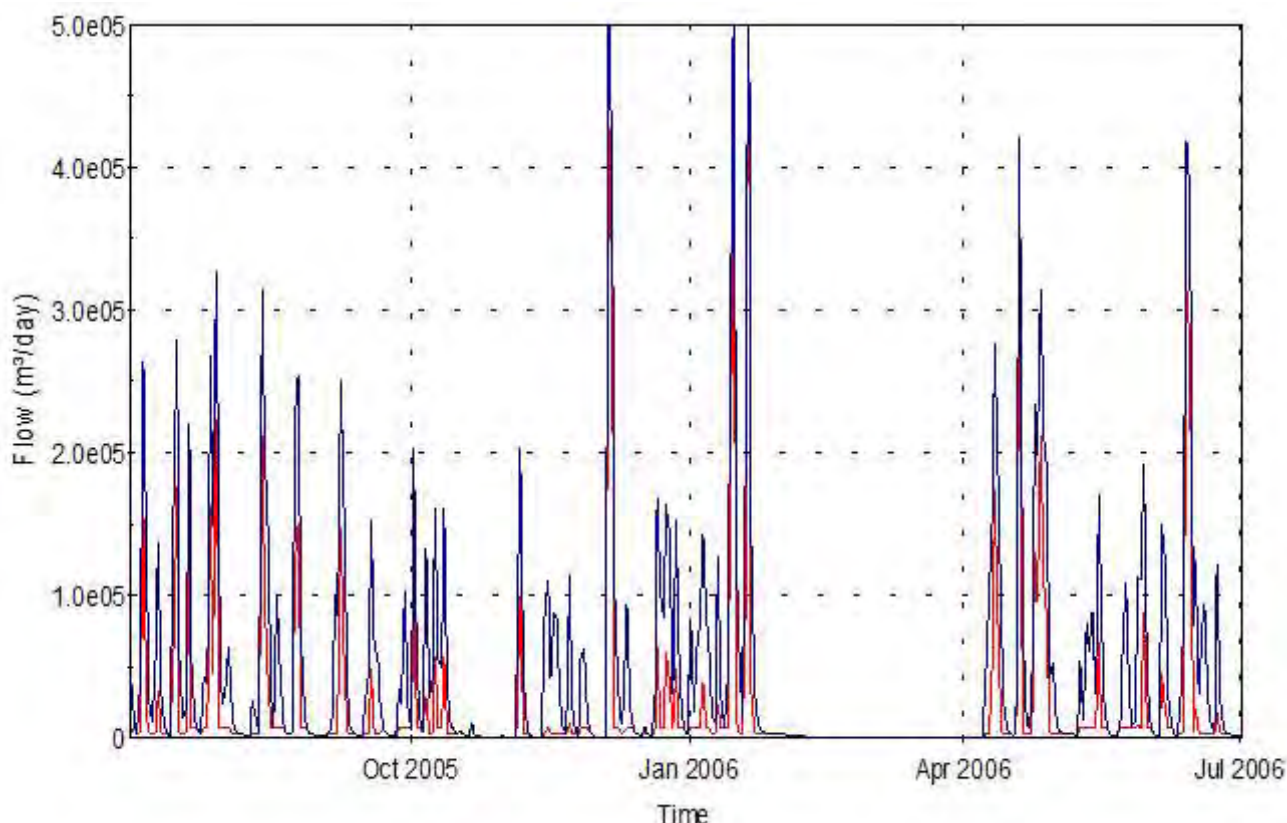


Figure 18: Simulated pre-mine flow in the Whareatea River above (blue) and below (red) the proposed Kawatiri Energy Limited's (KEL) hydro-electric take for the 5th percentile rainfall (dry) year of 1 July 2005 to 1 July 2006.

9.2.3 Pit sump volume and pit pump rate sizing

A sump is to be located at the base of the pit to collect runoff from the active pit and recently constructed ELF surfaces, as well as leachate from the ELF. The sump is to be located on the pit floor and progressively moved as the pit moves. If the sump floods the water will spread out over the pit floor and potentially disrupt mining operations. The pit sump must be sized so that it does not significantly disrupt mining. A large pit sump will flood less often but will reduce the operational area of the pit floor. Conversely, a smaller pit sump will allow a larger operational area but will flood more frequently. The size of the pit sump pump determines how quickly the volume of water stored in the sump can be reduced.

BCL has indicated that disruptions to mining due to flooding of the pit floor of 1-2 days duration were acceptable but longer disruptions should be avoided (Rogers 2012). The model was used to trial various pit sump volumes and pump rates. A pit sump size of 15,000 m³ and a pump rate of 800 L/s results in the pit



sump overflowing a total of 52 times during the approximately 67 years that the model was run and a maximum disruption period of 3 days (Figure 19). The modelled pit sump does not overflow frequently, allowing BCL the future option of flooding the pit floor more frequently in order to reduce or control spillage from the MWI sump. A pit sump size of 15,000 m³ and a pump rate of 800 L/s were confirmed acceptable by BCL (Rogers 2012) prior to proceeding with subsequent model runs.

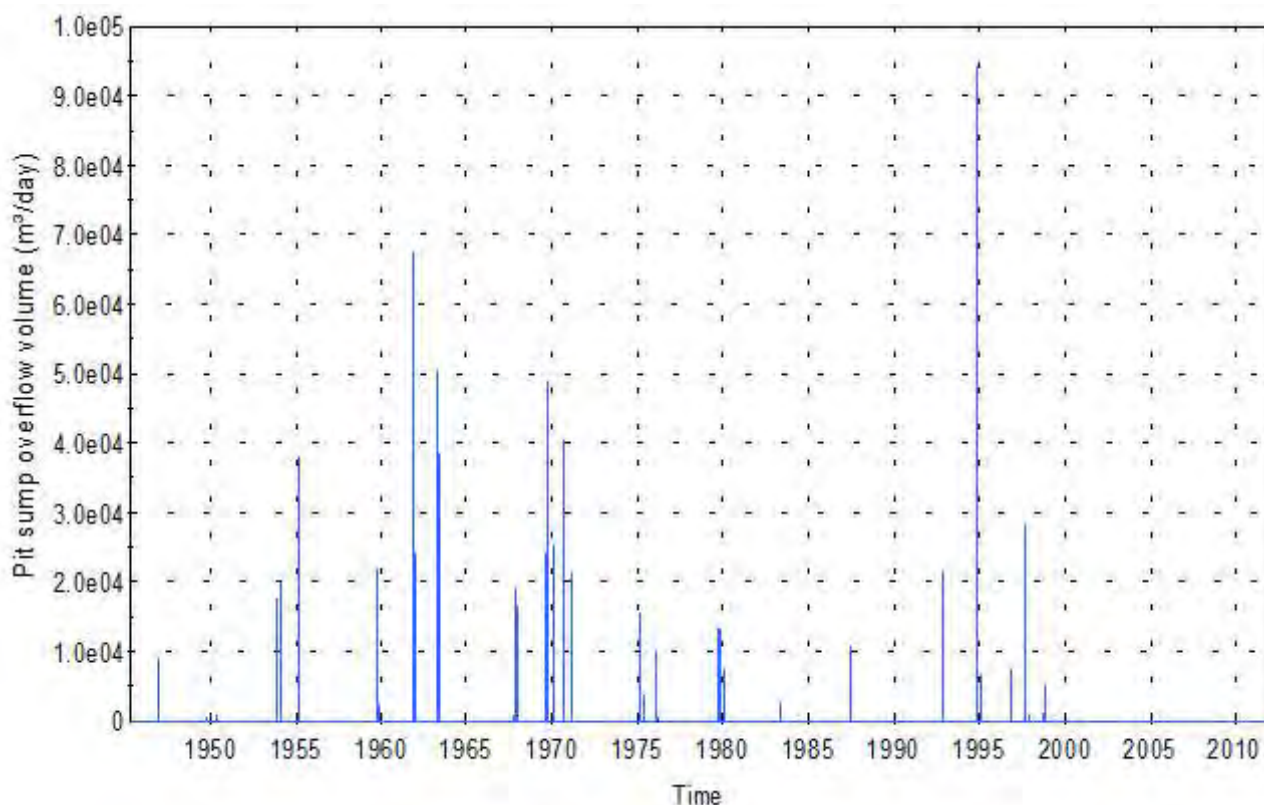


Figure 19: Operational Year 3 pit sump overflow volumes which represents periods when the pit floor is flooded, for the period 1 May 1945 to 1 April 2012.

9.2.4 MIW surge sump volume and water treatment plant sizing

There will be a critical period during the EMP's development, operation, rehabilitation and closure when the volume of water that requires treatment and its concentration will be greatest. This critical period will occur during the operational phase of the mine. It is likely to coincide with the maximum extent of the active mine but is strongly influenced by the extent and effectiveness of ELF rehabilitation activities. It is this critical period which determines the maximum size of the required mine water management infrastructure.

A pit sump volume of 15,000m³ and a pit pump capacity of 800 L/s (determined above) were incorporated into the EMP GoldSim model. A MIW surge sump volume of 200,000m³ and MIW-WTP capacity of 400 L/s were presented during the 2011 Council hearings and were considered a suitable start point for optimisation of the sizing of the MIW surge sump and MIW-WTP. The GoldSim model was run for all six land use scenarios during the operational period of the mine (i.e., Year 1, 1.5, 2, 3, 4 and 5) to determine which of the scenarios was critical for infrastructure sizing. The objective was to identify which land use scenario results in the most inflow into the MIW surge sump and the highest load on the MIW-WTP. The number of spill events and the total volume spilt from the MIW surge sump volume for each of the six scenarios is summarised in Table 23.



Table 23: MIW surge sump spill events and spill volumes.

Scenario	Number of spill events	Volume spilt (m ³)	Comments
Year 1	54	2.46 x 10 ⁶	-
Year 1.5	77	2.74 x 10 ⁶	-
Year 2	130	6.54 x 10 ⁶	-
Year 3	796	3.32 x 10 ⁷	Critical year as highest number of spill events and largest spill volume.
Year 4	339	1.63 x 10 ⁶	That part of the ELF within the Trent Steam and V40 Stream catchments effectively rehabilitated allowing runoff to be discharged directly to the streams.
Year 5	206 (3,526 [*])	7.51 x 10 ⁶ (1.96 x 10 ^{8*})	That part of the ELF within the Trent Steam, V40 Stream and S Stream catchments effectively rehabilitated allowing runoff to be discharged directly to the streams. * The values in brackets indicate the situation if the rehabilitation is not effective and all runoff requires treatment.

The mine is to be progressively rehabilitated. From mine operation Year 4, runoff from those parts of the mine that are rehabilitated initially (i.e., the part of the ELF within the Trent Steam and V40 Stream catchments) is expected to be of sufficient quality that it can be discharged directly to the receiving waterways and will not require treatment. On this basis, mine operation Year 3 was found to be the critical year for infrastructure sizing (Table 23). In operational Year 3, a large proportion of the site is being actively mined and while sections of the EFL have been capped and revegetated, the vegetation is not expected to be fully re-established. At this time runoff from the revegetated areas is expected to have elevated TSS and required treatment. If the rehabilitation is not as extensive or effective as anticipated the critical year becomes the year of maximum mine extent (namely Year 5) and larger treatment infrastructure would be required.

Various MIW sump volumes and MIW-WTP capacities were trialled until a combination was obtained that ensured that spillage from the sump occurred on average no more the 5 % of the time. Figure 20 presents the volume of mine water that overflows the MIW sump (sump volume of 200,000m³ and pit pump capacity of 350 L/s) under the operational Year 3 land use scenario.

Following sizing of the MIW sump and MIW-WTP for the operational Year 3 scenario, the MIW sump volume requirement and MIW-WTP capacities required for the other operational and post closure mine scenarios were derived from trialling various combinations of MIW sump volume and MIW-WTP capacity. The resulting MIW sump volumes and MIW-WTP capacities required for each stage of the mine life and the projected frequency of spill events from the MIW sump are summarised in Table 24.

Golder understands that one of the assumptions regarding the 95 % compliance level established in the 26 August 2011 consent decision was that spill events from the MIW sump would cause reduced water quality in the receiving environments. Spill events from the MIW sump are expected to coincide with periods of high flow in the lower Whareatea River due to runoff from undisturbed catchments. The model confirmed this was indeed the case. Figure 21 presents the concentration of TSS at W-M2, flow at W-M2 and spills from the MIW surge sump. Figure 22 presents the concentration of dissolved aluminium at W-M2, flow at W-M2 and spills from the MIW surge sump. There is a clear correlation between periods of high concentrations in the receiving environment, high flows in the receiving environment and spills from the MIW surge sump.

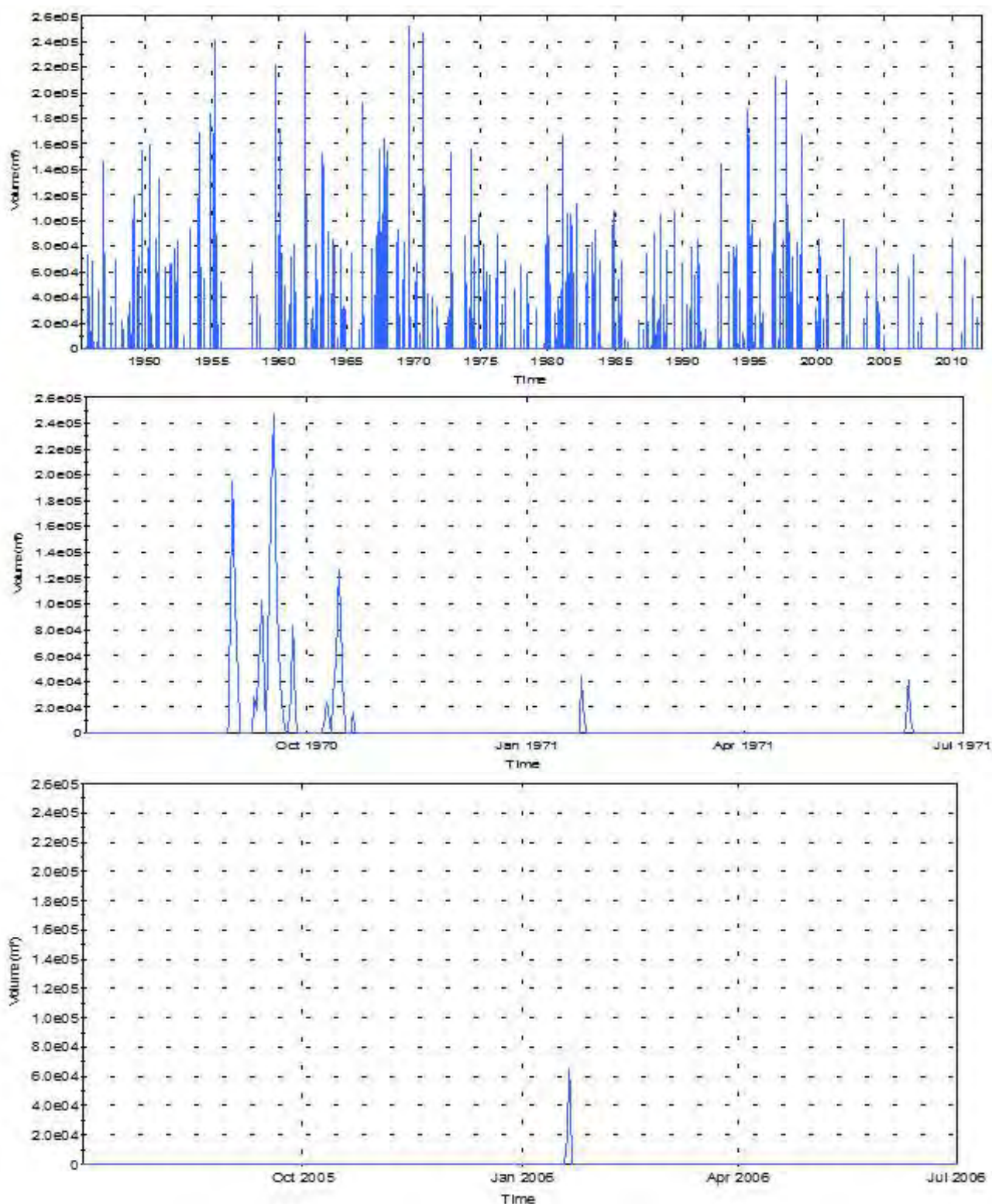


Figure 20: Operational year 3 MIW sump overflow volumes which represents periods when the sump overflows for the period 1 May 1945 to 1 April 2012 (upper plot), the 95th percentile rainfall (wet) year of 1970-1971 (middle plot) and the 5th percentile rainfall (dry) year of 2005-2006 (lower plot).



Table 24: MIW surge sump volumes and WTP capacities.

Scenario	MIW sump size (m ³)	MIW-WTP capacity (L/s)	Spill frequency number of days of sill per year			Comments
			Average for the full record	5 th percentile dry year i.e., 2005-2006	95 th percentile wet year i.e., 1970-1971	
Year 1	200,000	175	5.5	0	19	
Year 1.5	200,000	175	14.7	0	30	
Year 2	200,000	350	2.8	0	16	
Year 3	200,000	350	17.2	2	33	18 days represent 5 % of a year
Year 4 ⁽¹⁾	100,000	350	17.3	5	32	
Year 5	100,000	350	14.5	2	28	
Post mine ⁽²⁾	10,000	75	1.1	0	5	

Notes: (1) In Year 4 BCL are proposing to relocate the MIW Surge Sump, hence it is possible to construct a smaller surge sump.

(2) Post mining the size of the MIW surge sump can be greatly reduced as the MIW_WTP will essentially only be treating seepage from the ELF.

As highlighted in Table 24 basing the sizing of the MIW surge sump and the MIW-WTP capacities on the criteria that infrastructure did not spill for more than 5 % of the total model run time (i.e., 67 years) which equates to an average of 18 days per annum means that for 50 % of individual years (i.e., the years of above average rainfall) the MIW surge sump will spill for more than 18 days. During the 95th percentile wet year of 1970-1971 the surge sump will spill for 33 days or 9 % of the time. During the wettest year the MIW surge sump will spill for 41 days or 11 % of the time. To provide guidance on the infrastructure sizes required to reduce the occurrence of spills larger MIW surge sump volumes and MWI-WTP capacities were assessed.

For operational Year 3 if the MIW surge sump volume is held at 200,000 m³ a MIW-WTP capacity of 550 L/s is required to limit spills to 5 % of the time in the worst (wettest) year and a MIW-WTP capacity of between 1,500 L/s and 2,000 L/s is required to ensure there is no spills. Alternatively if the MIW-WTP capacity is held at 350 L/s a MIW surge sump volume of between 2,000,000 m³ 2,500,000 m³ is required to ensure there is no spills.

In regard to the SW-WTP associated with the CPP a treatment capacity of 140 L/s (12,096 m³/day) is required to ensure that the SW-WTP does not spill more than 5 % of the total model run time (i.e., 67 years) which equates to spill no more than an average of 18 days per annum. To prevent all spills from the SW-WTP either a SW-WTP capacity of approximately 1,500 L/s is required or an approximately 110,000 m³ surge sump needs to be added to the SW-WTP.



EMP - MINE WATER MANAGEMENT MODEL

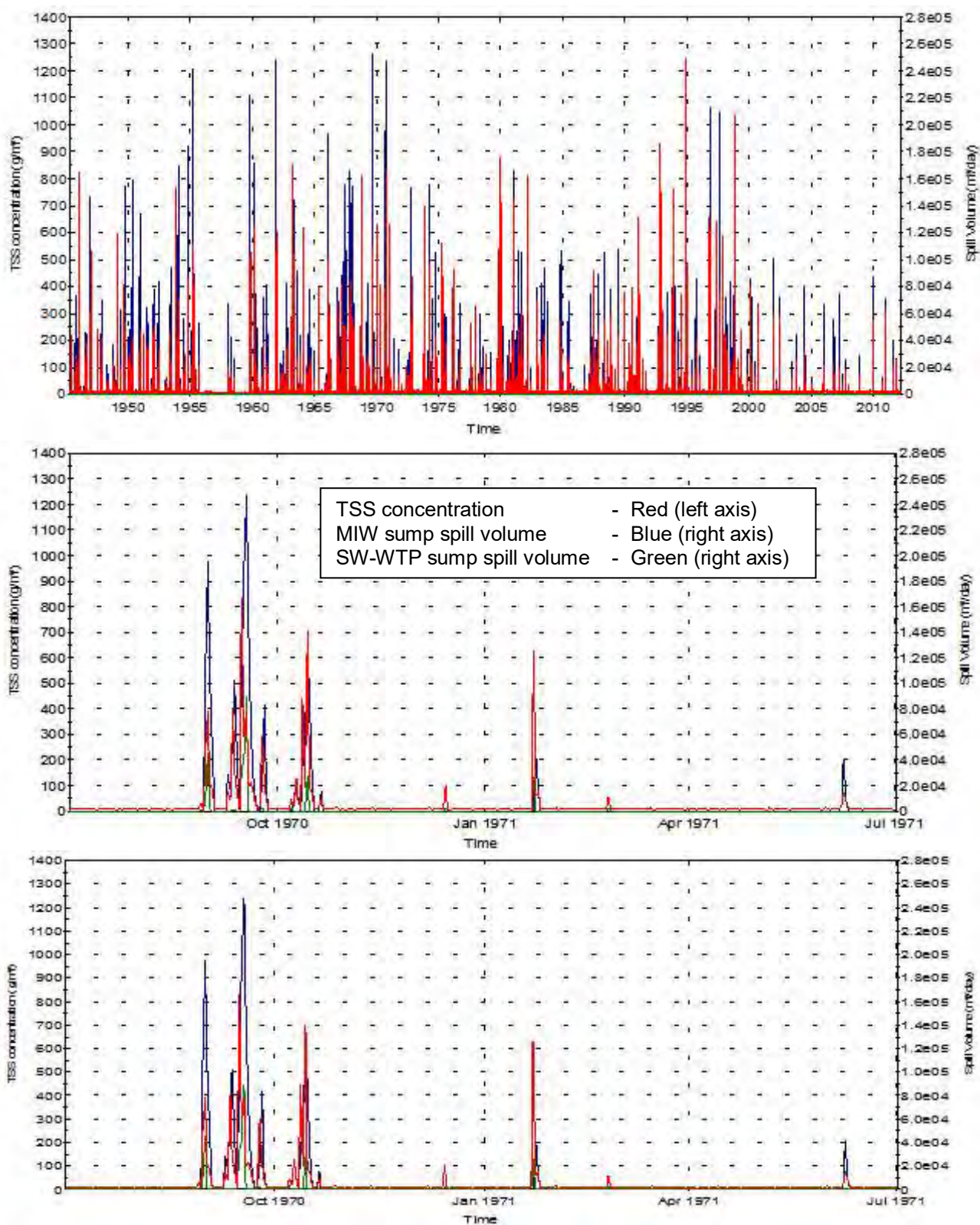


Figure 21: Operational Year 3 TSS concentrations at M-W2, MIW sump overflow volumes and SW-WTP sump overflow volumes for the period 1 May 1945 to 1 April 2012 (upper plot), the 95th percentile rainfall (wet) year of 1970-1971 (middle plot) and the 5th percentile rainfall (dry) year of 2005-2006 (lower plot).

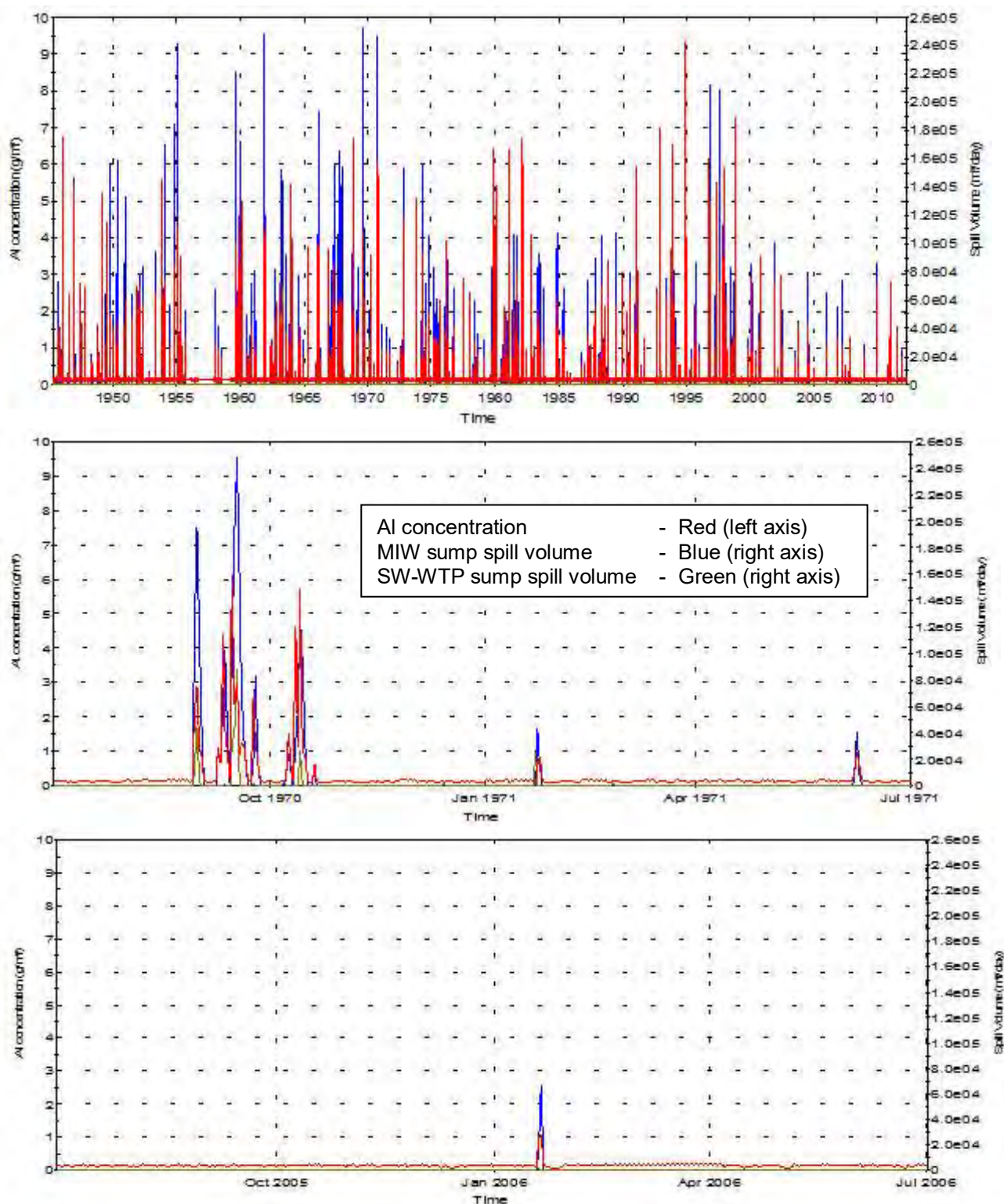


Figure 22: Operational Year 3 aluminium concentrations at M-W2, MIW sump overflow volumes and SW-WTP sump overflow volumes for the period 1 May 1945 to 1 April 2012 (upper plot), the 95th percentile rainfall (wet) year of 1970-1971 (middle plot) and the 5th percentile rainfall (dry) year of 2005-2006 (lower plot).



9.3 Simulated Flows at Receiving Waters

The EMP GoldSim model allows flows to be estimated at numerous nodes within the model and the model has considerable flexibility in regard to the display or outputting of flows information. A sample of the estimated flows, generated by the model are presented below which focuses on flow in Whareatea River at W-M2 and Trent Stream immediately above its confluence with the Whareatea River.

Flow in the small sub-catchments that lie within the EMP namely the upper catchment of Trent Stream, V40 Stream and S Stream is expected to be reduced during active mining as runoff is directed to the MIW sump and MIW-WTP. The MIW-WTP will discharge to the upper Whareatea River which will increase flows in that waterway. While the mine will divert water from various upper sub-catchments, mining is not expected to significantly alter flows in the lower Whareatea River.

Simulated flows in the Whareatea River at W-M2 during the 5th percentile rainfall (dry) year of 1 July 2005 to 30 June 2006 for the pre-mine, operational Year 3 and post-mine scenarios are presented in Figure 23. Mining will increase the storage within the catchment and is expected to attenuate flood flows and increase baseflows. The post-mine scenario includes a 10,000 m³ MIW sump and a 75 L/s MIW-WTP (Table 24) and base-flow in the Whareatea River at W-M2 is expected to be slightly higher post-mine than pre-mine. If passive treatment is considered post-mining then it is likely to take the form of settlement ponds and wetlands, which will also be expected to result in slightly higher base-flow post-mine than pre-mine.

Flow in Trent Stream immediately above its confluence with the Whareatea River during the 5th percentile rainfall (dry) year of 1 July 2005 to 30 June 2006 for the pre-mine, operational years 1, 1.5, 2, 3 and 4 and post-mine scenarios are presented in Figure 25. The upper Trent Stream catchment will be the first to be mined and rehabilitated. Flow in Trent Stream immediately above its confluence with the Whareatea River will decrease during active mining in the sub-catchment but following rehabilitation (i.e. by Year 4) these flows are expected to return to close to the pre-mine situation.

9.4 Simulated Water Quality at Receiving Waters

The EMP GoldSim model estimated water quality at numerous nodes within the model and the model has considerable flexibility in regard to the display or outputting of water quality information. Given the large number of model scenarios and reporting nodes, not all model water quality outcomes are reported. Selected results are provided and discussed to describe how the model was used to achieve the required water quality objectives, including:

- Evaluation of the effect of the pre-mine infrastructure development on water quality of downstream water bodies.
- Evaluation of the effect of mine operations and closure conditions on the water quality of downstream surface water bodies assuming mitigation measures including the MIW-WTP and sedimentation ponds are in operation.

As shown in Figure 21 and Figure 22 high contaminant concentrations in the Whareatea River at W-M2 correspond with periods when the MIW surge sump and/or the SW-WTP associated with the CPP spill. These modelled results meet the 95 % percentile compliance limits and no more than the 5 % spill allowance stipulated in the 26 August 2011 consent decision.



EMP - MINE WATER MANAGEMENT MODEL

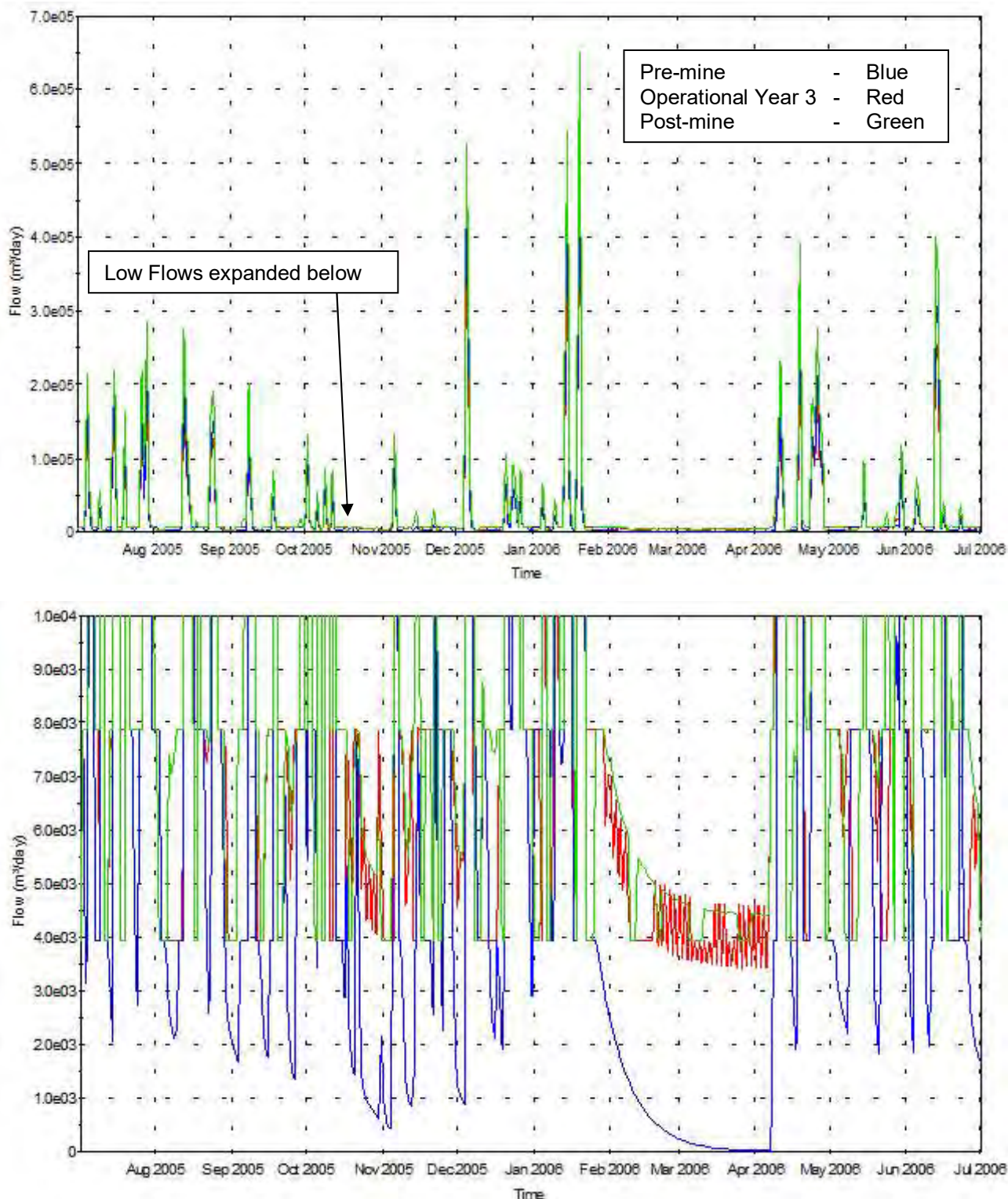


Figure 23: Simulated flow in the Whareatea River at M-W2 for the Pre-mine, operational Year 3 and post mine (active management) scenarios for the 5th percentile rainfall (dry) year of 2005-2006.



9.4.1 Total suspended solids (TSS)

TSS is a critical issue for all mining and earthmoving activities. The limited available pre-mine TSS data from Envirolink's water quality sampling programme (Envirolink, 2012) indicate that the Whareatea River and its tributaries are very clear with low concentrations of TSS¹⁰. TSS concentrations are usually strongly related to flow with higher flows (i.e., floods) tending to have higher TSS.

The Whareatea River has a relatively small and steep catchment and floods are usually of a short duration (hours rather than days), making water sampling of high flow events difficult. It is expected that the current pre-mine TSS data from the water quality sampling programme will be biased towards low flows. Envirolink have measured turbidity at W-M2 since conductivity and pH continuously¹¹ since March 2011. The maximum turbidity reading over that period was approximately 33 NTU which is relatively low and confirms that the upper Whareatea River and its tributaries are very clear. The turbidity data suggest that turbidity is slightly flow related but it is not a strong relationship. As highlighted in Table 5 the water quality compliance limits established in the 26 August 2011 consent decision are for a median turbidity of 15 NTU and a 95th percentile turbidity of 30 NTU. Given that pre-mine turbidity levels have exceeded the suggested 95th percentile compliance limit a very high level of treatment will be required.

Simulated TSS concentrations in the Whareatea River at W-M2 under both the pre-mine and operational Year 3 scenarios are shown in Figure 24 for the 5th percentile dry year of 1 July 2005 to 30 June 2006. Figure 24 indicates mining will increase downstream TSS concentrations and that simulated high TSS concentrations should coincide with both high flow events and spillage from the MWI sump and or the SW-WTP sump.

Treatment for TSS is undertaken in both the MIW-WTP and the SW-WTP. The basis for design of both the MIW-WTP and the SW-WTP has been assessed by Ellmuck (2012) who has indicated that the MIW-WTP will achieve a discharge TSS concentration of no more than 10 g/m³ TSS while the SW-WTP will have a TSS treatment efficiency of 98% removal (Ellmuck 2012). Based on these TSS treatment criteria, the mine water model indicates that simulated TSS concentrations in the Whareatea River at W-M2 will meet the TSS compliance limits of a median¹² TSS concentration of 15 g/m³ and a 95th percentile⁷ TSS concentration of 30 g/m³ as established in the 26 August 2011 consent decision.

Given the limited water quality data used to calibrate the EMP GoldSim model and particularly the lack of water quality data from catchments affected by mining Golder recommends that the model predictions be validated as new TSS data become available, particularly water quality data from catchments affected by mining operations.

9.4.2 Infrastructure development period

Water quality at the compliance point W-M2 was assessed based on the assumed model inputs, which include features such as haul roads, a surge sump, the MIW-WTP and amenities pad, a ROM pad and a small ELF comprised of the overburden from the surge sump area. The model projected values are shown in Table 25.

At W-M2, TSS compliance limits are likely to be exceeded if not mitigated, because of sediment entrained in runoff from the new haul roads and construction areas. Sediment control "best practice" will need to be employed, as well as potentially some form of sediment removal system prior to discharge of mine water to the receiving water. The pH is expected to be low, ranging from approximately 4.5 to 5, and the pre-treatment hardness is expected to range from 5 g/m³ to 50 g/m³ of CaCO₃.

¹⁰ The 50 discrete samples that have been collected from the Whareatea River at W-M1, W-M2 and W-M3 show an average TSS of 4.7 g/m³.

¹¹ Continuous monitoring refers to readings at approximately 15 minute intervals.

¹² The median and 95th percentile limits have been calculated for the full model period 1 May 1945 to 1 April 2012.

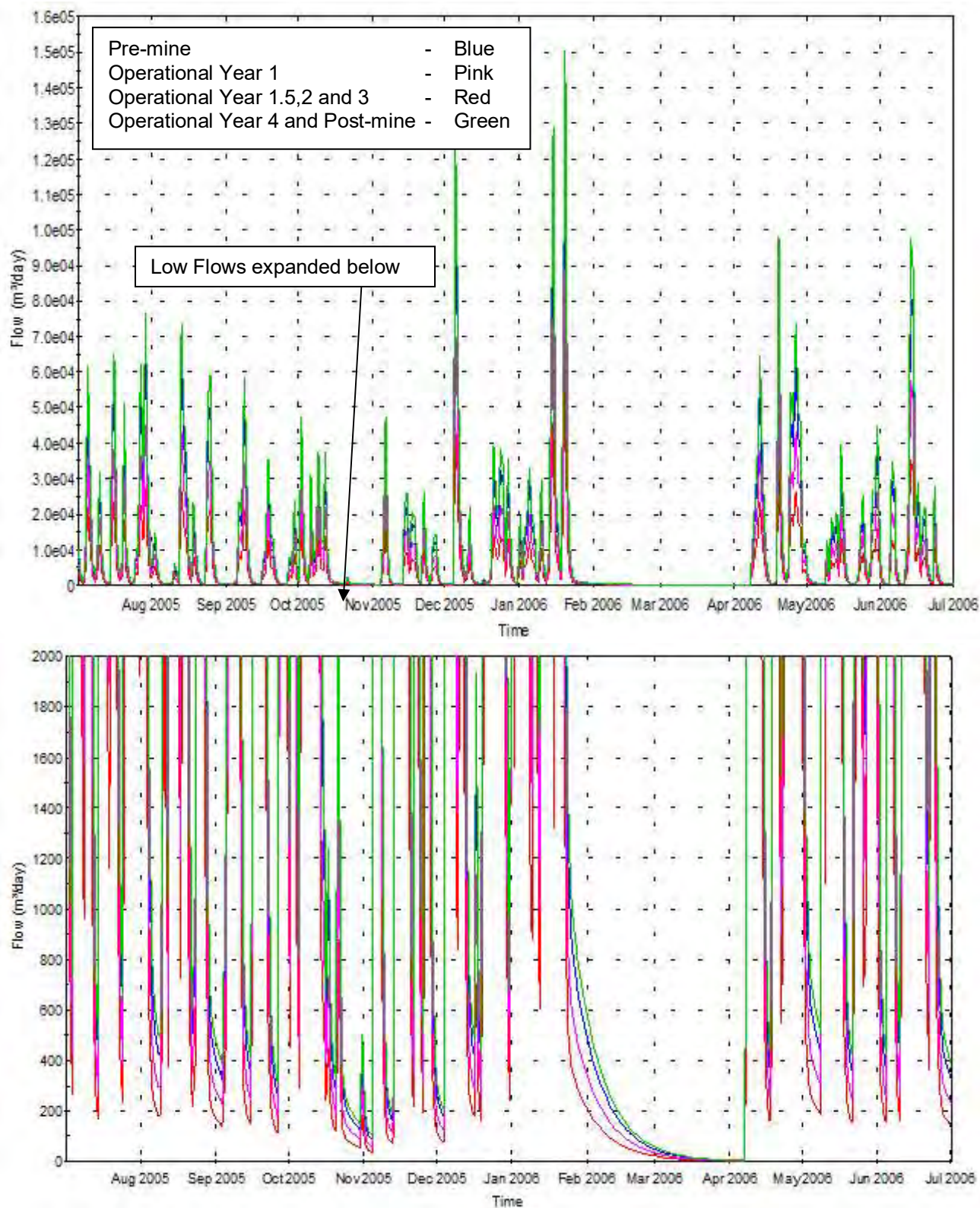


Figure 24: Simulated flow in Trent Stream immediately above its confluence with the Whareatea River during the 5th percentile rainfall (dry) year of 1 July 2005 to 30 June 2006 for the pre-mine, operational years 1, 1.5, 2, 3 and 4 and post-mine (active management) scenarios.

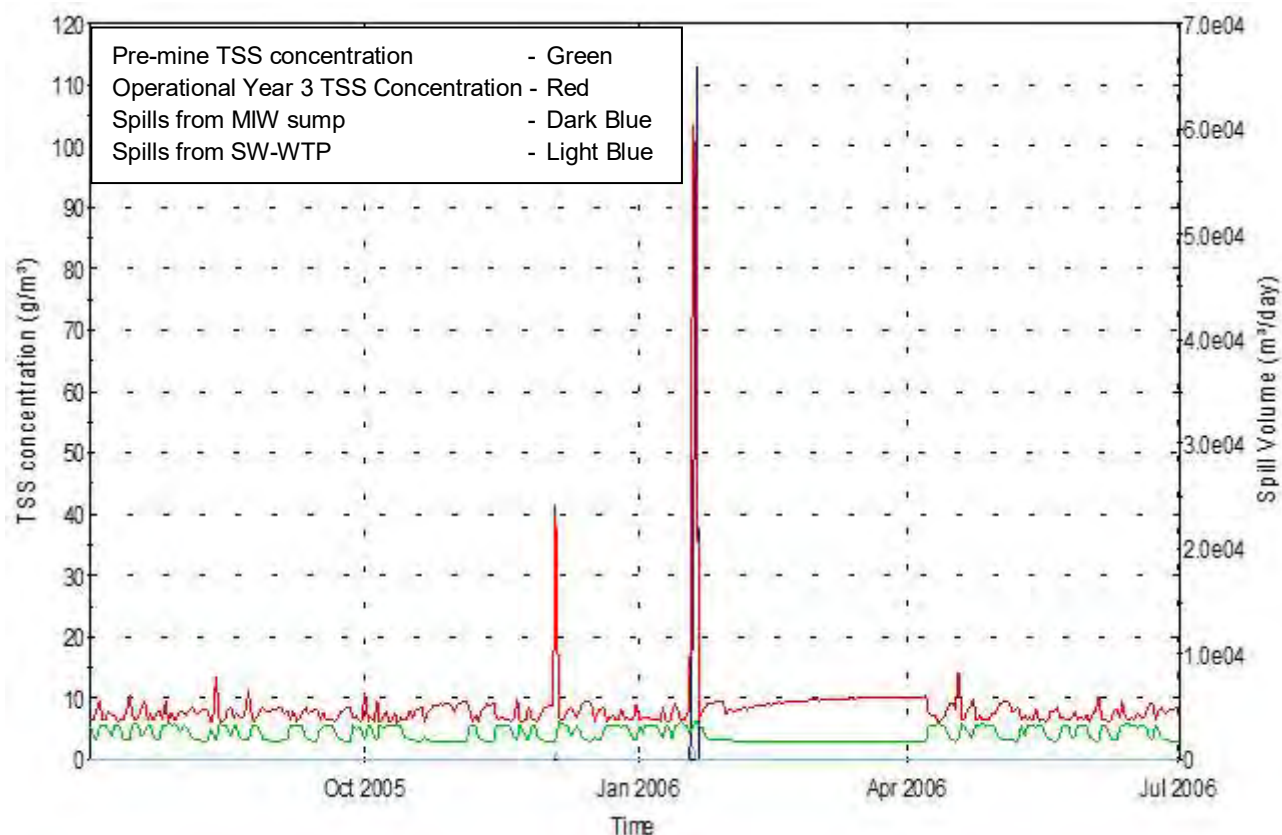


Figure 25: Simulated TSS concentrations in the Whareatea River at M-W2 and sump spills during the 5th percentile rainfall (dry) year of 1 July 2005 to 30 June 2006 for the pre-mine and operational Year 3 scenarios.

Due to the presence of uncovered waste rock, approximately 4 L/s of seepage with elevated dissolved metal concentrations is expected to drain from the ELF to the surge sump. The modelled water quality at W-M2 indicates that metals may be present at concentrations exceeding compliance limits during the infrastructure development period.

Mitigation for metals, if required, could be achieved by installation of a small scale temporary pH correction and flocculent dosing system, located between a seepage collection point at the toe of the ELF and the MIW surge sump. The low expected seepage flows increases the practicality of this solution.

BCL have indicated that construction is likely to take 6 months to 1 year and that the MIW sump is scheduled to be one of the first items constructed. Once constructed, the MIW sump will provide some buffer storage which can be used to capture sediment laden runoff during construction of the remainder of the mine infrastructure. Simulations suggest that the 200,000 m³ MIW sump that is proposed for operational Year 1 will take approximately 2 months to fill, although this is weather dependent. During filling of the MIW sump, BCL will be able to test the quality of the water within the sump and, if required, develop a sediment removal system prior to the MIW sump discharging (i.e., sump full and spilling) to the receiving waters.



Table 25: Modelled water quality at W-M2 during Year 0 infrastructure development.

Parameter ^(1,2)	Scenario	Model output		Current consent limits at W-M2 ⁽⁴⁾	Proposed consent limits at W-M2 ⁽⁵⁾	Proposed consent limits at W-M2 ⁽⁵⁾
		Median	95 %ile	95 th %ile	Median	95 %ile
TSS	Optimistic	37	550	30	15	30
	Typical	37	550	30	15	30
	Extreme	37	550	30	15	30
pH (unitless)	Optimistic	4.6	4.8	4.5 – 7.2	4.5-6.5	4.5-6.5
	Typical	4.5	4.8	4.5 – 7.2	4.5-6.5	4.5-6.5
	Extreme	4.4	4.8	4.5 – 7.2	4.5-6.5	4.5-6.5
Hardness ⁽³⁾	Optimistic	6.2	11			
Hardness ⁽³⁾	Typical	6.4	15			
Hardness ⁽³⁾	Extreme	6.7	21			
Aluminium	Optimistic	0.20	0.41	2	0.5	2.0
Aluminium	Typical	0.33	2.51	2	0.5	2.0
Aluminium	Extreme	0.56	5.93	2	0.5	2.0
Iron	Optimistic	0.24	0.26	2	1.0	2.0
Iron	Typical	0.40	2.6	2	1.0	2.0
Iron	Extreme	0.62	6.0	2	1.0	2.0
Cadmium ⁽²⁾	Optimistic	0.003	0.004		0.0012	0.004
Cadmium ⁽²⁾	Typical	0.003	0.004		0.0012	0.004
Cadmium ⁽²⁾	Extreme	0.003	0.004		0.0012	0.004
Copper ⁽²⁾	Optimistic	0.013	0.07		0.0013	0.004
Copper ⁽²⁾	Typical	0.015	0.07		0.0013	0.004
Copper ⁽²⁾	Extreme	0.018	0.07		0.0013	0.004
Lead ⁽²⁾	Optimistic	0.043	0.05		0.026	0.14
Lead ⁽²⁾	Typical	0.044	0.05		0.026	0.14
Lead ⁽²⁾	Extreme	0.045	0.05		0.026	0.14
Nickel ⁽²⁾	Optimistic	0.02	0.15	0.15	0.068	1.0
Nickel ⁽²⁾	Typical	0.04	0.29	0.15	0.068	1.0
Nickel ⁽²⁾	Extreme	0.04	0.21	0.15	0.068	1.0
Zinc ⁽²⁾	Optimistic	0.17	0.90	0.2	0.054	0.29
Zinc ⁽²⁾	Typical	0.17	0.75	0.2	0.054	0.29
Zinc ⁽²⁾	Extreme	0.17	0.61	0.2	0.054	0.29

Note: 1) All results in g/m³ unless otherwise stated. 2) Parameters are hardness dependant and have been normalised to a hardness of 50 g/m³ as CaCO₃. 3) Hardness reported in g/m³ as CaCO₃. 4) From the WCRC consent (2011), 5) Hickey (2012) – values for pH <5.5 reported. 6) Shaded and bolded values exceed the proposed consent limits. The light shaded values are close to the proposed consent limits.



9.4.3 Mining operations

Model scenarios for Year 1 through 5 of the mining operations have been simulated. For each scenario, the catchment areas for the haul road, pit and highwalls, uncovered ELF, covered ELF, CPP and amenities areas, freshwater and recycle dams, and rehabilitated areas were calculated as they changed year by year.

The model results at reporting node W-M2 for each scenario are summarised Table 26 and Table 27. Additionally, for Year 3 the results at each of the modelled nodes on the Whareatea River are reported in Table 28 and Table 29.

These results show the relative effectiveness of the MIW-WTP and the influence of dilution and water quality contributions from the natural catchments and underground workings.

As examples, Figure 26 and Figure 27 show simulated aluminium and cadmium concentrations at the five reporting nodes for a wet year and a dry year. The concentrations tend to decrease with dilution but in some cases there are slight increases in the concentrations with distance from the mine. For example, at Year 3, the natural watershed may have more influence on the stream water quality than the effluent from the MIW-WTP.

9.4.4 Site closure

Once the mine is closed and rehabilitated, the primary source of mine-influenced water will be seepage from the ELF. Surface water that seeps into the non-acid forming (NAF) protective layer, which immediately overlies a NAF low permeability layer (LPL), is not expected to leach high concentrations of dissolved metals and is to be directed along with surface runoff to the original stream catchments.

The LPL should impede infiltration of rainwater to the body of the ELF, thereby limiting seepage into the potentially acid forming (PAF) rock within the body of the ELF. Seepage flows from the ELF under the post-closure conditions are estimated to be 26 to 67 L/s (Golder 2012c). Initially the water is to be directed to the surge sump and then treated in the MIW-WTP, which will mitigate water quality issues in downstream receiving water environments (see Table 26 and Table 27).

A model scenario was developed for a simulated a passive treatment system that removes 80 % of aluminium and iron and 20 % for other metals/metalloids.

Passive treatment is likely to change pH but no treatment efficiency was specified for pH in this model run. The results (Table 30) show that this level of treatment is not likely to achieve compliance using the roughly estimated efficiencies.

Additional work is required to assess treatment efficiencies using passive treatment technologies.



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Table 26: Modelled concentrations at W-M2 (non hardness dependent).

Mine year	Scenario ⁽³⁾	pH (unitless) ⁽¹⁾			TSS ⁽¹⁾		Aluminium ⁽¹⁾		Arsenic ⁽¹⁾		Manganese ⁽¹⁾		Iron ⁽¹⁾		Cobalt ^(1,8)	
		5 th %ile	median	95 th %ile	median	95 th %ile	median	95 th %ile	median	95 th %ile	median	95 th %ile	median	95 th %ile	median	95 th %ile
Current consent limits at W-M2 ⁽⁵⁾		4.5-7.2	4.5-7.2	4.5-7.2	15	30	0.50	2.00	NA	NA		1.2	1.0	2.0	NA	NA
Proposed consent limits at W-M2 ⁽⁶⁾		4.5-6.5	4.5-6.5	4.5-6.5	15	30	0.50	1.00	NA	NA	0.1	0.2	1.0	2.0	0.18	0.63
Yr 1	Optimistic	4.7	4.9	5.3	6.9	12	0.12	0.17	0.007	0.01	0.1	0.2	0.16	0.23	0.001	0.002
Yr 1	Typical	4.7	4.9	5.3	6.9	12	0.14	0.18	0.009	0.01	0.1	0.2	0.18	0.23	0.001	0.002
Yr 1	Extreme	4.7	4.9	5.3	6.9	12	0.21	0.36	0.012	0.02	0.1	0.2	0.24	0.32	0.001	0.002
Yr 2	Optimistic	4.8	4.9	5.4	6.9	11	0.14	0.17	0.007	0.01	0.1	0.2	0.17	0.23	0.001	0.002
Yr 2	Typical	4.8	4.9	5.4	6.9	11	0.15	0.17	0.008	0.01	0.1	0.2	0.18	0.23	0.001	0.002
Yr 2	Extreme	4.8	4.9	5.4	6.9	11	0.21	0.36	0.011	0.02	0.1	0.2	0.24	0.32	0.001	0.002
Yr 3	Optimistic	4.8	4.9	5.5	7.8	21	0.15	0.18	0.008	0.01	0.1	0.2	0.16	0.21	0.001	0.002
Yr 3	Typical	4.8	4.9	5.5	7.8	21	0.15	0.19	0.008	0.01	0.1	0.2	0.17	0.22	0.001	0.002
Yr 3	Extreme	4.8	4.9	5.5	7.8	21	0.18	0.41	0.010	0.02	0.1	0.2	0.22	0.34	0.001	0.003
Yr 4	Optimistic	4.6	4.8	5.3	7.2	15	0.15	0.21	0.008	0.01	0.1	0.2	0.18	0.21	0.002	0.003
Yr 4	Typical	4.6	4.8	5.3	7.2	15	0.15	0.22	0.008	0.01	0.1	0.2	0.18	0.21	0.002	0.003
Yr 4	Extreme	4.6	4.8	5.3	7.2	15	0.19	0.40	0.010	0.02	0.1	0.2	0.21	0.34	0.002	0.003
Yr 5 ⁽⁴⁾	Extreme	4.5	4.7	5.1	6.8	14	0.16	0.37	0.008	0.02	0.1	0.2	0.18	0.32	0.003	0.004
Post – closure ^(2,4)	Extreme	4.4	4.5	4.9	5.1	9	0.18	0.36	0.009	0.02	0.1	0.2	0.20	0.31	0.004	0.005

Notes: 1) All results in g/m³ unless otherwise stated. 2) Post closure water quality where WTP is assumed to still be active (flow rate of 75 L/s). 3) Each mine year has three modelled scenarios (optimistic, typical, and extreme). 4) Year 5 and Post-sump use only extreme input values. 5) Current consent limits from the WCRC consent (2011). 6) Proposed consent limits from Hickey (2012). 7) Bold values exceed the proposed consent limits. 8) The reported proposed consent limits for cobalt are based on pH <5.5.



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Table 27: Model concentrations at W-M2 (hardness dependent).

Mine year	Scenario ⁽⁵⁾	Hardness ⁽²⁾		pH (unitless) ⁽¹⁾			Cadmium ^(1,3)		Copper ^(1,3)		Chromium ^(1,3)		Lead ^(1,3)		Nickel ^(1,3)		Zinc ^(1,3)	
		median	95 th %ile	5 th %ile	median	95 th %ile	median	95 th %ile	median	95 th %ile	median	95 th %ile	median	95 th %ile	median	95 th %ile		
Current consent limits at W-M2 ⁽⁷⁾		NA	NA	4.5-7.2	4.5-7.2	4.5-7.2	NA	NA	NA	NA	NA	NA	NA	NA	0.05	0.15	0.10	0.20
Proposed consent limits at W-M2 ⁽⁸⁾		NA	NA	4.5-6.5	4.5-6.5	4.5-6.5	0.0012	0.004	0.0013	0.004	0.20	4.0	0.026	0.14	0.068	1.0	0.054	0.29
Yr 1	Optimistic	43	90	4.7	4.9	5.3	0.0004	0.0019	0.001	0.004	0.001	0.002	0.002	0.020	0.004	0.01	0.02	0.04
Yr 1	Typical	29	57	4.7	4.9	5.3	0.0006	0.0023	0.001	0.004	0.005	0.008	0.005	0.027	0.01	0.02	0.03	0.05
Yr 1	Extreme	49	135	4.7	4.9	5.3	0.0004	0.0020	0.001	0.004	0.013	0.016	0.003	0.023	0.01	0.01	0.02	0.05
Yr 2	Optimistic	42	82	4.8	4.9	5.4	0.0004	0.0011	0.001	0.002	0.003	0.008	0.003	0.009	0.004	0.01	0.02	0.03
Yr 2	Typical	33	69	4.8	4.9	5.4	0.0005	0.0014	0.001	0.003	0.007	0.014	0.004	0.014	0.01	0.01	0.02	0.04
Yr 2	Extreme	49	140	4.8	4.9	5.4	0.0004	0.0015	0.001	0.003	0.019	0.025	0.003	0.015	0.01	0.01	0.02	0.04
Yr 3	Optimistic	62	110	4.8	4.9	5.5	0.0003	0.0010	0.001	0.003	0.003	0.015	0.002	0.009	0.003	0.01	0.02	0.03
Yr 3	Typical	50	86	4.8	4.9	5.5	0.0003	0.0013	0.001	0.003	0.007	0.016	0.002	0.013	0.01	0.01	0.02	0.04
Yr 3	Extreme	57	142	4.8	4.9	5.5	0.0003	0.0013	0.001	0.004	0.016	0.025	0.002	0.015	0.01	0.01	0.01	0.04
Yr 4	Optimistic	50	94	4.6	4.8	5.3	0.0004	0.0013	0.001	0.003	0.006	0.017	0.002	0.010	0.01	0.02	0.02	0.06
Yr 4	Typical	44	94	4.6	4.8	5.3	0.0004	0.0015	0.001	0.004	0.011	0.018	0.003	0.013	0.01	0.03	0.02	0.08
Yr 4	Extreme	53	148	4.6	4.8	5.3	0.0003	0.0015	0.001	0.004	0.019	0.025	0.002	0.014	0.01	0.03	0.02	0.08
Yr 5 ⁽⁶⁾	Extreme	50	139	4.5	4.7	5.1	0.0004	0.0012	0.001	0.003	0.013	0.025	0.002	0.008	0.01	0.03	0.03	0.07
Post –closure ^(4,6)	Extreme	31	140	4.4	4.5	4.9	0.0007	0.0025	0.002	0.007	0.017	0.025	0.004	0.019	0.02	0.07	0.05	0.16

Notes: 1) All results in g/m³ unless otherwise stated. 2) Hardness reported in g/m³ as CaCO₃. 3) Hardness dependant parameters and have been normalised to a hardness of 50 g/m³ as CaCO₃. 4) Post closure water quality where WTP is assumed to still be active (flow rate of 75 L/s). 5) Each mine year has three modelled scenarios (optimistic, typical, and extreme). 6) Year 5 and Post-closure use only extreme input values. 7) Current consent limits from the WCRC consent (2011). 8) Proposed consent limits from Hickey (2012) based on pH <5.5. 9) Bolded values exceed the proposed consent limits.



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Table 28: Modelled concentrations Year 3, all reporting nodes (non hardness dependent parameters).

Mine year	Scenario ⁽²⁾	pH (unitless) ⁽¹⁾			TSS ⁽¹⁾		Aluminium ⁽¹⁾		Arsenic ^(1,6)		Manganese ⁽¹⁾		Iron ⁽¹⁾		Cobalt ^(1,7)	
		5 th %ile	median	95 th %ile	median	95 th %ile	median	95 th %ile	median	95 th %ile	median	95 th %ile	median	95 th %ile	median	95 th %ile
Current consent limits at W-M2 ⁽³⁾		4.5-7.2	4.5-7.2	4.5-7.2	15	30	0.50	2.00	NA	NA		1.2	1.0	2.0	NA	NA
Proposed consent limits at W-M2 ⁽⁴⁾		4.5-6.5	4.5-6.5	4.5-6.5	15	30	0.50	1.00	NA	NA	0.1	0.2	1.0	2.0	0.18	0.63
MIW-WTP Inflow	Optimistic	2.7	3.2	3.5	248	1,286	5.95	30.07	0.003	0.01	0.4	0.7	5.18	28.47	0.061	0.146
MIW-WTP Inflow	Typical	2.7	3.1	3.3	248	1,286	11.06	30.60	0.004	0.01	0.4	0.7	11.27	31.14	0.061	0.146
MIW-WTP Inflow	Extreme	2.5	2.9	3.1	248	1,286	25.20	67.72	0.009	0.02	0.4	0.7	25.19	67.72	0.072	0.203
MIW-WTP Outflow	Optimistic	6.5	6.5	6.5	10	10	0.04	0.18	0.003	0.01	0.2	0.3	0.03	0.14	0.001	0.001
MIW-WTP Outflow	Typical	6.5	6.5	6.5	10	10	0.07	0.18	0.004	0.01	0.2	0.3	0.06	0.16	0.001	0.001
MIW-WTP Outflow	Extreme	6.5	6.5	6.5	10	10	0.15	0.41	0.009	0.02	0.2	0.3	0.13	0.34	0.001	0.002
W-M1	Optimistic	4.9	5.1	5.8	9.4	42	0.11	0.19	0.006	0.01	0.1	0.2	0.12	0.20	0.001	0.003
W-M1	Typical	4.9	5.1	5.8	9.4	42	0.13	0.19	0.006	0.01	0.1	0.2	0.13	0.21	0.001	0.003
W-M1	Extreme	4.9	5.1	5.8	9.4	42	0.18	0.42	0.009	0.02	0.1	0.2	0.19	0.35	0.001	0.003
W-M2	Optimistic	4.8	4.9	5.5	7.8	21	0.15	0.18	0.008	0.01	0.1	0.2	0.16	0.21	0.001	0.002
W-M2	Typical	4.8	4.9	5.5	7.8	21	0.15	0.19	0.008	0.01	0.1	0.2	0.17	0.22	0.001	0.002
W-M2	Extreme	4.8	4.9	5.5	7.8	21	0.18	0.41	0.010	0.02	0.1	0.2	0.22	0.34	0.001	0.003
W-M3	Optimistic	NR	NR	6.5	8.3	11	0.19	0.20	0.010	0.01	0.02	0.1	0.21	0.22	0.001	0.001
W-M3	Typical	NR	NR	6.5	8.3	11	0.19	0.20	0.010	0.01	0.02	0.1	0.21	0.22	0.001	0.001
W-M3	Extreme	NR	NR	6.5	8.3	11	0.20	0.27	0.010	0.01	0.02	0.1	0.21	0.24	0.001	0.001

Notes: 1) All results in g/m³ unless otherwise stated. 2) Each mine year has three modelled scenarios (optimistic, typical, and extreme). 3) Current consent limits from the WCRC consent (2011). 4) Proposed consent limits from Hickey (2012). 5) Bold values exceed the proposed consent limits. 7) The reported proposed consent limits for cobalt are based on pH <5.5.



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Table 29: Modelled concentrations Year 3, all reporting nodes (hardness dependant parameters).

Mine year	Scenario ⁽⁴⁾	Hardness ⁽²⁾		pH (unitless) ⁽¹⁾			Cadmium ^(1,3)		Copper ^(1,3)		Chromium ^(1,3)		Lead ^(1,3)		Nickel ^(1,3)		Zinc ^(1,3)	
		median	95 th %ile	5 th %ile	median	95 th %ile	median	95 th %ile	median	95 th %ile	median	95 th %ile	median	95 th %ile	median	95 th %ile	median	95 th %ile
Current consent limits at W-M2 ⁽⁵⁾		NA	NA	4.5-7.2	4.5-7.2	4.5-7.2	NA	NA	NA	NA	NA	NA	NA	NA	0.05	0.15	0.10	0.20
Proposed consent limits at W-M2 ⁽⁶⁾		NA	NA	4.5-6.5	4.5-6.5	4.5-6.5	0.0012	0.004	0.0013	0.004	0.20	4.0	0.026	0.14	0.068	1.0	0.054	0.29
MIW-WTP Inflow	Optimistic	37	104	2.7	3.2	3.5	0.0015	0.0015	0.122	0.122	0.066	0.066	0.022	0.024	0.227	0.28	1.32	1.62
MIW-WTP Inflow	Typical	45	104	2.7	3.1	3.3	0.0014	0.0014	0.117	0.117	0.109	0.109	0.028	0.028	0.43	0.59	1.16	1.53
MIW-WTP Inflow	Extreme	69	169	2.5	2.9	3.1	0.0011	0.0011	0.111	0.111	0.193	0.193	0.029	0.030	0.25	0.35	0.86	1.03
MIW-WTP Outflow	Optimistic	115	157	6.5	6.5	6.5	0.0001	0.0001	0.0001	0.0003	0.002	0.016	0.0002	0.001	0.002	0.01	0.005	0.02
MIW-WTP Outflow	Typical	93	116	6.5	6.5	6.5	0.0001	0.0001	0.0001	0.0003	0.007	0.016	0.0005	0.001	0.00	0.01	0.01	0.02
MIW-WTP Outflow	Extreme	94	169	6.5	6.5	6.5	0.0001	0.0001	0.0002	0.0003	0.017	0.026	0.001	0.001	0.00	0.01	0.01	0.01
W-M1	Optimistic	86	133	4.9	5.1	5.8	0.0002	0.0004	0.0003	0.001	0.003	0.016	0.001	0.002	0.003	0.01	0.01	0.02
W-M1	Typical	72	98	4.9	5.1	5.8	0.0002	0.0005	0.0004	0.001	0.007	0.016	0.001	0.004	0.01	0.01	0.01	0.03
W-M1	Extreme	79	162	4.9	5.1	5.8	0.0001	0.0006	0.0004	0.002	0.018	0.026	0.001	0.005	0.01	0.01	0.01	0.03
W-M2	Optimistic	62	110	4.8	4.9	5.5	0.0003	0.0010	0.0006	0.003	0.003	0.015	0.002	0.009	0.00	0.01	0.02	0.03
W-M2	Typical	50	86	4.8	4.9	5.5	0.0003	0.0013	0.0007	0.003	0.007	0.016	0.002	0.013	0.01	0.01	0.02	0.04
W-M2	Extreme	57	142	4.8	4.9	5.5	0.0003	0.0013	0.0006	0.004	0.016	0.025	0.002	0.015	0.01	0.01	0.01	0.04
W-M3	Optimistic	12	33	NR	NR	6.5	0.0017	0.0028	0.003	0.005	0.005	0.010	0.018	0.034	0.005	0.01	0.02	0.03
W-M3	Typical	11	30	NR	NR	6.5	0.0019	0.0029	0.004	0.006	0.006	0.011	0.021	0.037	0.01	0.01	0.02	0.04
W-M3	Extreme	11	47	NR	NR	6.5	0.0019	0.0029	0.004	0.006	0.009	0.020	0.021	0.038	0.005	0.008	0.02	0.04

Note: 1) All results in g/m³ unless otherwise stated. 2) Hardness reported in g/m³ as CaCO₃. 3) Hardness dependant parameters and have been normalised to a hardness of 50 g/m³ as CaCO₃. 4) Each mine year has three modelled scenarios (optimistic, typical, and extreme). 5) Current consent limits from the WCRC consent (2011). 6) Proposed consent limits from Hickey (2012) based on pH <5.5. 7) Bold values exceed the proposed consent limits.

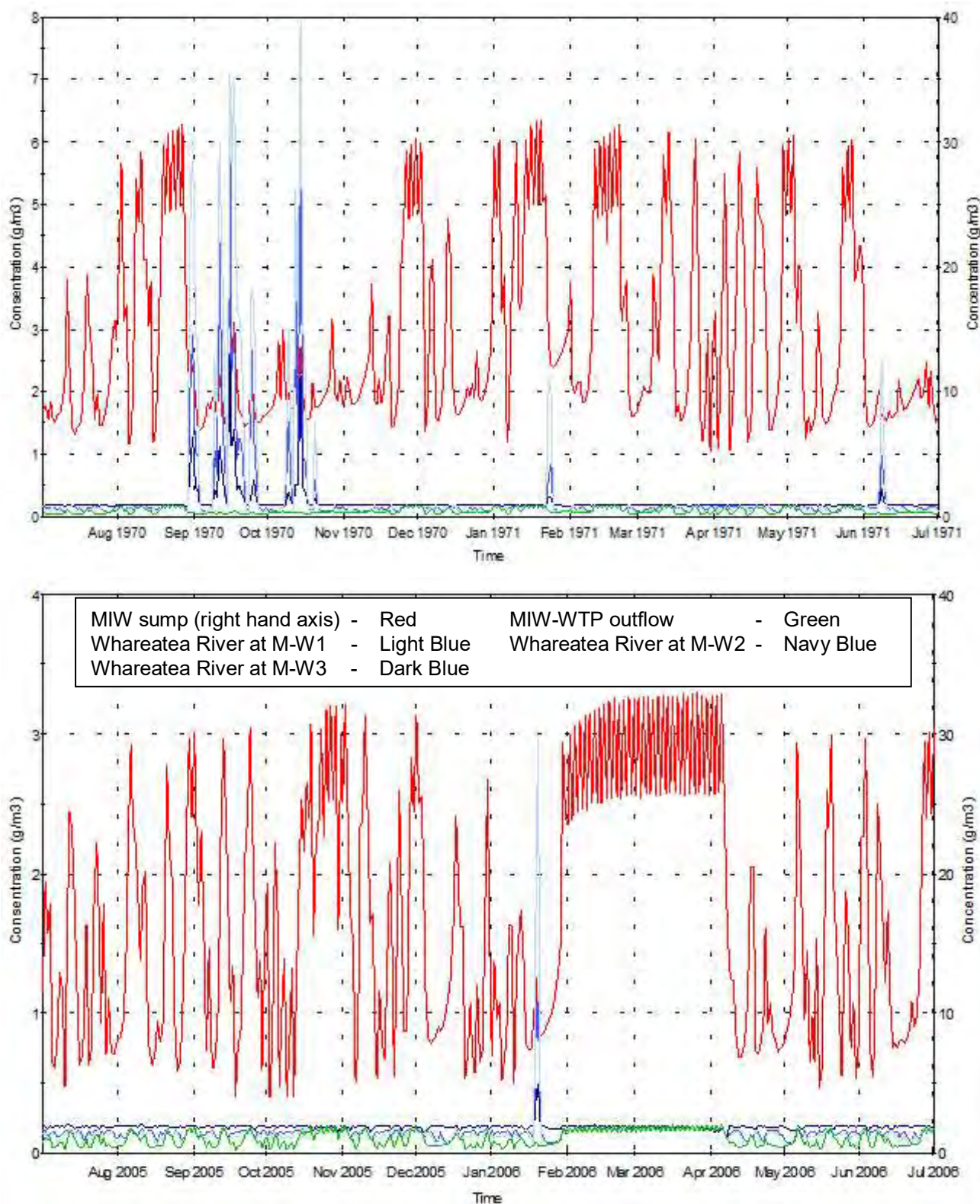


Figure 26: Operational Year 3 simulated Aluminium concentrations at various locations within and downstream of the EMP for the 95th percentile rainfall (wet) year of 1970-1971 (upper plot) and the 5th percentile rainfall (dry) year of 2005-2006 (lower plot).

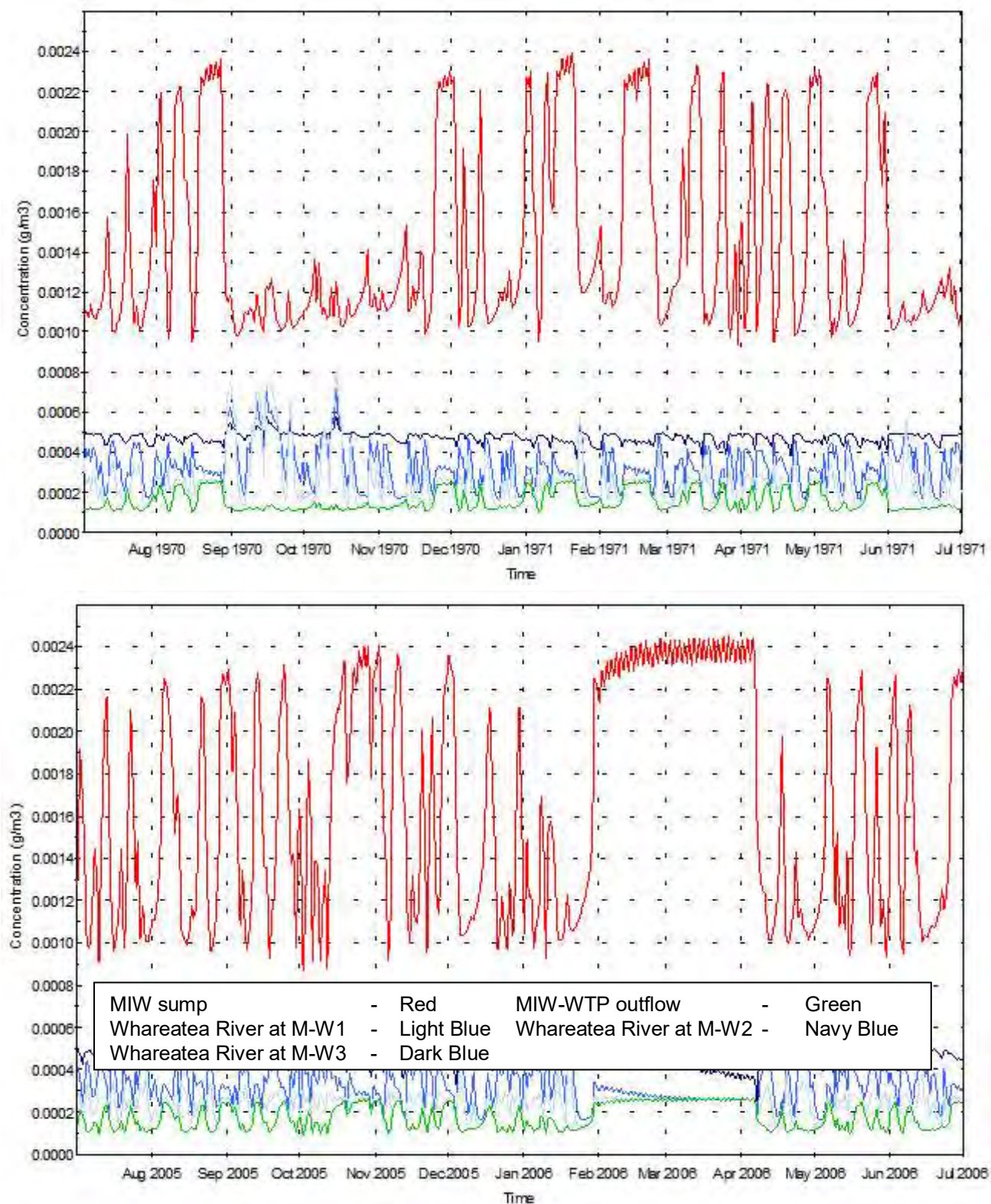


Figure 27: Operational Year 3 simulated cadmium concentrations at various locations within and downstream of the EMP for the 95th percentile rainfall (wet) year of 1970-1971 (upper plot) and the 5th percentile rainfall (dry) year of 2005-2006 (lower plot).



Table 30: Modelled water quality at W-M2 at site closure (rehabilitated ELF and passive treatment system).

Parameter ⁽¹⁾	Model output concentration		Current consent limits		Proposed consent limits	
	Median	95 th %ile	Median	95 th %ile	Median	95 %ile
TSS	42	412	15	30	15	30
pH (unitless)	3.3	4.1	4.5-7.2	4.5-7.2	4.5-6.5	4.5-6.5
Hardness ⁽²⁾	32	139				
Aluminium	2.7	12.9	0.5	2	0.5	2.0
Cobalt	0.022	0.097			0.18	0.63
Iron	2.7	12.9	1.0	2	1.0	2.0
Manganese	0.16	0.47		1.2	0.1	0.2
Cadmium ⁽³⁾	0.0012	0.0026			0.0012	0.004
Copper ⁽³⁾	0.074	0.107			0.0013	0.004
Lead ⁽³⁾	0.002	0.009			0.026	0.14
Nickel ⁽³⁾	0.14	0.19	0.05	0.15	0.068	1.0
Zinc ⁽³⁾	0.58	0.81	0.1	0.2	0.054	0.29

Note: 1) All results in g/m³ unless otherwise stated. Results are rounded. 2) Hardness reported in g/m³ as CaCO₃. 3) Parameters are hardness dependant and have been normalised to a hardness of 50 g/m³ as CaCO₃. 4) Current consent limits from the WCRC consent (2011), 5) Proposed consent limits from Hickey (2012) based on pH <5.5. Shaded and bolded values exceed the proposed consent limits.

10.0 CONCLUSIONS

The EMP GoldSim mine water management model was developed with the best available information to simulate flow and water quality conditions associated with the EMP. The limited amount of flow and water quality data (particularly the lack of data from catchments affected by mining) available for calibration, is the biggest limitation to the model. Golder recommends that the model be validated as new water quality and quantity data become available, particularly water quality and quantity data from catchments affected by mining operations.

The EMP GoldSim model was used to assess the conceptual EMP mine plan proposed by BCL at the consent stage of mine planning.

The EMP GoldSim model was used to identify a reasonable approach to water management which minimises potential technical issues and mitigates environmental effects.

A conceptual site model was assembled of the EMP which integrated the available information on surface water and groundwater systems including flows and water quality. The information was derived from available pre-mine site data and from knowledge of other mines in the region.

A GoldSIM model was developed from the conceptual site model allowing numerical mass balance modelling of flows and water chemistry for the site. The pre-mine scenario was calibrated using available information. Proposed mine stage plan scenarios were developed based on the calibrated model.

The EMP GoldSim model can be used as an effective tool to facilitate decision making associated with design and future management of WTP operations and overall site water management. The model has



considerable inbuilt flexibility allowing it to be quickly run for a variety of possible mine infrastructure options. Interpretation of model predictions requires care and needs to fully consider the models limitations.

Using mine water infrastructure considered implementable by BCL (e.g., a pit sump with a volume of 15,000 m³, a pit pump with a capacity of 800 L/s, a MIW surge sump volume of approximately 200,000 m³, a MIW WTP with a capacity of 350 L/s and a SW WTP with a capacity of 140 L/s, etc) the anticipated effects on downstream water body flows and the related changes to water quality were assessed.

The overall mine water treatment system is based on the compliance limits and performance criteria that were established in the 26 August 2011 consent decision document, namely the 95 % compliance limits for downstream water quality and restricting the spilling of untreated MIW to less than 5 % of the time. Golder understands that the thinking behind the compliance limits and performance criteria established in the 26 August 2011 consent decision was that spill events from the MIW surge sump would cause reduced water quality in the receiving environments. Spill events from the MIW surge sump are expected to coincide with periods of high flow in the lower Whareatea River due to runoff from undisturbed catchments. The model confirmed this was indeed the case. There is a clear correlation between periods of high concentrations in the receiving environment, high flows in the receiving environment and spills from the MIW surge sump.

The model predicts that the EMP will divert water from the upper catchments of Trent, V40 and S streams and discharge it into the upper Whareatea River. Mining will also increase the storage within the catchment and is expected to attenuate flood flows and increase baseflows. Neither the predicted diversion of water nor the increase in storage is predicted to significantly alter flows in the lower Whareatea River. The upper Trent Stream catchment will be the first to be mined and rehabilitated. Flow in Trent Stream immediately above its confluence with the Whareatea River is predicted to decrease during active mining in the sub-catchment but following rehabilitation these flows are expected to return to close to the pre-mine situation.

The model predicts that the EMP will reduce water quality in the downstream receiving waters. However, water quality in the Whareatea River at W-M2 is predicted to comply with the compliance limits that were established in the 26 August 2011 consent decision during operations with only a minor exceedance of the pH limit during post closure (predicted 5th percentile pH of 4.4, limit 4.5-7.2). Concentrations of copper and manganese during both mine operation and post closure are predicted to be close to the proposed consent limits developed by Hickey (2012). The worst downstream water quality occurs when the MIW surge sump and/or the SW-WTP associated with the CPP spill untreated water. Such spill events are associated with either short duration extreme rainfall events or periods of continual rainfall and coincide with the 5 % of the time that the 95th percentile concentrations limits in the Whareatea River at W-M2 are exceeded.

During construction of the haul roads, surge sump and MIW-WTP a small ELF will be constructed from overburden excavated from the surge sump. Water management during this stage is likely to required treatment, conceptually in the form of temporary settling ponds and dosing facilities to manage TSS and metals which may leach from the ELF due to AMD conditions.

At closure, the modelled seepage rate from the ELF is projected to be less than 70 L/s. The operation of a small MIW sump and MIW-WTP (i.e., MIW sump volume of 10,000 m³ and MIW-WTP capacity of 75 L/s is more than sufficient) should enable ongoing compliance with water quality limits applicable to the downstream receiving environment, as may a passive treatment system. However, further assessment of appropriate model inputs and passive treatment system efficiencies is required to confirm the likely effectiveness of passive treatment as a long term water quality mitigation measure post closure of the EMP.

Based on a preliminary assessment of the predicted water quality at the downstream compliance point (the Whareatea River at W-M2) the performance of the modelled EMP water management infrastructure is considered likely to comply with proposed consent conditions. This conclusion has been further discussed in evidence prepared by Dr Chris Hickey (Hickey 2012) to be presented at the Environment Court Hearing.

While the EMP GoldSim model has inherent limitations, it can effectively be used to assist with other aspects of mine management planning which are described in the following section of this report.



11.0 RECOMMENDATIONS

11.1 Ongoing Use of EMP GoldSim Model

The EMP GoldSim model can be used as an effective tool to facilitate decision making associated with design and future management of WTP operations and overall site water management. The model has considerable inbuilt flexibility allowing it to be quickly run for a variety of possible mine infrastructure options. The GoldSim player version of the model supplied to BCL contains various dashboards which allow catchment areas, water treatment infrastructure sizes and efficiencies to be easily changed. The flexibility provided by the dashboards coupled with the relatively short run time for the model (in the order of a few minutes) will allow BCL to rapidly assess infrastructure options additional to the numerous options already documented in this report. To facilitate BCL's use of the model Golder recommends that appropriate BCL staff be trained on use of the player version of the EMP GoldSim model.

Once design criteria are established the model can be used to assess flows and water quality associated with various mine infrastructure options, allowing expected performance to be estimated and providing useful feedback to the design process. Section 11.2 provides some context for this process.

If new mitigation methods are conceived through the design process which result in a change to the process flow diagram (Figure 4) the model can be adapted, as required, although the time involved to adapt the model is dependent on the complexity of any new mitigation methods and associated infrastructure.

Once consents for the mine are granted and the mine/water management design process is complete Golder recommends that the EMP GoldSim model be checked and if necessary updated to ensure that model structure, inputs and assumptions match both the final design and the final consent conditions. Golder recommends that the model be run to reflect final design and consent conditions as this will provide BCL with projected outcomes on how the system is likely to perform. Such predictions particularly for performance during extreme events allow refinement of operational plans and development of contingencies, if required. This is described further in Section 11.3.

Although a degree of conservatism has been used throughout the modelling process there remains some uncertainty in model assumptions which could be reduced through access to a longer and more robust flow and water quality monitoring record. Additional data both in the pre-mine conditions and during mine operations could be collected and used to periodically check the values estimated by the EMP GoldSim model and if necessary update the model, hence improving its suitability as a design tool. Recommendations for reducing model uncertainty are provided in Section 11.4.

Finally, passive treatment is likely to be a key component of final closure and successful rehabilitation of the EMP. The EMP GoldSim model contains the flexibility necessary to assess the mitigation potential for various passive treatment options. Golder recommends that the model be used as part of the design process associated with development of passive treatment options. However, presently the treatment efficiencies for potential passive treatment systems are not well understood. Also, the current model contains a number of assumptions regarding treatment efficiencies for passive treatment systems which are not well constrained. Further assessment is required to update and refine the assumptions regarding passive treatment system efficiencies. Recommendations for reducing uncertainty regarding the passive treatment model assumptions are discussed in Section 11.5.

11.2 Design of EMP Water Management Infrastructure

The model outputs generated to date for the EMP were based on conceptual mine plans and preliminary mine and water management design assumptions. Should the conceptual plans or preliminary assumptions change during the design process the model should be updated accordingly. As highlighted above the model has potential to greatly assist the design process. However, actual design needs to consider many factors and use a variety of tools of which the model is only one. In using the model to assist with design it is imperative that the model is run correctly and that the designers recognise the inherent uncertainties and



limitations of the model, ensuring that designs include a level of conservatism which is consistent with BCLs preferred risk threshold.

There are some fundamental aspects of the design process which were not part of Golder's brief, but which in Golder's opinion warrant consideration prior to proceeding with final design of water management infrastructure at the EMP. These elements were highlighted in Golder's proposal for Engineering, Procurement and Construction Management (EPCM) Services dated 30 January 2012.

Upon completion of the design Golder recommends that the EMP GoldSim model be checked and if necessary updated to ensure that model structure, inputs and assumptions match the final design. Golder recommends that the model be run to reflect final design as this will provide BCL with information on how the system is likely to perform and facilitate both the development of operational plans and contingency planning.

11.3 Upon Receipt of Consent

Final consent for the EMP will be dependent on a set of conditions set out in an Environment Court decision document. The present EMP GoldSim model was developed in consideration of the current consent issued by the WCRC and BDC. As there may be new requirements in the final consent Golder recommends that the EMP GoldSim model be reviewed and if necessary updated to ensure that model structure, inputs and assumptions match the final consent conditions. Golder recommends that the model be run to reflect final consent conditions. As emphasised above, running the model with final design and consent condition constraints allows BCL to be informed regarding likely system performance especially during extreme events. This knowledge may facilitate discussions with the regulatory bodies regarding consent compliance and consent monitoring.

11.4 Reducing Model Uncertainty through Ongoing Monitoring

Model assumptions which could be strengthened through additional monitoring include the following:

- Flow monitoring: Envirolink is proceeding with monitoring flow in a number of watercourses in the EMP area on behalf of BCL. Bi-annual or annual assessment of this flow data would be a proactive method to continually increase the confidence level of the GoldSim model planning tool, whenever it is required.
- Climate monitoring: Envirolink is proceeding with monitoring climate at Lake Brazil on behalf of BCL. Currently the climate station does not monitor all the variables needed to calculate PET and the EMP GoldSim model uses Penman PET from NIWA virtual climate station network. Golder recommends that the climate station at Lake Brazil be upgraded to monitor all the climate conditions required to calculate Penman PET so that the PET data from NIWA virtual climate station network that was used in the EMP GoldSim model can be verified. Golder also recommends that rainfall continues to be monitored at both Lake Brazil on the Denniston Plateau and at M1-R2 on the Stockton Plateau so that the current rainfall correlation developed by Envirolink and used within the EMP GoldSim model can be re-examined as new data becomes available.
- Water quality monitoring: Envirolink monitors water quality at a number of locations in the EMP area on behalf of BCL. The majority of this monitoring is based on discrete sampling and data up to 23 February 2012 was used to calibrate the EMP GoldSim model. Golder recommends that the water quality monitoring be continued. On-going water quality monitoring (particularly continuous monitoring) at the current locations and additional monitoring at underground adits would add to the understanding of previously existing water quality conditions. Similarly, water quality data (particularly continuous monitoring data) from an existing operational opencast coal mine in a similar location could



be used to verify and potentially improve calibration of the EMP GoldSim model. Once mine operations commence, monitoring points should be established to evaluate the actual water quality from ELF runoff and seepage. This information can be used to verify and if necessary update the calibration of the EMP GoldSIM model and therefore improve model predictions. Assuming additional water quality monitoring commences with mine start up, Golder recommends that the model be checked and if necessary updated at both the end of construction (6 months) and after the first year of mining (Year 1) to verify the models water quality predictions and confirm treatment system requirements.

11.5 Passive Treatment Assessment

Presently Golder is not aware that assessment of passive treatment options for the EMP has been undertaken by CRL or any other qualified consultant. Golder recommends that a strategy for assessing passive treatment of ELF seepage is developed prior to or during mine operations. This would provide time to evaluate the efficacy of available materials through a phased series of bench top studies, field trials or even pilot scale systems. The results of these studies could be used to assess the practicality of passive treatment to mitigate effects associated with long-term seepage of low quality water from the ELF. Development of a successful passive treatment approach could substantially reduce post closure site management costs and positively impact bond requirements. The EMP GoldSim model contains the flexibility necessary to assess the potential of various passive treatment options and Golder recommends that the model be used as part of the design process associated with passive treatment options.

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APPENDIX A

Report Limitations



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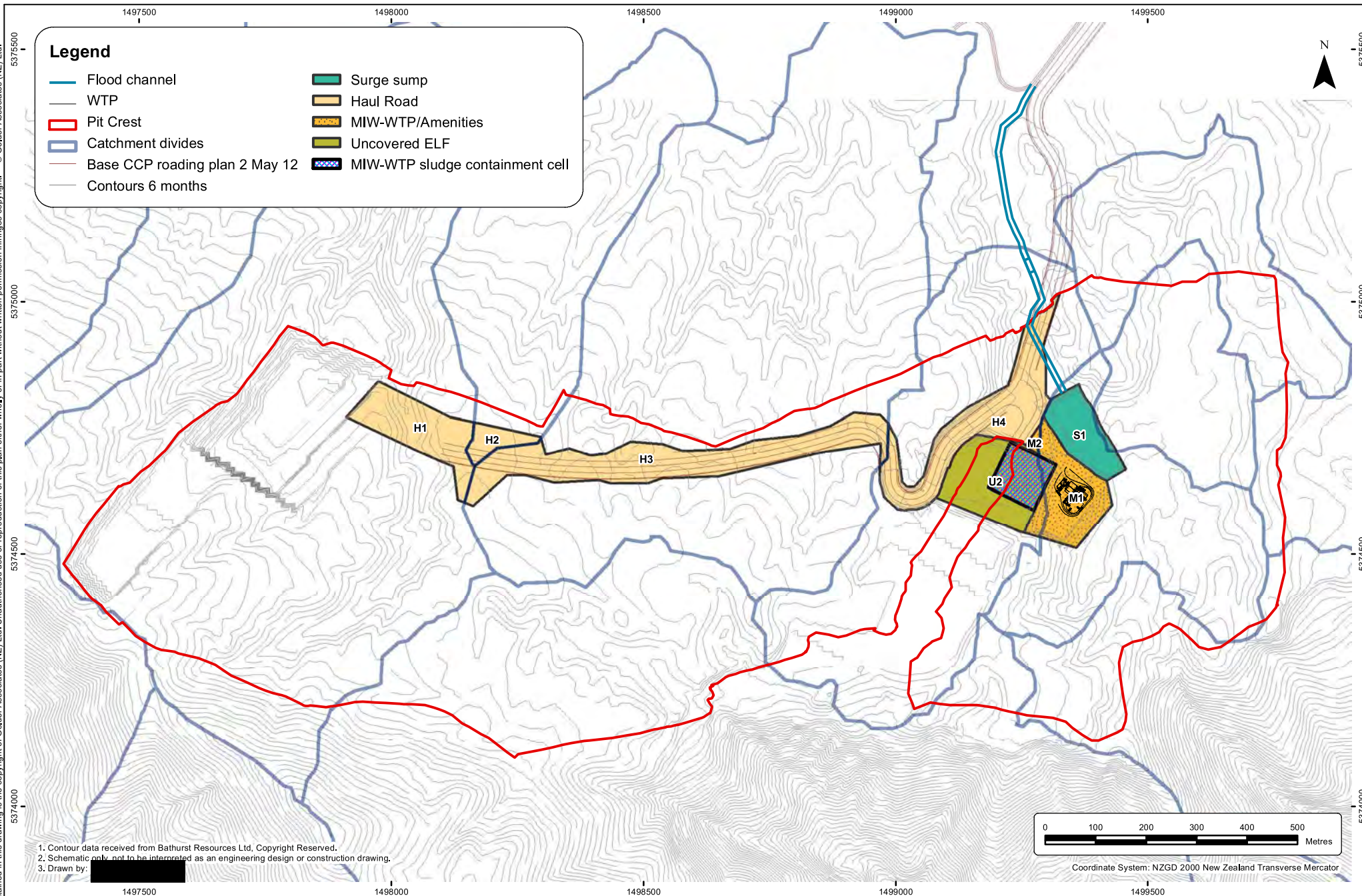
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APPENDIX B

Progressive Mine Plan Catchment Area

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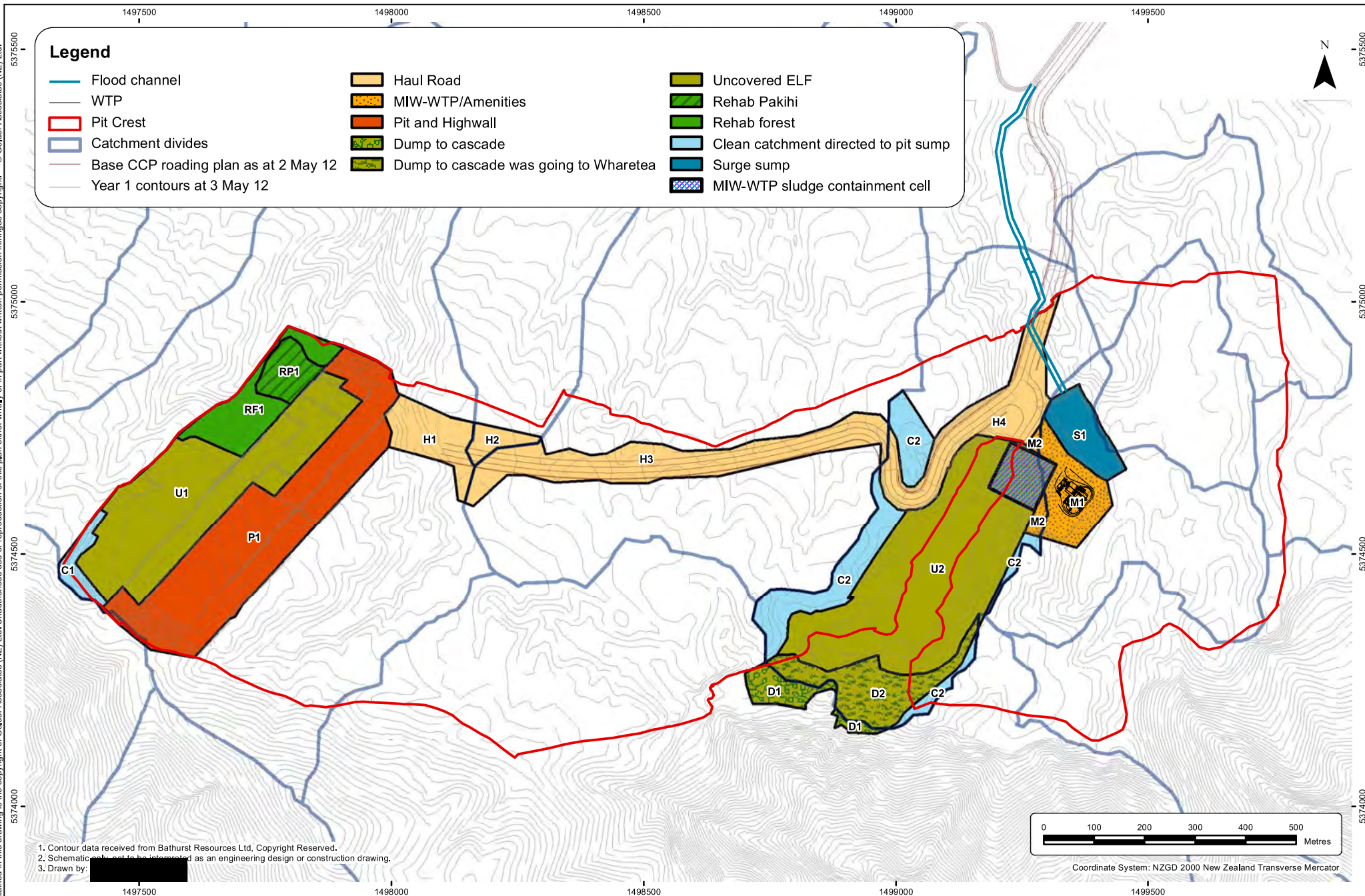
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AUGUST 2012

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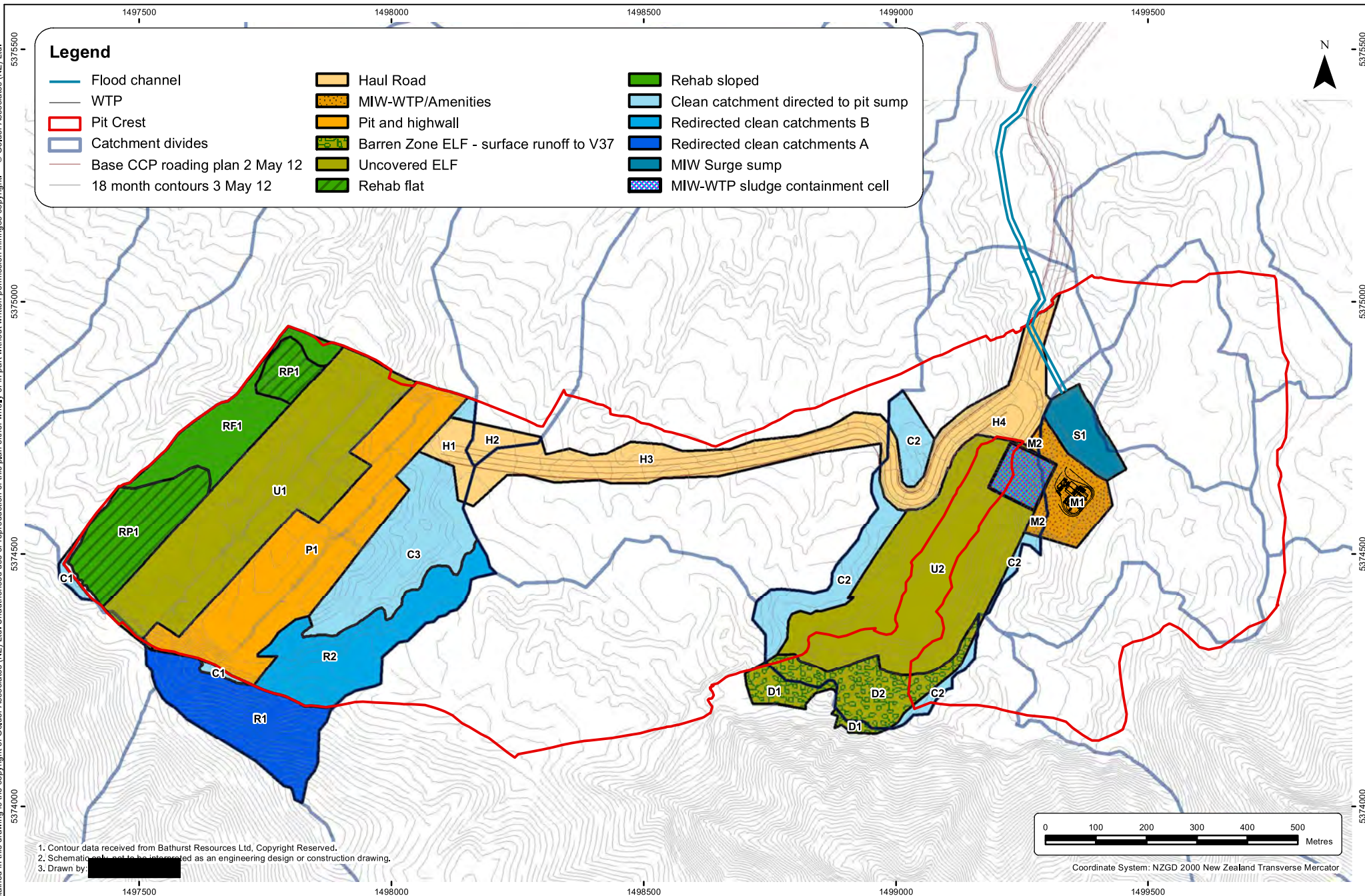
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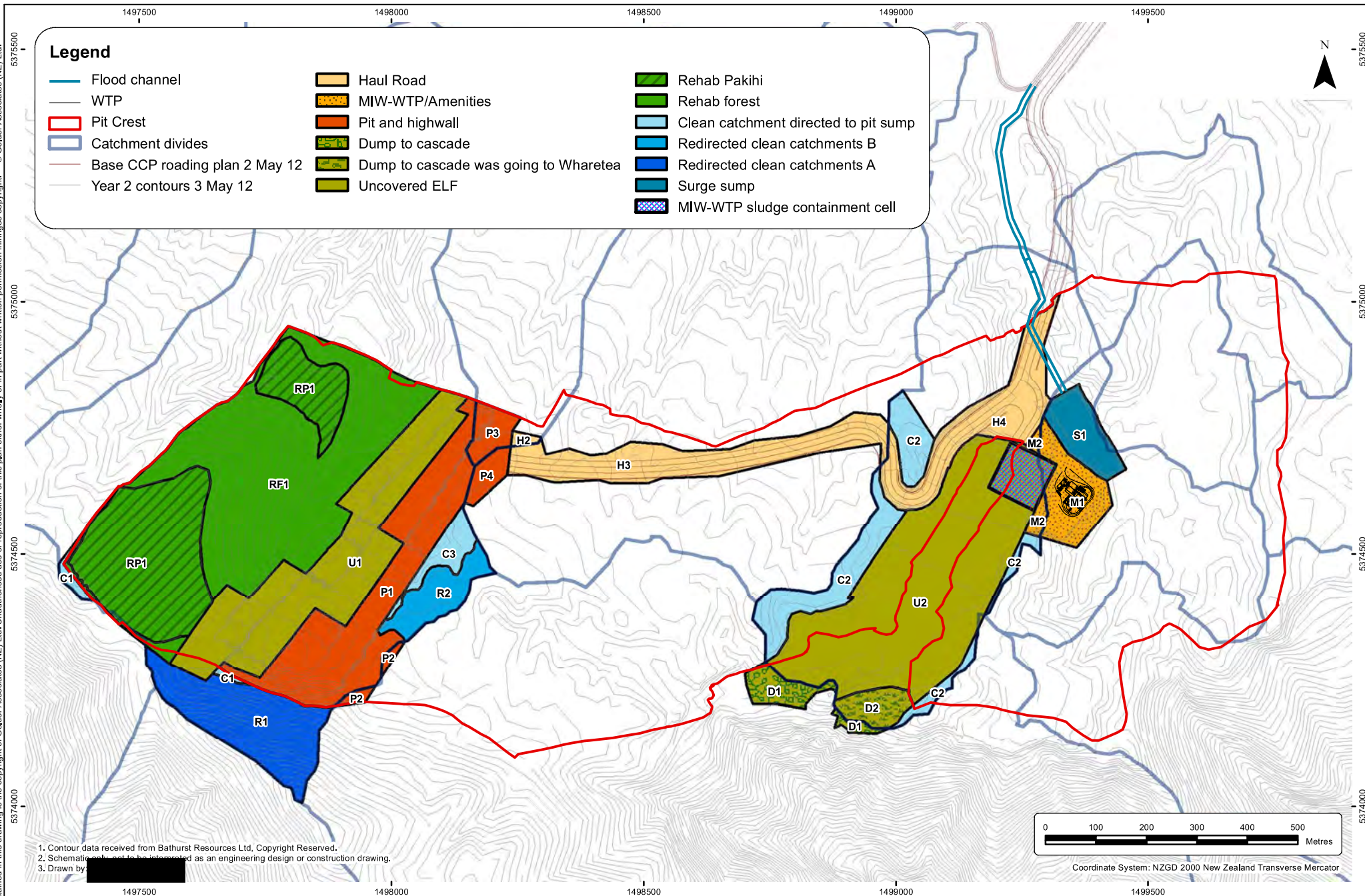
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AUGUST 2012

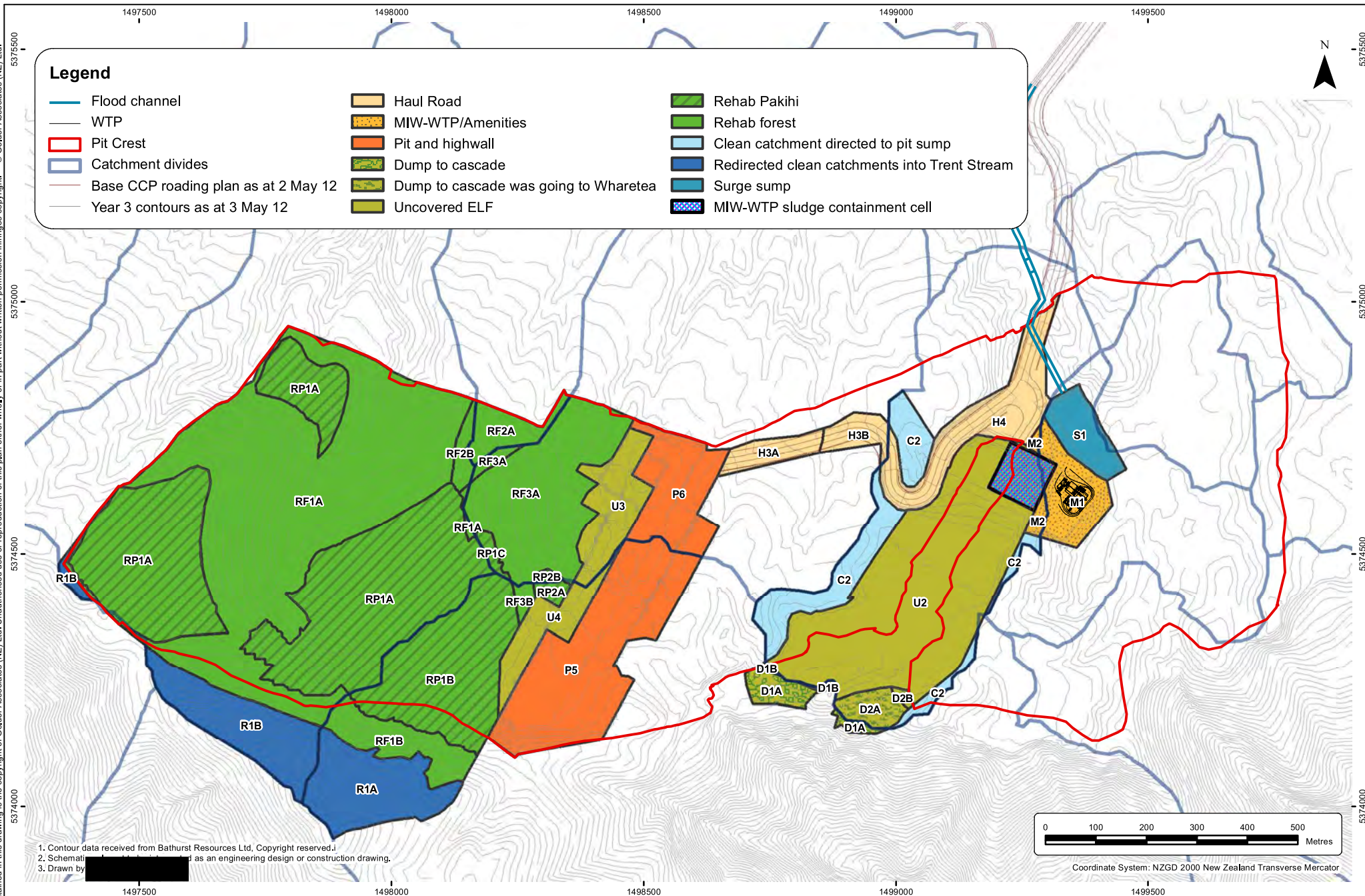
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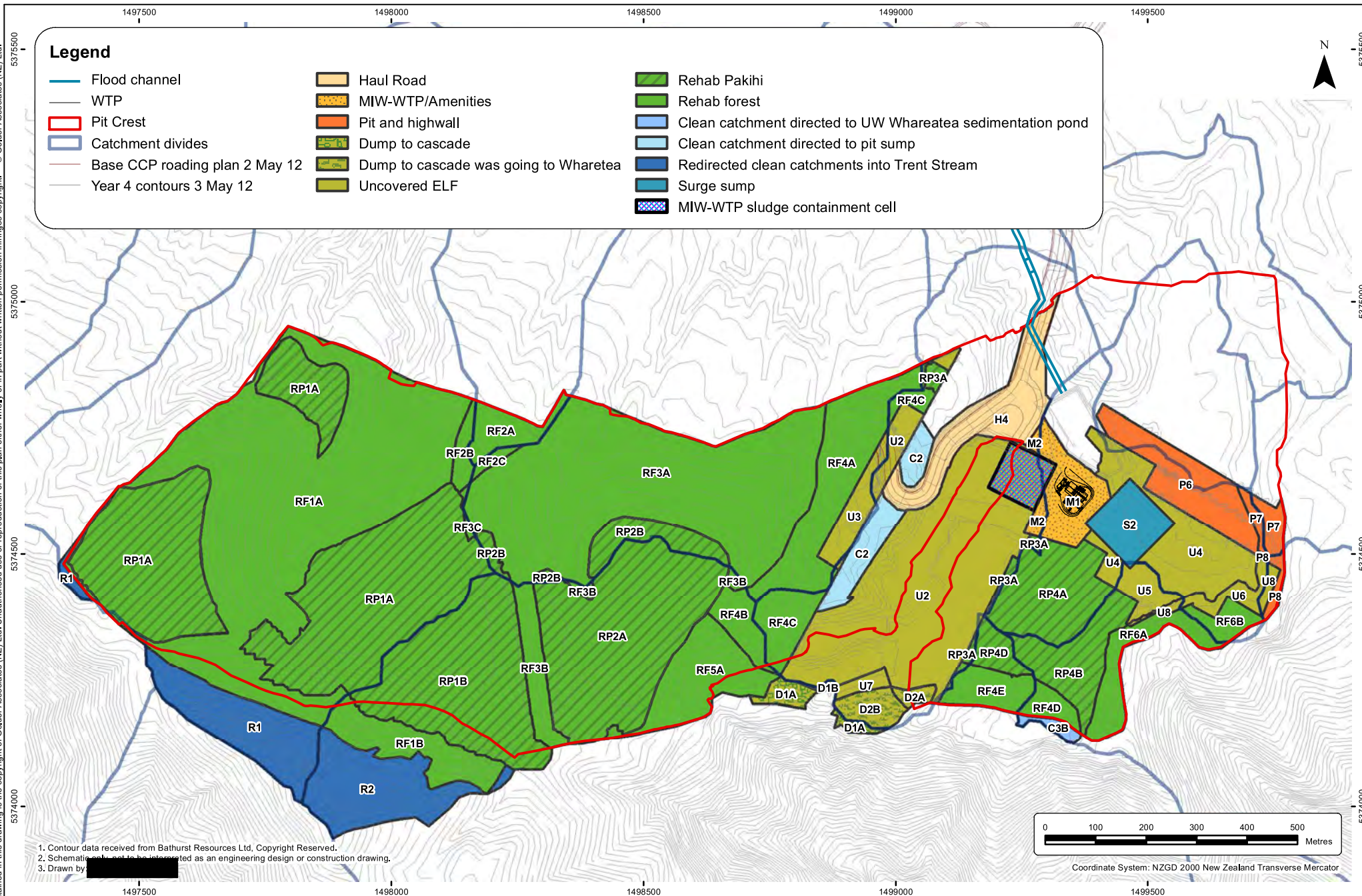
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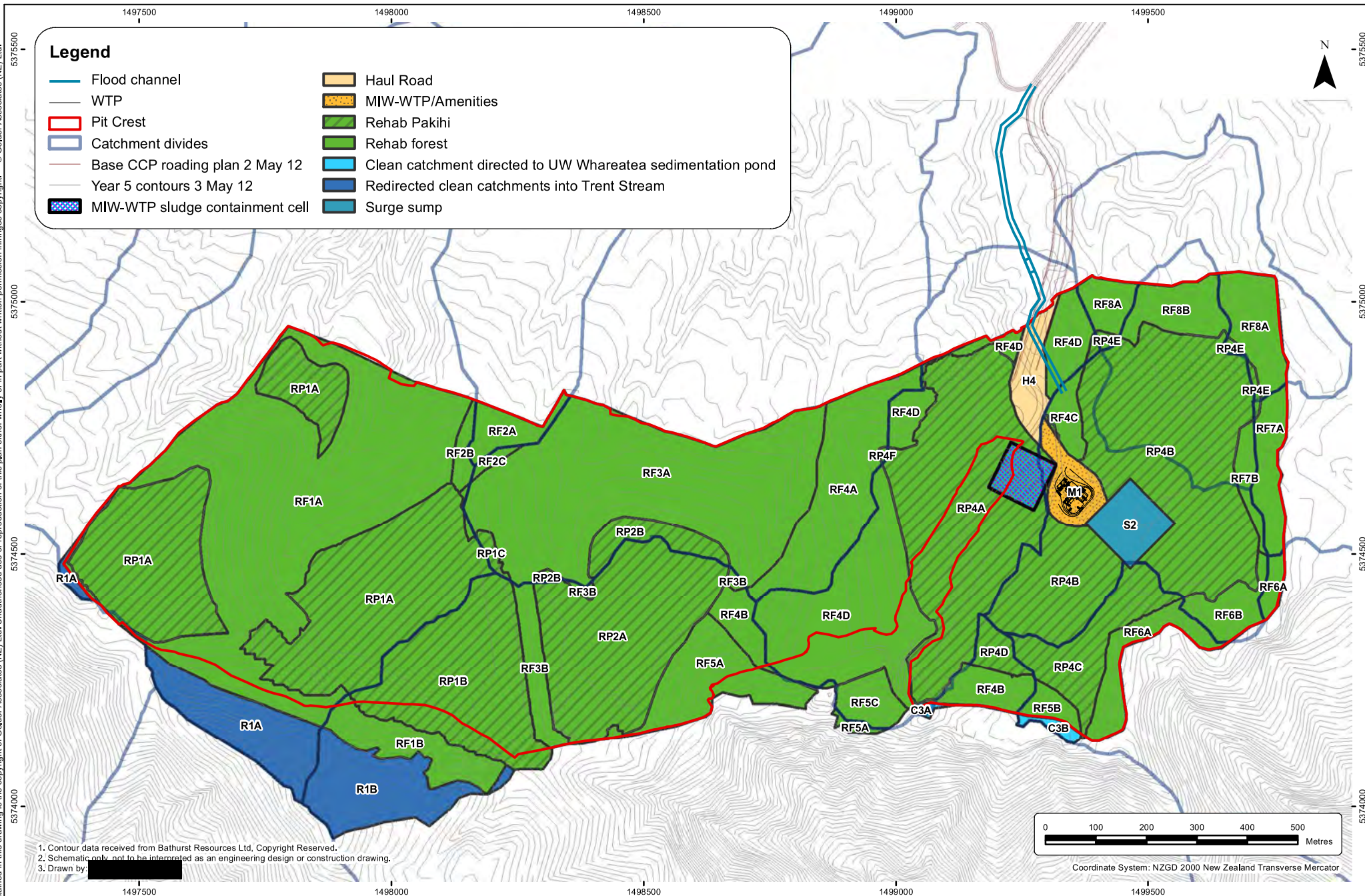


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APPENDIX C

Natural Catchment Run-off Water Quality Assessment



APPENDIX C

Natural Catchment Water Quality Model Input Assessment

IRON:

The initial input parameters for iron from natural catchments adequately enveloped measured concentrations in the Whareatea River at W-M1 but tended to overestimate concentrations at W-M2 when flows were above approximately 20 L/s and generally at W-M3 (Figure C-1). The input parameters for the catchments above both W-M2 and W-M3 were reduced slightly to provide a better fit with the monitored data (Figure C-1). The initial and final calibrated iron input parameters are summarised in Table C-1.

Table C-1: Calibration of natural catchment iron input parameters.

Flow yield ⁽¹⁾ (L/s/ha)	Iron Concentrations (g/m ³)			
	Initial input for all Natural catchments	Final input		
		Natural catchment above W-M1	Natural catchment above W-M2	Natural catchment above W-M3
0	0.15	0.15	0.15	0.05
0.01	0.15	0.15	0.15	0.05
0.05			0.25	
0.07	0.31	0.31		0.05
0.3	0.31	0.31	0.25	0.22
100	0	0.005	0.005	0.005
1E+13 ⁽²⁾	0	0.005	0.005	0.005

Notes: (1) The GoldSim model linearly interpolates between daily rainfall or flow yield values.
(2) An arbitrary large number which is never exceeded in the model. The long term rainfall record for the site indices a maximum daily precipitation of approximately 760 mm which if it all runs off equates to a maximum yield of approximately 88 L/s/ha.

MANGANESE:

The initial input parameters for manganese from natural catchments tended to overestimate concentrations in the Whareatea River at W-M1 and W-M2 when flows were above approximately 10 L/s and 50 L/s, and for all flows at W-M3 (Figure C-2). The input parameters for the catchments above W-M1, W-M2 and W-M3 were reduced slightly to provide a better fit with the monitored data (Figure C-2). The initial and final calibrated manganese input parameters are summarised in Table C-2.

Table C-2: Calibration of natural catchment manganese input parameters.

Flow yield ⁽¹⁾ (L/s/ha)	Manganese Concentrations (g/m ³)			
	Initial input for all Natural catchments	Final input		
		Natural catchment above W-M1	Natural catchment above W-M2	Natural catchment above W-M3
0	0.025	0.025	0.025	0.005
0.01	0.025	0.025	0.025	
0.1	0.025	0.025	0.025	
1		0.01	0.01	
100	0.001	0.001	0.001	
1E+13 ⁽²⁾	0.001	0.001	0.001	

Notes: (1) The GoldSim model linearly interpolates between daily rainfall or flow yield values.
(2) An arbitrary large number which is never exceeded in the model. The long term rainfall record for the site indices a maximum daily precipitation of approximately 760 mm which if it all runs off equates to a maximum yield of approximately 88 L/s/ha.



MAGNESIUM:

The initial input parameters for magnesium from natural catchments tended to overestimate concentrations in the Whareatea River at W-M1, particularly when flows are less than 1 L/s (Figure C-3). At W-M2 the initial input parameters tended to overestimate concentrations when flows were below approximately 5 L/s, but slightly underestimated concentrations at high flows (Figure C-3). At W-M3, the initial input parameters tended to overestimate concentrations when flows were below approximately 100 L/s but underestimated concentrations at high flows (Figure C-3). The input parameters for the catchments above W-M1, W-M2 and W-M3 were adjusted slightly to provide a better fit with the monitored data (Figure C-3). The initial and final calibrated magnesium input parameters are summarised in Table C-3.

Table C-3: Calibration of natural catchment magnesium input parameters.

Flow yield ⁽¹⁾ (L/s/ha)	Magnesium Concentrations (g/m ³)			
	Initial input for all Natural catchments	Final input		
		Natural catchment above W-M1	Natural catchment above W-M2	Natural catchment above W-M3
0	0.9	0.01	0.01	0.01
0.01	0.9	0.8	1.0	1.6
0.3	0.9	0.8	1.0	1.6
1				1.0
100	0.001	0.001	0.001	0.001
1E+13 ⁽²⁾	0.001	0.001	0.001	0.001

Notes: (1) The GoldSim model linearly interpolates between daily rainfall or flow yield values.
(2) An arbitrary large number which is never exceeded in the model. The long term rainfall record for the site indices a maximum daily precipitation of approximately 760 mm which if it all runs off equates to a maximum yield of approximately 88 L/s/ha.

ZINC:

The initial input parameters for zinc from natural catchments adequately enveloped measured concentrations in the Whareatea River at W-M1 but tended to overestimate concentrations at both W-M2 and W-M3 (Figure C-4). The input parameters for the catchments above both W-M2 and W-M3 were reduced slightly to provide a better fit with the monitored data (Figure C-4). The initial and final calibrated zinc input parameters are summarised in Table C-4.

Table C-4: Calibration of natural catchment zinc input parameters.

Flow yield ⁽¹⁾ (L/s/ha)	Zinc Concentrations (g/m ³)			
	Initial input for all Natural catchments	Final input		
		Natural catchment above W-M1	Natural catchment above W-M2	Natural catchment above W-M3
0	0.02	0.02	0.01	0.005
0.01	0.02	0.02	0.01	
1	0.02	0.02	0.01	
100	0.001	0.001	0.005	
1E+13 ⁽²⁾	0.001	0.001	0.005	

Notes: (1) The GoldSim model linearly interpolates between daily rainfall or flow yield values.
(2) An arbitrary large number which is never exceeded in the model. The long term rainfall record for the site indices a maximum daily precipitation of approximately 760 mm which if it all runs off equates to a maximum yield of approximately 88 L/s/ha.



APPENDIX C

Natural Catchment Water Quality Model Input Assessment

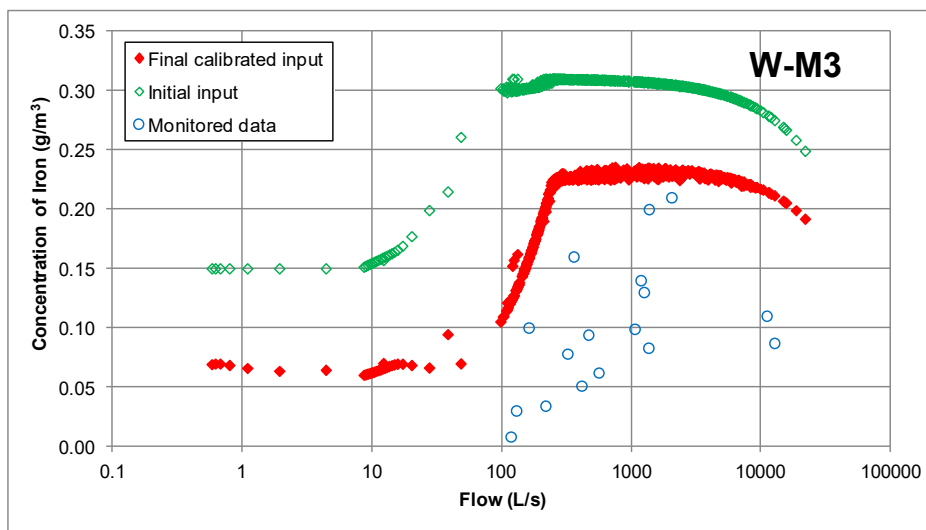
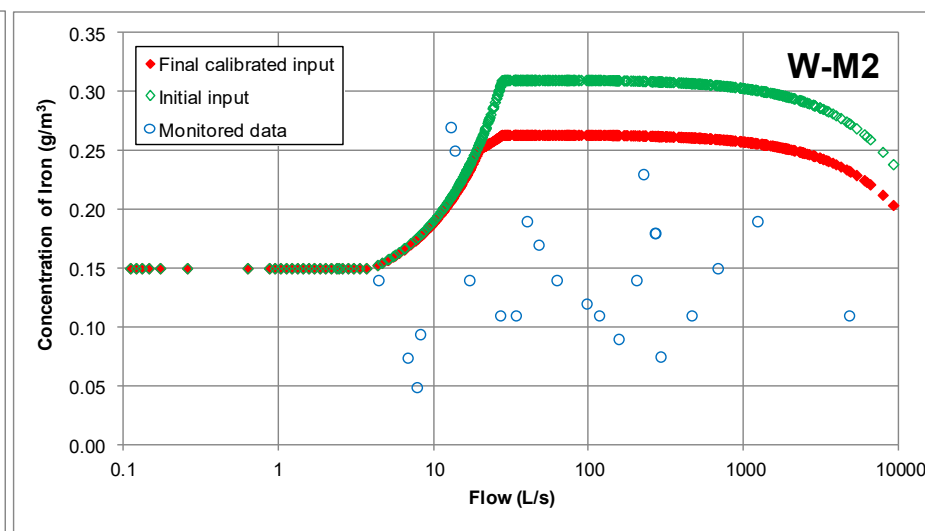
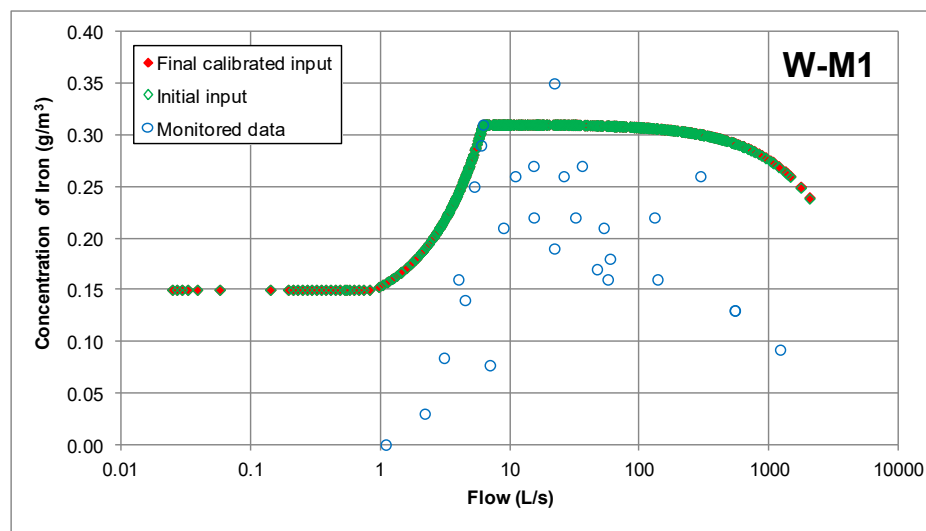


Figure C-1: Calibration plots of natural catchment iron input parameters

Monitored data from 12 November 2010 to 23 February 2012.

Simulated predictions from 1 November 2010 to 1 April 2012.



APPENDIX C

Natural Catchment Water Quality Model Input Assessment

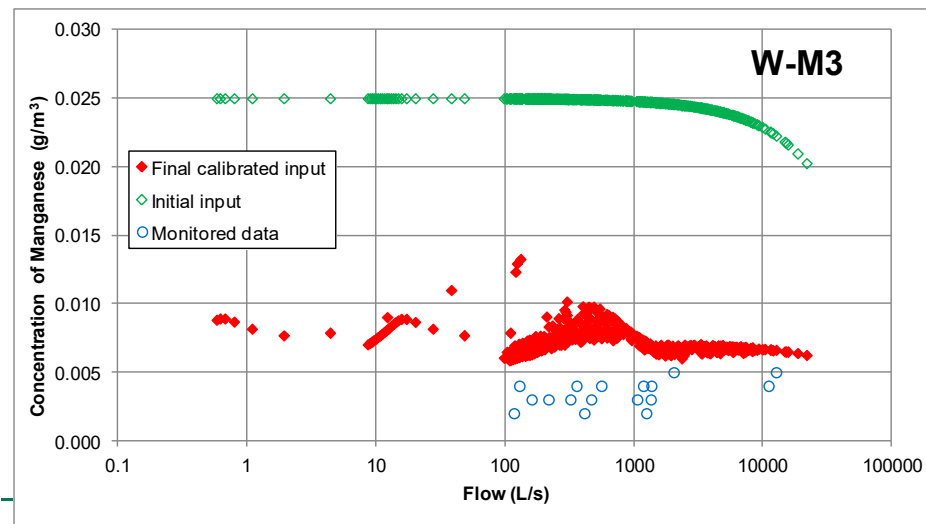
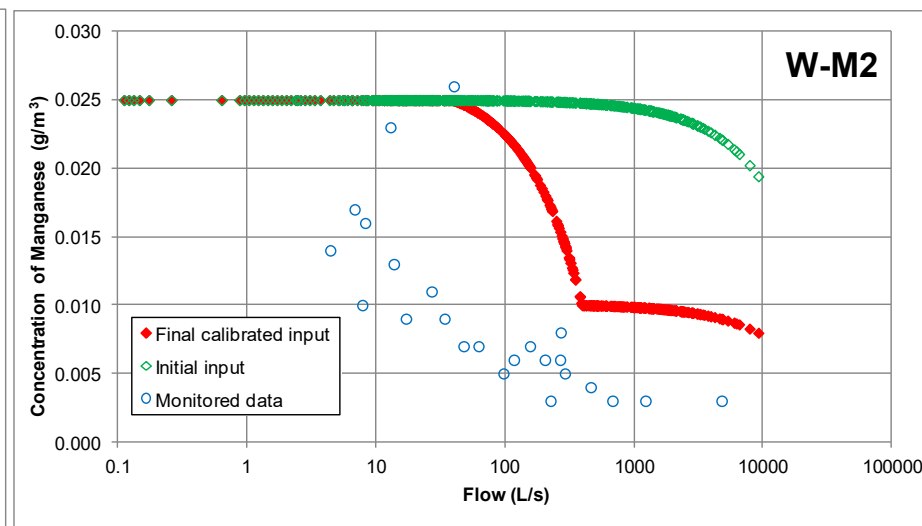
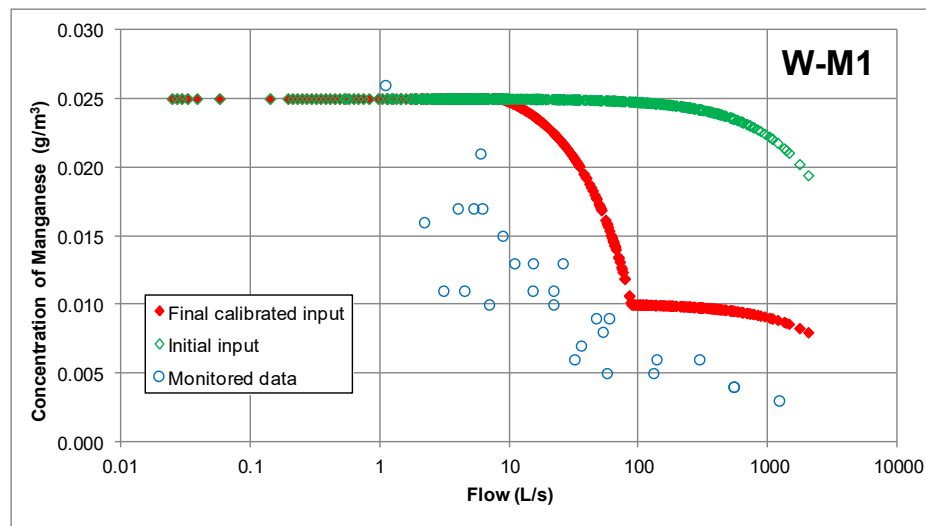


Figure C-2: Calibration plots of natural catchment manganese input parameters

Monitored data from 12 November 2010 to 23 February 2012.

Simulated predictions from 1 November 2010 to 1 April 2012.



APPENDIX C

Natural Catchment Water Quality Model Input Assessment

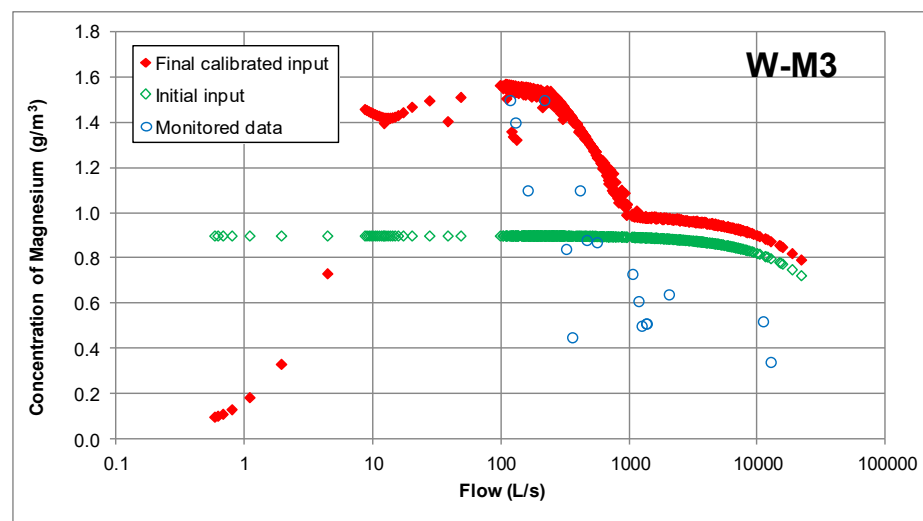
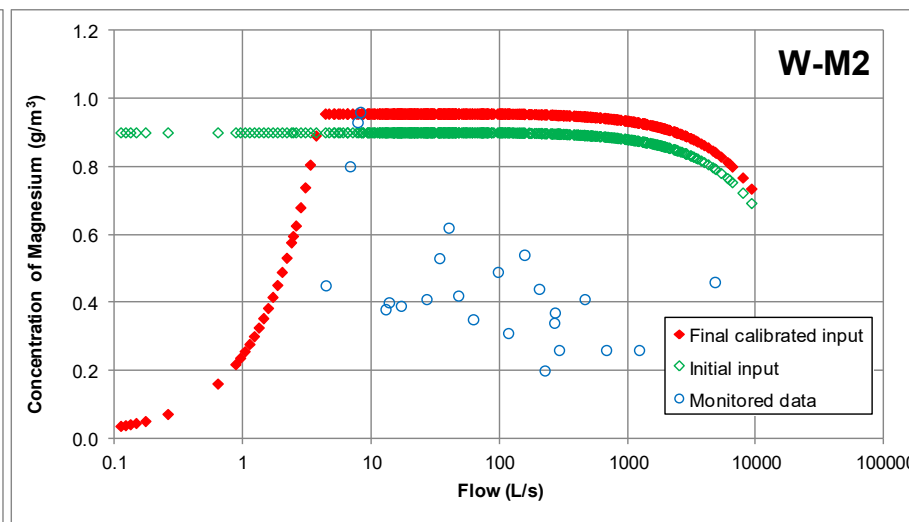
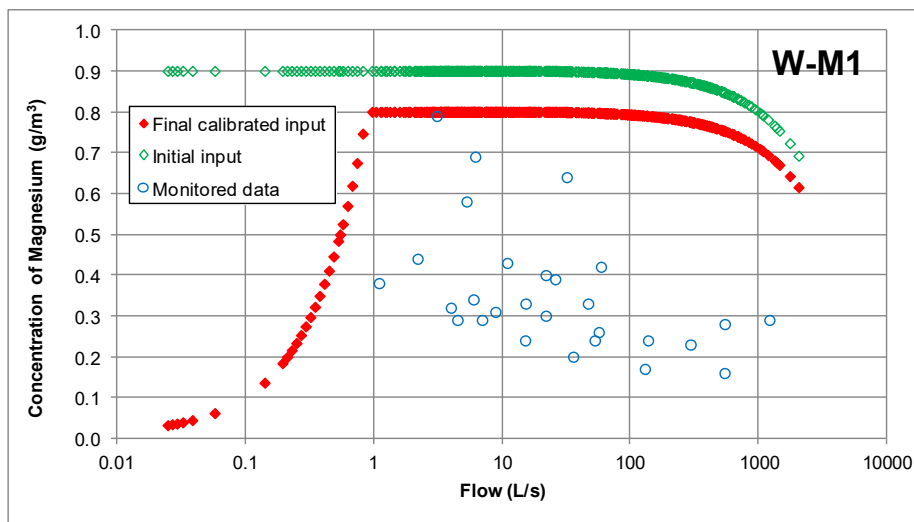


Figure C-3: Calibration plots of natural catchment magnesium input parameters

Monitored data from 12 November 2010 to 23 February 2012.

Simulated predictions from 1 November 2010 to 1 April 2012.



APPENDIX C

Natural Catchment Water Quality Model Input Assessment

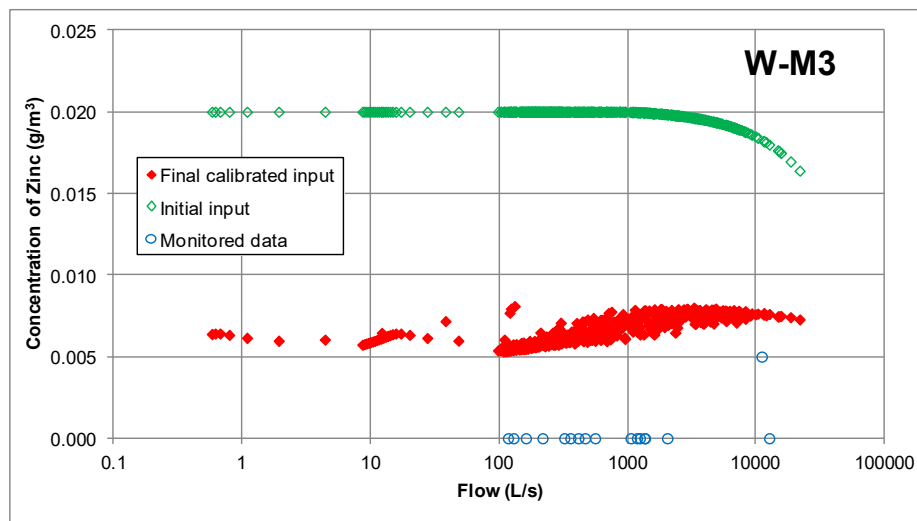
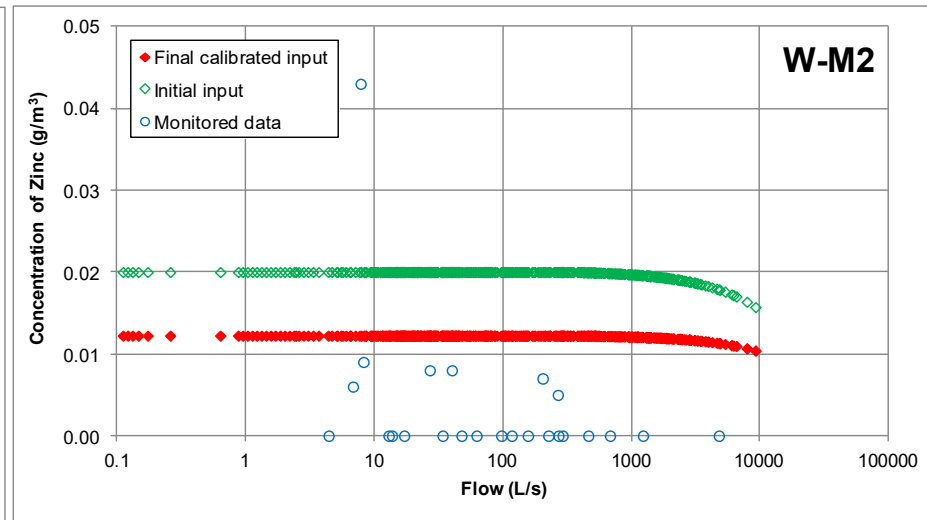
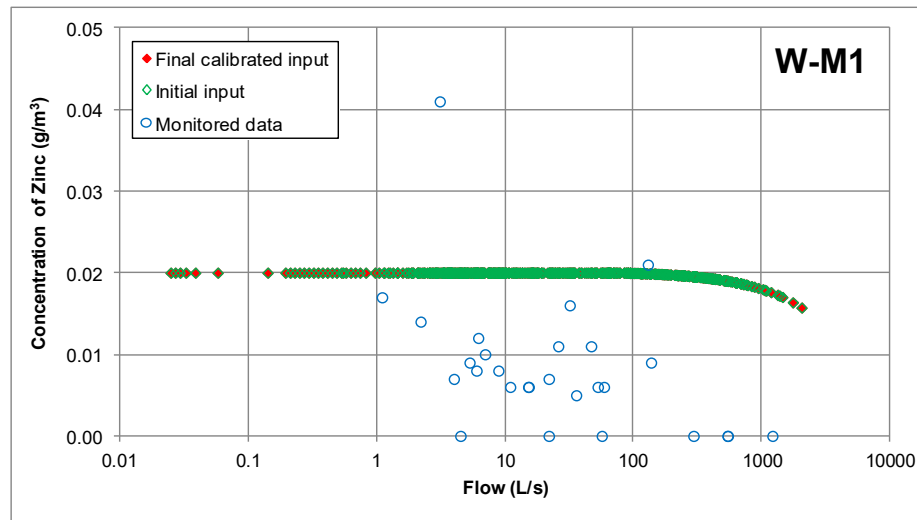


Figure C-4: Calibration plots of natural catchment zinc input parameters

Monitored data from 12 November 2010 to 23 February 2012.

Simulated predictions from 1 November 2010 to 1 April 2012.



APPENDIX C

Natural Catchment Water Quality Model Input Assessment

pH:

The initial input parameters for pH from natural catchments tended to overestimate pH in the Whareatea River at W-M1 and W-M2 but underestimated pH at W-M3 (Figure C-5). As explained in the main body of the report, pH estimated were simplified by omitting [OH⁻] concentrations, alkalinity and acidity, which in part explain the poor fit. Input parameters for the catchments above W-M1, W-M2 and W-M3 were adjusted slightly to provide a better fit with the monitored data (Figure C-5).

The initial and final calibrated pH input parameters are summarised in Table C-5.

Table C-5: Calibration of natural catchment H⁺ ion for pH input parameters.

Flow yield ⁽¹⁾ (L/s/ha)	H ⁺ ion for pH Concentrations (unitless)			
	Initial input for all Natural catchments	Final input		
		Natural catchment above W-M1	Natural catchment above W-M2	Natural catchment above W-M3
0	0.032	0.4	0.025	-0.00253
0.01	0.032	0.3	0.025	
0.1	0.016	0.05	0.02	
0.5		0.02	0.016	
100	0.016	0.001	0.01	
1E+13 ⁽²⁾	0.016	0.001	0.004	

Notes: (1) The GoldSim model linearly interpolates between daily rainfall or flow yield values.
(2) An arbitrary large number which is never exceeded in the model. The long term rainfall record for the site indicates a maximum daily precipitation of approximately 760 mm which if it all runs off equates to a maximum yield of approximately 88 L/s/ha.

TOTAL SUSPENDED SOLIDS (TSS):

The initial input parameters for TSS from natural catchments adequately envelope measured concentrations in the Whareatea River at W-M1 but tended to overestimate concentrations at W-M2 when flows were above approximately 100 L/s. At W-M3 the initial input parameters tend to underestimate concentrations during medium flows (Figure C-6). The input parameters for the catchments above W-M2 and W-M3 were adjusted slightly to provide a better fit with the monitored data (Figure C-6). The calibration was unable to account for unusually high TSS concentrations at low flows, but was considered to still provide a reasonable approximation of TSS under most circumstances. The initial and final calibrated TSS input parameters are summarised in Table C-6.

Table C-6: Calibration of natural catchment TSS input parameters.

Flow yield ⁽¹⁾ (L/s/ha)	TSS Concentrations (g/m ³)			
	Initial input for all Natural catchments	Final input		
		Natural catchment above W-M1	Natural catchment above W-M2	Natural catchment above W-M3
0	3	3	3	3
0.01	3	3	3	3
1	7	7	5	9
100	10	10	10	10
1E+13 ⁽²⁾	10	10	10	10

Notes: (1) The GoldSim model linearly interpolates between daily rainfall or flow yield values.
(2) An arbitrary large number which is never exceeded in the model. The long term rainfall record for the site indicates a maximum daily precipitation of approximately 760 mm which if it all runs off equates to a maximum yield of approximately 88 L/s/ha.



APPENDIX C

Natural Catchment Water Quality Model Input Assessment

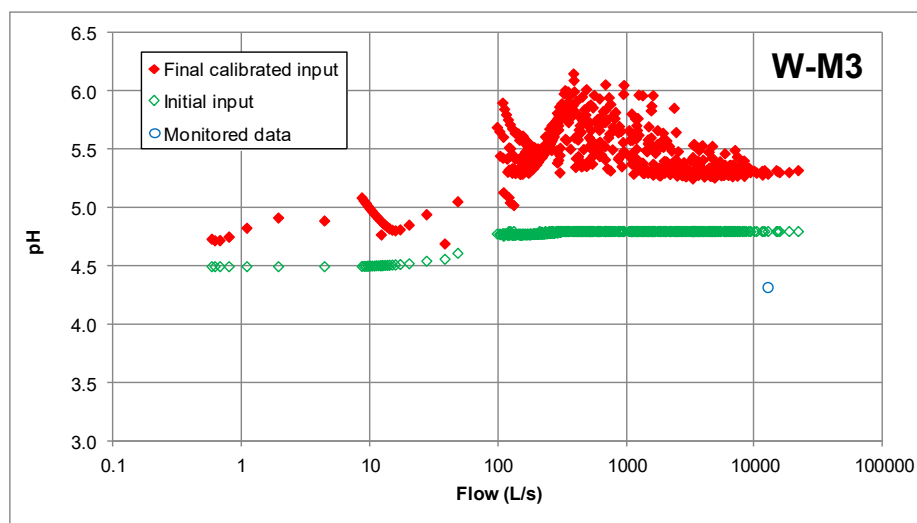
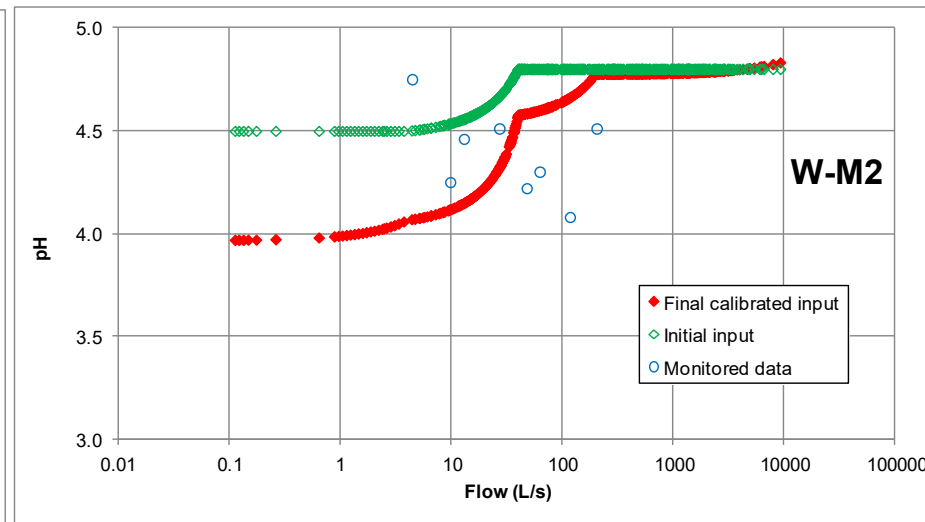
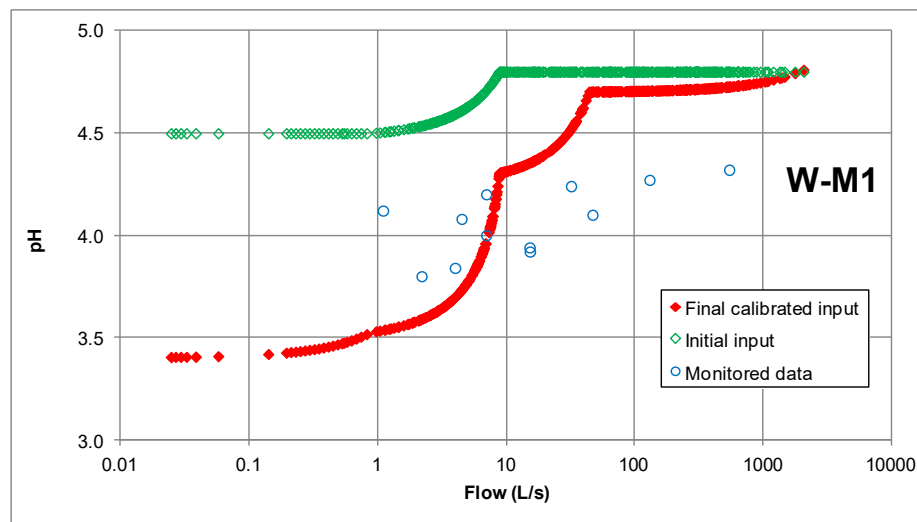


Figure C-5: Calibration plots of natural catchment pH input parameters

Monitored data from 12 November 2010 to 23 February 2012.

Simulated predictions from 1 November 2010 to 1 April 2012.



APPENDIX C

Natural Catchment Water Quality Model Input Assessment

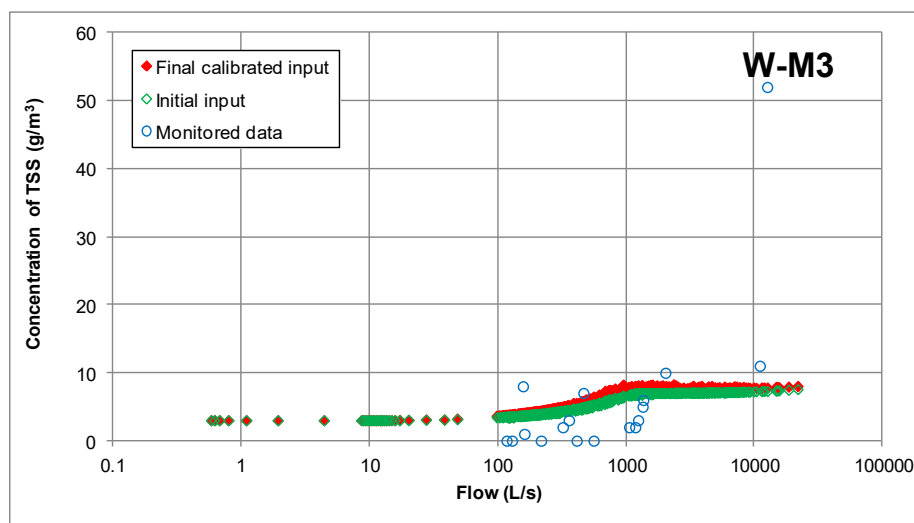
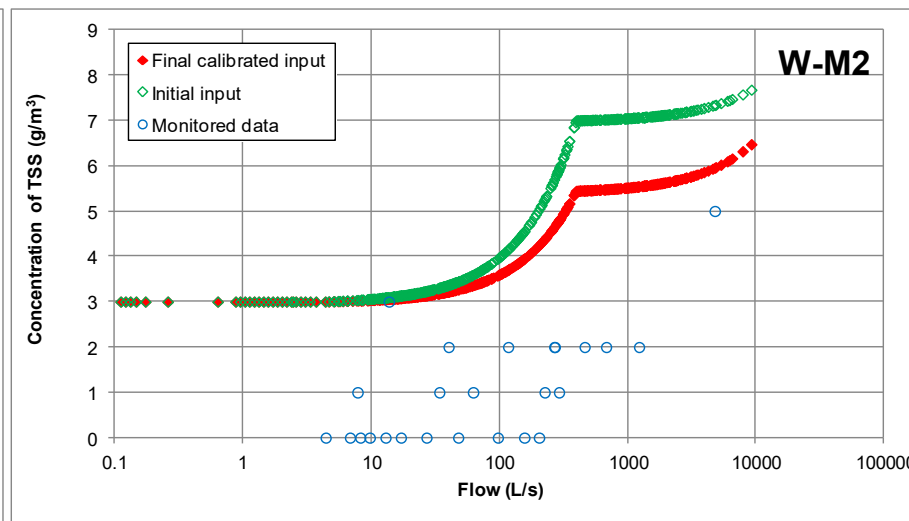
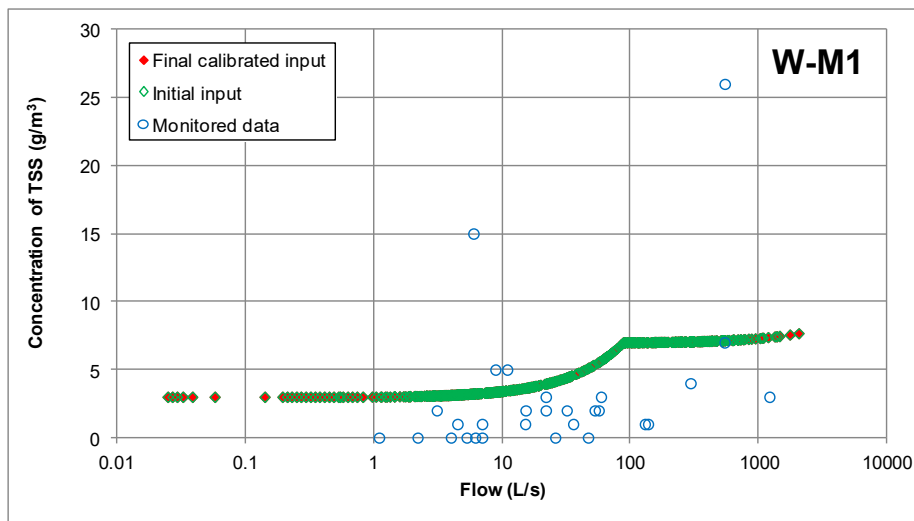


Figure C-6: Calibration plots of natural catchment TSS input parameters

Monitored data from 12 November 2010 to 23 February 2012.

Simulated predictions from 1 November 2010 to 1 April 2012.

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**ATTACHMENT F - SEDIMENT AND EROSION CONTROL PLAN: ESCARPMENT MINE PROJECT
(GOLDER ASSOCIATES, 2013)**



November 2013

SEDIMENT AND EROSION CONTROL PLAN

Escarpment Mine Project

Submitted to:
Buller Coal Limited
PO Box 290
Westport



REPORT



Report Number. 1078101422-075-R-Rev1

Distribution:

Ainsley Ferrier - Buller Coal Limited





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APPENDICES

APPENDIX A

Report Limitations

APPENDIX B

Toolkit Design Sheets



1.0 INTRODUCTION

1.1 Background

Buller Coal Limited (Buller) is proposing to establish an opencast coal mine, the Escarpment Mine Project (EMP) on the Denniston Plateau, West Coast of the South Island of New Zealand (Figure 1). This report represents the sediment and erosion control plan (SECP) and toolkit for the EMP. The plan and toolkit detail the site concept for controlling erosion and sediment on the site as well as design methodology for development of site infrastructure in the SECP.

This toolkit¹ is based on current understanding of the hydrology of the mine site; knowledge of conditions at the site will improve as the mine develops. The toolkit should therefore be considered a “live document”, to be updated based on learnings from the Escarpment Mine during the early development stages. Good monitoring and documentation of the performance of erosion and sediment control infrastructure will be a key part of this.

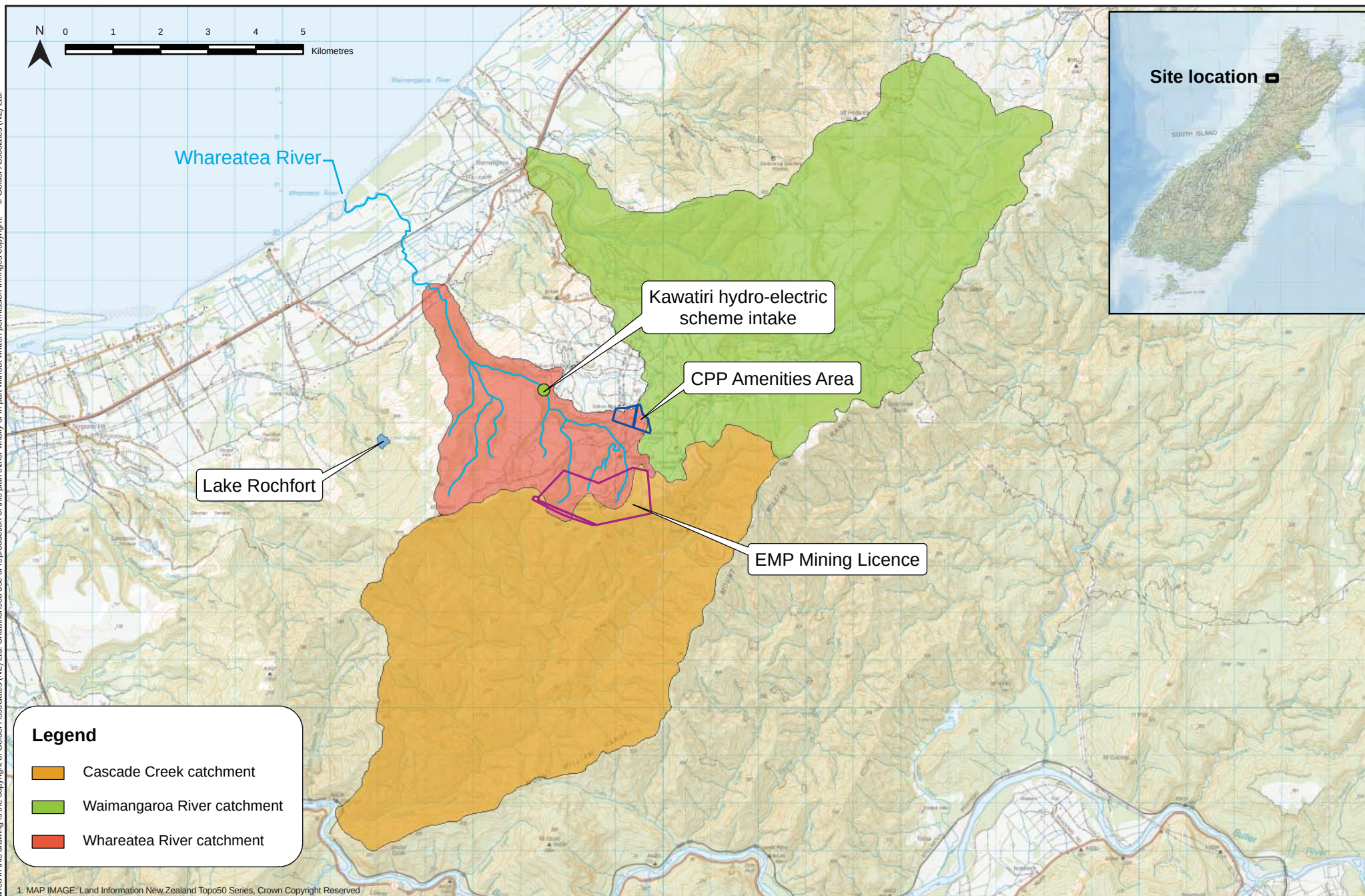
The proposed mine area covers 148 hectares and is estimated to contain approximately 6.1 million tonnes of recoverable coal. The opencast coal mine and associated mining infrastructure include the construction of the infrastructure listed below (Figure 2). This toolkit provides a basis for management of erosion and sediment for these areas:

- Haul roads
- Escarpment opencast coal mine pit
- Workshop, Amenities and Utilities
- Engineered Landform (aka backfill, dump) (ELF)
- Mine Influenced Water – Water Treatment Plant (MIW WTP) hardstand

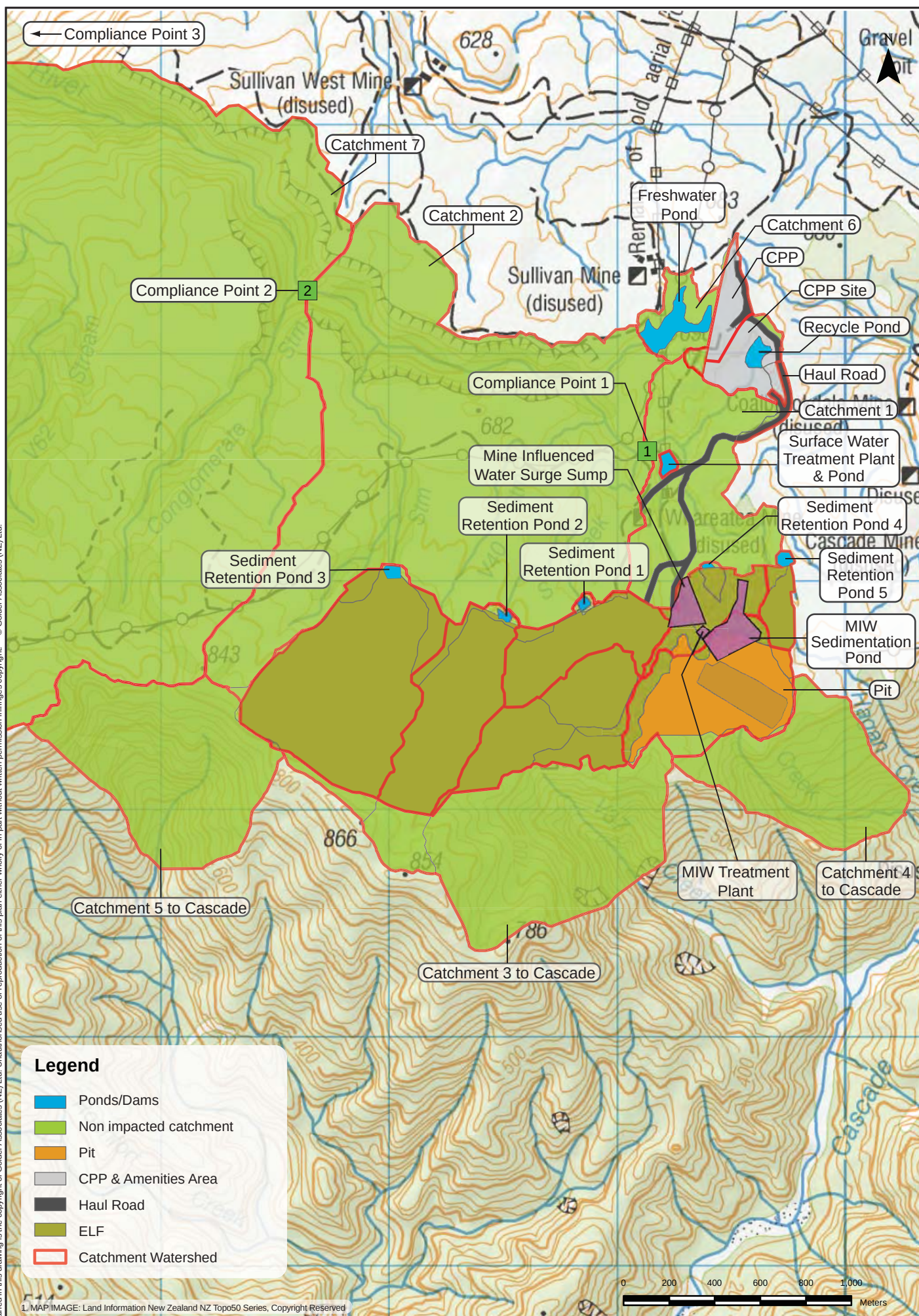
Site specific conceptual designs have been developed as a part of the SECP for the construction and operations phase of the mine, amenities and haul roads. A toolkit has also been developed as a component of the SECP to allow for the plan to evolve with the site, as the opencast pit and the ELF are developed. The SECP toolkit provides techniques to be implemented for the operational mine life, covering the period until the coal mine is closed and rehabilitation has stabilised the soils. The soils are considered stabilised when suspended sediment concentrations (TSS or suspended solids) in the runoff to the Upper Whareatea River and its tributaries meet the mine closure criteria.

The water infrastructure specifications in this document are tailored to the operational life of the mine, until rehabilitation is completed. Permanent infrastructure (principally stream channels) will be required for the rehabilitated mine. This infrastructure will need to be more robust to accommodate larger storm events than expected over the mine life, and to avoid the need for on-going maintenance. It is expected that permanent stream channel designs will be developed as part of the rehabilitation plan. Parts of the infrastructure developed for the operational mine will become permanent at the end of mine life, however, and hence consideration should be given to designing this infrastructure to the mine closure standards in order to maximise the efficiency of the mine.

¹ Your attention is drawn to the document, “Report Limitations”, as attached. The statements presented in that document are intended to advise you of what your realistic expectations of this report should be, and to present you with recommendations on how to minimise the risks to which this report relates which are associated with this project. The document is not intended to exclude or otherwise limit the obligations necessarily imposed by law on Golder Associates (NZ) Ltd, but rather to ensure that all parties who may rely on this report are aware of the responsibilities each assumes in so doing.



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2.0 USER GUIDE

2.1 Document Structure

It is expected that this guide and toolkit will be used by suitably experienced site personnel and that implementation of the design guides will be checked by an experienced engineer. There are two components to this document and it includes the following elements:

- Section 3.0: Toolkit objectives
- Section 4.0: Hydrological data underpinning the toolkit
- Section 5.0: Summary information on the mine site and ground conditions
- Section 6.0: Details of runoff calculations and derivation of flow rates for channel sizing
- Section 7.0: Basic principles of erosion
- Section 8.0: Basic principles and methods for erosion and sediment control
- Section 9.0: Key supporting information for use of the toolkit
- Section 10.0: Index to the toolkit
- Section 11.0: Inspection and maintenance principles
- Section 12.0: Continual improvement process
- Appendix B: Toolkit sheets: sizing and design guides for stream channels and erosion and sediment control infrastructure

First time users of the toolkit should read this entire document. Regular users of the toolkit sheets (Appendix B) should read these in conjunction with Sections 9.0, 11.0 and 12.0 of the document.

2.2 Scope

The SECP and design toolkit cover the anticipated land use and activities for the EMP as follows:

- Conceptual design of SECP facilities for the construction phase of site infrastructure, where temporary controls are different from operational facilities (amenities, workshop, and MIW-WTP).
- Conceptual designs of SECP facilities for the operational phase of the site.
- Procedures and design principles for adapting the SECP to changes in the site plan or mine operation. The toolkit contains design guides for the sediment and erosion control facilities included in the SECP, allowing for them to be resized and adapted to changes in the mine plan.

3.0 OBJECTIVES

The objectives of this toolkit are to:

- Provide a basis for design of infrastructure to convey water across the site
- Provide designs which assist with the control of upstream erosion and sedimentation in order to maintain sediment concentrations at the WTP within the design range
- Present erosion and sediment control design tools for disturbed land from which runoff will not be channelled into the WTP but will instead discharge to receiving waters



Consents for the EMP require that discharges of Total Suspended Solids (TSS) to the aquatic environment meet the following constraints at the WM-2 monitoring station on the Whareatea River:

- Rolling median concentration of 15 g/m³
- 30 mg/l 95 % of the time

Although the current consent conditions for the EMP do not state a compliance period for the above limits, a reporting/compliance period of one year has been assumed for both of these consent objectives (i.e., the above figures are assumed to apply to a 12 month rolling period).

During operation of the mine, it is planned that runoff and seepage from the major disturbed catchments will be directed to the Mine Influenced Water (MIW) Sump for treatment at the Water Treatment Plant (WTP). The water treatment system for the EMP will be designed to meet consent requirements listed above, based on a specific range of influent TSS concentrations. Management of soil erosion together with design, installation and maintenance of sediment control structures upstream of the WTP are therefore required such that WTP influent TSS concentrations meet the design specification. Poor control of soil erosion, inadequate sedimentation infrastructure and/or insufficient maintenance of sediment control infrastructure could result in failure of the WTP to deliver water quality within the consent condition limits.

A primary objective of this toolkit is therefore to provide infrastructure design, monitoring and maintenance guide which assist with control of erosion and sedimentation, such that the MIW-WTP inflow requirements can be met.

Runoff from certain disturbed catchments within the mine area will discharge directly to the receiving environments. This SECP and toolkit therefore also provides design, monitoring and maintenance guidelines for erosion and sediment control in these catchments.

4.0 CLIMATE

4.1 Previous Assessment

A detailed analysis of the rainfall and evaporation experienced by the EMP site was previously undertaken by Water Management Group (2013). A synthetic daily rainfall series from March 1945 to June 1992 and August 2005 to June 2013 was produced as a part of this analysis and has been adopted as the rainfall series used to generate flow series for the SECP. The analysis also included the development of high intensity events (storms) for various annual recurrence intervals (ARI).

4.2 Rainfall Series

The SECP uses two methods of rainfall categorisation for the toolkit design: treatment methods have been designed based on the rainfall-time series, and the hydraulic capacities of the infrastructure have been designed based on the design storms.

The treatment systems (settlement ponds and dams and pocket ponds) have been designed using the rainfall time series because their capacities are governed by the consent conditions of a 95 % annual exceedence limit. This means that the erosion and sediment control infrastructure and maintenance programme are designed to deliver TSS concentrations at the WTP inflow within the WTP design range for 95 % of each year. The infrastructure do not need to deliver TSS concentrations within the design range during the top 5th percentile of flow events because the WTP will not be designed to treat the top 5 % of flows, in accordance with consent conditions.



The 55 year synthetic rainfall series for the site was analysed to determine the 365 day period which contains the highest 95th percentile rainfall. The 365 day period with the highest 95th percentile rainfall was determined to be from 15 March 1967 to 14 March 1968, where the design rainfall (i.e., the 95th percentile) is 114 mm/day.

Sediment and erosion control infrastructure detailed in this plan are temporary structures with design lives of less than or equal to the mine life (8 years) and it is expected that influences of climate change will be minor.

By using a 55 year rainfall record and designing to the wettest 365 day period for a proposed 8 year mine life, there is a 15 % probability that the design rainfall event will occur during the mine life. Furthermore, the erosion and sediment control (ESC) infrastructure and WTP will be constructed to meet consent conditions during peak mining operations, which will only occur for part of the five year period.

4.3 Design Storms

The conveyance systems (drains and channels) and all other sediment and erosion control infrastructure on the site have been designed for short duration storms based on the contributing catchment size and the consequence associated with infrastructure failure. The infrastructure designs have been divided into two ARI categories of 10 year and 100 year recurrence interval.

The 10 year category represents a low consequence scenario where failure of the infrastructure causes inconvenience to the mining operation, but is not catastrophic and would not result in an uncontrolled discharge to the environment. An example of this is a contour drain on a slope, where overflow from it can be captured by a downstream conveyance system.

The 100 year category is used for infrastructure with a higher consequence of failure where failure would result in significant damage or interruption to the mining operations or would result in an uncontrolled discharge to the environment. The design storms used for this plan and toolkit are provided in Table 1.

Table 1: Design storms for EMP sediment and erosion control toolkit (WMG 2013).

	10 minutes	20 minutes	30 minutes	1 hour
10 year ARI	153 mm/hr	119 mm/hr	102 mm/hr	78.8 mm/hr
100 year ARI	247 mm/hr	191 mm/hr	164 mm/hr	127 mm/hr

5.0 CONTRIBUTING CATCHMENTS

5.1 Overall Site Description

5.1.1 Topography

The proposed Escarpment Mine is located near the top of a gently rolling plateau ranging in elevation from 600 to 800 m above sea level. The plateau slopes gently to the north and is bounded by valleys to the east and south. The terrain is rocky, and predominantly scrubland with some trees.

5.1.2 Layout

To the south of Whareatea River, in the mine permit area (51279 MPA), Buller is proposing to establish an opencast coal mine and engineered landform (ELF). A single opencast pit is planned, comprising a conventional open cut coal mine utilising diesel powered hydraulic excavators matched with suitably sized end-dump haul trucks for effective removal of overburden, parting waste material and to mine and haul the coal.

The EMP is located around the upper Whareatea River and its associated tributaries. The opencast mine will be located at the head of the one of the tributaries of the Trent Stream, V40 Stream, S Creek,



Whareatea, and V8 Creek. The V8 Creek currently discharges into the Cascade Creek catchment. In the later stages of the open cast mine, runoff from approximately 6.2 ha of catchment in the vicinity of Lake Brazil will be redirected to the Upper Whareatea River.

5.1.3 Soils and vegetation

The geology of the Denniston Plateau is dominated by thick coarse sandstones within minor mudstones. The sandstone is typically thickly bedded and is very resistant to erosion (L&M 2010). The BCM sandstone overburden rocks are close to the ground surface below a thin soil cover. In some areas the soil cover is absent, directly exposing the sandstone below. Ground cover is dominated by V40 Soils, estimated as 65 % soil cover (L&M 2010). These soils are found on the rock pavement with Trent Soils which are estimated as 30 % cover and Denniston Soils estimated as 5 % cover. Trent Soils are also present on more stable areas of the site. The soils in the EMP area comprise infertile, acidic, poorly drained soils. Vegetation growing on the coal measures pavement areas, escarpment faces, and stream gullies are adapted to this very low fertility, permanently saturated soils. Soils are considered to be permanently saturated due to the high levels of rainfall received by the site and the minimal drainage afforded by the sandstone. Plants are generally very slow growing given the soil characteristics.

The erodibility and settlability of sediments associated with mining on the Denniston Plateau have not yet been quantified. But it is anticipated that the characteristics of the Denniston Plateau soils and sediments will be similar to those on the Stockton Plateau, which have been extensively investigated in association with the mining operation at the Stockton Coal Mine (URS 2005).

Based on the characteristics of the Stockton Plateau, managing and controlling stripping activities and stockpiling of these soils is likely to be key to successful erosion and sediment control at the EMP. Design of sediment ponds to standard erosion and sediment control guidelines should provide sufficient control of sediments where the topsoil and overburden have been managed effectively. It is noted that sediment has been managed at the neighbouring Stockton mine through sediment control and gravity settling.

6.0 ESTIMATION OF RUNOFF

6.1 Design Basis

As described in the Section 4.0 of this report, two rainfall runoff methods have been used in the design of the infrastructure for the SECP: time series and design event. Proposed water management infrastructure designs are also based on the likely consequences of failure, as detailed in Section 4.3.

The first is to size the conveyance infrastructure to ensure that where overflows or failures to the system would be inconvenient they are likely to be infrequent, and where overflows or failures would be catastrophic they are rare. Sizing of the conveyance system has been based on the design storms (Golder 2012) for the EMP ranging in durations from 10 minutes to 1 hour.

The other is to provide an effective level of treatment to the runoff prior to reaching the MIW sump and treatment at the water treatment plant. This is achieved by constructing sediment ponds at the base of each of the high sediment yielding catchments (ELFs and pit). The treatment components have been sized based on the synthetic rainfall record developed for the site, as described in Section 4.2.



6.2 Design Storm Runoff

The Rational Method (Chow et. al 1988), provided below as Equation 1, has been used to determine the peak flows for a variety of catchments and catchment types on the site. The Rational Method uses catchment size, shape and land use to relate rainfall to runoff.

Equation 1: Rational Method

$$Q = 0.278 C \cdot A \cdot I$$

Q = Flow (m^3/s)
 C = Runoff Coefficient
 A = Catchment area (ha)
 I = Rainfall Intensity (mm/h)

The catchment size and shape are used to determine the appropriate rainfall intensity based on the time of concentration of the catchment. The time of concentration is the time required for rainfall on the furthest portion of the catchment to reach the outlet of the catchment, and thereby represents the shortest duration storm during which the entire catchment contributes to runoff. The time of concentration is then used to select a design storm intensity of the equivalent duration from Table 1. Times of concentration have been estimated for a range of catchment areas using the Bransby-Williams method (CCC 2003) as per Equation 2 below. The expected times of concentration for catchments ranging from 0.5 ha to 50 ha are shown in Table 2 below. For the purposes of the design toolkit the catchments have been assumed to be square and have a slope of 5 %. Longer catchments or catchments that slope more gradually will tend to have longer times of concentration.

Equation 2: Bransby-Williams's equation for Time of Concentration

$$ToC = 14 \cdot L \cdot A^{-0.1} \cdot S^{-0.2}$$

ToC = time of concentration
 L = Length (km)
 A = Area (km^2)
 S = Slope ($\frac{m}{m}$)

Table 2: Indication of times of concentration by catchment area for EMP site.

Area (ha)	ToC (min)
0.5	5
1	5
5	10
10	10
20	15
50	20

The catchment land use is used to determine a runoff coefficient, which is the proportion of rainfall intercepted by the catchment that translates directly into runoff. For example a highly permeable ground cover would readily infiltrate rainfall and thus a relatively small proportion would become runoff, whereas the



low permeability ground cover associated with frequently compacted haul roads is likely to result in a high proportion of rainfall becoming runoff. Runoff coefficients used in this study are summarised in Table 3 below. These factors are currently subject to some uncertainty, and infrastructure design is sensitive to this uncertainty. Runoff rates from the ELF areas (both active and when vegetated) in particular should be verified as part of the proposed ELF trial programme and early mine development stage monitoring. This document should be updated in observed runoff rates are significantly higher than anticipated. Depending on the results of this monitoring programme, development of runoff estimate using the SCS method may be appropriate.

Table 3: Runoff coefficients¹.

Catchment land use	Runoff coefficient	Description
Natural	0.6	The natural catchment on the plateau is generally composed of well saturated topsoil interspersed with sandstone outcrops. Natural catchments in the area have been estimated between 0.2 and 0.5 previously. A runoff coefficient of 0.6 has been assumed for this study to allow for antecedent moisture.
Opencast Pit	1.0	The pit surface is presumed to be predominantly low permeability rock.
ELF (Active)	0.8	The active ELF, which consists predominantly of freshly dumped and uncapped waste material, is likely to have high infiltration rates.
ELF (covered and vegetated)	0.9	The covered and revegetated ELF is capped with an impermeable layer which limits infiltration, and is not yet covered with the thicker revegetation of the rehabilitation process which intercepts rainfall, and will therefore likely result in the highest proportion of runoff.
Rehabilitated Landforms	0.7	The rehabilitated landforms, predominantly ELFs. Assumed higher than natural due to low permeability cap and potential for steeper slope angles.
Haul Roads	1.0	
Pond/Dam	1.0	
Mine Infrastructure and Utilities	1.0	

Note: ¹ Taken from Schwab et al. 1971.

Design runoff rates have been calculated for several catchment areas and land use types. These flows were used in the development of sizing charts for those components of the water management infrastructure which are designed on an event basis (e.g., 10 year ARI). This includes channels, channel protection, chutes etc.

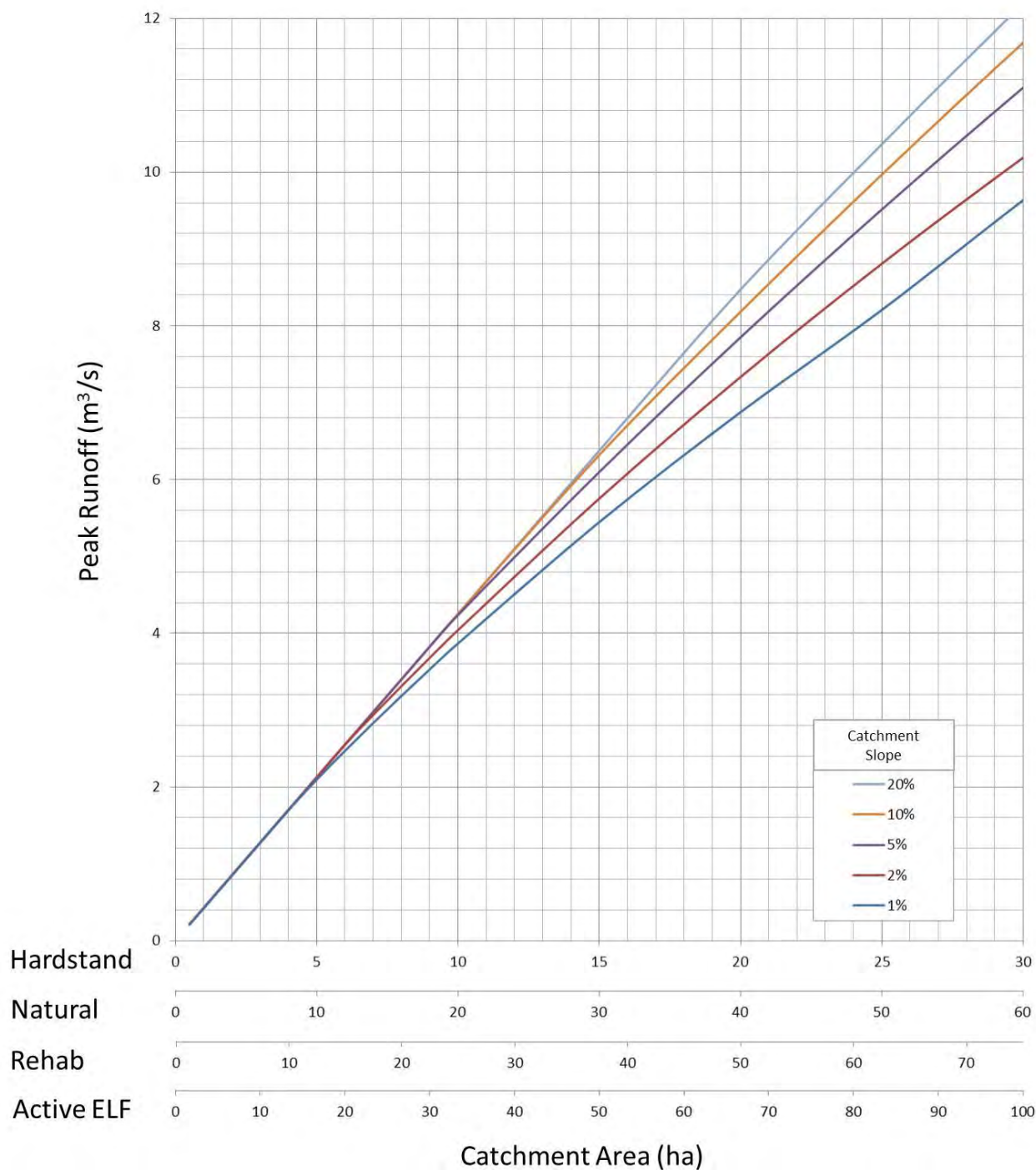


Figure 3: Peak runoff design flows for 10 year ARI.

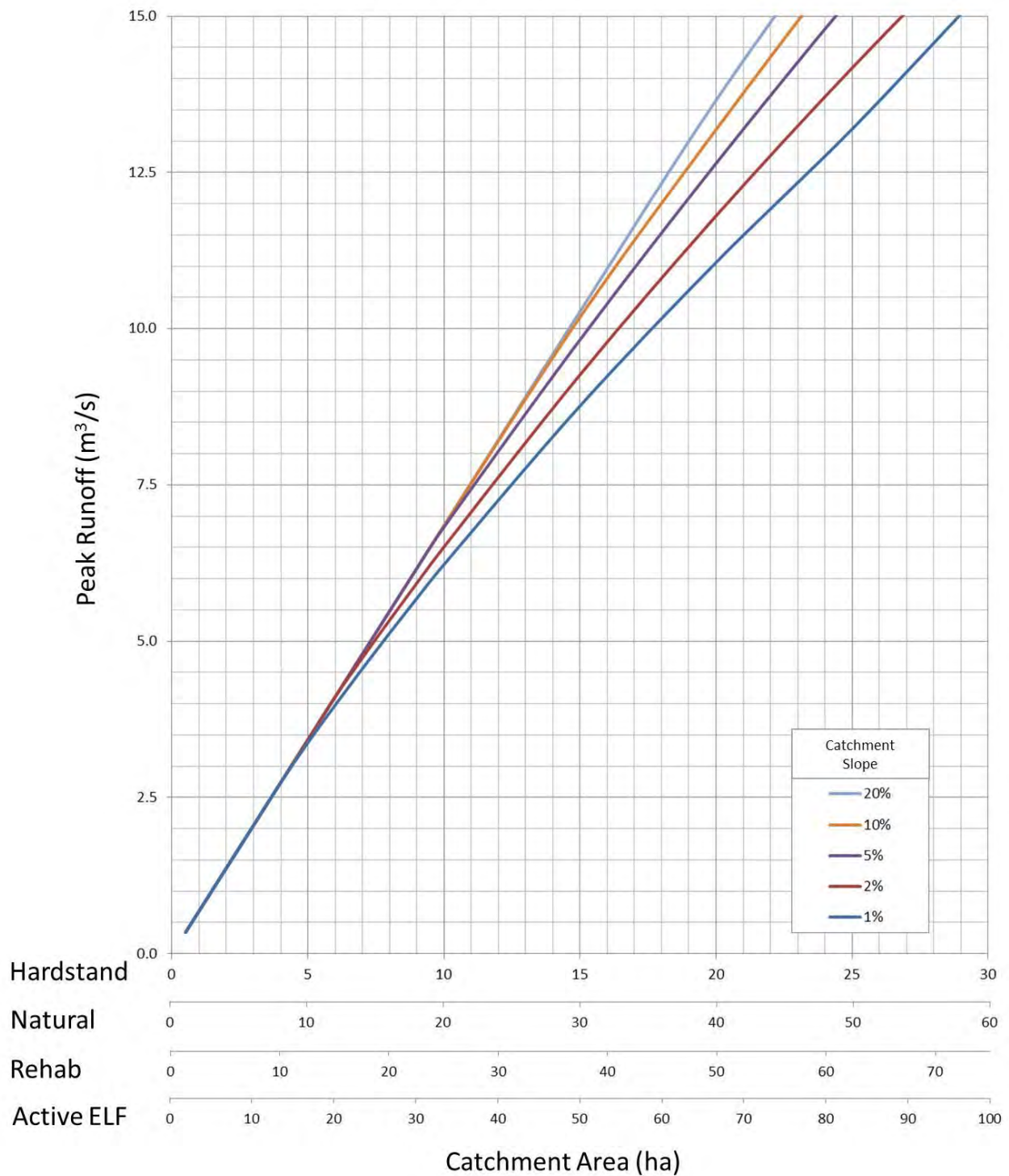


Figure 4: Peak runoff design flows for 100 year ARI.



6.3 Design Rainfall Runoff

The Rational Method (Equation 1) has also been used to transform the design rainfall depth (114 mm/day – see Section 4.2) developed for the EMP from the synthetic rainfall series into a daily flow volume. Estimates of flows requiring treatment have been determined using the rational method for a range of catchments and are provided in Figure 5. This flow rate is used for design of sedimentation structures.

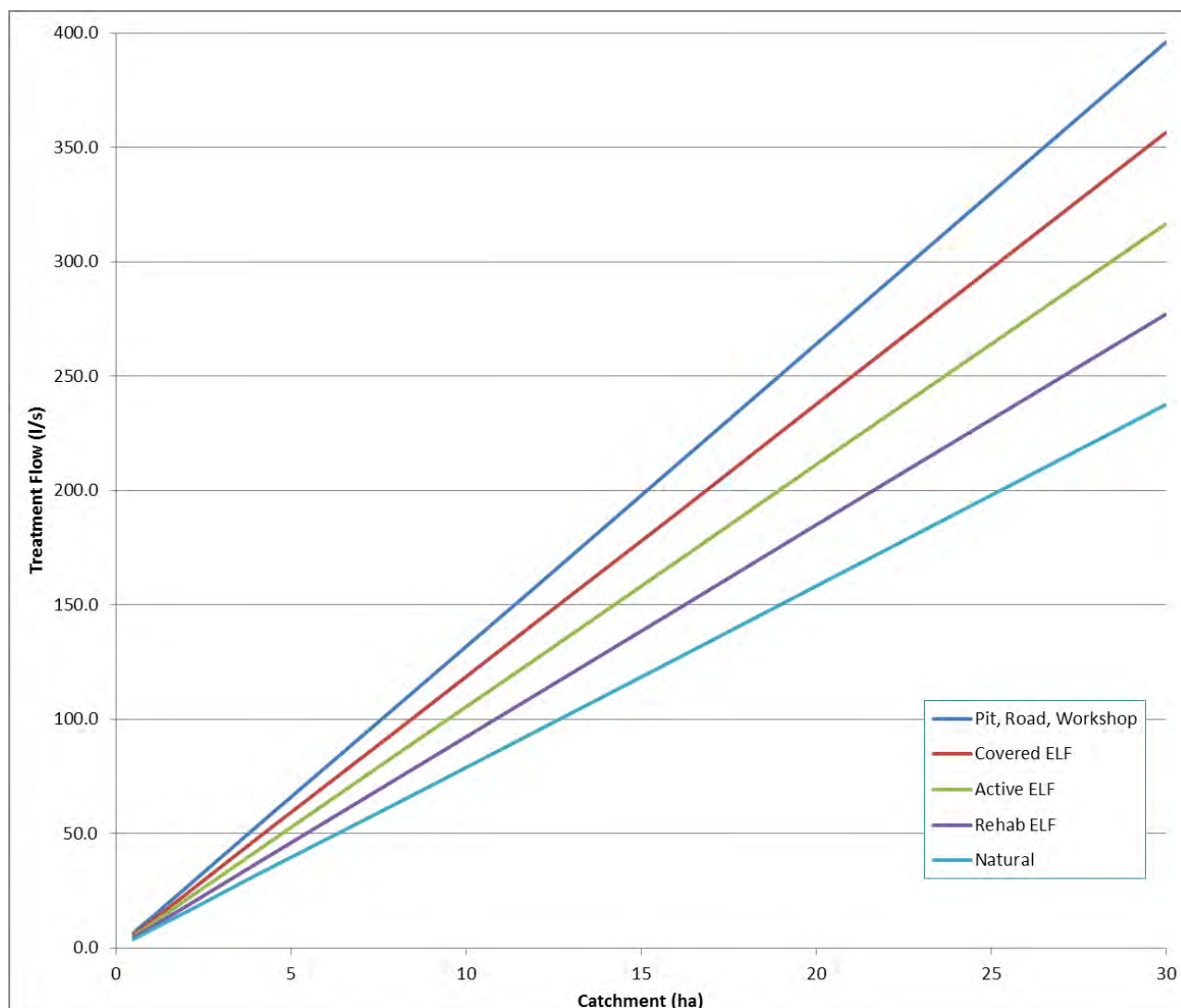


Figure 5: Treatment flows by catchment land use.

7.0 EROSION PROCESSES AND POTENTIAL

7.1 Erosion Principles

When rain falls on un-vegetated soil or disturbed overburden material, material is eroded by two primary mechanisms: surface erosion and mass erosion. **Surface erosion** occurs when rain-induced runoff flows over the soil surface and dislodges the loose particles that can be mobilised by the velocity of the running water and by raindrop impact. As this process occurs, the surface water may begin to concentrate from



sheet flow into a rivulet with more erosive power. These rivulet can develop into rills and then into small gullies, with increasing soil removal. As a gully forms, the banks of the gully can give way and result in **mass erosion** of sediment. Significant erosion can also occur when water runs over a sharp decline, where soil is unsupported on the down gradient side.

The mechanics of erosion can also be increased by site traffic. Repeated site traffic can cause surface material to crush, reducing the grain size of soils, which are then more readily entrained in surface runoff.

The consequences of erosion are numerous but primarily relate to water quality issues in which flora and fauna are negatively impacted. Erosion can also be a hazard to infrastructure where road beds, culverts, or bridge abutments can be put at risk. The costs associated with erosion are associated with lost storage capacity in reservoirs, need for maintenance of eroded sites, environmental health, flooding risk and aesthetics.

7.2 Road Erosion

Erosion can occur during construction of roads, as well as from road surfaces themselves. The required erosion control measures for temporary (i.e., construction or exploration) roads are usually less extensive than for permanent or long term mine roads, due to the fact that the risk of significant erosive events occurring during the time this infrastructure is in place is lower and the cost of armouring the roads is not justified by the short length of time the roads will be in place.

7.3 Pit and Mine Facilities Erosion

Erosion on mine area slopes can transport sediment into or out of mine pits, and can cause gullying on slopes. Proper drainage design and grading within the mine area can help minimise erosion. Applicable erosion control measures include capturing runoff such as drainage ditches with appropriate armouring, chutes with aprons or stilling basins to convey flows down steep slopes, pocket ponds, and infiltration trenches and ponds, and treatment systems, such as sediment ponds and dams, to reduce the amount of sediment discharged from these areas into the natural environment.

Revegetation and rehabilitation of the mined area can significantly decrease site erosion, and should be conducted as soon as practicable after mining is complete. Bioengineering techniques such as wattles, coir rolls, live staking and brush layering can provide both vegetation and structural stability on the slope, reducing erosion and increasing slope stability.

7.4 ELF Erosion

Overburden disposal areas, or waste rock dumps, can be a significant source of sediment loss. Proper drainage design is essential for ELFs. Incorporation of armoured ditches, chutes with aprons or stilling basins, pocket ponds and disposal area berms with rock drains for drainage can help minimise erosion. Practices such as sediment ponds and dams are used to further reduce the amount of sediment released to the environment from disposal areas.

Successful revegetation and rehabilitation of the disposal area will significantly decrease site erosion, and should be conducted as soon as practicable after dumping is complete. Bioengineering techniques such as straw mulching, wattles, coir rolls, live staking and brush layering can provide both vegetation and structural stability on the slope, reducing erosion and increasing slope stability.



8.0 EROSION PREVENTION AND SEDIMENT CONTROL PRINCIPLES

8.1 Erosion Prevention Principles

Preventing erosion on the site is the most effective form of reducing TSS concentrations, decreasing the amount of treatment necessary further along in the system. Prevention of erosion has three core components: reducing the amount of water acting on any given soil particle (controlling runoff), strengthening or protecting the soil particles against sheet erosion (ground treatment for the catchment), and protecting soil particles against concentrated flow (channel protection). The key erosion principles comprise:

- **Controlling Runoff** by diverting water away from erosion-prone areas, and reducing the distance runoff travels in overland flow. Sediment entrainment in flow is proportional to the depth and slope angle. Where the slope angle cannot readily be reduced, the depth of flow can be reduced by intercepting flow at regular intervals, and thereby reducing the contributing catchment of any given overland flow path.
 - **Diversion channels** placed throughout the site to prevent clean water runoff from undisturbed catchments from draining through disturbed catchments.
 - **Cut-off drains** to intercept sheet flow on a sloping catchment and prevent concentration of flows.
- **Ground Treatment** either through armouring with course material (gravels and cobbles) or through binding the soils to form a cohesive structure on the surface (vegetation).
 - **Vegetation** is an effective erosion control mechanism as it allows for some infiltration as well as binding the soil together. Vegetation requires a period of time to grow before it can offer full protection, however, and ground cover is susceptible to erosion prior to this time. Vegetation will be planted to prevent erosion on final landforms that are not expected to be disturbed again (i.e., ELF's ready for rehabilitation) and on those areas that will be undisturbed for a considerable period of time (1 year).
 - **Surface Armouring and Roughening** are two methods of treating the ground surface in areas of active mining operations. Armouring is most appropriate for surfaces that are subject to site traffic movement (i.e., roads and stockpiles). Armouring functions as a preventative ground treatment by reducing the exposure of soil to erosion. Surface roughening is most appropriate for active and inactive areas that involve or will be subject to further excavation or dumping. Surface roughening effectively creates a large number of miniature plunging pools and sediment ponds, which slow down the flow and settle-out some of the TSS in the flow.
 - **Straw-mulching** comprises spreading hay over disturbed ground in order to reduce rain-drop impact and reduce overland flow velocities. This increases infiltration rates and reduces sheet flow and associated erosion. Tests have shown that erosion can be reduced by more than 80 % on mulched areas compared to open ground (Erosion Control 2012).
 - **Slope Reinforcement** is used to reduce velocity and the degree of flow concentration and associated rill erosion and gully formation on steep slopes that are being rehabilitated. The most appropriate slope reinforcement for the EMP site is likely to be use bundles of brush tied together (wattles) and staked along the contour of the slope. The stakes used to hold the wattles in place can either be made of standard lumber or of live tree stalks that will root into the soil and further anchor themselves.
- **Channel Protection** is required because channels are susceptible to erosion from high velocity flows. The two options for reducing the amount of erosion in a channel are protection of channel surfaces (lining and armouring) and reduction of the flow velocity (check dams and armouring).

Channel Armouring helps to prevent the loss of channel integrity during conveyance of high flows. The velocity of flow in a channel is primarily affected by the depth of flow and the slope of the channel. For channels where the flow velocity is expected to be high, channels will need to be armoured to prevent significant scour. The appropriate type of channel armouring depends on channel size, peak flow velocities and gradient. Lining option selection depends on these factors; options include riprap, concrete mattress or a geotextile lining and rip rap combination. It is noted



that armouring with rip rap increases the channel roughness and slows down flow, whereas armouring with concrete mattresses generally results in a smoother surface, increasing velocities and allowing for more flow within the same channel size.

- **Check Dams** are also used in channels with a steep slope (greater than 4 %), where velocities would otherwise be very high, and act as a series of short cascades and ponds which slow down the flow in the channel. Check dams are constructed such that the crest of each dam is the same height as the toe of the previous dam; this transforms the channel into a series of small reservoirs. Some sediment is also trapped in the pools which develop behind the check dams.

8.2 Sediment Control Principles

The underlying principal for sediment control at EMP is to remove as much suspended sediment as is practically possible close to source in pre-settlement ponds. These ponds are designed to drain-down naturally and to be relatively easy to maintain. This in turn will help to reduce the maintenance requirements for stream channels further downstream, in which sediment would otherwise settle out at low points.

- **Sediment dams and ponds** are planned to be the primary method for removing TSS through settlement for the EMP. The water management plan for the site includes sediment dams at the downstream end of each of the major ELF catchments (Figure 2). Preliminary designs for each of the sediment dams are provided in Section 9.6. The toolkit design procedures can be used to adapt the designs for changes in contributing catchment area and the proportions of those catchments that will be exposed at any given point in time. Sediment dams and ponds will be used on the site as long-term (life of stage/mine) sediment control systems.
- **Pocket ponds** are intended to be used as a temporary treatment method for small catchments on the site, to reduce the TSS loading downstream during construction of more permanent treatment systems (e.g., during dam construction), and as local treatment for temporary works where it is not practical to direct runoff to the MIW sump. Pocket ponds are infiltration ponds that have a constructed overflow weir and effectively act as a small sediment pond during high flows. Pocket ponds are simple and quick to construct but do not offer sufficient treatment during high flows to replace sediment dams and ponds required in the long term.
- **Silt Fences** act as a flow retarding barrier to allow for ponding of sediment laden flow and as a filter for overland flow and should be installed in small catchments that comprise predominantly hardstand areas at the mine site (mine utilities and amenities area, yards, buildings and road margins where runoff from disturbed land is not otherwise captured). Silt fences effectively filter sheet flow and allow for settling without concentrating runoff into channelized flow. Silt Fences are most appropriate for small catchments of predominantly hardstand areas, and can be used without downstream treatment.

8.3 Catchment Land Use Categories

The anticipated site activities (land use) for the EMP are categorised as follows:

- **Natural**; consisting of unaltered catchments inside or outside of the EMP area. Natural catchments do not require treatment, but runoff from some of these undisturbed areas will require diversion around the disturbed mine area. Some natural catchments may be incidentally treated in the event that runoff cannot practically be diverted away from disturbed ground.
- **Opencast Pit** is defined as the area draining to the in-pit sump for the purposes of this document. The opencast pit catchments are the most active areas of the site; runoff is managed by maintaining a surface gradient and drainage paths directed to the in-pit sump. The in-pit sump will be sized based on an acceptable balance between pit flooding risks, sump size and pump capacity. Pond sizing for the opencast pit are included in the design sheets, although it is noted that these are not the only criteria for sizing of the in-pit sump. It is considered that any ground treatment would not be practical within the



opencast pit catchment (excluding backfill areas) and hence these measures have not been considered.

- **ELF (Active)** is the term used in this document to describe ELF areas that have been subject to overburden placement or disturbed within the previous 6 months. These areas are considered to have the highest potential to generate sediment.
- **ELF (Inactive)** is the part of the ELF that has not been disturbed in the previous 6 months and has not been fully rehabilitated. ELFs and backfill material comprise a well graded particle size distribution – (i.e., a wide range of material sizes, from silt through to boulders). This grading is associated with a natural armouring process, whereby finer surface material is eroded within the first few significant rainfall events after placement, leaving a surface armour of coarse material.
- **Rehabilitated** is the part of the ELF (or the site in general) that has been fully rehabilitated and can be considered, for the purposes of sediment and erosion control, to be a natural catchment.
- **Site Roads** consists of hard packed soil where traffic compacts and crushes the surface material. Road widths and traffic levels will vary widely over the site, ranging from high frequency and heavy traffic on the haul roads to the infrequent and often light traffic for access roads around the site.
- **Mine Infrastructure and Utilities** areas include the mine site office, workshops, car parks and yards. The critical period for sediment generation from the building components of these areas will be during construction. The yards continue to have a sediment generation potential throughout the operational life of the mine, particularly in areas of heavy traffic.
- **Stockpiles** are likely to have a high sediment generation potential associated with traffic movement and coal processing. Sediment will be dominated by coal fines. Coal fines can stay suspended in water for a long period of time unless mixed effectively with siliciclastic sediment (i.e., TSS from overburden material) and can therefore be more difficult to settle out than TSS from the rest of the site.

9.0 INFRASTRUCTURE DESIGN

9.1 Toolkit Overview and Function

The toolkit consists of a series of design sheets (Appendix B) covering all components of SECP infrastructure. The first design sheet functions as an index of the site activities and can be used to identify the infrastructure components required for each anticipated activity on the site.

9.2 Channels

9.2.1 Capacity

The required channel capacities are determined based on the design storm runoff (Section 0) for the appropriate contributing catchment area and the storm recurrence interval. Manning's equation (Equation 3), which uses channel dimensions, slope and surface roughness to determine flow rate, was used to develop appropriate channel sizes for a range of catchment areas.

The channel dimension components of Manning's equation are cross sectional area (A) and the hydraulic radius (R_h). The channel dimensions have been standardized where possible for consistency. All channels are designed as trapezoidal, with 1V:2H side slopes (where practical) and 300 cm of freeboard. Channel sizes have been designed for flows ranging from 0.1 m³/s (the expected flow for a 10 year ARI storm on a 0.5 ha natural catchment) to approximately 15 m³/s (the expected flow from a 100 year ARI storm on a 30 ha impermeable catchment).

Standard channel designs are provided for flow rates up to 10 m³/s. Specific engineering design should be undertaken for channels required to convey flows in excess of 10 m³/s.



Channel design for the EMP is mostly governed by the site topography, most notably longitudinal slope. For a given channel size, channels with lower slope angles convey less flow (at a lower velocity) compared to a steeper channel. Flow velocity and channel erosion are directly correlated and hence it is expected that steeper channels will require armouring to prevent erosion.

Equation 3: Manning's equation

$$Q = \frac{1}{n} \cdot A \cdot R_h^{2/3} \cdot S^{1/2}$$
$$Q = \text{flow } (m^3/s)$$

n = manning's roughness coefficient
 A = area (m^2)
 R_h = hydraulic radius (m)
 S = slope (m/m)

9.2.2 Channel lining

Channels constructed in erodible material (e.g., ELFs, in mudstone bedrock or highly weathered rock) should be protected through rock armouring, gabion mattresses or rock grouting. The type and depth of protection recommended is based on the channel size and slope. The primary form of channel armouring proposed for the site is gravel, cobbles or larger riprap, depending on the intensity of the flow. The exact method of channel protection on the site will depend on material availability on site and cost of installation. Riprap is expected to be available from appropriately screened sandstone overburden. Consideration should be given to the acid-forming potential of overburden material used for channel lining. Where flows are too intense for riprap lining, the channel is to be lined with a gabion mattress or a grouted rock liner, for example.

Rock Armouring

Rock armouring designs in the toolkit are based on the Hydraulic Engineering Circular No. 15 produced by the Federal Highway Administration (FHWA 2005). The armour design is characterised by a median size (D_{50}), and is determined from the channel shape and flow depth. The principle of channel armouring is balancing the shear stress acting on the channel lining, against rock size and weight. For channels with slopes of less than 10 %, the minimum D_{50} can be determined from Equation 4.

Equation 4: rock armour sizing equation

$$D_{50} \geq \frac{SF \cdot d \cdot S}{F_* \cdot (SG - 1)}$$

D_{50} = mean riprap size (m)
 SF = Safety factor
 d = depth of flow (m)
 S = average channel slope
 F_* = Shield's parameter
 SG = specific gravity of rock

Appropriate safety factors and Shield's parameters are determined based on the particle's Reynolds number during peak flow (Equation 5).



Equation 5: Reynolds number equation for particles

$$R_e = \frac{\sqrt{g \cdot d \cdot S} \cdot D_{50}}{\nu}$$

R_e = Reynolds number
 $g = 9.81 \text{ m/s}^2$
 ν = kinematic viscosity (m^2/s)

The thickness of the channel lining is the size of the largest rock used (i.e. if D_{50} is 100mm and sizes range from 50 mm to 300 mm then the channel lining would be 300 mm).

The gradation of the riprap is dependent on the availability of material on the site, generally the ratio of the largest rock to the median rock (D_{100}/D_{50}) and the ratio of the median rock to the 20th percentile rock (D_{50}/D_{20}) should be between 1.5 and 3 (FHWA 2005).

Gabion Mattresses

Where riprap rock sizes are impractical for the site or are not appropriate due to steep slopes, gabion mattresses should be used for channel armouring. A gabion mattress (comprising coarse grade rock in a mesh cage) provides considerably more protection than un-caged rock material of equivalent sizing. Gabion mattresses are cellular in nature, to allow for easier manoeuvrability and to ensure that any failure of the structures are isolated and contained. The size of the rock-fill material within the gabion mattresses is determined by the size of the wire mesh, where 70 % of the rock-fill by mass (D_{30}) is larger than the mesh openings (FHWA 2005).

The thickness of the mattresses is a function of the soil material on the site and the maximum velocities expected in the channels. The soils on the site, for the purposes of gabion mattress sizing, can be summarised as silts and fine sands, and the maximum velocities in the channels are below 4 m/s. On this basis the minimum mattress thickness recommended is 30 cm (FHWA 1989). The sizing of the gabion mattress is primarily a function of the available materials, where cages are either purchased commercially or manufactured on-site.

Where gabion mattresses are placed on soils that are predominantly finer than gravel, a filter material is used to prevent water flowing through the riprap within the cages. The filter material size is gravel (15-64 mm) and is to be 15 cm thick. The gravel filter layer can be replaced with a suitably thick and durable geotextile fabric.

Grouted Rock Liner

Where riprap rock sizes are impractical for the site or are not appropriate due to steep slopes, and gabion mattresses are not feasible, riprap can be grouted in place forming a rigid channel liner. Rigid liners are more resistant to erosion during fast flows, but are less adaptable to scour of foundation material, and can crack and fail if support is lost.

The thickness of the riprap layer, when grouted, is dependent on the maximum velocities in the channel. The relationship between riprap thickness and flow velocity is provided in Figure 6.

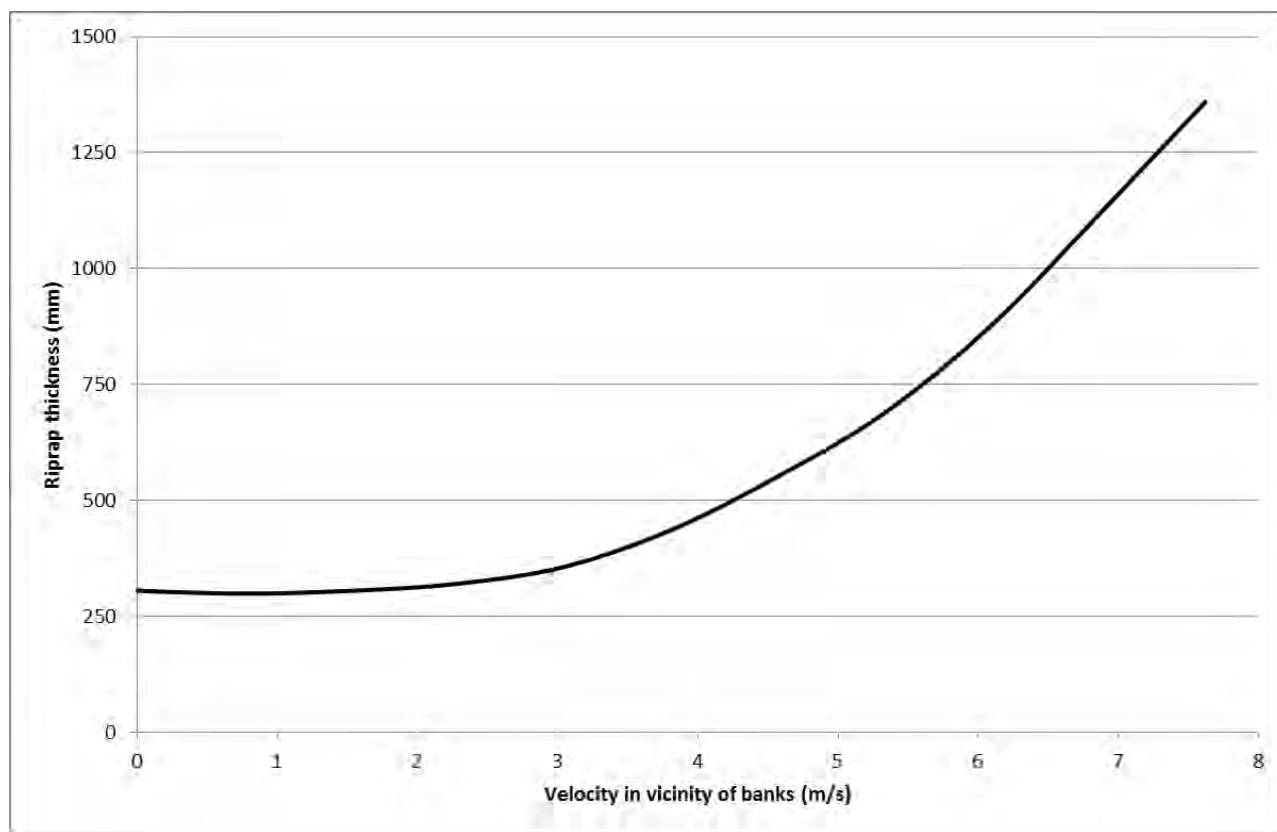


Figure 6: Grouted riprap thickness by flow velocities (FHWA 1989).

9.2.3 Chutes

Chutes comprise channel structures designed to convey water down steep terrain (referred to as hydraulic jumps). The design of chutes is highly site specific, and appropriate designs cannot effectively be supplied as charts and tables in a toolkit format. The Cooperative Research Centre for Catchment Hydrology (CRC) has produced a spread-sheet based hydraulic design tool called [CHUTE \(2003\)](#). CHUTE is a program for modelling the hydraulic jump that can occur when flow travels down a steep gradient and meets slower moving flow at the bottom. A hydraulic jump is a natural phenomenon in which super-critical flow meets sub-critical flow.

9.2.4 Check dams

Check dams are small dams constructed in channels, and act to slow flows in the channel, reducing channel bed erosion, and allowing sediment to be deposited behind the dam. Check dams are to be used on the site in channels that are not grouted and have slopes of greater than 4 % (ARC 1999). Check dams can be constructed from a variety of materials, generally selected for their accessibility and appropriateness. For the EMP check dams are to be constructed from rocks, sand bags or gabions.

Check dams should be constructed to be less than half of the peak water depth, and no more than 0.5 m high at their centre line (ARC 1999). The check dam height is added to the channel design depth to accommodate the reduction in cross sectional area through the dam section. The primary function of the check dams in this plan is to reduce flow velocities of in steep channels. Although it is expected that some settlement of sediment will occur behind the dams, particularly during smaller events, the treatment potential of the check dams has been excluded from the overall sedimentation design. This is conservative.



The portion of the channel just downstream of the check dam should be lined with riprap sized (130 mm – 550 mm) rock or stronger (i.e., if the channel is armoured with a gabion mattress or larger rock sizes, then these armouring methods should be used downstream of the check dam).

The maintenance requirements for check dams are discussed in Section 10.0.

9.2.5 Channel confluences

The confluence of two or more channels can result in an array of hydraulic forces acting on the embankments of the contributing or exiting channels. A stilling pool is to be included at the confluence of the channels to slow the velocity in the basin down, and reduce the potential for scour. The stilling pool size and shape is generally governed by the size and shape of the channels contributing. The height of the outlet of the stilling pool is to be 0.5 x the water depth in the downstream (exiting) channel to a maximum of 0.5 m. The freeboard (nominally 0.3 m) surrounding the confluence should be doubled (0.6 m) to accommodate increases in splash or turbulence.

Confluences of channels with slopes greater than 10 % (chutes) should be designed so that the hydraulic jump of the chutes occurs prior to the stilling pool, and the contributing channel flows will not be super-critical. If there is insufficient space for the chutes to reach sub-critical flow, a suitably qualified engineer will design proper structure.

9.2.6 Culverts

Culverts, like chutes, can be complicated hydraulic structures that are highly dependent on a number of site specific variables, notably the length and drop of the culvert itself but also the upstream reservoir and the downstream channel and outlet. As a result, culvert design is not included in this toolkit. The FHWA have produced a culvert hydraulic and design program (HY-8, version 7.2) which is straight forward to operate when all of the site information is known, and allows for an efficient culvert design.

9.3 Ground Treatment

9.3.1 Vegetation

The EMP site will be rehabilitated progressively throughout the life of the mine as landforms become final. Revegetation of final landforms is expected to be in the form of either placement of recently relocated topsoil and living plants as vegetative direct transfer (VDT), or as stockpiled or imported topsoil planted with new vegetation. Relocation and planting of new plants takes some time to establish an effective vegetation cover, and may not provide sufficient protection to the rehabilitated area for several years. On-going water management will be required until runoff from rehabilitated areas meets the closure criteria defined in the rehabilitation plan (expected to be less than 2 years).

Once a landform has reached its final contour, and is not expected to be heavily trafficked again, seeding should be undertaken to develop a protective grass layer. Grasses should be selected for the site under consultation with the rehabilitation vegetation designer or other suitably qualified professional to ensure that it does not interfere with the growth of the long term vegetation (Pakihi and Native Forrest). If grassing of the landforms is considered to be impractical or unfeasible, the catchment should be considered an inactive bare catchment and receive pre-treatment from the sediment ponds until the rehabilitated catchment produces sufficiently little sediment that it can be considered a natural catchment.

Protective grass layers can also be developed on other areas of the site which are not expected to be disturbed for an extended period of time (one year), such as areas within the mine facilities or long term stockpiles.

Optional temporary seeding and straw mulching practices are included in the toolkit, which can be applied to areas of potentially high TSS production to reduce the overall loading of the downstream system, in particular sediment ponds and the MIW-WTP. Temporary seeding is appropriate for land areas that will remain exposed for 30 days or longer.



Design procedures have also been provided in the toolkit for hydro-seeding, which is to be used on slopes that require grassing protection but are too steep for safe and feasible access by machinery.

9.3.2 Slope stabilisation

In the context of the SECP, slope stabilisation refers to protection of the slope face from erosion. Slope stabilisation for the site consists of effectively creating a series of small terraces by bundling brush and clippings (wattles) and staking them along the contours of a slope. These provide reinforcement to the slope by reducing the distance that water can flow uninterrupted, and encourage plant stability during the early growth stages of the rehabilitation.

Waste wood (slash) from the land clearing process can be used as a ground cover to protect the topsoil from surface erosion. Where tree branches and trunks are available that are too heavy to be effectively used as bundled brush stops, they can be evenly distributed on the exposed ground surface. The slash works as a partial barrier to rainfall, intercepting it and thereby reducing erosion resulting from impact. The slash also reduces the velocities in sheet flow and holds the topsoil in place.

Slash and Brush layering can be used in conjunction with revegetation or rehabilitation techniques and provide stability during the early stages of plant growth.

9.3.3 Surface roughening

Surface roughening can be used as a temporary measure on disturbed slopes, and reduces erosion by creating shallow soil depressions, which attenuate small surface water flows and allow sediment to be deposited. This practice can be applied both as a temporary measure, to assist in reducing erosion on cleared slopes or graded areas, as well as a permanent measure on rehabilitated slopes. This practice is ideally applied to sites that will be revegetated, as the surface roughness will increase water retention after rainfall, allow more water to infiltrate and promote vegetative growth.

Running a tracked vehicle (i.e., bulldozer) up and down the slope leaves divots perpendicular to the slope length that can roughen the hill slope. Driving the tracked vehicle along the contour of the slope should be avoided, as this will leave track divots that channel water down slope and thereby concentrate flows and enhance erosion rates.

9.4 Treatment Systems

9.4.1 Treatment requirements

The purpose of treatment systems within the sediment and erosion control plan is to reduce TSS in runoff close to the source. Removal of TSS prior to the MIW sump reduces the overall load on the MIW-WTP, in particular through the removal of large easily-settled particles. Removal of TSS close to the source also reduces the amount of sediment which settles in slow moving sections of the reticulation system.

The level of treatment required for each pre-settlement basin has been determined based on influent TSS concentration estimates derived using the Modified Universal Soil Loss Equation (MUSLE) and the MIW-WTP design inflow TSS concentrations (Golder 2012c), which comprise the effluent TSS concentration requirements. The WTP design inflow TSS concentrations, which form the basis for the SECP designs, are shown in Table 4 below.



Table 4: Design inflow TSS concentrations for MIW-WTP (Golder 2012c).

Rainfall (mm/day)	TSS (mg/l)
Pit	2,500
ELF – Uncovered runoff	5,000
ELF – Covered and revegetated runoff	250
Hardstand	1,250
Road	1,875

The MUSLE relates a storm flow intensity and runoff volume to total storm sediment yield as a tonnage by applying several multiplicative factors (Haan et al. 1998). The MUSLE (see Equation 6) factors for the EMP site have been determined for the given land uses and are provided in Table 5, along with a description of the criteria used to select them. Total runoff volume and peak runoff are determined using the rational method for the site. The runoff volume was determined from the 114 mm/day design rainfall described in Section 6.3. The peak runoff was determined from short duration storm events described in the Rainfall and Evaporation Assessment (Golder 2012a), scaled to the 114 mm/day design rainfall.

Equation 6: Modified Universal Soil Loss Equation (MUSLE)

$$Y = 11.8 \cdot (Q \times q_p)^{0.56} \cdot K \cdot LS \cdot C \cdot P$$

Y = soil yield per storm (tonnes)
 Q = total runoff volume (m^3)
 q_p = peak runoff (m^3/s)
 K = erodibility factor
 LS = length – slope factor
 C = cover factor
 P = supporting conservation practices factor

Development of TSS load estimates from the various catchment land uses is described below and the derived loading values are provided in Table 6.

Estimated TSS loads from the different land uses have been determined as a mass load (tonnage) per storm event. The mass load can be converted to a concentration using Equation 7 (Hann et al. 1998).

Equation 7: Sediment distribution

$$c = k \cdot q^a$$

c = TSS concentration (mg/l)
 q = flow rate (m^3/s)
 k, a = constants

“k” and “a” are constants where “a” must be between 0.5 and 1 and ‘k’ can be determined using Equation 8. The coefficient “a” shapes the intensity of the runoff concentrations, where a value of 1 provides the highest peak, and a value of 0.5 distributes the TSS concentrations across the entire event. A value of 1 was used for the purposes of this investigation.



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Table 5: MUSLE parameters by land use.

Land use	K – Erodibility		LS – Length – Slope		C – Cover		P – Practices	
Pit	0.16	Fine Sand with 0.5 % organic material	0.9	5 % grade at 50 m	0.99	No cover	1	No management practices
ELF – Uncovered runoff	0.16	Fine Sand with 0.5 % organic material	1.91	5 % grade at 200 m	0.99	No cover	1	No management practices
ELF – Covered and revegetated runoff	0.14	Fine Sand with 2 % organic material	0.35	5 % grade at 8 m	0.2	Near complete vegetative cover	0.5	Contour drains, wattles
Hardstand	0.05	Fine sand armoured with gravel and cobbles	0.43	2 % grade at 100 m	0.99	No cover	0.5	Armouring, various land use and treatments (buildings, yards, impermeable pads)
Road	0.05	Fine sand armoured with gravel and cobbles	0.43	2 % grade at 100 m	0.99	No cover	0.8	Road armouring



Equation 8: Formula to determine “k”

$$k = \frac{Y}{\sum q_i^{a+1} \cdot \Delta t}$$

$\Delta t = \text{storm duration (hr)}$

Sediment yields for the various catchment land uses are provided in Table 6. It is the peak TSS that has been used in determining required treatment for the EMP site; the yield and average TSS have been included for reference. The nearby Stockton mine has published TSS concentrations they have experienced during an 80 mm/day rainfall event for several mine catchments (Pizey et al. 2012) which compare favourably to the concentrations determined from the MUSLE.

Table 6: Expected average TSS concentrations for mine influenced water.

	Yield (tonnes)	Average TSS (mg/l)	Peak TSS (mg/l)	Stockton (Pizey et al. 2012) (mg/l)
Pit	26.05	10,000	45,000	22,348
ELF- Uncovered runoff	14.4	18,500	82,000	49,260
ELF- Covered and revegetated runoff	0.697	330	1,500	31-74
Hardstand	1.95	800	3,400	N/A
Road	3.12	1,200	5,400	N/A

The SECP includes a design basis for the pre-settlement basins required to remove sufficient TSS for the MIW-WTP inflow concentration to fall within plant influent design concentrations (Table 4 and Table 5 respectively). The pre-settlement basin removal efficiencies (aka trap efficiencies) required to deliver TSS concentrations to the WTP within the design specification are provided in Table 7 for each land use type.

Table 7: Required pre-settlement basin trap efficiency.

Catchment type	TSS removal (%)
Pit	94 %
ELF uncovered	95 %
ELF Covered and partially revegetated	83 %
Hardstand	63 %
Roads	65 %

The data in Table 6 and Table 7 show that high TSS concentrations that could potentially occur in runoff from various parts of the mine and that high trap efficiencies may be required for pre-settlement basins as a result. This underlines the importance of well managed pre-settlement in the catchments upstream of the WTP. Large, well-maintained basins with surface outlets can retain well over 90 % of the sediment entering them, compared to 35-57 % found for the standard traps (McLaughlin et al. 2007), and hence these treatment efficiencies should be achievable.



9.4.2 Use of multiple sedimentation ponds

The pre-settlement system design comprises a treatment train, with a series of small ponds distributed throughout the catchment. The benefits of using multiple smaller sedimentation ponds as an alternative to a single larger pond of the same total capacity are discussed in US Department of Interior, 1982. The study cites field applications which have shown that multiple sediment ponds in series are more efficient in removing finer particles than a single pond of equal surface area. It is also noted that solids with higher settling velocities will settle in the first pond and finer sediments will settle in the final pond: One particular advantage of this type of system is that maintenance (i.e., excavation of sediment from the pond) is generally limited to the first settling pond. A disadvantage of multiple ponds is that a greater area is disturbed during construction (USDI 1982). Furthermore, it is expected that a considerable proportion of TSS generated on the site will be heavy, easily settled particles and providing ponds for these particles to be removed early in the catchment reduces the potential for sediment to build up in channels where flow slows down.

Optimising pond sizes within a treatment train is an iterative process, and requires the simultaneous sizing of all ponds. A method has been developed for this toolkit to estimate the combined treatment efficiency that can be achieved by several ponds in one system. The method uses settlement rate data generated from Stokes Law and the runoff loading rates to determine the Required Pond Area (RPA) needed to reduce MIW-WTP influent TSS concentrations to within the design concentration. The RPA is then used to assess all treatment chains in the catchment required to deliver sufficient treatment for each flow path.

9.4.3 Required Pond Area (RPA)

The RPA is effectively the total pond area that is required to treat the runoff TSS concentrations for a particular catchment. RPA is the ratio between overflow (m/s) and flow (m³/s), as detailed below.

Overflow rate

The surface overflow rate (referred to as the overflow rate in this document) is the representative speed at which water moves through a treatment pond. By factoring the effective pond area from the flow through the pond for an ideal rectangular continuous flow basin, the critical particle settling velocity (V_c) at which a particle will settle in a pond can be evaluated from the pond surface area and the flow rate through the pond. The critical settling velocity concept is illustrated in Figure 7.

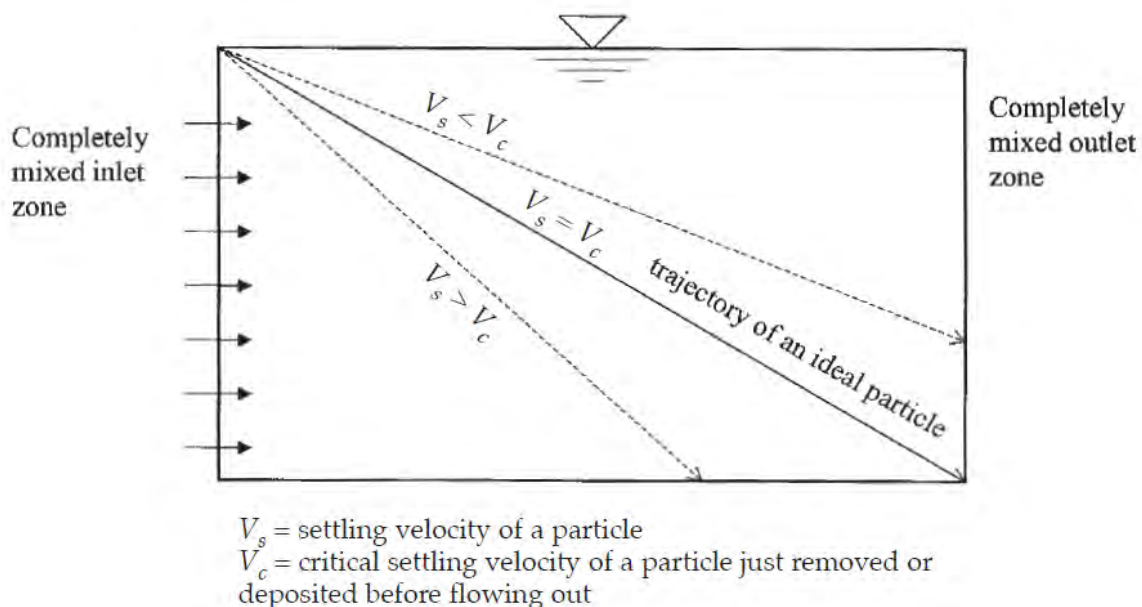


Figure 7: Critical particle settling velocity (after Verstraeten and Jean Poesen 2000).



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Particle settling velocity is a function of the physical characteristics of the sediment on site. To determine settlement velocities, a grain size distribution was assumed based on site soil descriptions in the report *Soils and Indicative Land Rehabilitation, Escarpment Mine Project, Denniston Plateau, Buller* by Landcare Research (2008) and experience with sites in the area. The distribution of grain sizes assumed to be transported by runoff from the site is shown in Figure 8.

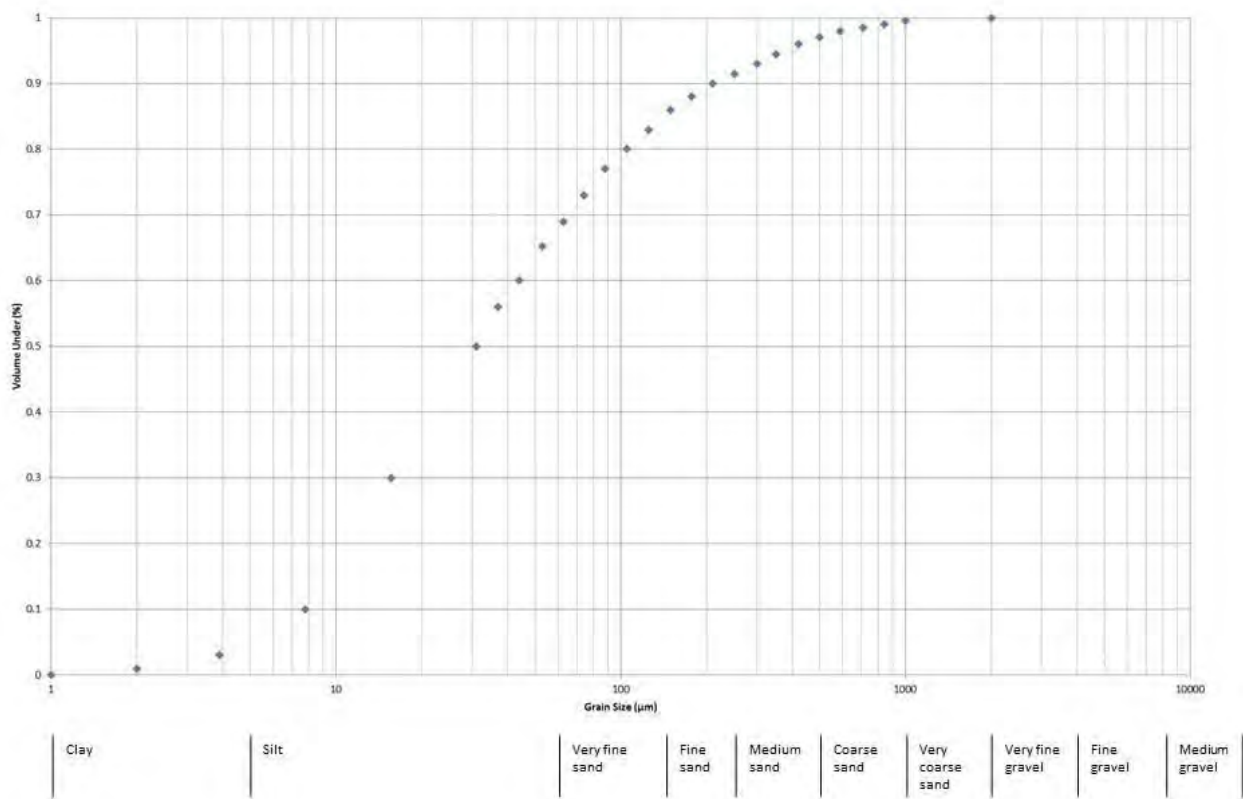


Figure 8: Estimated grain size distribution for the EMP.

Settling velocities for each of the grain sizes in Figure 8 have been determined using Stokes Law (Equation 9). The soil density of the material was assumed to be 1900 kg/m³ for the purposes of this assessment. By relating the grain size distribution to the settling velocities, a chart has been developed indicating the proportion removed for a given settling velocity (Figure 9).

Equation 9: Stokes Law (Batchelor, 1999)

$$V = \frac{D^2 \cdot g \cdot (\rho_{solid} - \rho_{fluid})}{18 \cdot \mu}$$

V = settling velocity (m/s)

D = particle diameter (m)

ρ_{solid} = solid density (kg/m³)

ρ_{fluid} = fluid density (water, 1000 kg/m³)

μ = viscosity (kg/m · s)

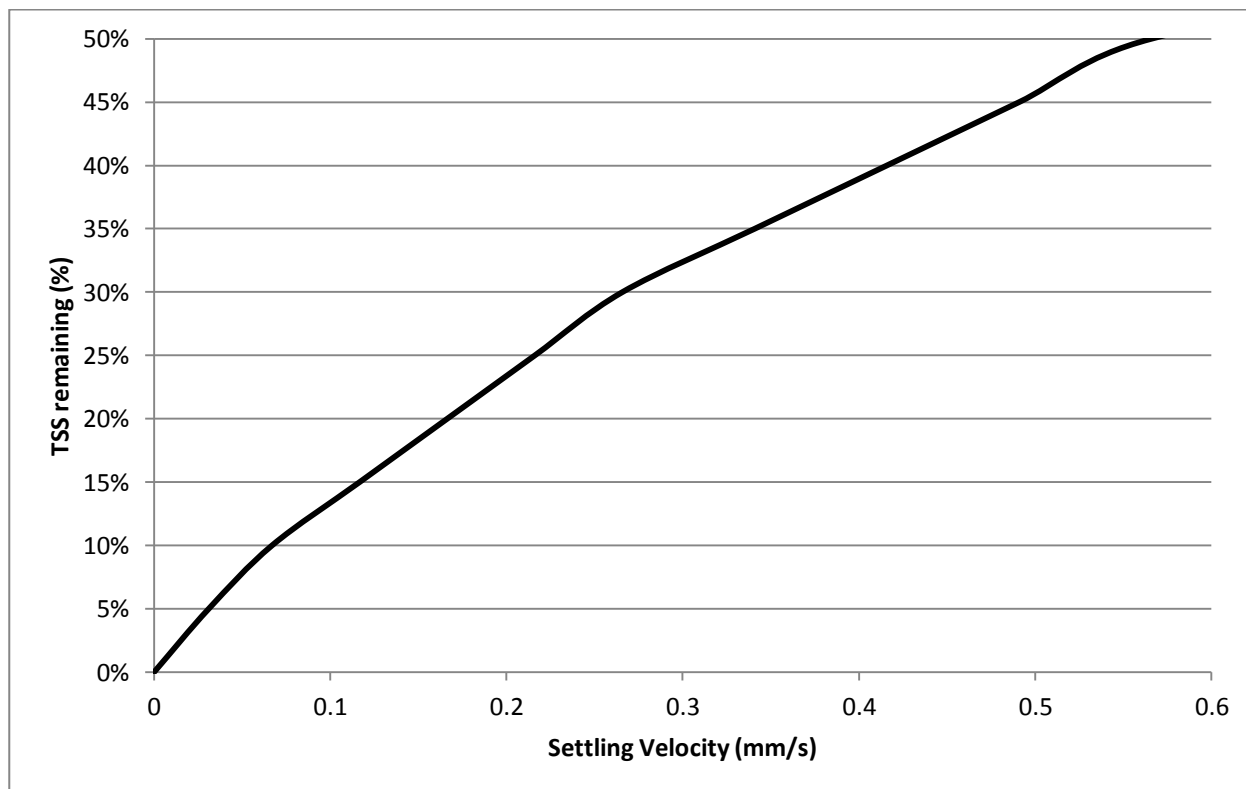


Figure 9: Proportion of TSS remaining for given settling velocities.

In the above chart the settling velocity for the appropriate TSS removal efficiency is equivalent to the pond overflow rate, where the overflow rate is the ratio between flow through the pond and the ponds effective area, and the removal efficiency is the inverse of the TSS remaining.

Sedimentation pond sizing is sensitive to the assumed particle size distribution. In particular, a higher proportion of fine particles would result in a significant increase in the RPA. Given that no site-specific data are available for the EMP, a carefully controlled monitoring programme is required during the early stages of mine development to gather the data required to adapt the sediment control structure design to meet actual conditions encountered.

Treatment Flows

The pre-settlement pond designs in this toolkit are based on sediment control during peak flow rates in order to provide sufficient pre-treatment of site water to support the effective operation of the MIW-WTP. As identified previously in this report, consent conditions require that the MIW-WTP should discharge runoff at or below 30 mg/l 95 % of the time. The 95th percentile daily rainfall for the site during the wettest year is 114 mm.

The rational method can be used to determine a daily flow rate from the 95 % rainfall. For the purposes of determining an RPA, a 1 hectare unit area has been used for assessing treatment flows. Treatment flows for the site are provided in Table 8.



Table 8: Treatment flows.

Catchment	Treatment Flow
Pit, Hardstand, and Roads	1600 m ³ /day
ELF Uncovered, ELF Covered and partially revegetated	1300 m ³ /day
ELF Rehabilitated & Natural*	500 m ³ /day

RPA by catchment

The RPA has been determined for each of the catchment land use types based on the required TSS removal (Table 7), settling velocities (Figure 9) and the treatment flows (Table 8) for a unit area (1 ha). RPA's are summarised in Table 9 below.

Table 9: RPA by catchment land use.

Catchment Land use	RPA (m ² /ha)
Pit	540
ELF- Uncovered	560
ELF- Covered and partially revegetated	140
Hardstand	60
Road	60

Treatment Train

The RPA approach has been adopted to allow for treatment of runoff from to be distributed throughout the catchments, allowing for greater adaptability to the site layout and topography and the utilisation of multiple ponds to improve the overall trap efficiency.

Treatment trains include sediment dams, ponds and pocket ponds although it is expected that smaller infrastructure such as check dams and bundled brush stops (slope reinforcement) will provide some retention of sediment, these structures have not been included in the treatment train assessments as they are primarily for velocity control.

The accounting of RPA throughout the system must be evaluated from the top of the catchment and down to the bottom and not by treating the entire catchment as a whole. This is because a given pond can only provide treatment to catchment upstream, and there is no means of proportioning the pond sizes to the upstream catchments without assessing them individually. The formula below (Equation 10) can be used to calculate the remaining RPA at the outlet of a pond.

Equation 10: RPA tabulation

$$R_{p1} = C_1 \cdot RPA + R_{p\#} + \dots + R_{p\#} - P_1$$

R_{p1} = remaining RPA at pond outlet
 C_1 = Area of catchment 1 (ha)
 RPA_1 = RPA of immediate contributing catchment (m²/ha)
 $R_{p\#}$ to $R_{p\#}$ = remaining RPA from all upstream catchments (m²)
 P_1 = Pond Area (m²)



An end of catchment pond is sized using Equation 10 by setting the remaining RPA at pond outlet (R_{P1}) to 0 m², and solving for the pond area that should be constructed for each catchment. The in catchment pond areas can be optimised to reduce the end of catchment pond size according to topography and space availability.

9.5 Treatment Facilities

9.5.1 Facility dimensions

All treatment ponds and dams on the site have been assumed to have the following proportions:

- Length to Width Ratio of 4:1. A ratio of 3:1 to 5:1 optimises the length of the flow path between the inlet and the outlet, allowing flow to spread laterally from the point of entry as it travels through the pond and reducing the potential for short circuiting. The length to width ratio of sedimentation structures should therefore be kept within the 3:1 and 5:1 range. Where a minimum ratio of 2:1 cannot be achieved, baffles should be installed in larger ponds. Baffles should be installed such that maintenance and sediment removal operations are not encumbered.
- 2H:1V bank slopes have been assumed for the purposes of dimensioning ponds for hydraulic analysis. As a rule, the slopes can be made more gradual, provided the dimensions of the base and the depth are maintained.
- Short circuiting factor of 1.5, the short circuiting factor is similar to a safety factor and has been introduced to accommodate for potential concentration of flow through the centre of the pond, which effectively reduces the treatment area of the facility. The effective area of the facility is equivalent to the actual depth averaged area² divided by the short circuiting factor. A short circuiting factor of 1.5 is considered to be conservative for a rectangular pond and has been applied to accommodate for distortions in the dimensions of dams or ponds due to site constraints. As noted above, baffles should be installed in ponds where an appropriate length to width ratio is not feasible.

Where adaptation of ponds and dams to site constraints are required the following criteria should be maintained in the final design:

- Effective area as identified in the design toolkit.
- Length to width ratio of between 3:1 and 5:1. Where a rectangular surface shape is not practicable, the width and length should be taken as average dimensions which are normal to each other.
- Pond base dimensions.
- Pond depth and volume, where the facility is constructed with an uneven base (in the case of a dam) the depth should be an area weighted average depth, and the overall volume should be maintained.

Pocket ponds are assumed to be square with 2H:1V side slopes, be less than 150 m² at surface, and have level spreaders installed across the outlet to ensure full pond use (as shown in the design sheets). Pocket ponds should be minimally adjusted to the site, and if available space is constrained then the ponds should be reduced in size and be placed more frequently.

Sediment ponds and dams can be used in a low areas or natural drainage ways. They should be located where surface water naturally flows or collects. Sediment ponds/dams should be located to intercept the largest possible amount of runoff from the site. Drainage into the basin can be improved by diversion dikes and ditches.

Drainage options to restore available capacity in the pond following periods of rainfall include armoured spillways, floating skimmers, stand pipes and infiltration. A floating siphon or skimmer (aka decant) is the

² Depth averaged area is the plan area of the facility at half of the water depth.



recommended method, as it continuously dewateres the pond by removing the cleanest water from the top of the water column at the surface of the pond. The ponds are not intended to provide any storage capacity for the site, so they do not require a dewatering system for day to day operation. If the ponds do not drain naturally through the base and sides during dry periods dewatering will be required for removal of captured sediment. This can either be accomplished by a permanent structure (described above) or by pumping the water temporarily. If a pumping option is used, care should be taken to avoid the re-entrainment of sediment in the pond if discharging downstream.

A staff gauge should also be installed in the pond. This will allow the water level to be read during or after rainfall, as well as enabling an accurate reading of the depth of sediment accumulated in the pond to be taken during dry periods. In place of a staff gauge a well secured pole can be installed in the pond which has critical depths recorded on it for reference (e.g., maximum sediment level, maximum water level, bottom of spillway).

9.6 Major Sediment Control Structure

Preliminary sediment control structures have been designed previously for the EMP site (Golder, 2012d). It is expected that as the mine plan progresses and the sediment and erosion control system goes into a detailed design phase, these pond sizes can be reassessed and the end of catchment ponds can be resized to account for the inclusion of treatment and erosion prevention practices upstream and to incorporate monitoring data from existing structures.

10.0 DESIGN TOOLKIT

The design toolkit (Appendix B) has been developed based on this SECP as detailed in previous sections of this document, and provides a design basis for development of sediment control and erosion prevention practices on the EMP site. The toolkit has been developed to progress in a logical design manner, where the catchment is first laid out (final topography is determined, sub-catchments are delineated, drain locations are chosen, and preliminary pond locations are chosen), the conveyance systems are designed followed by pond sizing. Design of a sediment and erosion control system is an iterative process, which requires an initial estimation of required infrastructure and then optimisation on the basis of monitoring results to determine the most effective and efficient setup. The design sheets in the Toolkit are as follows:

Table 10: Design Toolkit

Design Sheet		Description
A	Runoff Estimation – 10 year	Tabulation of peak storm flows for 1/10 year design storms by catchment land use type.
B	Runoff Estimation – 100 year	Tabulation of peak storm flows for 1/100 year design storms by catchment land use type.
C	Channel Dimension Guide	Example design sections for channels on the EMP site, including some design notes for reference.
D	Channel Sizing	Tabulation and details of various channel sizes determined using Manning's equation for open channel flow. These design sheets also include channel lining requirements.
E	Channel Sizing – Continued	
F	Grouted Rock and Gabion	Details of grouted rock and gabion mattress design methods and criteria.
G	Chute and Apron	Design details for chute and apron design, including details of recommended programs for detailed design.
H	Check Dams	Details of check dam design and placement.



Design Sheet		Description
I	Confluence Structure	Details of confluence structure layout and design.
J	Contour Drains	Details of contour drain layout and design.
K	Required Pond Area (RPA)	Method to determine pre-settlement basin RPA and to track RPA requirements through treatment train.
L	Pond and Dam Dimensions	Pond dimensions based on effective area.
M	Pond and Dam Inlet and Outlet	Details of inlet and optional outlet layout and design.
N	Spillway Design	Details of spillway design.
O	Typical Rock Spillway	Details of typical spillway layout.
P	Typical Excavated Pond	Details of typical pond excavation.
Q	Pocket Pond Design	Pocket Pond dimensions and typical layout.
R	Typical Diversion Design	Method for aligning construction phase diversion, including typical layout.
S	Revegetation	Details of revegetation including grassing and hydroseeding methodology.
T	Ground Cover and Stabilisation	Details of Straw and Wood Mulch covering for immediate protection of disturbed areas.
U	Slope Stabilisation	Details of bundled brush stops and slash cover for the purposes of slope stabilisation.
V	SECP – Emergency Response	Considerations for emergency responses in the event of a sediment or erosion control system failure.

11.0 INSPECTION, CLEANING AND MAINTENANCE

US Department of Interior 1982 notes that poor maintenance is one of the major problems in performance of existing sedimentation ponds, and hence development of a maintenance programme is a significant part of the pond design.

A core component of the SECP is the trapping of sediment, and as such the infrastructure which traps the sediment requires regular sediment removal. Prior to operation of the sediment and erosion control system, an inspection program should be developed for the site, including details of the planned infrastructure. When new infrastructure is added to the system, the inspection plan should be revised to include it. The inspection plan should include frequency of inspections (monthly intervals, and after significant rainfall events), record keeping procedures and clean out or maintenance triggers for each of the infrastructure types or for individual infrastructure on the site. It is imperative that all sedimentation structures are constructed such that regular removal of sediment can be undertaken efficiently.



12.0 CONTINUAL IMPROVEMENT FEEDBACK

This toolkit is based on current understanding of likely runoff rates and soil properties at the mine site, based on experience from other mine sites and analysis of available hydrological records. The toolkit should be considered a ‘live document’, to be updated based on learnings from the Escarpment Mine during the early development stages. Good monitoring and documentation of the performance of ESC infrastructure is a key part of this. To this end it is recommended that one of the major sediment ponds constructed at the foot of the ELF in the first year of mine operation should be installed with basic flow monitoring equipment, with regular monitoring of sediment concentrations both into and out of the pond. The catchment area draining to the pond and the land use within the catchment (e.g., 30 ha partially rehabilitated, 5 ha uncapped dump) should also be recorded at regular intervals.

A TSS sampling programme should be implemented within the first year of mining operations to determine whether the TSS concentrations assumed for this toolkit are representative of concentrations encountered in runoff from the mine site. Samples should also be collected and tested for particle size distribution and settling velocities.

The information gathered from the sampling and monitoring recommended above should be reviewed after one year of mining operations and the results used to update the toolkit as required. The results of this review could indicate either that sediment concentrations are higher than expected and hence larger sedimentation infrastructure are required, or conversely that future infrastructure could be downsized. The continual improvement process will therefore help to control both risks and costs.



13.0 REFERENCES

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APPENDIX A

Report Limitations

Report Limitations

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APPENDIX B

Toolkit Design Sheets

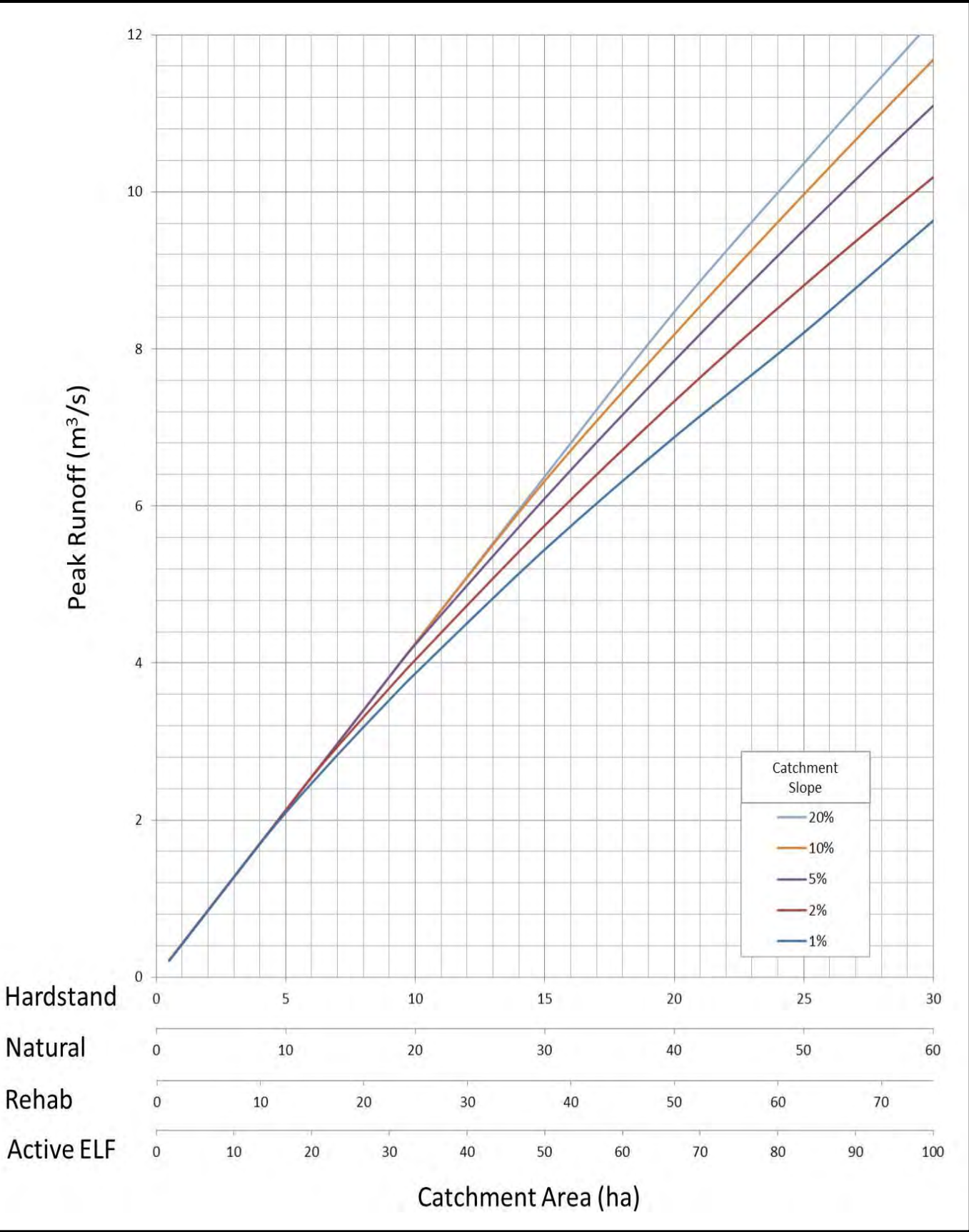
RUNOFF ESTIMATION – 10 year
RUNOFF ESTIMATION – 100 year
CHANNEL DIMENSION GUIDE
CHANNEL SIZING
CHANNEL SIZING CONTINUED
GROUTED ROCK & GABION
CHUTE AND APRON
CHECK DAMS
CONFLUENCE STRUCTURE
CONTOUR DRAINS
REQUIRED POND AREA (RPA)
POND AND DAM DIMENSIONS
POND AND DAM INLET AND OUTLET
SPILLWAY DESIGN
TYPICAL DAM EMBANKMENT
TYPICAL EXCAVATED POND
POCKET POND DESIGN
TYPICAL DIVERSION DESIGN
REVEGETATION
GROUND COVER AND STABILIZATION
SLOPE STABILISATION
EMERGENCY RESPONSE
EMERGENCY RESPONSE CONTINUED

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RUNOFF ESTIMATION – 10 year

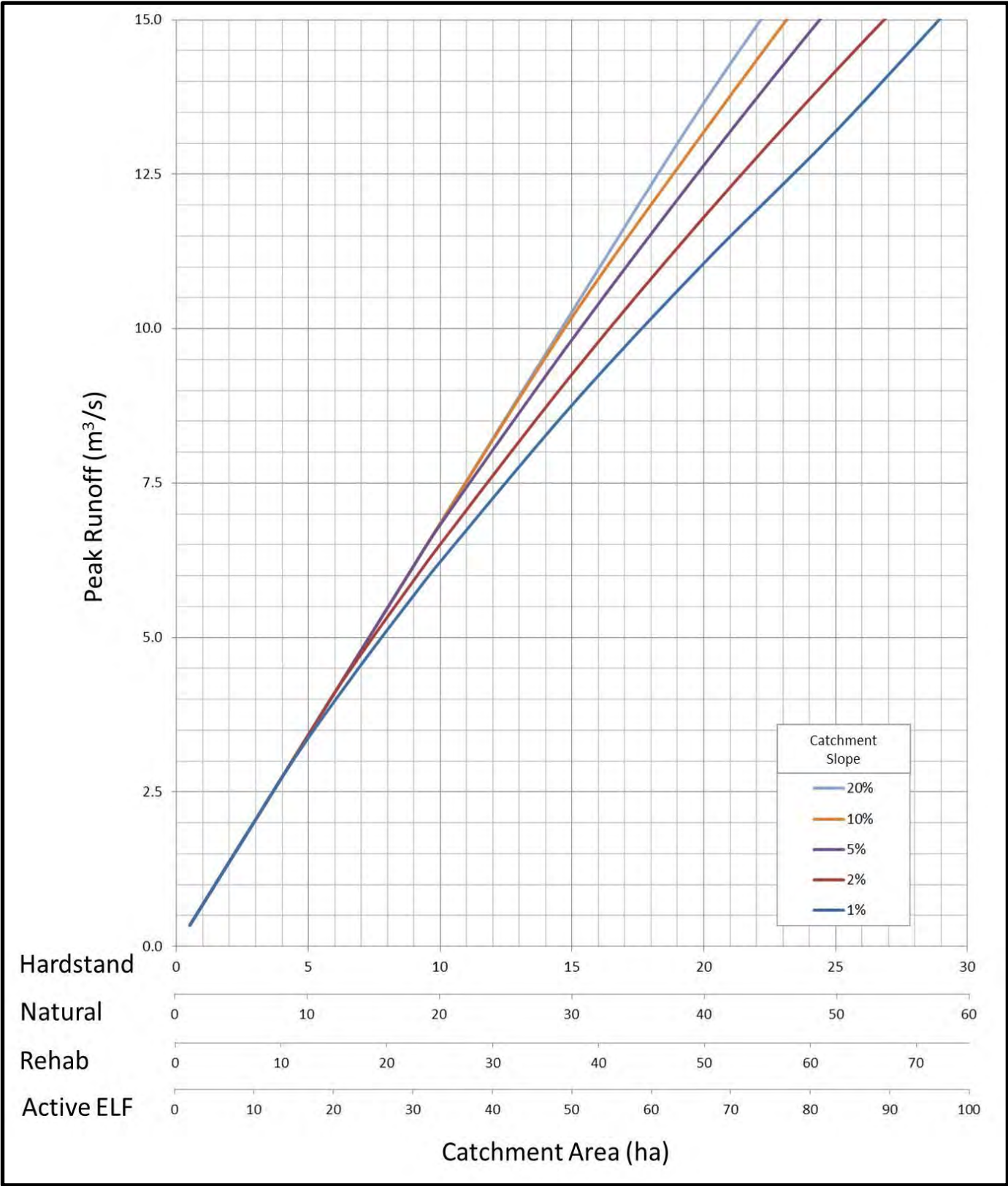
A

Application:
The chart provided in this design sheet and in Design Sheet B can be used to estimate catchment runoff rates for the EMP site from storms of 10 year and 100 year recurrence intervals respectively. Runoff flows are selected using the relevant land use and slope for the catchment in question. Refer to Section 6 of the Sediment and Erosion Control Plan for details.



RUNOFF ESTIMATION – 100 year

B



Design Notes:

Use the contributing catchment area, consequence of failure and the governing landuse to determine the relevant design flows for downstream infrastructure from the table or charts above.

Consequence of failure within the EMP operating area is to be estimated by the Mine operators.

Where failure of the infrastructure would result in a direct discharge to the surrounding environment (i.e. there are no appropriately sized intercepting drains between the point of failure and the receiving environment) a design storm of 100 year ARI should be used.

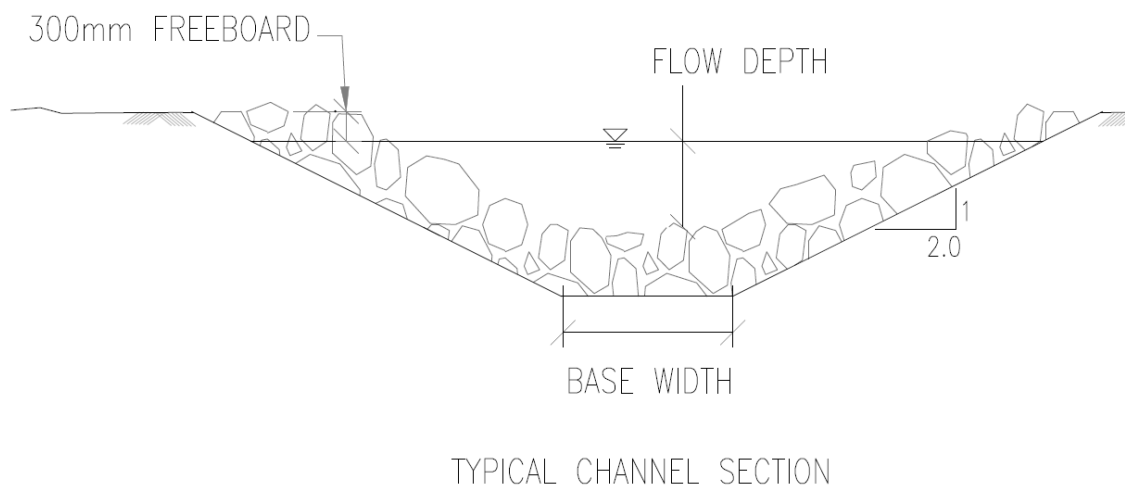
CHANNEL DIMENSION GUIDE

C

Application:

The following sections and notes are to be used to estimate the relative placement and designs of all channels for the EMP site. Refer to Section 9 of the Sediment and Erosion Control Plan for details.

Typical Channel Sections



Design Notes:

Channel size is determined from Design Sheets D (slopes $\leq 2\%$) and E (slopes $> 2\%$ & $< 10\%$) based on design flows determined from Design Sheet A and B.

Where the channel is excavated in hard rock, lining or riprap are not required. Channel's excavated in hard rock may be considerably less costly because they do not require protection. Where possible channels should be constructed in hard rock.

Where longitudinal slopes greater than 10% are necessary, channels should be designed as chutes (Design Sheet G).

Where longitudinal slopes are greater than 4% or flow velocities are greater than 1.5 m/s, flow dissipating check dams should be installed (Design Sheet H).

Armouring of channels should be applied at or exceeding the size requirements identified in Design Sheet D and E.

Channel designs have been standardized for the purposes of this toolkit and assume a 1V:2H bank slope, a 300 mm freeboard and an armouring rock specific gravity of 2.64. Where these assumptions are not feasible or are not appropriate (e.g. the bank slope is unstable at this slope, or armouring rock is lighter than the design) the channel designs should be reassessed by a qualified professional.

Placement of riprap should be hand placed or machine placed under direction to prevent excessive segregation or breakage of the stone. Dumping, re-handling and/or dragging operations to place and smooth the revetment surface should be avoided where possible to reduce segregation and breakage. Where dumping and spreading of riprap is necessary, care should be taken to reduce the height from which riprap is dropped and re-handling should be reduced where possible. Riprap design details are discussed further on Design Sheet E.

Where the channel is constructed above loose PAF fill, an impermeable liner should be installed between the riprap and the ground surface. The impermeable liner should be sourced and placed such that punctures are minimized.

Machine access should be maintained to all operational channels for maintenance purposes.

CHANNEL SIZING

D

Application:

The following tables are a series of standardized channel sizes based on flow, base width, and slope. The channels all have a bank slope of 1V:2H and include 300 mm of freeboard. More channel sizes are provided in Design Sheet E. Refer to Section 9 of the Sediment and Erosion Control Plan for details.

Flow	Base Width	Manning's n	Flow Depth	Channel Depth	Velocity	Minimum D ₅₀	Armouring Bracket D ₁₀ to D ₁₀₀
(m³/s)	(m)		(m)	(m)	(m/s)	(mm)	
1% Slope							
0.1	0.5	0.041	0.2	0.5	0.6	30	Unlined
0.25	0.5	0.045	0.35	0.65	0.7	50	Unlined
0.5	0.5	0.048	0.45	0.75	0.8	70	Unlined
1	0.5	0.05	0.65	0.95	1	90	Unlined
2.5	1	0.052	0.85	1.15	1.2	120	60 mm to 360 mm
5	1	0.054	1.2	1.5	1.3	160	80 mm to 480 mm
10	2	0.053	1.4	1.7	1.6	170	90 mm to 510 mm
15	4	0.054	1.3	1.6	1.7	190	100 mm to 570 mm
2% Slope							
0.1	0.5	0.057	0.2	0.5	0.6	60	Unlined
0.25	0.5	0.061	0.3	0.6	0.8	90	Unlined
0.5	0.5	0.066	0.45	0.75	0.9	130	70 mm to 390 mm
1	1	0.063	0.5	0.8	1	140	70 mm to 420 mm
2.5	1	0.063	0.8	1.1	1.3	180	90 mm to 540 mm
5	1	0.063	1.1	1.4	1.6	210	100 mm to 630 mm
10	2	0.061	1.2	1.5	1.9	230	110 mm to 690 mm
15	4	0.059	1.2	1.5	2.1	230	110 mm to 690 mm

Flow	Base Width	Manning's	Flow Depth	Channel Depth	Velocity	Minimum D ₅₀	Armouring Bracket
(m³/s)	(m)	n	(m)	(m)	(m/s)	(mm)	D ₁₀ to D ₁₀₀
5% Slope							
0.1	0.5	0.061	0.15	0.45	0.8	140	70 mm to 420 mm
0.25	0.5	0.06	0.25	0.55	1.1	190	100 mm to 570 mm
0.5	0.5	0.061	0.35	0.65	1.2	250	130 mm to 750 mm
1	0.5	0.057	0.5	0.8	1.6	180	Gabion / Grouted
2.5	1	0.088	0.75	1.05	1.4	300	Gabion / Grouted
5	1	0.056	0.8	1.1	2.4	400	Gabion / Grouted
10	2	0.064	0.8	1.1	2.4	500	Gabion / Grouted
15	3	0.067	1.1	1.4	2.7	700	Gabion / Grouted
10% Slope							
0.1	0.5	0.059	0.15	0.45	1.1	50	Gabion / Grouted
0.25	0.5	0.051	0.2	0.5	1.5	50	Gabion / Grouted
0.5	0.5	0.049	0.3	0.6	1.9	180	Gabion / Grouted
1	0.5	0.066	0.4	0.7	1.9	400	Gabion / Grouted
2.5	1	0.066	0.5	0.8	2.3	500	Gabion / Grouted
5	1	0.071	0.8	1.1	2.6	700	Gabion / Grouted
10	2	0.07	0.9	1.2	3.1	800	Gabion / Grouted
15	3	0.072	1	1.3	3.3	900	Gabion / Grouted

Design Notes:

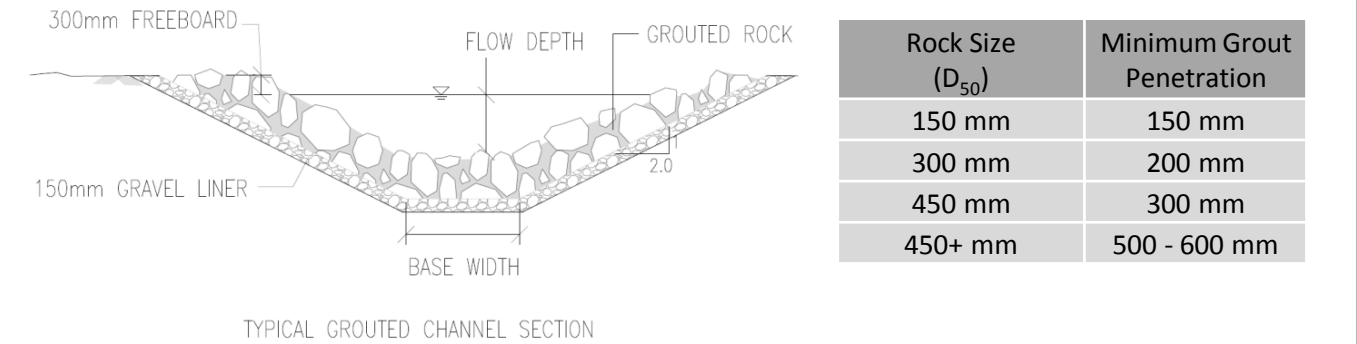
The channel dimensions provided above are exclusive of the channel armouring layer for excavation dimensions, the liner thickness should be added to the total depth.

The thickness of the channel lining should be either 300 mm or 30% deeper than the largest rock size used (i.e. if D₅₀ is 100mm and sizes range from 150 mm to 600 mm then the channel lining would be 780 mm). The additional 30% is to account for a general lack of control during placement. Where the rip rap is or sufficient size that it is placed by machine and there is considerable direct control over the placement, the additional 30% is not likely to be required provided that the required channel dimensions can be achieved.

Refer to Design Sheet F for details of gabion mattresses and grouted rock linings.

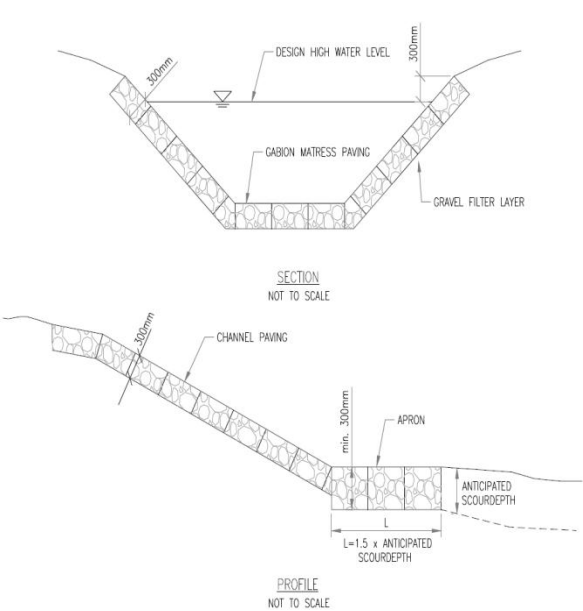
Application:
 Grouted Rock Channel Linings and Gabion Mattresses - stabilized liner for steep slopes. The need for a grouted liner can be determined from design sheet C. Refer to Section 9 of the Sediment and Erosion Control Plan for details.

Grouted Rock Channel Lining



Design Notes:
 Grouted riprap is rigid but not extremely strong, and requires even support from the ground to prevent cracking. The embankment and the stream bed should be lightly compacted, and large stones removed to provide even support.
 Grouted rock channels should be constructed as a regular rock lined channel, with grout applied after placement. The grout should penetrate to the depth provided in the above table. Spading, rodding and other manual work may be required to reach the minimum penetration requirements. The rock should be wetted prior to grouting.
 Approximately ¼ of rock diameter should protrude from grout to achieve an appropriate roughness.
 A filter layer of gravels, 150 mm thick is required below grouted rip rap to provide drainage of seepage and reduce the hydrostatic pressure on the underside of the grout layer.
 Weep holes should be installed in the grouted riprap. Weep holes are to be 75 mm in diameter and be spaced 2 m laterally and 3 m longitudinally. Plastic mesh cages should be installed on the buried end of the weep hole to prevent transmission of gravel.
 For Riprap of D₅₀ greater than 250 mm an alternative to grouting riprap for , a highly angular AP65 (D₁₀₀ of 65 mm) can be used in it’s place. Where AP65 is used instead of grout it should be monitored frequently and losses should be replaced as soon as practicable.

Gabion Mattress Channel Lining



Design Notes:
 Gabion mattresses and cages should be constructed of plastic or PVC coated mesh due to the high potential for acid generation on the site. Care should be taken in the construction of gabions such that the PVC coating is not disturbed.
 Gabions should be monitored for corrosion and where corrosion is identified should be repaired with a non-corrodible material or the rock should be grouted in place.
 An alternative to Gabions which can be considered is a geotextile rock and sand container system sewn together to form a continuous streamlining barrier (see [Elcorock](#)). Sizing and placement of such a system should be undertaken by a suitably qualified professional.
 Stones in mattresses are to be well graded with 70% (by weight) larger than the mesh openings of the gabion.
 Gabion thickness should be at least 300 mm, or D₁₀₀ of the fill material.
 Protection should extend to the top of the freeboard.
 Gabions should be divided into compartments to reduce the impact of individual failures.
 Gabion units should be a size that is easily manoeuvrable on-site.

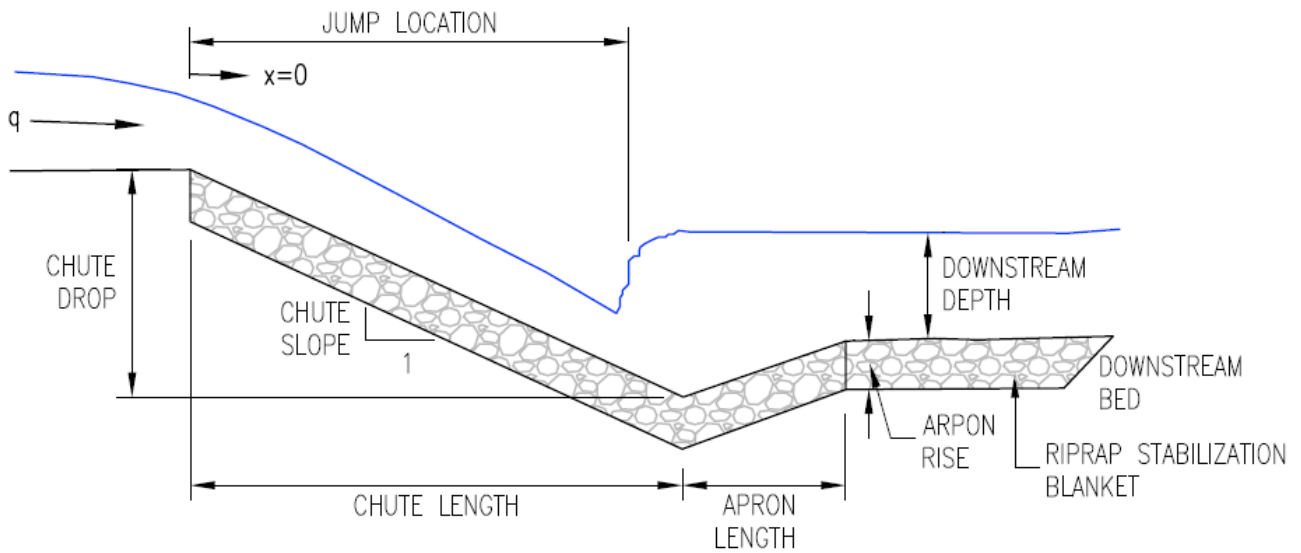
CHUTE AND APRON

G

Application:

All steep channel sections with a longitudinal slope between 10% and 20%, including pond inlets and drainage chutes conveying water from contour drains down steep slopes. For chutes with a longitudinal slope greater than 20% use a concrete chute. Refer to Section 9 of the Sediment and Erosion Control Plan for details.

Conceptual design of a Rock Chute and Apron



Source: CHUTE Version 1.0.0, CRC for Catchment Hydrology (2003)

Required Inputs:

- Chute drop (m)
- Chute Length (m)
- Apron Rise (m)
- Apron Length (m)
- Min Flow ($0 \text{ m}^3/\text{s}$)
- Max Flow (m^3/s)
- Chute Width (m)
- Rock Angle of Repose (37°)
- Specific Gravity of Rock
- Factor of Safety
- Downstream
 - Bed Slope
 - Roughness
 - Channel Width (m)

Design Notes:

Use CHUTE 1.0.0 program (Cooperative Research Centre for Catchment Hydrology) or similar program for chute and riprap sizing.

Determine maximum flow from Design Sheet A and B

Adjust chute slope (drop/length), width and apron dimensions until an acceptable liner and shape are achieved.

Where a concrete chute is required, the design should be based on the method described in "Design of Small Dams, 1977" Section 9.21 – *Hydraulic Jump Basins*.

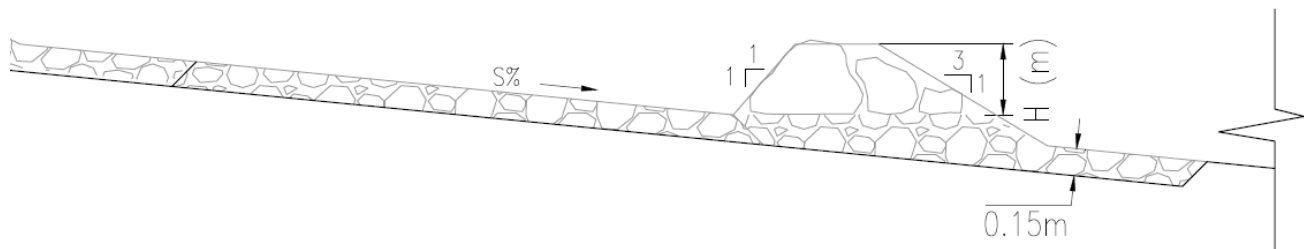
Where chutes are constructed in bedrock, the apron and rise can be formed using large rocks from the site bolted in place with grouted anchors.

Chutes should be designed by a qualified professional.

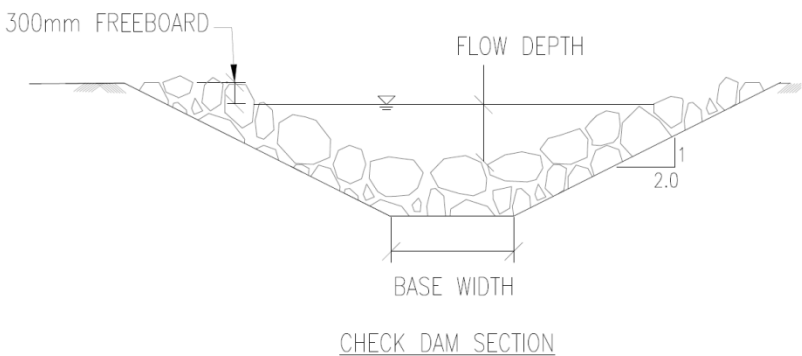
Application:

Check dams are used in channels with velocity greater than 1.5 m/s to reduce the velocity of the water. Check dams are not applicable to grouted channels, and may be constructed from armour rock or rock gabions as determined from the channel armouring in design sheets D, E and F. Refer to Section 9 of the Sediment and Erosion Control Plan for details.

Check Dam standard layout and dimension



DRAINAGE LONGITUDINAL SECTION WITH CHECK DAMS



Example 0.5 m high dams	
Channel Slope	Spacing (m)
<2%	24
2 – 4%	12
4 – 7%	8
7 – 10%	5

Design Notes:

- Check dams should be constructed of large rocks the lesser of 0.5 m in diameter or 0.5 x flow depth.
- Where the size of the riprap lining the channel is larger than 0.5 m, check dams should be constructed of larger rocks extending no more than 0.5 m into the stream channel.
- Where the channel is excavated in bedrock, check dams should be bolted in place with a corrosive resistant bolt.
- Where the channel is lined with gabion or grouted rock, gabions or grouted rock piles should be used to construct the check dams. The proportions shown above should be maintained.
- Channel banks should be increased in the areas surrounding check dams to maintain the require flow depth over them.
- The spacing between check dams is to be such that the height of a given check dam is at or above the same level of the preceding one, and can be determined from the table provided above for dams with a height of 0.5 m.

Reference:

For further information on the constructability of check dams use Auckland Regional Council (ARC) Erosion and Sediment Control Guideline, 2007

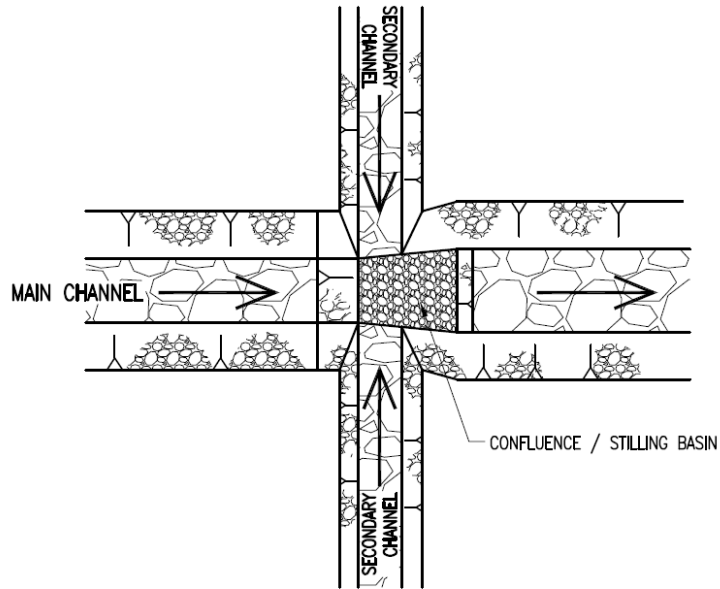
CONFLUENCE STRUCTURE

I

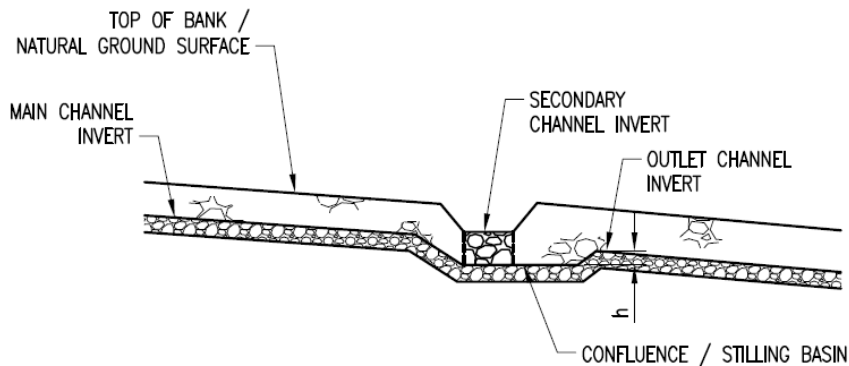
Application:

A stable bed structure to prevent erosion at channel and contour drain confluences. This design can also be applied to pond inlets with more than one tributary. Refer to Section 9 of the Sediment and Erosion Control Plan for details.

Conceptual confluence layout



PLAN VIEW
NOT TO SCALE



PROFILE VIEW
NOT TO SCALE

Design Notes:

Determine inflow channel sizes from Design Sheet C.

The stilling pool can be sized as a square with sides equivalent to the downstream channel width.

An apron rise of the lesser of $0.5 \times$ water height or 0.5 m is included to form a stilling basin at the confluence.

The apron rise can be constructed similarly to the check dams described in Design Sheet H.

All inlet channels should be constructed such that they have a drop into the stilling pool.

Where the confluence receives water from one or more chutes, the chutes should be designed so that the hydraulic jump occurs prior to the stilling pool, or the basin should be designed by a qualified professional.

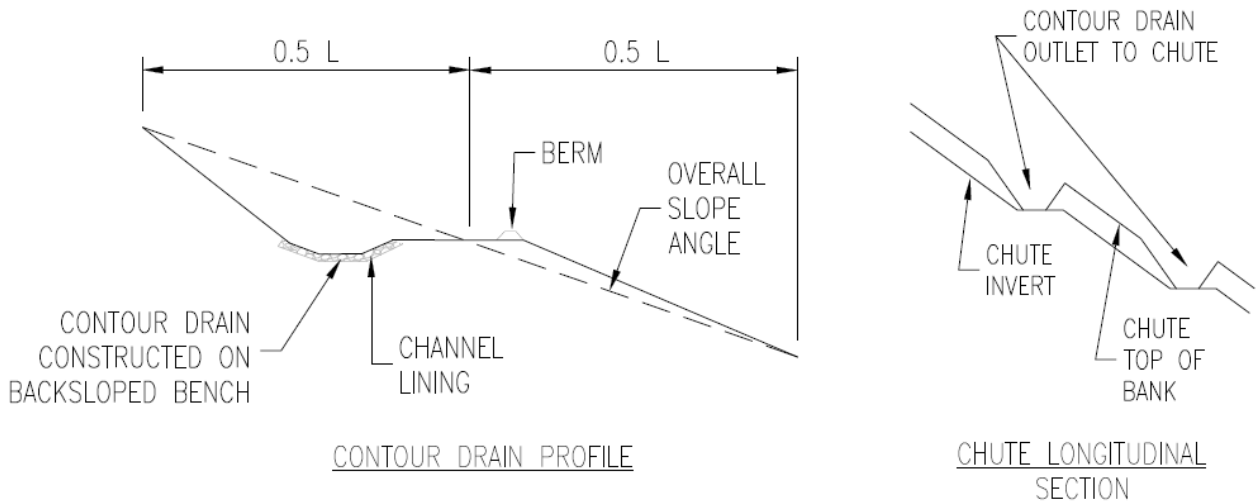
CONTOUR DRAINS

J

Application:

Contour drains are used on benches of constructed slopes to reduce the overland flow path in steep areas and to reduce the opportunity for concentration of flow. These drains should exit into chutes designed to convey flow down the steeper slope without causing gullying or erosion.

Contour drain standard layout



Design Notes:

Contour drains should follow the contour of the reconstructed landscape with the minimum slope required to facilitate flow in the channel towards the chutes and maintain stability within the width of the bench.

Contour drains are to be designed using Design Sheet C.

Typically contour drains require minimal armouring. Where contour drains are to be permanent structures post closure, they should be grassed.

Where contour drains are to be permanent, care should be taken to ensure rehabilitation vegetation does not block critical sections and reduce the cross sectional area of flow without providing reinforcement of the surface material (i.e. avoid planting trees and pakihi in channel sections with large contributing catchments).

Design and placement of contour drains should be made in conjunction with the staging of the land form construction and placement of access roads. Care should be taken in the locating of drains relative to access ways such that they do not cross each other unnecessarily as this will result in installation of a culvert.

REQUIRED POND AREA (RPA)

K

Application:

The following table can be used to estimate the total Required Pond Area* (RPA) for pre-settlement of runoff from a given hectare of catchment.

The effective treatment areas are used to ensure that runoff from each catchment receives sufficient treatment prior to discharge to the MIW-WTP. An effective treatment area is the total functional pond area that provides sufficient detention time to reduce the TSS in runoff to the MIW-WTP design inflows.

Effective Treatment Areas

Landuse	Required Pond Area RPA (m ² /ha)
Pit	540
ELF- Uncovered runoff	560
ELF- Covered and revegetated	140
ELF- Rehabilitated	0
Hardstand	60
Roads and CPP	60

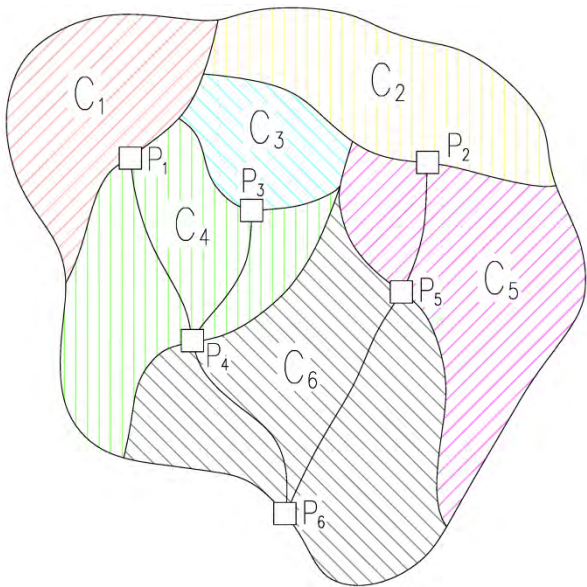
Notes:

Plan preliminary pond network and sizes, and determine appropriate areas by landuse.

Catchments are total areas upstream of ponds. Where catchments have multiple land uses the RPA for each sub-area of the catchment should be summed to determine the total RPA for that catchment.

Determine required pond area for each catchment from the adjacent table.

Treatment train setup for analysis



$$R_{Pi} = C_i \cdot RPA + R_{Pj} + \dots + R_{Pk} - P_i$$

Formula variables (see notes below for concept)

R_{Pi} is the remaining RPA for all upstream catchments after treatment in pond i (m²)

C_i is the catchment area (ha).

RPA is the required pond area for the catchment from the table above (m²/ha).

R_{Pj} to R_{Pk} are the remaining RPAs from all ponds directly upstream (m²)

P_i is the pond area (m²).

Notes:

Formula is used to calculate the total remainder RPA at the outlet of a pond. Loading from runoff is represented as a balance of RPA and pond area through the treatment train, and ensures that the pond areas upstream are not assumed to provide treatment for catchments downstream.

A negative R_p should be considered as an $R_p = 0$. negative R_p 's are an indication of over design.

Design Notes:

Determine RPA (m²) from the table above for each sub-catchment.

Assume a pond layout and preliminary pond sizes based on ease of construction and topography. Pond sizes should be less than or equal to the RPA for the upstream catchment.

Working from top of catchment to bottom, determine remaining RPA at the outlet of each pond using the formula above.

Calculate the end of catchment pond size using the formula above by making the remainder RPA (S_{P1}) equal to 0.

In-catchment pond areas can be adjusted to reduce the overall size of the end of catchment pond. Multiple small ponds are more effective than a large single pond of equivalent size.

Where sufficient treatment is provided throughout the catchment by a series of local ponds, an end of catchment pond should be included as a catchment sump and can be used to help regulate flows in the conveyance channel

Notes:

*The concept supporting an RPA weighted treatment train system is complex, refer to the Section 9.4 of the Sediment and Erosion Control Plan for a description of the principles and processes involved.

POND AND DAM DIMENSIONS

L

Application:

The table below can be used to determine appropriate proportions of a pond or a dam for a given effective pond area. In this instance, dams have been generalized as ponds. Refer to Section 9 of the Sediment and Erosion Control Plan for details.

Pond Sizes

Effective Pond Area (m ²)	Water Depth (m)	Pond Depth (m)	Base Width (m)	Base Length (m)	Volume (m ³)	Footprint (m ²)
25	1.0	1.3	1	10	38	84
50	1.0	1.3	2	15	75	138
75	1.0	1.3	3	19	113	188
100	1.0	1.3	4	23	150	236
125	1.0	1.3	5	25	188	283
150	1.0	1.3	6	28	225	329
200	1.0	1.3	7	33	300	419
250	1.0	1.3	8	37	375	508
300	1.0	1.3	9	40	450	595
400	1.0	1.3	10	47	600	766
500	1.0	1.3	12	53	750	935
750	1.0	1.3	15	65	1,125	1,350
1,000	1.5	1.8	16	75	2,250	1,862
1,500	1.5	1.8	21	92	3,375	2,690
2,000	1.5	1.8	24	107	4,500	3,506
3,000	1.5	1.8	31	131	6,750	5,117
4,000	1.5	1.8	36	152	9,000	6,710
5,000	2.0	2.3	39	169	15,000	8,517

Design Notes:

The pond dimensions in the table above are based on a standard rectangular pond with a 4:1 width to length ratio, and a short circuiting factor of 1.5, and bank slopes of 2H:1V. Pond and dam shape is governed by site topography, where possible the above dimension should be applied. However there is some conservatism built in to these dimensions which allows for adaptability to the environment.

The pond depth and footprint include a 300 mm freeboard, and are included for construction considerations.

The width to length ratio of the pond should be between 3:1 and 5:1. This width to length ratio range is used to reduce the potential for short circuiting. For non-rectangular areas (notably those common with dams), the width and length should be taken as averages.

Ponds should be designed and constructed in a form that will allow for effective cleaning and maintenance. If the pond is narrow enough and access is maintained to both sides such that the entire pond can be reached by an excavator then access into the pond itself is not necessary. Where ponds are larger, and cannot be accessed entirely from the banks, a ramp should be included and a method identified for dewatering the pond for cleaning and maintenance.

The treatment area of each pond is a depth averaged area, and is taken at the midpoint of the pond's depth.

A short circuiting factor is applied to the effective pond area to obtain an actual pond area. The short circuiting factor accounts for a reduced retention time due to flow concentrating through only part of the pond or dam. A short circuiting factor of 1.5 is conservative for the dimensions in the table above and allows for a degree of deviation from the design specifications above. In circumstances where the pond deviates significantly from the design specification (i.e. width/length ration <2, and highly irregular ponds with inlet close to outlet), baffles should be installed.

The depth has been determined based on the size of the ponds and the anticipated sediment loading between clean outs. Pond layout, sizing and access should incorporate cleaning. Where a pond is sufficiently narrow, it may be able to be cleaned out from access along one or both sides, otherwise access into the pond and the ability to dewater are required.

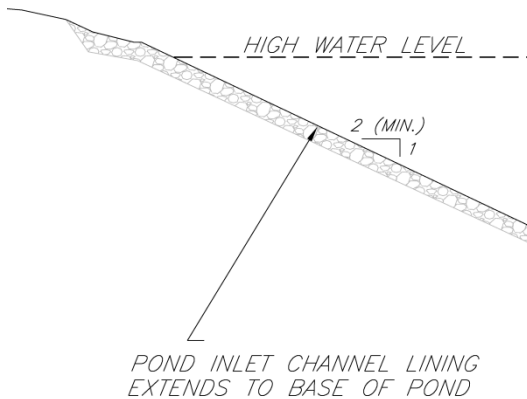
POND AND DAM INLET AND OUTLET

M

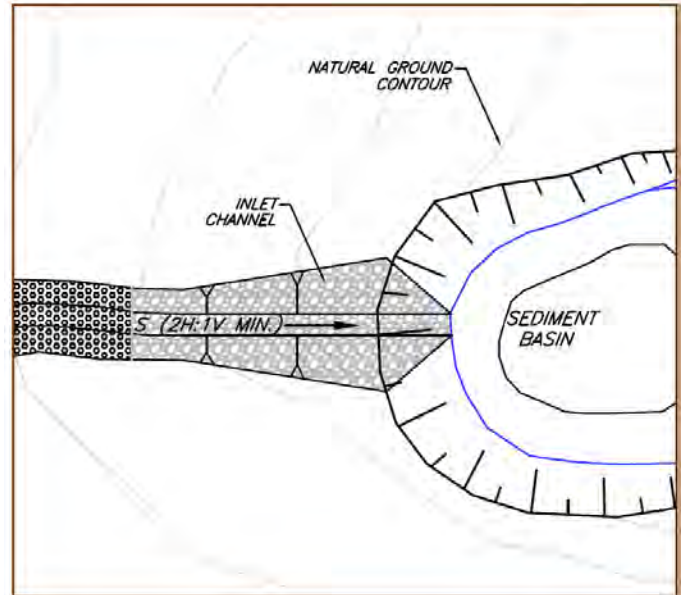
Application:

The following are design considerations for pond inlet and outlet structures. SECP Ponds within the EMP are not intended to provide any storage and therefore do not need outlet structures other than overflow weirs. A decanting option has been provided below to be used at the discretion of the mine operator. Installation of a decant could be undertaken in response to poor performance of pre-settlement ponds. Refer to Section 9 of the Sediment and Erosion Control Plan for details.

Inlet Structure



EXCAVATED SEDIMENT POND INLET PROFILE



Design Notes:

The inlet is the portion of a channel discharging to a pond where the base of the channel is below the ponds highest water level.

Pond inlets should be constructed with gabion mattresses or grouted rock (Design Sheet F)

Outlet Structure (optional)

Design Notes:

The primary outlet of ponds during rainfall events is the spillway. If it is advantageous for the ponds to drain between events, a dewatering structure should can be installed.

Outlet structures allow for the ponds to drain between storm events resulting in more storage volume being available during rain events. Optimizing the storage potential of the ponds yields higher treatment efficiencies as there is a greater lag between the start of the storm and the pond spilling. Dewatering also reduces the overall number of rain events that result in pond spilling.

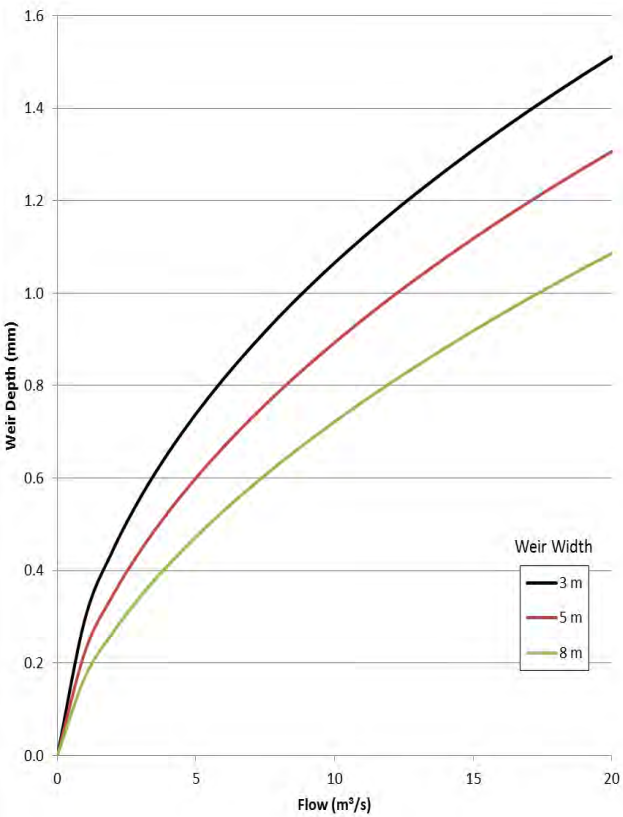
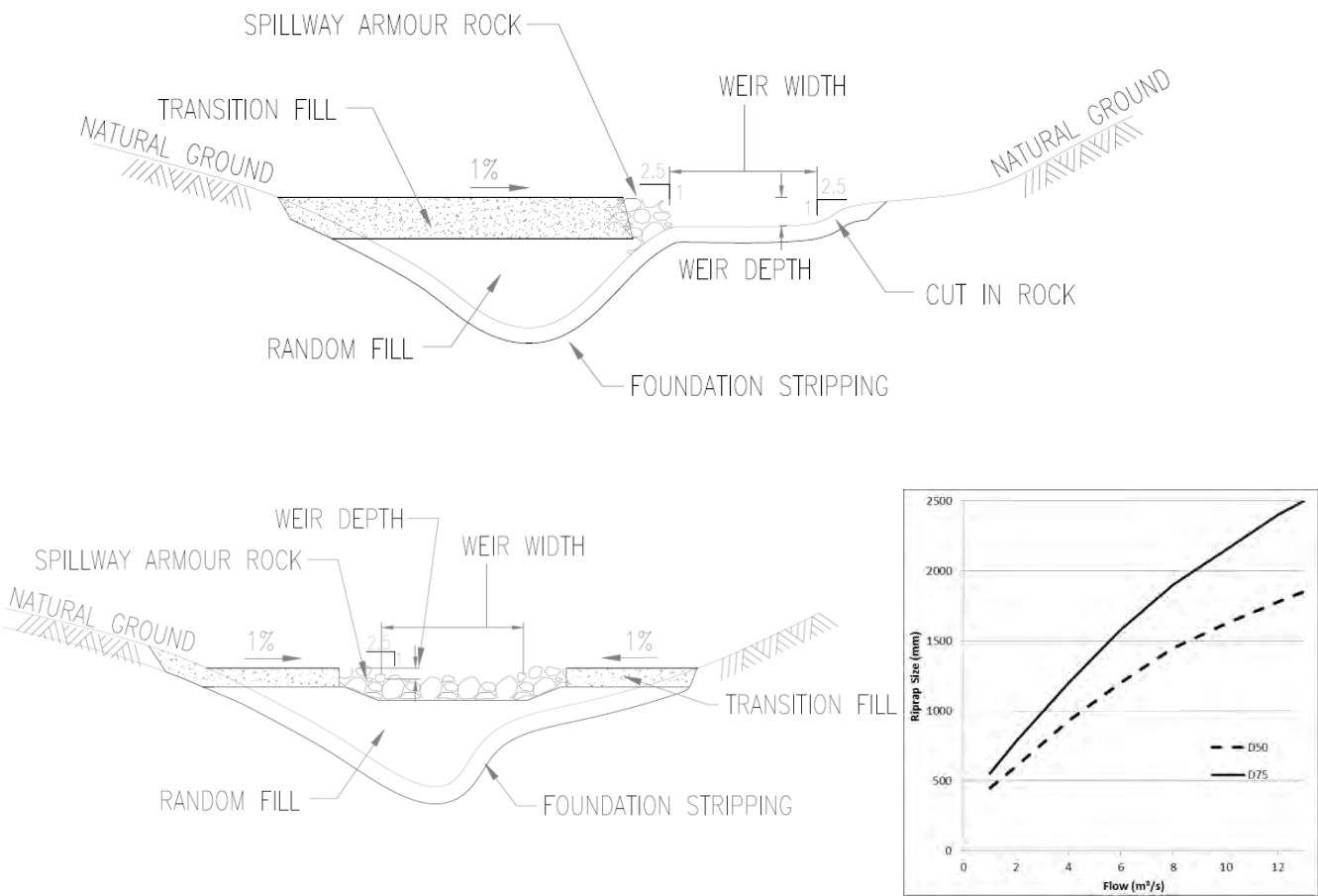
Dewatering of the ponds also reduces the amount of effort involved in cleaning the ponds, where a dewatering device is not installed, the ponds must be pumped dry prior to cleaning and for larger ponds this can be an intensive process.

Dewatering devices that have been used effectively in a context similar to Escarpment Mine are:

- Floating decants, where a flexible pipe is attached to a floating raft, with an inlet to the pipe suspended just below the water surface. The floating pipe is then directed through the embankment and discharges to the channel below.
- Dewatering Tower (Glory Hole), where a vertical culvert is installed to the height below the crest of the spillway. A pipe is then installed at the base of this tower and runs through the embankment to discharge to the channel below.

Where dewatering structures are to be used, the design and construction of them should be such that they will not hamper the cleaning of the pond, and such that sediment in the base of the pond will not effect the operation of the device (e.g. when part of the device is buried in sediment it does not pin the device down).

Dewatering devices require a discharge pipe to run through the embankment. When a pipe is installed through an embankment there is an increased risk of piping failures and the design and construction of these conduits should be done such that piping is not likely to pose any issues. A method available to reduce the potential for piping is to install the discharge conduit (PVC pipe) inside of a concrete culvert and fill the culvert with concrete. The culvert should then be lined as a standard culvert in an embankment.



Design Notes:

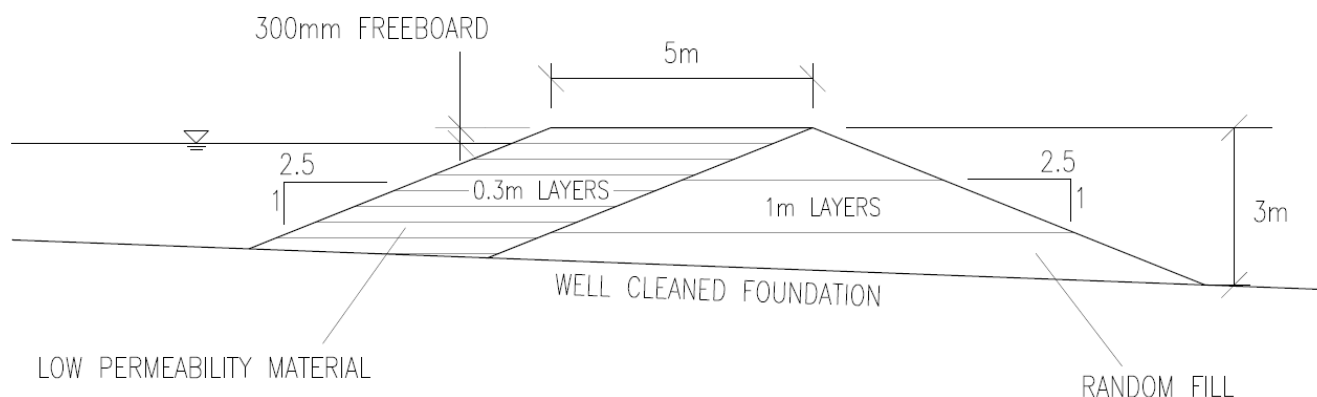
- Final layout and dimensions are specific to each sediment control structure.
- Design all spillways with flows of 100 yr ARI.
- Standard batters of 2.5H:1V have been used for spillway sizing.
- Use the adjacent chart to determine the depth of flow over the spillway.
- Include 300 mm of freeboard.
- Spillway channel should be designed as a chute (refer to Design Sheet G).
- Determine spillway riprap size from the chart above, and refer to Design Sheet F for design notes.
- Spillways should be placed to best utilise surrounding rock structures. Where ponds or dams are constructed in or on bedrock and it is possible to use the bare rock as a spillway surface, then it can be constructed without riprap armouring the crest. Where riprap is required when construct on bare rock, such as for spillway batters or to create a jump at the end of the chute below, the rock should be bolted to the bedrock. Refer to Section 9.5 of the Sediment and Erosion Control Plan for details.

TYPICAL DAM EMBANKMENT

O

Application:

The figure and notes below can be used as a guide to constructing the pond/dam embankments. There are risks involved with the design and construction of any embankment, and suitably qualified professionals should be contacted where elicited by the design notes below. Refer to Section 9 of the Sediment and Erosion Control Plan for details.



Design Notes:

The pond and dam embankments should be constructed as layered earth structures on a thoroughly cleaned foundation. The embankments should have a low permeability component to them to limit the overall seepage rates and reduce the potential for undermining and piping failure.

Embankments higher than 3 m or retaining a volume greater than 20,000 m³ should be designed individually and require building consent under the Building Act. The [ORC](#) (who process dam consents on behalf of WCRC) have other consent requirements for construction of some smaller dams. Prior to construction, it should be determined if further consent is required from the ORC or WCRC.

Embankments should be constructed such that the crest is 300 mm above the highest flow in the spillway to ensure that the dam is not overtopped in a major flood event.

The crest of the embankment should be 5 m wide in section, and both the upstream and downstream faces should be sloped at 1V:2.5H (see figure above).

Prior to construction, the foundation surface should be thoroughly cleaned to remove all vegetative cover, soil and weak rock. It is noted that a major cause of failure in dam structures is the insufficient removal of cover material from the embankments foundation.

After the foundation has been cleaned it should be inspected by a suitably qualified professional. This inspections should cover the following:

- Sufficient cleaning of the foundation surface;
- Final grading of foundation surface is appropriate (e.g. not too steep in some places, not susceptible to localised failures);
- Foundation is comprised of sufficiently strong materials to support the embankment (e.g. not unstable mudstones or highly weakened material).

The embankment should have a low permeability layer constructed into the upstream portion of the embankment. Once suitable material becomes available on the site and prior to the construction of the embankment, a material grading curve should be developed to be used in the construction of the low permeability layer. The material grading curve should be developed such that it can be replicated in the construction phase of the dams (material will be available and crushed to match it) and can be compacted to achieve a permeability of 1×10^{-6} or a permeability which has otherwise been determined to be suitable. It is expected that appropriate low permeability material will be sandstone or basement rock and will be graded to a maximum diameter of 200 mm.

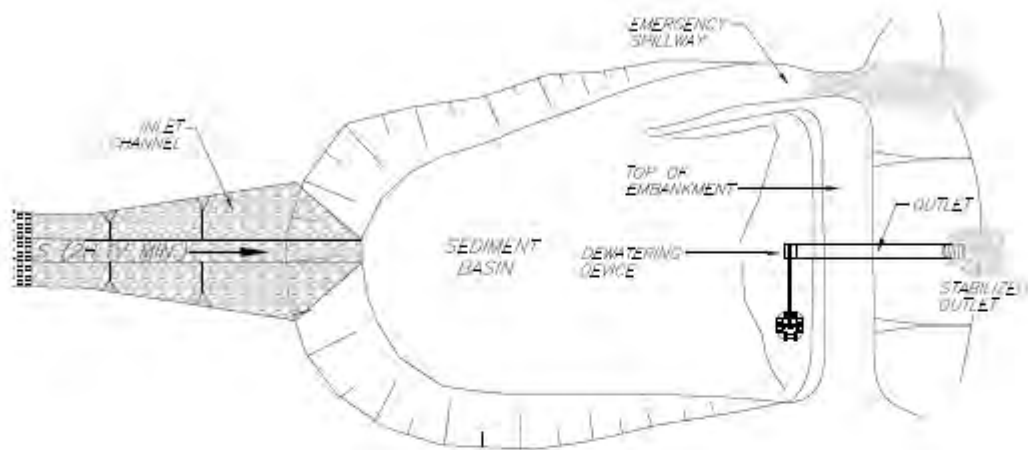
Both the Low permeability layer and the segment of random fill will require compaction. Once suitable material becomes available and prior to construction a compaction standard should be developed to meet the permeability requirements above and to ensure that the structure is stable. It is expected that the low permeability layers will need to be 300 mm thick and the random fill layers to be 1 m thick. Required compaction is likely to consist of passes with heavy machinery.

TYPICAL EXCAVATED POND

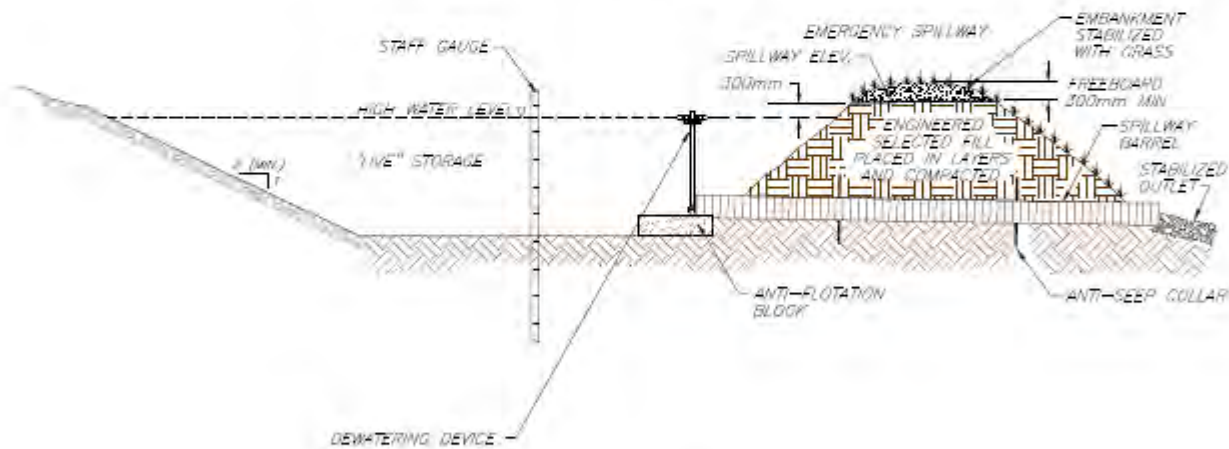
P

Application:

The figures below can be used in conjunction with the design criteria in Design Sheet O in the detailed design of excavated ponds. Embankment and spillway design should be assessed structurally and geotechnically to ensure stability. Refer to Section 9 of the Sediment and Erosion Control Plan for details.



PLAN
NOT TO SCALE



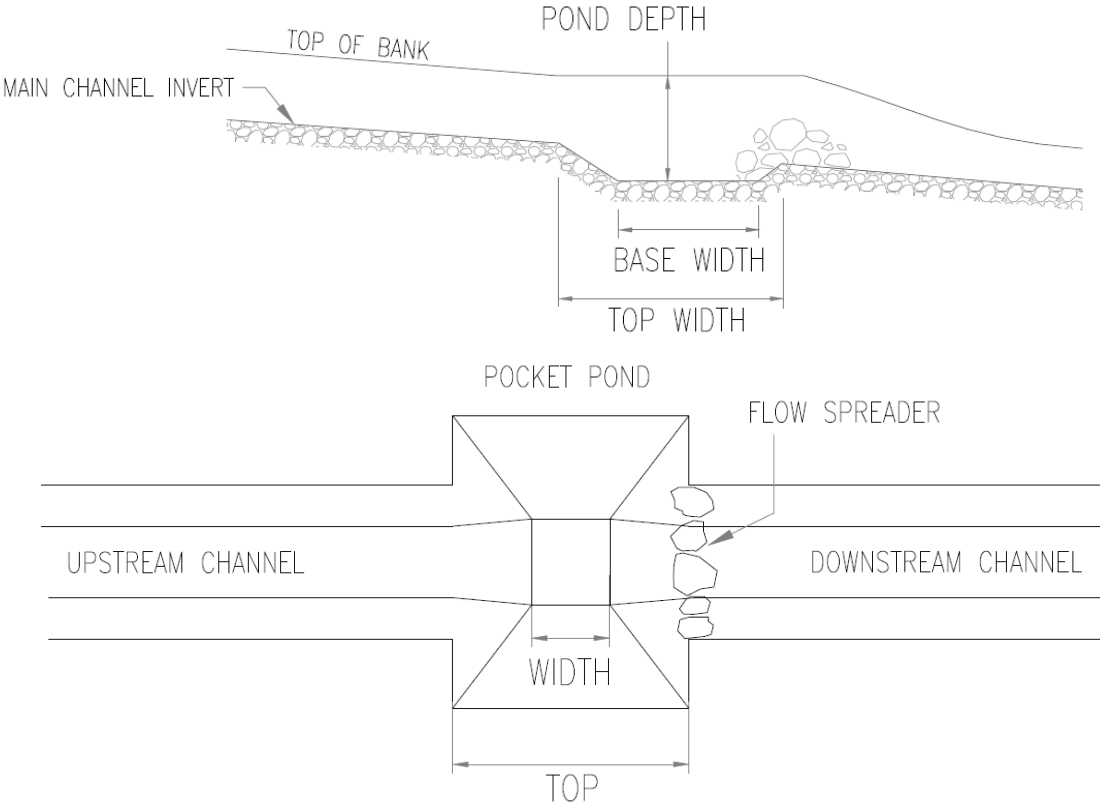
SECTION
NOT TO SCALE

Application:

Pocket ponds are typically used throughout road side drains or collection drains at the base of large slopes to collect sediment at source. Pocket ponds often require frequent clean out, and should be placed with consideration of access. Pocket pond sizing is based around a required volume and the clean out frequency, and can be considered as part of the treatment train in the calculation of RPA. Refer to Section 9 of the Sediment and Erosion Control Plan for details.

Pocket Pond Sizes

Depth (m)	Base width (m)	Top Width (m)	Total Volume (m³)	Storage Volume (m³)	Footprint (m²)	Effective Area (m²)
2	2	6	34	16	36	16
2	3	7	52	36	49	25
2	4	8	74	64	64	36
2	5	9	100	100	81	49
3	3	9	117	55	81	64
3	4	10	156	97	100	36
3	5	11	201	151	121	49



Design Notes:

- Pocket ponds should be designed and placed periodically throughout minor channels and upstream of confluence with major channels.
- Pocket ponds should not receive runoff from catchments larger than 4 ha.
- A flow spreader should be included as the pond outlet to ensure flow is distributed evenly throughout the pond and reduce short circuiting. The flow spreader should be constructed as either a level pre-cast concrete beam or placed rocks with an even elevation across the top. The width of the pond or 7.5 m, and the pond should be have a bund of 700 mm around it (400 mm for water level and 300 mm as freeboard).
- Pocket ponds provide the most effective treatment when they are not full of sediment. Pocket pond should be placed such that they can be cleaned out frequently (following major flow events).

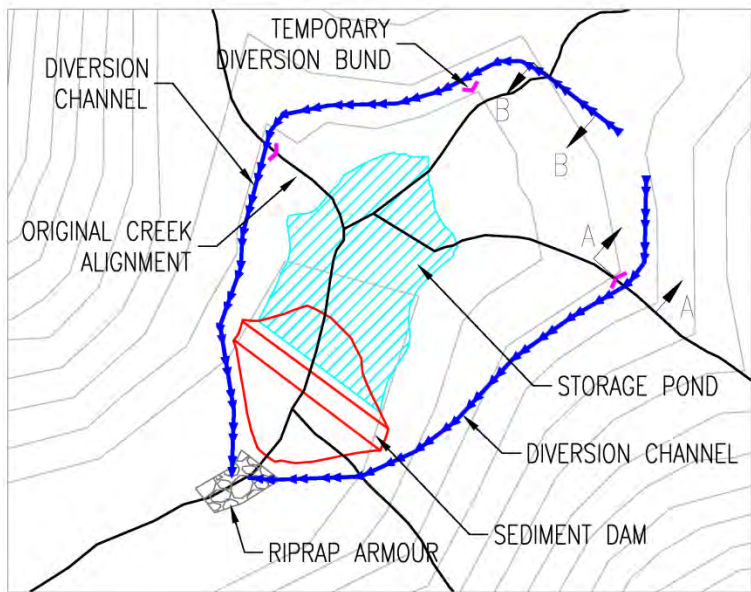
TYPICAL DIVERSION DESIGN

R

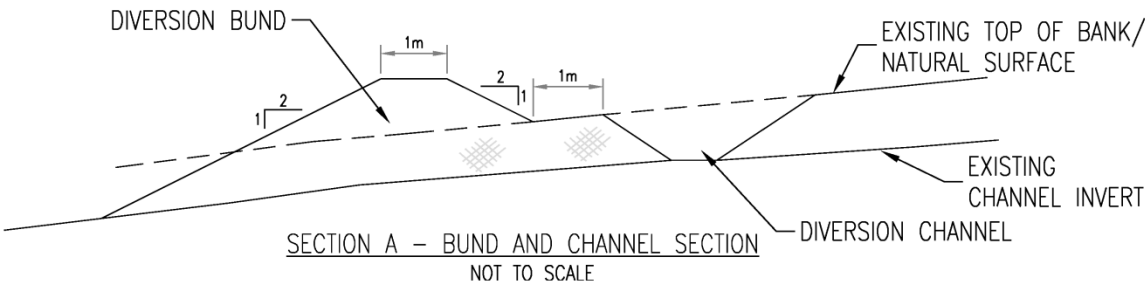
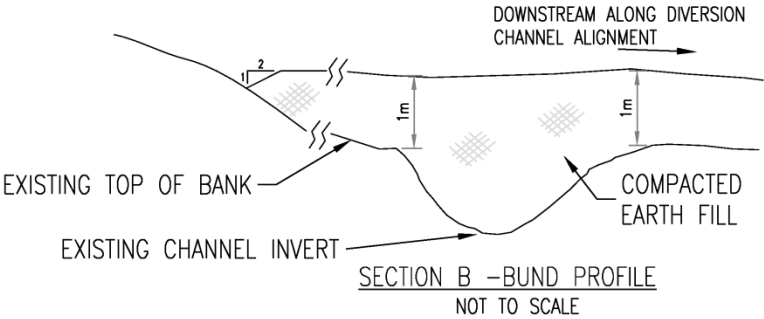
Application:

Surface water must be diverted around a construction site and re-enter the existing watercourse downstream of the site during the construction of sediment ponds, dams and other structures. These diversions are temporary, as the watercourse will be rerouted through the sediment control structure along its original alignment once construction of the structure is complete. Refer to the Sediment and Erosion Control Plan for details.

Pocket Pond Sizes



PLAN
Scale 1:2000



Design Notes:

- Channels should be designed to follow contours as much as possible to avoid the need for significant lining requirements.
- Channel dimensions and lining should be determined from Design Sheet C.
- The outlet to the existing channel should be designed as a confluence (refer to Design Sheet I).
- The diversion bund should comprise compacted earth and should extend 1 m above the top of the bank of the natural channel.

Application:

Revegetation of landscape should be done as soon as the final grading has been completed at a site. Revegetation will help to stabilize the banks and surface soils, reduce the overall runoff and decrease erosion. Revegetation can be conducted as part of a phased construction program, where an area is complete. A phased method reduces sediment load in control structures and reduces the total loss of material by reducing the time soil is exposed on site. Refer to the Sediment and Erosion Control Plan for details.

Temporary Seeding

Fast growing grasses planted on cleared areas that will remain exposed for longer than 90 days or will be exposed to seasonal rains. A quickly established grass cover can reduce soil erosion from the slope, reducing the sediment load in pocket ponds and sediment basins.

Permanent Seeding

Permanent revegetation cover should be established on all final grade slopes and cleared areas to bind the soils while the rehabilitating vegetation establishes itself over several years. Permanent seeding can be done in conjunction with temporary erosion control mats or geotextiles while the grasses establish.

Design Notes

A seed mix appropriate to the site specific conditions should be applied with broadcast seed spreaders, seed drills or similar methods which ensure uniformity of application. Slopes greater than 2H:1V should be hydro-seeded to avoid machine access or safety issues.

Proper seedbed preparation and quality seed are required to establish an adequate stand of vegetation.

The growth environment can be enhanced and erosion reduced during establishment period by applying a layer of mulch, which should be applied after seeding.

Freshly seeded areas should be inspected regularly, and areas of limited growth should be re-seeded as soon as identified.

Hydro-seeding

Hydro-seeding, or hydro-planting is the application of a slurry consisting of seed, fertilizer, mulch, tackifiers and water, to a slope. The slurry is kept agitated in a tank and sprayed using hoses and high pressure pumps. This method should be used when site conditions (i.e., steep or rocky slopes) make manual seeding difficult or unsafe. Hydraulic planting techniques may be relatively more expensive, but should be considered for seeding and mulching for sites with the following conditions:

- Slopes steeper than 3V:1H that cannot receive adequate seedbed preparation and mulch would be difficult to otherwise anchor.
- Where the slope surface is irregular with large clods or stones, or a high percentage of rock.
- Rehabilitation sites which are accessible by hydraulic application equipment. Remote locations with steep slopes that can be reached by hoses.
- On sites where it is desirable to apply water, seeds and mulch in one operation.

Design Notes

Hydraulic planting generally requires less seedbed preparation than manual seeding (i.e., the surface may be left as irregular).

The seed mix should be appropriate for the site specific conditions.

The planting site should be inspected after heavy rainfalls, and areas with limited growth or areas that are damaged should be reseeded.

References

McCullah, John, CPESC, "Erosion Draw: Erosion and Sediment Control Manual for Computer Aided Drafting", Salix Applied EarthCare, Redding, CA, 1994.

Transportation Association of Canada, "Erosion and Sediment Control on Roadway Projects", 2004.

GROUND COVER AND STABILIZATION

T

Application:

Disturbed ground should be stabilized using the methods described below as soon as practicable after the final landform is created, or when a temporary landform will go untouched for more than 4 months. Ground cover and stabilization can be applied as a control measure on its own or with hydro-seeding or conventional seeding. Refer to the Sediment and Erosion Control Plan for details.

Straw Mulch

Straw mulch can be applied to an exposed surface mechanically and is a fast and effective form of erosion prevention. Straw mulch can be combined with hydro-seeding and conventional seeding and can be reinforced by including a binding agent to the straw during application.

Design Notes:

Application rates should be adjusted as required to ensure that there is 100% cover of the ground surface (anticipated application rates are between 4000 and 6500 kg/ha).

Mulch naturally breaks down and as such reduces in effectiveness with time. Where straw mulch is the only erosion control in place it should be reapplied on a 3-monthly basis.

Hay should not be used for mulch, as its lighter weight and finer texture reduce its overall effectiveness against wind. It also may contain possible agricultural weed seeds that could interfere with the rehabilitation program or with the grassing.

Where slopes are steeper than 2H:1V, straw mulch should be applied as a Bonded Fibre Matrix (BMF), see below).

Run-on water should be diverted away from straw mulched catchments. Straw Mulching is designed to prevent erosion resulting from high wind speeds or rainfall impact, and may be displaced if exposed to high sheet flow.

Bonded Fibre Matrix (BFM)

By including a non re-wettable binder (typically a cross-linked guar), a straw mulch can be strengthened into a spray-on geotextile. Use of a binding agent allows for the mulch to be readily applied to a wider range of surfaces (including steep grades), prolongs the overall life (up to 1 year) of the cover and further reinforces it against high winds or sheet flow runoff.

Design Notes:

Where the binding agent used is a bitumen emulsion, polymer or starch, it can be applied directly to the airstream as the BFM is installed and does not require mixing before hand. These binding agents should be applied at a rate of 2500 l/ha.

BFM should be applied from two different directions, preferably from the top and bottom of an area, to avoid areas being shadowed and ensure an even coverage.

Wood Chip Mulch

Wood chip is slower to break down, and has a longer protective life because of it.

Design Notes:

Where wood chip is to be used in conjunction with re-vegetation, the health of the vegetation should be monitored more closely and nitrogenous fertilisers applied as required. Wood chip is slow to break down and can tie up nitrogen from reaching the plants as a result.

Wood chip should not be used in and around areas where water ponds frequently. Wood chip can leach tannins and saps from bark mulch which has a low pH.

Where possible wood should be chipped in such a way that long and narrow chips are created instead of a more spherical shape. This will ensure the chips form more of a matrix and are more resistant to wind and water.



Application:

Bioengineering techniques combine living plants with non-living structural elements, and can be applied in a variety of situations to help control erosion and stabilize slopes. Bioengineering methods are generally suitable to sensitive and rehabilitated environments while still being practical in disturbed catchments. Refer to the Sediment and Erosion Control Plan for details.

Bundled Brush stops

Bundled brush stops are used to reduce erosion and stabilize slopes by preventing rill and gullies from forming, creating a series of small terraces, and enhancing the conditions for vegetation establishment.

Design Notes

Bundled brush stops are to be harvested and installed during the dormant season.

Bundled brush stops are to be installed on slope contours.

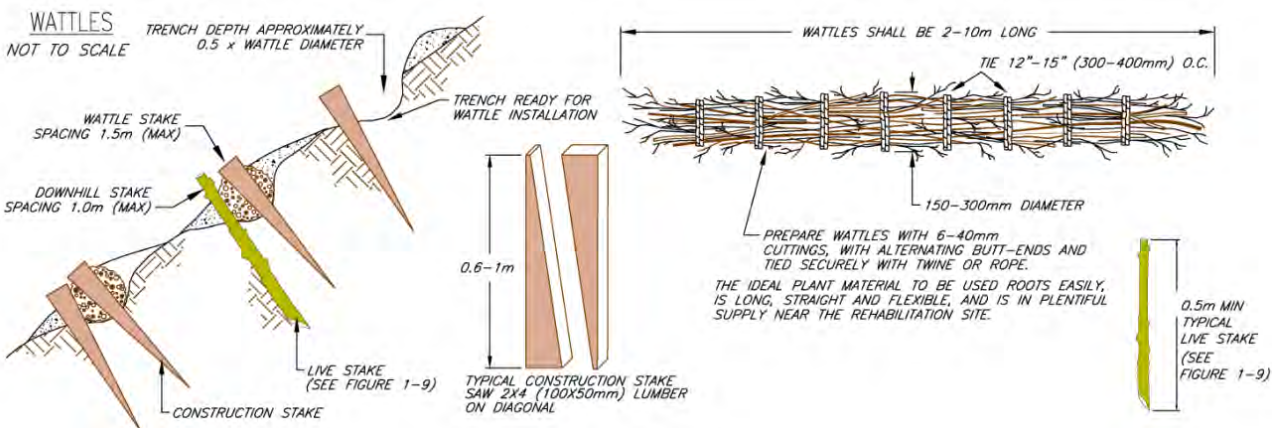
Installation is to proceed from the bottom to the top of the slope.

Soil from the slope or trench above should be used to fill or partially cover the wattle, and should be compacted or worked into the completed wattle.

Bundled brush stops should be spaced according to soil type and slope (see adjacent table)

Regular inspections should be made, especially within the first year, and stakes or repairs made where required.

Slope	Spacing
1.5H:1V	1 m
2H:1V	1.5 m
3H:1V	3 m
4H:1V	4 m
4.5H:1V	5 m
5H:1V	6 m



Slash and Brush Layering

Waste wood (slash) from the land clearing process can be used as a ground cover to protect the topsoil from surface erosion. Where tree branches and trunks are available that are too heavy to be effectively used as bundled brush stops, they can be evenly distributed on the exposed ground surface. The slash works as a partial barrier to rainfall, intercepting it and thereby reducing erosion resulting from impact. The slash also reduces the velocities in sheet flow and holds the topsoil in place.

Slash and Brush layering can be used in conjunction with revegetation or rehabilitation techniques and provide stability during the early stages of plant growth.

Design Notes:

Slash should be placed either by hand or with directed machinery such that it is evenly spread and is well connected to the ground surface. Placement of slash such that the majority of it is not in contact with the ground will not be as effective at reducing erosion.

Where native slash is used, and on areas where new growth is desirable, the slash should be placed soon after it is cut (< 48 hours) so that it has the opportunity to root or seed after placement.

Slash should be composed of only trees smaller than 200 mm in diameter, trunks and branches larger than this should be turned into wood chips and used for mulching (see Design Sheet T).

EMERGENCY RESPONSE

V

Application:

This procedure covers actions to be implemented in the event of an infrastructure failure. This could comprise embankment failure, channel erosion, uncontrolled discharges, TSS consent breaches, major slope erosion etc. Refer to the Sediment and Erosion Control Plan for details.

Emergency Response Team

An response team should be identified and trained in responding to emergency failure situations. All mine site employees should be trained in recognizing and reporting emergency situations.

Emergency Response

- 1.) Assess immediate hazard to life, property and the environment at the failure location and downstream.
- 2.) Take immediate measures to minimise the identified hazards
- 3.) Identify the cause of the failure (i.e., washout, erosion, seismic activity, slope instability, etc.)
- 4.) Reconstruct the infrastructure or implement interim control prior to enhancement of infrastructure to protect against future failure.

Channel Failure

If a channel bank should collapse, the channel should be re-excavated in the location of the collapse, the bank reconstructed from NAF overburden material, and the bed and bank armoured.

If the channel failed due to a failure of the previous lining, the channel should be relined with the next size category up of riprap, or gabion mattresses or grouted rock. Gabion baskets should be used as a temporary patchwork where required or to replace check dams temporarily.

If the failure was due to a washout from an inflow to the channel, a confluence structure should be constructed in the location of the inflow.

If the channel fails due to head cutting, the channel should be filled in and reconstructed in a new location. Armouring and sacrificial zones should be placed in the new channel to prevent head cutting in the future.

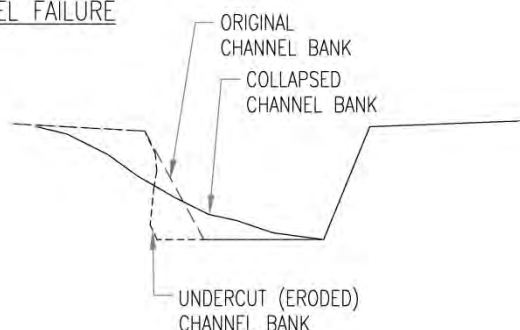
Slope Failure

If a slope fails, an assessment should be made of the possibility of another failure and the hazard to downstream life and property. Failed slopes should be re-graded at a stable gradient and slope stabilization measures such as terracing and proper drainage should be applied. For slopes to be rehabilitated, bio-engineering structures can provide additional slope stability and may be applied.

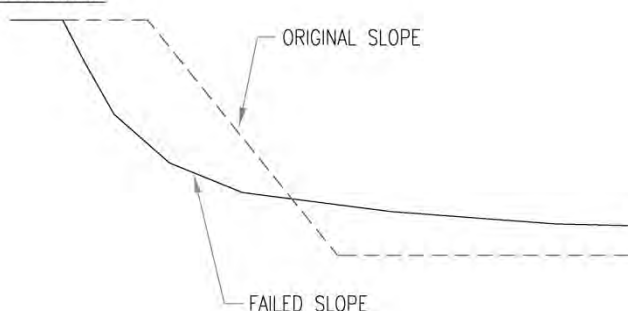
Embankment failure

If signs of failure are observed at a dam or embankment (e.g., leaks, cracks, soil movement, etc.), immediate measures should be taken to assess the risk of failure and appropriate repair should be undertaken. Each embankment or dam should have specific emergency response measures outlined in an Operations and Maintenance Manual. If a dam or embankment fails, an assessment should be conducted by a qualified professional. Temporary drainage, diversions and sediment control structures should be constructed and used until the dam is repaired or rebuilt.

CHANNEL FAILURE



SLOPE FAILURE



Channel Failure

Failures and remedial measures should be assessed by an engineer.

All repairs and reconstructions should be conducted in a manner that does not generate excessive sediment or cause additional disturbance.

Temporary Sediment control measures should be used while repairing or reconstructing failed structures.

Uncontrolled discharges

Uncontrolled discharges to receiving waters could occur under a number of circumstances including channel failure/overtopping and slope failure. Response measures could include rapid deployment of hay bales and/or silt fences, straw mulching to control sediment erosion and construction of basic sedimentation ponds. Suitable equipment and supplies should be stockpiled to facilitate rapid deployment under these circumstances.

TSS/turbidity compliance failure

Consent condition breaches could occur as a result of extended wet periods, major land disturbances, slope failures and associated sediment discharges to water channels, disturbance of fine grained material with poor settling capacities or the under-performance of sedimentation infrastructure. Options to address elevated sediment concentrations include expansion of sedimentation ponds, installation of baffles and deployment of a flocculent dosing system, such as flock blocks. Floc blocks comprise solid blocks of slow release flocculent which work by releasing small concentrations of flocculent into the water stream, which binds fine particles and increases settling rates.

Floc blocks have been used successfully as a rapid response to sediment discharge issues and could be stockpiled and deployed at the EMP site as an emergency response measure for elevated TSS or turbidity levels in the site discharge.

The effectiveness and optimum methodology for use of floc blocks varies from site to site and hence a site trial is required before an EMP-specific methodology can be developed. The trial should be undertaken during the first year of site operation, on completion of the first major sedimentation pond. The trial should broadly comprise installation of floc blocks into a stream channel upstream of the sedimentation pond, either in plastic mesh bags, cages or tethered (as per Figure 1 below), coupled with detailed monitoring of sediment pond performance with and without the flock blocks. The trial should include a range of dosing rates and flock block deployment methods. The trial should be designed by a suitably qualified professional. The final EMP consent conditions should also be reviewed to confirm that flocculent dosing in this manner is permitted.



Figure 1 Tethered flock blocks with check dam system¹

1. Source: <http://encapinc.net/services/erosion-sediment-control/dewatering/>

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TAURANGA

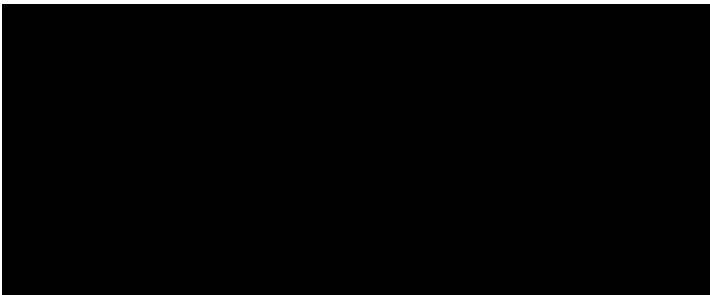
HAMILTON



NELSON

CHRISTCHURCH

DUNEDIN



**ATTACHMENT G – PERFORMANCE OF EROSION CONTROL PRODUCTS AT STOCKTON
OPENCAST MINE (SHADBOLT AND WEBER, 2007).**

PERFORMANCE OF EROSION CONTROL PRODUCTS AT STOCKTON OPENCAST MINE

A. A. K. Shadbolt, P. A. Weber
Solid Energy New Zealand Ltd

ABSTRACT

Solid Energy New Zealand Ltd's Stockton Opencast Mine is located north-east of Westport, New Zealand, on the Stockton Plateau at an elevation of 800m-1100m above sea level. The coal mine is exposed to high annual rainfall (>6000mm/pa). During the mining process, soil is removed to stockpile so that it may be then re-applied on completion to engineered landforms. The retention of soil on these landforms is essential for the successful rehabilitation of the mine site as it provides the primary growing medium for revegetation.

A field trial was conducted at Stockton to evaluate the performance of three erosion-control products. Five plots of between 205m² and 232m² were established on a recently soiled engineered landform to assess the effectiveness in preventing erosion of hydroseeding (Plot 1: 35kg grass seed mix/ha, Plot 2: 13kg grass seed mix/ha), straw mulching (Plot 4: 3.5t/ha, Plot 5: 5t/ha), and a chemical binding agent (Plot 6: Binder8). A bare soil control was also established (Plot 3).

At the base of each slope a collection gutter diverted a tenth of each plot's runoff into a collection drum. Runoff volume (l) and sediment yield (kg) were recorded and representative water samples taken and analysed for turbidity and total suspended solids. Findings demonstrated that straw mulch was the most effective form of erosion control with mean turbidity values of 70.35 NTU for Plot 4, and 69.65 NTU for Plot 5, in comparison to plot 3 at 797.84 NTU. Hydroseeding rated second, although the application was undertaken in May, at the end of the growing season. As a result, hydroseeding did not yield significantly different values to those of the control until the second half of the sampling period when, in the case of gutter sediment, there was a decrease of 54.3% for Plot 1 and 43.4% for Plot 2 as the grass became established in Spring (October). Binder8 was found to be the least effective of the three products, on some occasions even yielding more sediment than the control plot. As a result of the trial's findings, an integrated erosion-control programme has been initiated at Stockton.

KEYWORDS. Engineered landforms, erosion control, runoff, straw mulching, hydroseeding.

1. INTRODUCTION

Stockton is the largest opencast coal mine in New Zealand, with an active mining area of over 600ha. This makes Stockton the largest continuous rehabilitation project in New Zealand, with 80ha returned to native vegetation in the past five years and 46ha in 2006/07. Thin, alpine soil horizons and historical discarding of soil during the mining process has resulted in a shortage of soil on the site. Successful rehabilitation at Stockton therefore relies heavily on the retention of remaining soil once it is re-applied to engineered landforms (ELFs) at the completion of the mining process. Due to the area's high rainfall (>6000mm/pa) and rainfall intensity (>30mm/hr), erosion of re-applied soil is extremely high. Erosion control procedures are required.

The application of straw mulch had been utilised prior to the trial without analysis of its effectiveness. A previous study by Jennings and Jarrett (1985) found that straw mulch reduced erosion by between 2% and 27% in comparison to bare soil controls. Benik et al. (2003) observed a roughly one-tenth reduction between straw mulch and bare soil controls, whilst Meyer et al. (1970) found that soil loss from straw mulch plots was reduced by more than a third.

Hydroseeding, like straw mulching, had also been used for erosion control, as a shelter for native plant regeneration, and as a beautification technique. A study by Albaladejo Montoro et al. (1999) found the application of hydroseed in conjunction with combinations of vegetable mulch and humic acid led to a reduction in runoff of between 72.3% and 86%, and a reduction in sediment yield of between 94.8% and 98.5% in comparison to a bare soil control.

Chemical agents are a third erosion control. Used widely in the mining industry, mainly as a dust suppressant on large stockpiles or long conveyors, chemical binding agents have also been used to prevent erosion. "Many recent studies have shown that the use of synthetic organic polymers, such as polyacrylamide (PAM), as surface soil amendments results in benefits including reduction of runoff volumes, decrease in sediment yield, and stabilisation of soil structure." (Seybold, 1994). Flanagan et al. (2002) found PAM treatments significantly reduced cumulative runoff and soil loss, and that vegetation establishment rates also improved.

This field experiment investigated the performance of three erosion control products: straw mulching (3.5t/ha and 5t/ha), hydroseeding (35kg/ha and 13kg/ha) and a chemical binding agent (Binder8). Effectiveness was evaluated by collecting runoff volume (l), sediment yield (kg), and representative water samples were analysed for turbidity (NTU) and total suspended solids (mg/l). This is the first study of its type undertaken at Stockton Opencast Mine.

2. MATERIALS AND METHODS

The research site was located on an east-facing batter slope of the Collis Dump, an ELF rehabilitation site at Stockton Opencast Mine north of Westport, South Island, New Zealand.

2.1 SITE DETAILS

A total area of 15ha of the Collis Batters was rehabilitated in accordance with site rehabilitation standards. After the bulk overburden was shaped into 18° batter slopes, a 500mm layer of weathered granite was applied to the slope surfaces and compacted to a permeability of 10^{-6} to 10^{-7} meters per second, effectively capping the ELF to exclude oxygen and water. A 300mm layer of soil, from a stockpile of material earlier removed during the stripping process, was then applied to the ELF. This process was undertaken between November 2005 and March 2006.

2.2 PLOT DETAILS

Six plots at an average of 217m² were set aside for the trial, whilst the remainder of Collis Dump was planted with a mix of transplanted and nursery-grown native seedlings. In May 2006, the three erosion control products were applied to their corresponding plots:

- Plot 1 – Hydroseeding; paper 1t/ha, Browntop 5kg/ha, Yorkshire Fog 5kg/ha, Tama Ryegrass 25kg/ha, DAP¹ 400kg/ha, **(HH)**
- Plot 2 – Hydroseeding; paper 1t/ha, Browntop 2.5kg/ha, Yorkshire Fog 2.5kg/ha, Tama Ryegrass 8kg/ha, DAP 400kg/ha, **(HM)**
- Plot 3 - Control plot; bare soil **(C)**
- Plot 4 - Straw mulching; wheat straw 3.5t/ha **(SM)**
- Plot 5 - Straw mulching; wheat straw 5t/ha **(SH)**
- Plot 6 - Polyvinyl alcohol-based binding agent, Binder8² **(B8)**

2.3 MONITORING EQUIPMENT

At the base of each slope a 5m length of 300mm diameter polythene pipe (cut in half to act as a sediment- and water-catch trough) was built into the slope. Above it, a 4m by 4m sheet of black polythene plastic was laid, with 2m buried in the soil and the remaining 2m exposed and attached to the catch trough so that all plot runoff entered the catch trough. Each Catch trough was lain at an angle so runoff ran first through a course mesh to separate large sediment (>10mm), then a splitter to separate a one tenth of the remaining runoff (see Figure 1). This tenth of the runoff then entered a 50mm black polythene pipe leading to a 350l collection drum.

2.4 DATA COLLECTION

Data initially was collected from the trial on a weekly basis over 25 weeks, then sporadically for the remaining 27 weeks of the trial. During the trial, data was collected as follows:

- Catch troughs emptied of sediment and sediment weights (kg) recorded
- Water/fine sediment volume (l) in collection drums recorded
- Collection drums thoroughly stirred, mobilising sediment, and a representative 1l sample taken

¹ DAP fertiliser, di-ammonium phosphate

² Binder 8 is a polyvinyl alcohol based product specially formulated for use in suppressing fugitive coal dust emissions.

-
- 1l sample sent to independent laboratory for analysis of turbidity (NTU) and total suspended solids (mg/l).
 - Weekly rainfall recorded



Figure 1. Catch trough showing upslope polythene sheeting and mesh filter/splitter at the outflow.

3. RESULTS AND DISCUSSION

Due to replication restrictions and the theme of practical application, detailed statistical analysis of findings from this field experiment was not possible. The findings, however, do present a relative picture of the effectiveness of the three erosion-control products utilised.

3.1 CATCH TROUGH SEDIMENT WEIGHT

Over the 12-month trial period, straw mulch proved the most successful erosion control in regards to catch trough sediment weight. At the lower rate of 3.5t/ha (**SM**), straw mulching had a mean sediment yield of 3.87kg/week in comparison to the

control plot of 8.38kg/week. No other treatment had an overall mean lower than that of the control. This can be explained by analysing the first and second six-monthly means. In the first six months, the control plot yielded fine sediment which passed through the mesh filter and did not remain in the catch trough for measurement. During the first six months, a proportion of the hydroseed material washed off before grass became established - the wet, heavy paper skewing results. Following grass establishment, in the second six months, both rates of hydroseed outperformed the control (**HM**= 12.8kg/week, **HH**= 5.6kg/week, **C**=22.2kg/week). Both rates of straw mulch outperform the control for the first six months by a factor of more than 8, yet as the straw decomposed and sediment became available for mobilisation, only **SM** outperformed the control (**SM**= 20.8kg/ week **SH**= 52.6kg/week, **C**=22.2kg/week). During all three periods, Binder8 (**B8**) showed no discernable difference to that of the control.

3.2 COLLECTION DRUM VOLUMES

With regards to collection drum volumes; there is very little difference between treatments and the control over all three time periods (12 months, first six months, and second six months of the trial). This result is most likely due to the very high rainfall the trial site experienced (approximately 6000mm for the 12 month period). **SM** was the only treatment that showed any discernable difference to that of the control, with an overall mean drum volume of 186l, in comparison to 214l for the control. It may be that straw retains moisture and thus enables greater infiltration of water into the underlying soil. This was not replicated in the **SH** plot, however. Results for the **SH** plot may be compromised by a blowout where an area not covered by straw released sediment which then covered the straw lower down the slope and so enabled greater amounts of sediment and water to enter the catch trough.

3.3 COLLECTION DRUM TURBIDITY

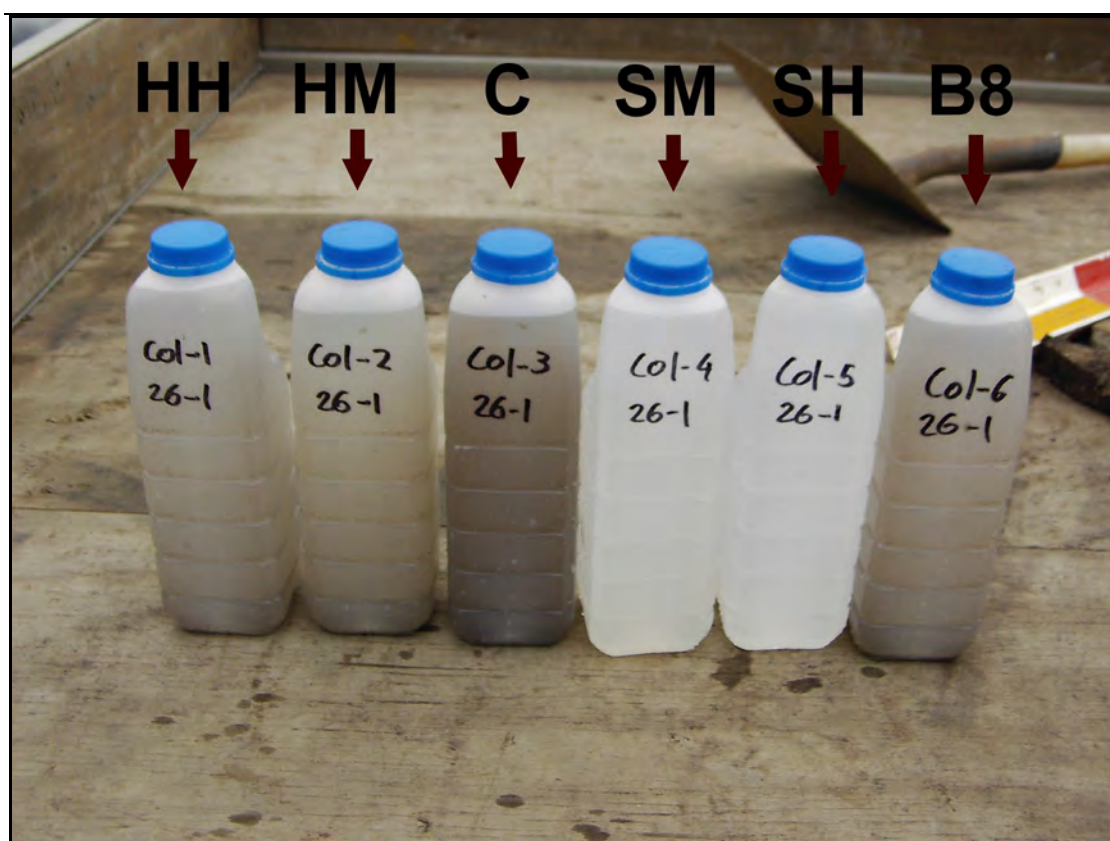


Figure 2. Typical samples demonstrating turbidity differences between treatments

Mean collection drum turbidity clearly demonstrates the effectiveness of all three products utilised. Figures 2 and 3 illustrate that, over the length of the trial, straw at both rates proved the most effective erosion control. The fact that there is little discernable difference between straw rates has specific implications for large scale field application. Figure 3 also shows how, once grass became established in the second six months (application in May being at the end of the growing period), hydroseeding proved very effective. The Binder8 plot (**B8**) for the first six-month period experienced a far higher rate of erosion, as indicated by mean collection drum turbidity, than the control (**C**= 867.76 NTU, **B8**= 1238.39 NTU). This result was verified when it was discovered post-trial that the chemical composition of Binder8 in fact enhances erosion when applied to sandy silt loam soils such as those at Stockton. However, the use of Binder8 for the trial did prove beneficial, results clearly demonstrating the effect of armouring of soiled slopes. Armouring is a common occurrence at Stockton, with its thin soil horizons eroding and exposing the rocky substrate. Once this has occurred, erosion decreases, the rocky substrate not mobilising as readily with finer soil particles. During the second six-month period of the trial, mean collection drum turbidity for Binder8 (**B8**) and the control (**C**) decreased markedly (by more than 9 and 4 times respectively as a result of armouring).

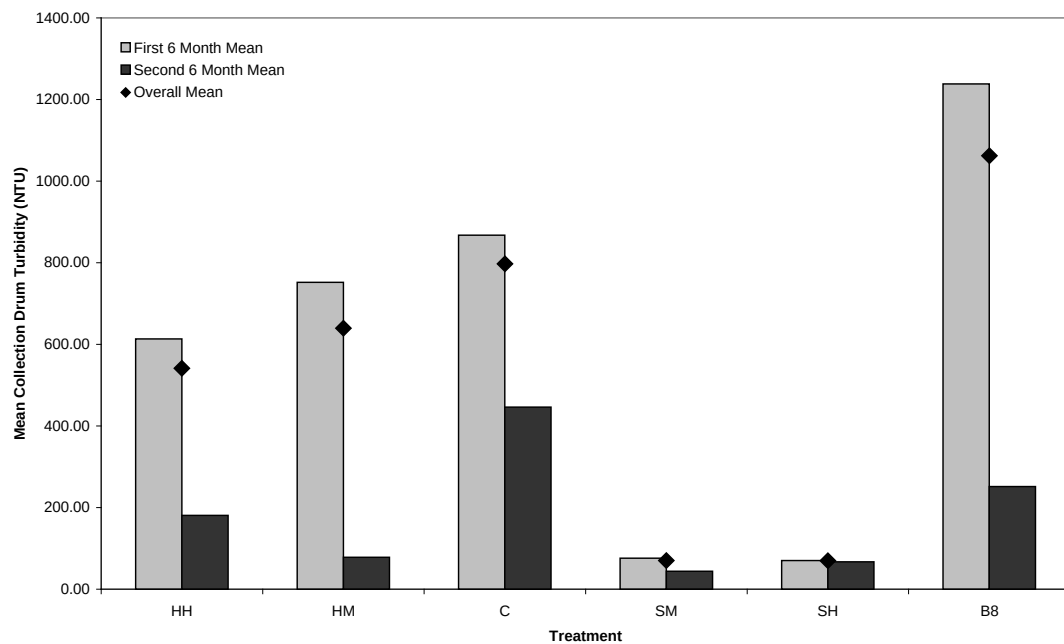


Figure 3. Mean collection drum turbidity (NTU) for all plots over three time periods

3.4 COLLECTION DRUM TOTAL SUSPENDED SOLIDS

The results for collection drum mean total suspended solid reflect the results for turbidity. Straw mulching at both rates overall proved the most effective at reducing erosion, followed by hydroseeding once grass had become established during the second six months of the trial. Figure 4 clearly highlights how Binder8 enhanced erosion, with total suspended solids levels markedly higher than those of the control over all three time periods.

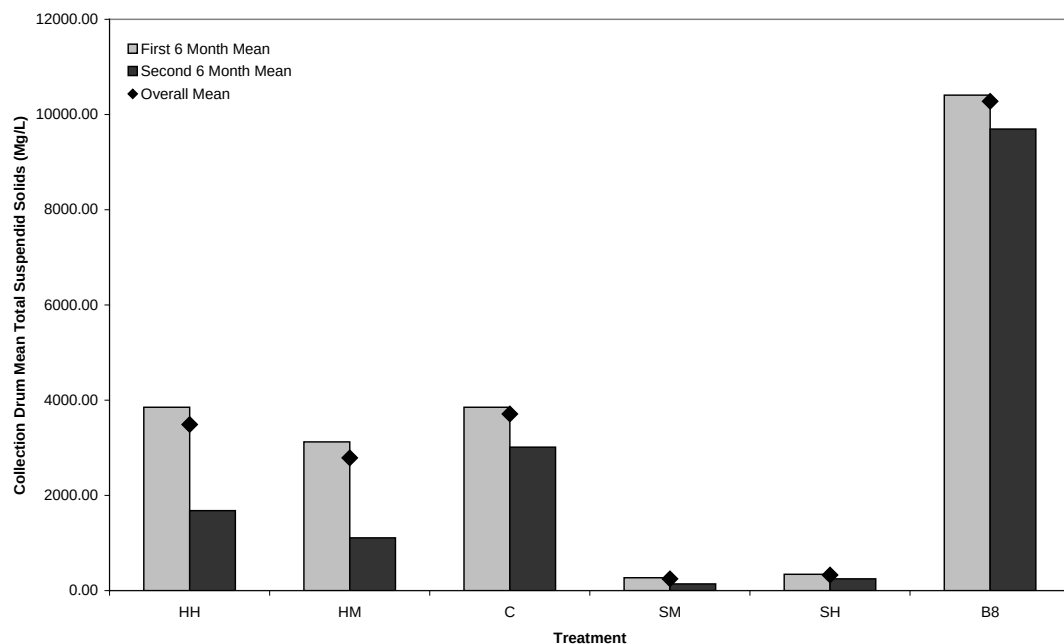


Figure 4. Mean collection drum total suspended solids (mg/l) for all plots over three time periods

3.5 PRACTICAL IMPLICATIONS

Findings from this field experiment have led to the development of a site-wide integrated erosion control programme. From Spring to Autumn (October-March), hydroseeding is used on recently soiled areas. Hydroseeding has a higher cost per hectare but has a longer field life and has the added aesthetic value of “greening” what is largely a “brown” landscape. For the other months of the year, straw mulching is utilised. Straw has an immediate effect in reducing erosion at a time of year when grass will not establish, as demonstrated during the first six months of the trial. Straw is applied at a rate of 4t/ha as the trial demonstrated there is no significant advantage in applying it at a heavier rate.

Currently on site trials are being undertaken in the use of post peel as an alternative to straw. This is a byproduct of fence post manufacture (material is pre-treatment). Early results, as shown in figure 5, demonstrate that post peel, at 4t/ha, is equivalent to straw mulch at 4t/ha. Post peel will have a longer field life (5-10 years) compared to straw (< 2 years at Stockton; < 3 months in Auckland) and, being denser than straw, can be spread over greater distances. This is an advantage at Stockton where batter slopes are regularly over 30m long and experience strong winds which hamper straw application.

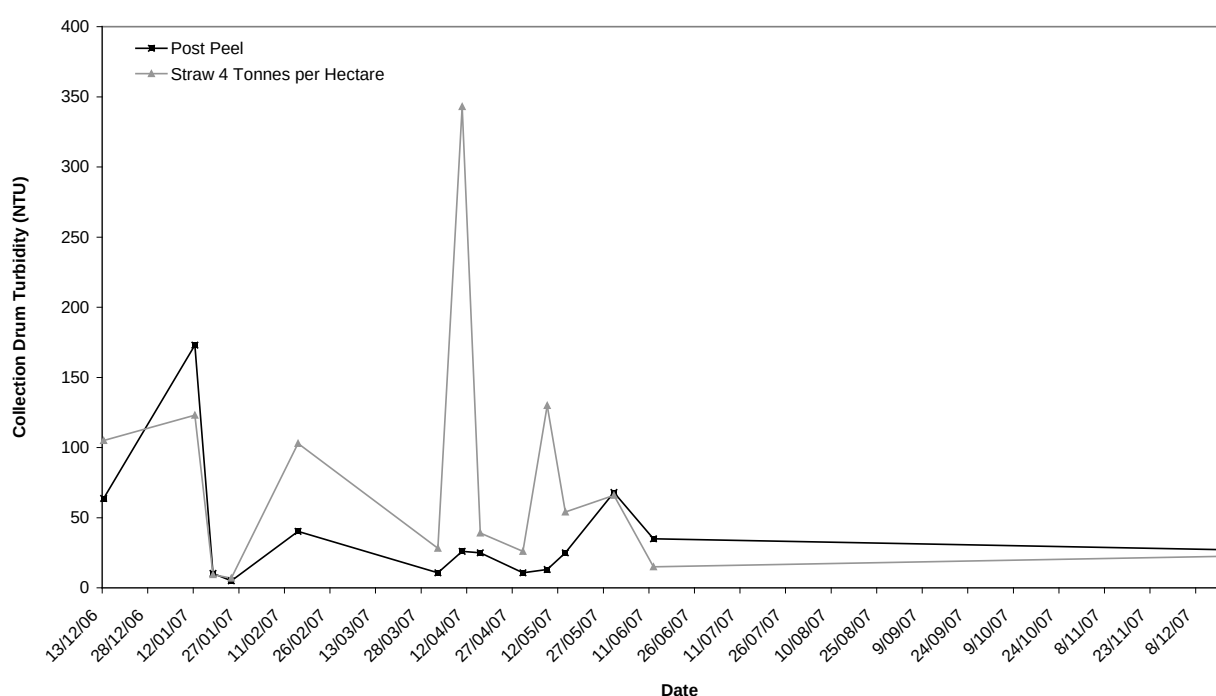


Figure 5. Collection drum turbidity (NTU) for post peel and straw

Financially, therefore, the benefits of post peel may outweigh those of straw application for erosion control. Currently on site, large scale operational trials (1ha plots) are being undertaken to determine operational procedures for deploying this material.

Table 1. Mean results for all treatments and values over three time periods

Time Period Mean	Value	Treatments					
		HH	HM	C	SM	SH	B8
Overall Mean (12 months)	Catch Trough Sediment Weight (Kg)	21.45	12.13	8.38	3.87	9.37	12.80
	Collection Drum Volume (Litres)	221.32	220.98	214.69	186.00	207.94	278.94
	Collection Drum Turbidity (NTU)	541.29	639.66	797.48	70.35	69.65	1062.18
	Collection Drum TSS (Mg/L)	3489.45	2787.40	3710.35	249.33	328.06	10279.18
First 6 Month Mean	Catch Trough Sediment Weight (Kg)	23.94	13.83	5.85	0.42	0.71	12.04
	Collection Drum Volume (Litres)	200.89	213.59	203.56	181.69	194.87	268.05
	Collection Drum Turbidity (NTU)	613.40	751.96	867.76	75.84	70.19	1238.39
	Collection Drum TSS (Mg/L)	3851.54	3123.03	3849.79	271.59	344.57	10406.40
Second 6 Month Mean	Catch Trough Sediment Weight (Kg)	12.80	5.60	22.20	20.80	52.60	19.00
	Collection Drum Volume (Litres)	329.04	297.18	300.64	238.99	300.64	329.04
	Collection Drum Turbidity (NTU)	180.74	78.16	446.10	44.02	67.07	251.60
	Collection Drum TSS (Mg/L)	1679.02	1109.22	3013.14	142.48	248.80	9693.98

4. SUMMARY AND CONCLUSIONS

During the 12-month trial, straw mulching proved to be the most effective erosion control for Stockton conditions, although it has been found that after two years, further straw application is required. Once established, hydroseeding proved to be a very effective erosion control and has a longer assumed field life than that of straw. Binder8 was found to be the least effective of the three products, in fact enhancing erosion. Including it in the trial, however, yielded valuable data about the effect of slope armouring. Findings have resulted in the establishment of a site-wide integrated erosion-control programme. Further trials have been established, trialling new products such as post peel, and the use of both straw and post peel in combination, with hydroseeding to form a one-pass immediate and long-term erosion-control product. Early results from these further trials are promising and, if proven effective, this method will become part of the site-wide programme. It is anticipated that results from this trial will be utilised at other Solid Energy sites when formulating erosion-control strategies and that other groups managing disturbed sites in high-rainfall alpine areas will also find the results beneficial.

5. ACKNOWLEDGEMENTS

Thanks to [REDACTED], [REDACTED] for assistance during the installation and monitoring of the trial, Solid Energy New Zealand Ltd for funding this field trial. Thanks to [REDACTED] for input during the collection of data and the writing of this paper.

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**ATTACHMENT H – STOCKTON SEDIMENTATION POND SIZING METHOD REVIEW
(URS NEW ZEALAND LIMITED, 2011)**

22 September 2011
Project No. 42184540

Stockton Alliance
PO Box 250
Westport 7866

Attention: [REDACTED]
Environment, Community and Security Manager

Dear [REDACTED]

Subject: Stockton sedimentation pond sizing method review

Further to recent discussions, we are pleased to present the findings of the above study.

Executive summary

This document reviews Beca's 2005 Stockton Sediment Pond Sizing report and the subsequent Stockton Alliance Procedure for Design and Sizing of Sumps. The purpose of the review is to determine whether the current procedure is likely to achieve compliance with the Stockton Water Right for sediment discharges to receiving waters, and to update the procedure with new information collected since the current version was drafted.

We understand that a sedimentation pond discharge limit of 20 mg/l for 90% of the time has been adopted. The target aims to deliver good environmental stewardship and to meet the sediment discharge limits specified in the Stockton Water Right.

The term "90% of the time" is somewhat ambiguous and makes it difficult to assess whether a pond is performing adequately in the short term. Specification of a compliance period and a sampling frequency (e.g. samples collected daily, with a 30 day compliance review period) would resolve these issues, and is one of the recommendations of this report.

The Stockton Procedure for the Design and Sizing of Sumps states that ponds sized under the procedure are likely to remove 80-95% of sediment. Settling column data reviewed in this current study broadly align with this estimate. A review of estimated Total Suspended Solids (TSS) concentrations in 90th percentile pond inflows indicates that discharge concentrations are likely to be in the 250 – 3000 mg/l range for ponds treating active backfill areas and 250 – 1250 mg/l range for ponds treating active pit areas. Data therefore indicate that construction of gravity settling ponds of sufficient capacity to achieve the 20 mg/l 90th percentile target in the pond discharge water is unlikely to be feasible. This was also one of the conclusions of the Beca study.

URS consider that it would be reasonable to account for dilution within the receiving water as part of the pond sizing methodology and water right compliance assessment. This report concludes with an outline revision of the pond sizing procedure, which includes assessment of dilution. Continual improvement is integrated into the proposed revision, through specification of a performance monitoring and improvement programme.

Proposed short term actions are:

[REDACTED]

- Discuss the proposed revision of the sediment discharge limit (to include dilution in the receiving water and a specified compliance period) with internal stakeholders and then with regional council if appropriate; and
- Make minor modifications to current procedure to align with approach recommended in this study (e.g. use multiple smaller ponds in place of single pond where possible, install baffles for irregular pond shapes, monitor pond performance and improve engineering as appropriate).

Medium term actions:

- Repair Downerton rain gauge record and recalculate design rainfall events;
- Design and implement sampling programme to allow better understanding of sediment yields from mine areas;
- Investigate passive flocculent dosing systems. If passive treatment system feasible for Stockton, develop concept design to facilitate efficient deployment of system when required; and
- Finalise pond sizing procedure when initial performance evaluation data are available and when TSS compliance criteria are confirmed.

1 Background

The Stockton Water Right states that runoff from the coal mining and overburden areas should be treated in sedimentation ponds prior to discharge to the receiving water. Sedimentation ponds should be sized to ensure that no water quality degradation occurs under a design storm event of 233 mm/d. This requirement has been implemented by the Stockton Alliance as a 20 mg/l limit for discharges from sedimentation ponds for 90% of the time.

A sedimentation pond sizing standard was developed for the Stockton Mine based on a study undertaken by Beca in 2005. The Beca study was based on a limited data set; additional data have been collected since the time of the study. Recent investigations by the Stockton Alliance have indicated that use of the sizing standard may not achieve the 20 mg/l TSS target.

URS were commissioned to review and update the current sizing method based on the following scope of work:

- Review and comment upon Beca study methodology (the methodology was designed according to the data available at that time)
- Comment on key areas of uncertainty
- Comment on the adequacy of the current sizing methodology;
- Utilise TSS, flow and settlement column data previously collated by SENZ / SA / URS to update pond sizing method.
- Comment on key areas of uncertainty and define any additional work that is required to finalise the pond sizing method.
- Discuss use of use of multiple ponds to achieve total size requirement; and
- Comment on pond design (e.g. use of baffles, sump geometry)

This study has been structured as follows:

Section 2: Review and update of current pond sizing methodology

Section 3: Discussion of uncertainties and limitations of current sizing method

Section 4: Recommendations for variations to current method, pond design and future work

Section 5: Final recommendations for development of sedimentation pond design going forward

2 Current sediment pond sizing review and update

The stated goal of the Beca study is "the design and implementation of sediment controls that will result in the Stockton Mine complying with the target of 20 mg/l TSS 90% of the time/year" The main components of the pond sizing assessment are as follows:

1. Analysis of long term rainfall records from the Stockton S5 Gauge Site (aka Downerton Gauge) to define the 90th percentile 24 hour storm intensity;
2. A runoff coefficient was estimated from rainfall records and flow data from the S14 gauging site. This information was used with rainfall data (Rational Method) to estimate sediment pond inflow rates;
3. Sediment yields from different mining land uses were estimated;
4. Settlement characteristics were estimated from hydrometer test results;
5. The sediment pond trap efficiency was calculated using the Hazen-Camp method

The above components are discussed further below. Data and results from the Beca study are compared to more recent data and data analysis where relevant.

2.1 Storm intensity and rainfall runoff

2.1.1 Rainfall record

MWH were commissioned in late 2005 to review rainfall data presented in the Stockton Water Quality Management Plan report drafted by Beca (the same rainfall data were used in the Beca pond sizing study). The findings of the MWH review are summarised in their 2007 report entitled Stockton Mine: Site Hydrology and Rainfall-Runoff Modelling. An extract of the report is provided below:

The hydrological work carried out by BECA was based on data from the Downertown and Webb gauges. The report describes gaps in the Downertown data and the apparent inclusion of accumulated totals at the end of some gaps. The approach taken by BECA was to delete all cumulative readings, which of course might have contained actual daily extreme values. A review of the report concluded, among other things, that this approach would underestimate daily rainfall extremes.

As an additional comparison, historical hydrological data from the Downertown gauge presented in Water and Soil Technical Publication No. 19 "The Frequency of High Intensity Rainfalls in New Zealand" (Tomlinson, 1980) was also included in the review. Based on data collected from 1945 to 1977, it was reported the 24-hour 5-year ARI rainfall depth at the Downertown gauge as 425mm. This compares with a value of 356mm calculated by BECA for the "Stockton Mine Area" and

approximately 200mm obtained from HIRDS v2. Comparison of various events over a 24-hour period shows that rainfall depths from TP19 are up to 40% greater than the BECA values.

In order to avoid both these situations, MWH examined the original Downertown records and an attempt was made to “repair” the record by spreading out the accumulations in the most likely distribution across the missing days. This was completed by applying the pattern of rainfall recorded at sites in Westport and Millerton. A “clean” record was created for the period 1945 to 1969. This period was chosen due to the presence of comparable records at the two neighbouring sites and due to time and budget constraints. Although the Millerton record ends in 1969, the record from Westport continues until the present day and a dataset from Ngakawau is available from 1979 onwards. The period 1945 to 1969 was deemed to be a sufficient length to conduct an initial frequency analysis. The “cleaning” of the Downertown record could be extended using data from neighbouring sites at Westport and Ngakawau but would involve a significant additional amount of time input.

MWH recalculated design rainfall depths using the repaired Downertown record in their 2007 report. Results are summarised in Table 1 below. The MWH depths are compared to the Beca data in Table 2.

Table 1 Recommended design rainfall depths (mm) (from MWH 2007)

Duration (Hours)	1	2	3	3.5	4	5	6
5 year	73.7	103.2	126.8	139.3	146.4	162.6	178.7
10 year	88.4	122.0	149.9	164.5	173.1	192.2	211.2
20 year	102.9	140.5	172.6	189.5	199.4	221.3	243.3
50 year	122.0	164.9	202.6	222.3	233.9	259.7	285.4
100 year	136.3	183.2	225.1	247.1	260.0	288.6	317.2

Duration	10 mins	30 mins	1 hour	3.5 hours	12 hours	24 hours
5 year	30.2	53.1	73.7	139.3	250.1	329.1
10 year	36.2	63.6	88.4	164.5	299.9	388.1
20 year	42.1	74.0	102.9	189.5	349.0	446.3
50 year	49.9	87.8	122.0	222.3	413.7	522.7
100 year	55.8	98.1	136.3	247.1	462.4	580.5
1000 year	74.8	131.5	182.8	327.1	619.9	775.0

Table 2 Comparison of Beca and MWH rainfall depths for 5 year ARI

Duration	10 mins	30 mins	1 hour	3.5 hours	12 hours	24 hours
MWH	30.2	53.1	73.7	139.3	250.1	329.1
Beca	26	40	60	-	-	371
Difference	14%	25%	19%	0%	0%	13%

Results indicate that the Beca data set could underestimate stormwater flows by 15-25% for short duration events, although it should be noted that the MWH rainfall depths are based on the 1945 –

1969 record period whereas the Beca depths are based on the 1945 – 2004 record. Differences between the MWH rainfall estimates and the Beca data are likely to be less pronounced for the 90th percentile rainfall depth used for the pond size analysis, since exclusion of the top 10% of the record removes the high rainfall events that are identified as a source of bias in the MWH study.

A 90th percentile 24 hour storm intensity of 54.8mm was calculated by Beca for use in the pond sizing assessment. We note that this is significantly less than the 233 mm/d design storm specified in the Water Right.

2.1.2 Compliance review period

Use of a long term (1945 to 2004) 90th percentile rainfall depth is a fundamental component of the Beca analysis, in that it necessitates review of compliance over a very long period. In wetter than average years, more than 1 in 10 (i.e. >90% of) rainfall events will be greater than the long term 90th percentile, and conversely in dryer than average years fewer than 1 in 10 rainfall events will exceed the design event. This means that in wetter than average years it is likely that ponds sized using the long term 10 % recurrence event would not meet TSS limits, unless the design had sufficient margin of safety to cover this. More frequent exceedances of the TSS target in wet years would be balanced by fewer exceedances during dry years in the long term, and hence the Beca study assumes that compliance with the target is reviewed on a cumulative long term basis. This is not clear from the report, however, which states that *“The overarching goal is the design and implementation of sediment controls that will result in the Stockton Mine complying with the target of 20 mg/l TSS 90% of the time/year”*.

The Stockton Water Right and current TSS discharge target do not specify a compliance period or monitoring frequency for sediment discharges. Recently issued water quality consents incorporate a compliance review period by specifying a sampling frequency, together with a percentage exceedance limit. If the Stockton Water Right sediment discharge limit was evaluated over a 30 day compliance period, the current sizing method would be unlikely to achieve compliance for several months in each year.

Under the Cypress Mine consent conditions, a 90th percentile TSS limit of 20 mg/l was specified for the 8W compliance point, located in an undisturbed stretch of St Patricks Stream with sensitive bryophytes. The consent condition requires compliance to be assessed over a 30 day period for daily sampling, or any 10 consecutive samples where monitoring has been decreased to weekly (potentially after 12 months of sampling at 8W). Implementation of the Stockton Water Right TSS target using this approach would be preferable to the current interpretation. Compliance with the limit should be assessed in the receiving water at a location sufficiently far downstream to allow for full mixing with the sedimentation pond discharge.

2.1.3 Runoff estimates

A runoff coefficient of 0.62 was used by Beca to estimate runoff from undisturbed catchment. This is likely to underestimate flows from the sparsely vegetated areas of the plateau. Analysis of base flow data from various streams on the Stockton Plateau (e.g. Plover Stream) indicates that the average runoff coefficient is high – in the order of 0.85-0.95. Use of a low runoff coefficient will result in underestimation of the proportion of clean runoff entering the sediment pond and thus a

potential over estimation of the TSS concentration (since this appears to be calculated on a weighted mean of the proportion of flows from each land use type), and under estimation of flows. Runoff coefficients used for the remaining mine areas are considered reasonable and/or suitably conservative.

2.2 Sediment yields

Sediment yields were estimated from an interpreted relationship between rainfall intensity and TSS concentration data from S14. We note that the correlation between TSS and rainfall intensity is very poor ($R^2 = -0.24$). This relationship was used in the study in preference to the S14 flow versus TSS concentration relationship. The Beca study concluded that there is no clear relationship between TSS and flow despite the fact that statistically, the relationship between flow and TSS ($R^2 = 0.31$) is stronger than the relationship between rainfall intensity and TSS. Under these circumstances it would have been appropriate to calculate an uncertainty envelope around the TSS concentration predictions used for the pond sizing.

TSS predictions from the stormwater samples collected as part of the Beca study were compared to S14 TSS sampling data, using the rational method and estimated runoff coefficients. The comparison revealed that stormwater sample TSS concentrations were approximately 2.5 times greater than actual concentrations recorded at S14. This discrepancy was accommodated in the study through use of Low and High TSS concentration scenarios.

A simplistic analysis of TSS data from Mangatini Sump was recently undertaken by URS for the Lower St Pats Reservoir capacity assessment study. The aim of the analysis was to estimate TSS concentrations in runoff from various mine areas for use in water balance models run on a daily time step basis and using flow records rather than rainfall data. It should be noted that whilst use of daily mean flow records data is appropriate for design of large sedimentation structures (e.g. the Lower St Pats Reservoir), higher resolution data are required for design of smaller sedimentation ponds.

Table 2-3 below summarises the URS and Beca estimates.

Table 2-3 TSS concentration estimates

Mine area	90 th percentile TSS concentration	
	URS estimate (mg/l)	Beca estimate (mg/l)
Active Pit	2,500	6,300
Active Backfill	5,000	31,000
Haul Road:	1875	6,850
Old backfill/partial rehabilitation	250	390
Rehabilitated backfill	12	190

TSS concentrations derived for the URS study are less than the Beca estimates due to the differing time series resolution used in the analysis. As noted above, the URS estimates are daily averages, whereas the Beca estimates are based on a 1 hour target storm (approx 8 mm/hr).

URS consider that both estimates are subject to a high level of uncertainty due to the methods employed and the limited data sets available for analysis. Actual concentrations could potentially be above or below the range of estimates above. Both estimates have been used in this current study.

2.3 Settlement characteristics

Raw water samples were collected from various areas of the mine as part of the Beca study, in order to characterise the principal mining land use types. Settlement rates were analysed using a double hydrometer test. The testing process encountered a number of issues, with additional uncertainty associated with the particle density assumed for the final results analysis.

A number of sediment samples were collected from the Mt William North old mine workings area as part of the Water Management Plan study for the proposed Mt William North mine. Settlement rates for these samples were investigated through 24 hour settlement column tests. Figure 2-1 below plots settling rates from the 2004 Beca samples and the recent Mt William North samples. Samples comprise coal pit/coal fines from an opencast working area and stormwater samples from backfill areas.

The two sets of samples give reasonably consistent results, despite the differences in testing method and sampling locations. In both instances the coal fines samples settle significantly faster than the backfill samples (which predominantly comprise siliciclastic sediment).

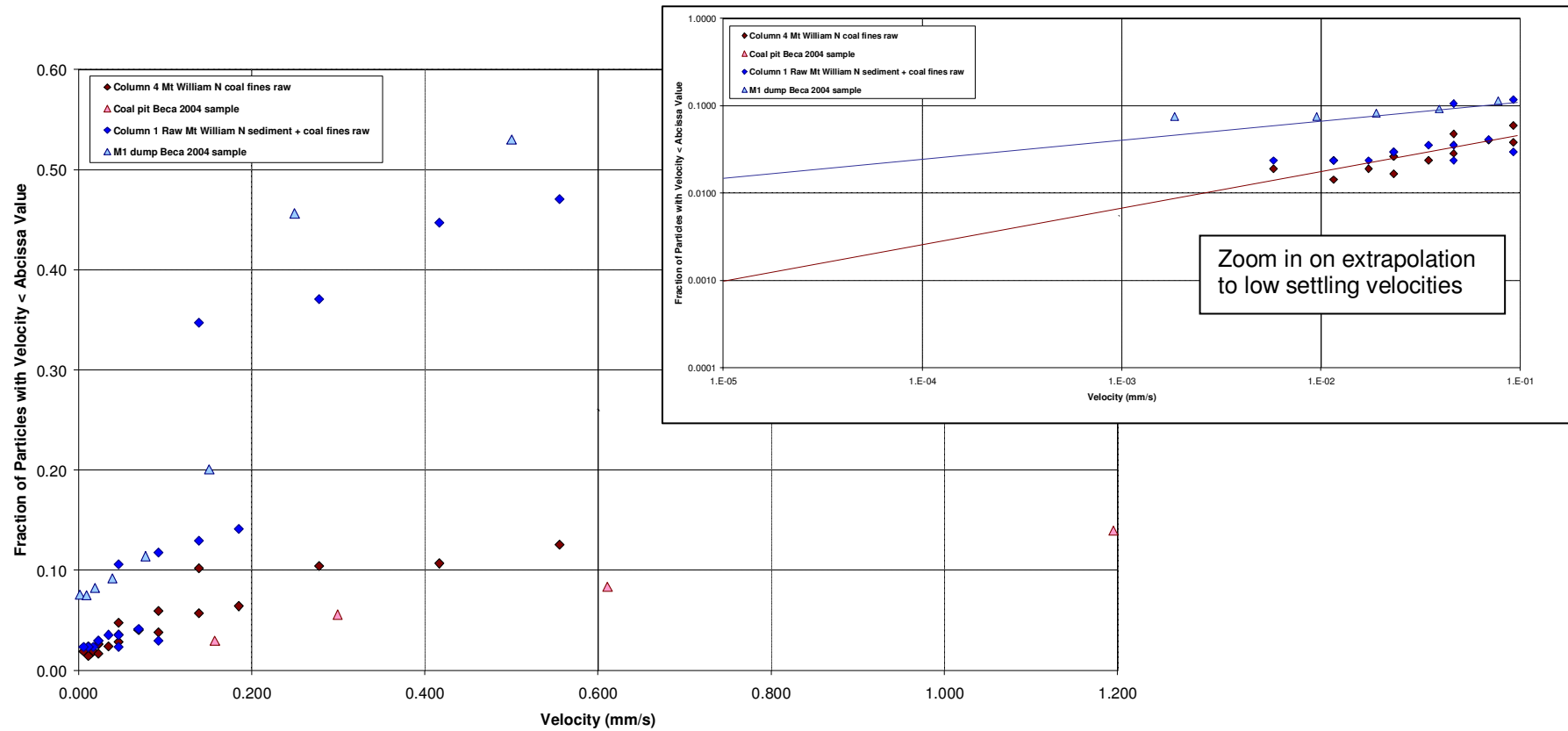


Figure 2-1 Settlement rate results comparison with extrapolated settling velocities – Active Pit and Backfill areas.

All settling column results indicate a maximum removal of 93 – 98% of the initial sediment concentration within the column testing period. Minimum effluent concentrations have been estimated in Table 2-4 below for these removal efficiencies for sediment ponds located downstream of the five mine areas and for the two sets of influent concentration estimates in Table 2-3 above.

Table 2-4 Sedimentation pond minimum TSS discharge concentration estimates

Mine area	90 th percentile TSS concentration			
	URS estimate (mg/l)		Beca estimate (mg/l)	
	Influent concentration	Effluent concentration	Influent concentration	Effluent concentration
Active Pit	2,500	50-175	6,300	125-450
Active Backfill	5,000	100-350	31,000	620-2200
Haul Road:	1875	40-130	6,850	140-480
Old backfill/partial rehabilitation	250	5-20	390	8-27
Rehabilitated backfill	12	<1	190	4-13

The Stockton Procedure for the Design and Sizing of Sumps states that ponds sized under the procedure are likely to perform as follows:

- For lesser disturbed areas (e.g. rehabilitating and rehabilitated areas) and areas with low coal fines content, almost all of the sediment should be settled out.
- For areas with mainly disturbed ground and some source of coal fines, around 90 to 95% of the sediment should be settled out.
- For high coal content areas, only 80% of the sediment *or less* will settle out

Based on the TSS concentration estimates in Table 2-3, these removal rates would deliver the following suspended sediment discharge concentrations:

Active pit: 250 – 1250 mg/l

Active backfill: 250 – 3000 mg/l

Haul Road: 90 – 700 mg/l

These concentrations are of the same order as those in Table 2-4. The data therefore suggest that for the majority of mine areas it is unlikely that the 20 mg/l target could be achieved by gravity settling alone. This also aligns with the findings of the Beca study, which concludes:

“the TSS target of 20mg/l TSS at the site boundaries may not be practicably achievable. The indication from our modelling is that the target cannot be met by treatment via sediment ponds alone. The modelling work was undertaken to identify a practical sizing for sediment treatment ponds within the Stockton Mine area, and identify if the use of ponds in all areas will reduce the TSS runoff (within each area) to a level where it could ‘average’ out (potentially via the proposed Mangatini Dam, or other such devices) to the target TSS at the site boundary.”

The maximum settled sediment proportions (and associated effluent concentration estimates) presented above are partly related to the duration of the settlement column test (24 hours). In reality material will continue to settle after this time, albeit at a diminishing rate. An extrapolation of settling rates is included on Figure 2-1, which shows this.

Table 2-5 below summarises the removal efficiencies and associated settling velocities (based on the extrapolated settling rates from Figure 2-1 above) required to achieve the 20 mg/l TSS limit. These data have been used in the pond sizing assessment in Section 2.3.1 of this report.

Table 2-5 Required trap efficiency estimates

Mine area	90 th percentile TSS concentration					
	URS 90 th percentile TSS estimate			Beca 90 th percentile TSS estimate		
	Influent concentration (mg/l)	Removal efficiency ¹ (%)	Settling velocity (mm/s)	Influent concentration (mg/l)	Removal efficiency ¹ (%)	Settling velocity (mm/s)
Active Pit	2,500	99.2	<2E-5 - 2E-3	6,300	99.68	<2E-5
Active Backfill	5,000	99.6	<2E-5	31,000	99.94	<2E-5
Haul Road:	1875	98.9	<2E-5 - 3E-3	6,850	99.71	<2E-5
Old backfill/partial rehabilitation	250	92.0	0.02 – 0.6	390	94.87	2E-3 – 0.14
Rehabilitated backfill	12	-	-	190	89.47	0.05 – 0.5

1. Removal efficiency required to reduce influent sediment concentration to target concentration of 20 mg/l

2.3.1 Sedimentation pond size assessment

The Hazen-Camp method was used in the Beca study to estimate the pond size required to achieve the discharge water quality objectives. A low pond efficiency factor of 2 was used. The Overflow Method and Depth/Detention Time (DDT) models provide alternative (but similar) approaches for sediment pond sizing. All are based on ideal settling theory. The DDT model is mathematically equivalent to the Overflow Method for regular rectangular sedimentation ponds, but differs for ponds with sloping bottoms. Tapp (1981) and other authors have concluded that of the overflow method models, the DDT approach provides the best representation of the hydraulic conditions of a sloping bottom sedimentation pond.

The Overflow Method can be used to determine the pond size required to remove a given proportion of sediment with a specified settling velocity termed V_c (the critical settling velocity) as follows:

$$V_c = Q/A \quad \text{Where:}$$

V_c = critical settling velocity

Q = pond throughflow rate

A = pond surface areas

Pond size calculations using the Rational Method with the Beca rainfall estimates and a runoff coefficient of 0.8 indicate that pond sizes in excess of 15% of the mined catchment area would be required for a V_c of 0.01 mm/s or less. The settling velocities required to achieve the 20 mg/l effluent concentration target summarised in Table 2-5 above are significantly less than 0.01 mm/s for all active mine areas, indicating that it is unlikely to be feasible to construct a sufficiently large sedimentation pond to meet the TSS discharge target - i.e. pond sizes substantially greater than 15% of the mined area could be required, unless downstream dilution is accounted for.

For a pond size equal to 10% of the mined catchment, influent sediment concentrations would need to be between 200 and 700 mg/l. This is significantly lower than both the URS and Beca estimates of sediment concentrations in runoff from active mine areas at Stockton, and unlikely to be borne out in reality.

Simple calculations indicate that for a pond size equal to 10% of its catchment area, it would be necessary to limit the active backfill area (the greatest source of sediment in stormwater from mine areas) as follows in order to achieve a sediment pond influent concentration of 700 mg/l:

- 15% of the pond catchment according to the URS TSS concentration estimates, and
- 2% of the catchment according to the Beca estimates,

This assumes that the remainder of the catchment comprises old/partially rehabilitated backfill areas.

In order to achieve the 20 mg/l target for a 10% pond size where dilution with clean runoff is available, the dilution factors required for ponds draining the various mine areas are estimated as follows:

- Active Pit: 2.5 - 25
- Active Backfill: 5 - 125
- Haul Road: 2 - 30
- Old backfill/partial rehabilitation: 0 - 1.5
- Rehabilitated backfill: 0

This means sediment ponds would need to discharge at locations with receiving water upstream clean catchment areas of between 3 and 125 times the mine area discharging to the sediment pond, in order to achieve the 20 mg/l target. The large range is a reflection of the range of estimates used for TSS concentrations in runoff from the mine areas and for sediment settling rates in the pond.

Dilution within the receiving water body from a clean upstream catchment area 4 to 170 times greater than the mined catchment would be required for a sediment pond size equal to 5% of the mined catchment area.

All of the above are based on an assumed rectangular sedimentation pond (length to width ratio of 4:1 or 5:1) with a flat bed. Additional engineering (installation of baffles) is likely to be required for irregular shaped ponds to achieve the same results.

3 Uncertainties and limitations of current pond sizing approach

A review of Beca's Stockton sediment pond sizing evaluation has identified a number of limitations and areas of uncertainty. These are summarised below:

- The method used to process the Downerton rainfall record is likely to have resulted in an underestimation of runoff rates during design storm events;
- The study assumes that compliance with the TSS target will be assessed on a long term basis. If compliance is evaluated over a shorter period (e.g. monthly), discharges from ponds designed with this method are likely to exceed the 20 mg/l target on a regular basis;
- Current data on sediment yields from the various mine areas is very limited, and hence sediment pond influent concentration estimates are highly uncertain;
- The end result of the Beca study is not a pond sizing method that will achieve compliance with the 20 mg/l target, and this is stated in the final part of the report. One of the conclusions of the study is that pond settling alone is unlikely to achieve the 20 mg/l target.
- The analysis in this report concurs with the Beca report conclusion: compliance with the 20 mg/l TSS target is unlikely to be achievable at the pond discharge point for a reasonably sized sedimentation basin. Additional treatment (e.g. flocculent dosing) would be required to meet this target.
- Discharges from a sediment pond sized at 5-10% of the catchment area are likely to require significant dilution in the receiving water in order to achieve consistent compliance with the TSS target.

The current procedure is therefore not designed to achieve a discharge target of 20 mg/l for active mine areas. Discharges from sedimentation ponds downstream of old backfill and rehabilitated areas, which are sized according to the procedure, should generally meet the 20 mg/l target.

4 Sedimentation pond design recommendations

This section of the report comprises a brief review of sedimentation pond design features that would assist in meeting the sediment discharge target specified in the Stockton Water Right.

4.1.1 Use of Multiple sedimentation ponds

The benefits of using multiple smaller sedimentation ponds as an alternative to a single larger pond of the same total capacity are discussed in US Department of Interior, 1982. The study cites field applications which have shown that multiple sediment ponds in series are more efficient in removing finer particles than a single pond of equal surface area. It is also noted that solids with higher settling velocities will settle in the first pond and finer sediments will settle in the final pond: One particular advantage of this type of system is that maintenance (i.e. excavation of sediment from the pond) is generally limited to the first settling pond. A disadvantage of multiple ponds is that a greater area is disturbed during construction.

4.1.2 Baffles and decants

Installation of baffles and decant structures are known to improve the performance of sedimentation ponds. The potential benefits of these installations should be quantified through review of research papers to facilitate cost benefit analysis of incorporating them into the standard sedimentation pond construction procedure. Baffles should be designed and installed to prevent short circuiting at locations where physical constraints at the site mean that irregular-shaped ponds are unavoidable.

4.1.3 Maintenance

US Department of Interior 1982 notes that poor maintenance is one of the major problems in performance of existing sedimentation ponds, and hence development of a maintenance programme is a significant part of the pond design.

4.1.4 Recommendations for pond design and operation

We recommend the following broad approach to sedimentation pond sizing:

1. Define maximum extent of disturbed catchment area that will discharge to the pond;
2. Select a suitable pond location downstream of the disturbed area;
3. Estimate the undisturbed catchment area for the receiving water upstream of the sediment pond discharge point;
4. Calculate the pond size required based on the disturbed area, design storm flows (recalculated based on the compliance review period and repaired Downerton rainfall record) and dilution available in the receiving water;
5. If required pond size cannot feasibly be constructed, review performance improvement options (e.g. baffles, flocculent dosing) and incorporate appropriate measures into treatment system design;
6. Assess sediment pond sites to determine whether multiple smaller ponds can be constructed (preferred option);
7. Design pond inflow channel(s) and spillway(s) using design storm flow (based on the repaired Downerton rain gauge record - see Recommendations below);
8. Apply appropriate factor or safety to all components of the design (factor will depend on whether dilution in receiving water is available);
9. Design maintenance access and maintenance programme;
10. Construct sedimentation pond(s), minimising disturbed area around them;
11. Stabilise disturbed area around pond(s), replanting as necessary to minimise erosion;
12. Monitor pond influent and effluent TSS concentrations on an ongoing basis at a specified sample frequency. Pond outflows should be estimated at the time of sampling.

13. Compare actual pond performance to theoretical performance. If pond is underperforming significantly, review options to improve performance (e.g. installation of baffles, decant devices, increasing pond size);
14. Continue to monitor pond and improve as necessary.

5 Recommendations

The principal recommendations of this study are as follows:

The Downerton rain gauge data set should be repaired and design rainfall depths recalculated in order to provide a more robust basis for stormwater evaluation and infrastructure design;

Implementation of the Stockton Water Right sediment discharge limit as a 20 mg/l 90th percentile value, based on a specified sampling frequency and compliance evaluation period, and allowing for available dilution in the receiving water, should be discussed with internal stakeholders and then the regional council as appropriate;

A sampling programme should be developed to characterise sediment yields from the various mine areas (implementation of the sediment pond design method and associated sampling specified above will assist with this). This will reduce the uncertainty and hence factor of safety required for pond sizing;

The feasibility of using a system of flexible baffles should be investigated in terms of their potential for rapid and effective deployment to poorly performing sedimentation ponds, as a contingency measure;

Passive flocculent dosing systems should be investigated and a concept design drafted to facilitate efficient deployment of such a system when required; and

The Stockton Sediment Pond Sizing Standard should be redrafted to reflect the findings of this study. This will involve development of the broad pond sizing approach presented above into a more detailed procedure.

URS would welcome the opportunity to visit Stockton to discuss the findings of this draft report in the context of the operational and physical constraints of the mine area. A final report, together with a revised version of the pond sizing procedure if appropriate, could be issued after this visit.

Yours sincerely
URS New Zealand Limited

Associate Hydrogeologist

Principal

References

Beca 2005: Stockton Mine - Sediment Pond Sizing Details for Different Land Uses

MWH 2007: Stockton Mine Site Hydrology and Rainfall-Runoff Modelling

US Department of Interior, Office of Surface Mining, 1982 Design Manual for Sedimentation Control Through Sedimentation Ponds and Other Physical/Chemical Treatment

DRAFT

**ATTACHMENT I - ESCARPMENT MINE PROJECT: ASSESSMENT OF REVISED WATER
MANAGEMENT APPROACH (WMG, 2014)**

Escarpment Mine Project

Assessment of Revised Water Management Approach

Submitted to
Buller Coal Limited
PO Box 290
Westport



Report Number 12001-036-R-002

Distribution Buller Coal Limited

Status Final

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Further details of the limitations of this report are appended in Appendix A.

Revision Schedule

Rev. No	Date	Description
1	17/02/2014	Updated WMM with Revised Management Approach
2	18/02/2014	Correction to Table 36

Record of Issue

Company	Contact	Rev. No	Date	Method of Delivery
Buller Coal Limited	C Robertson	1	17/02/2014	Electronic (pdf)
Buller Coal Limited	C Robertson	2	18/02/2014	Electronic (pdf)

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Appendices

Appendix A – Report Limitations



1. Introduction

Buller Coal Limited (BCL) is currently developing an open cast coal mine, the Escarpment Mine Project (EMP) in part of the Buller Coalfield on the Denniston Plateau, New Zealand. BCL has engaged WM Group Limited (WM Group) to update an earlier hydrological assessment prepared by Golder Associates New Zealand Limited (Golder) during the consenting process (Golder 2012a).

2. Background

2.1 Consent Conditions

On 26 August 2011, the EMP obtained a Resource Consent (RC100193, WCRC 2011) from the West Coast Regional Council (WCRC) to discharge treated and partially treated water intercepted from the proposed open cast mine into the Whareatea River (WRC 2011). The resource consent was subsequently appealed to the Environment Court. On 24 October 2013 the Environment Court issued consent conditions as part of the Environment Court Decision that gave approval for the project to proceed.

The Environment Court consent conditions of 24 October 2013 include several conditions that specified the compliance water quality limits at a downstream monitoring site from the EMP, being site W-M2. The Environment Court conditions are unlikely to be consistently met under the original water management approach developed by Golder. Condition 263 (extract of which is reproduced below) effectively provides another water quality limit in addition to the anticipated compliance water quality limits at W-M2 (Condition 255).

263 *Compliance shall be assessed on the basis of a 6 monthly seasonal monitoring periods... ..The permitted exceedence of the median limits shall be no more than 15 samples for the monitoring period. The permitted exceedence of the 95th percentile limits shall not be more than 3 samples for the monitoring period, **and any exceeding samples must not exceed the limit by more than 20%.** Continuously monitored parameters (turbidity and pH) shall compare statistically-derived median and 95th percentile values, calculated from daily mean values for the compliance period, with the compliance limits listed in Table 3.*

The implication of the phrase "...and any exceeding samples must not exceed the limit by more than 20%" has the effect of applying a maximum water quality criteria at BCL's compliance monitoring site W-M2. In turn this has the implication of applying an upper limit on the permissible water quality of all surface discharges from the EMP. As the 95th percentile limits are relatively stringent, in effect any and all discharges from the EMP will need to be treated to a high standard.

Due to the constraint implied by Condition 263, the implementation plan of the water management strategy outlined in the Regional Council and Environment Court hearings may not be satisfied, without complete treatment of all discharges. Specifically the proposal to fully treat MIW and ELF surface runoff 95% of time and partially treat the water the remaining 5% of time is likely to result in routine exceedences of the effective maximum allowable concentrations of TSS, turbidity and likely most dissolved metals limits at W-M2. To comply with Condition 263, in effect BCL will be required to treat all discharges from the EMP.

2.2 EMP Rainfall Projections

Golder completed a hydrological assessment of the climatic conditions on the Denniston Plateau and extreme rainfall events that are likely to occur at the proposed EMP (2012b). The daily synthetic rainfall data-set generated for the EMP site as part of the hydrological assessment was applied to the Goldsim Water Management Model originally developed by Golder (2012a) that formed the basis of the predictions of the size / capacity selection of the MIW Surge Sump and MIW-WTP. The Goldsim Water Management Model originally developed by Golder (Golder GoldSim Model) was also used to derive water quality projections for downstream water quality monitoring points on the Whareatea River.



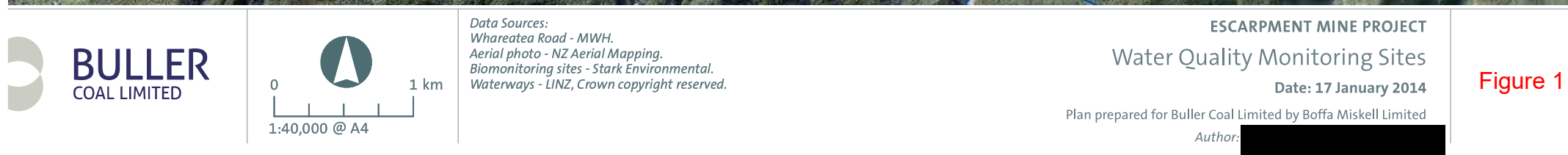


Figure 1

The hydrological assessment drew upon a correlation between the rainfall intensity at the Solid Energy New Zealand Limited (SENZ) M1-R2 rainfall site and V8-M1 (BCL's rainfall site at Lake Brazil), on the basis that the only long term rainfall series in the vicinity (being the Downertown rainfall series 1945-1997) was located near M1-R2 (Golder 2012). SENZ has subsequently suggested that the Downertown rainfall record was actually collected at the historic Stockton Open Cast which is closer to the Stockton Top Office, and is some 200 m greater in elevation compared to M1-R2 (SENZ 2013).

Following a comparative probabilistic frequency distribution assessment Envirolink (2013) is of the "...opinion that the Downertown rain-gauge was at Stockton Top Office area between 1945 and 1992, rather than the Bathhouse location as originally thought." On this basis, WM Group has reassessed the rainfall intensity correlation between Downertown and V8-M1.

3. Scope of Works

WM Group was engaged by BCL to:

1. Develop a revised water management approach that would ensure compliance with the consent conditions issued as part of the Environment Court Decision of 24 October 2013.
2. Revise the existing GoldSim Water Management Model to incorporate the changes that have been made to the water management approach.
3. Update the rainfall data for the site and apply the updated data to the water management model.
4. Re-evaluate the effects of mine operations and closure conditions on the water quality of downstream surface water bodies, taking into account the new water management approach.

Items 1, 2 and 4 are addressed in this report. The outcomes of the reassessment of the rainfall data for the EMP site and the Denniston plateau (Item 3) are presented in a separate report (WM Group 2013a).

4. Revised Water Management Approach

4.1 Introduction

A revised water management approach has been developed to comply with the consent conditions issued as part of Environment Court Decision of 24 October 2014. This approach offers a higher level of service, and proposes to treat *all* the MIW and runoff from the EMP. The principal variation between approaches is presented in Table 1.

As presented graphically in Figure 2, the implementation plan envisages the following:

- Cut off drains around the pit and infrastructure areas, to divert clean runoff into natural water bodies
- Pit high wall and waste dump runoff directed to the pit sump(s)
- AMD from dewatered underground workings to be directed to the pit sump
- MIW from the pit sumps pumps to be pumped to a forebay/ $\text{Ca}(\text{OH})_2$ dosing channel prior to discharging into the MIW Sedimentation Sump
- ELF basal drainage¹ to gravitate into a forebay/ $\text{Ca}(\text{OH})_2$ dosing channel prior to discharging into the MIW Sedimentation Sump
- Infrastructure area and Barren Zone ELF surface runoff to pass through a forebay prior to discharging into the MIW Sedimentation Sump

¹ ELF basal drainage is the flows (or leachate) typically observed at the base (basal) of the ELF or waste dump



- the incoming MIW is dosed in a $\text{Ca}(\text{OH})_2$ channel upstream of the MIW Sedimentation Sump; to remove neutralise a majority of the incoming acidity
- MIW Sedimentation Sump (including the forebay and $\text{Ca}(\text{OH})_2$ channel) to serve three purposes:
 - Primary sedimentation of sediment and AMD sludge formed following the mixing of AMD with $\text{Ca}(\text{OH})_2$
 - Provide additional time for $\text{Ca}(\text{OH})_2$ to dissolve
 - Attenuate the pumped and gravity (ie.; stormwater runoff) inflows within permissible freeboard thresholds
- From the MIW Sedimentation Sump partially treated MIW is pumped into the MIW-WTP for final treatment prior to discharge
- MIW-WTP provides secondary treatment of the MIW with the addition (trimming) $\text{Ca}(\text{OH})_2$ and a proprietary heavy metal chelating agent (eg. MetalsorbTM or similar). Secondary treatment is required to affect final pH correction and remove the remaining target dissolved metals). Lamella clarifiers will be used to separate the MIW waste sludge from the treated water
- Waste MIW sludge will be returned to bottom of the MIW Sedimentation Sump. The sludge will be encapsulated (capped) within the MIW Sedimentation Sump when MIW treatment transitions from active to passive treatment at the end of mine life
- The ELF surface runoff is proposed to be managed independently of the MIW. In accordance with Condition 249, ELF runoff management will “.adopt best practical option for stormwater management...” and shall be developed “... in accordance with TP10 (ARC 2007) following adaption for rainfall conditions at Denniston Plateau.”. It is likely it will take the form of a TP10 flocculant assisted sediment separation process, with the treated runoff discharging into the respective tributary of the Whareatea River.



Notes: *1 Contingency to redirect inflows to Whareatea River if the MIW Sedimentation Sump may overflow
*2 Sludge accumulates in sump. Ultimately encapsulated when Passive Treatment System installed

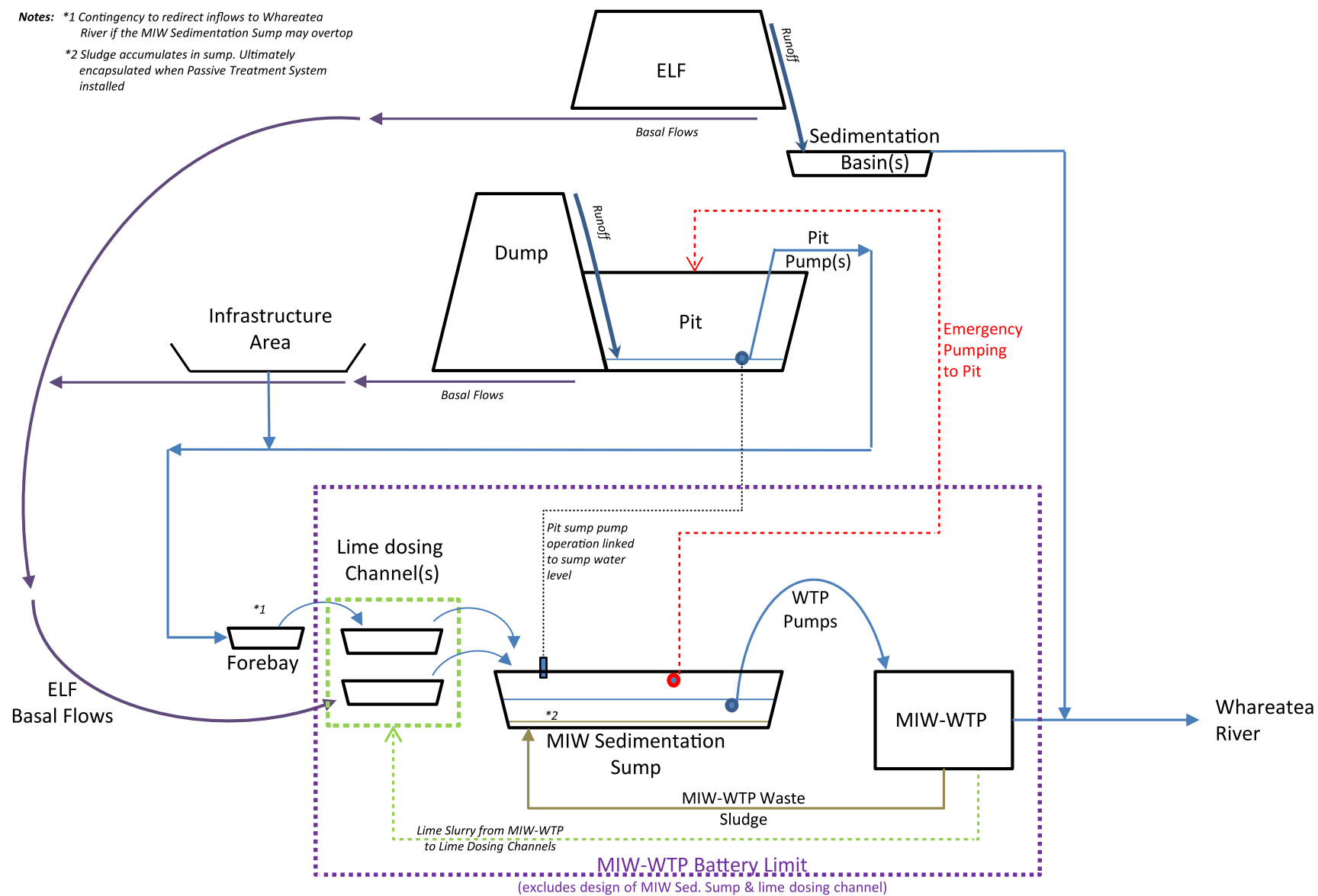


Table 1: Principal Variations Between the Original and Revised Water Management Approach.

Original Water Management Approach	Revised Water Management Approach
ELF surface runoff directed to the MIW-WTP until the sediment load in the runoff was sufficiently low for the runoff to be redirected into tributaries of the Whareatea River.	ELF surface runoff directed to the catchment based sedimentation basins. Treated runoff will enter tributaries of the Whareatea River. Once the source sediment load in the runoff is sufficiently low the sedimentation basin(s) will be disestablished.
MIW Surge Sump to provide primary sedimentation treatment & attenuate MIW inflows	MIW Sedimentation Sump to provide primary AMD and sedimentation treatment & attenuate MIW inflows
Excess MIW from MIW Surge Sump to periodically spill into Whareatea River (flood channel)	MIW will not spill from MIW Sedimentation Sump
MIW Waste Sludge disposed of within containment cells within the ELF	MIW Waste Sludge disposed and eventually encapsulated in the bottom of the MIW Sedimentation Sump; passive treatment system established on top of cap at end of mine life

4.2 Contingency measures

WM Group proposes the following contingency measures to manage the risks associated with the revised water management approach and provide the additional controls necessary to comply with the draft Environment Court Resource Consent conditions:

- The MIW-WTP and MIW Sedimentation Sump shall be sized to mitigate the risk of discharging primary treated MIW from the MIW Sedimentation Sump to the Whareatea River.
- The MIW-WTP shall be sized in excess of that required to treat possible ELF basal inflows
- Pit sump pumps to be specified in a duty/duty arrange and to be diesel powered to provide additional redundancy and independence of the local electricity grid
- The operation of the pit sumps shall be linked via telemetry to the MIW-WTP. Whereby the pumps can be automatically disengaged if the water level in the MIW Sedimentation Sump exceeds a predetermined water level
- The following hierarchy of actions shall be employed to mitigate the risk of overtopping the MIW Sedimentation Sump:
 - Normal operation
 - High Level 1 – Pit sump pump(s) automatically stop pumping. Begin to flood the pit(s)
 - High Level 2 – Relocated pit sump pump(s). Pump MIW from the MIW Sedimentation Sump back to the pit
 - High Level 3 – Controlled diversion of runoff from the Infrastructure Area & Barren Zone ELF into the Whareatea River; whilst routinely (continuously) monitoring to attempt to operate within consented compliance limits at W-M2
 - High Level 4 – Unregulated diversion of runoff from the Infrastructure Area & Barren Zone ELF into the Whareatea River

As the water level in the MIW Sedimentation Sump will be continuously monitored, the response to the hierarchy of high level actions (or alarms) can be automated and routinely revised as the mine evolves. This in combination with the selection of an appropriate water level set-point(s) is likely, based on results from the water balance analysis (WM Group 2013b), to ensure that MIW will not overtop the MIW Sedimentation Sump.



4.3 ELF Cover System

This assessment is based on the assumption that BCL install a compacted lower permeability layer (LPL) to reduce the infiltration of stormwater and oxygen into the ELF, as presented in the environment court (Golder 2012c). Subsequently the AMD Management Plan (MOMP, Appendix 1.K) is proposing to replace the LPL with a geosynthetic clay liner (GCL). A GCL cover system will offer a significantly lower hydraulic conductivity compared to the LPL cover system.

Whilst this assessment is based on the LPL cover system, if BCL were to implement GCL cover system, it is anticipated that the ELF flows and loads presented in this report would be overstated, and that properly installed GCL cover would provide a lower rate of ingress of water and oxygen into the ELF. In turn the baseline flows and loads on the MIW treatment system would be lower.

4.4 ELF Surface Runoff

The water management strategy and the draft Environment Court Resource Consent conditions distinguish between MIW and stormwater runoff from mining operations. However collectively the combined effect of the treated MIW and stormwater runoff is required to comply with the water quality limits at W-M2 including Condition 263.

ELF surface runoff (stormwater) will occur once the ELF low permeability layer (LPL) has been placed, and the runoff is no longer influenced by AMD or coal sediments. The Total Suspended Solids (TSS) in the runoff will be high during placement of the LPL, protective non-acid forming (NAF) layers & topsoils. The solids load in the runoff will decline following the placement of recovered vegetation (VDT and VIT) and/or planting (including placement of slash & mulching). The solids load will continue to decline with time as the vegetation becomes established and/or the topsoils self-armour. Self-armouring occurs when the final sediments are washed away leaving larger stones and gravels that resist further sediment transport from the ELF slope (Cochrane et al. 2007).

If the MIW and ELF surface runoff are managed separately (as per indicated by Conditions 249 -251) the risk of exceeding Condition 263 can be mitigated. Redirecting ELF surface runoff away from the sump will reduce the contributing catchments contributing to the MIW Sedimentation sump by approximately 57% (WM Group 2013c) in the order of 57%. In the unlikely event that partially treated water leaves the EMP, it is likely to be from the ELF Sedimentation Basins and/or from the diverted runoff from the Infrastructure Area catchment.

4.5 Rehabilitated ELF Sediment Control

The original water management approach was formulated prior to the general arrangement of the ELF cover had been documented in the ELF Landform Design Philosophy Report (Golder 2012c). Based on our current understanding of the ELF construction and rehabilitation plans, the assumption in the original water management approach that the sediment load from the rehabilitated ELF will be high, for up to two years following placement of the rehabilitation soils and vegetation may be overly conservative.

Proposed ELF and rehabilitation controls and procedures that have been developed and documented (ELF, ESC, rehabilitation management plans; BCL 2013) provide greater confidence that it is possible to manage the ELF runoff and minimise the mass of sediment leaving the ELF. Buller's ELFMP risk assessment has identified that the effective implementation of these controls is required for Buller to comply with the resource consent.



As the principal contaminant in the ELF surface runoff is likely to be TSS, the best practical management option is likely to be a wet sedimentation basin. Assuming that the target discharge water quality from the ELF Sedimentation Basin will be similar to the compliance requirements at W-M2 (i.e.; Median TSS $\leq 15 \text{ g/m}^3$, 95th percentile $\leq 30 \text{ g/m}^3$, and maximum of 36 g/m^3); then to achieve this level of treatment it is likely that an automated (i.e. flow paced) flocculent dosing system will be required, followed by an engineered sedimentation basin to allow the TSS in the runoff to separate from the treated water.

The implementation of effective rehabilitation techniques (summarised below) as soon as the LPL has been placed is likely to significantly reduce the rate of soil erosion from the ELF:

- VDT (vegetation direct transfer)
- Soiling
- Transplanting
- Planting
- Hydro seeding
- Slash and Mulch Utilisation

This is supported by the observations of Pizey et al. (2012) who noted that at Stockton the VDT was very effective at mitigating the release of TSS in the runoff, followed by straw mulch and hydro-seeding (61 g/m^3 , 31 g/m^3 and 74 g/m^3 respectively). Reducing the sediment load on the catchment based sedimentation basin will increase the confidence that the sedimentation system could achieve the required level of treatment. Periodically the sedimentation basins will require de-silting, it is possible that the recovered soils could be blended with existing soil stockpiles and beneficially reused to further rehabilitation of the ELF.

To manage the risk of PAF overburden being placed in the protective NAF (non-acid forming) layer above the LPL (lower permeability layer) and generating dilute AMD in the runoff, a monitoring and targeted spot limestone treatment programme will need to be developed and implemented. If the pH in the runoff is acidic and the presence of AMD contaminants are likely to lead to an exceedance at W-M2, then it is suggested that the source of the depressed pH (indicative of an acidic discharge) in the runoff is traced back up the ELF to the general location of the acidic seep. An assessment of the acid load in the ELF seep will allow an estimate of the likely mass of limestone to be placed at the discharge of the seep to mitigate the potential adverse effects of the discharge.

4.6 MIW Sedimentation Sump and MIW-WTP

To aid BCL understand the implications of the revised water management approach on the capacity of the MIW Sedimentation Sump and MIW-WTP, WM Group (2013b) has prepared a water balance model². A series of assessments of the various stages of the proposed mine plan suggests that a $418,000 \text{ m}^3$ ($250,000 \text{ m}^3$ active volume) MIW Sedimentation Sump in combination with a 220 L/s MIW-WTP has the potential to mitigate the risk of MIW spilling from the EMP (Table 2). Like the original approach the MIW-WTP development can be staged, to allow for future improvements in the MIW-WTP to be implemented in response to changes in consent conditions and/or treatment plant performance.

² The water balance model was developed to confirm that the revised water management approach is feasible. Further analysis is required to confirm the size of and treatment objectives of the proposed water management infrastructure prior to detailed design.



Table 2: Proposed Capacity of the MIW Sump and MIW-WTP for the Original and Revised Water Management Approach.

Mine Stage	Original Water Management Approach		Revised Water Management Approach	
	Volume MIW Surge Sump Total (active) m ³	MIW-WTP L/s	Volume MIW Sedimentation Sump Total (active) m ³	MIW-WTP L/s
EOY 1	360,000 (320,000)	166	418,000 (220,000)	110
EOY 2	360,000 (320,000)	166	418,000 (220,000)	220
EOY 3	360,000 (320,000)	332	418,000 (220,000)	220
EOY 4	360,000 (320,000)	332	418,000 (220,000)	220
EOY 5	360,000 (320,000)	332	418,000 (220,000)	220
EOY 6	360,000 (320,000)	332	418,000 (220,000)	220
EOY 7	360,000 (320,000)	332	418,000 (220,000)	220
EOY 8	360,000 (320,000)	332	418,000 (220,000)	220

As tabulated in Table 2, the active volume capacity of the sump is anticipated to be 100,000 m³ smaller than the originally proposed sump. However the total volume of the sump is expected to increase from 360,000 m³ to 418,000 m³. The additional 58,000 m³ volume is due to the further sludge that is anticipated to accumulate in the sump. Whilst the ultimate design capacity of the MIW-WTP is 112 L/s less the originally proposed.

The original approach allowed for the deposition of solids in the MIW Surge Sump, in the order of 40,000 m³. The remaining solids were to be separated by the MIW-WTP, dewatered, and carted to a series of containment cells within the ELF. Provision was required in the cell to keep the sludge alkaline and encapsulated in a LPL to mitigate the risk of future resolubilisation of the captured metals. A series of sludge cells collectively occupying a volume in the order of 44,000 m³ is likely to have been required.

The revised approach to accommodate the MIW sludge in the MIW Sedimentation Sump envisages increasing the depth into basement rock below the coal seam. Sludge will settle, or be piped (into the case of the MIW-WTP waste sludge) to the base of the sump. The sludge will thicken and consolidate with time.

The risk of AMD in the basal flows resolubilising captured metals in the MIW sludge is mitigated by the inclusion of unreacted Ca(OH)₂ (from the MIW dosing basins) in the settled sludge. In addition, the sludge will ultimately be capped thereby reducing the interaction of AMD with the sludge.

In summary, the revised water management approach proposes to *treat all* the MIW generated or intercepted by the EMP whilst the original approach allowed for *partial treatment* of the MIW for up to 5% of time (on an annual basis).



5. GoldSim Water Management Model

5.1 Introduction

For the hydrological assessment, WM Group has used a revised version of the existing Golder GoldSim Site-Wide Management Model (Golder GoldSim Model). The limitations of the Golder GoldSim Model described in the modelling report (Golder 2012a) also apply to this Revised GoldSim Model. A Process Flow Diagram illustrating the input parameters and linkages within the Revised GoldSim model is provided in Figure 3. The Revised GoldSim Model was developed using GoldSim version 10.50.

5.2 Mine Development and Model Scenarios

The Revised GoldSim Model has been modified to include the assessment of the updated mining stages, provided by BCL. The mining stages used in the Revised GoldSim Model do not correspond to the stages applied to the Golder GoldSim Model. The mining stages in the Revised GoldSim Model are as follows:

- Pre-mining stage: Represents undisturbed conditions before mining.
- Mine operational stages: The mine operational period consists of 8 years (Year 1, 2, 3, 4, 5, 6, 7 & 8) from 2013 to 2021.
- Post active: Post-closure (rehabilitated conditions following mining), involving active management (continued operation of the MIW-WTP and SW-WTP).
- Post Passive: Post-closure (rehabilitated conditions following mining) involving passive management.

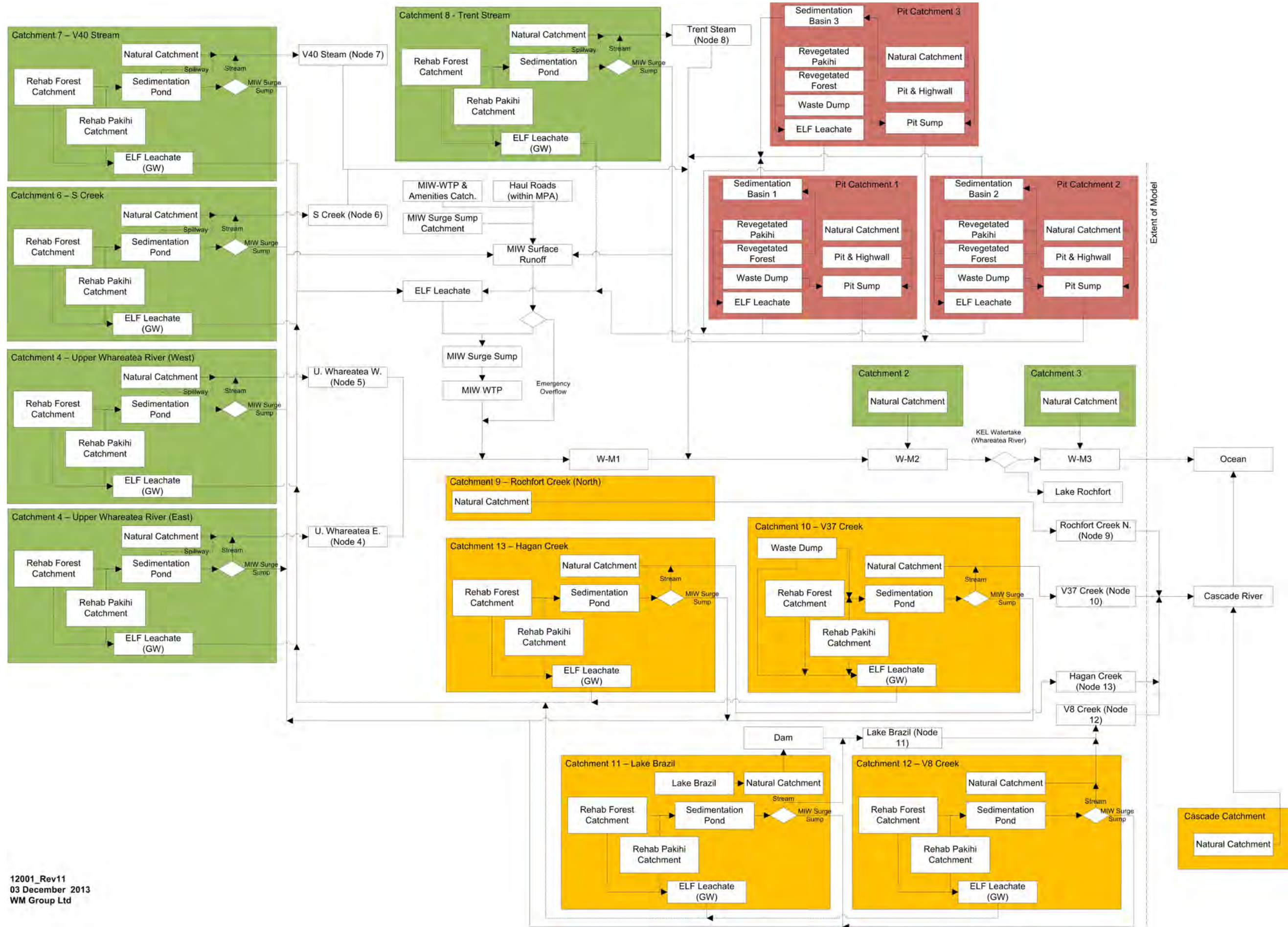
5.3 Model input parameters

5.3.1 Rainfall and Evaporation data

A synthetic daily rainfall dataset for the V8-M1 rain-gauge, for the period from 1 March 1945 to 31 August 2013 was applied to the Revised GoldSim model. The synthetic daily rainfall dataset was generated from the analysis of the rainfall records from the V8-M1 rain gauge and other rain-gauges in the surrounding area (WM Group 2013a). Daily and monthly statistics for the synthetic rainfall data set applied to the Revised GoldSim Model are presented in Table 3 and Table 4 respectively.

The evapotranspiration data applied to the Revised GoldSim Model was based on Penman PET records from the nearest National Institute of Water and Atmospheric Research (NIWA) virtual climate station 19209 (Golder 2012b). Daily evapotranspiration rates based on monthly PET statistics from the NIWA record (Table 5) were applied to the Revised GoldSim Model.





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5.3.2 Catchment Areas and Landuse

WM Group has used staged mine plans provided by BCL to estimate the size of the different land-use areas for different mining stages. BCL also provided the location of key infrastructure (haul roads, sedimentation sumps, MIW-WTP and amenities area). The conceptual ELF design includes covering the waste rock with a 1 m thick low permeability layer (LPL) and an overlying protective layer which is 1 to 5 m thick depending on the re-vegetation plan. The relatively flat areas of the final landform will be re-vegetated with pakihi and the sloped areas with scrub or forest. These areas have been considered separate catchment types due to the variation in groundwater infiltration and runoff. Newly re-vegetated rehabilitated areas are considered to have a different effect on runoff and produce different water quality than more mature rehabilitated areas and therefore considered different catchment types. The catchment areas are tabulated in Table 6 (natural sub-catchments) and Table 7 (mine affected catchments).

Table 3: Daily Rainfall Statistics of the Synthetic Rainfall Series at V8-M1.

Month	Average daily rainfall (mm, all days)	Max daily rainfall (mm)
January	15	389
February	15	350
March	15	385
April	15	254
May	15	287
June	14	272
July	13	390
August	14	240
September	16	381
October	18	279
November	19	381
December	17	311
Average	16	327
Extreme		390

Note: ⁽¹⁾ Source: WM Group, 2013.



Table 4: Monthly rainfall statistics for the synthetic rainfall series at V8-M1

Month	Average monthly rainfall (mm)	Max monthly rainfall (mm)
January	474	977
February	428	1,623
March	449	1,229
April	448	1,225
May	459	1,229
June	423	806
July	397	778
August	422	911
September	489	1,552
October	556	1,051
November	577	1,296
December	530	1,049
Average	471	1,144
Extreme		1,623

Note: ⁽¹⁾ Source: WM Group, 2013.

Table 5: Statistics for the synthetic evapotranspiration series developed for the EMP site (1945 – 2012)

Month	Average daily potential evapotranspiration (mm)
January	3.2
February	2.8
March	1.9
April	1
May	0.4
June	0.3
July	0.3
August	0.6
September	1.2
October	1.9
November	2.5
December	2.7

Note: ⁽¹⁾ Source: Golder 2012b.



Table 6 : Catchment areas - Natural sub-catchments

Catchment	Area (ha)										
	Pre-Mine ⁽¹⁾	Yr.1	Yr.2	Yr.3	Yr.4	Yr.5	Yr.6	Yr.7	Yr.8	Post-Active ⁽²⁾	Post-Passive ⁽³⁾
Whareatea Stream sub-catchments											
West Upper Whareatea	43.5	14.7	14.6	14.6	14.6	14.6	14.6	13.9	13.9	13.9	13.9
East Upper Whareatea	31.3	22.1	22.1	22.1	22.1	22.1	22.1	18.5	18.5	18.5	18.5
Upper Whareatea above W-M1	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8
Mid Whareatea above W-M2	63.3	63.3	63.3	63.3	63.3	63.3	63.3	63.3	63.3	63.3	63.3
Lower Whareatea above W-M3	730	730	730	730	730	730	730	730	730	730	730
Trent Stream	117.9	117.9	117.9	115.1	93.2	75.6	73.6	80.1	80.1	80.1	80.1
V40 Stream	125.2	124	112.5	102.1	100.6	100.6	102.1	106.4	106.4	106.4	106.4
S Creek	0	0	0	0	0	0	0	0	0	0	0
West Upper Whareatea – Rehab Forest	0	0	0	0	0	0	0	0.8	1.4	35.0	44.1
West Upper Whareatea – Rehab Pakihi	0	0	0	0	0	0	0	0	0	7.6	7.6
V40 Stream–Rehab Forest	0	0	0	0	2.7	9.0	20.7	23.2	25.8	25.8	25.8
V40 Stream – Rehab Pakihi	0	0	0	0	2.5	5.6	12.0	13.0	13.0	13.0	13.0
Trent Stream – Rehab Forest	0	0	0	0	0	0	0	9.6	31.5	31.5	31.5
Trent Stream – Rehab Pakihi	0	0	0	0	0	0	0	7.6	12.4	12.4	12.4
Cascade Stream sub-catchments											
Rochefort Creek	0	0	0	0	0	0	0	0	0	0	0
V37 Creek	154.8	153.3	140.6	130.6	134.6	133.9	131.4	121.8	121.8	121.8	121.8
V8 Creek	42.6	34.4	34.4	34.4	34.4	34.4	23.5	23.5	23.5	23.5	23.5
Hagans	1.6	1.6	1.6	1.6	1.6	1.6	1.6	0	0	0	0
V37 Creek-Rehab Forest	0	0	0	0	3.7	7.2	9.2	6.6	6.6	6.6	6.6
V37 Creek-Rehab Pakihi	0	0	0	0	4.0	7.1	7.8	5.8	5.8	5.8	5.8
V8 Creek- Rehab Forest	0	0	0	0	0	0	0	0	0	5.2	5.2
V8 Creek- Rehab Pakihi	0	0	0	0	0	0	0	0	0	0.5	0.5

Notes ⁽¹⁾ Pre mine = pre mining period.

⁽²⁾ Post-Active = Post-mining stage with active management (continued operation of the MIW-WTP and SW-WTP).

⁽²⁾ Post-Passive = Post-mining stage with passive management.



Table 7: Catchment areas – Mining affected catchments

Catchment	Area (ha)										
	Pre-Mine ⁽¹⁾	Yr.1	Yr.2	Yr.3	Yr.4	Yr.5	Yr.6	Yr.7	Yr.8	Post-Active ⁽²⁾	Post-Passive ⁽³⁾
Pit 1 (Western Pit area)											
Natural	0	1.0	0	0.6	0.5	0.2	0	0.2	0	0	0
ELF2a (Forest)	0	0.1	0	0	0	0	0	21.1	0	0	0
ELF2b (Pakihi)	0	2	0	0	0	0	0	4.8	0	0	0
Pit & Highwall	0	14.2	10.6	10.4	12.7	10.8	0	0	0	0	0
Waste Dump	0	4.1	11.4	17.5	11.4	13.1	0	7.0	0	0	0
Pit 2 (Covered ELF area)											
Natural	0	0	0	0	0.9	2.1	0.8	0	0	0	0
ELF2a (Forest)	0	0	6.4	16.2	23.5	24	31.4	8.7	0	0	0
ELF2b (Pakihi)	0	0	6.5	12.7	13.3	13.7	11.4	6.3	0	0	0
Pit & Highwall	0	0	0	0	0	0	0	0	0	0	0
Waste Dump	0	0	9.6	9.6	9.6	9.6	7	16.4	0	0	0
Pit 3 (Lake Brazil Stockpile area)											
Natural	0	5.8	5.8	5.8	5.8	5.8	7.9	0	0	0	0
ELF2a (Forest)	0	0	0	0	0	0	0	0	38.8	0	0
ELF2b (Pakihi)	0	0	0	0	0	0	0	0	8.1	0	0
Pit & Highwall	0	0	0	0	0	0	5.4	3.1	0	0	0
Waste Dump	0	2.9	2.9	2.9	2.9	2.9	15.7	1.0	0	0	0
Mine influenced water											
MIW Sedimentation Sump catchment	0	1.9	1.9	1.9	1.9	1.9	1.9	1.5	8.3	8.3	0
Haul Road	0	2.5	3.5	4.3	5.9	6.6	6.6	6.6	0.9	0.9	0
MIW WTP Amenities	0	8.7	8.7	8.7	8.7	8.7	8.7	9.3	0	0	0
Waste Dump	0	5.7	5.7	5.7	5.7	5.7	1.4	0	0	0	0

Notes ⁽¹⁾ Pre mine = pre mining period.

⁽²⁾ Post-Active = Post-mining stage with active management (continued operation of the MIW-WTP and SW-WTP).

⁽³⁾ Post-Passive = Post-mining stage with passive management.



5.3.3 Surface runoff and the Australian water balance model (AWBM)

Surface runoff in the Revised GoldSim Model for mining affected areas is calculated using a look-up table with runoff coefficients for various rainfall depths. The mining affected catchments were separated into the following five categories: the pit, waste dumps (i.e., uncovered ELF), haul roads, and two categories associated with the covered ELF. The two covered ELF situations represent conditions when the ELF has been covered with a low permeability later (LPL) and re-vegetated with either forest (on the sloping areas) or pakihi (on the flat areas). The surface runoff coefficients used in the Revised GoldSim Model (Table 8) were the same as the coefficients applied to the Golder GoldSim Model (Golder 2012a).

Surface runoff from both natural catchments and rehabilitated mine catchments was calculated from site rainfall and evaporation data using the AWBM (Broughton 1993). The GoldSim Model includes an AWBM module which requires user-defined input parameters (AWBM coefficients) to calculate runoff. The AWBM coefficients used in the revised model (Table 9) were the same as the coefficients applied to the Golder GoldSim Model. The AWBM coefficients applied to the Golder GoldSim Model were obtained through a calibration process (Golder 2012a). Although updated rainfall and evaporation datasets have been applied to the Revised GoldSim Model (Section 5.3.1), WM Group have assumed that the AWBM coefficients applied to the Golder GoldSim Model are applicable to Revised GoldSim Model.

5.3.4 Groundwater seepage inputs

In the AWBM, groundwater discharges to streams in natural catchments and rehabilitated catchments are included in the baseflow component of the total stream runoff. The baseflow index coefficient and baseflow recession coefficient (Table 9) are applied to the AWBM to calculate the relative proportion of net rainfall that percolates to the groundwater system and discharges to streams in natural catchments.

Groundwater seepage rates from beneath the ELF (Table 10) were calculated using simple 2-D groundwater models (Golder 2012d). In the previous water management modelling carried out at the site by Golder it was assumed that groundwater inflows to the proposed pits were insignificant (Golder 2012a). The same assumption has been applied to the Revised GoldSim Model (Table 10).

Table 8: Surface runoff coefficients for mining affected areas

Daily rainfall ⁽¹⁾ (mm)	Surface runoff coefficients ⁽²⁾					
	Pit	Waste dump (uncovered ELF)	CPP	Haul Roads	LPL with re-vegetated forest	LPL with re- vegetated pakihi
0	1	0	0	0	0	0
5			0.5	0.5	0	0
10			1	1	0.75	0.35
12		0				
20	1	0.2				
50	1					
80	1	0.52	1	1	1	1
800	1	0.8	1	1	1	1

Notes ⁽¹⁾ The GoldSim Model linearly interpolates between daily rainfall values.

⁽²⁾ AWBM coefficients are the same as coefficients applied to the Golder GoldSim Model (Golder 2012a).



Table 9: AWBM coefficients applied to the Revised Model

Coefficient ⁽¹⁾		Catchment		
		W-M1	W-M2	W-M3
Surface store capacities (mm)	C1	10	10	10
	C2	50	50	50
	C3	150	150	150
Surface store area split (%)	A1	0.4	0.4	0.4
	A2	0.3	0.3	0.3
	A3	0.3	0.3	0.3
BFI – Base flow index		0.96	0.96	0.85
Ks – Surface runoff recession constant		0.92	0.92	0.97
Kb – Baseflow recession constant		0.2	0.2	0.35

Notes ⁽¹⁾ AWBM coefficients are the same as coefficients applied to the Golder GoldSim Model (Golder 2012a).

Table 10: Groundwater seepage rates applied to the Revised GoldSim Model.

Groundwater seepage component	Seepage rate (mm/day/ha)
Inflow to proposed pits	0
Discharges from Hardstand	0
Discharge from uncovered ELF	12
Discharge from re-vegetated forest	1.87
Discharge from re-vegetated pakihi	4
Discharge from rehabilitated forest	1.87
Discharge from rehabilitated pakihi	4

Notes ⁽¹⁾ Seepage rates applied to the Revised GoldSim Model are the same as the rates applied to the Golder GoldSim Model; and are based on a LPL cover system (Golder 2012c).



5.3.5 Water Quality

Introduction

The water quality inputs applied to the Revised GoldSim Model are presented in this section. All the water quality inputs applied to the Revised GoldSim Model are similar to inputs applied to Golder GoldSim Model (Golder 2012a).

Water quality input parameters – Natural catchments

The natural catchment water quality inputs for flow-dependent parameters and non-flow dependent parameters applied to the Revised GoldSim Model are presented in Table 11 and Table 12 respectively.

Table 11: Flow-dependent water quality input concentrations - natural catchments

Flow yield ⁽¹⁾ (L/s/ha)	Concentrations (g/m ³ unless stated)							
	Aluminium	H ⁺ ion for pH	Iron	Manganese	TSS	Calcium	Magnesium	Zinc
0	0.15	0.032	0.15	0.025	3	0.8	0.9	0.02
0.01	0.15	0.032	0.15	0.025	3	0.8	0.9	0.02
0.07	0.25		0.31					
0.1		0.016		0.025		0.8		
0.2	0.25							
0.3			0.31				0.9	
1					7			0.02
100	0	0.016	0	0.001	10	0.001	0.001	0.001
1x 10 ¹³ ⁽²⁾	0	0.016	0	0.001	10	0.001	0.001	0.001

Notes ⁽¹⁾ The GoldSim Model linearly interpolates between daily rainfall values.

⁽²⁾ An arbitrary large number which is never exceeded in the model.

⁽³⁾ Unit-less GoldSim coefficient, not a measurement concentration.

Table 12: Non-flow dependent water quality input concentrations – natural catchments

Chemical parameter	Concentration (g/m ³)
Arsenic	0.01
Cadmium	0.0005
Copper	0.001
Lead	0.003
Nickel	0.001
Cobalt	0.0015
Chromium	0.001



Water quality inputs - Mining affected catchments

For mining affected catchments, three scenarios were simulated (Table 13) to assess the possible range of water compositions that could result from mine drainage and acid formation management. Different water chemistry inputs were assigned for each scenario (Table 15). The flow-dependent TSS input values to the Revised GoldSim Model are presented in Table 16.

Table 13: Model scenarios - Mine drainage and acid formation management

Scenario	Description
Optimistic	The potential acid forming (PAF) rocks are covered and capped by suitable material in a manner that minimises acid formation reactions.
Typical	The PAF rocks are covered and capped but the process cannot be scheduled to prevent acid forming reactions. As a result, uncovered rocks produce acid.
Extreme	All rocks that are not covered produce maximum acid. Acid composition is based on field column leach testing data and mine drainage chemistry from similar sites.

Simulation of pH in the Revised GoldSim Model

pH in the Revised GoldSim Model is calculated during the model simulation process from the hydrogen ion concentration. The hydroxyl concentration is not considered during the pH calculation which produces results with a bias towards acidic pH values (Golder 2012a).

Compliance limits

The water quality compliance limits established in the 24th of October 2013 Environment Court consent decision for the primary downstream compliance monitoring point W-M2 on the Whareatea River are presented in Table 14.

Table 14: Receiving Waters Compliance Limits at Monitoring Site W-M2

Parameter	Compliance Limits, g/m ³ unless stated otherwise ^{(1), (2)}			
pH (unitless)	Shall not fall outside a range of 4.5 6.5.			
	Median concentrations		95 th percentile concentrations	
Total suspended solids	15		30	
Turbidity	15 NTU		30 NTU	
Iron + Manganese	1.1		2.2	
Aluminium	0.5		1.0	
	Median pH > 5.5	Median pH < 5.5	Median pH > 5.5	Median pH < 5.5
Cadmium	0.0003	0.0012	0.0011	0.004
Chromium	0.05	0.2	1.0	4.0
Cobalt	0.044	0.18	0.17	0.63
Copper	0.002	0.0013	0.007	0.004
Lead	0.0065	0.026	0.03	0.14
Nickel	0.017	0.068	0.26	1.0
Zinc	0.012	0.054	0.067	0.29

Notes: ⁽¹⁾ All compliance limits are based on dissolved metal concentrations.

⁽²⁾ Limits for cadmium, copper, chromium, lead, nickel and zinc are based on a median water hardness of (50 g CaCO₃)/m³.



5.4 Simulation of mine water treatment infrastructure.

5.4.1 MIW Sedimentation Sump and MIW-WTP

In the revised water management approach, the MIW Sedimentation Sump provides primary acid mine drainage (AMD) treatment and sedimentation treatment as well as attenuation of MIW inflows. This modelling approach has been implemented in Revised GoldSim Model in the following:

- MIW is stored primarily in the Sedimentation Sump. The maximum MIW Sedimentation sump active volume capacity applied to the Revised GoldSim Model is 220,000 m³.
- MIW is pumped from the Sedimentation Sump to the MIW-WTP for AMD treatment and sedimentation treatment. The maximum pumping rate assigned in the model for the pumping from the Sedimentation Sump to the MIW-WTP is 220 L/s. Treated water from the MIW-WTP is released to the Whareatea River
- As an emergency measure, MIW is pumped from the Sedimentation Sump to the Pit to prevent the Sedimentation Sump from overflowing and discharging to the Whareatea River.
 - The emergency pumping is activated when the volume of MIW in the Sedimentation Sump exceeds 200,000 m³.
 - The maximum pumping rate from the Sedimentation Sump to the Pit is 116 L/s (10,000 m³/day).

A summary of the operational parameters for the Sedimentation Sump and MIW-WTP assigned to the Revised GoldSim model are presented in Table 17. The treatment efficiencies assigned to the MIW Treatment System (MIW Sedimentation Sump and MWI-WTP) are presented in Table 18.

5.4.2 Sedimentation basins

In the revised water management approach ELF runoff is to be treated to remove TSS in catchment-based sedimentation basins. The treated runoff will then discharge to tributaries of the Whareatea River. Three mining affected catchments have been defined which will each contain sedimentation basin. The maximum treatment capacities of the sedimentation basins are presented in Table 19. Excess surface runoff, above the maximum treatment capacity will discharge, via a bypass channel, to tributaries of the Whareatea River. The flow-dependent TSS treatment efficiencies assigned to the Revised GoldSim Model are presented in Table 20.

It should be noted that the treatment capacities presented in Table 19 and evaluated in the Revised Goldsim Model are idealised basin capacities. Additional evaluation(s) are required to firm up the size of the sedimentation basins prior to detailed design.

5.4.3 Sedimentation ponds in natural catchments and rehabilitated mine catchments

The maximum treatment capacities for TSS in sedimentation ponds in natural and rehabilitated catchments are presented in Table 21. Excess surface runoff, above the maximum treatment capacity overflows, untreated, to streams. The TSS removal efficiencies for settlement of suspended sediment in the sedimentation ponds assigned to the Revised GoldSim Model are presented in Table 22.



Table 15: Model water quality inputs - Mining-affected water

Parameter	Concentrations (g/m ³)																										
	Pit			ELF – uncovered runoff			ELF- Uncovered seepage			ELF – Covered and re-vegetated runoff			ELF-Covered and re-vegetated seepage			ELF – Rehabilitated Forest Runoff			ELF – Rehabilitated Pakihi Runoff			ELF – Rehabilitated seepage			Road		
	Optimistic	Typical	Extreme	Optimistic	Typical	Extreme	Optimistic	Typical	Extreme	Optimistic	Typical	Extreme	Optimistic	Typical	Extreme	Optimistic	Typical	Extreme	Optimistic	Typical	Extreme	Optimistic	Typical	Extreme	Optimistic	Typical	Extreme
Al	4	5	70	4	5	70	4	5	70	0.03	0.03	0.03	5	5	70	0.03	0.03	0.03	0.03	0.03	0.03	70	70	70	0.02	0.02	0.02
As	0	0	0.02	0	0	0.02	0	0	0.02	0	0	0	0	0	0.02	0	0	0	0	0	0	0.02	0.02	0.02	0.01	0.01	0.01
Cd	0.001	0.002	0.003	0.001	0.002	0.003	0.001	0.002	0.003	0.0007	0.0007	0.0007	0.002	0.002	0.003	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.003	0.003	0.003	0.0001	0.0001	0.0001
Cu	0.22	0.22	0.4	0.22	0.22	0.4	0.22	0.22	0.4	0.003	0.003	0.003	0.22	0.22	0.4	0.003	0.003	0.003	0.003	0.003	0.003	0.4	0.4	0.4	0.002	0.002	0.002
Fe	1	6	70	1	6	70	1	6	70	0.01	0.01	0.01	0.01	0.01	70	0.01	0.01	0.01	0.01	0.01	0.01	70	70	70	0	0	0
Pb	0.02	0.03	0.12	0.02	0.03	0.12	0.02	0.03	0.12	0.0007	0.0007	0.0007	0.0007	0.0007	0.12	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.12	0.12	0.12	0.001	0.001	0.001
Mn	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.3	0.3	0.3	0.3	0.3	0.7	0.3	0.3	0.3	0.3	0.3	0.3	0.7	0.7	0.7	0.16	0.16	0.16
Ni	0.32	1.2	0.7	0.32	1.2	0.7	0.32	1.2	0.7	0.05	0.05	0.05	0.05	0.05	0.7	0.05	0.05	0.05	0.05	0.05	0.05	0.7	0.7	0.7	0.03	0.03	0.03
Zn	2.6	2.6	3	2.6	2.6	3	2.6	2.6	3	0.1	0.1	0.1	0.1	0.1	3	0.1	0.1	0.1	0.1	0.1	0.1	3	3	3	0.06	0.06	0.06
H ion for pH	10 ⁻³	10 ^{-2.8}	10 ^{-2.5}	10 ⁻³	10 ^{-2.8}	10 ^{-2.5}	10 ⁻³	10 ^{-2.8}	10 ^{-2.5}	10 ⁻⁴	10 ⁻⁴	10 ⁻⁴	10 ⁻⁴	10 ⁻⁴	10 ^{-2.5}	10 ⁻⁴	10 ⁻⁴	10 ⁻⁴	10 ⁻⁴	10 ⁻⁴	10 ⁻⁴	10 ^{-2.5}	10 ^{-2.5}	10 ^{-2.5}	10 ^{-5.1}	10 ^{-5.1}	10 ^{-5.1}
Ca	15	15	45	15	15	45	15	15	45	3	3	3	3	3	45	3	3	3	3	3	3	45	45	45	1.92	1.92	1.92
Mg	6	6	15	6	6	15	6	6	15	1	1	1	1	1	15	1	1	1	1	1	1	15	15	15	0.92	0.92	0.92
Co	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.013	0.013	0.013	0.013	0.013	0.15	0.013	0.013	0.013	0.013	0.013	0.013	0.15	0.15	0.15	0.01	0.01	0.01
Cr	0.002	0.003	0.7	0.002	0.003	0.7	0.002	0.003	0.7	0	0	0	0	0	0.7	0	0	0	0	0	0	0.7	0.7	0.7	0.002	0.002	0.002

Table 16: Model water quality inputs -TSS concentration of mining affected water.

Rainfall ⁽¹⁾	Concentrations (g/m ³)							
	Pit	ELF – uncovered runoff	ELF- Uncovered seepage	ELF – Covered and re-vegetated runoff	ELF-Covered and re-vegetated seepage	ELF – Rehabilitated Forest Runoff	ELF – Rehabilitated Pakihi Runoff	ELF – Rehabilitated seepage
0	50	100	10	5	3	3	3	100
21.6	50	100	10	5	3	3	3	100
95.1	2,500	5,000	20	250	5	12	12	5,000
800	2,500	5,000	20	250	5	12	12	5,000

Note ⁽¹⁾ The GoldSim Model linearly interpolates between daily rainfall or flow yield values.



Table 17: Capacities for the MIW Sedimentation Sump assigned to the Revised GoldSim Model.

Item		Units	Value
MIW Sedimentation Sump	Maximum Sump Volume	m ³	220,000
	Maximum pump rate to MIW-WTP	L/s	220
	Trigger volume for pumping to Pit.	m ³	200,000
	Emergency maximum pumping rate to Pit	L/s	116

Table 18: Assumed treatment efficiencies for the MIW Treatment System (MIW Sed. Sump & MIW-WTP)

Parameter	Treatment efficiency ⁽¹⁾
Aluminium	99.4%
Arsenic	0% i.e., not removed
Cadmium	89.1%
Copper	99.8%
Iron	99.5%
Lead	96.1%
Manganese	62.3%
Nickel	98.1%
Zinc	99.0%
Cobalt	99.1%
Chromium	89.7%
pH (as H ⁺)	Varies with pH as follows: If pH ≤ 6.5, then treatment efficiency = 0%. If pH > 6.5, then treatment efficiency varies according to the % efficiency required to reduce pH to 6.5
Total suspended solids (TSS)	Varies with TSS concentration as follows: If TSS concentration ≤ 10 g/m ³ , then treatment efficiency = 0%. If TSS concentration > 10 g/m ³ , then treatment efficiency varies according to the % efficiency required to reduce concentration to 10 g/m ³ .
Calcium	Varies with flow and pH (Golder 2012a)
Magnesium	Varies with flow and pH (Golder 2012a)

Note: ⁽¹⁾ Source Golder (2012a)



Table 19: Treatment capacities assigned to mine catchment sedimentation basins in the Revised GoldSim Model.

Sedimentation Basin	Maximum Treatment Capacity (m ³ /day)
Sedimentation Basin 1 (Western Catchment)	15,000
Sedimentation Basin 2 (Eastern Waste Dump & ELF)	60,500
Sedimentation Basin 3 (Eastern Lake Brazil Block)	35,000

Table 20: Removal efficiencies for TSS settlement in mine catchment sedimentation basins

Through flow (m ³ /day) ⁽¹⁾	Treatment Capacity (%)
0	100
10,000	99
15,000	98
100,000	95

Notes ⁽¹⁾ The GoldSim Model linearly interpolates between "Through Flow" values.

Table 21: Nominal treatment capacities for sedimentation ponds in natural and rehabilitated catchments.

Pond	Maximum treatment capacity (m ³ /day)
Trent Stream Sediment Pond	86,400
V40 stream Sediment Pond	86,400
S Creek Sediment Pond	86,400
West Upper Whareatea Sediment Pond	86,400
East Upper Whareatea Sediment Pond	86,400
V37 Sediment Pond	86,400
Lake Brazil Sediment Pond	86,400
V8 Sediment Pond	86,400

Table 22: Removal efficiencies for TSS settlement in sediment ponds in natural catchments.

Through-flow (m ³ /day) ⁽¹⁾	Treatment Capacity (%)
0	100
10,000	99
15,000	98
100,000	95

Notes ⁽¹⁾ The GoldSim Model linearly interpolates between "Through-flow" values.



6. Results

6.1 Mine Water Management Infrastructure Sizing

The Revised GoldSim Model was used to assist with the conceptual sizing of the various mine water treatment infrastructure. Historical climatic data for the period between 1 March 1945 and 31 August 2013 was used in the model simulations for the sizing process. The conceptual sizing of the various mine water treatment infrastructure was achieved by setting performance criteria for the treatment system which were based on consideration of operational requirements (i.e., space limitations within the mining licence, proposed mine scheduling etc.) and the compliance limits that were established in the 24th of October 2013 Environment Court consent decision for the primary downstream compliance monitoring point W-M2 on the Whareatea River. The compliance limits outlined in the 24th of October 2013 Environment Court consent decision document have two components that required consideration during the sizing process.

Firstly, the stipulated downstream receiving environment water quality compliance limits which are summarised in Table 14 and which stipulate both median (rolling) and 95th percentile limits for the concentration of various parameters. Secondly condition 263 which states the following:

263 *Compliance shall be assessed on the basis of a 6 monthly seasonal monitoring periods... ...The permitted exceedence of the median limits shall be no more than 15 samples for the monitoring period. The permitted exceedence of the 95th percentile limits shall not be more than 3 samples for the monitoring period, **and any exceeding samples must not exceed the limit by more than 20%.** Continuously monitored parameters (turbidity and pH) shall compare statistically-derived median and 95th percentile values, calculated from daily mean values for the compliance period, with the compliance limits listed in Table 3.*

The implication of the phrase "...and any exceeding samples must not exceed the limit by more than 20%" has the effect of applying a maximum water quality criteria at BCL's compliance monitoring site W-M2. In turn this has the implication of applying an upper limit on the permissible water quality of all surface discharges from the EMP. As the 95th percentile limits are relatively stringent, in effect any and all discharges from the EMP will need to be treated to a high standard.

The requirement to fully treat MIW and ELF surface runoff 95% of time and partially treat the water the remaining 5% of time is likely to result in routine exceedances of the effective maximum allowable concentrations of TSS, turbidity and likely most dissolved metals limits at W-M2. To comply with Condition 263, in effect BCL will be required to treat all discharges from the EMP.

In sizing the MIW Sedimentation sump volume and MIW-WTP capacity it is acknowledged that there are a number of combinations that would achieve the desired objectives. WM Group assessed various combinations, with the selected sizes based on the following considerations:

- Ensuring the desired performance goal is achieved.
- Selecting sizes that are considered both feasible and practical in terms of construction and fit with BCL's development plans and proposed site layouts.

The results of the sizing process for the pit sump rate are summarised in Section 6.1.1. The results of the sizing for the MIW Sedimentation Sump and the MIW-WTP are summarised in Section 6.1.2.

6.1.1 Pit pump rate sizing.

For Operational Year 1 to Year 5, the active mine pit is to be located at the western side of the EMP Site (Western Pit). For Operational Year 6 and Year 7 the active pit is to be located in the area close to Lake Brazil (Eastern Pit). MIW from pit-wall runoff, historical underground workings and recently constructed ELF surfaces (waste dumps) is expected to accumulate in sumps located on the pit floors. Accumulation of MIW in the pit could potentially disrupt mining operations due to flooding of the pit-floor. MIW is to be pumped from the pits to



the MIW Sedimentation Sump. As a contingency measure, MIW may occasionally be pumped from the MIW Sedimentation Sump to the pits. The volume of MIW stored in the sump will depend mainly on the pumping rate from the pit to the MIW Sedimentation Sump and the rainfall intensity. The Revised GoldSim Model was used to select a suitable pumping rate for the pit dewatering pumps. The assessment was carried out for the period of maximum active extent of the Western Pit (Operational Year 5) and the period of maximum active extent of the Eastern Pit (Operational Year 7). For a pumping rate of 160 L/s the model results indicated the following:

- **Operational Year 5 - (20211 day simulation period):** The Western Pit is expected to be empty (i.e. contain an insignificant amount of MIW) for approximately 70% of the time and to hold less than 900 m³ MIW for 95% of the time (Figure 4).
- **Operational Year 5: – (Extreme Wet Year, 1 July 1969 to 31 June 1970):** For the extreme wet year the Western Pit is expected to be empty for approximately 50% of the time and to hold less than 15,400 m³ for approximately 90% of the time (Figure 5). The maximum volume of MIW in the pit was projected to be approximately 232,500 m³ (Figure 6). For a pumping rate of 160 L/s it would take approximately 20 days to reduce the pit water volume from 232,500 to 25,000 m³. During this high rainfall event, contingency measures shall be implemented which involve pumping from the MIW Sedimentation Sump to the Western Pit (Figure 7).
- **Operational Year 7- (20211 day simulation period):** The Eastern Pit is expected to be empty for approximately 60% of the time and to hold less than 750 m³ for approximately 95% of the time (Figure 8).
- **Operational Year 7 – (Extreme Wet Year, 1 July 1969 to 31 June 1970):** The Eastern Pit is expected to be empty for approximately 50% of the time and to hold less than 12,600 m³ for approximately 95% of the time (Figure 9). The maximum volume of MIW in the pit was projected to be approximately 87,100 m³ for an extreme wet year (Figure 10). For a pumping rate of 160 L/s it would take approximately 6 days to reduce the pit water volume from 87,100 to 15,900 m³. During the high rainfall period, contingency measures involving pumping from the MIW Sedimentation Sump to the Western Pit would have to be activated (Figure 11).

Based on this assessment, WM Group recommend a maximum pumping rate of 160 L/s for the pumping from the active pit to the MIW Sedimentation Sump. During extreme wet conditions, the Western Pit MIW volume could potentially increase to approximately 232,500 m³ resulting in flooding of the pit floor. The flooding of the pit could potentially result in stoppage to mining operations of up to 20 days as the pit is dewatered to a volume below 25,000 m³. The likelihood of this modelled extreme wet condition occurring is rare (1 in 68 year event). Based on the full 68 year rainfall record the volume of water stored in the Western Pit is expected to be less than 900 m³ for 95% of the time, for a pumping rate of 160 L/s.

The accumulation of up to 232,500 m³ of water in the Western Pit under extreme wet conditions will not necessarily result in the disruption of mining activities. If mining is occurring on the upper pit benches, the mining activities could potentially still continue during the period of flooding. In addition it is likely during this extreme wet events the operation of other mining infrastructure will be compromised by the weather (e.g.; roads too and within the mine permit boundary may be washed away). As a consequence BCL's ability to extract and deliver coal off the plateau may be impacted.



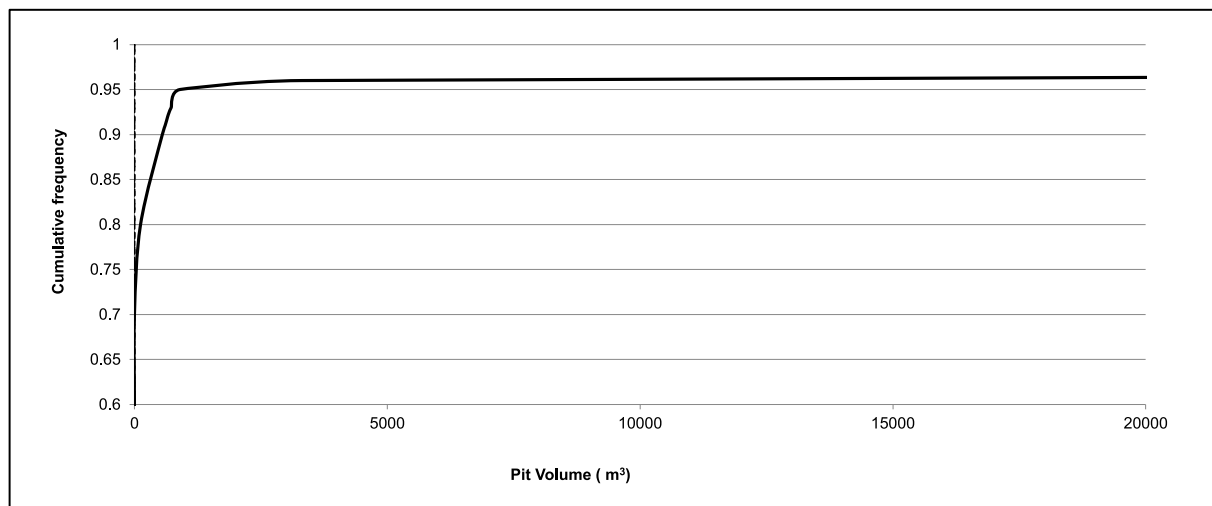


Figure 4: Pit volume cumulative frequency for 20211 day simulation period - Year 5.

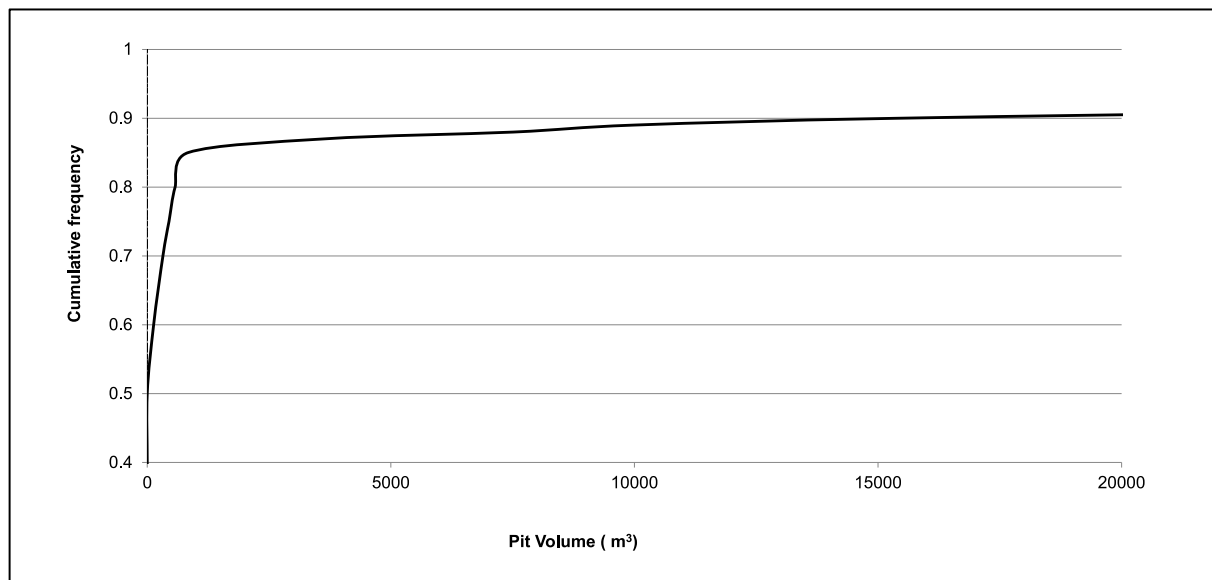


Figure 5: Pit Volume cumulative frequency for Wet Year (1 July 1969 to 31 June 1970) – Year 5.



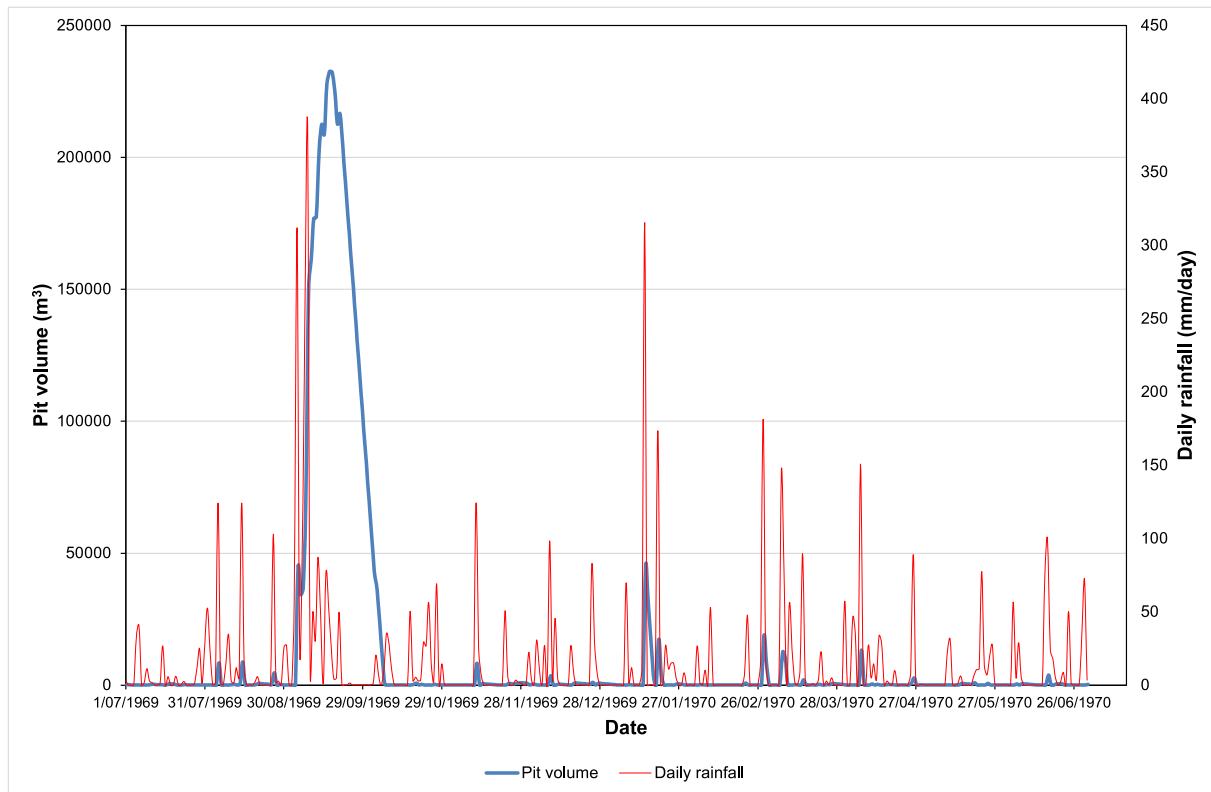


Figure 6: Western Pit daily pit Volume for extreme wet year (1 July 1969 to 31 June 1970) – Year 5.

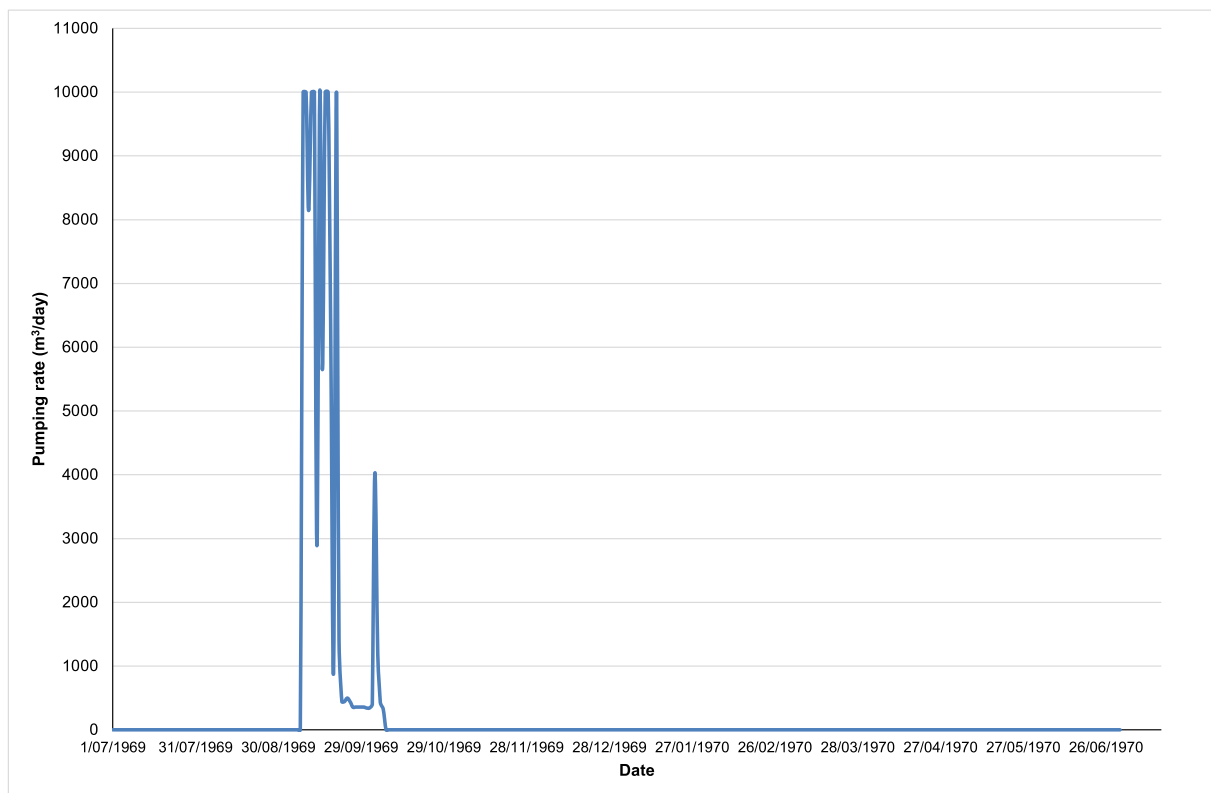


Figure 7: Pumping rate from MIW Sedimentation Sump to Western Pit for extreme wet year – Year 5.



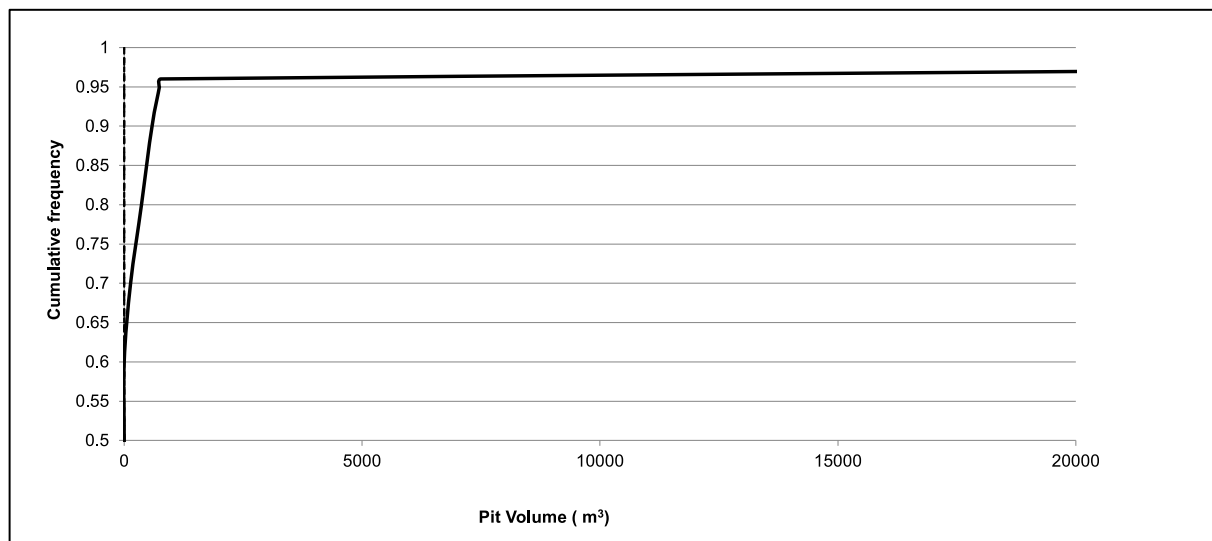


Figure 8: Pit volume cumulative frequency for 20211 day simulation period - Year 7.

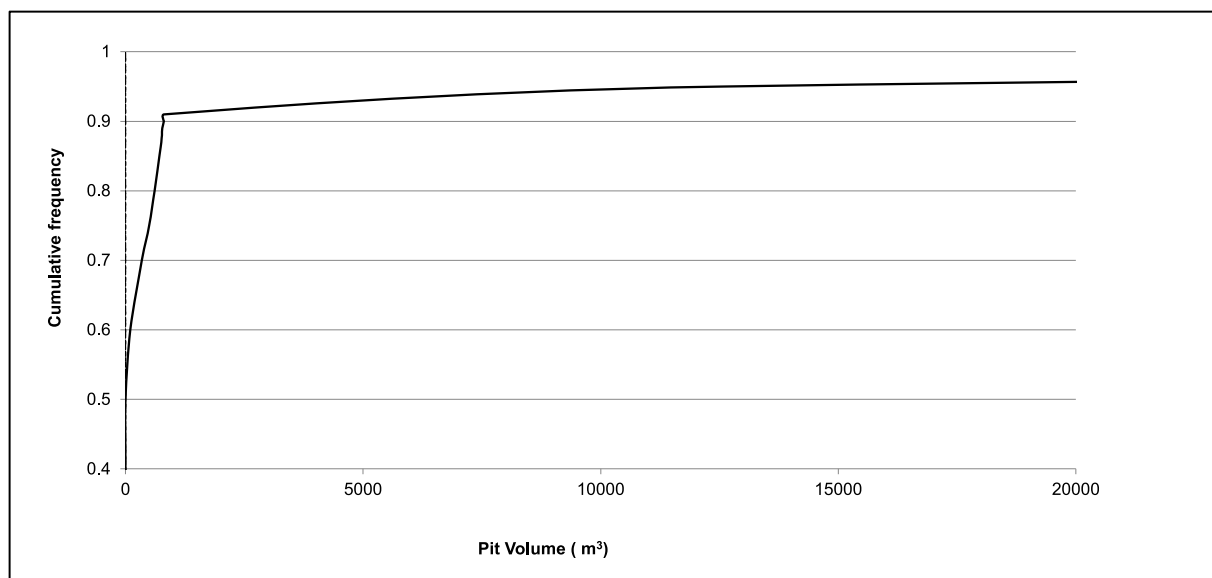


Figure 9: Pit Volume cumulative frequency for Wet Year (1 July 1969 to 31 June 1970) – Year 7.



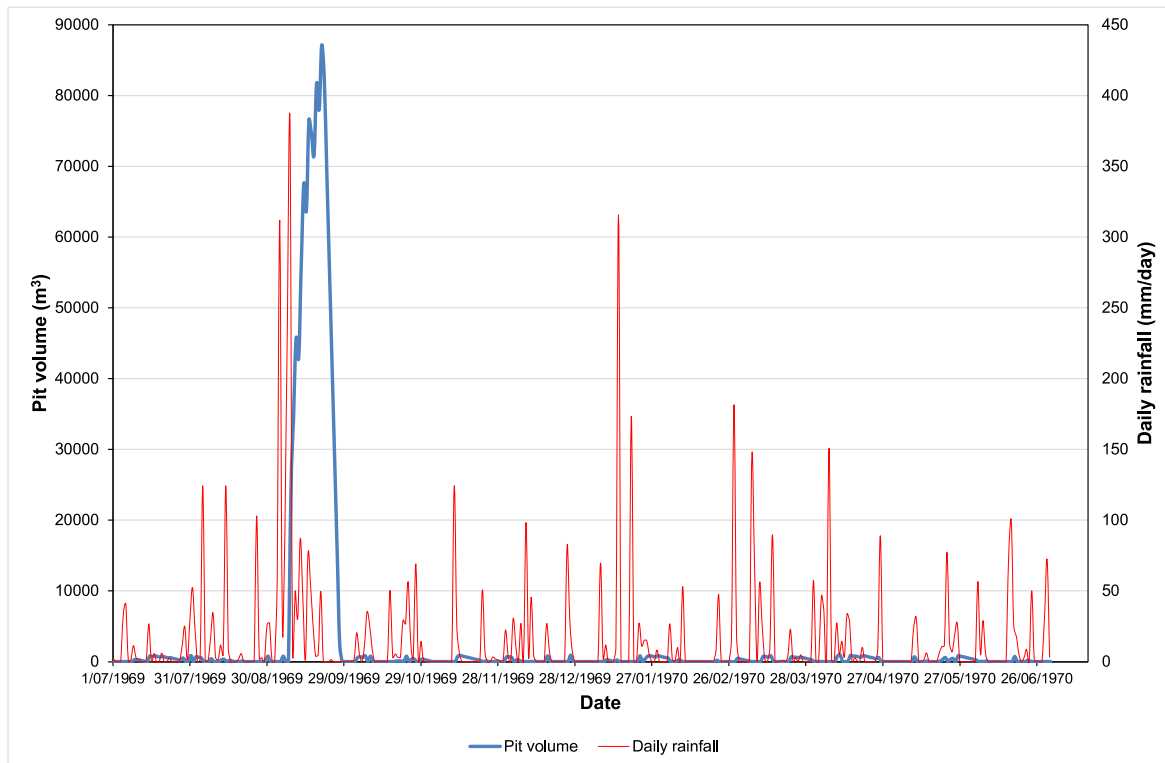


Figure 10: Eastern Pit daily pit Volume for extreme wet year (1 July 1969 to 31 June 1970) – Year 7.

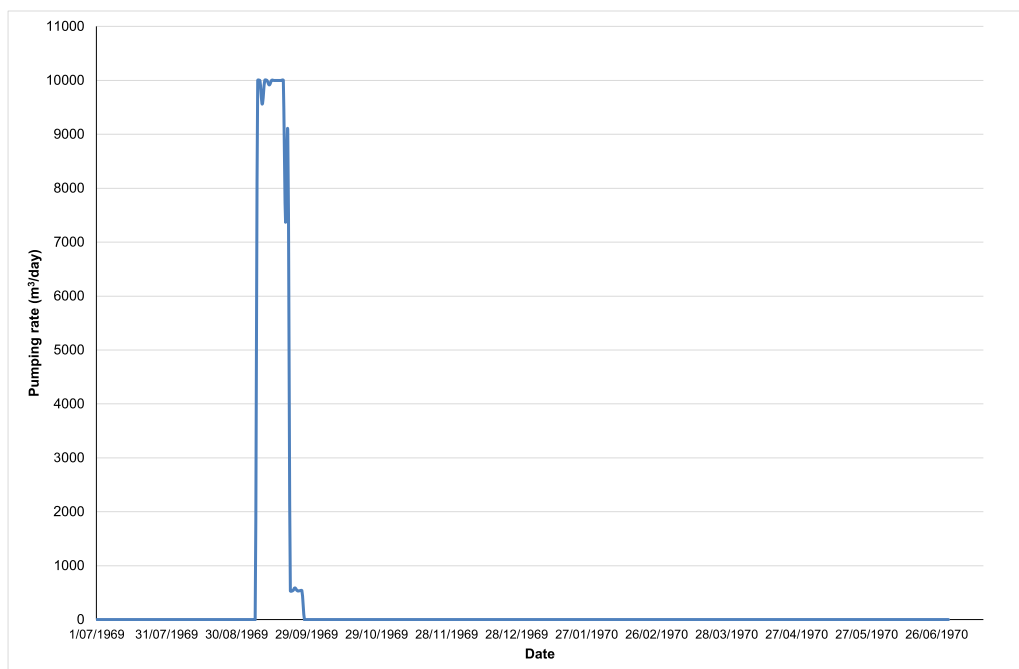


Figure 11: Pumping rate from MIW Sedimentation Sump to Eastern Pit for extreme wet year – Year 7.



6.1.2 MIW Sedimentation Sump and MIW-WTP sizing

The sizing of the MIW Sedimentation Sump (Table 23) was completed on the basis of ensuring the MIW Sedimentation Sump will not spill at any time (during the model simulation). For the sizing assessment, a maximum pumping rate of 160 L/s was applied to the model for the pumping from the active pit sump to the MIW Sedimentation Sump (Section 6.1.1).

The simulated inflows to the MIW-Sedimentation Sump for each of the operational years are summarised in Table 24. The critical operational years in terms of inflows to the MIW Sedimentation Sump are Year 5 and Year 7. In Year 5, the active Western pit will be at its maximum active extent and in Year 7, the active Eastern pit (in the area of Lake Brazil) will be at its maximum extent.

For the recommended capacities for the MIW-Sedimentation Sump and the MIW-WTP (Table 23), the simulated volumes of water in the MIW Sedimentation Sump for a 20211 simulation period (continuous rainfall record between 1945 and 2013) are presented in Figure 12 to Figure 20.

The results for Year 4 and Year 5 of mine operation indicate that the MIW-Sedimentation sump is expected to overflow on one day out of the 20211 day simulation period. This suggests that the likelihood of an overflow event occurring is extremely rare. For the simulated date on which overflow is predicted to occur (17/09/1970) the simulated volumes were 1,300 m³ and 9,000 m³ for Year 4 and Year 5 respectively.

The model for the other years of mine operation indicate that for the recommended capacities for the MIW-Sedimentation Sump and the MIW-WTP, the MIW-Sedimentation sump is not expected to overflow at any time over the 20211 day simulation period.

For the assessment it has been assumed that the proposed MIW-WTP will be capable of treating up to a maximum of 220 L/s of MIW from the MIW Sedimentation Sump.

Table 23: Recommended capacities for the MIW Sedimentation Sump.

Item		Units	Value
MIW Sedimentation Sump	Maximum Sump Volume	m ³	220,000
	Maximum pump rate to MIW-WTP	L/s	220
	Trigger volume for pumping to Pit.	m ³	200,000
	Emergency maximum pumping rate to Pit	L/s	116



Table 24 Simulated inflows to MIW-Sedimentation Sump

Inflow	Units	Year									
		1	2	3	4	5	6	7	8	9	10
Inflows from Pit Sump Pumps & Amenities Areas											
Minimum ⁽¹⁾	m³/day	684	684	684	913	1,103	652	355	355	473	473
25 th Percentile	m³/day	770	770	770	1,000	1,189	738	442	355	473	473
75 th Percentile	m³/day	6,064	6,155	6,697	7,345	7,362	5,391	4,366	1,929	2,046	2,046
90 th Percentile	m³/day	15,029	16,628	18,045	18,865	18,744	15,447	14,179	4,541	4,659	4,659
95 th Percentile	m³/day	22,912	26,964	28,892	29,877	29,956	25,032	23,876	6,878	6,995	6,995
Mean	m³/day	5,250	5,779	6,216	6,714	6,817	5,355	4,832	1,775	1,892	1,892
Median	m³/day	964	1,020	1,083	1,309	1,493	933	626	534	651	651
Maximum	m³/day	73,296	91,018	94,136	100,602	103,520	95,346	109,653	36,217	36,334	36,334
ELF Leachate Inflows											
Calculated from model ⁽²⁾	m³/day	922	3,248	4,411	3,990	4,461	4,634	5,382	3,163	3,046	3,046
Maximum ⁽³⁾	m³/day	1,705	6,008	8,160	7,381	8,253	8,573	9,956	5,852	5,635	5,635
TOTAL MAXIMUM INFLOWS ⁽⁴⁾	m³/day	75,001	97,026	102,296	107,984	111,773	103,919	119,609	42,069	41,969	41,969

Note: ⁽¹⁾ At times the minimum flow into the MIW Sedimentation Sump may be zero, the minimum value presented in this table represents the model predictions during periods in which there is sufficient MIW to be pumped or gravitated to the sump.

⁽²⁾ The ELF Leachate flows calculated from the GoldSim model are based on average ELF groundwater seepage rates provided by Golder (2012d).

⁽³⁾ Maximum ELF Leachate flows calculated by applying a peaking factor of 1.85 to ELF Leachate flows calculated using average seepage flows (Golder 2012d).

⁽⁴⁾ Maximum simulated inflows from Pit Sump Pumps & amenities + maximum ELF leachate inflows calculated by applying peaking factor.



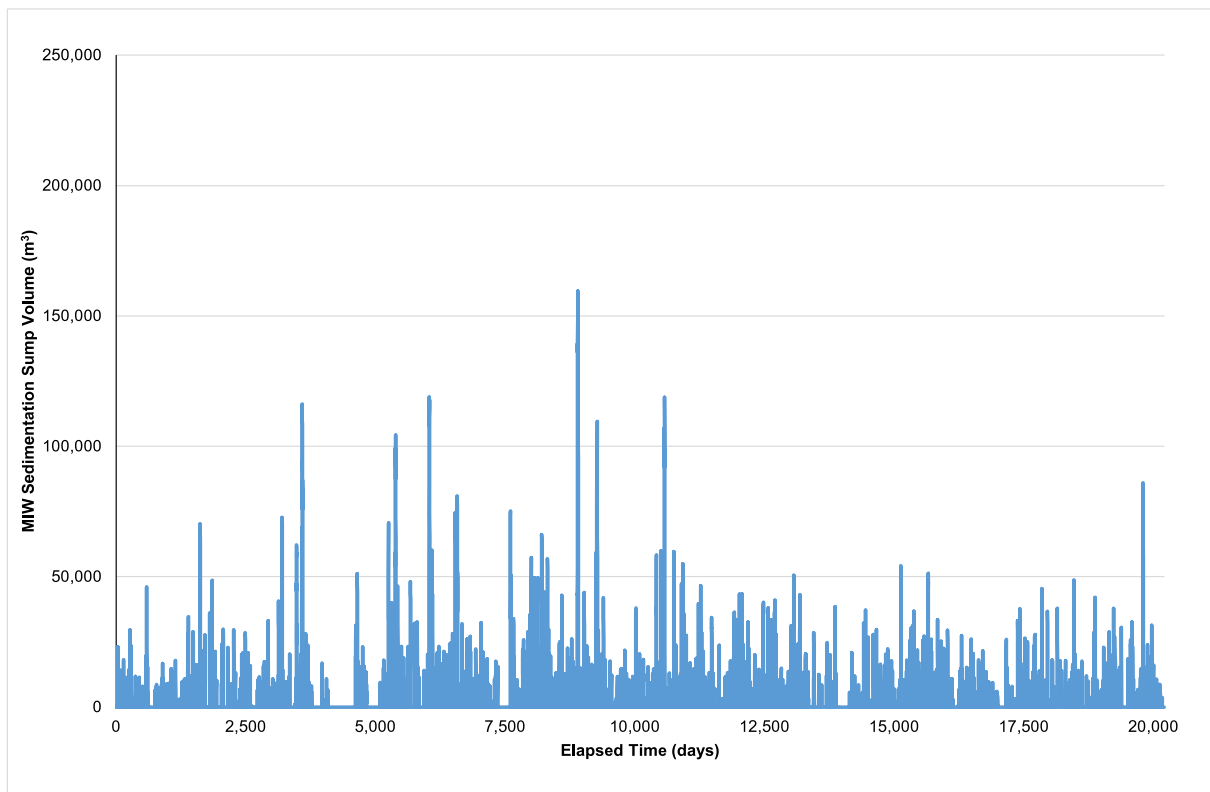


Figure 12: Volume in MIW Sedimentation sump for Year 1

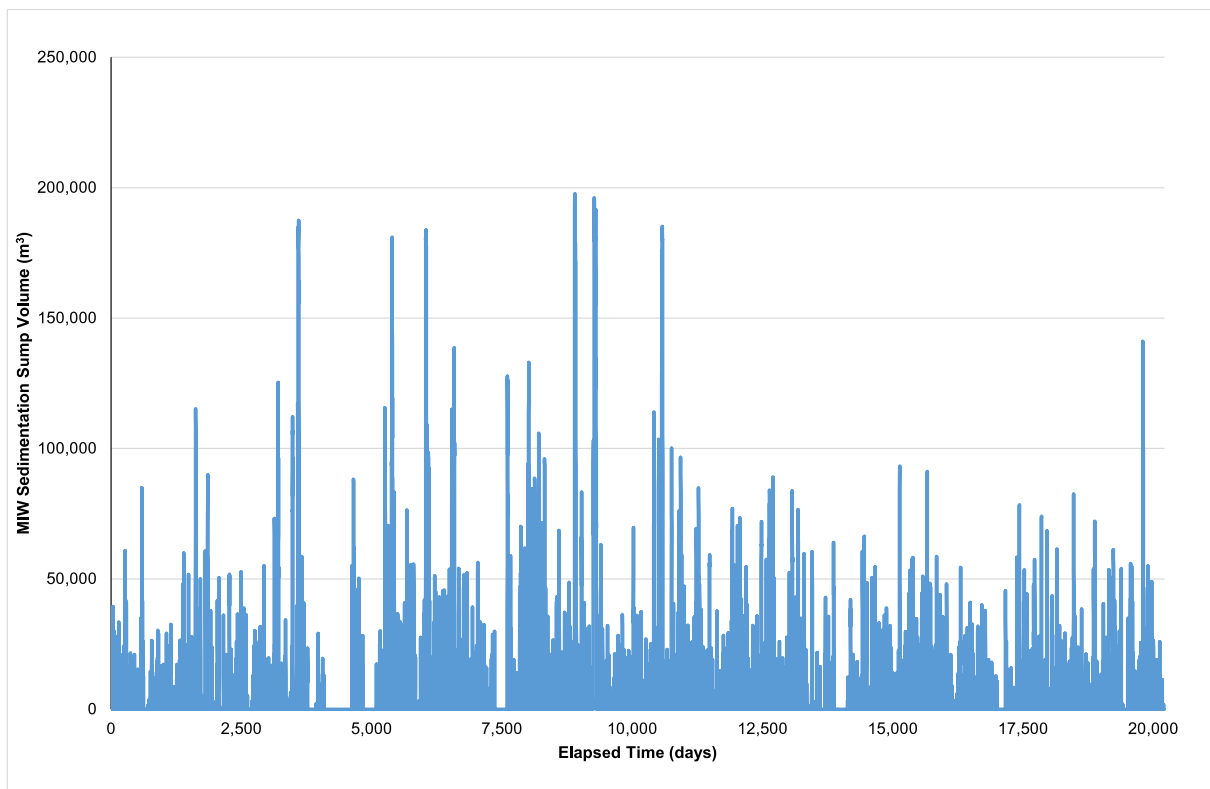


Figure 13: Volume in MIW Sedimentation sump for Year 2



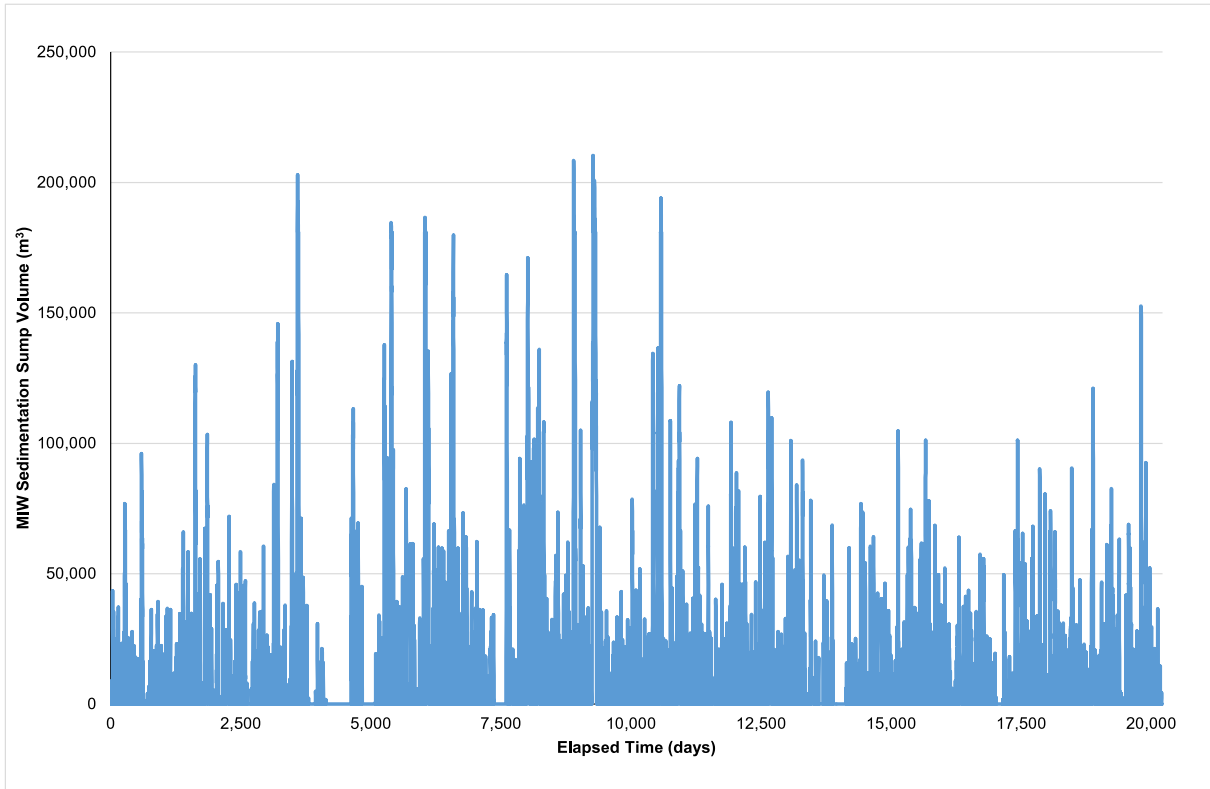


Figure 14: Volume in MIW Sedimentation sump for Year 3

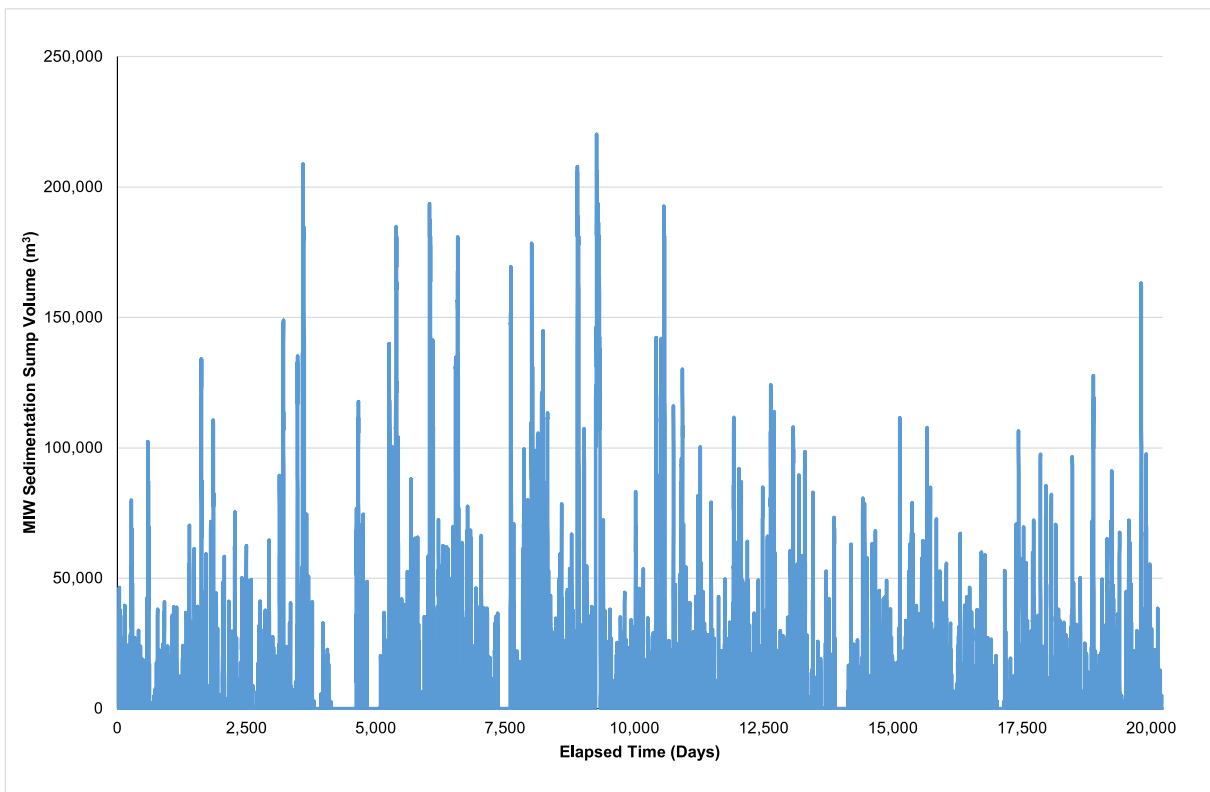


Figure 15: Volume in MIW Sedimentation sump for Year 4



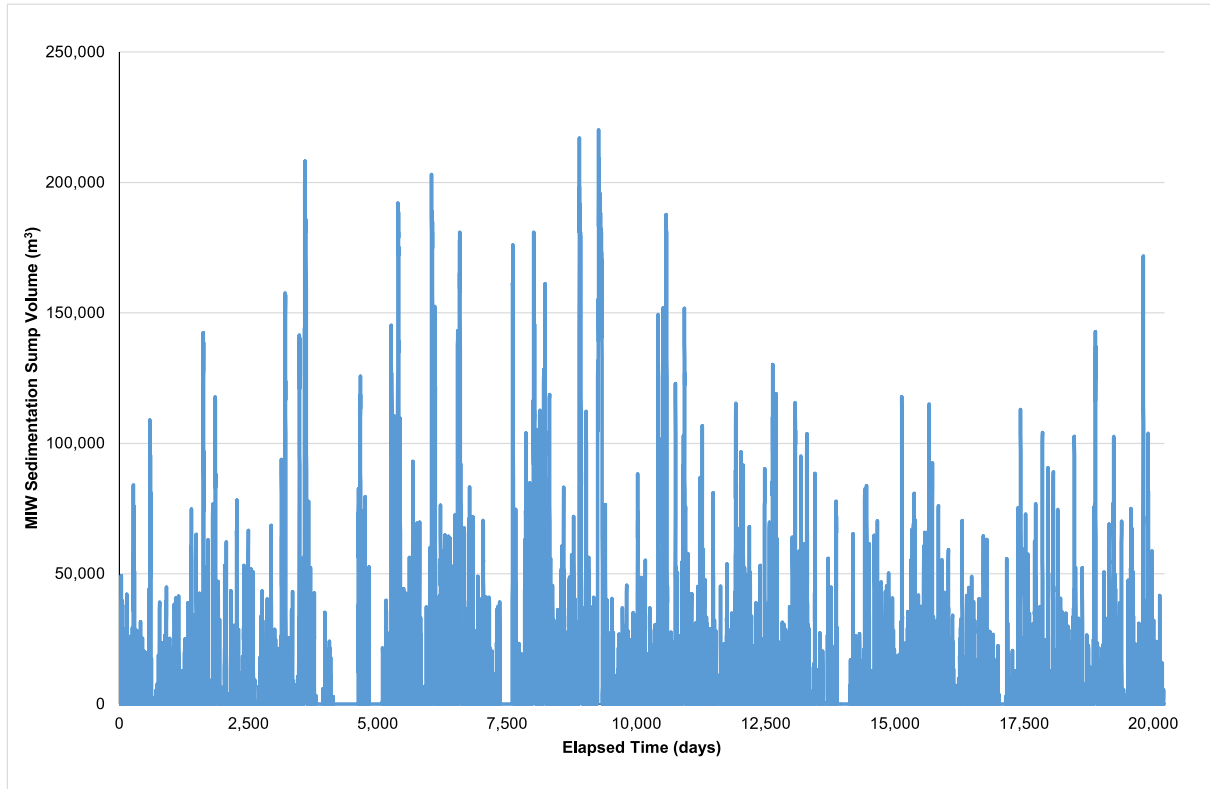


Figure 16: Volume in MIW Sedimentation sump for Year 5

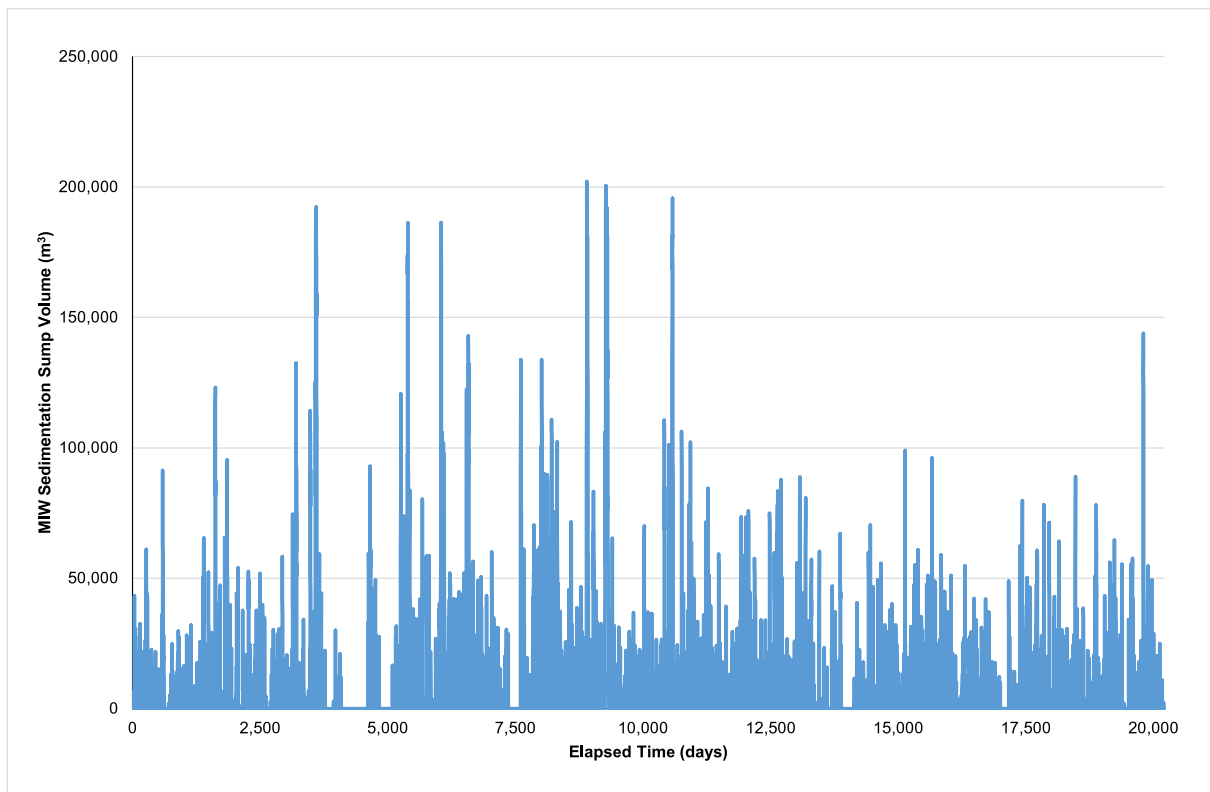


Figure 17: Volume in MIW Sedimentation sump for Year 6



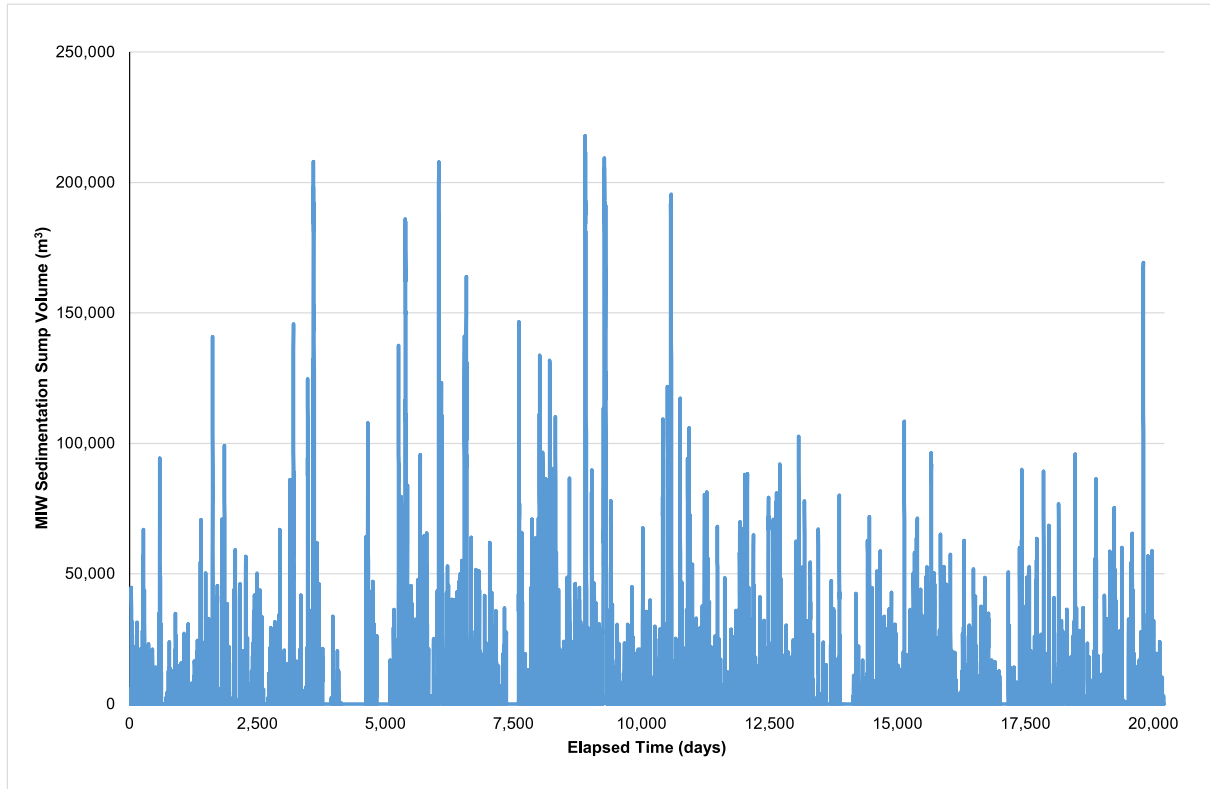


Figure 18: Volume in MIW Sedimentation sump for Year 7

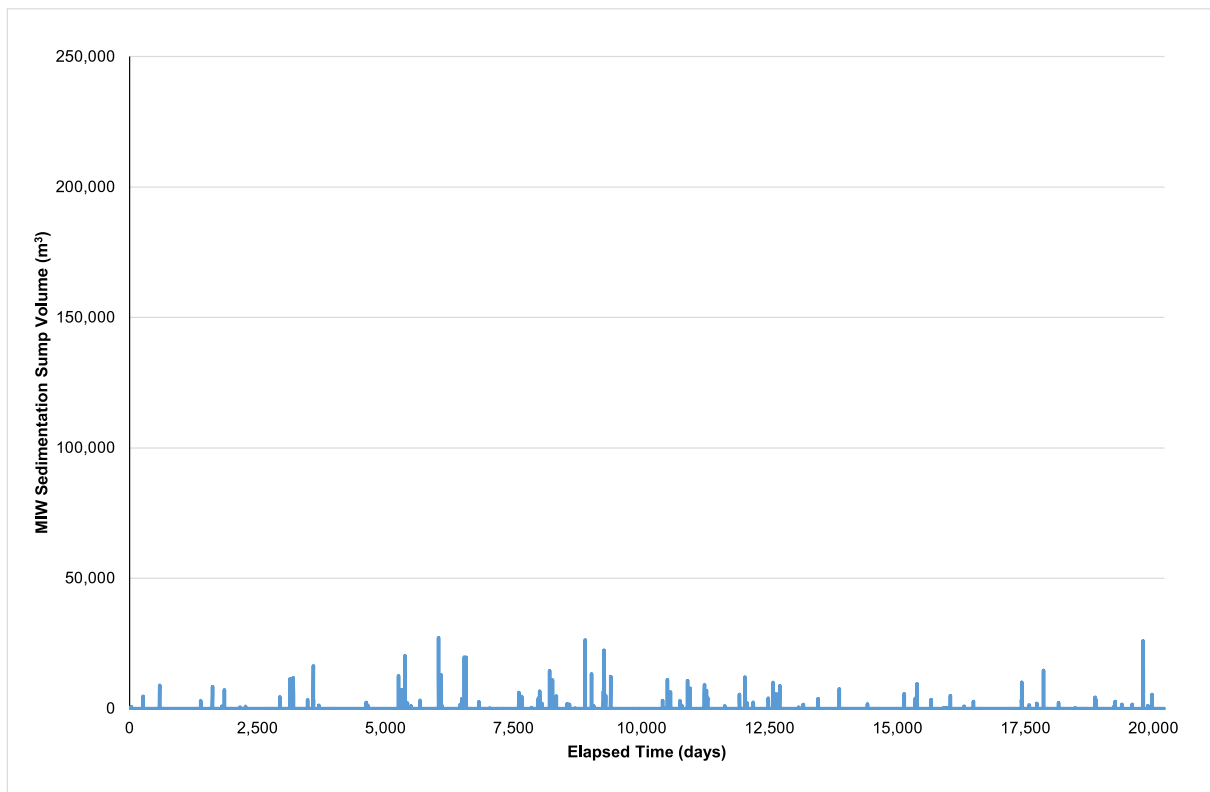


Figure 19: Volume in MIW Sedimentation sump for Year 8



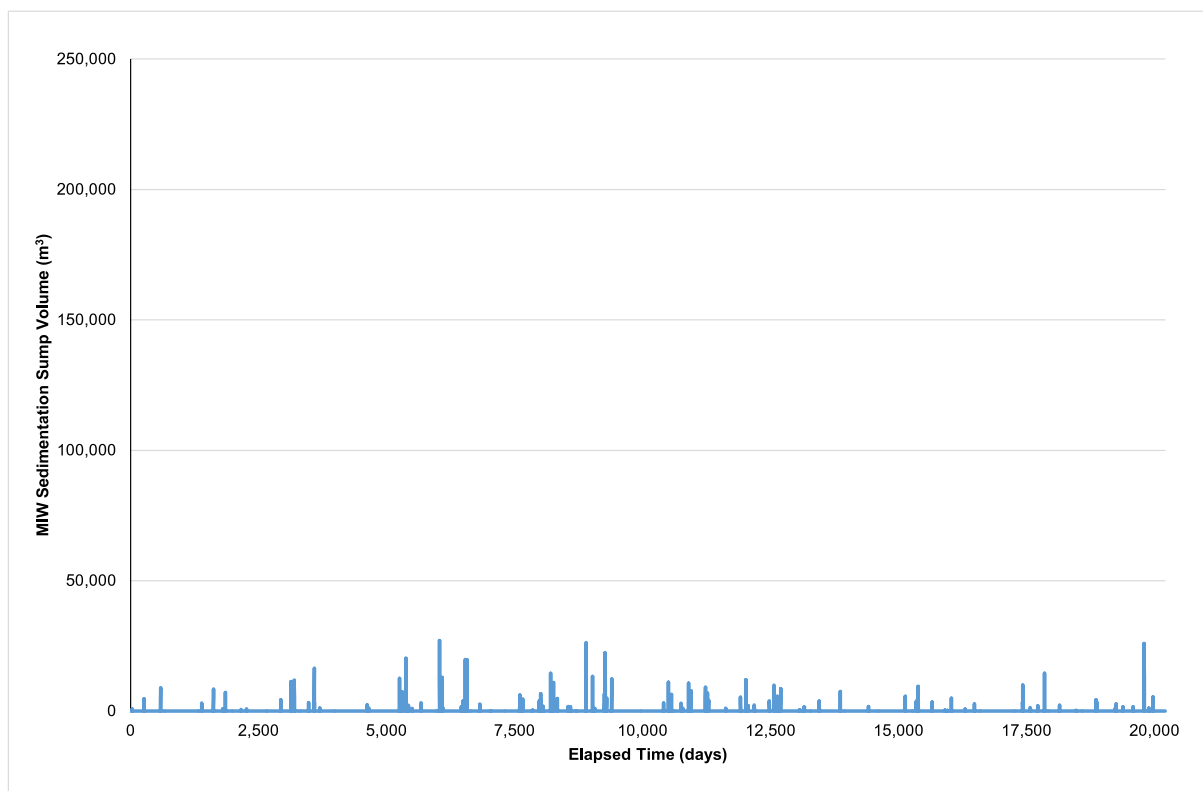


Figure 20: Volume in MIW Sedimentation sump for Year 9

6.2 Model projections: Acid loads to the MIW-Sedimentation Sump

The Acid Loads for the inflows to the MIW-Sedimentation Sump were calculated from Equation 1 (O'Kane 2013 & AusIMM 2012) and Equation 2. The flows applied in the calculation for Equation 2 are presented in Table 24.

$$\text{Acidity}_{\text{calc}}^5 = 50 \times (1000 \times (10^{-\text{pH}})) + 2(\text{Fe})/56 + 3(\text{Al})/27 + 2(\text{Mn})/55 + 2(\text{Ni})/58.7 + 2(\text{Zn})/65.4 \quad \text{Equation 1}$$

$$\text{Acid Load}^6 = \text{Acidity}_{\text{calc}} \times \text{Flow} \quad \text{Equation 2}$$

The acid loads calculated for the typical (or anticipated) geochemical environment in the ELF are presented in Table 25 to Table 28. Acid loads calculated for optimistic, typical and extreme geochemical scenarios are presented in Table 29 and Table 30.

⁵ Acidity_{calc} in units of g CaCO₃/m³

⁶ Acid Load in units of kg CaCO₃/d



Table 25: Pit Sump & Infrastructure Area - Predicted Daily Acidity Load by Year (kg CaCO₃/d)

	Minimum		Median	Mean	75th %ile	90th %ile	95th %ile	Maximum	
	Load	Flow (m ³ /d)						Load	Flow (m ³ /d)
Year 1	86	28,332	173	661	688	1,996	3,054	8,266	58,305
Year 2	86	42,156	155	1,184	795	3,857	6,859	19,588	74,417
Year 3	86	42,156	155	1,412	1,104	5,034	8,087	20,422	76,247
Year 4	241	42,385	295	1,388	1,114	4,196	7,047	19,263	80,137
Year 5	370	42,575	399	1,554	1,245	4,418	7,447	19,757	81,928
Year 6	350	28,300	389	1,306	1,024	3,702	6,007	16,441	33,339
Year 7	241	36,023	304	1,212	486	3,336	6,512	22,092	34,426
Year 8	241	355	241	241	241	242	242	245	21,405
Year 9	321	473	321	321	321	321	322	324	21,522
Year 10	321	473	321	321	321	321	322	324	21,522

Table 26 Pit Sump & Infrastructure Area - Predicted Weekly and Annual Acidity Load by Year

	Weekly Acid Load (kg CaCO ₃ /wk)			Annual Acid Load (t CaCO ₃ /yr)
	Minimum	Mean	Maximum	Mean
Year 1	599	4,631	28,900	241.4
Year 2	599	8,286	77,549	432.0
Year 3	599	9,887	78,087	515.5
Year 4	1,688	9,718	65,951	506.7
Year 5	2,589	10,878	68,793	567.1
Year 6	2,448	9,140	60,290	476.5
Year 7	1,689	8,485	87,474	442.4
Year 8	1,689	1,690	1,699	88.1
Year 9	2,247	2,248	2,256	117.2
Year 10	2,247	2,248	2,256	117.2

Table 27 MIW Sedimentation Sump Combined Inflow - Predicted Daily Acidity Load by Year (kg CaCO₃/d)

	Minimum		Median	Mean	75th %ile	90th %ile	95th %ile	Maximum	
	Load	Flow (m ³ /d)						Load	Flow (m ³ /d)
Year 1	201	29,254	288	777	803	2,112	3,169	8,381	59,227
Year 2	492	45,404	561	1,590	1,201	4,263	7,265	19,994	77,664
Year 3	637	46,567	706	1,964	1,656	5,585	8,639	20,973	80,658
Year 4	823	46,375	877	1,970	1,696	4,779	7,629	19,845	84,127
Year 5	1,145	47,036	1,174	2,329	2,020	5,193	8,223	20,532	86,389
Year 6	1,410	32,934	1,448	2,365	2,084	4,762	7,067	17,501	37,974
Year 7	1,719	5,737	1,781	2,690	1,963	4,814	7,989	23,570	39,807
Year 8	1,808	3,519	1,808	1,808	1,808	1,808	1,808	1,811	24,568
Year 9	2,389	3,519	2,389	2,389	2,390	2,390	2,390	2,393	24,568
Year 10	2,389	3,519	2,389	2,389	2,390	2,390	2,390	2,393	24,568



Table 28 MIW Sedimentation Sump Combined Inflow - Predicted Weekly and Annual Acidity Load by Year

	Weekly Acid Load (kg CaCO ₃ /wk)			Annual Acid Load (t CaCO ₃ /yr)
	Minimum	Mean	Maximum	Mean
Year 1	1,406	5,438	29,707	283.5
Year 2	3,441	11,128	80,391	580.2
Year 3	4,459	13,748	81,947	716.8
Year 4	5,764	13,794	70,027	719.2
Year 5	8,014	16,303	74,219	850.1
Year 6	9,867	16,559	67,709	863.4
Year 7	12,032	18,827	97,816	981.7
Year 8	12,655	12,656	12,665	659.9
Year 9	16,726	16,726	16,735	872.2
Year 10	16,726	16,726	16,735	872.2

Table 29 ELF Basal Drainage - Predicted Daily Acidity Load by Year (kg CaCO₃/d)

	Optimistic		Typical		Extreme	
	Load	Flow (m ³ /d)	Load	Flow (m ³ /d)	Load	Flow (m ³ /d)
Year 1	77	922	115	922	627	922
Year 2	276	3,248	406	3,248	2,208	3,248
Year 3	389	4,411	552	4,411	2,998	4,411
Year 4	453	3,990	582	3,990	2,712	3,990
Year 5	636	4,461	775	4,461	3,032	4,461
Year 6	937	4,634	1,060	4,634	3,149	4,634
Year 7	1,345	5,382	1,478	5,382	3,657	5,382
Year 8	1,567	3,163	1,567	3,163	2,148	3,163
Year 9	2,068	3,046	2,068	3,046	2,068	3,046
Year 10	2,068	3,046	2,068	3,046	2,068	3,046

Table 30 ELF Basal Drainage - Predicted Weekly and Annual Acidity Load by Year

	Weekly Acid Load (kg CaCO ₃ /wk)			Annual Acid Load (t CaCO ₃ /yr)
	Optimistic	Typical	Extreme	Typical
Year 1	541	807	4,387	42.1
Year 2	1,934	2,843	15,453	148.2
Year 3	2,720	3,861	20,986	201.3
Year 4	3,167	4,076	18,981	212.6
Year 5	4,453	5,426	21,222	283.0
Year 6	6,556	7,419	22,044	386.9
Year 7	9,415	10,343	25,597	539.3
Year 8	10,966	10,966	15,036	571.8
Year 9	14,479	14,479	14,479	755.0
Year 10	14,479	14,479	14,479	755.0



6.3 Simulated stream flows

Summary statistics for model projected flows at monitoring stations W-M1 and W-M2 are presented in Table 31 and Table 32 respectively. Simulated baseflows (minimum flow and 5th percentile flow in Table 31 and Table 32) during the mining period are higher than baseflows during the pre-mining period. The relatively higher baseflow flow rates during the mining period compared to the pre-mining period is a result of the gradual release of water stored within the mine catchments during dry periods.

During flood periods, simulated flow rates at W-M1 and W-M2 for the pre-mining phase are higher than simulated flood flows for the mining phase. The lower flow rates at W-M1 and W-M2 during flood conditions for the mining period is due to attenuation of flood flows as a result of storage of water in the mining catchments; specifically from the pit sump and the MIW Sedimentation Sump.

The slightly higher maximum flows during peak flow periods in the early post-mining period compared to the pre-mining phase are caused by higher surface runoff coefficients associated with mining disturbed surfaces during the early post-mining period compared to the pre-mining period. However, as the EMP site is rehabilitated, the post-mining flows are expected to tend towards pre-mining levels.

In summary an analysis of the model projected volumes of water storage in the MIW Sedimentation Sump indicates that the storage of water within EMP site during the mining period (Figure 12 to Figure 18) is expected to be much larger than during the post-mining period (Figure 19 and Figure 20) and the pre-mining period. The storage of water within the mining catchments during the mining period is expected to attenuate flows and increase baseflows in the Whareatea River (Table 31 and Table 32).

Table 31: Summary statistics for simulated flow ⁽¹⁾ at W-M1 in Whareatea River

	Minimum	5 th %ile	Median	Mean	75th %ile	90th %ile	95th %ile	Maximum
Pre-mining	4	214	1,596	11,794	13,837	33,364	52,947	341,161
Year 1	1,577	1,594	4,619	12,471	16,438	30,755	46,917	232,569
Year 2	3,888	3,920	7,336	15,201	19,445	34,771	51,128	232,233
Year 3	5,051	5,084	9,142	16,706	20,482	36,758	51,898	232,233
Year 4	4,874	4,892	9,225	16,730	20,600	37,186	51,926	232,233
Year 5	5,520	5,552	10,005	17,313	21,005	37,475	52,021	232,233
Year 6	5,242	5,275	8,404	16,232	19,763	35,264	51,274	232,233
Year 7	5,705	5,728	8,698	16,103	19,660	34,101	49,483	220,481
Year 8	3,269	3,469	5,387	11,408	13,342	25,611	37,517	222,496
Year 9	3,280	3,620	9,891	19,027	21,335	44,694	65,341	360,840
Year 10	3,280	3,620	9,891	19,027	21,335	44,694	65,341	360,840

Note ⁽¹⁾ Stream flow rate in m³/day



Table 32: Summary statistics for simulated flow ⁽¹⁾ at W-M2 in Whareatea River

	Minimum	5 th %ile	Median	Mean	75 th %ile	90 th %ile	95 th %ile	Maximum
Pre-mining	16	859	3,278	46,448	55,567	133,982	212,620	1,370,015
Year 1	1,594	1,594	7,163	47,949	57,408	132,328	208,199	1,280,248
Year 2	3,920	3,920	10,096	50,357	59,159	134,583	209,959	1,238,104
Year 3	5,051	5,084	12,429	52,064	62,396	135,974	207,662	1,211,620
Year 4	4,874	4,892	12,563	50,971	62,531	132,606	200,971	1,176,081
Year 5	5,520	5,552	13,464	50,819	62,277	130,768	197,629	1,155,046
Year 6	5,242	5,275	11,475	52,398	64,415	136,180	207,691	1,226,121
Year 7	5,705	5,728	11,639	54,669	66,673	141,918	217,000	1,283,590
Year 8	3,269	3,469	7,765	53,977	65,131	145,593	222,020	1,393,684
Year 9	3,280	4,364	14,202	65,466	73,597	171,779	257,167	1,477,335
Year 10	3,280	4,364	14,202	65,466	73,597	171,779	257,167	1,477,335

Note ⁽¹⁾ Stream flow rate in m³/day

6.4 Simulated water quality at receiving waters

6.4.1 Introduction

The Revised GoldSim model calculates concentrations of selected chemical species at specified locations. The water quality projections calculated from Revised GoldSim model are presented in Section 6.4.2 and a summary of the results of the water quality assessment is presented in Section 6.4.3.

6.4.2 Model projected concentrations

The model projected water quality at monitoring point W-M2 in Whareatea River for the mining period and for the early post-mining period are presented in Table 33 and Table 34 respectively. With the exception of copper, the projected concentrations of all the assessed chemical species were below the consent limits.

The model predicts that under several geochemical (acid mine drainage discharge) scenarios from the ELF, the median of the projected copper concentrations at W-M2 is expected to exceed the median consent limits in operational Year 1, Year 6, Year 7 and Year 8 (Table 33). In Year 8 the all three geochemical scenarios are expected to result in exceedance of the median consent limit in the order of 50%.

For the period of maximum disturbance at the mine site (Operational Year 7), results of the modelling (Table 35) indicate the following:

- Projected concentrations of all the chemical species in discharges from the MIW-WTP to the Upper Whareatea River are expected to be less than the consent limits.
- Projected concentrations of all the chemical species at monitoring point WM-1 in the Whareatea River are expected to be less than the consent limits.
- With the exception of copper the projected concentrations of all the chemical species at monitoring points W-M2 and W-M3 are expected to be less than the consent limits.
- The median of the projected copper concentrations at WM-3 are expected to exceed the median consent limits (for W-M2) by approximately 50% (Table 35).



Table 36 presents the projected water quality of discharges to tributaries of the Whareatea River from the Western and Central sedimentation basins in Year 7 and from the Eastern sedimentation basin in Year 8. The results for the Eastern Sedimentation Basin are presented for Year 8 because in the proposed water management plan there are discharges from the Eastern Sedimentation Basin until Year 8. The proposed treatment in the mine catchment sedimentation basins is only for the removal (settlement) of TSS and as a result, the concentration of inflows and outflows for mine catchment sedimentation basins of all the chemical species, except TSS, are the same.

Whilst the model suggests dissolved copper non-compliance, it is noted that the baseline dissolved copper concentrations observed at W-M2 (**Annual Work Plan 2013/2014**) currently exceeds BCL's discharge consent limit; however it is anticipated that subsequent reviews of the consent limits associated with the Site Specific Ecotoxicity & Compliance Limits studies (**MOMP, Appendix 1.G**) will address this technical non-compliance and result in a moderating of the dissolved copper limit at W-M2.

In addition further geochemical analysis and assessment of the potential water quality in the ELF basal drainage should result in a better understanding of the likely dissolved copper concentration. Potentially removing some of the conservatism from the model assumptions; which in turn may result in a reduction in predicted dissolved copper at W-M2. If however higher dissolved copper concentrations are predicted and/or the model prediction are realised, a higher level of dissolved copper removal will be required of the MIW-WTP.



Table 33: Modelled concentrations ⁽¹⁾ at W-M2 for mining period.

Year	Scenario	pH (unitless)		TSS		Aluminium		Arsenic		Manganese + Iron		Cobalt		Hardness ⁽²⁾		Cadmium ⁽³⁾		Copper ⁽³⁾		Chromium ⁽³⁾		Lead ⁽³⁾		Nickel ⁽³⁾		Zinc ⁽³⁾	
		Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile
Yr 1	Optimistic	4.8	5.0	5.9	8.8	0.16	0.19	0.009	0.010	0.27	0.44	0.001	0.001	23	89	0.0006	0.0016	0.0011	0.0031	0.001	0.003	0.003	0.003	0.003	0.004	0.018	0.038
Yr 1	Typical	4.8	5.0	5.9	8.8	0.16	0.19	0.009	0.010	0.28	0.44	0.001	0.001	17	60	0.0007	0.0018	0.0015	0.0034	0.002	0.004	0.003	0.003	0.007	0.011	0.023	0.041
Yr 1	Extreme	4.8	5.0	5.9	8.8	0.22	0.33	0.012	0.017	0.32	0.49	0.001	0.002	31	119	0.0005	0.0015	0.0009	0.0028	0.011	0.016	0.003	0.004	0.004	0.005	0.014	0.033
Yr 2	Optimistic	4.8	5.0	6.3	8.8	0.14	0.18	0.008	0.010	0.28	0.47	0.001	0.003	33	80	0.0004	0.0013	0.0009	0.0025	0.001	0.002	0.002	0.003	0.003	0.007	0.017	0.032
Yr 2	Typical	4.8	5.0	6.3	8.8	0.16	0.18	0.008	0.010	0.29	0.47	0.001	0.003	24	55	0.0005	0.0015	0.0012	0.0028	0.002	0.007	0.003	0.003	0.009	0.012	0.022	0.037
Yr 2	Extreme	4.8	5.0	6.3	8.8	0.24	0.37	0.012	0.018	0.36	0.55	0.001	0.003	48	146	0.0003	0.0011	0.0007	0.0021	0.012	0.016	0.003	0.004	0.005	0.008	0.014	0.028
Yr 3	Optimistic	4.8	5.1	6.6	8.9	0.14	0.18	0.007	0.010	0.29	0.48	0.001	0.005	36	77	0.0004	0.0012	0.0009	0.0023	0.001	0.002	0.002	0.003	0.004	0.013	0.019	0.037
Yr 3	Typical	4.8	5.1	6.6	8.9	0.16	0.18	0.008	0.010	0.31	0.48	0.001	0.005	27	57	0.0005	0.0013	0.0012	0.0026	0.002	0.007	0.003	0.003	0.011	0.018	0.025	0.043
Yr 3	Extreme	4.8	5.1	6.6	8.9	0.24	0.38	0.013	0.019	0.38	0.57	0.002	0.005	52	152	0.0003	0.0010	0.0007	0.0020	0.013	0.017	0.003	0.004	0.005	0.013	0.015	0.034
Yr 4	Optimistic	4.8	5.1	6.6	9.2	0.14	0.18	0.008	0.010	0.30	0.48	0.001	0.006	35	71	0.0004	0.0012	0.0010	0.0024	0.002	0.003	0.002	0.003	0.005	0.016	0.022	0.043
Yr 4	Typical	4.8	5.1	6.6	9.2	0.16	0.18	0.008	0.010	0.32	0.48	0.001	0.006	29	64	0.0005	0.0013	0.0012	0.0027	0.003	0.006	0.003	0.003	0.010	0.022	0.027	0.052
Yr 4	Extreme	4.8	5.1	6.6	9.2	0.24	0.38	0.013	0.019	0.38	0.57	0.002	0.006	52	153	0.0003	0.0010	0.0008	0.0021	0.012	0.017	0.003	0.004	0.005	0.016	0.016	0.040
Yr 5	Optimistic	4.7	5.1	6.7	9.3	0.14	0.18	0.008	0.009	0.31	0.48	0.002	0.006	37	74	0.0004	0.0011	0.0010	0.0024	0.003	0.005	0.002	0.003	0.006	0.017	0.023	0.046
Yr 5	Typical	4.7	5.1	6.7	9.3	0.16	0.18	0.008	0.010	0.33	0.48	0.002	0.006	31	71	0.0005	0.0012	0.0012	0.0027	0.005	0.007	0.003	0.003	0.009	0.023	0.027	0.054
Yr 5	Extreme	4.7	5.1	6.7	9.3	0.24	0.39	0.013	0.019	0.39	0.58	0.002	0.006	54	155	0.0003	0.0009	0.0008	0.0022	0.013	0.017	0.003	0.004	0.006	0.017	0.017	0.043
Yr 6	Optimistic	4.7	5.0	6.3	9.2	0.15	0.18	0.008	0.009	0.32	0.47	0.002	0.007	34	80	0.0005	0.0012	0.0012	0.0028	0.004	0.007	0.003	0.003	0.010	0.020	0.029	0.054
Yr 6	Typical	4.7	5.0	6.3	9.2	0.17	0.18	0.009	0.010	0.33	0.47	0.002	0.007	31	80	0.0005	0.0013	0.0014	0.0030	0.006	0.007	0.003	0.003	0.012	0.025	0.032	0.060
Yr 6	Extreme	4.7	5.0	6.3	9.2	0.22	0.38	0.012	0.019	0.38	0.57	0.002	0.007	47	154	0.0004	0.0010	0.0010	0.0025	0.012	0.017	0.003	0.004	0.008	0.021	0.022	0.052
Yr 7	Optimistic	4.6	5.1	6.2	9.6	0.15	0.16	0.008	0.008	0.32	0.45	0.003	0.006	35	86	0.0005	0.0012	0.0012	0.0029	0.005	0.008	0.002	0.003	0.012	0.023	0.031	0.060
Yr 7	Typical	4.6	5.1	6.2	9.6	0.16	0.17	0.008	0.010	0.33	0.46	0.003	0.006	32	87	0.0005	0.0012	0.0014	0.0030	0.007	0.009	0.003	0.003	0.015	0.026	0.034	0.064
Yr 7	Extreme	4.6	5.1	6.2	9.6	0.22	0.38	0.011	0.019	0.37	0.57	0.003	0.007	47	154	0.0004	0.0010	0.0010	0.0026	0.012	0.017	0.003	0.004	0.010	0.023	0.024	0.057
Consent limits at W-M2 ⁽⁴⁾		4.5-6.5	4.5-6.5	15	30	0.5	1.00	NA	NA	1.1	2.2	0.18	0.63	NA	NA	0.0012	0.004	0.0013	0.004	0.2	4	0.026	0.14	0.068	1.0	0.054	0.29

Note. ⁽¹⁾ All concentrations in units of g/m³ unless stated otherwise.
⁽²⁾ Hardness reported in g/m³ as CaCO₃.
⁽³⁾ These hardness dependent parameters have been normalised to a hardness of 50 g/m³ as CaCO₃.
⁽⁴⁾ Consent limits based on consent conditions in final decision of the Environment Court (Environment Court 2013). Consent limits based on pH < 5.5.
⁽⁵⁾ Values in bold numbers exceed the consent limits.



Table 34: Modelled concentrations ⁽¹⁾ at W-M2 for post mining period.

Year	Scenario	pH (unitless)		TSS		Aluminium		Arsenic		Manganese + Iron		Cobalt		Hardness ⁽²⁾		Cadmium ⁽³⁾		Copper ⁽³⁾		Chromium ⁽³⁾		Lead ⁽³⁾		Nickel ⁽³⁾		Zinc ⁽³⁾	
		Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile
Yr 8	Optimistic	4.5	4.8	5.1	14.7	0.18	0.27	0.009	0.013	0.34	0.49	0.003	0.009	27	117	0.0007	0.0016	0.0020	0.0040	0.008	0.014	0.003	0.004	0.020	0.037	0.049	0.090
Yr 8	Typical	4.5	4.8	5.1	14.7	0.18	0.27	0.009	0.013	0.34	0.49	0.003	0.009	27	117	0.0007	0.0016	0.0020	0.0040	0.008	0.014	0.003	0.004	0.020	0.037	0.049	0.090
Yr 8	Extreme	4.5	4.8	5.1	14.7	0.19	0.37	0.009	0.018	0.35	0.57	0.003	0.009	30	145	0.0006	0.0015	0.0018	0.0039	0.010	0.016	0.003	0.004	0.017	0.037	0.043	0.088
Yr 9	Optimistic	4.5	4.9	4.5	8.8	0.17	0.36	0.009	0.018	0.31	0.55	0.004	0.004	33	142	0.0005	0.0015	0.0013	0.0041	0.010	0.016	0.003	0.004	0.013	0.039	0.032	0.096
Yr 9	Typical	4.5	4.9	4.5	8.8	0.17	0.36	0.009	0.018	0.31	0.55	0.004	0.004	33	142	0.0005	0.0015	0.0013	0.0041	0.010	0.016	0.003	0.004	0.013	0.039	0.032	0.096
Yr 9	Extreme	4.5	4.9	4.5	8.8	0.17	0.36	0.009	0.018	0.31	0.55	0.004	0.004	33	142	0.0005	0.0015	0.0013	0.0041	0.010	0.016	0.003	0.004	0.013	0.039	0.032	0.096
Yr 10	Optimistic	4.5	4.9	4.5	8.8	0.17	0.36	0.009	0.018	0.31	0.55	0.004	0.004	33	142	0.0005	0.0015	0.0013	0.0041	0.010	0.016	0.003	0.004	0.013	0.039	0.032	0.096
Yr 10	Typical	4.5	4.9	4.5	8.8	0.17	0.36	0.009	0.018	0.31	0.55	0.004	0.004	33	142	0.0005	0.0015	0.0013	0.0041	0.010	0.016	0.003	0.004	0.013	0.039	0.032	0.096
Yr 10	Extreme	4.5	4.9	4.5	8.8	0.17	0.36	0.009	0.018	0.31	0.55	0.004	0.004	33	142	0.0005	0.0015	0.0013	0.0041	0.010	0.016	0.003	0.004	0.013	0.039	0.032	0.096
Consent limits at W-M2 ⁽⁴⁾		4.5-6.5	4.5-6.5	15	30	0.5	1.00	NA	NA	1.1	2.2	0.18	0.63	NA	NA	0.0012	0.004	0.0013	0.004	0.2	4	0.026	0.14	0.068	1.0	0.054	0.29

Note. ⁽¹⁾ All concentrations in units of g/m3 unless stated otherwise.
⁽²⁾ Hardness reported in g/m³ as CaCO₃.
⁽³⁾ These hardness dependent parameters have been normalised to a hardness of 50 g/m³ as CaCO₃.
⁽⁴⁾ Consent limits based on consent conditions in final decision of the Environment Court (Environment Court 2013). Consent limits based on pH < 5.5.
⁽⁵⁾ Values in bold numbers exceed the consent limits



Table 35: Modelled concentrations ⁽¹⁾ for Year 7at the monitoring stations (W-M1, W-M2 & W M3) and the MIW-WTP outflow.

Location	Scenario	pH (unitless)		TSS		Aluminium		Arsenic		Manganese + Iron		Cobalt		Hardness ⁽²⁾		Cadmium ⁽³⁾		Copper ⁽³⁾		Chromium ⁽³⁾		Lead ⁽³⁾		Nickel ⁽³⁾		Zinc ⁽³⁾	
		Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile	Median	95 th %ile
MIW-WTP Outflow	Optimistic	6.5	6.5	10	10	0.121	0.151	0.006	0.007	0.328	0.384	0.001	0.001	96	99	0.0001	0.0001	0.0002	0.0002	0.008	0.009	0.002	0.002	0.004	0.004	0.010	0.010
	Typical	6.5	6.5	10	10	0.152	0.163	0.007	0.011	0.363	0.403	0.001	0.001	88	99	0.0001	0.0001	0.0002	0.0002	0.009	0.012	0.002	0.002	0.007	0.007	0.010	0.010
	Extreme	6.5	6.5	10	10	0.358	0.423	0.018	0.020	0.532	0.618	0.002	0.002	150	175	0.0001	0.0001	0.0002	0.0002	0.016	0.017	0.004	0.005	0.004	0.004	0.007	0.007
W-M1	Optimistic	5.1	5.6	8.95	9.90	0.16	0.20	0.007	0.009	0.311	0.490	0.001	0.001	72	96	0.0001	0.0004	0.0003	0.0009	0.007	0.009	0.002	0.003	0.004	0.004	0.011	0.021
	Typical	5.1	5.6	8.95	9.90	0.17	0.21	0.008	0.011	0.336	0.499	0.001	0.001	67	96	0.0001	0.0004	0.0003	0.0009	0.009	0.011	0.002	0.003	0.007	0.007	0.011	0.022
	Extreme	5.1	5.6	8.95	9.90	0.30	0.42	0.015	0.020	0.467	0.608	0.001	0.002	101	171	0.0001	0.0003	0.0002	0.0007	0.015	0.017	0.003	0.005	0.004	0.004	0.008	0.016
W-M2	Optimistic	4.6	5.1	6.2	9.6	0.15	0.16	0.008	0.008	0.32	0.45	0.003	0.006	35	86	0.0005	0.0012	0.0012	0.0029	0.005	0.008	0.002	0.003	0.012	0.023	0.031	0.060
	Typical	4.6	5.1	6.2	9.6	0.16	0.17	0.008	0.010	0.33	0.46	0.003	0.006	32	87	0.0005	0.0012	0.0014	0.0030	0.007	0.009	0.003	0.003	0.015	0.026	0.034	0.064
	Extreme	4.6	5.1	6.2	9.6	0.22	0.38	0.011	0.019	0.37	0.57	0.003	0.007	47	154	0.0004	0.0010	0.0010	0.0026	0.012	0.017	0.003	0.004	0.010	0.023	0.024	0.057
W-M3	Optimistic	5.1	5.8	7.42	8.49	0.18	0.19	0.009	0.009	0.251	0.357	0.002	0.004	16	42	0.0009	0.0016	0.002	0.003	0.004	0.007	0.003	0.003	0.004	0.016	0.027	0.045
	Typical	5.1	5.8	7.42	8.49	0.18	0.19	0.009	0.010	0.256	0.358	0.002	0.004	16	40	0.0009	0.0016	0.002	0.003	0.005	0.007	0.003	0.003	0.005	0.017	0.028	0.048
	Extreme	5.1	5.8	7.42	8.49	0.21	0.27	0.011	0.013	0.269	0.387	0.002	0.004	22	66	0.0007	0.0015	0.002	0.003	0.009	0.013	0.003	0.004	0.005	0.017	0.022	0.044
Consent limits at W-M2 ⁽⁴⁾		4.5-6.5	4.5-6.5	15	30	0.5	1.00	NA	NA	1.1	2.2	0.18	0.63	NA	NA	0.0012	0.004	0.0013	0.004	0.2	4	0.026	0.14	0.068	1.0	0.054	0.29

Note. ⁽¹⁾ All concentrations in units of g/m3 unless stated otherwise.
⁽²⁾ Hardness reported in g/m³ as CaCO₃.
⁽³⁾ These hardness dependent parameters have been normalised to a hardness of 50 g/m³ as CaCO₃.
⁽⁴⁾ Consent limits based on consent conditions in final decision of the Environment Court (Environment Court 2013). Consent limits based on pH < 5.5.
⁽⁵⁾ Values in bold numbers exceed the consent limits.



Table 36: Modelled concentrations ⁽¹⁾ for Year 7 and Year 8 for sedimentation basin discharges.

Location	Scenario	pH (unitless)	TSS	Aluminium	Arsenic	Manganese + Iron	Cobalt	Cadmium	Copper	Chromium	Lead	Nickel	Zinc
		95 th %ile	95 th %ile	95 th %ile	95 th %ile	95 th %ile	95 th %ile	95 th %ile	95 th %ile	95 th %ile	95 th %ile	95 th %ile	95 th %ile
Sedimentation Basin 1 (Year 7, no discharge in Year 8)	Optimistic	4.7	13	0.25	0.01	0.6	0.013	0.0007	0.003	0.001	0.003	0.05	0.100
	Typical	4.7	13	0.25	0.01	0.6	0.013	0.0007	0.003	0.001	0.003	0.05	0.100
	Extreme	4.7	13	0.25	0.01	0.6	0.013	0.0007	0.003	0.001	0.003	0.05	0.100
Sedimentation Basin 2 (Year 7, no discharge in Year 8)	Optimistic	4.0	0.8	0.03	0	0.31	0.013	0.0007	0.003	0.007	0.007	0.05	0.1
	Typical	4.0	0.8	0.03	0	0.31	0.013	0.0007	0.0007	0.007	0.007	0.05	0.1
	Extreme	4.0	0.8	0.03	0	0.31	0.013	0.0007	0.0007	0.007	0.007	0.05	0.1
Sedimentation Basin 3 (Year 8, no discharge in Year 7)	Optimistic	4.5	18	0.28	0.01	0.7	0.013	0.0007	0.003	0.001	0.003	0.05	0.100
	Typical	4.5	18	0.28	0.01	0.7	0.013	0.0007	0.003	0.001	0.003	0.05	0.100
	Extreme	4.5	18	0.28	0.01	0.7	0.013	0.0007	0.003	0.001	0.003	0.05	0.100
Consent limits at W-M2 ⁽⁴⁾		4.5-6.5	30	1.00	NA	2.2	0.63	0.004	0.004	4	0.14	1.0	0.29

Note. ⁽¹⁾ All concentrations in units of g/m3 unless stated otherwise.
⁽⁴⁾ Consent limits based on consent conditions in final decision of the Environment Court (Environment Court 2013). Consent limits based on pH < 5.5.
⁽⁵⁾ Values in bold numbers exceed the consent limits.



6.4.3 Summary: Water quality assessment

- The projected concentrations of all the chemical species in discharges from the MIW-WTP to the Upper Whareatea River are expected to be less than the consent limits at compliance monitoring point W-M2 for the mining period and post-mining period.
- The projected concentrations of all chemical species, except copper, at compliance monitoring point WM-2 are expected to be less than the consent limits during the mining period and post-mining period.
- Under extreme conditions of acid mine drainage discharge from the ELF, the median of the projected copper concentrations at WM-2 are expected to exceed the median consent limits in operational Year 1, Year 6, Year 7 and Year 8. Despite the minor exceedences of the copper consent limits at WM-2, the water quality at monitoring point WM-2 is likely to be in compliance with Condition 263 of the 24 October 2013 Environment Court decision (Section 2.1).
- Projected concentrations of all the chemical species at monitoring point WM-1 in the Whareatea River are expected to be less than the consent limits at compliance monitoring point WM-2 at all times.
- The median of the projected copper concentrations at WM-3 are expected to exceed the median consent limits at compliance point WM-2 by approximately 50%. The relatively lower projected copper concentration in discharges from the MIW-WTP and from the mine catchment sedimentation basins suggest that the exceedences in copper concentrations at WM-3 are not related to mining activities at the EMP site.

7. Conclusions

Based on the results of pit pump capacity sizing process, WM Group selected a maximum pumping rate of 160 L/s for the pumping from the active pit to the MIW Sedimentation Sump. During extreme wet conditions, however, the Western Pit MIW volume could potentially increase to approximately 232,500 m³ resulting in flooding of the pit floor. The flooding of the pit could potentially result in stoppage to mining operations of up to 20 days as the pit is dewatered to a volume below 25,000 m³. The likelihood of the extreme wet conditions occurring is rare (1 in 55 year event). Based on the full 55 year rainfall record the volume of water stored in the Western Pit is expected to be less than 900 m³ for 95% of the time, for a pumping rate of 160 L/s.

The accumulation of up to 232,500 m³ of water in the Western Pit under extreme wet conditions will not necessarily result in the disruption of mining activities. If mining is occurring on the upper pit benches, the mining activities could potentially still continue during the period of pit flooding.

For the recommended capacities of the MIW Sedimentation Sump (Table 23) the model projections indicate that in Year 4 & Year 5 of mine operation, the Sedimentation Sump could overflow, but the likelihood of an overflow event occurring is extremely rare for both years. The model projections indicate that for both years, an overflow is projected to occur on only one day out of a simulation period of 20211 days. For the other years of the mine operation, the MIW Sedimentation Sump is not expected to overflow.

The accumulation of up to 232,500 m³ of water in the Western Pit under extreme wet conditions will not necessarily result in the disruption of mining activities. If mining is occurring on the upper pit benches, the mining activities could potentially still continue during the period of flooding. An analysis of the model projected volumes of water storage in the MIW Sedimentation sump indicates that the storage of water within EMP site during the mining period (Figure 12 to Figure 18) is expected to be much larger than during the post-mining period (Figure 19 and Figure 20) and the pre-mining period. The storage of water within the mining catchments during the mining period is expected to attenuate flows and increase baseflows in the Whareatea River (Table 31 & Table 32).



The Revised GoldSim Model was used to calculate the projected concentrations of selected chemical species at monitoring points WM-1, WM-2 and WM-3 in the Whareatea River. The model results indicate the following:

- For the MIW-WTP treatment efficiencies assigned to the Revised GoldSim Model (Table 18), the projected concentrations of all the chemical species in discharges from the MIW-WTP to the Upper Whareatea River are expected to be less than the consent limits at compliance monitoring point W-M2 for the mining period and post-mining period.
- With the exception of copper, the projected concentrations of all chemical species at compliance monitoring point WM-2 are expected to be less than the consent limits during the mining period and post-mining period.
- Under extreme conditions of acid mine drainage discharge from the ELF, the median of the projected copper concentrations at WM-2 are expected to exceed the median consent limits in operational Year 1, Year 6, and Year 7 by less than 16%. Despite the minor exceedences of the copper consent limits at WM-2, the water quality at monitoring point WM-2 is likely to be in compliance with Condition 263 of the 24 October 2013 Environment Court decision (Section 2.1).
- Projected concentrations of all the chemical species at monitoring point WM-1 in the Whareatea River are expected to be less than the consent limits at compliance monitoring point WM2 at all times.

In summary, the modelling indicates that the water quality at W-M2 during the mining and post-mining period is expected to be in compliance with the consent conditions of the 24 October 2013 Environment Court decision.



8. Recommendations

The modelling indicates that if the treatment efficiencies and water management strategies proposed in the revised water management approach are implemented then the water quality at W-M2 during the mining and post-mining period is expected to be in compliance with the consent conditions of the 24 October 2013 Environment Court decision. However, if significant exceedences of compliance limits at monitoring point W-M2 are observed during the monitoring, WM Group recommends that:

- The actual treatment efficiencies achieved in the MIW Sedimentation Sump and the Mine Catchment Sedimentation basins are evaluated to see if these treatment efficiencies meet the design specifications.
- The water quality of ELF runoff is monitored regularly to assess if it is comparable to the input water quality applied to the Revised GoldSim Model. If the actual concentrations of contaminants in ELF runoff significantly exceed the model input concentrations then WM Group suggest that a revision to the water management approach is implemented that would involve additional treatment of ELF runoff before discharge to the receiving environment.



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Appendix A – Report Limitations

This Document has been provided by WM Group Limited (the Water Management Group) subject to the following limitations:

1. This Document has been prepared for the particular purpose outlined in the Water Management Group's proposal and no responsibility is accepted for the use of this Document, in whole or in part, in other contexts or for any other purpose.
2. The scope and the period of the Water Management Group's Services are as described in Water Management Group's proposal, and are subject to restrictions and limitations. The Water Management Group did not perform a complete assessment of all possible conditions or circumstances that may exist at the site referenced in the Document. If a service is not expressly indicated, do not assume it has been provided. If a matter is not addressed, do not assume that any determination has been made by the Water Management Group in regards to it.
3. In addition, it is recognised that the passage of time affects the information and assessment provided in this Document. The Water Management Group's opinions are based upon information that existed at the time of the production of the Document. It is understood that the Services provided allowed Water Management Group to form no more than an opinion of the actual conditions of the site at the time the site was visited and cannot be used to assess the effect of any subsequent changes in the quality of the site, or its surroundings, or any laws or regulations.
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APPENDIX B MGIU TSS REVIEW

MEMORANDUM

Recipient: [REDACTED] – Bathurst Resources Limited

From: [REDACTED] – Hydro Geochem Group Limited (HGG); [REDACTED] – HGG

Date: 20 July 2026

Cc: [REDACTED] – Mine Waste Management Limited

Document Number: J-NZ0433-013-M-FINAL

Document Title: MGIU TSS Review

Mine Waste Management Limited (MWM) was engaged by Bathurst Resources Limited (BRL) to review total suspended solids (TSS) data for surface waters associated with the proposed Buller Plateaux Continuation Project (BPCP or the Project). This memorandum presents the review of the available data at Stockton Mine. The information will be used in water and load balance models (WLBM) to represent surface water reporting from disturbed areas to pit sump inlets and bypass channels. This work will also be used to support the assessment of environmental effects (AEE) for the Fast-track Approvals Act (FTAA).

BACKGROUND

The purpose of the Project is to secure the existing infrastructure and mining operations associated with the Stockton Mine and provide access to additional mining areas as the coal resources in the current operations are depleted. The Project proposes to mine 20 million tonnes of coking coal utilising existing infrastructure facilities over a 25-year timeframe, to support and extend the life of the current Stockton Mine operations. There are four key project areas:

- Stockton.
- Mount Frederick South.
- Escarpment Extended.
- Upper Waimangaroa Haul Road.

A WLBM is being developed for the Mount Frederick South and Escarpment Extension sub-areas to assess potential water quality effects at surface water receptors; TSS is a potential constituent of concern (PCOC) considered within these models. TSS source terms for catchment types other than disturbed areas (e.g., rehabilitated slopes, engineered landform (ELF) seepages, undisturbed catchments, etc.), have been derived for the WLBM in a separate document.

OBJECTIVES AND SCOPE

The objective of this memorandum is to:

- Provide sump inflow TSS source terms for surface waters from disturbed areas (using Stockton Mine analogue data), which will be used to represent TSS of pit sump inflows and sump bypass flows in the WLBM.
- Estimate sump sedimentation rates to allow sediment removal to be modelled through pit sumps and water treatment sumps, and thus estimate TSS of sump spill water and water treatment plant (WTP) inflows

Understanding surface water TSS from disturbed areas is required to identify potential effects on natural waterways if it is not managed, and to aid in the development of a WLBM to support other components of the AEE for the Project. It is necessary to build a relationship between daily rainfall and daily average TSS as the WLBM runs off a daily time step and utilise daily rainfall as an input.

SITE REVIEW

Surface water sampling data are available for multiple waterways within Stockton Mine, however, monitoring sites with TSS datasets are typically only found downstream of sedimentation/AMD treatment structures. Such sites are not representative of the higher TSS levels that would be observed in runoff directly from disturbed areas.

To obtain pit sump inflow and bypass source terms:

- TSS data are reviewed (including QA/QC¹) for three monitoring sites relative to upstream activities at each site, identifying TSS values that may represent disturbed upstream areas.
- TSS data from a single site is presented to define a common sump inflow TSS source term for all disturbed areas.
- The limitations of deriving TSS source terms in this way are noted.

Figure 1 presents the location of the Stockton Mine water monitoring sites. The following daily or weekly sampling sites exhibited high TSS and turbidity:

- Mangatini (sump) inlet untreated (MGIU) - data from July 2009 to April 2025.
- Ford Creek (sump) #3 (FC#3) - data from August 2022 to April 2025.
- Northern engineered landform sump (NELF Sump) - data from February 2015 to August 2023.

Sites S16, Rockies North Sump, and Fly5 were reviewed, however, low TSS and turbidity were observed relative to the other sites.

Upstream landform and landcover for each of the high TSS sites is described below:

- MGIU is located at the base of the Mangatini catchment which has historically been affected by significant mining activity; in recent years the catchment has predominantly undergone

¹ Quality Assurance / Quality Control

rehabilitation. The catchment contains the coal handling and processing plant (CHPP), and associated coal stockpiles. Surface water from the CHPP (and thus coal laden), was directed to MGIU for only part of the data sampling period. MGIU has been subject to sediment pretreatment, using an upstream sump within the historic Mangatini Quarry (dating back to approximately 2013), and pH correction upstream of the Mangatini Quarry sump in the past two years. The catchment upstream of the site also contains sedimentation ponds of various sizes.

- FC#3 is located within the Mangatini catchment, downstream of the CHPP (which generally exhibits greater coal fines in runoff water). The outflow reports through MGIU to the Mangatini Sump and has done throughout the sampling period. The catchment upstream of FC#3 contains two small sedimentation sumps, however, FC#3 would be considered a major sedimentation sump for this catchment and acted as a pre-settlement sump for the Ford Creek Dam, which is currently full of sediment. Samples at FC#3 are taken from the outlet of this sump.
- NELF Sump was located at the base of the northern engineered landform (NELF), associated with the overburden from Cypress North Pit until 2023. Water from the NELF was directed through this sump for sediment treatment prior to the water flowing through to the St Patrick Dam for final treatment. This sump is no longer in use and has been superseded. The upstream catchment was predominantly overburden and likely only contained natural catchment in its early years. It is suspected that water samples have been taken from the outlet of this sump.

It can be seen that for the above sites, upstream landforms and landcover have varied over time, with continual changes to the proportion of natural vegetation, overburden stripping, coal mining, overburden dumping, and rehabilitation.



TSS AND TURBIDITY REVIEW AND QA/QC

The following procedure has been applied to the collated water quality data:

- All data recorded at the limit of reporting (LOR) have been set to 3.0 mg/L; although not all limits were reported at 3.0 mg/L. Given that the purpose of this report is to identify sampling sites that exhibit high TSS (which will be used to derive source terms), the effect on the results was deemed negligible.
- Text was removed from datasets. Where there was any indication of questionable data from accompanying text, then data were excluded from analysis.
- TSS values reported as being greater (>) than the same value as the LOR (e.g. >3), were assumed to be mistyped and were reported as 3.0 mg/L.
- No data were reviewed against laboratory certificates. For the purposes of this memorandum, it is assumed these data are reliable.
- TSS and turbidity data were assumed to be consistently reported as mg/L and NTU respectively.
- Simple rules were used to transform the data into a useable format for analysis.

Figure 2 illustrates annual average TSS for MGIU and FC#3 (where data is available). Figure 3 illustrates annual average turbidity data for MGIU, FC#3, and NELF Sump. The exact values are shown in Table 1.

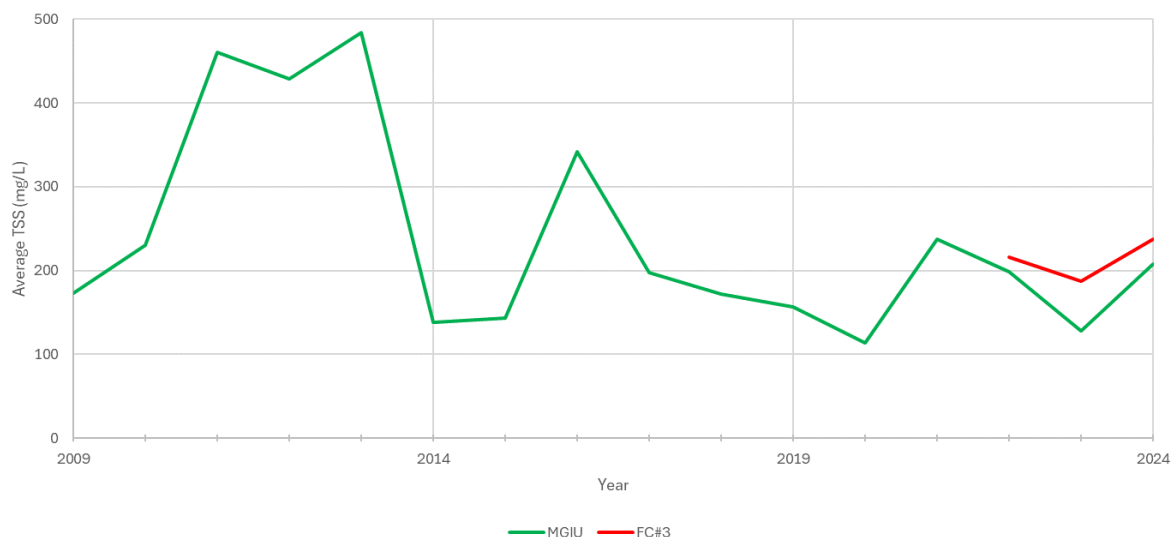


Figure 2: Annual average TSS at MGIU and FC#3 from 2009 to 2024.

Dataset sources: Supplied by BRL



Figure 3: Annual average turbidity at MGIU, FC#3, and NELF Sump from 2009 to 2024.

Dataset sources: Supplied by BRL

Table 1: Average annual water quality.

YEAR	MGIU		FC#3		NELF SUMP
	TURBIDITY (NTU)	TSS (mg/L)	TURBIDITY (NTU)	TSS (mg/L)	TURBIDITY (NTU)
2024	68.5	207.3	222.8	237.9	
2023	114.3	128.1	189.2	187.8	196.9
2022	308.8	198.9	175.6	215.7	78.3
2021	192.3	237.6			59.3
2020	70.5	114.1			194.3
2019	185.7	156.7			399.4
2018	44.4	171.9			89.1
2017		197.9			56.7
2016	18.9	341.4			37.4
2015	25.7	143.4			39.0
2014	108.5	138.7			
2013	291.9	483.6			
2012	270.2	429.2			
2011	410.7	460.7			
2010	116.9	230.7			
2009	116.1	173.4			

Dataset sources: Supplied by BRL

NELF Sump data was limited to turbidity data

It can be observed from Figure 2 that TSS is highest at MGIU between 2011 and 2013. TSS observed at FC#3 exhibits a similar trend to MGIU from 2022 to 2024. Maximum annual average turbidity at both the NELF Sump and MGIU is approximately 400 NTU (Figure 3). Comparison of sub-annual TSS at MGIU and FC#3 is illustrated in Figure 4. Sub-annual variability of turbidity at the three sites indicates peak turbidity was seen at MGIU (Figure 5).

In summary, it is noted that:

- Highest TSS and turbidity was observed at MGIU.

- FC#3 displayed similar TSS to MGIU from 2022 to 2024.
- NELF Sump displayed a similar annual average turbidity range to MGIU.

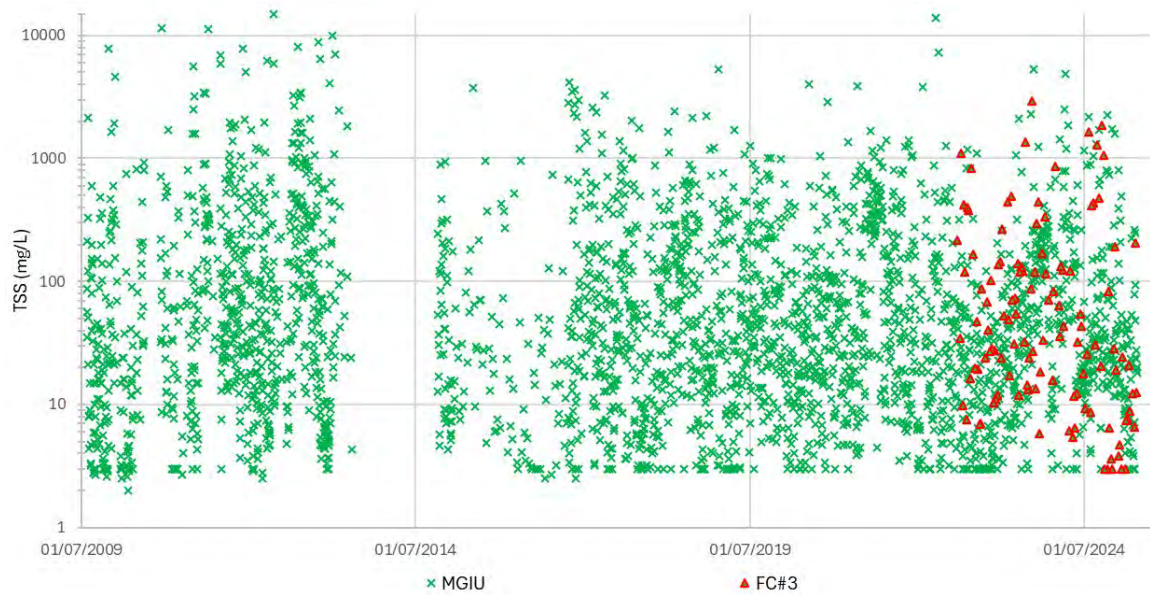


Figure 4: TSS datasets for MGIU and FC#3.

Note: logarithmic scale

Dataset sources: supplied by BRL

MGIU data sampled predominantly daily; FC#3 data sampled predominantly weekly,

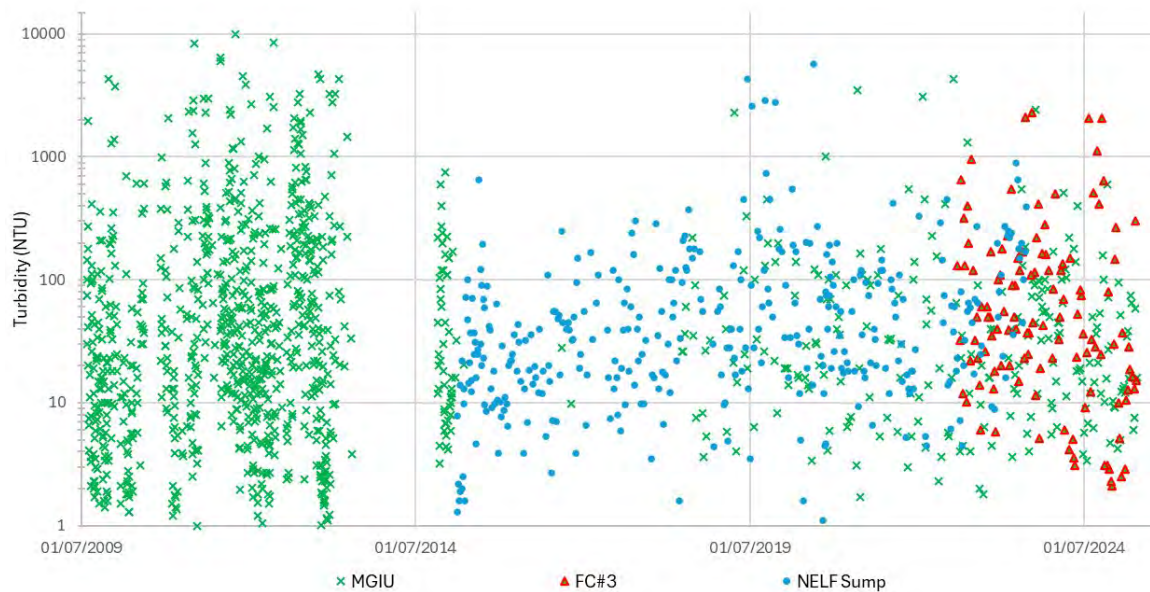


Figure 5: Turbidity datasets MGIU, NELF Sump, and FC#3.

Note: logarithmic scale

Dataset sources: Supplied by BRL

2015 through to present sampled predominantly weekly; MGIU data 2009 through 2014 sampled predominantly daily

The comparable range of turbidity observations at MGIU, FC#3, and the NELF Sump, indicates all these sites are suitable for derivation of surface water source terms from disturbed areas. As noted, whilst their upstream catchments are not directly relatable, they do carry similarities. It must be acknowledged however, that these sites are located downstream of sedimentation sumps where the extent of TSS capture has not been quantified.

Of the three sites described above, 2011-12 data from the MGIU site has been deemed most appropriate for use in derivation of the sump inflow TSS source terms for the following reasons:

- A mass-based measurement is required for use in the WLBM (i.e., not turbidity)
- Average annual TSS at MGIU decreased after 2013 due to progressive rehabilitation in the upper catchment and construction of the Mangatini Quarry sump in 2013 (which led to a reduction of TSS).
- Maximum average annual turbidity at MGIU from 2011 is similar to the NELF Sump from 2019, which indicates that runoff water from the Mangatini catchment in 2011 was similar to that from an active overburden dump.
- MGIU contains 16 years of data, with at least two of those years reflecting heavy disturbance with limited upstream sedimentation.

Table 2 presents annual median and mean TSS data from MGIU. It is noted that the data from 2011 and 2012 contained the first and third highest median values, and second and third highest mean values; these two consecutive years are considered the best analogue source term data available. The frequency distribution of TSS data from this period is presented in Table 3. Figure 6 illustrates the disturbed nature of the MGIU catchment in 2012.

Table 2: MGIU annual TSS data.

YEAR	MEDIAN (mg/L)	MEAN (mg/L)	SAMPLE COUNT
2024	36.3	207.3	236
2023	41.9	128.1	244
2022	20.9	198.9	230
2021	79.5	237.6	245
2020	28.8	114.1	246
2019	40.4	156.7	245
2018	44.4	171.9	238
2017	37.4	197.9	241
2016	20.0	341.4	95
2015	21.8	143.4	71
2014	53.6	138.7	44
2013	24.0	483.6	105
2012	82.8	429.2	276
2011	76.5	460.7	223
2010	18.0	230.7	125
2009	21.0	173.4	131

Red data identifies highest combination of median and average values

Table 3: Frequency distribution of MGIU TSS data from years 2011 and 2012.

PERCENTILE	TSS (mg/L)
100	14,996
95	1,880
90	947
85	606
80	428
75	324
70	242
65	178
60	123
55	94
50	79
45	59
40	44
35	34
30	27
25	21
20	16
15	12
10	9
5	5
0	3



Figure 6: Stockton Mine 2012 site imagery identifying the approximate MGIU catchment and upstream bodies of water providing sedimentation.

Note: Blue Polygon = MGIU catchment, Yellow Polygons = upstream bodies of water.

Source: supplied by BRL

SOURCE TERM GENERATION

For use within WLBMs the source term must be related to rainfall and be based on mean daily values.

Relationship of TSS to surface water flow

TSS data for 2011 to 2012 at MGIU data can be related to surface water flow monitored at S14B (located downstream of MGIU (see Figure 1)). Table 4 illustrates median and mean values of TSS data for 10 m³/s increments. Figure 7 presents this data and displaying the upward trend of TSS relative to flow. This method aids to remove 'data noise' within the TSS results observed during low flows and assumes that surface flow has a linear relationship with rainfall. It should be noted that these figures reflect daily averaged data and that at sub-daily intervals individual high TSS values can occur at both high and low flow conditions.

Table 4: Grouped MGIU TSS and S14B flow data.

FLOW BAND (m ³ /s)	MEDIAN FLOW (m ³ /s)	MEAN FLOW (m ³ /s)	MEDIAN TSS (mg/L)	MEAN TSS (mg/L)	SAMPLE COUNT
0 - 10	2.9	3.9	484	1148	453
10 - 20	13.6	14.5	1330	1102	5
20 - 30	25.1	25.1	4529	4529	2
30 - 40	32.3	32.8	5058	5682	3

Data is limited to the 2011 and 2012 dataset

Dataset sources: Supplied by BRL

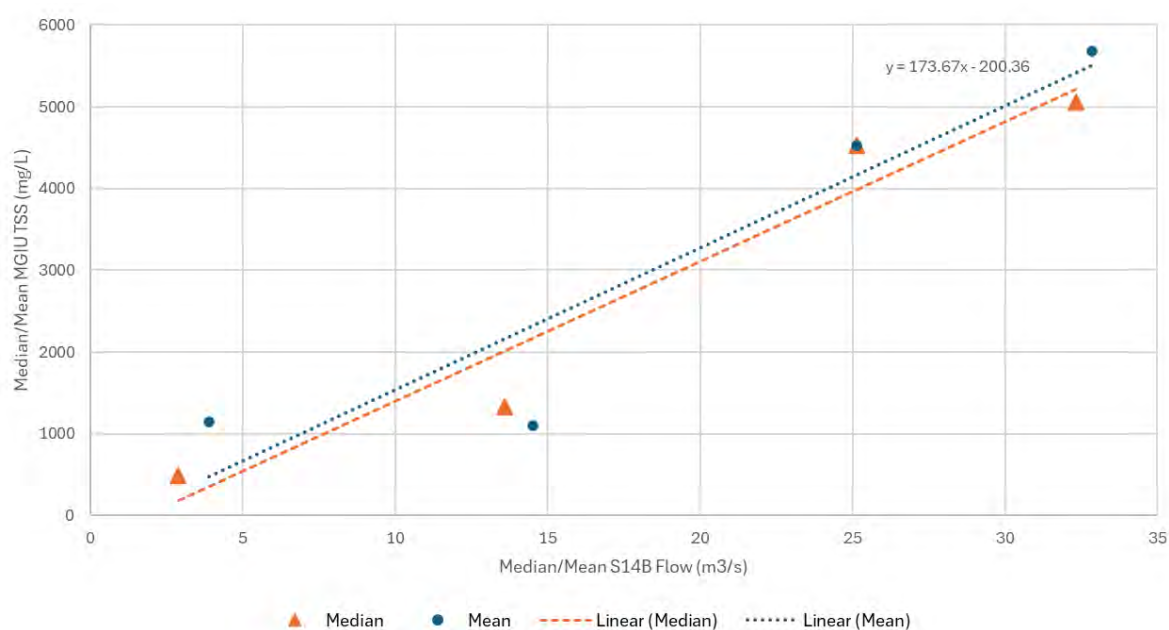


Figure 7: Mean and median MGIU TSS data plotted against mean and median surface water flow at S14B.

Data is limited to the 2011 and 2012 dataset

Dataset sources: Supplied by BRL

Relationship of TSS to turbidity

To convert instantaneous TSS data into a mean daily TSS timeseries that can be used by the WLB, a relationship between TSS and turbidity was first characterised at four sampling sites. Figure A1 through A4 in Attachment A illustrate these relationships at MGIU, FC#3, Rockies North Sump, and S16. R^2 values ranged from 0.61 to 0.94. The ratio of mean daily TSS to turbidity was found to range from approximately 0.89:1 to 1.27:1. Generally, sampling sites with a high proportion of upstream coal exposure tend to have a ratio of less than 1:1. Conversely, sites with a lower proportion of exposed coal tend to have a ratio greater than 1:1.

Given the linear relationship between TSS and turbidity, it is assumed that conversion factors, calculated from instantaneous and daily average turbidity data are translatable as TSS conversion factors.

Relationship of 10-minute and daily timeseries turbidity

Data from three continuous turbidity monitoring sites around Stockton Mine were reviewed (including MGIU, S16, and S14 (locations shown in Figure 1)) and were collated into 10-minute, and moving daily mean time series, from which frequency distributions were then derived. A ratio conversion factor to calculate mean daily turbidity from 10-minute turbidity was then derived from the two frequency distributions. These data are presented in Attachment B as Table B1, and Figure B1.

Estimating mean daily TSS from instantaneous TSS values

The average turbidity (10 minute to daily mean) conversion factor is then applied to the TSS frequency distribution data to produce a frequency distribution of estimated daily average TSS. Given, the average conversion factor from the 80th non-exceedance percentile results in a factor of ~0.8, 0.8 has been used for all values below the 80th non-exceedance percentile.

Relating derived mean daily TSS to rainfall

As indicated, the WLBM's make use of a daily rainfall record to estimate surface water flows. Therefore, a daily rainfall frequency distribution from the Stockton Meteorological Station (Met) can be used to provide a reference dataset from which to obtain estimates of TSS. Table 5 illustrates the frequency distribution of observed (sub-daily) TSS, estimated daily TSS, and observed daily rainfall. It should be noted that although the observed 14,996 mg/L TSS figure was not during high flows or rainfall, it is used to provide for a realistic upper limit for large rainfall events.

Figure 8 illustrates the relationship between daily rainfall and TSS (from Table 5) for use in the WLBM and relies on the observed increase of TSS with flow identified in Figure 7. The 99th and 100th non-exceedance percentile figures are used to define the relationship, and the x and y axis intercepts are forced through zero.

Table 5: Resulting sump inflow TSS source term, using conversion results from instantaneous to daily average.

PERCENTILE	INSTANTANEOUS TSS (mg/L)	CONVERSION FACTOR	RESULTING DAILY AVERAGE TSS (mg/L)	DAILY RAINFALL (mm)
100	14,996	3.32	4,518	457.6
99	6,218	1.65	3,757	148.6
95	1,880	1.11	1,688	72.6
90	947	0.92	1,035	48.4
85	606	0.82	735	35.4
80	428	0.80	535	25.2
75	324	0.80	405	18.6
70	242	0.80	302	12.9
65	178	0.80	222	9.0
60	123	0.80	154	5.9
55	94	0.80	117	3.4
50	79	0.80	99	2.0
45	59	0.80	73	1.0
40	44	0.80	55	0.4

PERCENTILE	INSTANTANEOUS TSS (mg/L)	CONVERSION FACTOR	RESULTING DAILY AVERAGE TSS (mg/L)	DAILY RAINFALL (mm)
35	34	0.80	43	0.2
30	27	0.80	34	0.1
25	21	0.80	26	0.1
20	16	0.80	20	0.1
15	12	0.80	15	0.1
10	9	0.80	11	0.1
5	5	0.80	7	0.1
0	3	0.80	3	0

Dataset sources: supplied by BRL

Figures identified in **bold** represent the determined pit sump inflow and sump bypass flow TSS source terms

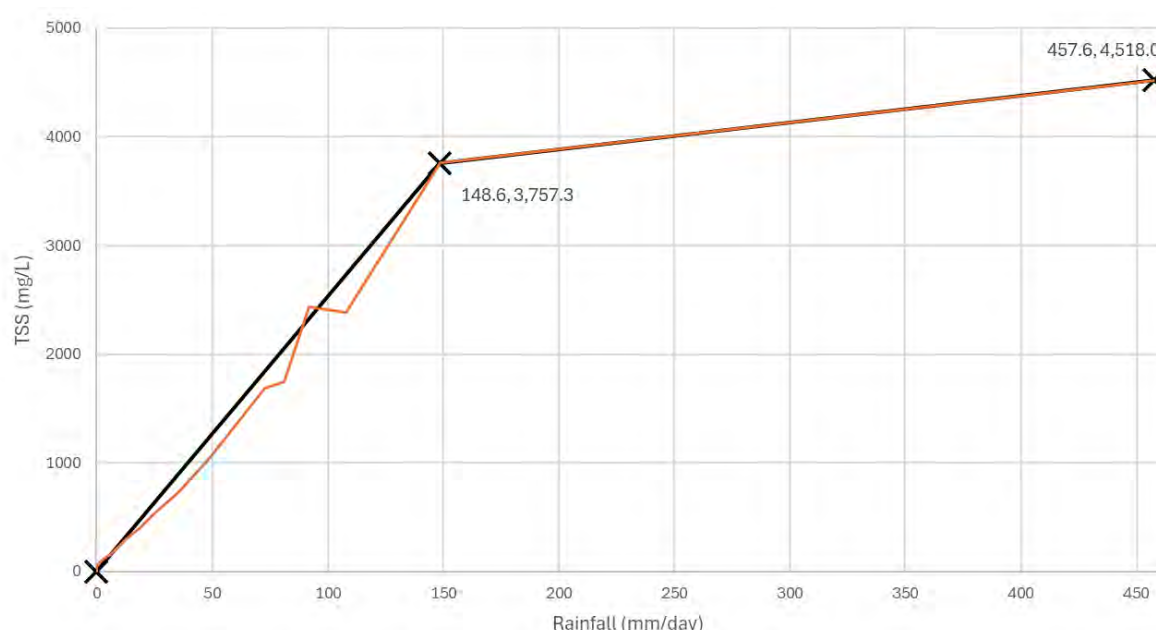


Figure 8: Simplified relationship between rainfall and daily TSS (for use in the WLBM).

As noted, the over-riding assumption within Figure 8 is that high mean daily TSS will be produced as a result of high daily rainfall.

SUMP TSS OUTFLOW ESTIMATION

In the absence of empirical or modelled sedimentation rate data, TSS pumped and spilled from sumps can be estimated using the observed reduction of TSS at MGIU that occurred since the installation of the Mangatini Quarry Sump. To understand this reduction, frequency distributions of TSS before (2011 to 2012) and after (Nov 2014 to Oct 2015) sump installation are performed, illustrated in Table 6.

A reduction of TSS load of approximately 75% occurs within the upper 5th percentile of the frequency distribution. This decreases to no reduction below the lower 5th percentile of the frequency distribution, as is illustrated in Figure 9. This relationship could be expected, given the higher flows have more available energy to carry larger sediment particles. These larger particles would settle out quickly in a sump and represent a high proportion of sediment removed. Conversely, at lower flows, there is limited

energy to carry large particles, therefore the TSS would be made up of lighter particles with lower settling velocities, which are less likely to settle out.

Table 6: TSS load change before and after installation of the Mangatini Quarry Sump.

	2011 AND 2012	NOV 2014 TO OCT 15	
PERCENTILE	INSTANT. TSS (mg/L)	INSTANT. TSS (mg/L)	DIFFERENCE OF SEDIMENT LOAD
100	14996	3727	75%
99	6218	1310	79%
95	1880	453	76%
90	947	314	67%
85	606	206	66%
80	428	151	65%
75	324	112	65%
70	242	73	70%
65	178	63	65%
60	123	46	62%
55	94	33	65%
50	79	29	63%
45	59	25	57%
40	44	21	53%
35	34	15	56%
30	27	13	53%
25	21	10	54%
20	16	9	45%
15	12	8	39%
10	9	6	28%
5	5	6	-7%
0	3	4	-72%

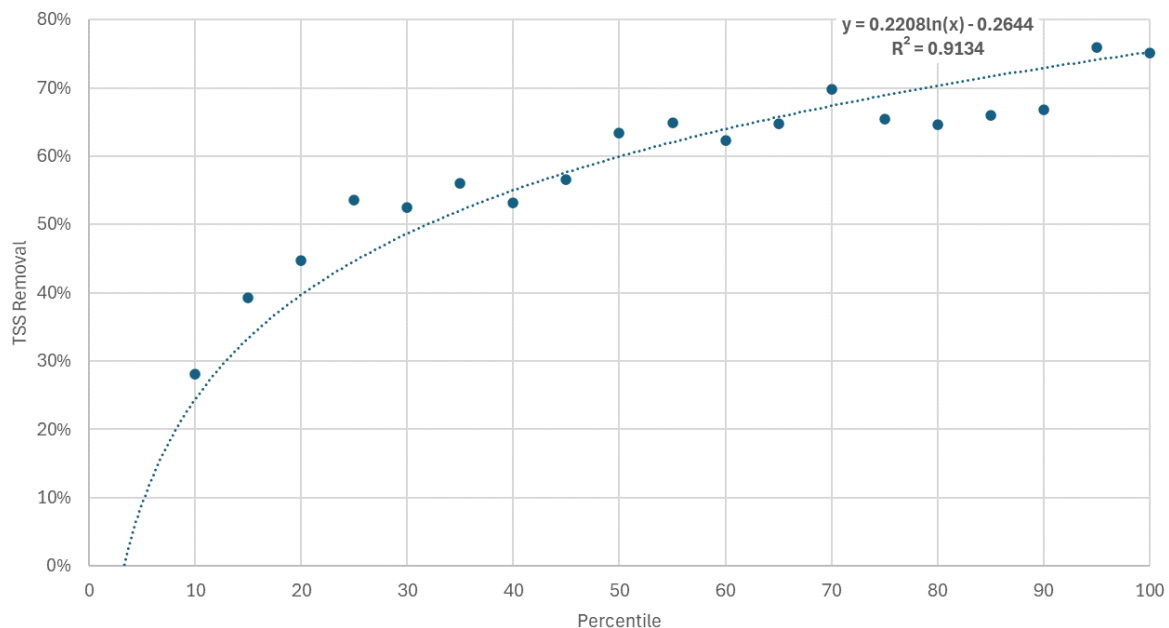


Figure 9: Reduction in TSS after inclusion of the Mangatini Quarry Sump.

The November 2014 to October 2015 time-period was chosen as rainfall accumulation was similar to the years of 2011 and 2012 (6 m/year); it is also unlikely that a significant portion of any surface rehabilitation was undertaken between the two periods. For context, the Mangatini Quarry Sump in 2013 had a surface area of approximately 10,500 m² and had an estimated catchment area of 450 Ha reporting to it; a ratio of 0.0023:1. The Mangatini Quarry Sump is positioned immediately upstream of the MGIU sampling site and was installed in 2013².

The assumption surrounding this observed reduction in TSS is that the two datasets observe the relationship identified in Figure 7, where the spread of TSS figures are relative to flow.

DISCUSSION

To produce source terms relevant to WLBM it is important to relate TSS to model inputs, in this case daily rainfall. To understand the strength of the relationship between rainfall and TSS datasets, Figure 10 plots the previous 24 hours of rainfall (observed at Stockton Met) against MGIU TSS data; this illustrates a relatively poor relationship. Figure 11 looks to improve on this by relating the TSS with stream flows observed nearby at monitoring site S14B. Neither of these relationships would be considered strong. This is, in part, due to S14B being located six kilometres downstream of MGIU, and the rainfall period not being proportional to the time of concentration of the MGIU catchment. The weak relationships are also impacted by factors such as mining activities, soil armouring, and time of sampling after a storm event.

It is important to note, that as the WLBM is based on a daily timestep, surface water flows are estimated as average daily flow rates (from daily rainfall). As a result, the model cannot represent sub-daily flow fluctuations, and therefore cannot represent all the idiosyncrasies of TSS fluctuations.

² Based on historic imagery

Given this modelling timestep, the assumption of a positive relationship between TSS relative to flow can be considered a reasonable one. As flow increases with rainfall in the model (with the exception of seepage flows), this translates to a generally positive relationship between TSS and rainfall. Although not strong, this relationship allows for a simple method to estimate the TSS load associated with flows within the modelled mining areas.

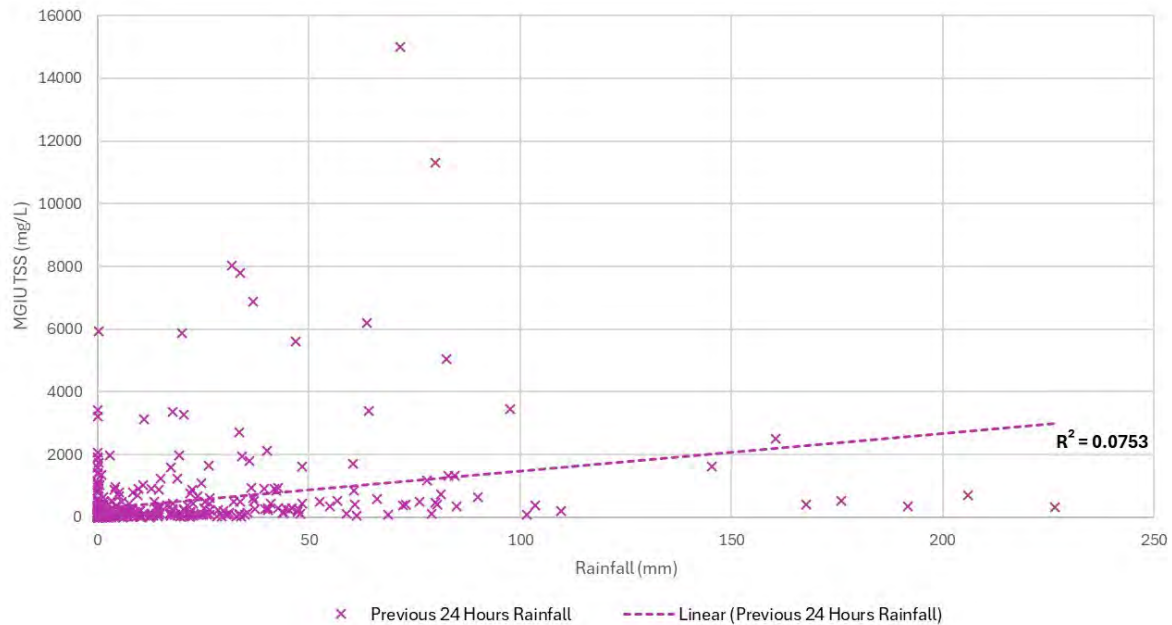


Figure 10: MGIU TSS data plotted against Stockton Met rainfall accumulation.

Data is limited to the 2011 and 2012 dataset

Dataset sources: Supplied by BRL

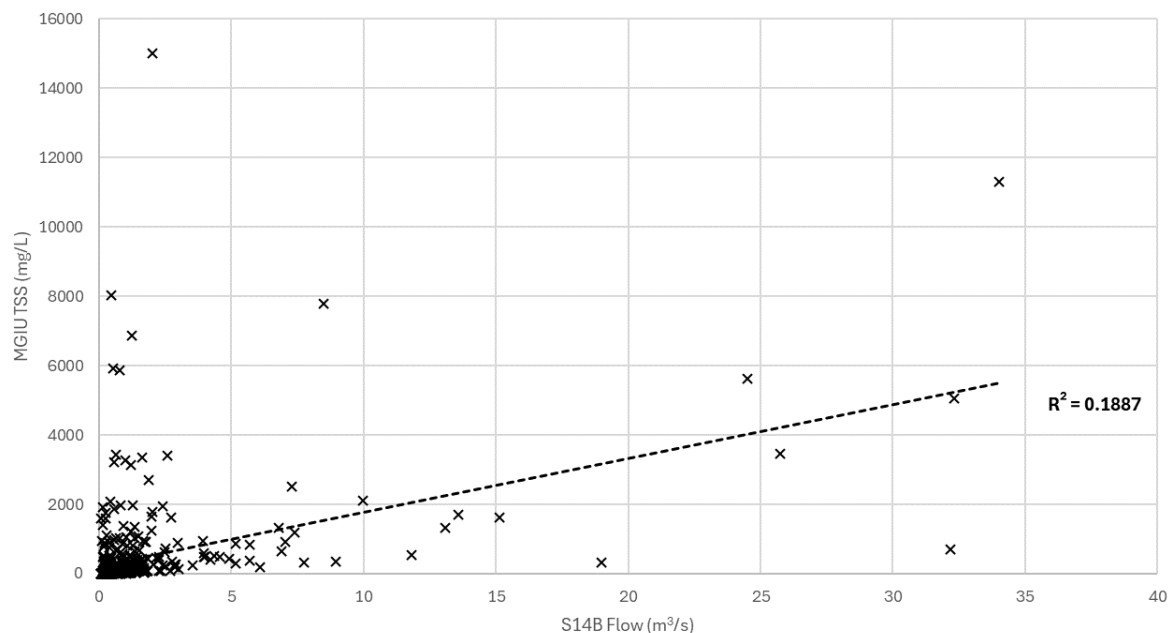


Figure 11: MGIU TSS data plotted against instantaneous flows observed at S14B.

Data is limited to the 2011 and 2012 dataset

Dataset sources: Supplied by BRL

Analysis of the MGIU data has provided a TSS source term dataset for pit sump inflows and estimates of sediment removal efficiencies for use within the WLBMs. The established relationship between daily rainfall and daily mean TSS compares well with active pit TSS figures provided by The Water Management Group (WMG, 2014³) for the existing Escarpment Mine, however, appears to underpredict TSS from engineered landforms (ELFs), especially for lower rainfall accumulation. This is illustrated below in Table 7 and Figure 12.

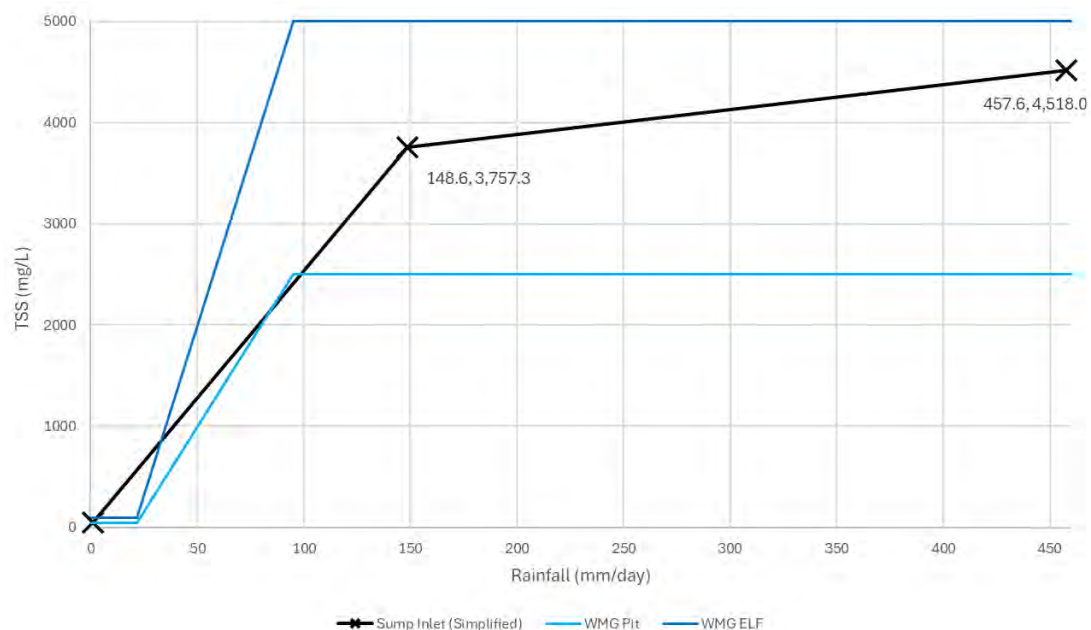
It must also be noted that the MGIU catchment includes a wide range of land-surface types such as overburden stripping, overburden placement areas, coal pits, stockpiling areas, vegetation stripping, and partially/fully rehabilitated areas. The determined sump inflow source terms for TSS are therefore the result of multiple sediment sources of unquantified magnitude. This differs from figures presented by WMG.

The MGIU catchment incorporates limited upstream sediment controls, and it is assumed that the WMG figures are estimated without consideration of potential sedimentation. For these reasons, the MGIU based TSS source term data is expected to fair reasonably with site expectations, given similar upstream controls are incorporated within the mine plan.

Table 7: Water Management Group (WMG) TSS source term data.

DAILY RAINFALL (mm)	PIT TSS (mg/L)	ELF – UNCOVERED RUNOFF TSS (mg/L)
800	2,500	5,000
95.1	2,500	5,000
21.6	50	100
0	50	100

Source: WMG, 2014. Escarpment Mine Project: Assessment of Revised Water Management Approach. Report 12001-036-R-002. Dated February 2014



³ WMG, 2014. Escarpment Mine Project: Assessment of Revised Water Management Approach. Report 12001-036-R-002. Dated February 2014

Figure 12: Comparison of MGIU TSS source term data with Water Management Group figures

With the lack of empirical sediment removal data from sumps at Stockton Mine, it is difficult to understand how representative the relationship illustrated in Figure 9 is. It is expected that removal efficiency is higher at the upper flow rates due to the carry of heavier particles; these particles likely make up a large proportion of the TSS and are more likely to settle out due to their mass. Further data collection would be required to validate these numbers.

SUMMARY

Various sites were identified for the purpose of determining sump inflow TSS source terms for surface water runoff from disturbed areas. However, given the lack of monitoring sites immediately downstream of disturbed areas (and upstream of any treatment systems), only two sites were found to be appropriate. These were the MGIU and NELF Sump sites; MGIU being located upstream of the Mangatini Sump, and the NELF Sump being located at the base of the Cypress Mine overburden dump (upstream of the St Patrick Dam). Unfortunately, the NELF Sump data only contained turbidity, not TSS, and therefore was omitted from the analysis. However, comparison of the MGIU and NELF Sump average annual turbidity indicated that the sites had a similar maximum average turbidity, which indicated that the MGIU site may provide a suitable source term for the overburden dumps.

MGIU TSS data from 2011 to 2012 was identified as being suitable for establishing a source term for large, disturbed areas. It was noted that the site catchment had less vegetation during 2011-2012 than in more recent years (see MGIU catchment imagery illustrated in Figure 6) and construction of the Mangatini Quarry sump upstream MGIU had not been completed at that time. The MGIU TSS dataset from 2011-2012 was characterised using a frequency distribution, which was then adjusted to form a daily average TSS distribution (for use in the WLBM). The conversion from instantaneous to daily average was achieved by applying a factor that was derived from instantaneous and 24-hour average turbidity sensor data. The resulting daily average TSS was then aligned with a frequency distribution of Stockton Met daily rainfall data to provide a look-up table for use in the WLBM. This simplified approach (in the absence of comparable daily TSS and rainfall data) assumes that high daily rainfall produces high TSS under all conditions.

It is noted that whilst the relationships between TSS and rainfall, and TSS and flow, are not strong, they assume that rainfall induced flow produces an upward TSS trend with increasing flows. The relationship between daily rainfall and TSS distributions has been presented in Table 5 and will be used within the WLBM to determine TSS load.

As MGIU is located downstream of sedimentation sumps with unquantified TSS capture rates, it represents the result of partial sedimentation. It may be that bypass water and water reporting to pit sumps resemble sources that have undergone partial upstream sedimentation, and therefore the use of MGIU data as a source term can be more easily justified. Given MGIU is a combination of many upstream sources such as overburden, coal and soil, MGIU would be most appropriate as a collective source term TSS for pit sumps and bypass channel inflows in the absence of individual source terms.

An estimation of pond sedimentation efficiency has been completed from the observed reduction in TSS after installation of the Mangatini Quarry Sump. It was found that there was a reduction of up to 79% of TSS, as presented in Table 6. This figure will reduce to no observed sediment removal during what has been assumed as low flow periods.

LIMITATIONS

As discussed within this memo, limitations of the reported information include:

Pre-sedimentation occurring upstream of the MGIU sampling location

- It must be acknowledged that in the absence of the upstream sediment retention ponds, the resulting TSS at MGIU could have been higher; this difference is unquantifiable.
- It is difficult to confirm if additional sediment controls were implemented within the years following installation of the Mangatini Quarry sump. Therefore, there is a potential for the sedimentation rates to be overestimated. Without relevant TSS and flow data upstream of the Mangatini Quarry Sump it is difficult to quantify the actual removal rate.

Datasets being limited to daily sampling

- This results in a need to convert the data from an instantaneous value to a daily average, which leads to reduced accuracy. This may also limit the accuracy of the TSS results in general as the observed TSS values are relative to specific sampling times and do not (in reality) represent an even spread of time throughout a day. This approach then reduces the opportunity to capture high flow storm events, and identification of potentially higher peak sediment discharges.

No immediate downstream flow gauging site for the MGIU 2011-2012 dataset

- Should a flow gauging site be located closer to MGIU, there may be an observed improvement in the TSS to flow relationship, allowing for more confidence within the formed relationship between TSS and rainfall. It must be acknowledged, however, that multiple variables impact TSS, all which can not be represented within the WLBMs.

Limited datasets, upstream of sedimentation controls

- Surface water data were not available from disturbed areas upstream of sediment control structures, and therefore the source term relied on the interpretation of available datasets.

Insufficient operational information

- Limited operational information from during the sampling periods meant that interpretation of TSS data, such as high TSS results during low flows/rainfall, was not possible, resulting in potential inaccuracy. For example, we were unable to identify the occurrence of failures of upstream water controls that would have impacted the observations used in the analysis.

RECOMMENDATIONS

Source Terms

TSS source terms should be validated during the Construction Phase and during the first two years of the Operational Phase. These activities will benefit development of future iterations of WLBMs as BPCP works progress and aid in validating the source terms presented in this memo.

Suggested TSS sampling locations, under a range of rainfall and runoff conditions, should include:

- Overburden placement areas (Kaiata Mudstone and Brunner Coal Measures).
- Coal pits.
- Coal handling and processing areas and coal stockpile areas.
- Overburden stripping areas (identifying the rock type).
- Soil stripping areas (making note of subsurface material).
- Soil placement areas.
- Partially rehabilitated areas.
- Fully rehabilitated areas.
- Haul roads.
- Hard stand areas.

This will be achieved by:

- Sensor placement within TSS impacted water channels, pre-sedimentation, for continuous measurement of TSS or turbidity.
- Manual/automatic sampling of TSS impacted water channels, pre-sedimentation, for formation of a dataset and calibration of available sensor data.

Sediment Retention Ponds

It will be beneficial to validate BPCP sediment retention pond efficiencies at the start of the Operational Phase of the BPCP to:

- Validate TSS removal rates and the predicted pond sedimentation rates.
- Validate TSS of surge pond spill waters and outflows to the WTP.

This can be achieved by:

- Sensors and/or manual/automatic sampling located at the inlet and outlet of various sumps/ponds.
- Development of a database of sediment removal efficiencies for various BPCP sumps/ ponds over the operational range of flow rates.

Management

During the Operational Phase of the BPCP, sediment control structures similar to those placed upstream of MGIU should be installed to achieve comparable TSS results at pit sump inlets.

Adaptive management is required using performance monitoring to ensure the same level of TSS removal is achieved as used in the WLBM. If TSS removal is not appropriate, then other management controls may be required (e.g., coagulant and flocculant dosing of TSS impacted waters).

CLOSING REMARKS

Please do not hesitate to contact Paul Weber at [REDACTED] or [REDACTED] should you wish to discuss this memorandum in greater detail.

Attachments: Attachment A – Total Suspended Solids to Turbidity Relationships
Attachment B – Instantaneous to Daily Average Conversion Data

ATTACHMENT A – TOTAL SUSPENDED SOLIDS TO TURBIDITY RELATIONSHIPS

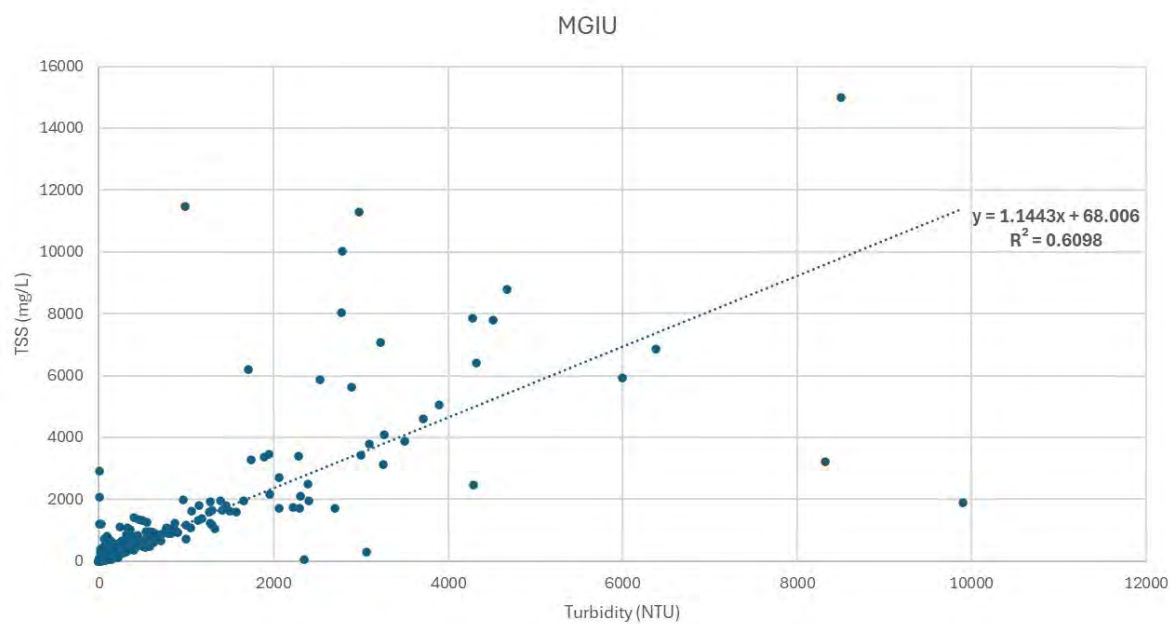


Figure A1: MGIU relationship between TSS and turbidity.

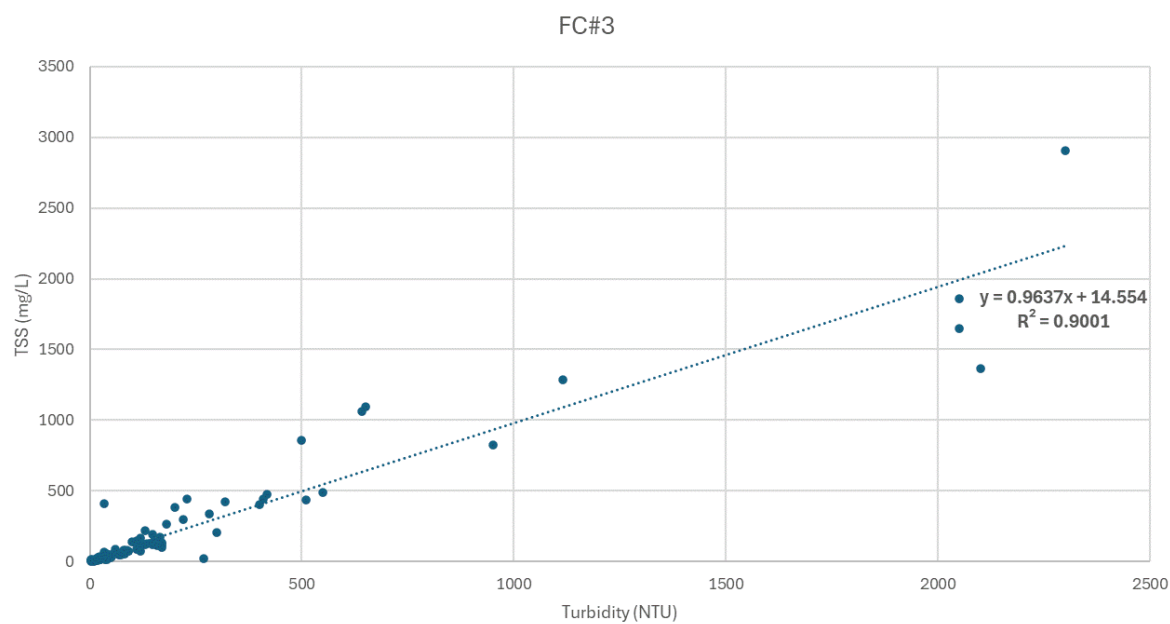


Figure A2: FC#3 relationship between TSS and turbidity.

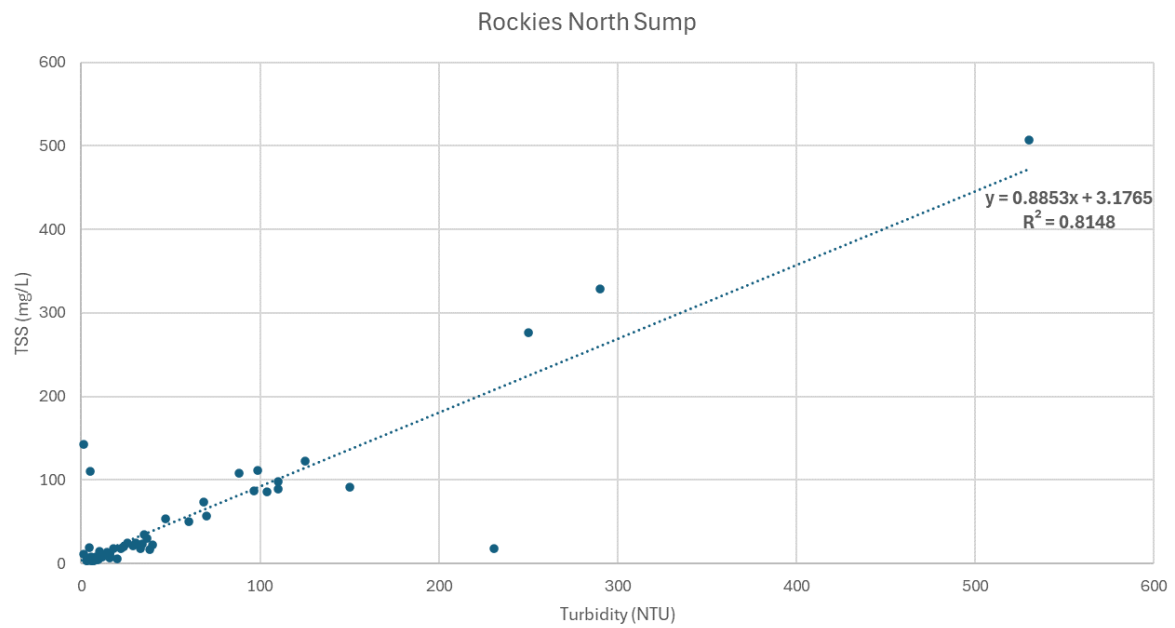


Figure A3: Rockies North Sump relationship between TSS and turbidity.

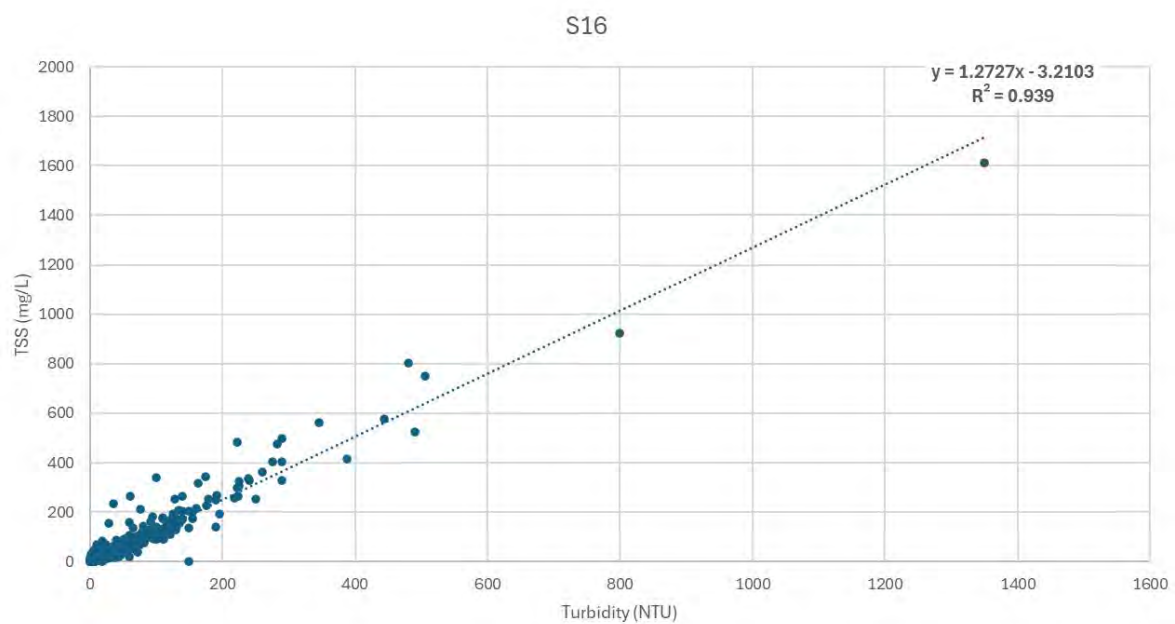


Figure A4: S16 relationship between TSS and turbidity.

S16 dataset limited to 2010 through 2025

Notes relating to Figures A1 through A4:

Dataset sources: Supplied by BRL

Data has been omitted where LOR is reached

ATTACHMENT B – INSTANTANEOUS TO DAILY AVERAGE CONVERSION DATA

Table B1: Frequency distribution and instantaneous turbidity readings to moving daily average.

PERCENTILE	MGIU			S16			S14			AVERAGE RATIO
	INSTANT-ANEOUS READING (NTU)	MOVING DAILY AVERAGE (NTU)	RATIO	INSTANT-ANEOUS READING (NTU)	MOVING DAILY AVERAGE (NTU)	RATIO	INSTANT-ANEOUS READING (NTU)	MOVING DAILY AVERAGE (NTU)	RATIO	
100	5,682.0	1,099.4	5.17	1,129.0	387.8	2.91	1,540.0	820.0	1.88	3.32
95	468.9	392.4	1.19	49.7	47.5	1.05	239.0	217.0	1.10	1.11
90	223.7	303.6	0.74	32.4	35.0	0.93	168.0	155.0	1.08	0.92
85	142.7	240.4	0.59	24.9	28.3	0.88	127.0	127.0	1.00	0.82
80	103.3	181.4	0.57	20.5	23.9	0.86	98.2	106.0	0.93	0.78
75	82.6	141.6	0.58	17.5	20.5	0.86	73.6	84.4	0.87	0.77
70	68.2	110.6	0.62	15.3	17.7	0.86	57.5	68.4	0.84	0.77
65	58.1	88.2	0.66	13.7	15.7	0.87	44.9	55.9	0.80	0.78
60	49.8	75.9	0.66	12.3	14.0	0.88	35.1	44.3	0.79	0.78
55	42.9	64.5	0.67	11.1	12.5	0.89	27.5	35.2	0.78	0.78
50	36.6	55.1	0.66	10.2	11.2	0.91	22.4	28.6	0.78	0.78
45	31.0	46.1	0.67	9.1	10.2	0.89	18.9	23.7	0.80	0.79
40	26.3	38.3	0.69	8.1	9.1	0.90	16.0	20.1	0.80	0.79
35	22.2	31.0	0.72	7.3	8.0	0.91	13.5	17.1	0.79	0.81
30	18.6	25.9	0.72	6.6	7.1	0.92	11.8	14.5	0.81	0.82
25	15.2	21.7	0.70	5.7	6.3	0.90	10.0	12.3	0.81	0.81
20	11.9	18.2	0.65	4.8	5.3	0.91	8.4	10.4	0.81	0.79
15	8.9	13.9	0.64	3.9	4.3	0.92	6.7	8.4	0.80	0.78
10	6.4	9.7	0.66	3.1	3.3	0.95	5.0	6.3	0.79	0.80
5	3.7	5.5	0.67	2.1	2.4	0.90	3.2	4.1	0.78	0.78

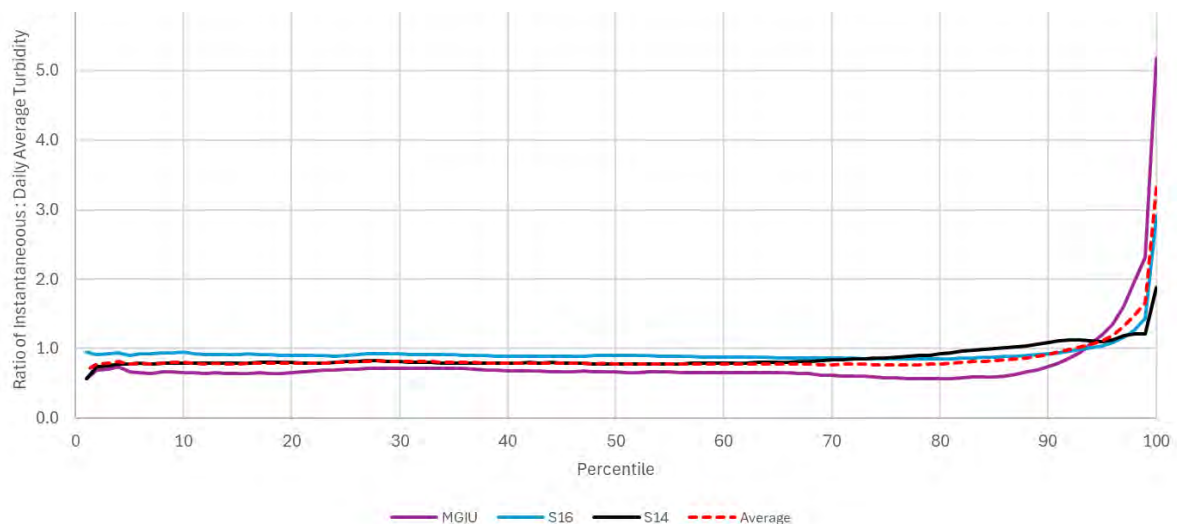


Figure B1: Frequency distribution of ratio of instantaneous to moving daily average turbidity ratio.

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