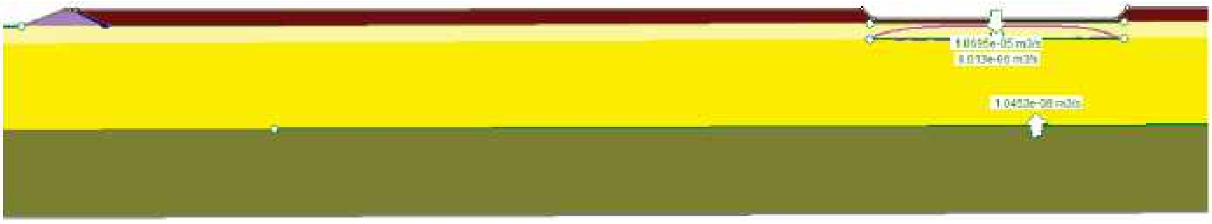


Figure D-12-6 Seepage model – Year 15

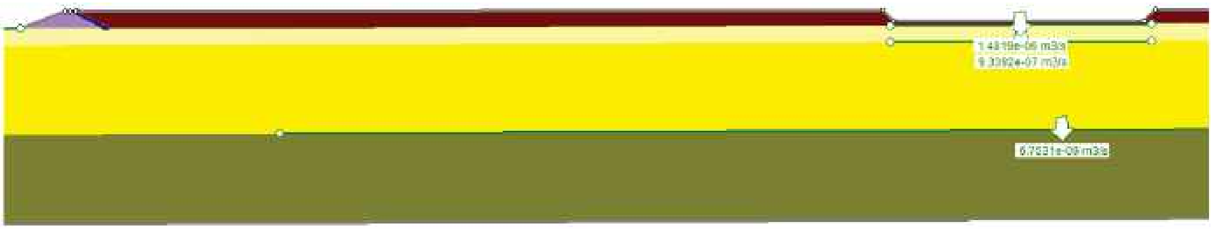
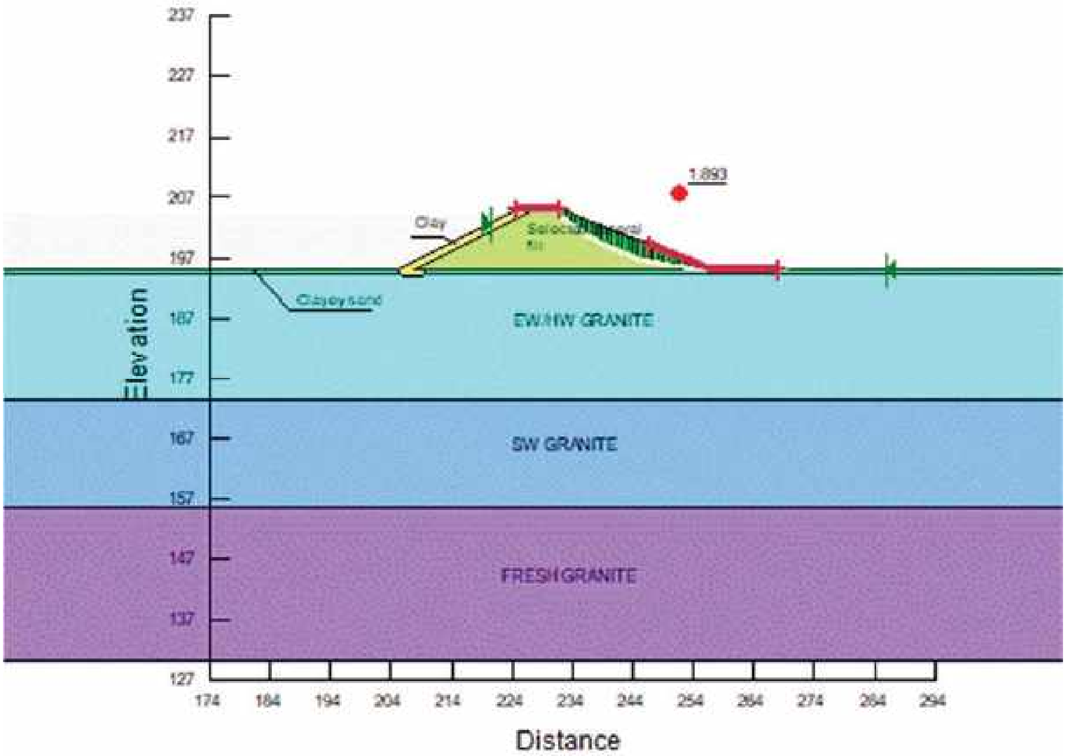


Figure D-12-7 Seepage model – Year 100

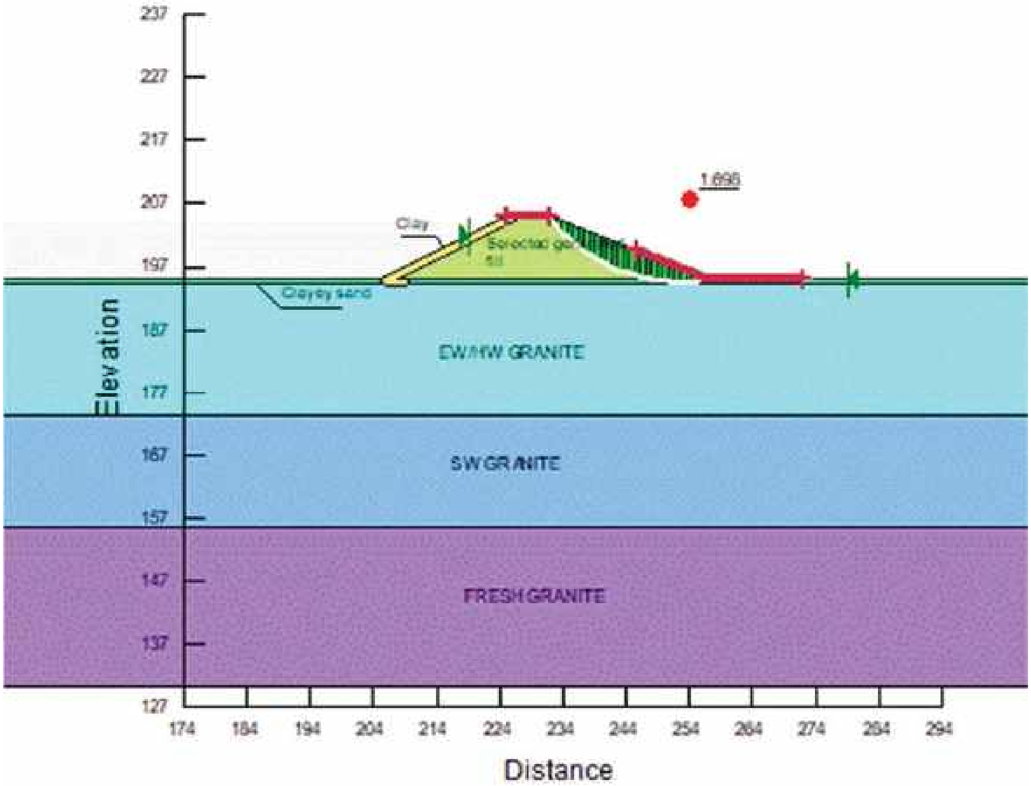
Appendix E
Stability Analysis

SLOPE STABILITY ANALYSIS

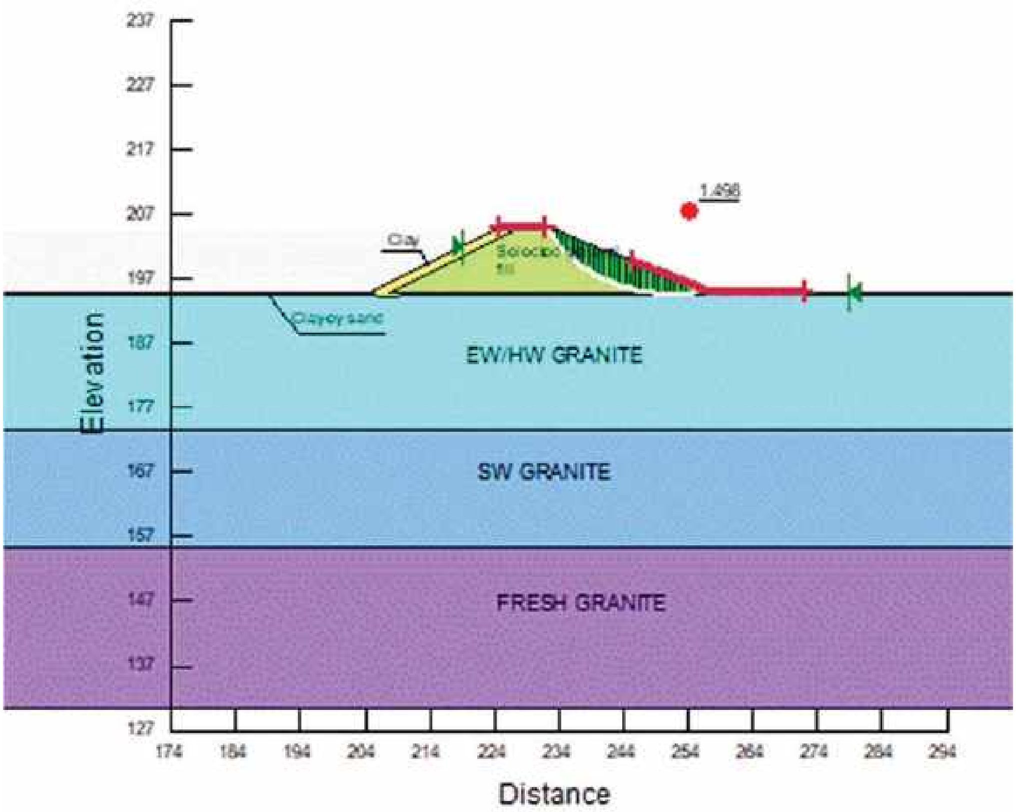
1) END OF CONSTRUCTION - UNDRAINED CONDITIONS - DOWNSTREAM



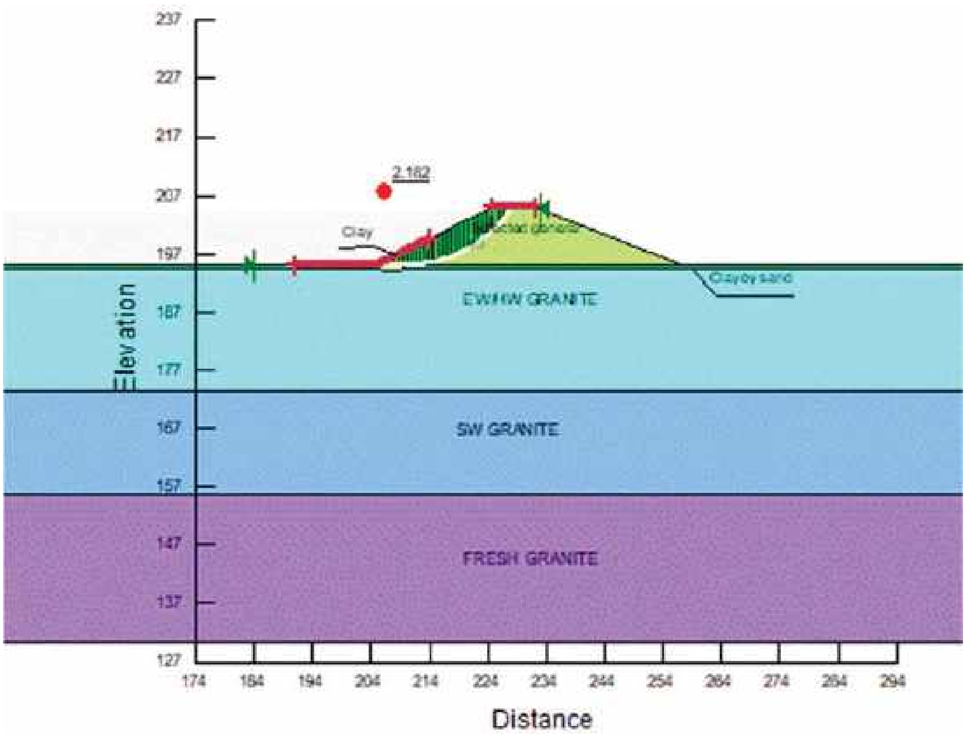
2) END OF CONSTRUCTION - DRAINED CONDITIONS - DOWNSTREAM



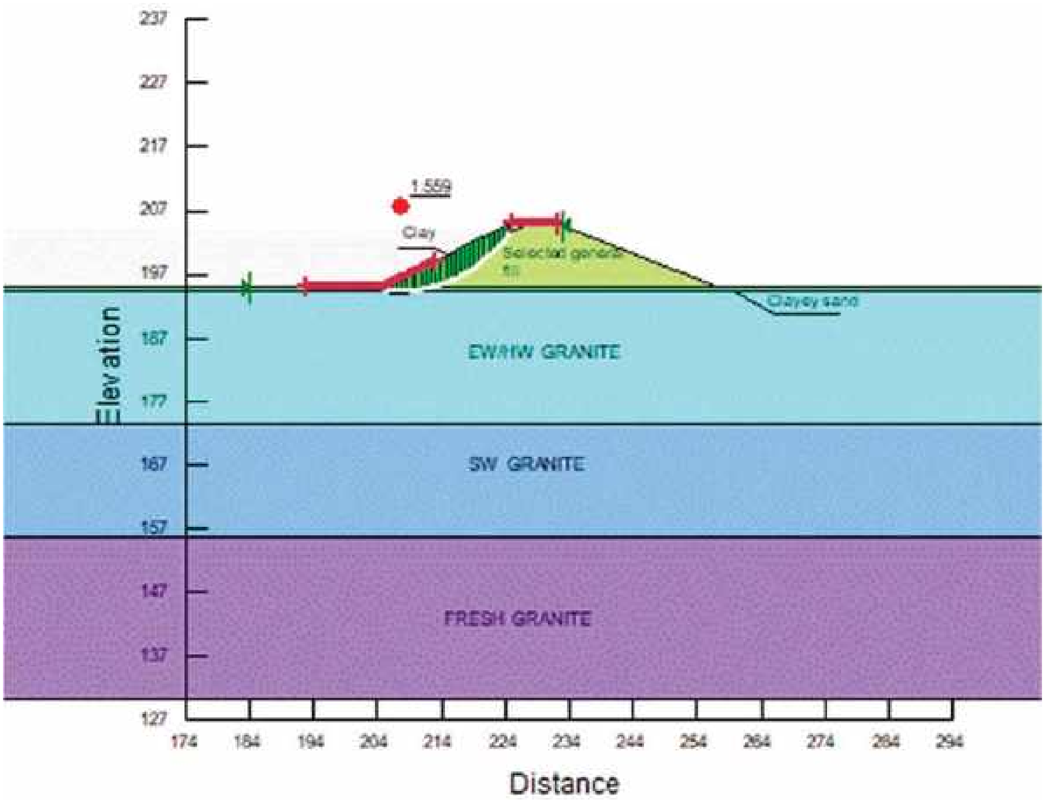
3) END OF CONSTRUCTION - DRAINED CONDITIONS WITH Ru = 0.5 - DOWNSTREAM



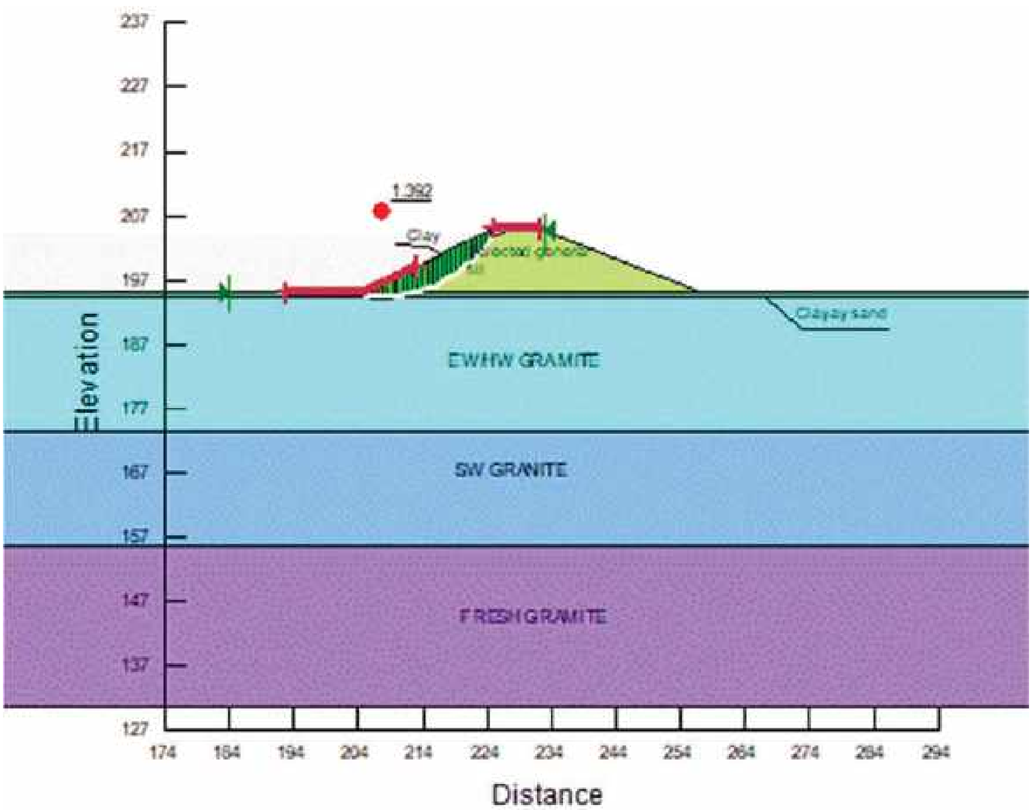
4) END OF CONSTRUCTION- UNDRAINED CONDITIONS - UPSTREAM



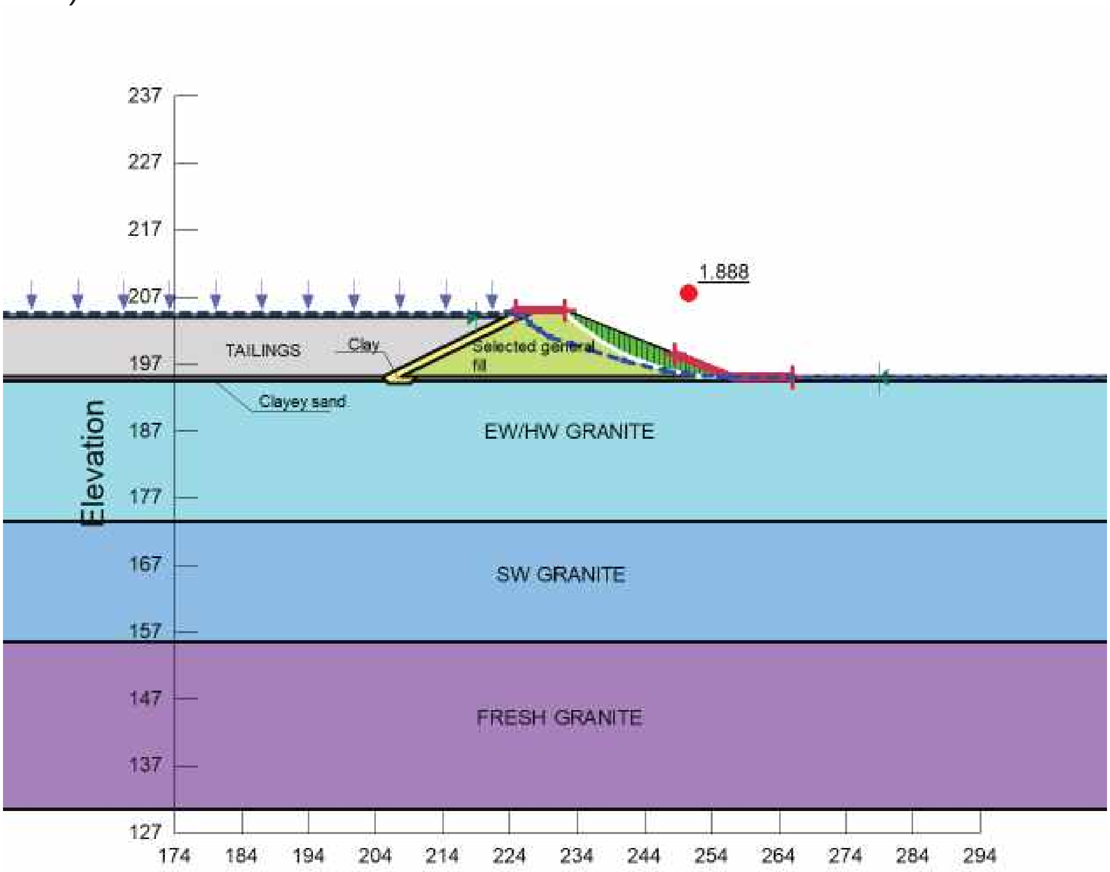
5) END OF CONSTRUCTION- DRAINED CONDITIONS - UPSTREAM



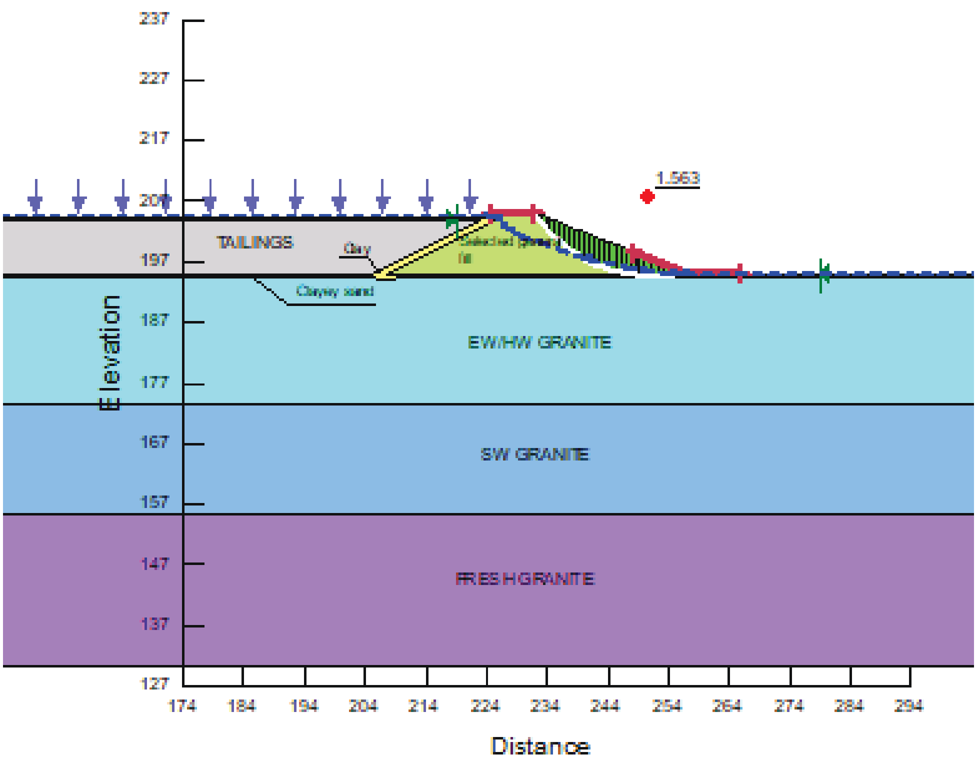
6) END OF CONSTRUCTION - DRAINED CONDITIONS WITH Ru - UPSTREAM



7) TAILING – UNDRAINED CONDITIONS



8) TAILING - DRAINED CONDITIONS



Appendix F
Consequence Category Assessment

CONSEQUENCE CATEGORY ASSESSMENT

Sunny Day Failure Scenario

Client Name	Yangibana		
Dam Name	Beneficiation TSF		
Dam ID. No. (If existing dam)			X X X X
Stream Name	N/A		
Dam Height (Metres)	11m	**Crest RL**	**339.0 m**
Estimated Capacity at FSL (Megalitres)	5,500		
Location	Yangibana		

Damage and Loss	Estimate	Severity Level: Minor	Medium	Major	Catastrophic
TOTAL INFRASTRUCTURE COSTS (costs are indicative only)					
Residential	<10M	YES	.	.	.
Commercial	<10M	YES	.	.	.
Community Infrastructure	<10M	YES	.	.	.
Dam replacement or repair cost	<10M	YES	.	.	.
TOTAL INFRASTRUCTURE COSTS severity level		**MINOR**			
IMPACT ON DAM OWNER'S BUSINESS					
Importance to the business	Essential to maintain supply	.	.	YES	.
Effect on services provided by the owner	Severe restictions would be applied for at least 1 yr	.	.	YES	.
Effect on continuing credibility	Severe widespread reaction	.	YES	.	.
Community reaction and political implications	Severe widespread reaction	.	YES	.	.
Impact on financial viability	Significant with considerable impact in the long term	.	YES	.	.
Value of water in storage (assessed by the owner in relation to the business)	Can be absored in one financial year	YES	.	.	.
IMPACT ON DAM OWNER'S BUSINESS damage and loss severity level		**MAJOR**			
HEALTH and SOCIAL IMPACTS					
Public health	<100 people affected	YES	.	.	.
Loss of service to the community	<100 people affected	YES	.	.	.
Cost of emergency management	<1,000 person days	YES	.	.	.
Dislocation of people	<100 person months	YES	.	.	.
Dislocation of businesses	<20 business months	YES	.	.	.
Employment affected	<100 jobs lost	YES	.	.	.
Loss of heritage	Local facility	YES	.	.	.
Loss of recreational facility	Local facility	YES	.	.	.
HEALTH and SOCIAL IMPACTS damage and loss severity level		**MINOR**			
NATURAL ENVIRONMENT					
Area of Impact	<5km2	.	YES	.	.
Duration of Impact	<1 (wet) year	YES	.	.	.
Stock and Fauna	Discharge from dambreak would not contaminate water supplies used by stock and fauna.	YES	.	.	.
Ecosystems	Discharge from dambreak would have short term impacts on ecosystems with natural recovery expected after 1 wet season. Remediation possible.	.	YES	.	.
Rare and endangered fauna and flora	Species exist but minimal damage expected. Recovery within one year.	YES	.	.	.
NATURAL ENVIRONMENT damage and loss severity level		**MEDIUM**			
HIGHEST DAMAGE AND LOSS SEVERITY LEVEL		**MAJOR**			

Population at Risk (PAR) PAR includes all those persons who would be directly exposed to flood waters within the dam break affected zone if they took no action to evacuate.	**≥1-10** **CONSEQUENCE CATEGORY =**	**HIGH C**

Note 1: With a PAR in excess of 100, it is unlikely Damage will be minor. Similarly with a PAR in excess of 1,000 it is unlikely Damage will be classified as Medium.

Note 2: Change to 'High C' where there is the potential of one or more lives being lost. The potential for loss of life is determined by the charateristics of the flood area, particularly the depth and velocity of flow.

Reasons for recommending the consequence category (refer ANCOLD "Guidelines on the Consequence Categories for Dams", 2012) which MUST include comments on PAR, buildings, roads, other infrastructure and natural environment downstream of the dam and the potential impacts arising from a dambreak *(NOTE: Provide photographs to support reasons):*

— The costs for the infrastructure and dam replacement and clean-up costs would be likely to exceed 10 million dollars but be less than 100 million dollars giving a medium level of damage to ANCOLD.
— The impact of a sunny day failure failure on the dam owners business is 'Major' as the operation of the tailings dam is critical to the ongoing extraction and processing of the rare earth minerals and would lead to major economic impacts.
— The impact of a dam failure on health and social impacts is minor due to the regional location of the dam.
— The environmental impacts of a sunny day failure of the embankment is minor due to the benign nature of the material and low expected radiological impacts.
— The environmental impacts of a flood loading failure scenario are considered to be moderate due to the benign nature of the material and the lack of expected long-term effects of the material within the surrounding environment.
— Population at Risk (PAR) in flow path in case of failure would be limited to itinerants given no current permanent residences or mine facilities downstream. However, flooding could affect the site haul road. Arguably the PAR could be <1 but conservatively between 1 and 10.

Completed and Reviewed By	[redacted]
Date	26/03/2019

CONSEQUENCE CATEGORY ASSESSMENT

Environmental Spill Scenario

Client Name	Yangibana				
Dam Name	Beneficiation TSF				
Dam ID. No. (If existing dam)		X	X	X	X
Stream Name	N/A				
Dam Height (Metres)	11 m	**Crest RL**		**339.0 m**	
Estimated Capacity at FSL (Megalitres)	5,500				
Location	Yangibana				

Damage and Loss	**Estimate**	**Severity Level** Minor	Medium	Major	Catastrophic
TOTAL INFRASTRUCTURE COSTS (costs are indicative only)					
Residential	<10M	YES	.	.	.
Commercial	<10M	YES	.	.	.
Community Infrastructure	<10M	YES	.	.	.
Dam replacement or repair cost	<10M	YES	.	.	.
TOTAL INFRASTRUCTURE COSTS severity level			**MINOR**		
IMPACT ON DAM OWNER'S BUSINESS					
Importance to the business	Restrictions needed during dry periods	YES	.	.	.
Effect on services provided by the owner	Minor difficulties in replacing services	YES	.	.	.
Effect on continuing credibility	Some reaction but short lived	YES	.	.	.
Community reaction and political implications	Some reaction but short lived	YES	.	.	.
Impact on financial viability	Able to absorb in 1 financial year	YES	.	.	.
Value of water in storage (assessed by the owner in relation to the business)	Can be absored in one financial year	YES	.	.	.
IMPACT ON DAM OWNER'S BUSINESS damage and loss severity level			**MINOR**		
HEALTH and SOCIAL IMPACTS					
Public health	<100 people affected	YES	.	.	.
Loss of service to the community	<100 people affected	YES	.	.	.
Cost of emergency management	<1,000 person days	YES	.	.	.
Dislocation of people	<100 person months	YES	.	.	.
Dislocation of businesses	<20 business months	YES	.	.	.
Employment affected	<100 jobs lost	YES	.	.	.
Loss of heritage	Local facility	YES	.	.	.
Loss of recreational facility	Local facility	YES	.	.	.
HEALTH and SOCIAL IMPACTS damage and loss severity level			**MINOR**		
NATURAL ENVIRONMENT					
Area of Impact	<5km2	.	YES	.	.
Duration of Impact	<1 (wet) year	YES	.	.	.
Stock and Fauna	Discharge from dambreak would not contaminate water supplies used by stock and fauna.	YES	.	.	.
Ecosystems	Discharge from dambreak is not expected to impact on ecosystems. Remediation possible.	YES	.	.	.
Rare and endangered fauna and flora	Species exist but minimal damage expected. Recovery within one year.	YES	.	.	.
NATURAL ENVIRONMENT damage and loss severity level			**MEDIUM**		

HIGHEST DAMAGE AND LOSS SEVERITY LEVEL	**MEDIUM**

Population at Risk (PAR)	**<1**	**LOW**
PAR includes all those persons who would be directly exposed to flood waters within the dam break affected zone if they took no action to evacuate.	**CONSEQUENCE CATEGORY =**	

Note 1: With a PAR in excess of 100, it is unlikely Damage will be minor. Similarly with a PAR in excess of 1,000 it is unlikely Damage will be classified as Medium.

Note 2: Change to 'High C' where there is the potential of one or more lives being lost. The potential for loss of life is determined by the charateristics of the flood area, particularly the depth and velocity of flow.

Reasons for recommending the consequence category (refer ANCOLD "Guidelines on the Consequence Categories for Dams", 2012) which MUST include comments on PAR, buildings, roads, other infrastructure and natural environment downstream of the dam and the potential impacts arising from a dambreak *(NOTE: Provide photographs to support reasons):*

The Environmental Spill Consequence Category for the Beneficiation TSF has been assessed as Low, due to the benign nature of tailings, and low environmental risk due to lack of radionuclides and low metals concentration in the leachate.

Completed and Reviewed By	[redacted]
Date	26/03/2019

CONSEQUENCE CATEGORY ASSESSMENT

Sunny Day Failure Scenario

Client Name	Yangibana				
Dam Name	Hydromet TSF				
Dam ID. No. (If existing dam)		X	X	X	X
Stream Name	N/A				
Dam Height (Metres)	9m	**Crest RL**		**341.0 m**	
Estimated Capacity at FSL (Megalitres)	1,200				
Location	Yangibana				

Damage and Loss	Estimate	Severity Level: Minor	Medium	Major	Catastrophic
TOTAL INFRASTRUCTURE COSTS (costs are indicative only)					
Residential	$10M - $100M	.	YES	.	.
Commercial	<10M	YES	.	.	.
Community Infrastructure	<10M	YES	.	.	.
Dam replacement or repair cost	<10M	YES	.	.	.
TOTAL INFRASTRUCTURE COSTS severity level		**MEDIUM**			
IMPACT ON DAM OWNER'S BUSINESS					
Importance to the business	Essential to maintain supply	.	.	YES	.
Effect on services provided by the owner	Severe restictions would be applied for at least 1 yr	.	.	YES	.
Effect on continuing credibility	Severe widespread reaction	.	YES	.	.
Community reaction and political implications	Severe widespread reaction	.	YES	.	.
Impact on financial viability	Able to absorb in 1 financial year	YES	.	.	.
Value of water in storage (assessed by the owner in relation to the business)	Can be absored in one financial year	YES	.	.	.
IMPACT ON DAM OWNER'S BUSINESS damage and loss severity level		**MAJOR**			
HEALTH and SOCIAL IMPACTS					
Public health	<100 people affected	YES	.	.	.
Loss of service to the community	<100 people affected	YES	.	.	.
Cost of emergency management	<1,000 person days	YES	.	.	.
Dislocation of people	<100 person months	YES	.	.	.
Dislocation of businesses	<20 business months	YES	.	.	.
Employment affected	<100 jobs lost	YES	.	.	.
Loss of heritage	Local facility	YES	.	.	.
Loss of recreational facility	Local facility	YES	.	.	.
HEALTH and SOCIAL IMPACTS damage and loss severity level		**MINOR**			
NATURAL ENVIRONMENT					
Area of Impact	<1km2	YES	.	.	.
Duration of Impact	<1 (wet) year	YES	.	.	.
Stock and Fauna	Discharge from dambreak would contaminate water supplies used by stock and fauna. Health impacts not expected.	.	YES	.	.
Ecosystems	Discharge from dambreak would have short term impacts on ecosystems with natural recovery expected after 1 wet season. Remediation possible.	.	YES	.	.
Rare and endangered fauna and flora	Species exist with losses expected to be recovered over a number of years.	.	YES	.	.
NATURAL ENVIRONMENT damage and loss severity level		**MEDIUM**			

HIGHEST DAMAGE AND LOSS SEVERITY LEVEL	**MAJOR**

Population at Risk (PAR) PAR includes all those persons who would be directly exposed to flood waters within the dam break affected zone if they took no action to evacuate.	**≥1-10** **CONSEQUENCE CATEGORY =**	**HIGH C**

Note 1: With a PAR in excess of 100, it is unlikely Damage will be minor. Similarly with a PAR in excess of 1,000 it is unlikely Damage will be classified as Medium.

Note 2: Change to 'High C' where there is the potential of one or more lives being lost. The potential for loss of life is determined by the charateristics of the flood area, particularly the depth and velocity of flow.

Reasons for recommending the consequence category (refer ANCOLD "Guidelines on the Consequence Categories for Dams", 2012) which MUST include comments on PAR, buildings, roads, other infrastructure and natural environment downstream of the dam and the potential impacts arising from a dambreak *(NOTE: Provide photographs to support reasons):*

— The costs for infrastructure and dam replacement and repair costs are estimated to be below 10 million dollars giving a low level of impact to ANCOLD.
— The impact of a sunny day failure on the dam owners business is 'Major' as the operation of the tailings dam is critical to the ongoing extraction and processing of the lithium.
— The impact of a dam failure for sunny day loading on health and social impacts is minor due to the regional location of the dam.
— The environmental impacts of a sunny day failure of the embankment is major.
— The environmental impacts of a flood loading failure scenario are considered to be major due to the nature of the material and the lack of expected long-term effects of the material within the surrounding environment.
— Population At Risk (PAR) in flow path in case of failure would be limited to itinerants given no current permanent residences or mine facilities downstream. However, flooding could affect the site haul road. Arguably the PAR could be <1 but conservatively between 1 and 10.

Completed and Reviewed By	[redacted]
Date	26/03/2019

CONSEQUENCE CATEGORY ASSESSMENT

Environmental Spill Scenario

Client Name	Yangibana				
Dam Name	Hydromet TSF				
Dam ID. No. (If existing dam)		**X**	**X**	**X**	**X**
Stream Name	N/A				
Dam Height (Metres)	9 m	**Crest RL**		**341.0 m**	
Estimated Capacity at FSL (Megalitres)	1,200				
Location	Yangibana				

Damage and Loss	Estimate	Severity Level: Minor	Medium	Major	Catastrophic
TOTAL INFRASTRUCTURE COSTS (costs are indicative only)					
Residential	<10M	YES	.	.	.
Commercial	<10M	YES	.	.	.
Community Infrastructure	<10M	YES	.	.	.
Dam replacement or repair cost	<10M	YES	.	.	.
TOTAL INFRASTRUCTURE COSTS severity level			**MINOR**		
IMPACT ON DAM OWNER'S BUSINESS					
Importance to the business	Restrictions needed during peak days and peak hour	.	YES	.	.
Effect on services provided by the owner	Minor difficulties in replacing services	YES	.	.	.
Effect on continuing credibility	Some reaction but short lived	YES	.	.	.
Community reaction and political implications	Some reaction but short lived	YES	.	.	.
Impact on financial viability	Able to absorb in 1 financial year	YES	.	.	.
Value of water in storage (assessed by the owner in relation to the business)	Can be absored in one financial year	YES	.	.	.
IMPACT ON DAM OWNER'S BUSINESS damage and loss severity level			**MEDIUM**		
HEALTH and SOCIAL IMPACTS					
Public health	<100 people affected	YES	.	.	.
Loss of service to the community	<100 people affected	YES	.	.	.
Cost of emergency management	<1,000 person days	YES	.	.	.
Dislocation of people	<100 person months	YES	.	.	.
Dislocation of businesses	<20 business months	YES	.	.	.
Employment affected	<100 jobs lost	YES	.	.	.
Loss of heritage	Local facility	YES	.	.	.
Loss of recreational facility	Local facility	YES	.	.	.
HEALTH and SOCIAL IMPACTS damage and loss severity level			**MINOR**		
NATURAL ENVIRONMENT					
Area of Impact	<1km2	YES	.	.	.
Duration of Impact	<1 (wet) year	YES	.	.	.
Stock and Fauna	Discharge from dambreak would contaminate water supplies used by stock and fauna with contaminant uptake.		.	YES	.
Ecosystems	Discharge from dambreak would have short term impacts on ecosystems with natural recovery expected after 1 wet season. Remediation possible.	.	YES	.	.
Rare and endangered fauna and flora	Species exist but minimal damage expected. Recovery within one year.	YES	.	.	.
NATURAL ENVIRONMENT damage and loss severity level			**MAJOR**		

HIGHEST DAMAGE AND LOSS SEVERITY LEVEL	**MAJOR**

Population at Risk (PAR) PAR includes all those persons who would be directly exposed to flood waters within the dam break affected zone if they took no action to evacuate.	**<1** / **CONSEQUENCE CATEGORY =**	**SIGNIFICANT**

Note 1: With a PAR in excess of 100, it is unlikely Damage will be minor. Similarly with a PAR in excess of 1,000 it is unlikely Damage will be classified as Medium.

Note 2: Change to 'High C' where there is the potential of one or more lives being lost. The potential for loss of life is determined by the charateristics of the flood area, particularly the depth and velocity of flow.

Reasons for recommending the consequence category (refer ANCOLD "Guidelines on the Consequence Categories for Dams", 2012) which MUST include comments on PAR, buildings, roads, other infrastructure and natural environment downstream of the dam and the potential impacts arising from a dambreak *(NOTE: Provide photographs to support reasons):*

The Environmental Spill Consequence Category for the Hydromet TSF has been assessed as Significant due to the increased environmental risk resulting from a spill due to the increased concentration of Magnesium Sulphate and the concentration of radionuclides within the material.

Completed and Reviewed By	[redacted]
Date	26/03/2019

Appendix G
Environmental Benefits Summary Table

Environmental Risk	Comparative Comments (FS Design vs Refined Design)
Site Location and Land Clearing	The disturbed footprint location remains unchanged for the refined concept design. Slightly reduced clearing requirement associated with proposed refined design (**See Figure 1**). Any external borrow would likely be smaller for the refined design due to lesser clay/earthworks volumes associated with building the refined design. Refined design embankments have the same or better setback to existing watercourses. (**See Figure 2**)
Dam Height and Failure Consequence Category (ANCOLD 2012)	RWP RWP is eliminated from refined concept design (was Significant Consequence Category in FS design) TSF1 (now combined with TSF2 as the Beneficiation TSF) For the refined concept design, TSF1 perimeter embankment height is kept consistent with the FS design and ANCOLD Consequence Category is unchanged (**Significant).** Combining TSF1/2 does not increase the failure consequences. TSF2 TSF2 is likely eliminated from preferred concept design (was Significant Consequence Category in FS design) TSF3 The refined design for the Hydromet TSF that incorporates both TSF3 and Evaporation Pond has a reduced embankment height and similar or lesser consequences of failure/spill due to reduced height of tailings and ability to spill into Beneficiation TSF. Evaporation Pond For the refined concept design, the Evaporation Pond is eliminated (was **Significant** Consequence Category in FS Design)
Dam Spill Risk	RWP/TSF1 In the FS design, the RWP was designed to contain run-off from TSF1 catchment and designed to hold a 1:100 AEP 72hr flood event prior to spill. For the refined concept, the RWP is not required and the decant pond within TSF1 has significant additional stormwater storage capacity (relative to FS RWP design) and hence overall significantly reduced risk of spill to the environment. TSF2 In the FS design, TSF2 was designed to store a 1:100 AEP 72hr flood plus freeboard, but no emergency spillway provided (hence small risk of overtopping/failure if poorly managed or extreme flood occurs). The refined concept combines Bene plant tailings into single stream and hence eliminates TSF2 from the design by combining with TSF1. TSF3 In the FS design, TSF3 was designed to store a 1:100 AEP 72hr flood plus freeboard, but no emergency spillway provided. The refined concept allows the same flood storage on TSF3 but also includes an emergency spillway for containment of any spill within the capacity of Beneficiation TSF pond (i.e. no environmental release). The emergency spillway also eliminates the risk of overfilling and overtopping. Evaporation Pond

Environmental Risk	Comparative Comments (FS Design vs Refined Design)
	The Evaporation Pond is eliminated from proposed refined concept (now combined with TSF3 and has emergency spillway into TSF1 decant pond)
Geotechnical Stability and Dam Failure Risk	<u>RWP</u> The RWP dam failure risk is eliminated in refined concept. <u>TSF1</u> The refined concept design proposes conventional perimeter discharge. An Operations Manual will be developed requiring a central decant pond to be maintained with resulting low phreatic surface at perimeter embankment. This improves geotechnical stability and reduces piping risk (relative to CDF proposed in the FS design which relies on water ponding/drainage alongside the perimeter embankment). <u>TSF2</u> The feasibility study concept design proposes a 10 m high embankment with upstream clay zone and no filters. Ponding water against embankments means that piping is a plausible risk of dam failure/loss of containment. The refined concept design eliminates TSF2 risk. <u>TSF3</u> The FS concept design proposes a 10 m high turkey’s nest embankment with a geocomposite lining system. The refined design proposes a similar high standard lining system, but better uses the natural topography resulting in significantly reduced tailings height and therefore overall lower risk of dam failure/loss of containment.
Seepage and Groundwater Risk	The overall TSF domain footprint is unchanged and situated on similar foundation conditions (i.e. similar for FS and refined concept). The geology comprises in-situ sandy clays overlying granite at shallow depth. The refined design eliminates the need for the Return Water Pond which reduces risk posed by seepage impacting the watercourse at the toe of the dam (i.e. reduces risk of F and Mo concentrations in watercourse exceeding guidelines for stock drinking water). Conventional perimeter discharge of thickened tailings allows small decant pond in Beneficiation TSF to be positioned centrally which minimises the risk of downstream seepage expression (relative to FS design). The development of wide desiccated beaches upstream of the Beneficiation TSF embankment mean that seepage risk is reduced in the proposed refined design. TSF2 is eliminated in the proposed refined concept. Given the geochemistry similarities of TSF1 and TSF2 tailings, combining of the tailings is non-consequential and should reduce seepage due to eliminating a “wet” TSF for the proposed arrangement. A high standard lining system is proposed for TSF3 in both the FS and refined concept design Hydromet TSF (i.e. same level of seepage mitigation is proposed). Design maintains monitoring systems to allow early intervention prior to impact being caused.
Beach Slopes and Tailings Capacity/Beach Freeboard	The refined concept eliminates operational risk associated with Central Thickened Discharge (CTD) in TSF1. CTD can be very sensitive to thickener performance. Rather than rely on CTD, the proposed alternative arrangement for the Beneficiation TSF allows for perimeter tailings discharge via spigots. This removes the risks of flatter than expected beach slopes resulting in insufficient storage capacity during operations and potential overfilling of the TSF. Also, flattened beach slopes with CTD could result in significantly higher than expected

Environmental Risk	Comparative Comments (FS Design vs Refined Design)
	embankment heights and therefore greater geotechnical risk (relative to proposed refined design where embankment heights are more predictable due to less reliance on steep beach slope). The refined concept uses perimeter beaching to control where the pond develops and ensures no pond on wall i.e. achieves central pond further set-back from watercourses and low Ksat tailings minimise seepage into foundation. At closure a wide channel is excavated to ensure pond does not remain post closure. In the lead up closure, tailings discharge would adopt elements of CTD to maximise tails capacity and achieve suitable shedding surface with suitable network of drains. i.e. no change in philosophy.
Dust (including dust with elevated radiation levels)	Refined design combines TSF 3/Evaporation Pond into the Hydromet TSF. This reduces dusting risk in TSF3 that doesn't rely on top-up water being pumped from a separate Evaporation Pond. Flatter tailings beach slopes can be accommodated in the Beneficiation TSF using perimeter discharge method. This allows the combining of all Bene plant tailings streams for discharge into a combined TSF. Doing so further reduces the risk of dusting in the combined TSF1/2.
Surface Water Management	Refined design has less reliance on diversion of surface water run-off from TSF1. Overall the refined design has simplified water management which reduces risk of loss of containment. **See Figure 3 and 4** FS Design The CTD option requires significant drainage to be excavated and managed around the full perimeter of the TSF. The actual location of the required diversion channel/s will depend on the beach slope achieved and the channel will need to be relocated and managed as the TSF beach expands. This will need to be carefully managed to ensure that the channel remains free draining. The unlined channel would also be an additional seepage source. It is also noted that water ponds on the upstream face of the perimeter embankment associated with the drainage path to the decant pond. The embankment design includes a relatively narrow clay zone and no filters – while piping risk is low, it still remains a plausible failure mode for the FS design. Refined Design The refined concept uses perimeter beaching to control where the pond develops and ensures no pond on wall (hence extremely low piping risk). 3 separate decant ponds are reduced to 1 single pond, hence eliminating risks of transferring water between ponds (pipe burst, channel blockage, erosion etc). Developing a well formed beach around the perimeter will require carefully management – but is well proven where mines manage responsibly. At closure a wide channel is excavated to ensure pond does not remain post closure. In the lead up to closure, tailings discharge would adopt elements of CTD to maximise tails capacity and achieve suitable shedding surface with suitable network of drains.
Closure	Closure concepts, slopes and materials have not been altered. Elimination of the standalone Evaporation Pond from the design arrangement reduces the rehabilitation liability associated with removing salt accumulation at closure which may be difficult to achieve in practice.
Pipe leakage / spills	Risks are similar and manageable.

Figure 1 Comparative Disturbed Footprint

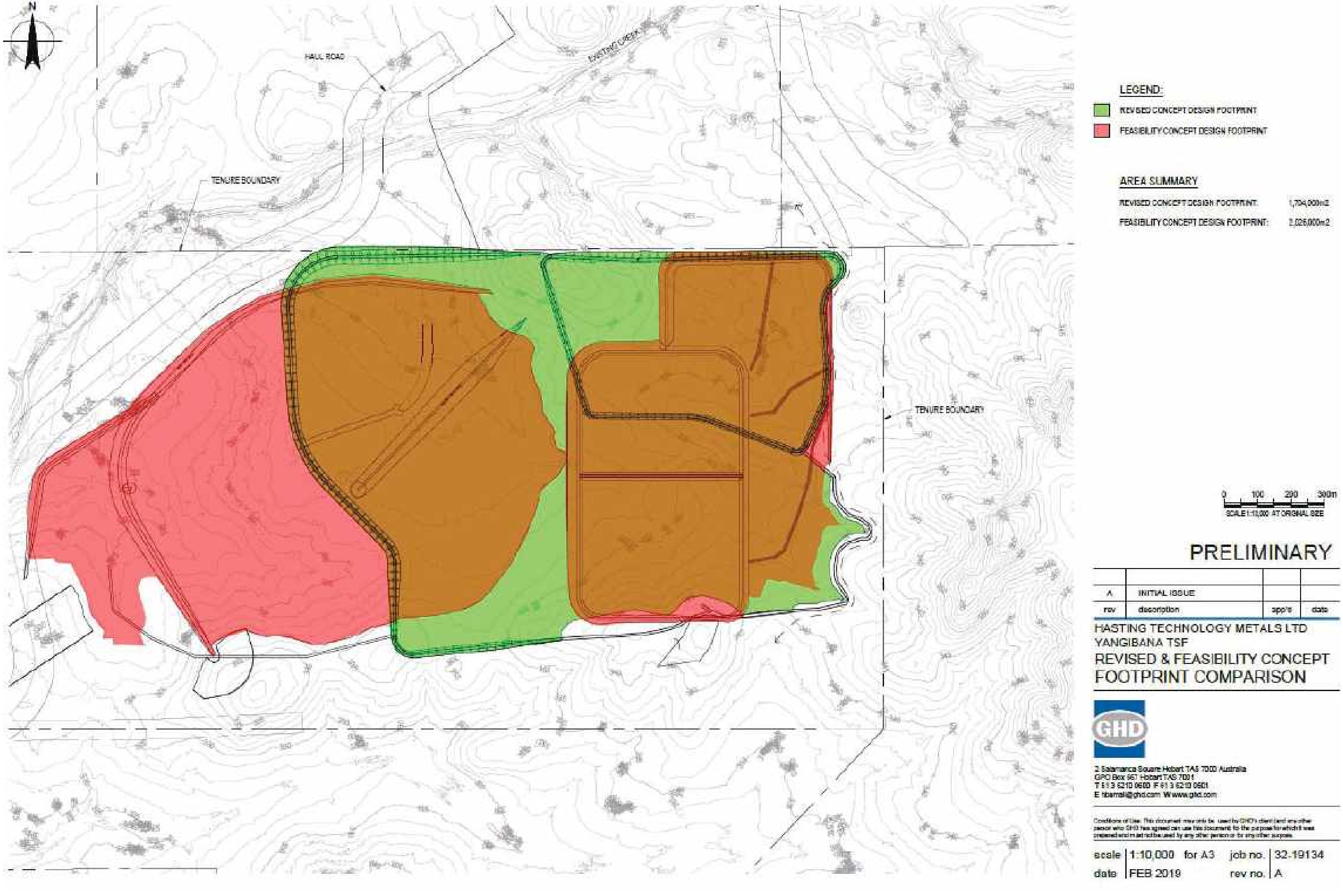


Figure 2 Comparative Embankments

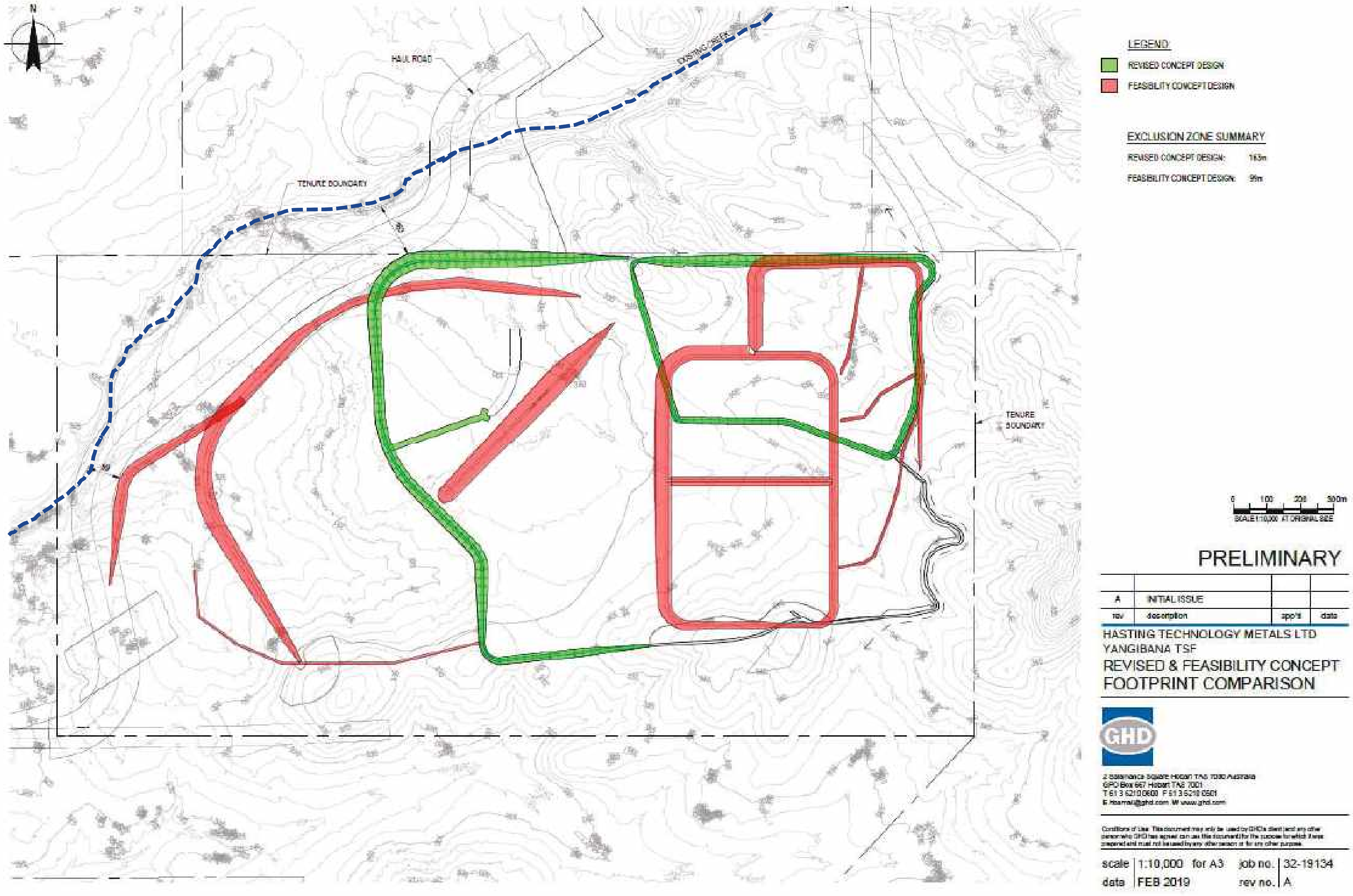


Figure 3 Original Feasibility Study Design – Water Management Requirements

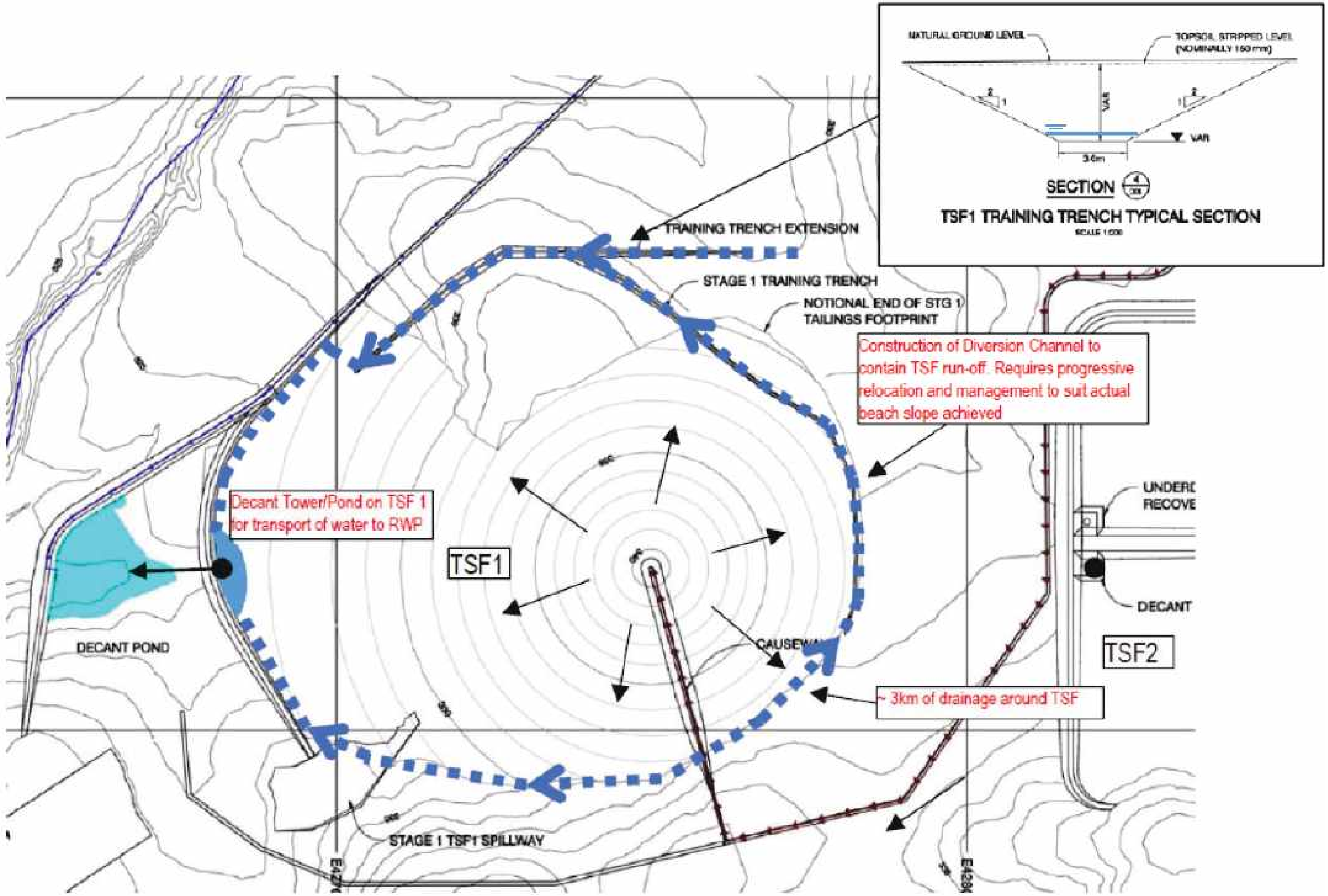
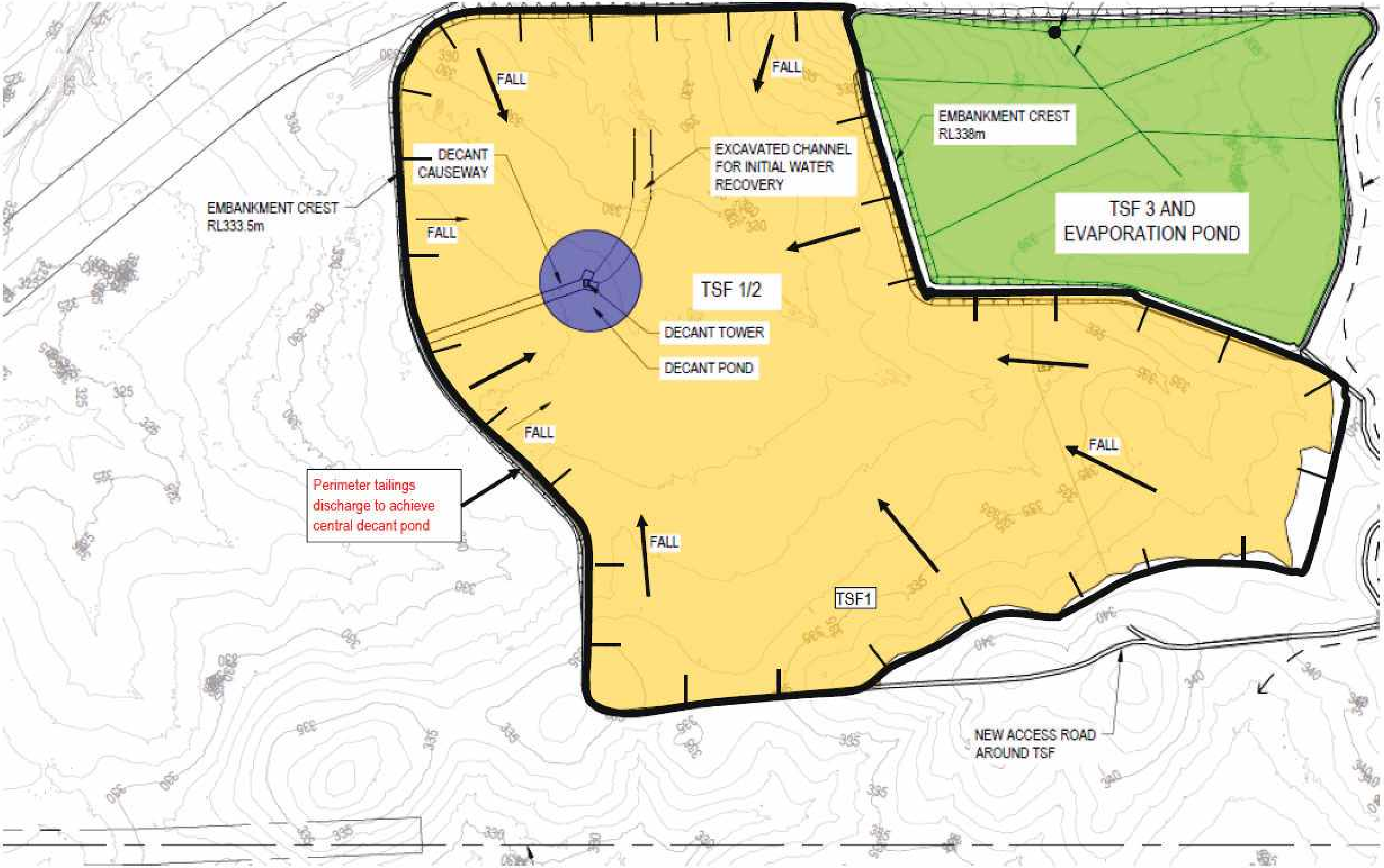


Figure 4 Refined Concept Design, Combined TSF with conventional perimeter discharge to form beaches and control pond location – no diversion channels required to contain TSF run-off



Appendix H
Example Geosynthetic Liner Specification

The Client

TSF xxx

Geosynthetic and Lining Specification

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Appendices

1. Introduction

1.1 General

This Specification contains the requirements for materials and procedures to be implemented for the construction of TSF xxx Lining Works (the Works) at xxx (the site) and must be read in conjunction with the other Contract Documents.

Where the Specification and any other Contract Documents do not agree, the Contractor shall seek clarification from the Manager.

1.2 Definitions

The Definitions described in the Contract Documents apply to this document. The following additional terms used in this Specification shall have the meanings ascribed to them below unless the context otherwise requires:

‘Contract Drawings’ – The construction drawings which form part of the Contract Documents

‘Contract Documents’ – The documents which form the Contract

‘Contractor’ – A company or person with a formal contract to do a specific job – supplying labour and/or materials and providing and overseeing staff as required

‘Contractor’s Independent Testing Firm’ – Independent testing firm(s) engaged by the Contractor to conduct construction quality control (CQC) testing

‘Construction Quality Assurance (CQA) Engineer’ – Suitably qualified professional responsible for administering the CQA requirements for the Works

‘Construction Quality Assurance (CQA) Engineer’s Independent Testing Firm’ – Independent testing firm(s) engaged by the CQA Engineer to conduct construction quality assurance testing

‘Construction Quality Assurance (CQA) Plan’ – Plan forming part of the Contract Documents, describing the construction quality assurance requirements for the Works

‘Field Crew Foreman’ – Foreman for the Geosynthetic Installer’s field crew, as defined by the Contractor

‘Geosynthetic’ – Synthetic material (man-made plastic and fabric) used in geotechnical and construction applications

‘Geosynthetic Installer’ – Firm subcontracted by the Contractor to complete the installation of geosynthetic for the Works

‘Manager’ – The person who is managing the Contract on behalf of the Owner and who supplies directions to the Contractor and to whom the Contractor refers in all matters.

‘MARV’ – Minimum average roll value – calculated as per *GRI White Paper #10, The Dual Roles for Using MARV* (http://www.geosynthetic-institute.org/papers/paper10.pdf)

‘MaxARV’ – Maximum average roll value – calculated as per *GRI White Paper #10, The Dual Roles for Using MARV* (http://www.geosynthetic-institute.org/papers/paper10.pdf)

‘Owner’ – xxx

‘PE’ – Polyethylene

‘Regulatory Authority’ – Authority responsible for licencing the Works

‘Seaming Crew’ – Crew responsible for the seaming activities performed by the Geosynthetic Installer, as defined by the Contractor

‘Seaming Foreman’ – Foreman for the seaming activities performed by the Geosynthetic Installer, as defined by the Contractor

‘Specification’ – This document

‘Work under the Contract' – The work which the Contractor is or may be required to execute under the Contract and includes variations, remedial work, constructional plant and temporary works

‘Works’ – The whole of the work to be executed in accordance with the Contract, including variations provided for by the Contract, which by the Contract is to be handed over to the Owner

‘Works Area’ – As shown on the Contract Drawings.

1.3 Lines of communication

The lines of communication for the Works are illustrated in Figure 1-1. The Manager shall be the main point of liaison between the Contractor and the CQA Engineer, as well as the Contractor and the Owner.

Figure 1-1 Lines of communication

1.4 Materials

The Contractor shall be responsible for the sourcing, delivery, storage, preparation, handling and installation of all materials, except as modified in individual sections of this Specification.

Material and installation specifications are included in the individual sections of this Specification for each material type.

1.5 Sequencing and scheduling

The Contractor shall be responsible for sequencing the installation of all materials, including surveys, testing and field trials.

In general, installation sequencing shall proceed from higher elevations to lower elevations to prevent precipitation runoff from flowing into and/or below installed products.

Individual components shall not be covered with the subsequent component until the underlying component has been accepted by the Manager.

1.6 Submittals

Submittals for each material are included in the individual chapters of this Specification.

The following pre-qualification submittals are required to be submitted by the Contractor at least 10 working days prior to construction for approval by the Manager.

1.6.1 Pre-qualification of the Geosynthetic Installer

Prior to construction, the Contractor shall provide a list documenting completed facilities for which the Geosynthetic Installer has completed the installation of a geosynthetic lining system similar to this Specification. For each facility, the following information shall be provided:

- The name and purpose of the facility, its location, and the date of installation
- The name of the owner, project manager, designer, manufacturer, and fabricator (if any)
- If requested, the name and telephone number of a reference contact at the facility who can discuss the project
- The name and qualifications of the supervisor(s) of the installer’s crew(s)
- The type(s) of seaming, patching, and tacking equipment
- Any available information on the performance of the geosynthetic lining system at the facility.

The Contractor shall also provide:

- Certification indicating an approval or licence from the proposed geosynthetic manufacturers for the Contractor to install the manufacturer’s materials
- Certification that the Geosynthetic Installer’s Field Crew Foreman has a minimum of 200 hectares of actual geosynthetic installation experience and a minimum of 100 hectares of supervisory experience for geosynthetic installation on a minimum of 10 different projects
- Certification that the Geosynthetic Installer’s Seaming Foreman is an International Association of Geosynthetic Installer’s Certified Welding Technician and has a minimum of 100 hectares of actual geosynthetic seaming experience and a minimum of 50 hectares of supervisory experience during the seaming of geosynthetic materials
- Certification that each individual on the Geosynthetic Installer’s Seaming Crew has a minimum of 10 hectares of geosynthetic seaming experience and a minimum of 5 hectares of seaming experience with geosynthetics similar to this Specification.

1.6.2 Pre-qualification of the Contractor’s Independent Testing Firm

Prior to construction, the Contractor shall provide a listing of qualifications for the proposed Contractor’s Independent Testing Firms(s) and its key personnel who shall perform the work described in this Specification. The Contractor’s Independent Testing Firms(s) shall be National Association Testing Authorities (NATA) accredited and proof of accreditation shall be maintained throughout the duration of the Works.

A listing of testing apparatus and testing standards typically performed by the testing firm shall be provided along with a letter stating that the testing firm is independent and has no financial interest in the Contractor, the Geosynthetic Installer or any of the manufacturers/suppliers that are providing materials for the Works.

1.6.3 Works program

The Contractor shall prepare a program for the Works. The program shall encompass all phases of the Works. The Contractor shall submit a draft of the program to the Manager for review and approval at least 10 working days prior to construction. The Contractor shall not undertake any works on the site until approval for such is given by the Manager. The program shall include regular progress meetings with the Manager.

1.6.4 Procurement plan

Prior to construction, the Contractor shall provide a procurement plan which considers each material to be supplied for the Works. For each material, the plan shall consider:

- Material sources and relevant quantities from each source
- Estimated timeframe for pre-qualification testing, provision of results and subsequent approval to deliver to site
- Estimated timeframe for delivery of material on-site
- Estimated timeframe for independent conformance testing, provision of results and subsequent approval for use (where required, refer Section 1.8.1).

The procurement plan shall align with the Works program, including installation timeframes.

1.6.5 Construction quality control plan

The Contractor shall prepare and implement a CQC Plan for the Works, and the plan shall address all quality considerations identified or outlined in this Specification. The CQC plan shall incorporate, as necessary, field testing, field verification, manufacturer's certifications and quality control testing at the manufacturing plant, to demonstrate that all Works comply with this Specification. The CQC plan shall also demonstrate how construction will occur and the methods by which the materials will be supplied, placed and tested to ensure compliance with this Specification.

Works shall not commence until the CQC plan has been approved by the Manager.

The Owner may, at its discretion, audit the Contractor's implementation of the CQC plan. The Contractor shall co-operate with all such auditing.

1.7 Construction quality control testing

All construction quality control (CQC) testing shall be arranged by the Contractor and shall be carried out by the Contractor's Independent Testing Firm. The cost of CQC testing shall be borne by the Contractor. Unless noted otherwise, copies of all test results shall be sent to the Manager as soon as available but in any event within two days of becoming available. The minimum testing frequencies shall be as nominated within this Specification.

At any stage throughout the Works, the Manager may arrange for independent testing and/or surveying to be carried out. If that testing reveals that any works are found to be not compliant with the requirements of this Specification and the Contract Drawings, the Contractor shall undertake rectification of the non-compliant items and conduct re-testing in accordance with this Specification. All costs of undertaking such rectification work and re-testing shall be borne by the Contractor.

1.8 Construction quality assurance

A Construction Quality Assurance (CQA) Plan has been developed in conjunction with this Specification and shall be implemented by the Owner to verify that the Works are undertaken in a manner that meets the requirements of the Contract Documents.

The Owner shall engage an independent organisation (the CQA Engineer), under contract to the Owner, who shall facilitate the requirements of the CQA Plan. This shall include independent CQA monitoring, observation, testing and documentation on behalf of the Owner.

The Contractor shall cooperate fully with the Manager and all representatives of the CQA Engineer during any independent CQA sampling, testing, and certification and shall ensure, at all times, safe access to the Works for the purpose of monitoring, observation, and CQA implementation. This shall include sampling of geosynthetic materials by the Geosynthetic Installer under the supervision of the CQA Engineer.

1.8.1 Independent conformance testing

The CQA Engineer shall arrange for independent conformance testing of the materials used in the Works, in accordance with the CQA Plan, to assure conformance with this Specification. Samples shall be collected at locations designated by the CQA Engineer and all independent conformance sampling shall be witnessed by the CQA Engineer. Where sampling of geosynthetics is necessary, the sampling shall be undertaken by the Geosynthetic Installer from the relevant materials for the independent conformance testing of the material. The Contractor shall make a suitable allowance for this testing within their construction program.

The sample frequency shall be in accordance with Table 1-1. The table also identifies the indicative sample size. The sample sizes shall be confirmed by the CQA Engineer prior to construction. Sampling shall include the first and last roll. The specified frequency assumes all rolls are from a single manufacturing run. If rolls are from different manufacturing runs then the frequency shall be applied to each manufacturing run. The test frequency for all rolls where, in the opinion of the CQA Engineer, the manufacturing run cannot be identified shall be every roll for all test types. Samples shall not be taken from the outer wrap of the roll.

Table 1-1 Independent sample size and frequency schedule

Material	Indicative size	Frequency
PE geomembrane	1 metre by roll width	1 per 5,000 m^2

As a minimum, a period of 6 weeks shall be allowed for from the completion of on-site sampling of all geosynthetic materials on-site to the receipt of independent conformance testing results and subsequent approval/rejection of the materials for use. This shall be confirmed by the CQA Engineer prior to construction.

If a sample records a non-conforming test result, it may be re-tested. If it passes this retest, both results shall be provided in the laboratory report from the relevant independent testing firm. If the retest produces a non-conforming test result, the Contractor shall remove and replace all rolls between the sampled roll and the nearest conforming rolls either side (based on the production order of the rolls). The Contractor may, by testing and verification of these intermediate rolls, reduce the range of rolls to be removed in this way. Such additional testing shall be for the full range of specified tests, not just the test or property which yielded a failure.

In the event of discrepancies between the CQA Engineer's test results and the Contractor's test results, the Contractor shall be responsible for arranging a third independent testing firm to verify the test results.

Any replacement material shall receive the independent conformance testing in accordance with the CQA Plan.

1.9 Work method statements

Prior to the commencement of each type of work, the Contractor shall submit to the Manager work method statements that detail how the work is to be carried out and the plant and equipment proposed.

The Contractor shall submit such work method statements to the Manager at least 5 working days prior to undertaking any work addressed by the work method statement.

The Manager may reject the submitted work method statement if, in the opinion of the Manager, the statement does not comply with the Specification or any other Contract Documents provided to the Contractor prior to or during construction.

Where a work method statement is rejected the Contractor shall revise and resubmit the statement. No work addressed by the work method statement shall be undertaken by the Contractor until the work method statement is approved by the Manager.

Acceptance by the Manager of a proposed work method statement in no way reduces the Contractor's liability to achieve the requirements described in this Specification.

Appendix A contains a schedule of activities for which the Contractor shall produce work method statements.

1.10 Survey requirements

Prior to commencing construction, the Contractor shall establish a survey grid over the Works footprint. The survey grid shall be a maximum 10 m spacing over the Works footprint, as well as any locations at which there is a change or break in grade and set out points identified on the Contract Drawings. The elevation of excavated surfaces and placed materials shall be recorded at these grid locations.

Survey data shall be provided to the Manager in graphical and tabular formats. All survey shall be to Mine Grid and levels shall be based on Australian Height Datum (AHD).

Table 1-2 contains a schedule of survey requirements for the Works.

Table 1-2 Survey requirements

Component	Survey requirements
Prepared subgrade	Upon completion of the prepared subgrade, survey the elevation at all grid locations and breaks in grade.
PE geomembrane	Ongoing survey during installation of the PE geomembrane, survey the location of all panels, seams, patches, destructive tests, defects and repairs.
Seepage collection drain	Following installation of the seepage collection drain, survey the levels and alignments of all pipework at maximum 10 m spacing and at any changes in grade.
Anchor trenches	Upon backfilling of anchor trenches, survey the alignment and level of all anchor trenches.

1.11 Witness and hold points

The following information applies to witness and hold points for the Works:

- A hold point is a defined position in the Works beyond which work shall not proceed without mandatory verification and acceptance by the Manager
- A witness point is a nominated position in the Works where the option of attendance may be exercised by the Manager, after notification of the requirement
- It shall be the Contractor's responsibility to ensure that all obligations are fulfilled in regards to the witness and hold points within the Contract
- The Contractor shall give the Manager a minimum 2 days' notice prior to the required inspection
- Where the witness or hold point relates to the condition of a surface or installed material, the Contractor shall verify that the completed surface has achieved full conformance with the Contract Documents
- Witness or hold points may be released for part of the Works Area only, as defined by the Manager, so that the Works can be completed in a sequenced manner. The Manager's

approval of the completed items is required prior to the release of each witness or hold point.

Table 1-3 contains a list of activities to which witness and hold points apply.

Table 1-3 Witness and hold points

Item	Description	Witness	Hold
1	**General**		
1.1	Provision of required pre-construction submittals, including general work method statements, management plans and details of proposed testing firm(s)		✓
1.2	Provision of work method statements and any associated design documentation (incl. panel layout drawings)		✓
2	**Subgrade preparation**		
2.1	Completion of subgrade preparation works (side slopes, seepage collection trench and anchor trench)		✓
2.2	Survey after completion of subgrade preparation works	✓	
3	**Lining System**		
3.1	Completion of trial seams, approval of work method statement and detail for connection to existing geomembrane liner		✓
3.2	Completion of installation of secondary geomembrane layer		✓
3.3	Survey of completed primary geomembrane layer		✓
3.4	Installation of pipework in seepage collection trench	✓	
3.5	Survey of pipework in seepage collection trench		✓
3.6	Completion of installation of drainage	✓	
3.7	Backfilling of seepage collection trench	✓	
3.8	Survey after backfilling seepage collection trench	✓	
3.9	Completion of the installation of primary geomembrane layer	✓	
3.10	Survey of completed primary geomembrane layer		✓

1.12 Works as Executed Drawings

The Contractor shall provide one (1) set of Works as Executed Drawings, which shall include all corrections and as-constructed information done in a professional draftsman-like manner. All Works as Executed Drawings shall be certified by a Registered Surveyor.

The following Works as Executed Drawings shall be prepared as a minimum:

- Finished installed contours of the subgrade (determined prior to placement of the PE geomembrane).
- Finished installed alignments, levels and grades of the prepared seepage collection trench and pipework.
- Finished installed contours of the completed lining system including the anchor trench.

All Works as Executed Drawings shall include test locations, showing as a minimum the approximate location, identification number, date sampled and type of testing completed.

2. PE geomembrane

2.1 General

This section contains the requirements for (PE) polyethylene geomembrane.

The Manager may reject any PE geomembrane that does not meet or exceed the requirements of this section.

Any PE geomembrane rejected by the Manager shall be removed from the site and replaced at the expense of the Contractor.

2.2 Standards

2.2.1 American Society for Testing and Materials Standards

Relevant American Society for Testing and Material (ASTM) standards are as follows:

- D792 Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
- D1004 Standard Test Method for Initial Tear Resistance of Plastic Film and Sheeting
- D1204 Standard Test Method for Linear Dimensional Changes of Non-rigid Thermoplastic Sheeting or Film at Elevated Temperature
- D1238 Standard Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer
- D1505 Standard Test Method for Density of Plastics by the Density Gradient Technique
- D1603 Standard Test Method for Carbon Black in Olefin Plastics
- D3895 Standard Test Method for Oxidative-Induction Time of Polyolefins by Differential Scanning Colorimetry
- D4218 Standard Test Method for Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique
- D4354 Standard Practice for Sampling of Geosynthetics and Rolled Erosion Control Products(RECPs) for Testing
- D4437 Standard Practice for Determining the Integrity of Field Seams Used in Joining Flexible Polymeric Sheet Geomembranes
- D4439 Standard Terminology for Geosynthetics
- D4833 Standard Test Method for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products
- D4873 Standard Guide for Identification, Storage, and Handling of Geosynthetic Rolls and Samples
- D5199 Standard Test Method for Measuring the Nominal Thickness of Geosynthetics
- D5397 Standard Test Method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load Test
- D5596 Standard Test Method for Microscopic Evaluation of the Dispersion of Carbon Black in Polyolefin Geosynthetics
- D5641 Standard Practice for Geomembrane Seam Evaluation by Vacuum Chamber
- D5721 Standard Practice for Air-Oven Aging of Polyolefin Geomembranes

- D5820 Standard Practice for Pressurized Air Channel Evaluation of Dual Seamed Geomembranes
- D5885 Standard Test Method for Oxidative Induction Time of Polyolefin Geosynthetics by High Pressure Differential Scanning Colorimetry
- D5994 Standard Test Method for Measuring the Core Thickness of Textured Geomembranes
- D6370 Standard Test Method for Rubber-Compositional Analysis by Thermogravimetry (TGA)
- D6392 Standard Test Method for Determining the Integrity of Non-Reinforced Geomembrane Seams Produced Using Thermo-Fusion Methods
- D6395 Standard Practice for Non-destructive testing of Geomembrane Seams using Spark Test
- D6693 Standard Test Method for Determining Tensile Properties of Non-Reinforced Polyethylene and Non-Reinforced Flexible Polypropylene Geomembranes
- D7238 Test Method for Effect of Exposure of Unreinforced Polyolefin Geomembrane Using Fluorescent UV Condensation Apparatus
- D7240 Leak Location using Geomembranes with an Insulating Layer in Intimate Contact with a Conductive Layer via Electrical Capacitance Technique (Conductive Geomembrane Spark Test)
- D7466 Standard Test Method for Measuring Asperity Height of Textured Geomembranes

2.2.2 Geosynthetic Research Institute Standards

Relevant Geosynthetic Research Institute (GRI) standards are as follows:

- GM9 Standard Practice for Cold Weather Seaming of Geomembranes
- GM10 Specification for the Stress Crack Resistance of Geomembrane Sheet
- GM13 Standard Specification for Test Methods, Test Properties, and Testing Frequency for High Density Polyethylene (HDPE) Smooth and Textured Geomembranes
- GM14 Standard Guide for Selecting Variable Intervals for Taking Geomembrane Destructive Seam Samples Using the Method of Attributes
- GM17 Standard Specification for Test Methods, Test Properties, and Testing Frequency for Linear Low Density Polyethylene (LLDPE) Smooth and Textured Geomembranes
- GM19 Standard Specification for Seam Strength and Related Properties of Thermally Bonded Polyolefin Geomembranes
- GM20 Standard Guide for Selecting Variable Intervals for Taking Geomembrane Destructive Seam Samples Using Control Charts
- GM29 Standard Practice for Field Integrity Evaluation of Geomembrane Seams (and Sheet) Using Destructive and/or Non-destructive Testing

2.3 Submittals

2.3.1 Prior to selection of the polyethylene geomembrane manufacturer

The Contractor shall submit the following to the Manager for review and approval prior to selection of a PE geomembrane manufacturer (per manufacturer and product):

- Product manufacturer
- Product name
- Material data sheet showing the material properties of the proposed PE geomembrane
- A list documenting no less than 40 completed facilities totalling a minimum of 200 hectares for which the manufacturer has manufactured PE geomembrane similar to this Specification. For each facility the following information shall be provided:
  - Name and purpose of the facility
  - The location and date of installation
  - The name of the owner, the project manager, designer, fabricator (if any), and the installer
  - If requested, the name and telephone number of the contact at the facility who can discuss the project
  - The PE geomembrane type, thickness, and total square metres of the installation surface.
- Documentation indicating that the polymer supplier has previously produced a minimum of 1,000 tonne of polymer of the same composition as that proposed for use in the manufacture of the PE geomembrane for the Works
- Manufacturer's quality control and assurance procedures.

2.3.2 Prior to delivery of polyethylene geomembrane to site

The Contractor shall submit the following to the Manager for review and approval prior to delivery of PE geomembrane to site (per PE geomembrane product):

- Manufacturer's certificate of compliance outlining conformance with the requirements of this Specification
- Manufacturer's quality control and assurance test results
- Certification that the PE geomembrane supplied for this work was manufactured as consecutive rolls from a single lot or from consecutive lots. If the PE geomembrane is not manufactured from consecutive lots, the resin manufacturer shall provide certification of quality and consistency of the resin characteristics
- Statement on the origin of the resin, its identification (type and lot number), resin supplier's name and production plant, resin brand name and type, and the maximum amount of recycling polymer material added to the raw resin
- Copies of quality control certificates issued by the resin supplier which shall include testing conducted to verify conformance with Table 2-1
- Certifications that the PE geomembrane and extrudate produced for the Works have the same properties and are of the same resin
- Complete description of the manufacturer's shipping, handling and storage procedures
- Manufacturer's installation procedures and requirements
- Work method statement for PE geomembrane delivery, storage, handling and installation. This shall include seaming and jointing, welding, procedures for testing and repairing, proposed handling equipment and restraining methods, and other information that shall promote proper use

2.3.3 Prior to installation of polyethylene geomembrane

The Contractor shall submit the following to the Manager for review and approval prior to installation of the PE geomembrane:

- Delivery, storage and handling log for all PE geomembrane rolls to be used in the Works, including delivery dockets, roll number and identification, delivery inspection checklist, details of storage and handling
- Proposed panel placement drawing, showing the location and reference number of all panels and expected seams, connections and penetrations, panel dimensions and layout, and the order of panel installation
- Survey of the underlying surface in accordance with Section 1.10
- Results of independent material conformance testing as provided by the CQA Engineer.

2.3.4 Following installation of polyethylene geomembrane

The Contractor shall submit the following to the Manager for review and approval following installation of the PE geomembrane:

- Panel placement log, providing details on panel number and associated roll number, date and time placed, condition of receiving surface, weather conditions and precipitation events, QA checks performed, and all other relevant information
- Trial weld log, recording all trial welds and testing undertaken
- Field welding log providing details of all field welding undertaken, including:
  - Weld type
  - Weld ID number
  - ID numbers of panels to be joined
  - Name of welder
  - Details of equipment used
  - Ambient air temperature
  - Geomembrane surface temperature
  - Weld temperature
  - Any problems or issues arising during welding.
- Field sampling and testing results, including non-destructive and destructive tests
- Results of electrical leak location survey as provided by the CQA Engineer (refer Section 2.14)
- Finalised panel placement drawing showing the as-built location of all panels, seams, connections and penetrations
- Defects and repairs log, showing details of all defects identified and repairs completed.

2.4 Manufacturer's quality control

The manufacturer shall follow a quality control program, approved by the Manager, throughout the manufacturing of all PE geomembrane for the Works.

Manufacturer's quality control submissions shall include:

- Date of manufacture
- Lot number, roll number, length and width

- Manufacturer quality control documentation for the particular lot of resin used in the production of the rolls delivered
- Cross-referencing list delineating the corresponding resin used in the production of the rolls delivered
- Quality control program laboratory-certified reports
- The manufacturer's approved quality assurance stamp and the technician's signature.

The frequency of sampling and testing shall be in accordance with Table 2-1.

The Manager may reject any PE geomembrane rolls that have not been sampled and/or tested in accordance with this section.

All PE geomembrane rolls rejected by the Manager shall be removed from the site and replaced at the expense of the Contractor.

2.5 Manufacturer's quality assurance

The manufacturer shall follow a quality assurance program, approved by the Manager, throughout the manufacturing of all PE geomembrane for the Works.

The frequency of sampling and testing shall be in accordance with ASTM D4354.

The Manager may reject any PE geomembrane rolls that have not been sampled and/or tested in accordance with this section.

All PE geomembrane rolls rejected by the Manager shall be removed from the site and replaced at the expense of the Contractor.

2.6 Material

The PE geomembrane shall:

- Be manufactured of new, first-quality resin and shall be compounded and continuously manufactured specifically for the Works. The resin manufacturer shall certify each batch for the acceptance criteria listed in Table 2-1
- Comply with the acceptance criteria specified in Table 2-1
- Not contain more than 1 percent non-volatile pigment or fillers other than carbon black
- Not be factory seamed.

The Contractor shall supply manufacturer's quality control and assurance testing results in accordance with the testing frequencies identified in Table 2-1 showing that the proposed material meets the requirements of this table. Samples taken shall be representative of the whole material source and shall be evenly distributed across the roll lots.

If required by the Manager, a sample of the PE geomembrane shall be provided (per product) and the Manager and/or CQA Engineer may undertake an inspection of the manufacturer's facility. The Contractor shall cooperate fully with the Manager and CQA Engineer to allow this inspection to occur.

PE Geomembrane shall be smooth surfaced. The primary geomembrane as shown on the Contract Drawings shall be 1.5 mm thick, '**conductive**' geomembrane. The geomembrane shall have a coextruded, electrically conductive bottom layer such that a leak location survey may be undertaken in accordance with the procedures outlined in ASTM D 7240.

The secondary geoemembrane as shown on the Contract Drawings shall be 1.5 mm thick '**non-conductive**' geomembrane.

Table 2-1 Acceptance criteria – PE geomembrane

Property	Test method	Acceptance criteria	Minimum testing frequency
Resin (1)			
Density (min)	ASTM D1505 or D792 (method B)	0.932 g/cm^3	per resin lot
Melt index (maximum) (2)	ASTM D1238	1.0 g/10 min	per resin lot
Sheet			
Thickness (min. average)	ASTM D5199	1.5 mm	every roll
Thickness (min.) - Lowest individual of 10 readings	ASTM D5199	1.35 mm	every roll
Density (min.)	ASTM D1505 or D792 (method B)	0.94 g/cm^3	90,000 kg
Tensile properties (min. average) (3) - yield strength - break strength - yield elongation - break elongation	ASTM D6693	22 N/mm 40 N/mm 12% 700%	9,000 kg
2% modulus (max.)	ASTM D5323	-	per each formulation
Tear resistance (min. average)	ASTM D1004	187 N	20,000 kg
Puncture resistance (min. average)	ASTM D4833	480 N	20,000 kg
Stress crack resistance (4)	ASTM D5397	600 hours	per each formulation
Dimensional stability	ASTM D1204	±2%	90,000 kg
Carbon black content (range)	ASTM D4218 (5)	2 to 3%	9,000 kg (HDPE) or 20,000 kg (LLDPE)
Carbon black dispersion (category) (6)	ASTM D5596	Cat 1 or 2 only	20,000 kg
Oxidative induction time (OIT) (min. average) (7) - standard OIT AND - high pressure OIT	 ASTM D3895 ASTM D5885	 100 min 400 min	90,000 kg

[1] Base resin density without carbon black or additives added

[2] Conducted at 190°C with 2.16 kg mass applied

[3] Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of five test specimens each direction:

- HDPE yield elongation is calculated using a gage length of 33 mm
- HDPE break elongation is calculated using a gage length of 50 mm
- LLDPE break elongation is calculated using a gage length of 50 mm at 50 mm/min

[4] The SP-NCTL test is not appropriate for testing geomembranes with textured or irregular rough surfaces. Test should be conducted on smooth edges of textured rolls or on smooth sheets made from the same formulation as being used for the textured sheet materials. The yield stress used to calculate the applied load for the SP-NCTL test should be the manufacturer's mean value via MQC testing

[5] Other methods such as ASTM D1603 (tube furnace) or ASTM D6370 (TGA) are acceptable if an appropriate correlation to ASTM D4218 (muffle furnace) can be established

[6] Carbon black dispersion (only near spherical agglomerates) for 10 different views:

- 10 in categories 1 or 2 only, none in category 3

[7] Samples to be evaluated at 30 and 60 days to compare with the 90 day response

Property	Test method	Acceptance criteria	Minimum testing frequency
Oven aging at 85°C (min. average) - standard OIT AND - high pressure OIT	ASTM D5721 ASTM D3895 ASTM D5885	55% retained at 90 days 80% retained at 90 days	per each formulation
UV resistance (min. average) [8] - high pressure OIT [9]	ASTM D7238 ASTM D5885	50% retained after 1600 hours	per each formulation

2.7 Roll and sample identification

All PE geomembrane rolls and samples shall be identified in accordance with ASTM D4873.

Each roll or panel shall carry a label which identifies, as a minimum:

- Product name, grade and name of manufacturer
- Date of manufacture, batch number
- Material thickness
- Roll number
- Roll length
- Roll weight
- Roll width
- Handling guidelines
- Reference numbers to raw material batch and laboratory certified reports
- The manufacturer's approved quality assurance stamp and the technician's signature.

The Manager may reject any PE geomembrane rolls or samples that have not been identified in accordance with this section.

All PE geomembrane rolls rejected by the Manager shall be removed from the site and replaced at the expense of the Contractor.

2.8 Delivery, storage and handling

The Contractor shall prepare a work method statement for delivery, storage, handling and installation of PE geomembrane, including repair methods (refer Appendix A). The work method statement shall be submitted to the Manager for review and comment prior to delivery of the PE geomembrane to site.

The delivery, storage and handling components of the work method statement shall be developed in accordance with the guidance provided below:

- Delivery, storage and handling of all PE geomembrane rolls and samples shall be undertaken in accordance with the manufacturer's instructions and ASTM D4873 as a minimum

[8] The condition of the test should be 20 hour UV cycle at 75°C followed by 4 hour condensation at 60°C

[9] UV resistance is based on percent retained value regardless of the original high pressure OIT value

- Rolls shall be delivered to site, handled and stored in such a manner that no damage occurs to the rolls
- Roll cores shall be sufficiently strong to ensure that they do not deflect by more than half their diameter during delivery, storage and handling
- Rolls shall be stored in a location away from construction traffic but sufficiently close to the installation area to minimise handling. The storage area shall be level, dry, well-drained and stable, and shall protect the product from precipitation, chemicals, excessive heat, UV radiation, standing water, vandalism and animals
- PE geomembrane roll stacks shall be limited to the height at which installation personnel can safely manoeuvre the handling equipment. The recommended maximum stack height is three rolls
- Rolls shall be handled using a spreader stinger bar. The bar shall be capable of supporting the full weight of the rolls without significant bending. Under no circumstances shall the rolls be dragged, lifted from one end, lifted in the middle of the roll, lifted with the forks of a forklift or pushed to the ground from the delivery vehicle. The Contractor may nominate alternate handling equipment and plant for approval by the Manager as part of their work method statement
- The Contractor shall inspect all PE geomembrane rolls for defects and damage upon delivery.

The Manager may reject any PE geomembrane rolls that have not been delivered, stored or handled in accordance with this section.

All PE geomembrane rolls rejected by the Manager shall be removed from the site and replaced at the expense of the Contractor.

2.9 Preparation of receiving surface

Prior to placement of PE geomembrane, the receiving surface shall exhibit the following characteristics:

- The surface shall be smooth, flat, firm and unyielding to the satisfaction of the Manager
- The surface shall not exhibit visible deformation, rutting, yielding and/or show signs of distress or instability during final proof rolling (if required)
- The surface shall be free of debris, roots, angular material (such as sharp rocks), desiccation cracks, abrupt breaks, indentations, sudden changes in grade, defects and/or imperfections that may result in damage to the overlying materials
- No loose, coarse-grained material shall remain on the surface. If required, the surface shall be raked or graded to remove any material penetrating out of the surface greater than 10 mm
- The surface shall promote drainage and excessive water shall not be allowed to pond on the surface
- The surface shall not be pebbly, tracked, rutted or otherwise disturbed by the equipment deploying overlying materials or other traffic. Pockets, holes, or discontinuities shall be repaired
- All construction stakes, hubs, or other items used for grade control shall be removed and any voids filled. Any unsuitable material shall be over-excavated to a depth of 100 mm and replaced with approved material

- The surface shall be maintained at sufficient moisture content to prevent desiccation during the Works.

The receiving surface shall be surveyed as per the requirements of Section 1.10.

Placement of PE geomembrane shall not proceed until the receiving surface has been inspected and approved by the Manager.

2.10 Installation

2.10.1 General

The Contractor shall prepare a work method statement for delivery, storage, handling and installation of PE geomembrane (refer Appendix A). The work method statement shall be submitted to the Manager for review and comment prior to delivery of the PE geomembrane to site.

The installation component of the work method statement shall be developed in accordance with the guidance provided below.

The Manager may reject any PE geomembrane rolls that have not been installed in accordance with this section.

All PE geomembrane rolls rejected by the Manager shall be removed from the site and replaced at the expense of the Contractor.

2.10.2 Weather conditions

The Contractor shall consider the weather conditions on a daily basis to confirm they are suitable for placement of PE geomembrane.

PE geomembrane shall not be placed or seamed:

- If moisture prevents proper subgrade preparation, panel placement and/or panel seaming
- During precipitation, during hail, during periods of excessive fog, during periods of excessive dust, in standing water, on excessively wet surfaces, in the presence of excess moisture (such as dew and/or ponded water)
- During periods of excessive winds (>30 kph) or when gusting wind conditions interfere with handling operations
- When sheet temperatures are lower than 0° or higher than 65° as measured by a calibrated infrared thermometer or surface thermocouple.

2.10.3 Traffic

Equipment used shall not damage the PE geomembrane by handling, trafficking, leakage of hydrocarbons, or by other means.

No vehicle shall be allowed to travel directly on the PE geomembrane unless approved by the Manager. Prior to approval, the Contractor shall provide the Manager the following information:

- Guidance from the manufacturer on suitable plant for trafficking for the proposed PE geomembrane and confirmation that the Contractor shall only use this plant
- Guidance from the manufacturer on suitable trafficking method for the proposed PE geomembrane and confirmation that the Contractor shall only use this trafficking method
- Certification from the manufacturer that the above trafficking method and plant shall not void the warranty for the proposed PE geomembrane.

2.10.4 Placement

PE geomembrane shall be placed in accordance with the following:

- The PE geomembrane shall be placed and seamed in accordance with this Specification, the Contract Drawings, the approved work method statement and the manufacturer's instructions. Any contradictions shall be clarified with the Manager
- Prior to placement, each roll shall be inspected by the Contractor for damage and/or defects, including tears, abrasion, indentation, cracks, thin spots or any other faults or defects. If damage or defects are identified, the roll shall be inspected by the Manager and approved or rejected
- PE geomembrane shall be protected from damage due to exposure to sunlight, dirt, dust and other hazards
- PE geomembrane shall be placed such that the panels are anchored at the crest of the slope and form a continuous layer down the side walls and slopes and across the base
- The arrangement of the PE geomembrane panels shall be in accordance with the approved panel placement drawing and any changes approved by the Manager
- Installation shall progress from the highest elevations to the lowest
- PE geomembrane rolls shall be placed in an orderly fashion which shall minimise or prevent surface water from flowing below previously installed PE geomembrane
- PE geomembrane shall not be allowed to ‘bridge over’ voids or low areas. The PE geomembrane shall be placed to allow intimate contact with the subgrade or underlying geosynthetic
- PE geomembrane shall be installed without undergoing excessive buckling, wrinkling or tensioning
- PE geomembrane shall not be dragged across an unprepared surface. If the PE geomembrane is dragged across an unprepared surface, it shall be inspected for defects and repaired or rejected if necessary
- Where there is a geosynthetic layer below, the installation of the PE geomembrane shall be undertaken in a manner so as not to damage the underlying layer
- Sandbags or equivalent ballast shall be used as necessary to temporarily hold the PE geomembrane in position and prevent uplift by wind. In case of high winds, continuous loading shall be placed along edges of panels to minimise wind flow under the panels. Sandbag material shall be sufficiently close-knit to prevent soil fines from working through the bags and discharging on the PE geomembrane
- Only those PE geomembrane rolls which can be seamed or permanently anchored on at least two sides on the same day shall be placed on a daily basis. All other sides shall be temporarily anchored
- PE geomembrane installed on slopes shall be fixed in anchor trenches as shown on the Contract Drawings and Section 2.10.5. PE geomembrane panels shall be anchored as soon as possible. The Geosynthetic Installer shall program anchor trenches backfilling when the temperature is coolest to minimise effects of material expansion

- Personnel working on the PE geomembrane shall not smoke, wear damaging shoes, excessively traffic or engage in other activities which may damage the PE geomembrane. PE geomembrane in heavy traffic areas shall be protected by a geosynthetic overlay
- PE geomembrane shall be cut from each roll with an approved hook blade knife with flat zones on each end
- PE geomembrane rolls shall be freely suspended during placement
- The method used to unroll the PE geomembrane shall not cause bridging, excessive wrinkles, scores, scratches and/or crimps
- Folds and wrinkles caused by PE geomembrane panel placement or thermal expansion shall be minimised
- After placement, the PE geomembrane shall be free of excessive buckles, wrinkles, ripples, creases, folds and irregular stressing before the overlying cover material or geosynthetic is placed.

2.10.5 Anchoring of geosynthetics

Anchor trench excavation, backfill, and compaction shall be completed to the line and grades shown on the Contract Drawings. A work method statement shall be prepared for the excavation and backfill of anchor trenches during the Works with consideration to the guidance below.

Anchor trenches shall be prepared with slightly rounded corners where the geosynthetics enter the trench so as to avoid sharp bends in the geosynthetic material. The base of the anchor trench must be a smooth uniform surface that is free of defects and loose material.

The geosynthetic layers shall be placed in the trench as per the Contract Drawings to ensure effective anchorage. Fill material shall be placed in maximum 100 mm loose lifts if compacted with hand-operated compaction equipment, or maximum 200 mm loose lifts if compacted with a self-propelled compactor.

The Contractor shall repair or replace any geosynthetics damaged as a result of placement or compaction of backfill.

2.10.6 Seaming

PE geomembrane shall be seamed in accordance with the following guidance.

General

- The PE geomembrane shall be field seamed into a continuous sheet across the Works by using either dual hot wedge fusion welding or extrusion welding seams
- Dual hot wedge fusion welding shall be the preferred method of welding and shall be used for primary welds between adjacent PE geomembrane panels. Extrusion welding shall only be used for detailed work, repair work, or in areas inaccessible for dual hot wedge fusion welding (where approved by the Manager)
- PE geomembrane placement shall be limited to that which can be seamed in one day
- Trial seams shall be completed each day as per Section 2.11
- All seams shall be ‘shingled’ down-slope to promote runoff (roof tile fashion)
- All field seaming operations shall be supervised by the Seaming Foreman and no field seams shall be made without the Seaming Foreman present
- Prior to welding, the prepared weld surfaces shall be free of dust, dirt, debris, markings, foreign material and any other potential contaminants that would inhibit welding. Where

contamination does occur, the prepared surfaces shall be thoroughly cleaned and the weld completed

- There shall be no free moisture in the weld area during welding. If free moisture is located in the weld area, mitigation measures during seaming shall be employed as approved by the Manager
- The Geosynthetic Installer shall have an independently calibrated handheld temperature measuring device to confirm the temperatures of each and every welding machine prior to the commencement of any test or field welds. All information regarding the results gained from the temperature device shall be recorded for each welding machine
- Any electric generators used in welding shall be placed on a smooth base such that no damage occurs to the underlying PE geomembrane
- Adjacent to anchor trenches, seaming shall extend up the panels a minimum of 300 mm past the crest of the anchor trench.

Weld locations

PE geomembrane panel placement shall take into consideration the site geometry including:

- Field seams shall be orientated parallel to the line of maximum slope
- For batters with a 10% grade or steeper, transverse (cross-slope) seams shall not be permitted
- No cross seams shall be allowed within 1,500 mm of the toe of any slope
- In corners and odd shaped geometric locations, the number and total length of field seams shall be minimised
- Seams shall not be located at low points
- All cross seams shall be offset at least 600 mm from the cross seam of the adjacent panel and be extrusion or wedge welded where they intersect
- All primary welds used to connect panel ends to sheets shall form T-joins (tees). These T-connections shall have a distance of at least 500 mm. The welding seams of the PE geomembrane cannot cross (no cruciform connections).

Dual hot wedge fusion welding

- The dual hot wedge fusion welding shall be conducted using the split head wedge fusion weld method, fusing the upper and lower overlapped PE geomembrane panels
- The welding equipment shall be capable of continuously monitoring and controlling the temperature in the zone of contact where the machine is actually fusing the PE geomembrane so as to ensure that changes to environmental conditions shall not adversely affect the integrity of the weld
- Seams shall have a finished overlap of a minimum of 150 mm for dual hot wedge fusion welding but in any event, sufficient overlap shall be provided to allow peel tests to be performed on the seam
- The dual hot wedge fusion welding shall form two contact fusion areas of a minimum width of 15 mm and a 5 mm minimum wide void between each of the separate parallel weld zones.

Extrusion welding

- The extruder may be a combination sheet pre-heat and extruder type or a combination dynamic mixing assembly and extruder type
- The extrudate shall be manufactured from the same resin type used in the manufacture of the relevant PE geomembrane being welded. All physical properties shall be identical to those possessed by the raw PE geomembrane material. The Geosynthetic Installer shall provide certification from the manufacturer that the relevant PE geomembrane and extrudate produced for the Works have the same properties and are of the same resin for each batch
- During welding, the Geosynthetic Installer shall be responsible for regularly checking, calibrating and recording of:
  - Preheat air flow and temperature at the nozzle
  - Extrudate flow and temperature at the barrel outlet
- Seams shall have a finished overlap of a minimum of 75 mm for extrusion welding but in any event, sufficient overlap shall be provided to allow peel tests to be performed on the seam
- The minimum width of the surface extruded bead shall be 30 mm
- Prior to welding, oxidation by-products shall be removed from the weld area by grinding or buffing. Grind marks shall not be deeper than 10% of the PE geomembrane thickness. Seam grinding shall be been completed less than one hour before seam welding. The end of welds more than five minutes old shall be ground to expose new material before restarting a weld
- Prior to welding, the extruder shall be purged until all the heat-degraded extrudate is removed
- Welding shall be undertaken in one direction only
- A smooth insulating plate or fabric shall be placed beneath the hot welding apparatus after use.

Pipe boots

- Pipe boots may be constructed in the factory or in the field in accordance with the detail shown on the Contract Drawings from relevant PE geomembrane conforming to this Specification.

2.11 Weld trial

The Contractor shall trial the proposed connection detail of the existing PE Geomembrane to the new PE Geomembrane as shown on the Contract Drawings. The weld trial shall be undertaken at a minimum of two locations (one in each pond cell) as nominated by the Manager.

The weld trial shall be verified in accordance with the general requirements outlined in Section 2.12 and Section 2.13 of this Specification. A minimum of three test locations shall be sampled at each trial location.

Approval of the weld trial shall be on the basis of demonstrated conformance testing as required by this Specification. If the requirements of this Specification and associated conformance testing are not met, the Contractor shall repeat the weld trials in locations nominated by the Manger, using an alternative methodology and/or weld detail if required. The weld trial shall be re-tested and repeated until the requirements of this Specification are met. The weld trial shall constitute a Hold Point.

2.12 Trial seams

The trial seams should be performed on the existing PE geomembrane prior to undertaking the trial seams connecting the new and existing PE geomembrane. The effectiveness of the trial seams shall be compared to the results of trials on the existing PE geomembrane to assess the effectiveness of the weld trial.

Trial seams shall be performed on fragment pieces of PE geomembrane to verify that seaming conditions are satisfactory and to supply test specimens for the CQA program.

Trial seams shall be conducted at the beginning of each seaming period and at least once each four hours for each seaming apparatus used that day. Trial seams shall be repeated if any welding stoppage exceeds one hour and if weather conditions change. Trial seams shall be made under the identical conditions as the actual seams.

Each seamer shall make at least one trial seam each day for each seam method for each seaming equipment apparatus to be used that day.

Trial seams shall be a minimum of 1,350 mm by 300 mm with seam centred.

The trial seam sample shall be cut into three subsamples (450 mm by 300 mm with seam centred).

The two subsamples from each end shall immediately be tested onsite for peel and shear strength in accordance with GM19.

If either specimen does not meet the acceptance criteria, the seamer and seaming apparatus and/or methods shall not be accepted and shall not be used for seaming until the deficiencies are corrected and two consecutive trial seams are successful.

The central portion of the trial seam sample shall be labelled and provided to the CQA Engineer for destructive testing at the CQA Engineer’s Independent Testing Firm. A minimum one trial seam sample per day shall be subjected to destructive testing. The Manager may reduce the frequency of trial seam destructive testing at the CQA Engineer’s Independent Testing Firm, in consultation with the CQA Engineer, if the field tensiometer appears adequate for assuring trial seam quality.

If a trial seam sample records a non-conforming result for a test conducted at the CQA Engineer’s Independent Testing Firm, a destructive test seam sample shall be taken by the Contractor from the seams completed by the seamer during the shift related to the considered trial seam. These samples shall be forwarded to the CQA Engineer’s Independent Testing Firm by the Contractor and if they recording non-conforming test results, the length of seam represented by the test sample shall be rejected.

The conditions of this section are considered as met for a given seam if a destructive seam test sample has already been taken from the considered seam(s).

2.13 Field seam sampling and testing

2.13.1 General

Testing parameters, requirements and anticipated schedules shall be continuously reviewed by the Contractor to ensure that adequate personnel and proper equipment shall be available.

Field seam sampling and testing shall be performed after seaming to verify that the mechanical characteristics of the seams do not compromise the PE geomembrane integrity.

Test results shall be provided to the Manager in accordance with Section 1.7.

2.13.2 Destructive seam testing

Destructive seam samples shall be taken and tested in accordance with Table 2-2.

Repair patches shall be extrusion welded over the areas where destructive seam samples have been taken and shall be subjected to non-destructive testing.

The location of each destructive seam sample shall be up to the discretion of the Manager and CQA Engineer and designated on a copy of the panel placement drawing, along with the date and time of sampling and the sample number.

Destructive test samples shall be a minimum of 1350 mm by 300 mm with seam centred.

The destructive seam sample shall be cut into 3 subsamples (450 mm by 300 mm with seam centred).

The two subsamples from each end shall be taken and tested on-site for peel and shear strength.

If both on-site subsamples meet the acceptance criteria of Table 2-2, the central portion of the test sample shall be labelled and provided to the CQA Engineer for destructive testing at the CQA Engineer's Independent Testing Firm.

If either on-site or off-site test results do not meet the acceptance criteria listed in Table 2-2, the length of seam represented by the test sample shall be rejected.

Table 2-2 Destructive seam testing requirements

Test description	Test method	Minimum test frequency (10)	Acceptance criteria (11)
Peel strength (12)	ASTM D6392	1 test per 150 m (13) (or part thereof)	As per GM19
Shear strength	ASTM D6392	1 test per 150 m (14) (or part thereof)	As per GM19

2.13.3 Non-destructive seam testing

All seams shall be non-destructively tested over the entire length of seam by at least one of the methods in Table 2-3. The tests shall be undertaken no earlier than one hour after welding. In addition to the above tests, the welds shall be visually inspected to assess the quality of the workmanship and the appearance of the welded seam.

Table 2-3 Non-destructive seam testing requirements

Test description	Test method	Minimum test frequency	Acceptance criteria
Vacuum box	ASTM D5641		No imperfections

[10] A minimum of one series of destructive tests shall be performed each day that seaming is performed

[11] All destructive test results shall be based on Film-Tear Bond (FTB) criteria. All samples which produce seam failures shall be considered unacceptable

[12] Peel strength testing shall be performed on both Weld A and Weld B

[13] When ambient air temperatures during seaming operations are less than 10°C, testing frequency shall be increased to one test per 75 linear meters

[14] When ambient air temperatures during seaming operations are less than 10°C, testing frequency shall be increased to one test per 75 linear meters

Test description	Test method	Minimum test frequency	Acceptance criteria
Air pressure [15]	ASTM D5820	All seams shall be tested by at least one of these three test methods as appropriate	Refer Table 2-4
Spark test	ASTM D6365		No spark

Table 2-4 Air pressure test schedule

Geomembrane thickness	Minimum pressure	Maximum pressure	Maximum pressure differential [16]
1.5 mm	190 kPa	250 kPa	20 kPa

2.13.4 Pipe boot seam testing

All pipe boot seams shall be spark tested with acceptable pipe boots showing no spark.

Alternative testing methods may be allowed at the discretion of the Manager.

2.13.5 Non-conforming test results

If any test specimen does not meet the acceptance criteria listed, the test series shall be considered unacceptable and all material or length of seam represented by the test series shall be rejected. The Geosynthetic Installer may, at no additional compensation, take additional samples for quality control testing in an attempt to minimise the amount of material represented by the non-conforming test result.

In the event of discrepancies between the CQA Engineer's test results and the Contractor's test results, the Contractor shall be responsible for arranging a third independent testing firm to verify test results.

An acceptable length of seam shall be defined as a length of seam which lies between conforming destructive test locations and has passed non-destructive seam testing.

2.13.6 Field testing summary

The Geosynthetic Installer shall prepare a field testing summary for all installed PE geomembrane. For each PE geomembrane layer, a separate copy of the panel placement drawing shall be utilised for this summary and shall indicate the PE geomembrane layer represented. On each sheet, the following information shall be recorded:

- The location, date, sample number and test result (conforming/non-conforming) of each destructive test series
- The location, identification number and date of each non-destructive air pressure seam test including the length of the tested seam and the result of the test (conforming/non-conforming)
- The location, date and lengths of non-destructive vacuum box testing performed on a daily basis and the result of the tests (conforming/non-conforming)
- The location, identification number and date of each non-destructive spark test including the length of the tested seam and the result of the test (conforming/non-conforming).

[15] All hypodermic needle punctures shall be repaired as per the requirements of this Specification

[16] Observe and record the pressure 5 min after the initial reading. If the loss of pressure exceeds that shown, or if the pressure does not stabilize, the faulty area should be located and repaired

2.14 Electrical leak location survey

2.14.1 General

Following the installation of each PE geomembrane layer, the Leak Location Contractor engaged by the Manager shall conduct an electrical leak location survey to detect leaks in the PE geomembrane.

2.14.2 Preparation and support

The Contractor shall responsible for preparing the survey area for the leak location survey. The Contractor shall be responsible for completing installation work around the edge of each PE geomembrane layer that provides electrical isolation of the PE geomembrane for the electrical leak location surveys. The Manager may provide further details on this procedure if requested.

The Contractor shall ensure the PE geomembrane surface is clean and dry prior to the survey.

2.14.3 Repairs

The Geosynthetic Installer shall be responsible for repairing any leaks found. Repairs shall be undertaken in accordance with Section 2.15.

After the leak is repaired, the Leak Location Contractor shall retest the area to ensure the leak was repaired and that there are no other leaks in the vicinity of the repair.

2.15 Defects and repairs

The Contractor and shall be responsible for inspecting the placed PE geomembrane to identify any damage or faults in the material. The Manager and/or CQA Engineer may also undertake inspections of the placed PE geomembrane to identify any damage or faults in the material. Any areas of PE geomembrane damaged during installation shall be repaired by the Contractor. All repairs shall be verified by the Manager.

The Contractor shall prepare a work method statement for delivery, storage, handling and installation of PE geomembrane (refer Appendix A). The work method statement shall be submitted to the Manager for review and comment prior to delivery of the geomembrane to site.

The installation component of the work method statement shall include work methods for defects and repairs, developed in accordance with the guidance provided below:

- All repairs shall be undertaken in accordance shall be undertaken in accordance with this Specification, the approved work method statement and the manufacturer's instructions. Any contradictions shall be clarified with the Client’s Representative. All repairs shall be verified by the Client’s Representative
- Patches and cap strips shall have rounded edges (minimum radius of 75 mm), shall be made of the same geomembrane and shall extend a minimum of 150 mm beyond the edge of defects. All patches shall be of the same compound and thickness as the PE geomembrane being patched over. Patches shall be seamed using extrusion (fusion) welding
- Punctures, pin holes, blisters, small tears and localised imperfections shall be repaired using a patch
- Large tears and lengths of seam shall be repaired using a cap strip. No reseaming over existing seams shall be permitted
- Tears which lie on slopes greater than 5% or which lie in areas of stress and have sharp ends shall have all sharp ends rounded prior to repair

- The PE geomembrane below large patches and cap strips shall be cut as necessary to prevent moisture or gas collection between sheets
- Excessive wrinkles which exist at the end of seaming operations and which may become creased during backfilling shall be cut and reseamed. Excessive wrinkles shall be defined as a wrinkle which at the time of covering and in the opinion of the Manager, meets any of the following criteria:

  – Is nominally >200 mm in height

  – May fold during backfilling

  – May adversely impede the flow along the surface of the geomembrane
- ‘Fishmouths’ or wrinkles at the seam overlaps shall be cut along the ridge of the wrinkle in order to achieve a flat overlap. The cut ‘fishmouths’ or wrinkles shall be seamed and any portion where the overlap is inadequate shall then be patched with an oval or round patch of the same geomembrane extending a minimum of 150 mm beyond the cut in all directions. All corners of the patch shall be rounded with a 25 mm minimum radius
- All repair seams shall be made in accordance with the requirements of Section 2.10.6
- Each repair shall be required to pass non-destructive tests (refer Section 2.13.3). Large cap strips may require destructive testing (refer Section 2.13.2), as directed by the Manager.

The Contractor shall submit to the Manager for review a log containing details of any defects identified and repairs carried out.

2.16 Acceptance

The Contractor shall retain all ownership and responsibility for all PE geomembrane until final acceptance of all work under this Contract by the Owner.

PE geomembrane shall be accepted by the Owner when all of the following conditions are met:

- Required submittals are provided by the Contractor to the Manager and approved
- Adequacy of all field seams, penetrations and repairs is verified by the Manager
- The electrical leak location survey has been completed and all required repairs have been completed by the Contractor
- Details of all defects identified and repairs performed have been provided by the Contractor to the Manager and approved
- The CQA Engineer has provided the Manager with a recommendation that the conditions of final acceptance have been met
- The Manager has inspected and approved the finished surface/s.

Appendices

Appendix A – Schedule of work method statements

Work Method Statements (non-exhaustive list)
Connection to existing liner
Construction of seepage collection trench
Excavation and backfill of anchor trenches
Geotextile installation and testing
Polyethylene geomembrane installation and testing

Appendix B – Example submittal forms

Pre-selection submittal form – geosynthetics

Submission data	
Project name and location:	
Submittal number:	
Material designation (as per the Specification):	
Reference section of Specification:	
Product manufacturer:	
Product name:	
Proposed placement location:	
Estimated quantity:	
Material sample provided:	☐ Yes ☐ No (provide reason below) ☐ N/A (provide reason below)
Additional comments (including other information provided as required):	

Attachments	
Material data sheet:	☐ Yes ☐ No (provide reason below) ☐ N/A (provide reason below)
Manufacturer's quality control and assurance procedures:	☐ Yes ☐ No (provide reason below) ☐ N/A (provide reason below)
Additional comments (including other information provided as required):	
Submitted by: (include title and signature)	Date:

Delivery submittal form – geosynthetics

Submission data	
Project name and location:	
Submittal number:	
Material designation (as per the Specification):	
Reference section of Specification:	
Product manufacturer:	
Product name:	
Proposed placement location:	
Estimated quantity:	
Material sample provided:	☐ Yes ☐ No (provide reason below) ☐ N/A (provide reason below)
Additional comments (including other information provided as required):	

Attachments	
Manufacturer’s certificate of compliance:	☐ Yes ☐ No (provide reason below) ☐ N/A (provide reason below)
Manufacturer’s quality control and assurance test results/reports:	☐ Yes ☐ No (provide reason below) ☐ N/A (provide reason below)
Manufacturer’s shipping, handling and storage procedures:	☐ Yes ☐ No (provide reason below) ☐ N/A (provide reason below)
Manufacturer’s installation procedures and requirements:	☐ Yes ☐ No (provide reason below) ☐ N/A (provide reason below)
Work method statement for material delivery, storage, handling and installation:	☐ Yes ☐ No (provide reason below) ☐ N/A (provide reason below)
Additional comments (including other information provided as required):	
Submitted by: (include title and signature)	Date:

Installation submittal form – geosynthetics

Submission data	
Project name and location:	
Submittal number:	
Material designation (as per the Specification):	
Reference section of Specification:	
Product manufacturer:	
Product name:	
Proposed placement location:	
Estimated quantity:	
Material sample provided:	☐ Yes ☐ No (provide reason below) ☐ N/A (provide reason below)
Material inspected by CQA Engineer:	☐ Yes ☐ No (provide reason below) ☐ N/A (provide reason below)
Additional comments (including other information provided as required):	

Attachments	
Delivery, storage and handling log (including roll numbers):	☐ Yes ☐ No (provide reason below) ☐ N/A (provide reason below)
Proposed panel placement drawing:	☐ Yes ☐ No (provide reason below) ☐ N/A (provide reason below)
Survey of underlying surface:	☐ Yes ☐ No (provide reason below) ☐ N/A (provide reason below)
Independent conformance test results/reports (provided by CQA Engineer)	☐ Yes ☐ No (provide reason below) ☐ N/A (provide reason below)
Additional comments (including other information provided as required):	

Submitted by: (include title and signature)	Date:

Appendix I – Ammonia Gas Modelling Reports

Memorandum

15 April 2019

To	Darren Tull (Hastings Rare Earth Minerals)		
Copy to	[redacted]		
From		Tel	[redacted]
Subject	Yangibana TSF Ammonia Evolution Modelling	Job no.	321913401

1 Appreciation of Issue

It is understood that “Hastings Technology Metals Ltd”, henceforth named “Hastings”, is enquiring about the magnitude of ammonia gas evolving from a Yangibana Tailings Storage Facility (TSF). The Hydromet TSF, under a worst case scenario, receives a stream at 76 t/h containing approximately 0.04 g/L of ammonium bicarbonate and 6.28 g/L of ammonium hydroxide solution. The quantity of ammonia evolution from the Hydromet TSF will be compared to that released from the plant into the TSF. This information will help to inform Hastings of potential health and safety risks to workers resulting from ammonia evolution, as well as the potential environmental implications as a result of the release of ammonia.

2 Methodology

To model the ammonia off-gas evolution from the Hydromet TSF, the software packages OLI Stream Analyzer and AqMB Designer were utilised. Both employ speciation chemistry modelling for the equilibrium analysis of complex aqueous systems, such as a multi-component TSF. AqMB Designer is more process design oriented (e.g. sizing of gas stripping equipment and other industrial water treatment units) whilst OLI Stream Analyzer is more chemistry oriented (i.e. it has a very sophisticated equation of state model however it cannot design or size process equipment). The preliminary AqMB results (i.e. modelling / sizing of a gas stripper – not reported here) corroborated with OLI Stream Analyzer results (i.e. a simplified representation of a TSF). The results presented cover the OLI Stream Analyzer modelling of the TSF system.

The composition data supplied by Hastings (representing a worst case scenario) is as follows.

Component	Concentration (g/L)
H_2O (l)	975.03
$CaSO_4$ (aq)	1.98
K_2SO_4 (aq)	0.22
$MgCl_2$ (aq)	0.23
$MnSO_4$ (aq)	1.06
Na_2SiO_3 (aq)	0.03
Na_2SO_4 (aq)	8.39
NaCl (aq)	0.41
NH_4HCO_3 (aq)	0.04
$C_{17}H_{35}CO_2Na$ (o)	1.38
Mg	0.06
NH_4OH (aq)	6.28

As the OLI Studio database did not include the surfactant, "$C_{17}H_{35}CO_2Na$ (o)", the inter-species interaction of the component was modelled via $NaC_2H_5O_2$ and $C_{17}H_{36}$. The former simulated the carboxy-sodium functional group, and the latter simulated the surfactant carbon chain.

In addition, elemental Mg was combined with $MgCl_2$ to simulate a more likely oxidation state in the pond. The resulting addenda to the above information is as follows.

Component	Concentration (g/L)
$NaC_2H_5O_2$	0.37
$C_{17}H_{36}$	1.08
$MgCl_2$	0.47

In order to model an approximate range of evolution conditions for ammonia off-gas, the temperature of the TSF was assumed to range from a low of 25°C to a high of 35°C (a typical range for TSFs at similar locations around Australia). The impacts of 'fresh' tailings entering the pond at ~52°C was ignored, as the system was assumed to be at equilibrium with the ambient air. Evaporation and rainfall has also been ignored (although it is expected that net evaporation will be positive).

Accordingly, the composition of air at both 25°C and 35°C was determined at 100% relative humidity and 1 atm of pressure. Within OLI Studio, the TSF and the surrounding air are modelled as separate streams that are then "mixed". In order to model the impact of different ammonia partial pressures in the atmosphere surrounding the Hydromet TSF, the air "stream" was set to 10 and 20 times the volume of the incoming tailings respectively. This

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also captures some of the variability in ammonia evolution resulting from different atmospheric conditions, such as increased mixing with air due to wind.

The table below summarises all investigated scenarios under varying conditions.

Air:Liquid Ratio	Solids Formation?	pH	Mix Temp (°C)
10	Yes	7.0	25
10	Yes	7.0	35
10	Yes	13.0	25
10	No	10.3	25
10	Yes	10.3	25
10	Yes	9.99	35
20	Yes	7.0	25
20	Yes	7.0	35
20	Yes	13.0	25
20	No	10.3	25
20	Yes	10.3	25
20	Yes	9.99	35

These scenarios cover the impacts of:

- Rough variation of partial pressure of ammonia in the atmosphere above the TSF (following ammonia off-gassing) via modification of the air to liquid ratio;
- Solids precipitation and interspecies interactions within solution;
- pH of the TSF on ammonia off-gas evolution;
- Variation in ambient air temperature.

With regards to solids formation, it was assumed that the precipitation of minerals such as dolomite, quartz, and chrysotile will not occur due to the timescales required for formation. As OLI Stream Analyzer assumes an equilibrium state and is not a dynamic model, minerals such as these were excluded from the model if they were predicted.

Note that reaction kinetics were ignored as this will not affect the magnitude of the ammonia off-gassing rate while the Hydromet TSF consistently receives inflow.

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3 Results

The results of the scenarios discussed above are as follows based on a ~76 t/h pond inflow worst case composition:

Pre-TSF Storage Scenarios				Resulting Mass of TSF Feed N(-3)* Lost to Atmosphere	
Air:Liquid Ratio	Solids Formation?	pH	Mix Temp (°C)	(% Mass of TSF Feed)	(kg/day as NH3)
10	Yes	7.0	25	0.6 %	33
10	Yes	7.0	35	1.0 %	56
10	Yes	13.0	25	88 %	5,000
10	No	10.3	25	68 %	3,855
10	Yes	10.3	25	70 %	4,018
10	Yes	9.99	35	74 %	4,203
20	Yes	7.0	25	0.7 %	39
20	Yes	7.0	35	1.2 %	67
20	Yes	13.0	25	93 %	5,297
20	No	10.3	25	73 %	4,167
20	Yes	10.3	25	77 %	4,424
20	Yes	9.99	35	79 %	4,503

*Note that this value is the total of ammonia and ammonium, N_2 from air is not included.

It is evident that at elevated pHs the predominant form of ammonia/ammonium (i.e. N(-3) oxidation state of nitrogen) is dissolved ammonia gas (rather than the ammonium ion) which has a propensity to off-gas due to low concentrations of ammonia in the atmosphere. Generally, over 98 % by mass of ammonia evolves as off-gas with the small remainder dissolved in the tailings pond. Therefore to reduce ammonia evolution, conditions within the TSF must favour ammonium formation.

It is also evident that higher temperatures result in greater off-gas production. As the ‘fresh’ tailings are at ~52 °C there is the potential for greater additional ammonia evolution than these results suggest.

When the tailings are neutralised, ~1% of the combined ammonia/ammonium sent to the Hydromet TSF by mass, escapes as ammonia off-gas. However, this would require approximately 16.4 t/d of sulphuric acid based on an influent pH of ~10, an inflow of ~78 m^3/h (at 76 t/h), and an influent composition as described previously. There would also need to be a consideration of the increased potential for algal blooms as a result of the neutral pH in the pond, if a carbon and phosphorous source inadvertently enters the TSF via run-off or leaf litter.

At a pH of ~10 and 13, the combined ammonia/ammonium that escapes as ammonia off-gas rises to greater than 67 and 87 %, by mass, respectively. It is evident that a higher pH results in greater ammonia evolution. For the Hydromet TSF, a pH of 13 would result in approximately 3,900-5,300 kg/day of ammonia being released as off-gas, based off a ~76 t/h of inflow to the pond.

The impact of this ammonia gas release on the environment and health and safety of nearby workers is unknown; would require further modelling of air quality and risk.

4 Literature Review

The evolution of ammonia off-gas from TSFs at an elevated pH is supported by literature. For wastewater containing high levels of ammonia, the adjustment of the stream to a high pH (greater than 10.5) is recommended as a means for ammonia removal. A gas stripping tower is often used for removal, as are ponds (more infrequently) where wind/waves aid removal by increasing contact at the gas-liquid interface (Boyd & Tucker, 1998; Jermakka, et al., 2015).

This can be explained by the equilibrium reaction of ammonia and water, as follows:

$$H_2O + NH_3 \rightleftharpoons OH^- + NH_4^+$$

It is evident that a higher concentration of hydroxide ions will shift the equilibrium towards ammonia formation, rather than ammonium. As ammonia gas readily evolves from water if unable to disassociate, a higher pH will result in greater quantities of off-gas than otherwise.

Figure 1 provides an illustration of this relationship under ideal conditions (i.e. for a simple ammonia/ammonium mixture).

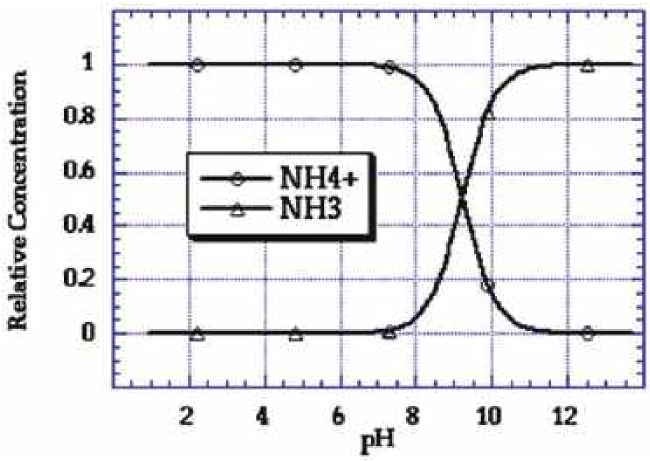

Figure 1: Ammonia/Ammonium Concentration vs pH **(Richard, 1996)**.

5 Conclusion

Speciation chemistry modelling demonstrated that ammonia off-gas evolution increases with an increase in pH. As the Hydromet TSF is likely to have a pH of 10 or greater, it can be expected that greater than two thirds of the ammonia/ammonium incoming to the pond will escape to the atmosphere as ammonia off-gas in the range of 3,900-5,300 kg/day (based on the worst case scenario).

Memorandum

The implications of this from an environmental, health and safety standpoint require further air quality modelling to quantify potential risks.

Kind Regards,

Matthew Brannock
Technical Director – Water and Brine

References

Boyd, C. E., & Tucker, C. S. (1998). *Pond Aquaculture Water Quality Management.* New York: Springer Science + Business Media.

Jermakka, J., Wendling, L., Sohlberg, E., Heinonen, H., Merta, E., Laine-Ylijoki, J., . . . Mroueh, U.-M. (2015). *Nitrogen compounds at mines and quarries: Sources, behaviour and removal from mine and quarry waters-Literature study.* Tekniikantie: VTT Technical Research Centre of Finland Ltd.

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Lara Jefferson
Environmental Manager
Hastings Technology Metals Limited
Level 8 Westralia Plaza
17 St Georges Terrace
Perth WA 6000

6 May 2019

Reference: 0504573

Dear Lara Jefferson

Subject: Screening level Air Quality assessment of Ammonia emissions from the Hydromet TSF.

Hastings Technology Metals Ltd engaged ERM to undertake a screening level air quality modelling assessment of ammonia emissions from its Tailings Storage Facility (TSF) at the Yangibana Rare Earths Project operations. The modelling exercise is built on the previous work undertaken by ERM (Pacific Environment, 2017 and ERM, 2018).

The model assesses the emission rate for ammonia under a worst-case scenario, presenting a level of conservatism in the modelled results. Ground level concentrations were evaluated at a number of onsite receptor locations (42 onsite receptors considering plant locations, the creek and internal roads around the Hydromet TSF) and three offsite sensitive receptors considering the accommodation camp and two homesteads. Concentrations were predicted for 1-hour, 8-hour, 24-hour, 3-minute and 15-minute averages and compared against relevant ambient and occupational health and safety (OHS) air quality criteria. The following observations were made:

- No exceedances of air quality criteria were predicted at the identified offsite sensitive receptors.
- One exceedance (25.75 mg/m^3) of the 15-min OHS criteria was predicted at an onsite receptor (TSF receptor 1) located within 250 m from the centre of the source (Figure 4-1) This exceedance occurred under worst-case conditions. The next worst case scenario predicted a concentration of 12.89 mg/m^3 at this same receptor. This concentration is well within the criteria (50% of the criteria).

In summary, the modelling results indicate that the maximum concentration is of low likelihood to occur and dependent on concurrence of worst case emission rate and worst case dispersion conditions (i.e., prevalence of calm conditions, transition from stable to unstable meteorological conditions, and winds blowing towards this receptor).

Yours sincerely,
pp.

Lavanya Gowrisanker
Senior Consultant

1. BACKGROUND

Hastings Technology Metals Limited ('Hastings') is currently developing the Yangibana Rare Earths Project ('Project'), which is located 270 km (line of sight) east-northeast of Carnarvon on Gifford Creek Station in the Gascoyne region of Western Australia.

This air quality assessment took into consideration the 2017 (Pacific Environment, 2017) assessment, which was submitted as part of the Environmental Approvals process. Additional modelling was undertaken (ERM, 2018) to determine the stack heights of point sources within the processing plant operations.

Hastings has now engaged ERM to undertake as screening level assessment to further understand the impact of ammonia emissions from the Hydromet TSF. The screening level assessment focuses on both ambient and occupational health and safety (OHS) levels of ammonia in the surrounding environment.

2. ASSESSMENT CRITERIA

Modelled concentrations are compared to the assessment criteria to provide an objective evaluation of the impact. In the absence of criteria specific to WA, criteria adopted by other States and Territories have been referenced. For assessment criteria specific to OHS, reference is made to Safe Work Australia's Exposure Standards. A summary of the assessment criteria adopted for this study is presented below

Table 2-1: Ambient and OHS assessment criteria for NH_3

	Averaging Period	Value	Unit	Value Qualifier	Source
Ambient air	24-hour[a]	104	µg/m^3	Maximum	Ontario Ministry of Environment (Ontario Ministry of the Environment, 2012)
	1-hour[a]	0.33 330	mg/m^3 µg/m^3	99.9th percentile	NSW EPA (NSW EPA, 2017)
	3-minute[a]	0.6 600	mg/m^3 µg/m^3	99.9th percentile	Victoria Government Gazette (Government of Victoria, 2001)
OHS	8-hour[b]	25 17[a]	ppm mg/m^3	Maximum	Australian Occupational Exposure Standards (Safe Work Australia, 2018)
	15-minute[c]	35 24[a]	ppm mg/m^3	Maximum	Australian Occupational Exposure Standards (Safe Work Australia, 2018)

Note:

a. Values at 273K and 101.3kPa

b. Time Weighted Average (TWA)

c. Short Term Exposure Limit (STEL)

2.1 Sub-hourly Concentration Results

Dispersion model predictions results are typically presented for hourly averages. For assessment criteria shorter than one hour, the hourly concentration must be scaled to estimate the sub-hourly peak concentration. The peak concentration was calculated using a peak-to-mean ratio. The power law relation equation shown below was used to calculate the sub-hourly concentrations (CSIRO, 2008).

$$C_p = C_m \times \left(\frac{t_p}{t_m}\right)^{-p}$$

where:

C_p	=	Peak concentration	µg/m^3
C_m	=	One hour average concentration	µg/m^3
t_p	=	Peak time period	minutes
t_m	=	One hour time period	minutes
p	=	Source type power law exponent	-

For this assessment, the value of ***p*** was set to 0.2 for ground level sources as presented in the Katestone report *Peak-to-Mean ratios for Odour Assessments* (1998). For this assessment, sub-hourly concentrations of 3 and 15 minutes were required for the pollutant modelled. The peak to mean ratios used in the assessment are summarised in Table 2.2 below.

Table 2.2: *Peak-to-mean ratios*

Averaging Period	Peak-to-mean Ratio
3 minute	1.82
15 minute	1.32

3. AMMONIA EMISSIONS

Aqueous solution of waste streams from the processing plant are sent to the Hydromet TSF at a maximum rate of 76 tonnes /hour (tph) (78 m^3/hour). This stream consists of approximately 0.04 g/L of ammonium bicarbonate and 6.28 g/L of ammonium hydroxide solution and releases ammonia once it comes into contact with ambient air (GHD, 2019). The formation and release of ammonia into the atmosphere is variable and highly dependent on the pH of the incoming waste stream and the frequency of the occurrence. The conditions favouring ammonia formation follow the equilibrium equation below.

$$H_2O + NH_3 \rightleftharpoons OH^- + NH_4{}^-$$

This equation shows that a higher concentration of hydroxide ions (higher pH – more alkaline solution) will shift the equilibrium towards the formation of ammonia. The rate at which ammonia is formed, is also proportional to the temperature of the waste stream.

For the current study, a worst-case scenario of 5,300 kg/day of ammonia was considered (GHD, 2019). This presents a level of conservatism in the model. The dispersion model was then set to run with a continuous unit emission rate of 61.3 g/s.

4. MODEL SET UP

For this assessment, dispersion modelling was undertaken using the USEPA approved model AERMOD (and AERMET, for the associated meteorological component). The model set up including selection of representative meteorological year; meteorological modelling, dispersion model setup remain unchanged from the 2017 modelling study (Pacific Environment, 2017). Given the remoteness of the Project location, background ammonia concentrations were assumed negligible.

Sensitivity analysis on the source configuration suggested that a smaller surface area expression of the volume source at the TSF stream entry point would result in higher concentrations at receptors in the vicinity. For the purposes of this assessment, source was configured whereby the surface area component of the volume source has a length of 450 m. This is selected because the formation of ammonia is an equilibrium driven process (occurring over a wider area) and not confined to the mouth of the TSF. An initial vertical dimension of 0.5 m was used as the depth at which ammonia was being formed.

4.1 Receptors

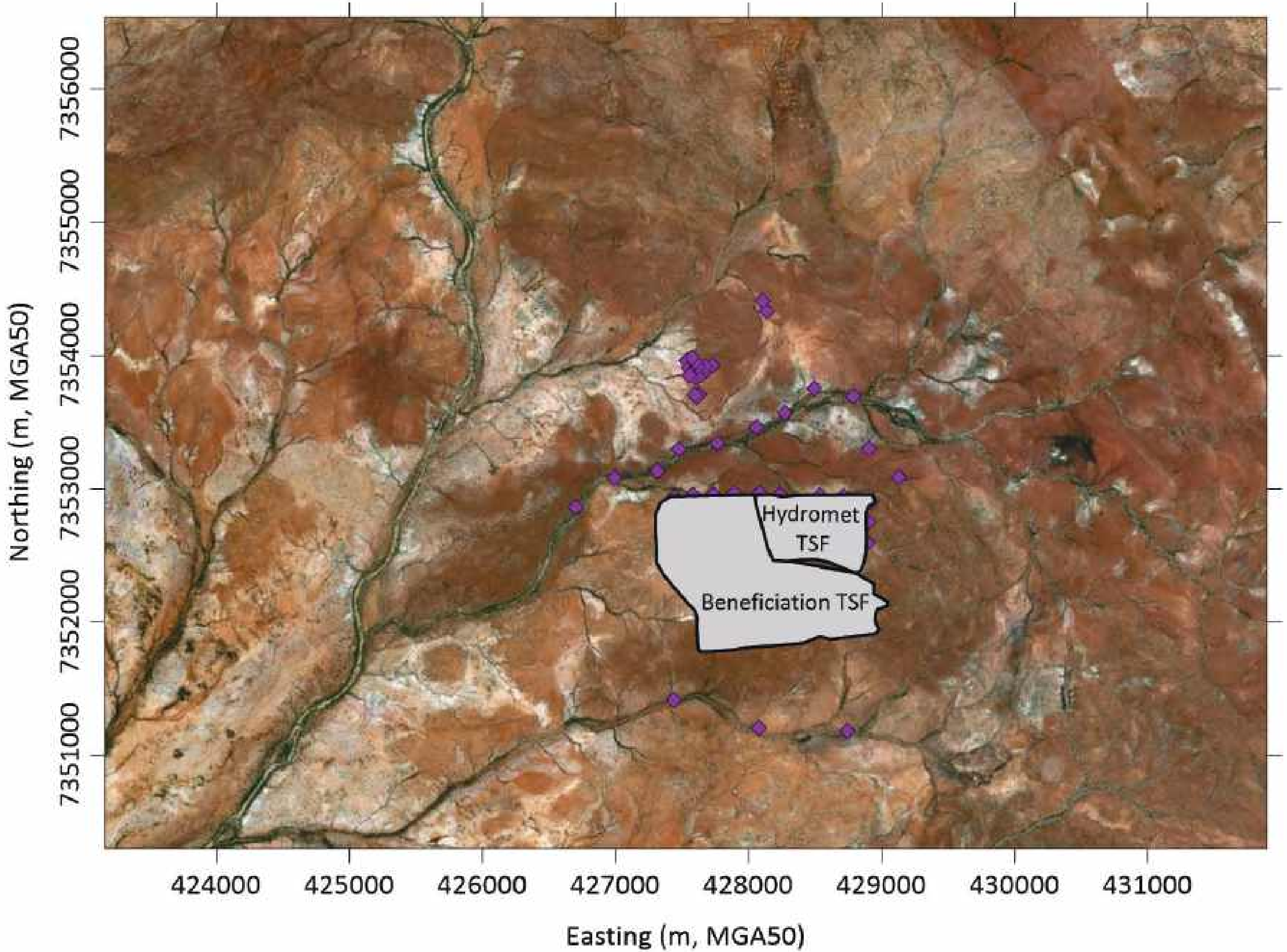
The model was set to predict ground level concentrations across the model domain and at nominated sensitive receptor locations. A total of 45 discrete receptors were defined (Table 4-1): these include 42 onsite receptors (i.e. receptors within the plant boundary defined for OHS purposes) and three offsite receptors (one accommodation camp and two homesteads).

Table 4-1: Discrete receptor locations (onsite and offsite)

Receptor Id	Description	Type	Easting (m, MGA50)	Northing (m, MGA50)
1	Plant 1	Plant Thoroughfare	427,534	7,353,963
2	Plant 2	Plant Thoroughfare	427,554	7,353,910
3	Plant 3	Plant Thoroughfare	427,578	7,353,875
4	Plant 4	Plant Thoroughfare	427,607	7,353,839
5	Plant 5	Plant Thoroughfare	427,640	7,353,856
6	Plant 6	Plant Thoroughfare	427,685	7,353,889
7	Plant 7	Plant Thoroughfare	427,728	7,353,927
8	Plant 8	Plant Thoroughfare	427,671	7,353,919
9	Plant 9	Plant Thoroughfare	427,619	7,353,921
10	Plant 10	Plant Thoroughfare	427,601	7,353,953
11	Plant 11	Plant Thoroughfare	427,574	7,353,987
12	Sample Preparation Laboratory	Plant Building	427,550	7,353,849
13	Administration	Plant Building	427,626	7,353,711
14	Crib and Locker Room	Plant Building	427,609	7,353,689
15	Mining Office	Plant Building	427,593	7,353,709

Receptor Id	Description	Type	Easting (m, MGA50)	Northing (m, MGA50)
16	Mining Crib and Locker Room	Plant Building	428,138	7,354,329
17	Heavy Vehicle Workshop	Plant Building	428,108	7,354,409
18	Accommodation Village	Workers Accommodation	421,700	7,346,593
19	Gifford Creek	Station Homestead	420,600	7,340,300
20	Edmund	Station Homestead	410,370	7,371,700
21	Creek 1	Existing creek	426,703	7,352,862
22	Creek 2	Existing creek	426,993	7,353,085
23	Creek 3	Existing creek	427,313	7,353,133
24	Creek 4	Existing creek	427,477	7,353,297
25	Creek 5	Existing creek	427,767	7,353,346
26	Creek 6	Existing creek	428,058	7,353,462
27	Creek 7	Existing creek	428,271	7,353,568
28	Creek 8	Existing creek	428,493	7,353,752
29	Creek 9	Existing creek	428,784	7,353,694
30	Creek 10	Existing creek	427,438	7,351,420
31	Creek 11	Existing creek	428,077	7,351,207
32	Creek 12	Existing creek	428,745	7,351,188
33	Mine Road 1	Internal mine road	429,128	7,353,090
34	Mine Road 2	Internal mine road	428,905	7,353,302
35	TSF Receptor 1	Vicinity of TSF	428,536	7,352,950
36	TSF Receptor 2	Vicinity of TSF	428,711	7,352,945
37	TSF Receptor 3	Vicinity of TSF	428,915	7,352,902
38	TSF Receptor 4	Vicinity of TSF	428,898	7,352,749
39	TSF Receptor 5	Vicinity of TSF	428,894	7,352,597
40	TSF Receptor 6	Vicinity of TSF	428,236	7,352,958
41	TSF Receptor 7	Vicinity of TSF	428,083	7,352,967
42	TSF Receptor 8	Vicinity of TSF	427,892	7,352,971
43	TSF Receptor 9	Vicinity of TSF	427,735	7,352,958
44	TSF Receptor 10	Vicinity of TSF	427,582	7,352,958
45	TSF Receptor 11	Vicinity of TSF	427,447	7,352,936

These receptors are plotted in Figure 4-1 and Figure 4-2.



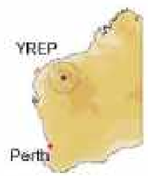
Legend:

TSF

Onsite receptors

Hastings Yangibana
Rare Earth Project (YREP)

Figure 4-1: Discrete receptor locations - Onsite OHS and environment receptors

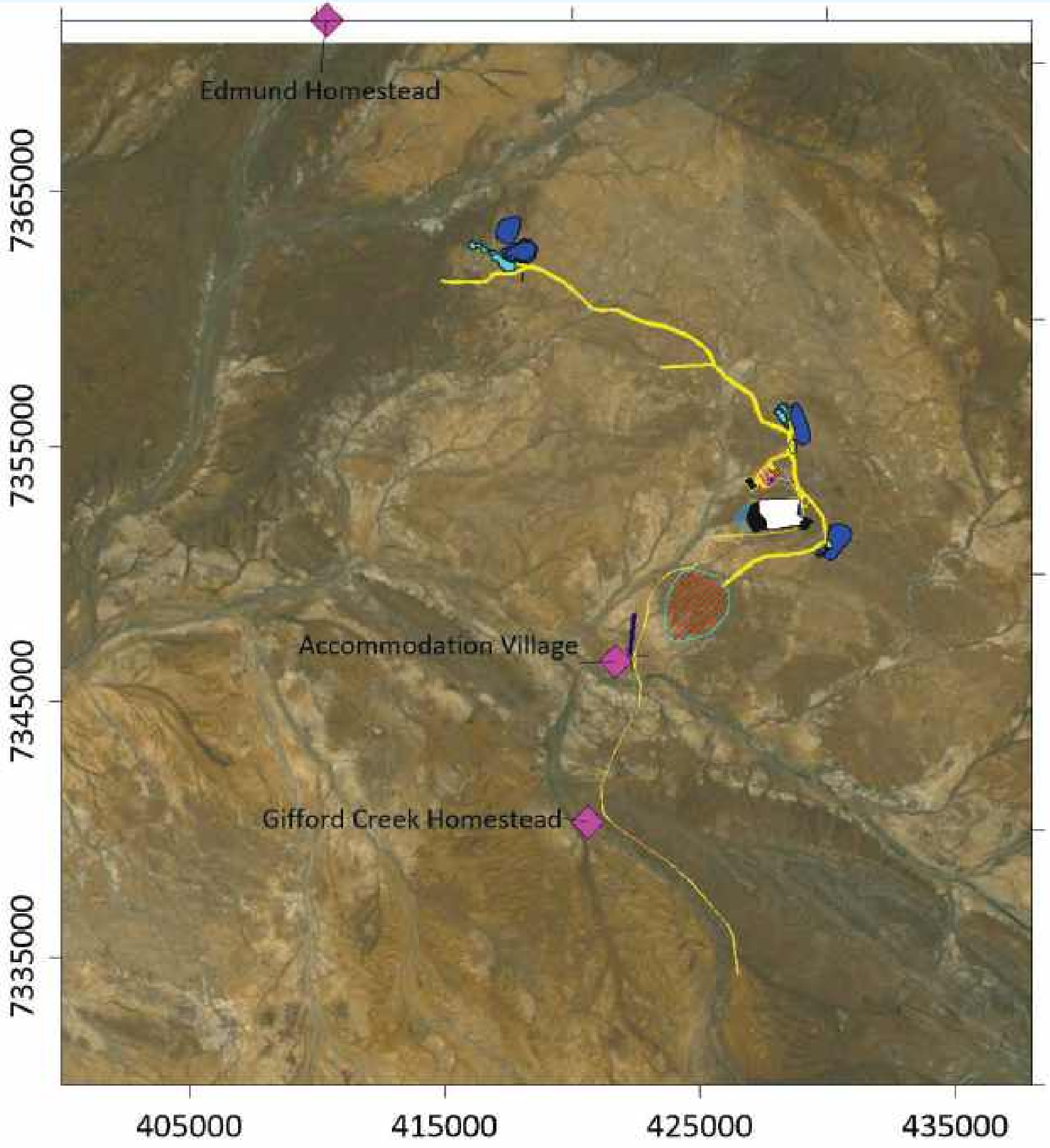


N W E S

WGS 1984 UTM Zone 50K
Projection: Transverse Mercator

ERM

Job no: 0504573
Date:18-04-2019



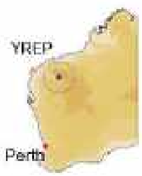
Legend:

Hydromet & Beneficiation TSFs

Offsite (sensitive) receptors

Hastings Yangibana
Rare Earth Project (YREP)

Figure 4 2: Discrete receptor locations – accommodation village & homesteads



WGS 1984 UTM Zone 50K
Projection: Transverse Mercator

ERM

Job no: 0504573
Date:18-04-2019

5. MODEL RESULTS

Ground level concentrations (maximum or 99.9th percentile) have been predicted across the model domain and interpreted at the nominated sensitive receptor locations. Modelled concentrations at:

- offsite receptors have been compared to ambient air quality criteria.
- onsite receptors have been compared to the relevant OHS guideline

5.1 Modelled results at offsite receptors

Modelled 1-hour, 24-hour and 3-minute average concentrations at offsite sensitive receptors are compared against ambient criteria in Table 5-1. The results indicate that concentrations predicted across three offsite receptors are well within the ambient air quality criteria.

Table 5-1: Modelled concentration at offsite receptors

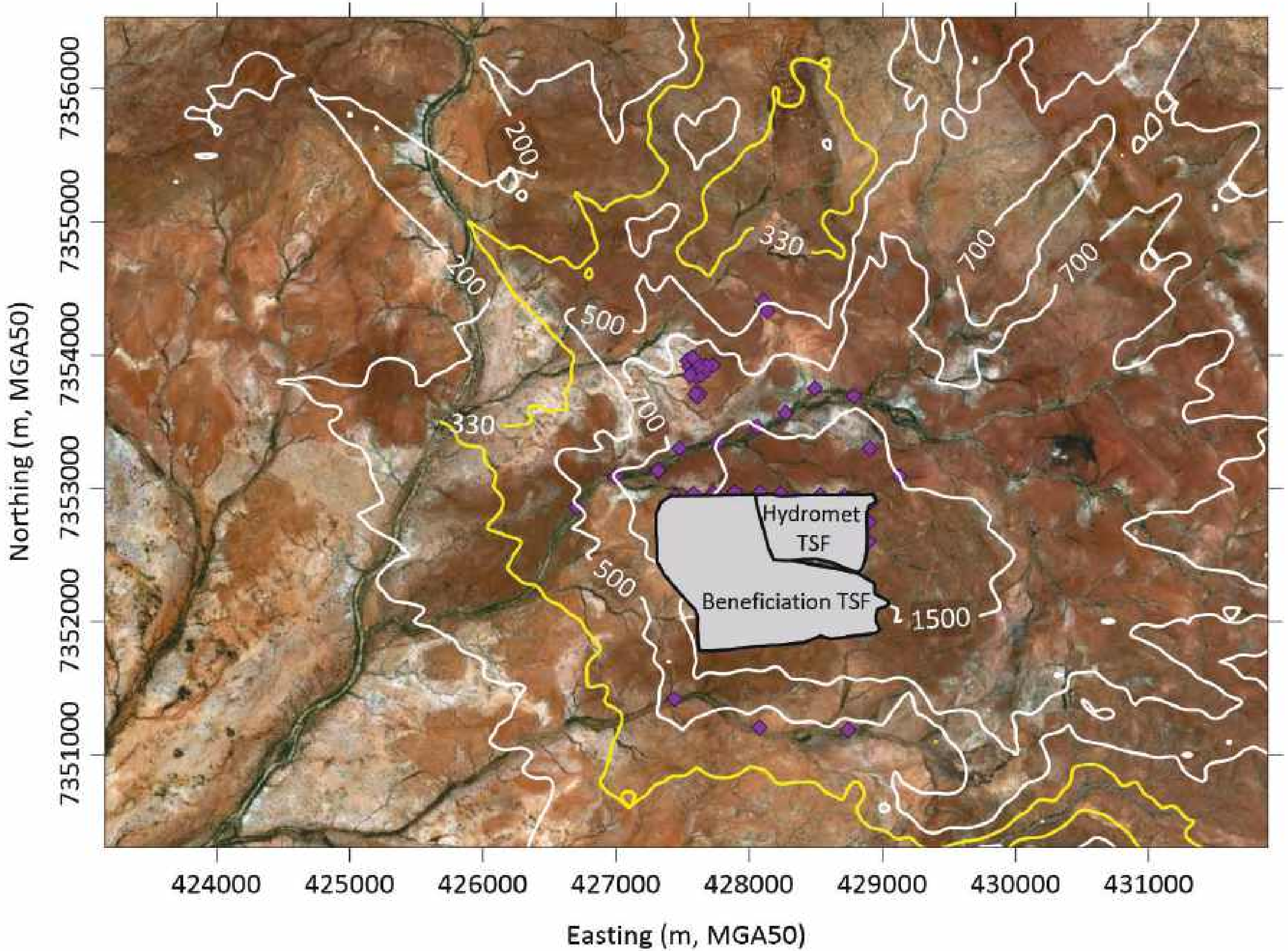
Receptor Id	Description	Type	1_hour[a] (μg/m³)	24_hour[b] (μg/m³)	3_minute[a] (μg/m³)
18	Accommodation Village	Workers Accommodation	28	7	51
19	Gifford Creek	Station Homestead	19	5	34
20	Edmund	Station Homestead	4	4	7
Ambient Air Quality Criteria			**330**	**104**	**600**

Note:

a. 99.9th percentile value

b. maximum value

Contour plots of 1-hour 99.9th percentile; maximum 24-hour and 3-minute 99.9th percentile concentrations are presented in Figure 5-1, Figure 5-2 and Figure 5-3 respectively.

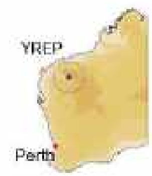


Legend:
TSF
Onsite receptors
Criteria 330µg/m³

Hastings Yangibana
Rare Earth Project (YREP)

Hydromet TSF NH_3 emission

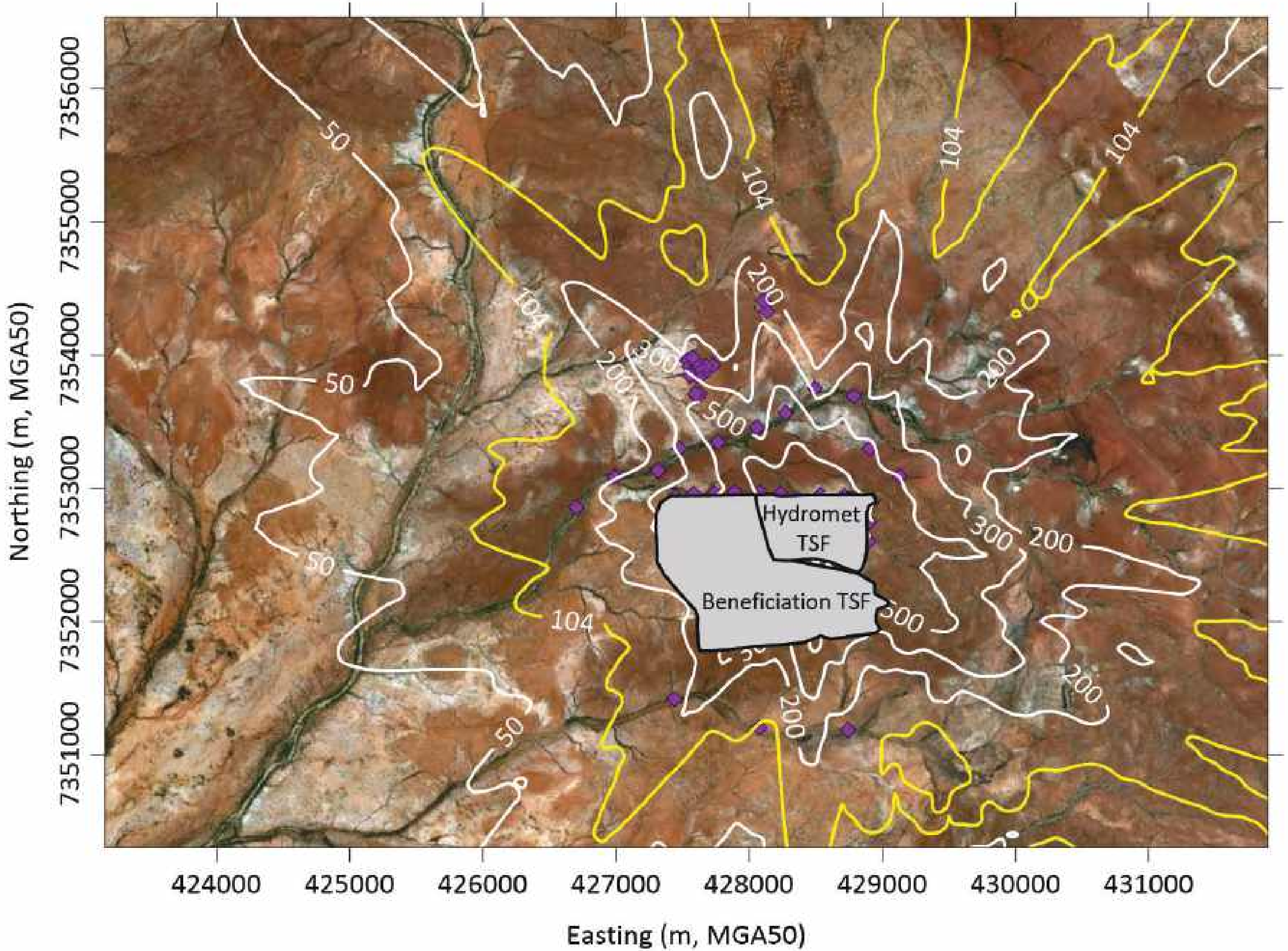
Figure 5 1: Contour plot 1-hour 99.9th percentile – ambient criteria (µg/m³)



WGS 1984 UTM Zone 50K
Projection: Transverse Mercator

ERM

Job no: 0504573
Date:18-04-2019

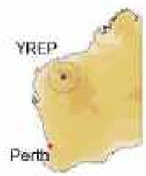


Legend:
TSF
Onsite receptors
Criteria 104µg/m³

Hastings Yangibana
Rare Earth Project (YREP)

Hydromet TSF NH_3 emission

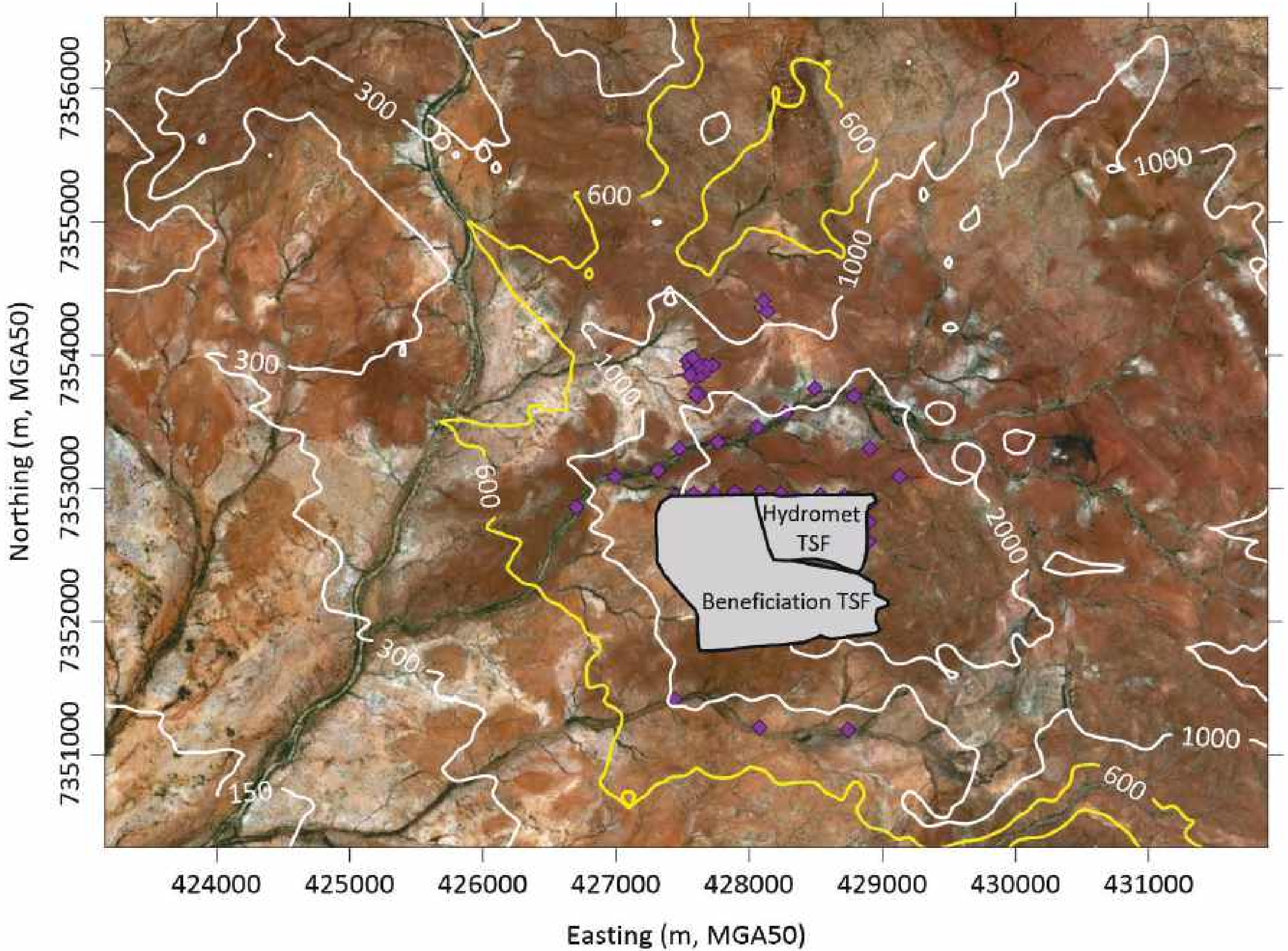
Figure 5 2: Contour plot 24-hour maximum – ambient criteria (µg/m³)



WGS 1984 UTM Zone 50K
Projection: Transverse Mercator

ERM

Job no: 0504573
Date:18-04-2019

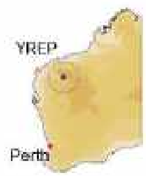


Legend:
- TSF
- Onsite receptors
- Criteria 600µg/m³

Hastings Yangibana
Rare Earth Project (YREP)

Hydromet TSF NH_3 emission

Figure 5 3:Contour plot 3-minute 99.9th percentile – ambient criteria (µg/m³)



N W E S

WGS 1984 UTM Zone 50K
Projection: Transverse Mercator

ERM

Job no: 0504573
Date:18-04-2019

5.2 Modelled results at onsite receptors

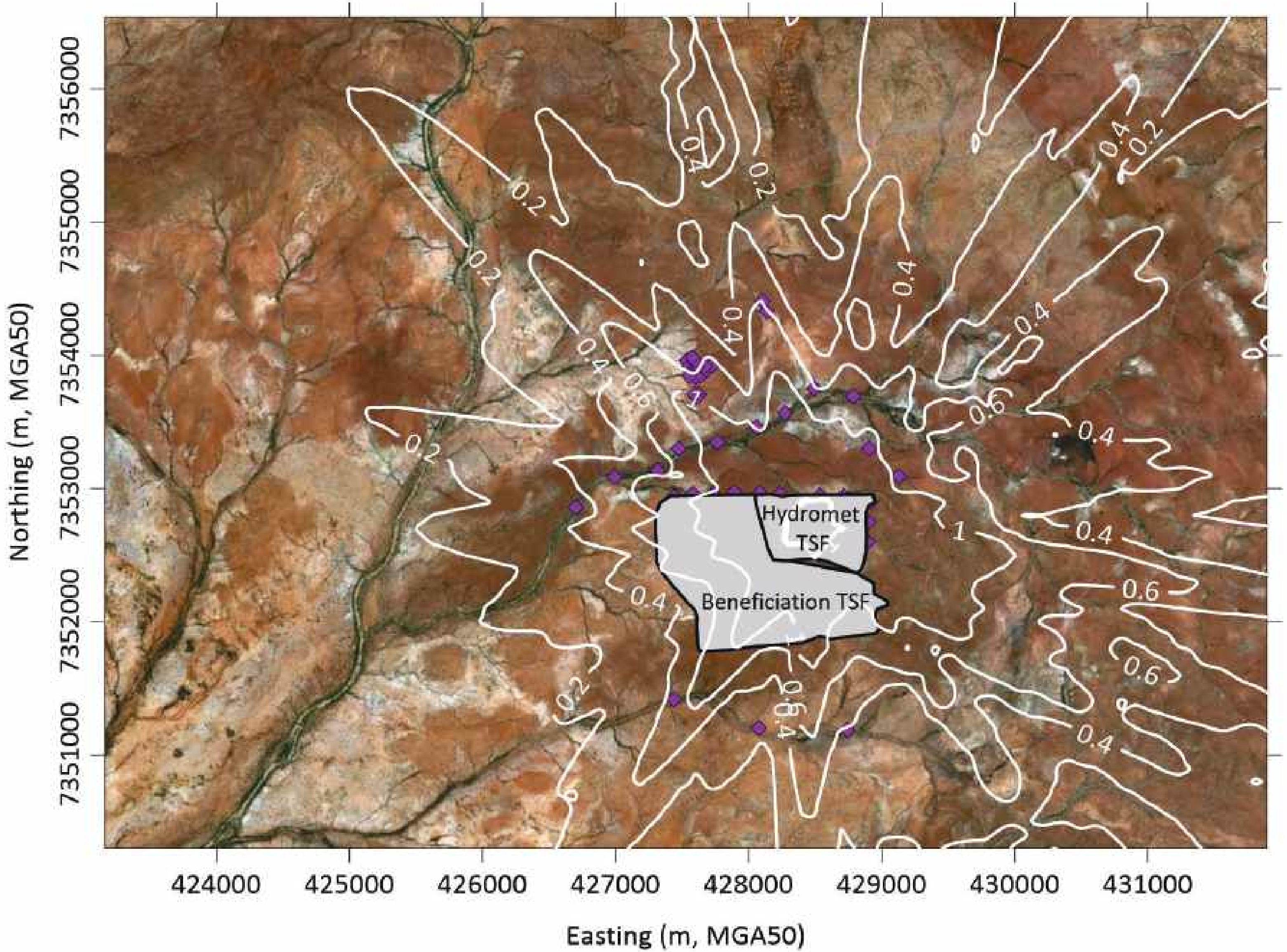
Modelled 8-hour and 15-minute average concentrations have been compared against relevant OHS guideline and presented in Table 5-2. Contour plots for 8-hour and 15-minute averages are presented in Figure 5-4 and Figure 5-5 respectively.

The results indicate that the 8-hour criteria was met at all 42 onsite receptors; 15-minute criteria was met at all 42 onsite receptors, except one (TSF Receptor 1, 25.8 mg/m^3). It should be noted that the second highest value (15-minute) predicted at this receptor was 12.2 mg/m^3 at about 50% of the criteria (24 mg/m^3). This is an indication that the likelihood of this predicted excursion is low.

Table 5-2: Modelled concentrations at onsite receptors

Receptor Id	Description	Type	8_hour (mg/m^3)	15_minute (mg/m^3)
1	Plant 1	Plant Thoroughfare	0.53	1.81
2	Plant 2	Plant Thoroughfare	0.54	1.90
3	Plant 3	Plant Thoroughfare	0.56	1.96
4	Plant 4	Plant Thoroughfare	0.58	2.03
5	Plant 5	Plant Thoroughfare	0.61	2.06
6	Plant 6	Plant Thoroughfare	0.65	1.98
7	Plant 7	Plant Thoroughfare	0.64	1.95
8	Plant 8	Plant Thoroughfare	0.64	1.91
9	Plant 9	Plant Thoroughfare	0.58	1.97
10	Plant 10	Plant Thoroughfare	0.57	1.92
11	Plant 11	Plant Thoroughfare	0.55	1.87
12	Sample Preparation Laboratory	Plant Building	0.62	1.98
13	Administration	Plant Building	0.87	2.12
14	Crib and Locker Room	Plant Building	0.98	2.20
15	Mining Office	Plant Building	0.95	2.16
16	Mining Crib and Locker Room	Plant Building	0.63	4.49
17	Heavy Vehicle Workshop	Plant Building	0.59	4.36
21	Creek 1	Existing creek	0.32	1.51
22	Creek 2	Existing creek	0.54	4.42
23	Creek 3	Existing creek	0.53	3.69
24	Creek 4	Existing creek	0.81	2.39
25	Creek 5	Existing creek	1.54	2.96
26	Creek 6	Existing creek	1.03	3.17
27	Creek 7	Existing creek	1.48	10.15

Receptor Id	Description	Type	8_hour (mg/m^3)	15_minute (mg/m^3)
28	Creek 8	Existing creek	0.62	2.62
29	Creek 9	Existing creek	0.73	2.76
30	Creek 10	Existing creek	0.45	3.95
31	Creek 11	Existing creek	0.25	0.74
32	Creek 12	Existing creek	0.40	0.79
33	Mine Road 1	Internal mine road	0.89	3.22
34	Mine Road 2	Internal mine road	1.21	3.89
35	TSF Receptor 1	Vicinity of TSF	6.45	25.75
36	TSF Receptor 2	Vicinity of TSF	2.95	7.43
37	TSF Receptor 3	Vicinity of TSF	1.65	5.51
38	TSF Receptor 4	Vicinity of TSF	2.00	6.04
39	TSF Receptor 5	Vicinity of TSF	2.52	14.44
40	TSF Receptor 6	Vicinity of TSF	4.14	10.69
41	TSF Receptor 7	Vicinity of TSF	2.36	5.91
42	TSF Receptor 8	Vicinity of TSF	1.34	7.00
43	TSF Receptor 9	Vicinity of TSF	1.06	7.73
44	TSF Receptor 10	Vicinity of TSF	0.94	7.14
45	TSF Receptor 11	Vicinity of TSF	0.86	6.18
Maximum across onsite receptors			**6.45**	**25.75**
OHS criteria			**17**	**24**



Legend:
- TSF
- Onsite receptors
- Criteria 17mg/m³

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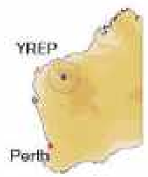
Figure 5-4: Contour plot 8-hour maximum – OHS criteria (mg/m³)



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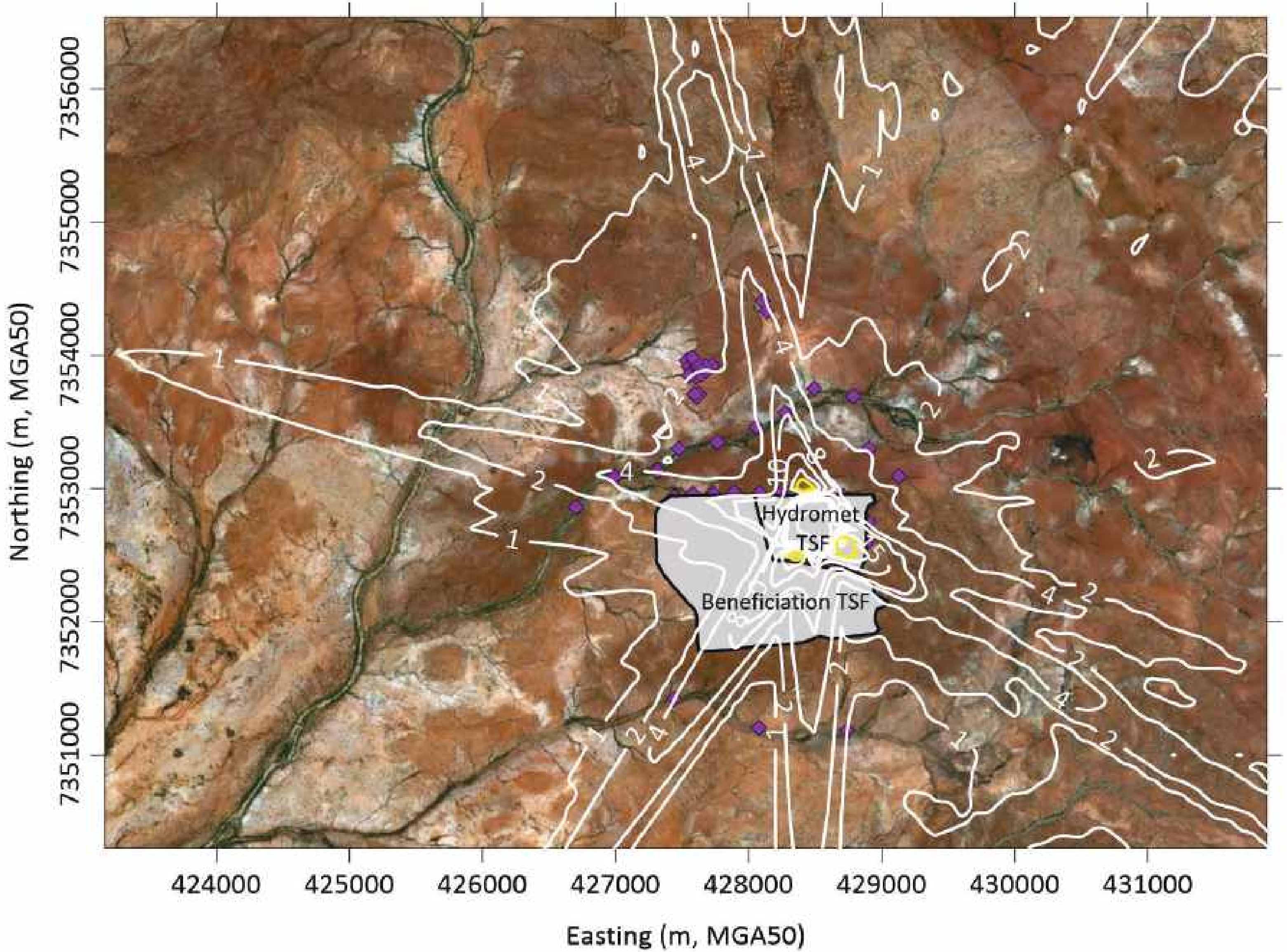

Legend:

TSF

Onsite receptors

Criteria 24mg/m³

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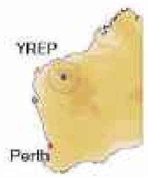
Figure 5-5: Contour plot 15-minute maximum – OHS criteria (mg/m³)



WGS 1984 UTM Zone 50K
Projection: Transverse Mercator

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Further analysis was undertaken to identify the meteorological/dispersion conditions that give rise to the exceedance at TSF Receptor 1. The findings are presented in Table 5-3. Meteorological parameters investigated include atmospheric stability, wind speed and wind direction.

The results infer that the exceedance is predicted to occur during calm conditions just before sunrise and was associated with low inversion layers and wind direction blowing from the source, towards the receptor.

Table 5-3: Meteorological conditions that led to 15-minute excursion at TSF Receptor 1

Timestamp	15-min concentration (mg/m^3)	Stability	Wind speed (m/s)	Wind direction
06/06/2011 01:00	3.93	Very Stable	0.8	232
06/06/2011 02:00	4.86	Very Stable	0.7	225
06/06/2011 03:00	7.87	Very Stable	0.5	217
06/06/2011 04:00	8.34	Very Stable	0.5	198
06/06/2011 05:00	6.29	Very Stable	0.9	182
06/06/2011 06:00	5.33	Very Stable	1.1	174
06/06/2011 07:00	5.68	Very Stable	1	171
06/06/2011 08:00	25.75	Very Stable	1.2	165
06/06/2011 09:00	1.00	Unstable	1.8	160
06/06/2011 10:00	0.83	Unstable	1.9	157
06/06/2011 11:00	0.77	Unstable	1.9	158
06/06/2011 12:00	0.87	Unstable	2	163

5.3 Occurrence of worst case meteorology

Additional investigation was undertaken to understand the hourly concentrations trends to aid in monitoring of NH_3 for OHS purposes should this be determined necessary. Analysis included concentration trends based on period (month), time of day, wind speed and atmospheric stability. The following can be observed:

- Higher concentrations are generally associated with lower wind speeds and very stable atmosphere.
- Concentrations start to increase from 4 pm in the evening reaching maxima around 10 pm and starts to drops after 6 am in the morning.
- Generally higher concentrations are predicted between July to October.

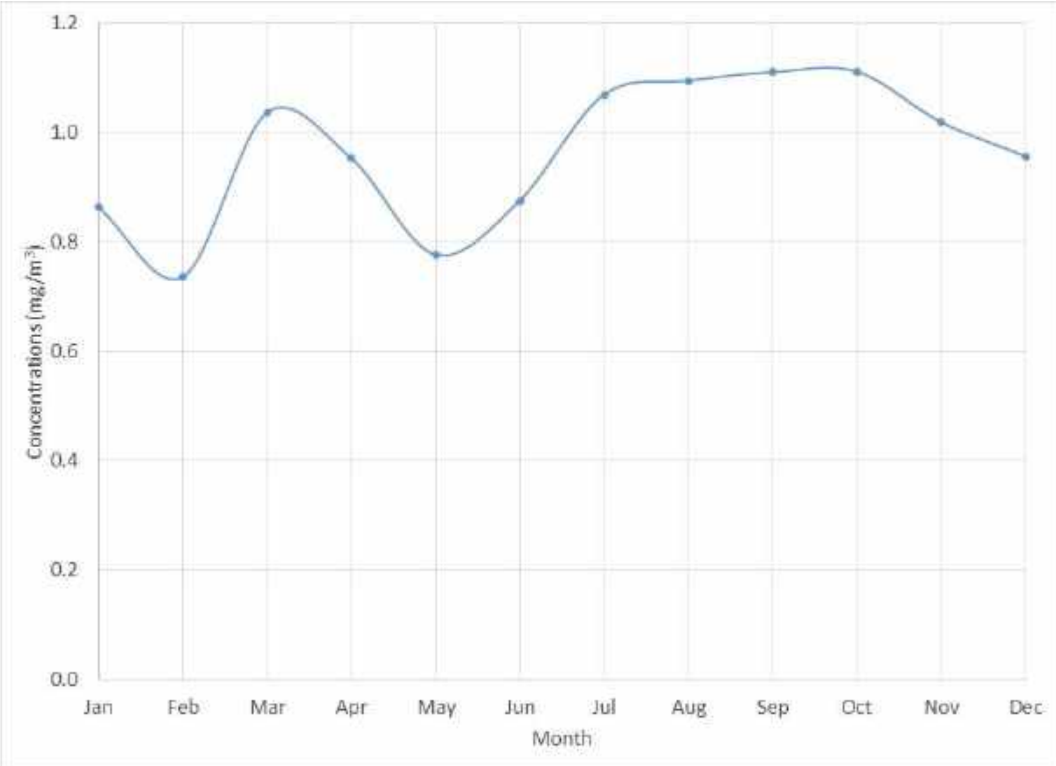

Figure 5-1: Predicted hourly concentration trends - month

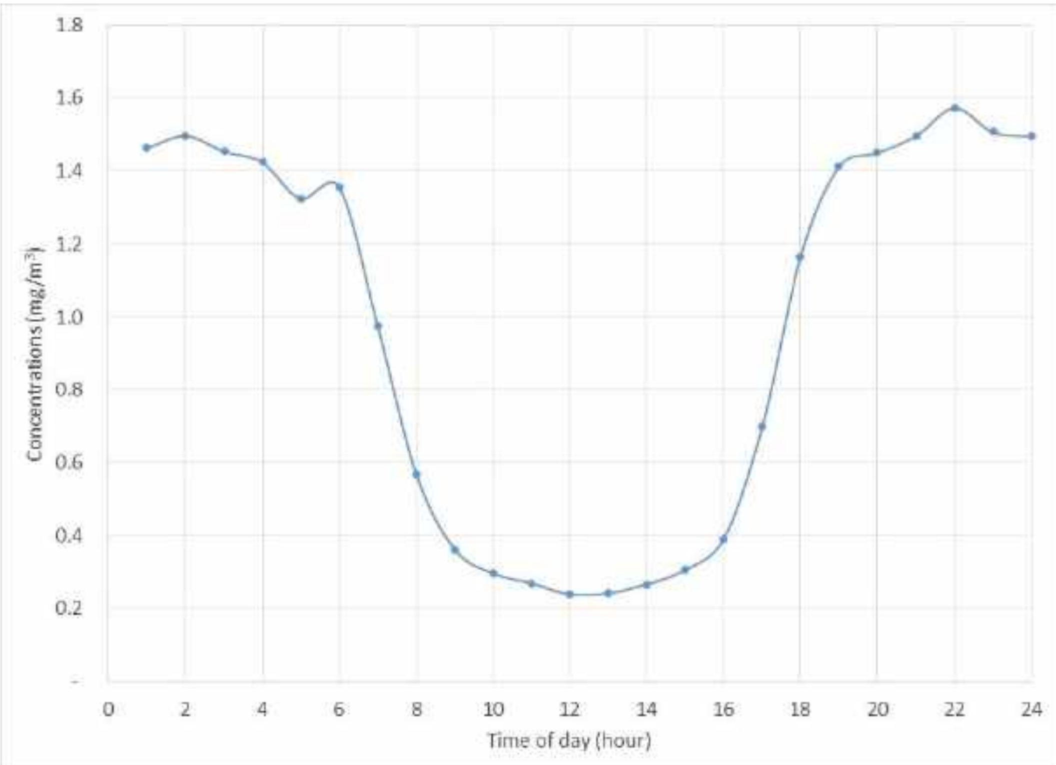

Figure 5-2: Predicted hourly concentration trends – time of day

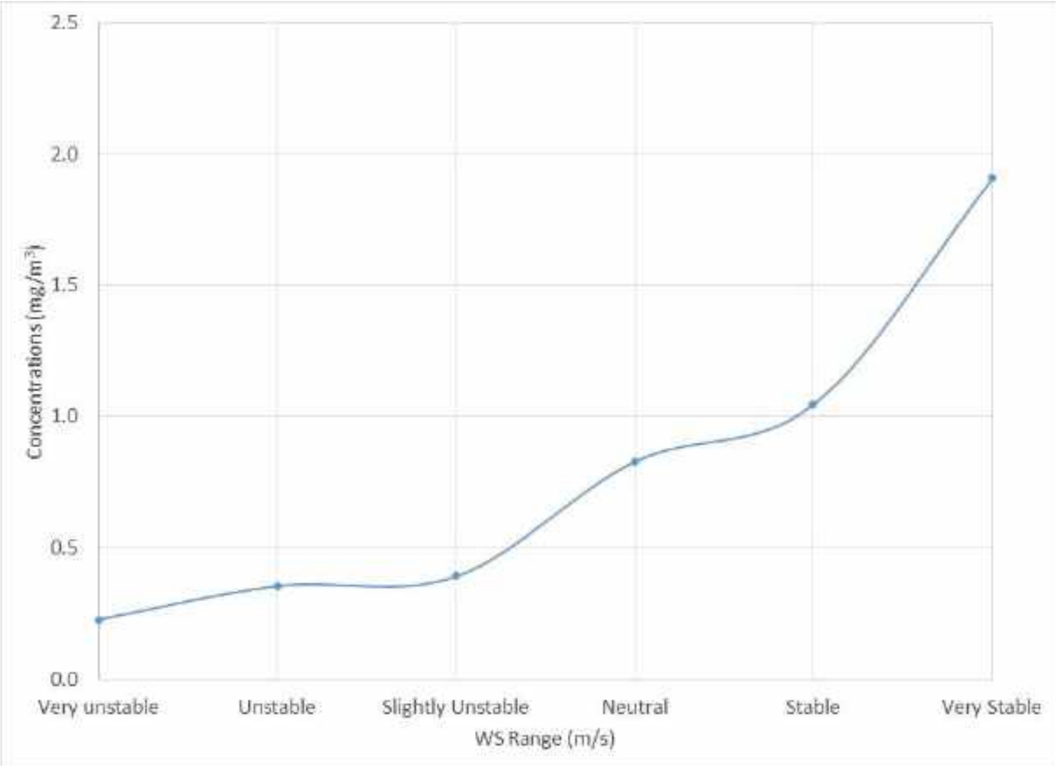

Figure 5-3: Predicted hourly concentration trends – wind speed

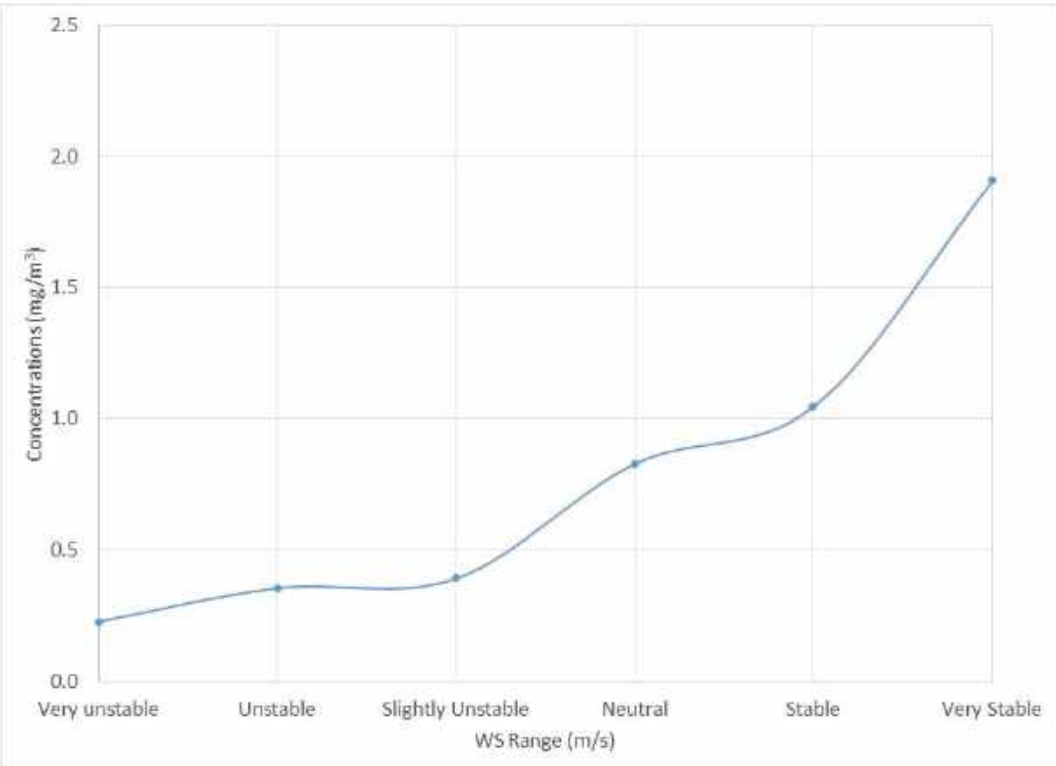

Figure 5-4: Predicted hourly concentration trends – atmospheric stability