Fortescue
The New Force in Iron Ore

Report

Western Hub Stage 1 - Eliwana and Flying Fish

Geochemistry Risk Assessment for Closure

16 February 2018

750WH-5700-RP-HY-0009_Rev0

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1. INTRODUCTION

Fortescue Metals Group Ltd (Fortescue) is proposing to develop the Western Hub Stage 1 Iron Ore Mine Project (the Project) comprising the Eliwana and Flying Fish deposits in the Pilbara region of Western Australia.

1.1 Objectives

The main aim of the Closure Risk Assessment is to outline and describe the contaminant-transport-receptor (CTR) model based on the *National Environmental Protection Measures* (NEPM) guidelines for assessing contamination (NEPM, 2013).

1.2 Reference documents

This *Western Hub Stage Geochemistry Risk Assessment for Closure* document number 750WH-5700-RP-HY-0009 was prepared using the following resources:

- *Acid and/or Metalliferous Drainage Management Plan*, Report Ref.: 100-PL-EN-1016_Rev1 (Fortescue, 2014);
- *Western Hub Stage 1 – Geological Summary Report* (Fortescue, 2015)*;*
- *Western Hub - Dewatering and Water Supply Assessment - Hydrogeological Conceptual Model Report*, Report Ref.: 1671484-002-R-Rev0; Golder Associates (Golder, 2017);
- *Western Hub Stage 1 – Eliwana and Flying Fish Subsurface Material Characterisation Assessment,* Report Ref.: 750WH-5700-RP-HY-0007 (Fortescue, 2017a);
- *Western Hub Stage 1 Conceptual Site Model and Operational Risk Assessment*, Report Ref.: 750WH-5700-RP-HY-0008 (Fortescue, 2017b);
- *Western Hub Stage 1 Conceptual Mine Void Water Assessment*, Report Ref.: 750WH-5700-RP-HY-0010 (Fortescue, 2017c).

2. QUALITATIVE RISK ASSESSMENT CRITERIA

In order to minimise AMD risk and optimise reserves the results from the geochemical testwork, geological distribution of ore, geotechnical data as well as surface and groundwater considerations have been incorporated into the mine planning design. This integrated approach is required to be conducted with the knowledge and expertise of geochemical and contamination issues as strict compliance with regulatory guidelines does not necessarily reduce risk. No legislation can adequately account for all potential geological and mining scenarios or risks to the environment, and guidelines only provide a strategic outline for how to address general concepts. While Australian and international references have been heavily relied on for this assessment, the conclusions, risks, recommendations and management options are entirely site specific.

2.1 Purpose

The purpose of a geochemical risk assessment is to highlight all potential risks to internal and external stakeholders such that the mitigation of risks is a collaborative effort where the best strategies are utilised to reduce harm and the most efficient use of resources is implemented. Mining operations are capital intensive and inherently hazardous and operational failures can be costly with significant impacts on the environment, if risk is not affectively assessed and managed (DIIS, 2016b). The goal of any risk management strategy is the sustainability of the environment while operating a successful business and being responsible for social and ecological aspects.

2.2 Geochemical risk

Figure 1 details the matrix used to determine the contamination risk soluble analytical concentration may pose to the environment and whether there would be a deleterious impact on any biota exposed to the concentration. Potential impact is based on three factors:

1. How often a particular parameter is detected in samples is the Likelihood of Occurrence;
2. The solubility and consequent ecotoxicology of a particular parameter in a natural system i.e. a highly soluble parameter, such as sodium is less toxic in an environment that has evolved to tolerate it, while a sparingly soluble parameter is naturally more toxic (except in an environment which has locally, naturally, high concentrations). Solubility can depend on the environmental and weathering conditions and can be changed by mineral processing; while ecotoxicology is dependent on the sensitivity of the receptor. For example in a highly saline environment additional salinity is unlikely to have a significant effect on biota, while in a pristine, sensitive glacial environment additional salinity could be toxic. Elements like arsenic or mercury would ordinarily be deemed to be highly toxic except in environments where they occur naturally and the local biota have evolved a tolerance;
3. The third determinant of risk takes into account specific, quantitative, legislative limits, also based on ecotoxicology, and local site specific trigger values based on the groundwater quality of the likely receptor.

A potentially high impact would occur when the ecotoxicology of the parameter given in the ANZECC Guidelines is high and the relative solubility of that species in local groundwater, as based

on the ITV, is very low, or “trace”; the concentration that the element occurs at exceeds the site specific trigger values *and* the occurrence of that element is possible to certain (ANZECC & ARMCANZ, 2000). Elements that are not detected are not considered to be of concern. In terms of risk, if a parameter is detected in less than 3% of samples (rare), exceeds the ITV and is a trace, highly toxic parameter, it is only a minor concern as a result of the rarity of occurrence on the balance of probability.

Any qualitative statements made concerning the relative risk of concentrations of any parameter can be interpreted according to this risk matrix.

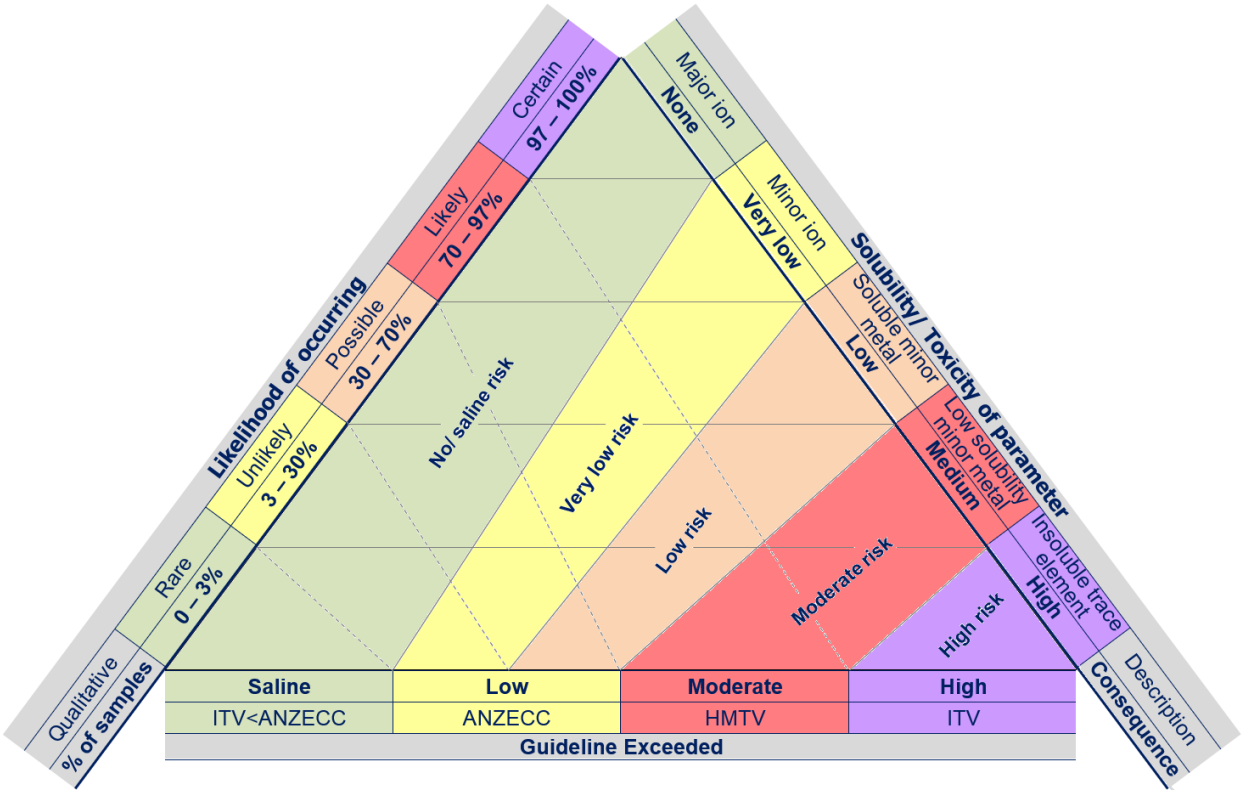

Figure 1: Qualitative risk matrix for evaluating dissolved element concentrations

2.3 Method

The geochemical study was conducted in a phased approach whereby analytical characterisation increased in detail. The preliminary assessment highlighted key issues and integrates detail from other studies such as the ore deposit geology, climate, topography, surface and groundwater regimes as well as pertinent mining detail, such as waste rock volumes and method of production and beneficiation. The detailed characterisation provided further information concerning where deleterious material is located, whether it remains in the wall rock, or will be excavated to waste, along with what potential for acid drainage exists, likely soluble metals, potential transport pathways and risk to water resources. Based on these considerations the risk of specific material located in the landscape that may constitute a source, and the likely connection to pathways to potential receptors has been assessed for the post-closure regime. A detailed description of the consequence, likelihood, duration and extent categories used for this assessment is given, with terminology definitions, in Tables 1, 2, 3, 4 and 5.

Table 1: Consequence Categories

Rating Level	Health and Safety	Social and Natural Environment	Reputation and Brand	Compliance
1	No medical treatment required.	Insignificant damage of low significance.	Public concern restricted to local complaints about Fortescue brand.	Low level legal issues.
2	No medical treatment required.	Slight effects on biological or physical or social environment.	Minor, adverse local public or media attention and complaints about Fortescue brand.	Multiple minor breaches of laws or regulations and potential complaints.
3	Minor first aid – no disabling.	Intermediate effects but not affecting ecosystem function or ongoing social issues.	Attention from local media and/or heightened concern by local community complaints.	Minor breach of laws or regulations could result in civil litigation. Closure delayed
4	Disabling incident requiring medical treatment with no permanent impact.	Medium environmental effects or ongoing serious social issues.	Independent review of outcomes required. Significant adverse national media and public attention impacting on Fortescue brand and shareholder brand.	Single significant breach of laws or regulations resulting in litigation and potential class actions. Relinquishment delayed
5	Serious (permanent) disabling injury that was life threatening – “near miss”.	Significant environmental impairment of ecosystem function or ongoing widespread social impacts.	Serious public or media outcry International coverage with significant impact on Fortescue brand and shareholder brand	Multiple significant breaches of laws resulting in major civil litigation, fines and penalties.
6	A fatality or very serious irreversible injury to a small number of people in localised area.	Very significant impact on highly valued species, habitat, or eco system or breakdown in social order.	International media condemnation with major impact on Fortescue brand and shareholder brand.	Major breach of laws or regulations. Potential fines and criminal prosecutions. Temporary closure of operating sites.
7	Multiple fatalities or very serious irreversible injury to multiple persons in localised area.	Severe impact on highly valued species, habitat or eco system or complete breakdown in social order.	Prolonged international condemnation with permanent damage to Fortescue brand and shareholder brand.	Objective impossible to achieve. Multiple major breaches of laws resulting in imprisonment of executives/directors. Loss of licence to operate.

Table 2: Likelihood

Rating		Qualitative Description	Probability
1	Extremely Remote	Not expected in most circumstances: Less than once in 100 years	<1%
2	Remote	Not expected to occur: Once in 100 years	1%-10%
3	Rare	May occur in exceptional circumstances: Once in 50 years	10%-25%
4	Unlikely	Could occur at some time: Once in 25 years	25%-50%
5	Possible	Should occur at some time: Once in 10 years	50%-75%
6	Likely	Probably occur in most circumstances: At least once in 2 years	75%-90%
7	Almost certain	Occurs in most circumstances: At least once per year	>90%

Table 4: Duration

Timeframe		Description
1	Hours	Negligible issue such as a spill, clean up/ resolved immediately
2	Days	Brief issue will attenuate naturally within days or require minimal attention
3	Weeks	Minor occurrence - can be resolved with a few weeks of action
4	Months	Moderate action required
5	Years	High consequence - large and sustained response required to resolve
6	Decades	Serious occurrence - management strategy and mine plan response required
7	Centuries	Severe action - rehabilitation and relinquishment impacted, liability not able to be ended

Table 5: Extent of disturbance

Distance		Description
1	Immediate	Several metres
2	Confined	Small area affected
3	Limited	Minor area, up to half of footprint
4	Internal	Will not exceed disturbance footprint
5	Local	Travel off disturbance footprint for some distance <10-20 km
6	Regional sub-catchment	Extended area of up to 100 km
7	Regional Basin	Large extent affected >100 km

Table 3: Key Definitions

Term	Definition
Action	Defined tasks and/or plans required to further mitigate the risk in addition to the existing risk mitigation strategies
Cause	Contributing internal or external factors which lead to a risk event occurring.
Consequence	The cumulative impact that is expected to arise should the risk event occur within the defined timeframe. This should consider both positive opportunities and negative impacts
Control	An activity that reduces or prevents (preventative controls) the likelihood of risk event or eliminates or reduces the impact on the business (mitigating controls) if the risk event occurs.
Control Owner	Person responsible for ensuring that a control is operating and / or further action is implemented
Hazard	Maximum reasonable outcome (consequence) given the current level of knowledge and effectiveness of implemented controls.
Inherent Risk Rating	Measure of the current risk given what has been implemented / constructed on site, the current level of knowledge and effectiveness of implemented controls.
Likelihood	Assessment of the probability and/or frequency of the event occurring with the expected consequence within the defined timeframe.
Residual Risk Rating	Measure of the risk remaining taking into consideration planned and/or implemented controls and other risk management strategies. The calculation of residual risk should assume that identified risk mitigation strategies (including controls) are operating effectively.
Risk	Negative effects from an uncertain future event or circumstance where Fortescue has limited ability to control the occurrence of the risk with the consequential impact to the business being mitigated by appropriate risk management strategies
Risk Owner	Person or function with the accountability and authority to manage a risk
Risk Response Plan	A defined set of activities or processes to manage the risk to an acceptable level. This would normally include the critical preventative and mitigating controls related to the risk
Status	State of whether an action or control is open/planned, completed/implemented or rejected/expired respectively

From the assessment of the Consequences of a source being connected to a receptor, the Likelihood of that occurring, the Duration it may occur for, and the likely Extent or distance that potential contamination could travel, a risk rating is calculated. The risk matrix is given below in Table 6 with each category given a rating out of seven for severity and has been adapted from *Preventing Acid and Metalliferous Drainage* guideline (DIIS, 2016c). The maximum possible risk rating would be a value of 2,401 which is the maximum severity of seven for all four categories multiplied i.e. 7 x 7 x 7 x 7.

The maximum risk rating for each risk level is the value when two of the four factors are in the next category (i.e. 1 x 2 x 2 x 1 = 4, 5 x 4 x 5 x 4 = 400 etc.). As a result of the multiplication of categorisation factors, not every number in the range of risk ratings is possible (i.e. prime numbers greater than 11 do not occur).

Table 6: Risk rating matrix

Lvl	Consequence	Likelihood	Duration	Extent	Risk Rating	Risk Level Description
1	Insignificant	Extremely Remote	Hours	Immediate	1 to 4	Very Low
2	Slight	Remote	Days	Confined	5 to 36	Low
3	Intermediate	Rare	Weeks	Limited	37 to 144	Minor
4	Medium	Unlikely	Months	Internal	145 to 400	Moderate
5	Significant	Possible	Years	Local	401 to 900	High
6	Very Significant	Likely	Decades	Catchment	901 to 1764	Serious
7	Severe	Almost Certain	Centuries	Regional	1765 to 2401	Extreme

3. CONCEPTUAL SITE MODEL

The conceptual site model (CSM) describes all the likely sources of potential contamination in the mining area and assesses the likely transport pathways to any local or regional receptors. This risk assessment is designed to highlight areas of high risk and potential uncertainty that require management to mitigate, or further study to quantify more fully. The potential sources, pathways and receptors are described in detail in the *Western Hub Stage 1 Conceptual Site Model and Operational Risk Assessment*, Report Ref. 750WH-5700-RP-HY-0008 (Fortescue, 2017b).

A summary of the predicted surface and groundwater regimes is given in Table 7. This table collates the planned depth of mining for each pit, with the surface and groundwater models to detail which mine void will intersect groundwater and have inflow in the current plan, and which mine voids are situated within a floodplain. With a large enough rainfall event any mine void in the floodplain could intercept surface water flow, even if just for a few hours. The table indicates whether mine void water will be permanent enough to form a pit lake and whether outflow may occur during rain events. The compilation of these scenarios has allowed the risk of contamination to be assessed.

Table 7: List of mine voids showing planned depth and water regime

	Pit name	Planned Depth (mAHD)	Groundwater Inflow	Position in Floodplain	Pit Lake	Surface water outflow
Eliwana	Broadway West 3	363	**Likely**	**Within**	**Likely**	**Almost certain - yearly**
	Broadway West 2	411	Remote	**Within**	Remote	N/A
	Broadway West 1	408	Remote	**Within**	Remote	N/A
	Broadway East 2	435	**Likely**	**Within**	**Likely**	Very Rare – Extreme
	Broadway East 1	453	**Likely**	**Within**	**Likely**	
	Broadway	483	Remote	Above	Remote	Very Rare – Extreme
	Broadway South	444	Remote	Above	Remote	Very Rare – Extreme
	Eagles Nest	492	**Likely**	Above	**Likely**	N/A
	East 1 (now called Swan)	543	Remote	Above	Remote	N/A
	East 2	510	Remote	Above	Remote	N/A
	East 3 (now called Piccadilly)	543	Remote	Above	Remote	N/A
	East 4	546	Remote	Above	Remote	N/A
	MM1 (now called Talisman East)	489	Remote	Above	Remote	N/A
	MM4-6 (now called M6)	450	**Likely**	Above	**Likely**	N/A
	P Tenement 1 (P1)	486	Remote	Above	Remote	N/A
	P Tenement 2 (P2)	570	Remote	Above	Remote	N/A
	P Tenement 3 (P3)	423	Remote	Above	Remote	N/A
	P Tenement 4 (P4)	417	Remote	Above	Remote	N/A
	Talisman 1	480	Remote	**Within**	Remote	N/A
	Talisman 2	426	**Likely**	**Within**	**Likely**	Very Rare – Extreme
	West End	310	**Likely**	Above	**Likely**	N/A
	West Side	456	**Likely**	Above	**Likely**	N/A
	Flying Fish 1	-	Remote	**Within**	Remote	Rare
	Flying Fish 2	-	Remote	Above	Remote	N/A

Table 8 gives the results of the risk assessment for closure while Figure 2 show the connections between source, pathways and receptors in operations graphically. All relevant potential sources of contamination are assessed for each likely transport pathway and each likely potential receptor. The unmitigated risk is rated based on the severity of the consequence that specific geochemical contaminants identified in the characterisation program would pose, the likelihood that such contaminants or transport pathway would occur, the duration a potential source or pathway may exist and the extent of distance that a pathway might affect.

The risk is then described with potential mitigation methods be implemented to reduce the risk. Not all unmitigated risks are sufficiently high to require mitigation as either likelihood of contamination is low or the consequence of any contamination is not of environmental significance. Where potential sources such as tailings storage facilities, waste rock landforms or mine voids will remain following closure the duration of these potential sources is the maximum time of centuries and cannot be mitigated. In these instances the only way mitigation of the risk can be achieved is to reduce the consequence, likelihood and extent. This may be achieved by excluding water and air from contact with material that may leach and/or oxidise. All risks that are rated as minor to serious have been indicated to require management (there are no extreme risks).

Table 8: Summary of conceptual site model post-closure (A3 size page)

Source	Specific concern	Transport	Potential Receptors	Consequence	Likelihood	Duration	Extent	Unmitigated Risk Rating	Description of risk and possible mitigation measures to reduce risk post- closure
Aboveground waste rock landforms	Acid generation and neutral/ alkaline metalliferous drainage containing aluminium, arsenic, manganese, selenium and zinc with minor beryllium, cobalt and thallium	Direct	Pastoralists/ Future/ Indigenous land users	1	1	1	1	1	***Very Low Risk*** that any people or animals exposed directly to waste rock will be effected by chemical contamination and does not require mitigation following closure.
		Seepage	Shallow Tertiary Detrital Aquifer	6	7	7	5	1470	***Serious Risk*** that deleterious waste rock can oxidise and cause AMD if not properly disposed of in the waste rock landform. The consequence, likelihood and extent can be **mitigated to *Low Risk*** if WRL design and waste scheduling is carefully managed and maintained to prevent the ingress of oxygen and water as the duration of WRL will remain centuries
			Mineralised Brockman Aquifer	2	3	1	2	12	***Low Risk*** that leaching of contaminants from waste rock material could reach the aquifer. The potential area of impact is limited to the immediate vicinity of the source by a low likely volume of seepage, and capture by nearby dewatering or only reaching the shallow groundwater aquifers.
			Wittenoom Aquifer	2	3	1	1	6	
		Surface water and runoff	Runoff	6	6	7	3	756	***High Risk*** that runoff from waste rock landforms will cause AMD if not properly disposed of. The consequences, likelihood and extent can be mitigated if the WRL is properly designed with only benign, water shedding, material as cover but the duration of WRL will remain centuries and as a result the risk can be **mitigated to *Low Risk***
			Pinarra Creek and other minor onsite tributaries	5	6	7	3	630	***High Risk*** that the Pinarra Creek, which is situated in the centre of the mining footprint, will be heavily impacted by either runoff or flow interruption. The consequence of this impact can be reduced to insignificant with properly managed WRLs and because the Pinarra Creek is not of specific ecological importance. The risk can be **reduced to *Minor Risk***.
			Boolgeeda Creek	4	3	7	3	252	***Moderate Risk*** that the Boolgeeda Creek, downgradient of the mining footprint will be impacted either by runoff or interruption of flow. It is likely that significant runoff will only result after large rainfall events in which any metal or salt load is likely to be diluted, however planned WRLs are situated in tributaries and material locations and compactions must be carefully planned to reduce the consequence and likelihood to insignificant and remote, respectively, in order for the risk to be **reduced to *Low Risk***
			Duck Creek	3	2	7	2	84	***Minor Risk*** that the Duck Creek, further downgradient of the mining footprint will be impacted either by runoff or interruption of flow. It is likely that significant runoff will only result after large rainfall events in which any metal or salt load is likely to be diluted as a result the consequence can be reduced to insignificant and the risk **reduced to *Low Risk***
Sub-grade ore stockpiles	Acid generation and aluminium, iron, manganese, selenium, thallium and zinc	Direct	Pastoralists/ Future/ Indigenous land users	1	1	1	1	1	***Very Low Risk*** that any people or animals exposed directly to sub-grade ore will be effected by chemical contamination and does not require mitigation following closure.
		Seepage	Shallow Tertiary Detrital Aquifer	3	5	7	2	210	***Moderate Risk*** that deleterious sub-grade ore can oxidise and cause AMD seepage if not properly stored. The consequence, likelihood and extent can be **mitigated to *Low Risk*** if sub-grade ore (specifically basal Dales Gorge Member unit D1) is assessed for AMD drainage potential prior to storage or sent to waste disposal instead, if the risk is high, and the stockpiles are capped with benign material on closure, as the duration of ore stockpiles my remain for centuries
		Surface water and runoff	Pinarra Creek and other minor onsite tributaries	2	5	7	2	140	***Minor Risk*** that deleterious sub-grade ore can oxidise and cause AMD runoff if not properly stored. The consequence, likelihood and extent can be **mitigated to *Low Risk*** if sub-grade ore (specifically basal Dales Gorge Member unit D1) is assessed for AMD drainage potential prior to storage or sent to waste disposal instead if the risk is high, and the stockpiles are capped with benign material on closure, as the duration of ore stockpiles my remain for centuries
			Boolgeeda Creek	2	1	2	4	16	***Low Risk*** that the Boolgeeda and Duck Creeks, downgradient of the mining footprint will be impacted by runoff. A significant volume of runoff could only reach these creeks during a very large event which would result in any metal or salt load being highly diluted.
			Duck Creek	1	1	2	5	10	
Tailings storage facilities	Early stage uncertainty and minor chromium drainage	Direct	Pastoralists/ Future/ Indigenous land users	1	1	1	1	1	***Very Low Risk*** that any people or animals exposed directly to tailings will be effected by chemical contamination and does not require mitigation following closure.
		Seepage	Shallow Tertiary Detrital Aquifer	1	6	5	2	60	***Minor Risk*** from tailings seepage into the Tertiary Aquifer. The water quality is unlikely to be poor and thus the consequence is low, however the likelihood and duration cannot be mitigated, the extent could be reduced by slurry return and dewatering operations to **mitigate to Low Risk**.
			Mineralised Brockman Aquifer	1	6	1	1	6	***Low Risk*** from tailings seepage to this aquifer: while the likelihood of seepage occurring is high, the quality is unlikely to adversely impact the aquifer and the consequence of any seepage is low.
			Wittenoom Aquifer	4	6	5	3	360	***Moderate Risk*** from tailings seepage into the Wittenoom Aquifer. The seepage may cause AMD if coming into contact with pyritic shale material and thus the consequence is higher and the likelihood and duration cannot be mitigated. The only mitigation measure available is to avoid this scenario by siting the TSF away from any pyritic shale material and reducing seepage volume by dewatering operations and efficient water return to **reduce to *Low Risk***.
		Surface water and runoff	Pinarra Creek and other minor onsite tributaries	1	5	5	1	25	***Low Risk*** from tailings seepage into the Pinarra Creek. While the likelihood of seepage occurring is high, the quality is unlikely to adversely impact the aquifer and the consequence of any seepage is low.
			Boolgeeda Creek	1	1	2	3	6	***Low Risk*** that the Boolgeeda and Duck Creeks, downgradient of the mining footprint will be impacted by tailings seepage as the distances are too great. A significant volume of seepage could only reach these creeks during a very large, rare event which would result in any metal or salt load being highly diluted.
			Duck Creek	1	1	2	5	10	

Source	Specific concern	Transport	Potential Receptors	Consequence	Likelihood	Duration	Extent	Unmitigated Risk Rating	Description of risk and possible mitigation measures to reduce risk post- closure
Mine void wall rock	Acid generation and neutral/ alkaline drainage containing aluminium, arsenic, manganese, selenium and zinc with minor beryllium, cobalt, chromium, copper, thallium and nickel	Direct	Pastoralists/ Future/ Indigenous land users	1	1	1	1	1	***Very Low Risk*** that any people or animals exposed directly to wall rock will be effected by chemical contamination and does not require mitigation following closure.
		Seepage	Shallow Tertiary Detrital Aquifer	4	4	6	2	192	***Moderate Risk*** from wall rock seepage into the aquifers. There is a risk to water quality if West Angela Member shale is exposed in the walls of mine voids that are in connection with aquifers the consequence, likelihood and duration can be reduced if exposure is reduced and risk can be **mitigated to *Low Risk***.
			Mineralised Brockman Aquifer	4	4	6	2	192	
			Wittenoom Aquifer	4	3	6	2	144	***Minor Risk*** from wall rock seepage into the Wittenoom Aquifer. There is a risk to water quality if West Angela Member shale is exposed in the walls of mine voids that are in connection with aquifers, however the risk is lower as the shale units will reduce the permeability into the Wittenoom Aquifer. The consequence, likelihood and duration can be reduced if exposure is reduced and risk can be **mitigated to *Low Risk***.
		Surface water and runoff	Pinarra Creek and other minor onsite tributaries	4	5	2	3	120	***Moderate Risk*** from wall rock seepage into the Pinarra Creek. There is a risk to water quality if West Angela Member shale is exposed in the walls of mine voids that are in connection with surface water. The consequence, likelihood and duration can be reduced if exposure is reduced and risk can be **mitigated to *Low Risk***.
			Boolgeeda Creek	2	3	2	3	36	***Low Risk*** that the Boolgeeda and Duck Creeks, downgradient of the mining footprint will be impacted by wall rock runoff as the distances are too great. A significant volume of runoff could only reach these creeks during a very large, rare event which would result in any metal or salt load being highly diluted.
			Duck Creek	1	2	2	5	20	
Backfill material / below or above water table waste rock / tailings storage	Acid generation and neutral/ alkaline drainage containing aluminium, arsenic, manganese, selenium and zinc with minor beryllium, cobalt and thallium	Direct	Pastoralists/ Future/ Indigenous land users	1	1	1	1	1	***Very Low Risk*** that any people or animals exposed directly to backfill will be effected by chemical contamination and does not require mitigation following closure.
		Seepage	Shallow Tertiary Detrital Aquifer	4	4	2	2	64	***Minor Risk*** that deleterious backfill material can oxidise and cause AMD if not properly disposed of in backfill. The consequence, likelihood and extent can be **mitigated to *Low Risk*** if backfill design and waste scheduling is carefully managed and maintained to prevent the ingress of oxygen and water as the duration of backfill will remain centuries
			Mineralised Brockman Aquifer	4	4	2	2	64	
			Wittenoom Aquifer	2	2	2	1	8	***Low Risk*** that deleterious backfill can oxidise and cause AMD if not properly disposed of in backfill as interbedded shale units will reduce the permeability into the Wittenoom Aquifer.
		Groundwater Flow	Shallow Tertiary Detrital Aquifer	4	5	6	1	120	***Minor Risk*** that groundwater in contact with backfill can cause AMD if deleterious material is not properly disposed of in backfill. The consequence can be reduced if only benign material is used and **mitigated to *Low Risk***.
			Mineralised Brockman Aquifer	4	5	6	1	120	
			Wittenoom Aquifer	1	1	1	1	1	***Very Low Risk*** from groundwater in contact with backfill impacting the aquifer as interbedded shale units will reduce the permeability into the Wittenoom Aquifer.
		Surface water and runoff	Pinarra Creek and other minor onsite tributaries	4	6	2	3	144	***Minor Risk*** that backfill runoff into the Pinarra and Boolgeeda Creeks can cause AMD if deleterious material is not properly disposed of in backfill. The consequence can be reduced if only benign material is used and **mitigated to *Low Risk***.
			Boolgeeda Creek	3	2	2	5	60	
			Duck Creek	1	2	2	5	20	***Low Risk*** that Duck Creek downgradient of the mining footprint will be impacted by backfill runoff as the distance is too great. A significant volume of runoff could only reach these creeks during a very large, rare event which would result in any metal or salt load being highly diluted.
Episodic, ephemeral/ semi-permanent mine void water	Acid generation and neutral/ alkaline drainage containing aluminium, arsenic, manganese, selenium and zinc with minor beryllium, cobalt and thallium	Direct	Pastoralists/ Future/ Indigenous land users	2	2	1	1	4	***Very Low Risk*** that any people or animals exposed directly to episodic, ephemeral or semi-permanent water will be effected by chemical contamination and does not require mitigation following closure.
		Groundwater Flow	Shallow Tertiary Detrital Aquifer	1	5	6	1	30	***Low Risk*** that groundwater quality in contact with episodic, ephemeral or semi-permanent water would deteriorate. The quality of ingress water will mostly be controlled by rainfall with minor addition of salts and metals in contact with wall rock and through evapoconcentration and will likely be less saline than the groundwater. Surface water and rainfall ingress may result in groundwater recharge with fresher water
			Mineralised Brockman Aquifer	1	5	6	1	30	
			Wittenoom Aquifer	1	1	1	1	1	***Very Low Risk*** from groundwater in contact with backfill impacting the aquifer as interbedded shale units will reduce the permeability into the Wittenoom Aquifer.
		Surface water and runoff	Pinarra Creek and other minor onsite tributaries	4	2	2	3	48	***Minor Risk*** that accumulated salts and metals from the evapoconcentration of episodic, ephemeral or semi-permanent water would impact the Pinarra Creek. A significant volume of precipitation could only resume creek flow during a very large, rare event (less than once in 100 years) which would result in any metal or salt load being highly diluted and not a risk of contamination. The consequence can be reduced if only benign material is used for any backfill and no deleterious wall rock is exposed and **mitigated to *Low Risk***.
			Boolgeeda Creek	3	1	2	5	30	***Low Risk*** that Duck and Boolgeeda Creeks, downgradient of the mining footprint will be impacted by episodic, ephemeral or semi-permanent water as the distance is too great. A significant volume of runoff could only resume creek flow during a very large, rare event (less than once in 100 years) which would result in any metal or salt load being highly diluted.
			Duck Creek	1	1	2	5	10	

Source	Specific concern	Transport	Potential Receptors	Consequence	Likelihood	Duration	Extent	Unmitigated Risk Rating	Description of risk and possible mitigation measures to reduce risk post- closure
Permanent groundwater-fed terminal sink	Acid generation and neutral/ alkaline drainage containing aluminium, arsenic, manganese, selenium and zinc with minor beryllium, cobalt and thallium	Direct	Pastoralists/ Future/ Indigenous land users	1	2	7	1	14	***Low Risk*** that any people or animals exposed directly to permanent water will be effected by chemical concentrations at acute levels so as to suffer from poisoning. It is far more likely that water would contain too much salt load to be palatable and does not require mitigation following closure.
		Gw Flow	Shallow Tertiary Detrital Aquifer	1	1	7	1	7	***Low Risk*** that aquifers or surface water will ever be connected to the permanent pit lake water. The mine voids are bounded to the north and south by impermeable shale and to east and west by impermeable dolerite dykes and groundwater movement is restricted. In addition the mine voids are large and is never likely to sustain sufficient direct rainfall or runoff to fill and impact creek flow. High evaporation will also ensure that these sources remains terminal sinks. Water quality will likely deteriorate with high salt load and possible metalliferous drainage from exposed Mount McRae or West Angela shales in the wall, but no transport pathways to any receptors exists.
			Mineralised Brockman Aquifer	1	1	7	1	7	
			Wittenoom Aquifer	1	1	7	1	7	
		Surface water & runoff	Pinarra Creek and other tribs	1	1	7	1	7	
			Boolgeeda Creek	1	1	7	1	7	
			Duck Creek	1	1	7	1	7	
		Fractures	Unexpected/ unknown connection to aquifers	4	1	7	3	84	***Minor Risk*** that permanent water from groundwater ingress in the West End mine void has an unknown connection to the Wittenoom Aquifer. This Likelihood is Extremely Remote considering that such a fracture, or other feature allowing transport of contaminated groundwater, would have to be contiguous through both Mount McRae and Mount Sylvia Formations. If mine void water is acidic it is likely that the dolomitic Wittenoom Formation would neutralise this acidity and low pH is not considered to be a risk. The prospect of metalliferous drainage would be reduced as a result of the throughflow of groundwater in the mine void and reduced evapoconcentration. The volume of any groundwater outflow would also be likely to be fairly low and potential metalliferous contamination may be diluted. However, there is the potential for groundwater dependent ecosystems to be in contact and certainty that connection does not exist will be gained in operations or mitigation measures will be implement if proven otherwise
Permanent surface and groundwater sourced mine void terminal sink	Acid generation and neutral/ alkaline drainage containing aluminium, arsenic, manganese, selenium and zinc with minor beryllium, cobalt and thallium	Direct	Pastoralists/ Future/ Indigenous land users	1	2	7	1	14	***Low Risk*** that any people or animals exposed directly to permanent water will be effected by chemical concentrations at acute levels so as to suffer from poisoning. It is more likely that water would contain too much salt load to be palatable and does not require mitigation following closure.
		Groundwater Flow	Shallow Tertiary Detrital Aquifer	4	4	7	1	112	***Minor Risk*** that permanent water from surface and groundwater ingress in the Talisman or Broadway East mine voids will impact the local groundwater quality of the shallow Tertiary Detrital Aquifer. As groundwater contains more dissolved salts than surface water the potential for groundwater evapoconcentration increases the risk of water quality deterioration. However, high evaporation rates will likely ensure that this permanent water remains a terminal sink. Surface water modelling indicates that only a significant volume of rainfall and creek ingress could increase the water level in the mine void to be in contact with the shallow aquifer, during a very large, rare event (less than once in 100 years), which would result in any metal or salt load being highly diluted and not a risk for contamination. Reducing the amount of deleterious wall rock in contact with permanent water could reduce the consequence of any connection to the shallow aquifer and **mitigate to *Low Risk***.
			Mineralised Brockman Aquifer	3	4	7	1	84	***Minor Risk*** that permanent water from surface and groundwater ingress in the Talisman or Broadway East mine voids will impact the local groundwater quality of the Mineralised Brockman Aquifer. As groundwater contains more dissolved salts than surface water the potential for groundwater evapoconcentration increases the risk of water quality deterioration. However, groundwater flow in this aquifer is severely restricted by the Roy Hill Jeerinah Shale Formation to the north and is further compartmentalised by vertical dolerite dykes. In addition high evaporation rates will likely ensure that this permanent water remains a terminal sink. Reducing the amount of deleterious wall rock in contact with permanent water could reduce the consequence of any connection to the shallow aquifer and **mitigate to *Low Risk***.
			Wittenoom Aquifer	1	1	7	1	7	***Low Risk*** that permanent water in the Talisman or Broadway East mine voids will impact groundwater quality as interbedded shale units reduces the permeability into the Wittenoom Aquifer.
		Surface water and runoff	Pinarra Creek and other minor onsite tributaries	3	2	7	1	28	***Low Risk*** of surface water outflow from mine voids with both surface and groundwater inflows. Ingress of groundwater and minor creek tributaries, likely to be captured by mine voids, may result in permanent water but high evaporation rates will also ensure that this water remains in the void as a terminal sink. Surface water modelling indicates that only a significant volume of surface water could resume creek flow during a very large, rare event (less than once in 100 years) which would result in any metal or salt load being highly diluted and not a risk for contamination. However, the sensitivity of the ecosystem to minor salt increases is not yet known and this uncertainty is captured in the consequence.
			Boolgeeda Creek	2	2	7	1	28	
			Duck Creek	2	2	7	1	28	
Permanent surface & groundwater fed throughflow mine void	Acid generation and neutral/ alkaline drainage containing aluminium, arsenic, manganese, selenium and zinc with minor beryllium, cobalt and thallium	Direct	Pastoralists/ Future/ Indigenous land users	1	3	7	5	105	***Low Risk*** that any people or animals exposed directly to permanent water will be effected by chemical concentrations at acute levels so as to suffer from poisoning. It is more likely that water would contain too much salt load to be palatable and does not require mitigation following closure.
		Groundwater Flow	Shallow Tertiary Detrital Aquifer	1	4	7	3	84	***Minor Risk*** that permanent water from surface and groundwater ingress in the Broadway West 3 mine void will impact the local groundwater quality of the shallow Tertiary Detrital Aquifer as quality would be natural groundwater diluted by surface water, with low risk from evapoconcentration.
			Mineralised Brockman Aquifer	2	1	7	1	14	***Low Risk*** that permanent water from surface and groundwater ingress in the Broadway West 3 mine void will impact the local groundwater quality of the Mineralised Brockman Aquifer as mine void is situated in the Marra Mamba Formation & has no connection to the Mineralised Brockman Aquifer.
			Wittenoom Aquifer	1	1	7	1	7	***Low Risk*** that permanent water in the Broadway West 3 mine void will impact groundwater quality as interbedded shale units will reduce the permeability into the Wittenoom Aquifer.
		Surface water & runoff	Pinarra Creek and other tribs	1	1	7	1	7	***Low Risk*** that the Pinarra Creek will be impacted as it is located upgradient of this mine void
			Boolgeeda Creek	2	2	7	1	28	***Low Risk*** that the Boolgeeda Creek will be impacted as the majority of its length is located upgradient of the Broadway West mine voids
			Duck Creek	3	7	7	5	735	***High Risk*** of surface water outflow from the Broadway West 3 mine void with both surface and groundwater inflows. It is estimated that the quality of this water will not be highly evapoconcentrated as a result of the throughflow but some West Angela wall rock may cause AMD. The likelihood is almost certain and duration will be centuries, with a possible extent offsite for 10-20 km. This risk could be reduced to ***Moderate*** by greater certainty that the water quality will not have a negative impact, and potentially controlling the volume of the out flow by changing the shape of the mine void to reduce the extent.

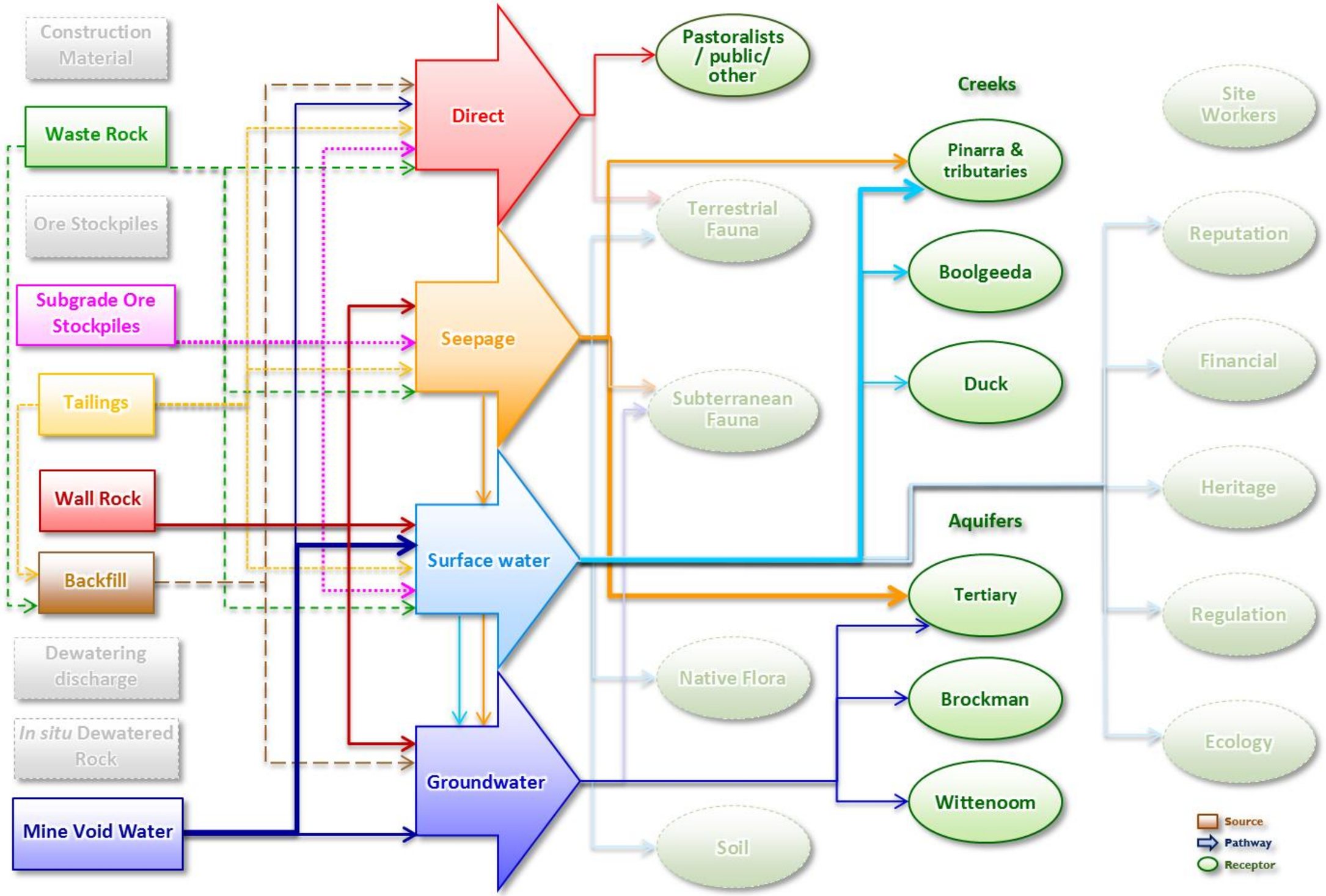

Figure 2: **Source-Pathway-Receptor connections post-closure** (A3 size page)

The conceptual site model is presented in Figure 3. The compartmentalised nature of the pre-mining groundwater levels is shown along with the likely surface and groundwater movement for different scenarios. The northern mine void is representative of the mine void risks situated in the Marra Mamba Formation while the southern mine void represents the risks from mine voids situated in the Brockman Formation. This conceptual model is a general case and specific detail, such as mine void volumes and exact extents, is subject to change. The key factors that require consideration are as follows:

- Shale units have very low permeability and risk of generating acid drainage from *in situ* dewatering of pyritic material is therefore low. Horizontal bores potentially installed to depressurise these units may cause AMD during operations, however the volume of this water would be very low and as such dewatered or depressurised units as a potential source are not considered to pose a risk to the environment in the assessment.
- Waste rock landforms require planning and management to ensure that material that may generate acid or leach metals is excluded from contact with air and water. These materials include but may not be limited to Mount McRae Shale and West Angela Member shale;
- All mine voids will temporarily contain water from direct precipitation and runoff. This water is likely to be episodic, ephemeral or semi-permanent and will quickly infiltrate and evaporate. Salt build-up as a result is not expected to be high or to pose a risk of contamination in the event of a flushing episode;
- Permanent water will occur where mining is conducted below the pre-disturbance water level ;
- Hydrological and hydrogeological modelling has indicated that groundwater-only dependent pit lakes will form in the West Side, West End, Eagles Nest and M6 (also called MM4-6) mine voids. The water quality is likely to deteriorate as a result of evaporation and runoff from Mount McRae and West Angela shale exposed in the wall rock and, over time, will contain high salinity and dissolved metals. These pit lakes will be terminal, evaporative sinks and are unconnected to any transport pathways or receptors. As such they are not considered to pose a risk to the environment, surface water or groundwater;
- The Talisman and Broadway East mine voids are highly likely to have inflows from both fresher surface water and more saline groundwater but will likely be evaporative sinks. Water quality will deteriorate over time as a result of evapoconcentration and potential exposure of West Angela Member shale in the footwall rock. There is a remote likelihood that very large, rare events of a 1:100-year's volume of rainfall will allow flushing and resumption of creek flow to occur. These events are unlikely to pose a risk of contamination from evapoconcentrated salts and metals as a result of the large dilution factor and high infiltration reducing the consequence and extent.
- The highest risk for surface and groundwater contamination is posed by the Broadway West mine voids. The risk of outflow is almost certain as a result of the larger rainfall catchment to which Broadway West is connected. This water may not undergo significant evapoconcentration as a result of significant dilution volumes but groundwater inflow is more saline naturally, there is some West Angela shale in the wall rock that may leach and impact the downstream environment.

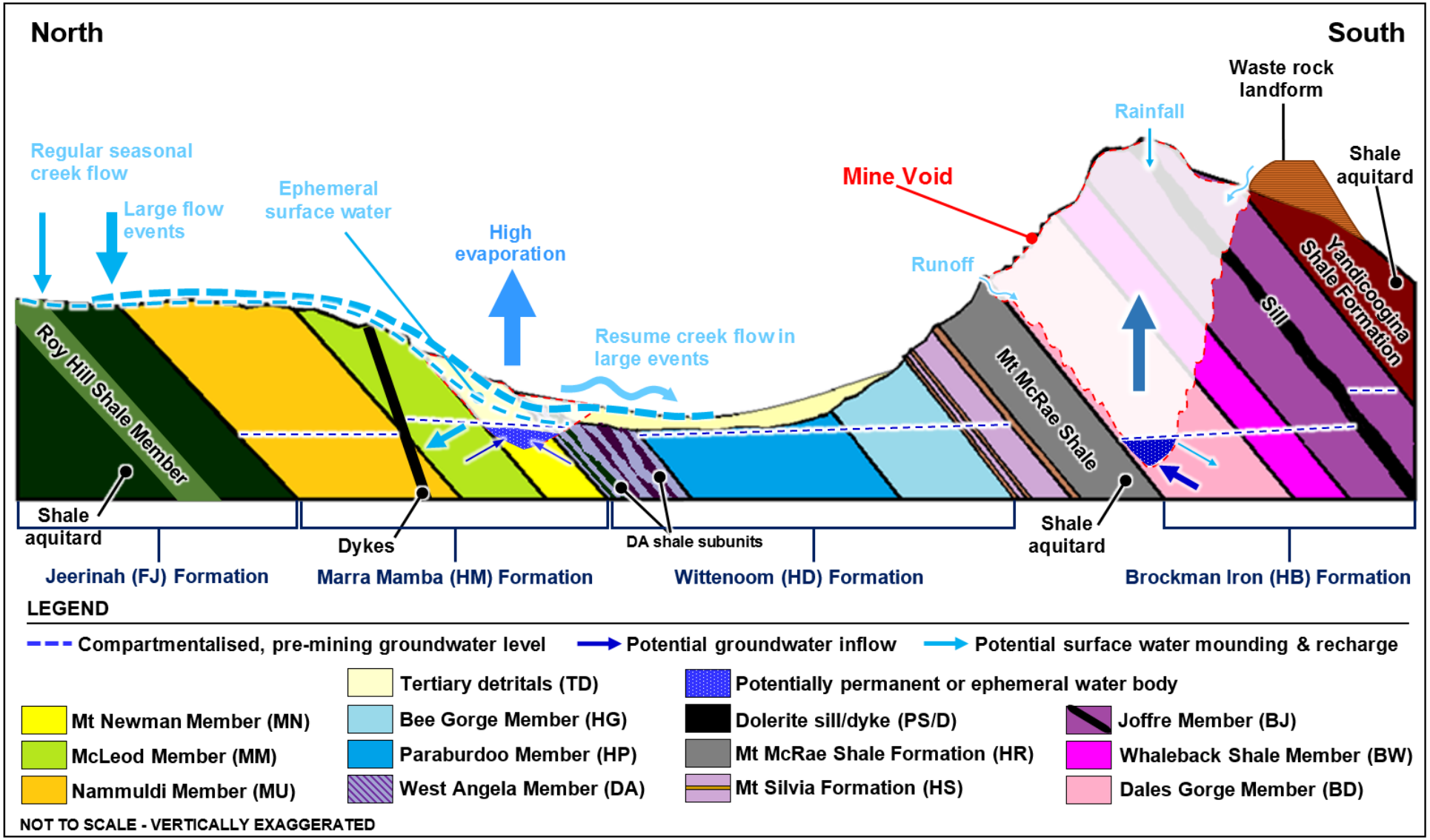

Figure 3: Conceptual site model

4. REFERENCES

1. DIIS, 2016b. *LPSDP-13: Risk Management - Leading Practice Sustainable Development Program for the Mining Industry,* Department of Industry, Innovation and Science, Commonwealth Government of Australia, Canberra: 14 September 2016, Pp 125.
2. Fortescue, 2014. *Acid and/or Metalliferous Drainage Management Plan.* FMG Report Ref.: 100-PL-EN-1016_Rev1; Fortescue Metals Group Pty. Ltd, 31 December 2014; Pp. 163.
3. Fortescue, 2015. *Western Hub Stage 1 - Geological Summary Report,* FMG Report Ref.: 2014_Draft; Fortescue Metals Group Pty Ltd.: 5 June 2015; Pp. 69.
4. Fortescue, 2017a. *Western Hub - Stage 1 Eliwana and Flying Fish: Subsurface Materials Characterisation,* FMG Report Ref.: 750WH-5700-RP-HY-0007; Fortescue Metals Group Pty. Ltd.: 31 December 2017; Pp 461.
5. Fortescue, 2017b. *Western Hub Stage 1 Conceptual Site Model and Operational Risk Assessment,* FMG Report Ref.: 750WH-5700-RP-HY-0008; Fortescue Metals Group Pty. Ltd.: 31 December 2017; Pp 41.
6. Fortescue, 2017d. *Western Hub Stage 1 Conceptual Mine Void Water Assessment,* FMG Report Ref.: 750WH-5700-RP-HY-0010; Fortescue Metals Group Pty. Ltd.: 31 December 2017; Pp 40.
7. Golder, 2017. *Western Hub - Dewatering and Water Supply Assessment - Hydrogeological Conceptual Model Report,* Report Ref.: 1671484-002-R-Rev0; Golder Associates Pty Ltd.: 30 August 2017; Pp 180.
8. NEPM, 2013. *National Environmental Protection Measure - Assessment of Site Contamination: Guideline on Site Characterisation,* Report Ref.: F2013C00288, Volume 3: Schedule B2; Office of Parliamentary Counsel, Canberra: 16 May 2013, Pp. 150.