

Pit 23 Groundwater

Assessment of Seepage Indicator Exceedances

Prepared for Iluka Resources Limited
November 2018



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Pit 23 Groundwater

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Executive Summary

A review of the groundwater and surface water environments surrounding Iluka's Pit 23 mineral sands by-product disposal facility (Pit 23) at the Douglas mine, has been undertaken to determine if recent water quality trigger level exceedances at McGlashin Swamp were caused by Pit 23 operations.

Exceedances of the precautionary trigger levels set for electrical conductivity and pH were confirmed at McGlashin Swamp based on data collected in 2017. Measurements from McGlashin Swamp are considered non-erroneous as most manually calculated ion balance errors were less than 3%.

Groundwater quality trends assessed for electrical conductivity, pH and chloride to sulphate ratio (Cl:SO₄) were analysed in the area surrounding Pit 23 and along the groundwater flow path between Pit 23 and McGlashin Swamp. No evidence of groundwater seepage and subsequent plume migration was evident. Similarly, no water quality exceedances were seen in surface water sites DUSW20 and DUSW25 located upstream of McGlashin Swamp. In addition, exceedances measured at McGlashin Swamp do not correlate with the modelled catchment runoff events. In summary, no evidence has been found to suggest the exceedances measured at McGlashin Swamp were caused by groundwater seepage or material transport via a surface water pathway from Pit 23.

The groundwater risk assessment of continued by-product disposal into Pit 23 undertaken by Jacobs (2014) stated that there was a low risk of impact to groundwater accessibility, groundwater quality and groundwater dependent ecosystems. This original assessment is deemed still valid.

The water quality exceedances measured at McGlashin Swamp were likely caused by natural phenomena including evapoconcentration and photosynthesis, which have also been noted to some degree in the nearby Jallumba Marsh and Redgum Swamp. These two wetlands should be added to the Douglas surface water monitoring program, as well as Brooksby's Swamp, an analogous surface water site for McGlashin Swamp, located outside the groundwater catchment zone of Pit 23 operations.

It is recommended that background concentrations of water quality parameters are recalculated once enough data has been collected at the new surface water monitoring locations, nominally after two years, allowing enough climatic variability in the system and ensuring statistical validity in the dataset. Precautionary and minimum trigger levels should also be implemented for ionic ratios to replace the current trigger system which uses a reduction percentage approach, making these parameters less sensitive to natural phenomena and variability.

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1 Introduction

1.1 Background

Iluka disposes of heavy mineral processing by-products generated by its Hamilton mineral separation plant to the Pit 23 Mineral Sands By-Products Disposal Facility (herein referred to as Pit 23); a mining void located at its Douglas mine.

In preparation of Iluka's Annual Environmental and Rehabilitation Performance Report for the 2017 calendar year, Iluka identified a potential indication of seepage from Pit 23. The following seepage indicators, as defined in the current endorsed Iluka Pit Mineral By-Products Disposal Environmental Management Plan (EMP; Rev 4, 6th July 2017), were noted in a down-gradient surface water monitoring point located at McGlashin Swamp:

- an observed reduction (>10%) of Cl:SO₄ during both routine and follow-up monitoring; and
- a simultaneous exceedance of the precautionary trigger values for pH and electric conductivity.

Where precautionary trigger levels are exceeded for ionic-balance and other parameters simultaneously, a requirement of the Pit 23 EMP is that Iluka initiates an investigation to determine the cause of the indicated (potential) impact.

1.2 Objectives of This Report

This report will focus on determining the cause of the water quality exceedances observed at McGlashin Swamp. This will be achieved by reviewing both the quality and pathways of groundwater and surface water in the surrounding area. The overall objectives of the review are to:

1. Evaluate the relevant Iluka-supplied monitoring data and validate that ionic balance ratios and precautionary trigger levels, as defined in the Pit 23 EMP, were exceeded in the 2017 reporting period.
2. Determine the likely cause of the identified exceedances with consideration of:
 - a) Seepage/groundwater flow rates in the Douglas Mine/Pit 23 groundwater model; and
 - b) Potential natural processes influencing the observed exceedances.
3. If the assessment determines that observed exceedances may be seepage driven, assess the likely level of impact to the receiving environment and any beneficial uses.
4. If the assessment determines that observed exceedances are not, or are unlikely to be, seepage driven:
 - a) validate the risk assessment findings of prior studies into Pit 23 seepage and risk/impact studies to downstream receptors, including McGlashin Swamp; and
 - b) assess the appropriateness of the current ionic balance ratios with consideration of observed fluctuations and provide recommendations on their revision, if relevant.

5. Evaluate the possibility of a surface water pathway for the observed water quality changes through a desktop review of:
 - a) the McGlashin Swamp surface water catchment's proximity to mine activity; and
 - b) rainfall data for the period preceding the observed changes in water quality parameters.

1.3 Previous Work

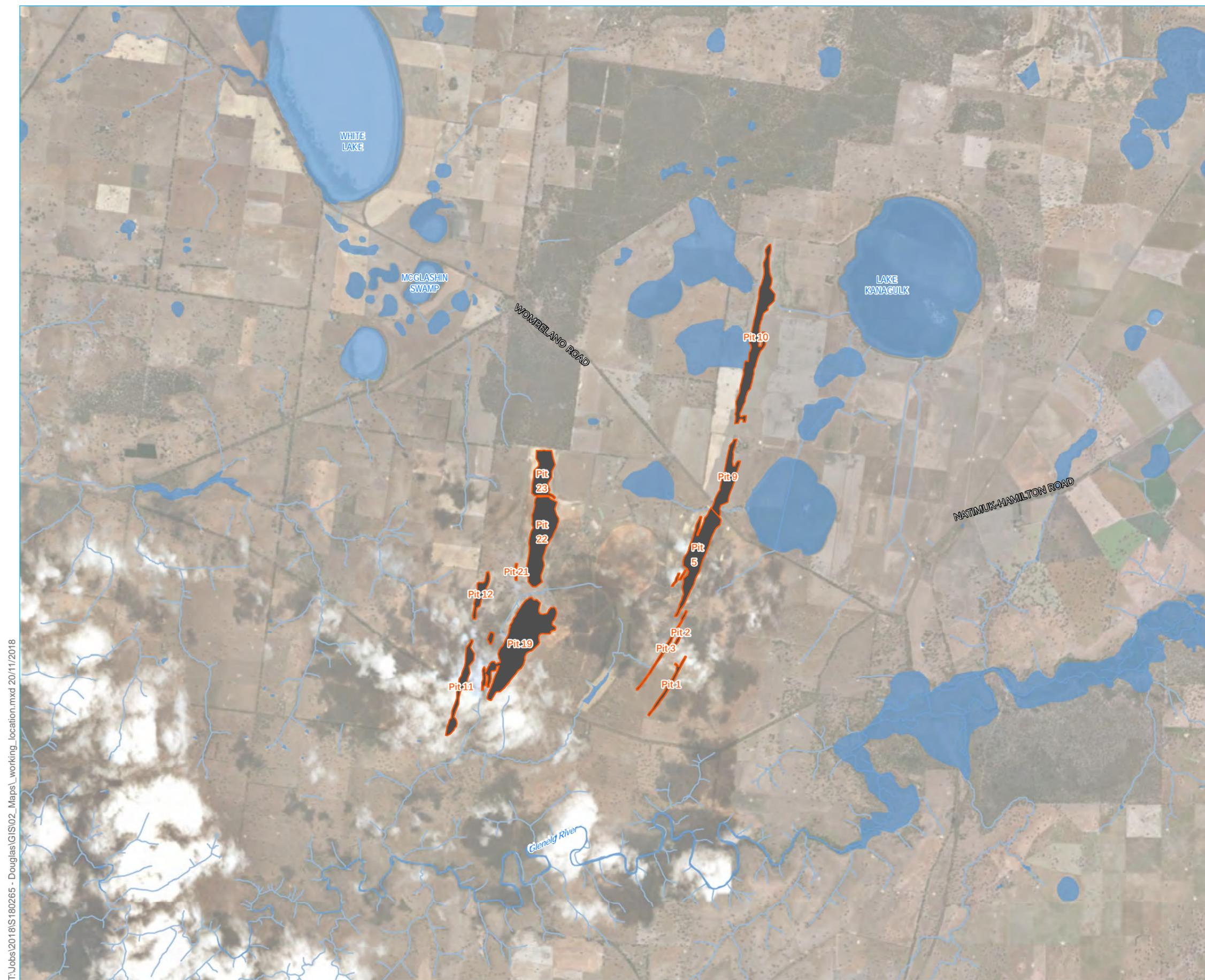
Reports by CDM Smith (2014, 2015) and Jacobs (2014) have investigated the hydrogeological risk associated with heavy mineral concentrate (HMC) by-product disposal into Pit 23 at the Douglas Mine. The aim of these reports were to support the environmental approvals process associated with long term disposal of by-products into Pit 23 by predicting the impacts on local groundwater resources and sensitive receptors.

Hydrogeological modelling was undertaken by CDM Smith (2014) to assess potential impacts on groundwater levels and to determine the behaviour of water particles originating from Pit 23. Modelling considered the scenarios where by-product disposal did and did not continue. In both cases, it was determined that particles from Pit 23 would discharge to the surface through either evapotranspiration, the North-West Drainage Line or McGlashin Swamp. Groundwater from Pit 23 is predicted to take 285 years to reach McGlashin Swamp in either case, and it is not predicted to reach any stock or domestic bores.

Particle tracking simulations of seepage water from the mined pits and the TSF at the Douglas Mine were completed by CDM Smith (2015). These simulations confirmed the Pit 23 groundwater path previously found by CDM Smith (2014) and estimated that particles would first start arriving at McGlashin Swamp between the years 2140 and 2160, depending on model assumptions.

An assessment of the risks posed by continued by-product disposal was undertaken by Jacobs (2014). As part of this assessment, leachability tests were performed on the by-products. These tests found that while contaminants such as radium-226, radium-228, chromium and arsenic are present in the by-products, they are not readily soluble and so have a low risk of entering the groundwater system. In addition to this, the majority of any contaminant dilution will occur within 500 m of Pit 23, meaning that negligible concentrations will be observed in the North-West Drainage Line or McGlashin Swamp which are 2000–3000 m away respectively.

Overall, Jacobs (2014) assessed the consequences as 'low', as the environmental impacts are predicted to be within natural variability and inter-connected systems are unlikely to be affected. The likelihood of impact was rated as 'unlikely' as the contaminant by-products were found to be not readily soluble and will dilute before reaching sensitive receptors. The overall hydrogeological risk of continued by-product disposal was therefore given an overall rating of 'low'.



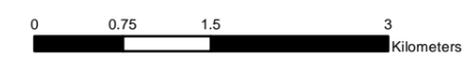
KEY

- Pre-mine drainage
- Pit
- Swamps and wetland

Figure 1.1
 Douglas mine site and
 surrounding environment
 Iluka Resources
 Douglas pit 23

T:\Jobs\2018\180265 - Douglas\GIS02_Maps\working_location.mxd 20/11/2018

Source: EMM (2018); CDMSmith (2015); GA (2015)



GDA 1994 MGA Zone 54



2 Validation of Observed Exceedances

2.1 Management Criteria

The water quality guidelines applicable to Pit 23 and the Douglas Mine site are detailed in the SEPP Guidelines (Waters; EPA Victoria 2018). The SEPP guidelines list beneficial uses that surface water bodies should meet the quality standards for; these uses are shown in Table 2.1, noting that only the water body types relevant to this investigation are shown. The “Lakes and Swamps” category includes wetlands like McGlashin Swamp, while “Murray & Western Plains Rivers and Streams” covers all other flowing bodies in the area. Table 2.1 shows that the streams and rivers surrounding Pit 23 should be suitable for all beneficial uses except navigation and shipping. McGlashin Swamp and other wetlands must be suitable for all purposes except for industrial and commercial use, and for navigation and shipping.

The SEPP guidelines state that these beneficial uses are protected, except in circumstances where the background levels of water quality indicators exceed the relevant quality guidelines. In these cases, the background levels become the environmental quality objective.

A summary of the water quality objectives specified in the SEPP guidelines are shown in Table 2.2. These are derived from the Australia and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018) using a protection level of 95% where applicable, as required by the SEPP guidelines for slight to moderately modified systems. Note that the quality objectives for pH, oxygen, turbidity, conductivity, total phosphorus and total nitrogen have only been listed in the SEPP in relation to rivers and streams, not wetlands and lakes. Water quality objectives that are compared to the 25th or 75th percentiles must be calculated from a minimum of 11 data points collected from monthly monitoring over one year.

In the case of McGlashin Swamp, baseline levels of some of the monitored parameters exceed the values shown in Table 2.2 and therefore the target values for these analytes are based on background measurements. In their Mineral Sands By-Product Disposal EMP (Rev 4, 6th July 2017), Iluka defines the background levels for naturally exceeding analytes as the 75th percentile value of past monitoring results, based on the mean, standard deviation and the assumption of a normal distribution of results. Table 2.3 summarises the revised quality objectives for monitored parameters at McGlashin Swamp where the background levels are naturally higher than those in Table 2.2.

Table 2.1 Surface water beneficial uses (EPA Victoria 2018)

Beneficial Uses	Lakes and Swamps	Murray & Western Plains Rivers and Streams
Aquatic ecosystem is considered:		
largely unmodified		
slight to moderately modified	✓	✓
highly modified		
Water suitable for:		
primary contact recreation	✓	✓
secondary contact recreation	✓	✓
aesthetic enjoyment	✓	✓
traditional owner cultural values	✓	✓
cultural and spiritual values	✓	✓
agriculture and irrigation	✓	✓
human consumption of aquatic foods	✓	✓
aquaculture	where the environmental quality is suitable, and an aquaculture licence has been approved in accordance with the <i>Fisheries Act 1995</i> .	
human consumption after appropriate treatment	where water is sourced for supply in accordance with the special water supply catchment areas set out in Schedule 5 of the <i>Catchment and Land Protection Act 1994</i> or the <i>Safe Water Drinking Act 2003</i> .	
industrial and commercial use		✓
navigation and shipping		

Table 2.2 SEPP (Waters; EPA Victoria 2018) surface water quality indicators and objectives

Analyte	Value	Units	Condition
pH	≥7.0	pH units	25 th percentile
	≤8.0	pH units	75 th percentile
Oxygen	≥65	% Saturation	25 th percentile
	≤130	% Saturation	maximum
Turbidity	≤20	NTU	75 th percentile
Conductivity	≤2,500	µS/cm at 25°C	75 th percentile
Total phosphorus	≤55	µg/L	75 th percentile
Total nitrogen	≤1,000	µg/L	75 th percentile

Table 2.2 SEPP (Waters; EPA Victoria 2018) surface water quality indicators and objectives

Analyte	Value	Units	Condition
Metals and Metalloids			
Aluminium	55	µg/L	maximum
Arsenic (III)	24	µg/L	maximum
Arsenic (V)	13	µg/L	maximum
Boron	370	µg/L	maximum
Cadmium	0.2	µg/L	maximum
Chromium (VI)	0.4	µg/L	maximum
Copper	1.4	µg/L	maximum
Lead	3.4	µg/L	maximum
Manganese	1,900	µg/L	maximum
Mercury (inorganic)	0.6	µg/L	maximum
Nickel	11	µg/L	maximum
Selenium (total)	11	µg/L	maximum
Silver	0.05	µg/L	maximum
Zinc	8	µg/L	maximum
Non-metallic Inorganics			
Ammonia	900	µg/L	maximum
Chlorine	3	µg/L	maximum
Cyanide	7	µg/L	maximum
Nitrate	700	µg/L	maximum
Hydrogen sulphide	1.0	µg/L	maximum
Radionuclides			
Radium-226	5	Bq/L	maximum
Radium-228	2	Bq/L	maximum
Uranium-238	0.2	Bq/L	maximum

Table 2.3 Revised quality targets for McGlashin Swamp (2017 monitoring data)

	pH	Aluminium (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)
Count	4	4	4	4
SEPP guideline	7.0–8.0	0.055	1	0.055
Background value (75 th percentile)	9.09	0.46	3.5	1.70

2.2 McGlashin Swamp Exceedances

Due to naturally high background levels of some analytes outlined in the SEPP (Waters; EPA Victoria 2018), the Pit 23 surface water management plan (Iluka 2017) compares water quality measurements from McGlashin Swamp to trigger levels derived from background data. Assuming sufficient data is available, the upper trigger levels are taken to be the background levels (Table 2.3), while the precautionary trigger levels are set at 85% of the upper trigger levels or at the SEPP objectives, whichever is higher. Where sufficient data has not been collected, the precautionary and upper trigger levels are set as 1.25 and 1.5 times the background value, respectively.

An investigation into the water quality is required when repeated exceedances are observed in Cl:SO₄ or sodium:calcium ratios (>10% reduction). To confirm an exceedance, the sampling and analysis process is repeated. As part of this investigation, monitored water quality parameters are compared to the trigger levels to determine if any exceedances are present. If the average of the two results (the initial measurement and the repeat) is greater than the precautionary trigger value, then the cause of the exceedance must be investigated.

Water quality data including Cl:SO₄, electrical conductivity and pH levels measured at McGlashin Swamp from 2017 is shown in Table 2.4. Table 2.5 shows the precautionary and upper trigger values calculated for these analytes based on the 2017 data as well as all the data, assuming the data collected is sufficient for these calculations. Values in Table 2.4 have been highlighted where they exceed the relevant trigger levels. Where measurements have been repeated to confirm an exceedance, the two-sample averages have been calculated and are shown in Table 2.6. From Table 2.4 through to Table 2.6, the following can be observed:

- pH values exceed the precautionary trigger levels in every measurement and exceed the upper trigger level in 4 out of the 10 measurements;
- electrical conductivity exceeds the precautionary trigger level for 8 out of 10 measurements. All conductivity measurements taken in 2018 have exceeded at least the precautionary trigger level;
- 7 out of 9 Cl:SO₄ reduction calculations have found reductions greater than 10% of the previous value;
- repeated Cl:SO₄ exceedances are seen between 26/06/2017 and 11/10/2017, as well as between 19/06/2018 and 12/09/2018. The fact that these exceedances have occurred over the same period in 2017 and 2018 could imply that they are due to natural variations;
- in each case where repeated Cl:SO₄ exceedances are seen, the two-sample averages of both pH and electrical conductivity are above the precautionary trigger levels; and
- the two-sample average of total nitrogen also exceeds precautionary trigger levels over Jun–Jul and Jul–Aug 2018.

Based on this assessment, and per the current endorsed Pit 23 EMP, the conditions that necessitate an investigation into the water quality at McGlashin Swamp have been met in 2017. Cl:SO₄, pH and electrical conductivity all exceed the trigger values derived when assuming enough data has been collected to represent background levels. This is likely not an accurate assumption however, as only four data points were collected over the span of 10 months. Table 2.7 summarises the trigger levels calculated for each analyte when assuming insufficient data has been collected. In this case, exceedances are still highlighted based on the two-sample averages, as indicated by the bold values for pH, electrical conductivity and total nitrogen (Table 2.6).

Table 2.4 McGlashin Swamp water quality measurements 2017–2018

Measurement Date	Cl:SO ₄	Reduction in Ratio	Electrical Conductivity (µS/cm)	pH	Aluminium (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Dissolved Oxygen (% saturation)
19/01/2017	312		1,500	8.57	0.3	1.2	1.66	-
26/06/2017	66.25	79%	2,530	8.91	0.47	5	1.8	110
12/09/2017	13.16	80%	2,120	8.61	0.45	2.8	0.92	82
11/10/2017	11.52	12%	2,290	9.61	0.09	3	0.69	85
15/01/2018	14.26	-24%	3,710	10.4	0.04	4.6	0.35	236
9/04/2018	42.31	-197%	8,336	8.76	0.09	11	1.9	64
19/06/2018	36.84	13%	6,900	9.07	0.17	6.1	0.76	218
17/07/2018	30.43	17%	6,800	9.4	0.12	6.1	0.73	-
14/08/2018	26.39	13%	6,200	9.7	0.12	5.6	0.60	-
12/09/2018	22.47	15%	6,700	9.7	-	-	-	-

Notes: Highlighted values exceed precautionary triggers from Table 2.5, or are Cl:SO₄ reductions greater than 10%.

Table 2.5 Trigger levels calculated for water quality parameters at McGlashin Swamp

Trigger Type	pH (upper)	Electrical Conductivity (µS/cm)	Aluminium (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Dissolved Oxygen (upper) (% saturation)
Precautionary Trigger (2017 data)	8.0	2,125	0.39	3.0	1.44	110
Upper Trigger (2017 data)	9.09	2,500	0.46	3.5	1.70	130
Precautionary Trigger (all data)	8.0	5,759	0.26	5.2	1.41	162
Upper Trigger (all data)	9.68	6,775	0.30	6.1	1.66	191

Table 2.6 McGlashin Swamp water quality parameter two-sample averages

Date Range	pH (upper)	Electrical Conductivity (µS/cm)	Aluminium (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Dissolved Oxygen (upper) (% saturation)
Sep–Oct 2017	8.76	2,205	0.27	2.9	0.81	84
Jun–Jul 2018	9.24	6,850	0.15	6.1	0.75	-
Jul–Aug 2018	9.55	6,500	0.12	5.9	0.67	-
Aug–Sep 2018	9.7	6,450	-	-	-	-

Notes: Highlighted values exceed the relevant precautionary trigger values from Table 2.5. Bolded values exceed trigger levels from Table 2.7

Table 2.7 McGlashin Swamp water quality trigger levels (assuming insufficient measurements (2017))

	pH (upper)	Electrical Conductivity (µS/cm)	Aluminium (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Dissolved Oxygen (upper) (% saturation)
Precautionary trigger (1.25x background level)	9.19	2,940	0.57	4.4	2.12	122
Upper trigger (1.5x background level)	9.27	3,530	0.68	5.3	2.54	146

2.3 Ion Balance Error

To check the validity of the laboratory supplied water quality results used to assess exceedances at the Douglas site, the ion balance errors were manually calculated from the reported major ion concentrations and compared to laboratory supplied values. It is noted however that samples taken from McGlashin Swamp (DUSW24) have not had laboratory supplied values for total anion and cation concentrations provided since January 2017, preventing comparison with manually calculated values for subsequent measurements. Various surface water and groundwater samples collected across the site during the period where the most recent exceedances were observed (July–September 2018) have also been analysed for ion balance errors to determine whether errors are observed across different sites.

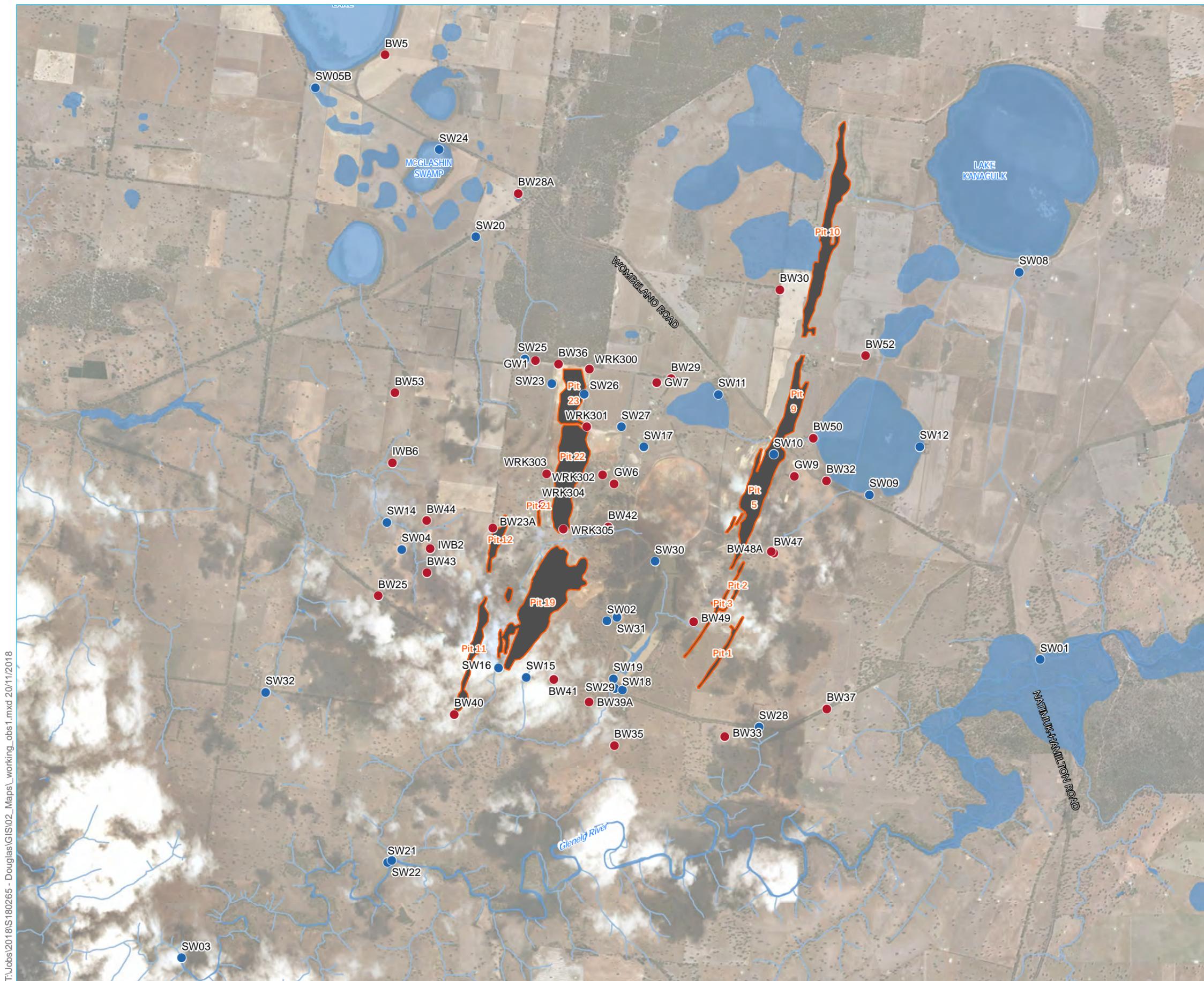
Bartram & Ballance (1996) state that the calculated ion balance error for groundwaters should be less than 5%, and less than 10% for surface waters. Exceeding these values suggests that errors are present, although it is possible for outliers to naturally occur. Errors that can lead to large ion balance errors include analytical error, not measuring a significant ion and analysing unfiltered samples.

Table 2.8 shows the ion balance errors manually calculated for each sample taken at McGlashin Swamp, while Table 2.9 compares manually calculated ion balance errors from other surface water and groundwater monitoring locations at Douglas to laboratory supplied values. Locations of all monitoring points sampled during the 2017 calendar year are also shown in Figure 2.1.

From Table 2.8 and Table 2.9, the following is seen:

- manually calculated ion balance errors for McGlashin Swamp samples are all very low (<5%), except for the sample taken on 26 June 2017, which has an error of 21%. This large error is likely due to an error in measuring alkalinity; the total alkalinity measured for this sample was 130 mg/L, compared to an average of 300 mg/L for other measurements;
- the manually calculated and laboratory supplied ion balance errors for the 19 January 2017 McGlashin Swamp sample are very similar, suggesting the results are valid;
- DUSW11, DUSW17 and DUSW26 all have high manual and laboratory derived ionic balance values. This may be a result of how fresh these water sources are. They are the freshest waters listed, and so a difference of 1–2 meq of ions leads to a large relative error;
- the manually calculated ion balance values are approximately the same as those reported by the laboratory for most of the other Douglas sites analysed. The largest difference between the calculated and reported value occurs in BW5, with a difference of 5.1%; and
- apart from the previously mentioned sites, all of the sample points show both manually calculated and laboratory reported ionic balance values that are lower than the 5 or 10 % guidelines as discussed.

Laboratory reported data from this period should therefore be considered valid, as only the freshest water systems showed evidence of error. McGlashin Swamp in particular, despite being a surface water body, showed very low ion balance errors of less than 3% in most cases.



- KEY**
- Groundwater monitoring site
 - Surface water monitoring site
 - Pre-mine drainage
 - Pit
 - Swamps and wetland

Figure 2.1
Monitoring locations
sampled during 2017
Iluka Resources
Douglas pit 23

T:\Jobs\2018\180265 - Douglas\GIS02_Maps\working_obs1.mxd 20/11/2018

Source: EMM (2018); CDMSmith (2015); GA (2015)



GDA 1994 MGA Zone 54



Table 2.8 Manual ionic balance calculations McGlashin Swamp samples

Sample Point	Date	Ionic Balance ² Manual Calculation (% error)	Ionic Balance Laboratory Value (% error)	Total Ions (Manual calculation) (meq/L)
DUSW24 ¹	19/01/2017	-4.8	-4.7	31
DUSW24	26/06/2017	21.0	-	45
DUSW24	12/09/2017	-1.1	-	52
DUSW24	11/10/2017	0.5	-	45
DUSW24	15/01/2018	2.8	-	71
DUSW24	9/04/2018	-1.9	-	139
DUSW24	19/06/2018	-2.6	-	128
DUSW24	17/07/2018	0.9	-	133
DUSW24	14/08/2018	-1.8	-	117

Notes: 1. DUSW24 refers to the McGlashin Swamp sampling point;
2. negative values for % error indicate more anions in the solution, while positive values indicate more cations; and
3. dashes (-) are used where laboratory values were not supplied.

Table 2.9 Manual ionic balance calculations for recent measurements compared to laboratory supplied values

Sample Point ¹	Date	Ionic Balance ² Manual Calculation (% error)	Ionic Balance Laboratory Value (% error)	Total Ions (Laboratory) (meq/L)
DUSW11	10/09/2018	18.8	19.3	5.7
DUSW17	10/09/2018	24.3	23.7	7.6
DUSW18	10/09/2018	4.6	3.5	8.7
DUSW19	10/09/2018	-0.1	0.0	10
DUSW03	10/09/2018	-2.1	-2.7	37
DUSW01	10/09/2018	0.4	0.0	40
BW28A	20/08/2018	0.1	0.0	460
BW5	20/08/2018	1.5	-3.6	560
WRK300	17/07/2018	-0.8	-0.9	111
DUSW26	16/07/2018	26.4	26.3	5.7
WRK301	10/07/2018	2.4	0.0	220
WRK302	10/07/2018	0.8	2.3	430
WRK304	10/07/2018	-1.3	0.0	150
WRK303	10/07/2018	-1.8	-1.3	158
BW40	5/07/2018	-1.5	-1.7	120
BW42	5/07/2018	-0.2	0.0	380

Table 2.9 Manual ionic balance calculations for recent measurements compared to laboratory supplied values

Sample Point ¹	Date	Ionic Balance ² Manual Calculation (% error)	Ionic Balance Laboratory Value (% error)	Total Ions (Laboratory) (meq/L)
BW49	5/07/2018	-0.8	0.8	131
BW48A	5/07/2018	-1.4	0.0	240
BW47	4/07/2018	0.0	0.0	420
BW50	4/07/2018	-1.7	-0.5	191
BW52	4/07/2018	0.3	-1.8	165
BW43	3/07/2018	2.3	0.0	10.6
IWB2	3/07/2018	2.1	1.3	77
IWB6	3/07/2018	2.1	0.0	30

Notes: 1. sample points beginning with 'DUSW' refer to surface water samples; and
 2. negative values for % error indicate more anions in the solution, while positive values indicate more cations.

3 Groundwater Seepage Assessment

Due to the repeated decreases of more than 10% seen in Cl:SO₄ in 2017, the possibility of groundwater seepage from Pit 23 to McGlashin Swamp must be assessed per Section 8.7 of the Pit 23 EMP.

A decrease in Cl:SO₄ can indicate groundwater seepage due to the different ionic ratios seen in surface water mixing with the potential leachate. These ratios are shown in Table 3.1 and are based on laboratory tests and in-pit dissolution modelling completed by Iluka (2016). The leachate is dominated by the Ca-SO₄ ion pair and has very low Cl:SO₄; therefore, it is expected that groundwater seepage from Pit 23 would cause a noticeable decrease Cl:SO₄ of groundwater-connected surface waters.

Table 3.1 Ionic ratios in surface waters and Pit 23 leachate (Iluka 2017)

	Surface Waters (all sites)			Pit 23 Leachate	
	Average	Maximum	Minimum	Laboratory	Model
Chloride/sulphate	7.32	8.76	5.62	0.008	0.015
Sodium/calcium	23.95	38.67	11.45	0.017	0.050

3.1 Groundwater Model Review

CDM Smith (2014, 2015) has produced two reports which model the groundwater system across the Douglas mine site, with attention given to groundwater seepage from Pit 23. These studies found that groundwater seepage from Pit 23 would flow to the north-west, eventually discharging to the surface at McGlashin Swamp, the North-West Drainage Line, or through evapotranspiration. The modelled groundwater seepage flow paths are shown in Figure 3.1.

In addition to determining the flow path of Pit 23 groundwater seepage, the travel time of water particles was also modelled. These predictions considered two different scenarios:

1. the base case, which assumes that no further disposal of by-products to Pit 23 continues after the processing of heavy mineral concentrate (HMC) produced at the Woornack, Rownack and Pirro (WRP) mine is completed at the Iluka Hamilton Mineral Separation Plant (MSP); and
2. the future disposal case, which assumes that by-product disposal to Pit 23 will continue for an additional 20 years after the HMC from WRP has been processed.

Figure 3.2 shows the modelled particle tracks and travel times, where the purple and blue lines represent the base and future disposal cases respectively. This figure shows that groundwater particles are expected to take at least 240 years to reach McGlashin Swamp, which corresponds to the year 2251 as by-product disposal into Pit 23 began in 2011. CDM Smith (2015) modelled uncertainty cases beyond what is shown in Figure 3.2 and found particle arrival years to McGlashin Swamp from Pit 22/Pit 23 ranging from 2140 to 2160. In any case, these modelled scenarios suggest it is very unlikely that by-product seepage from Pit 23 has reached McGlashin Swamp.

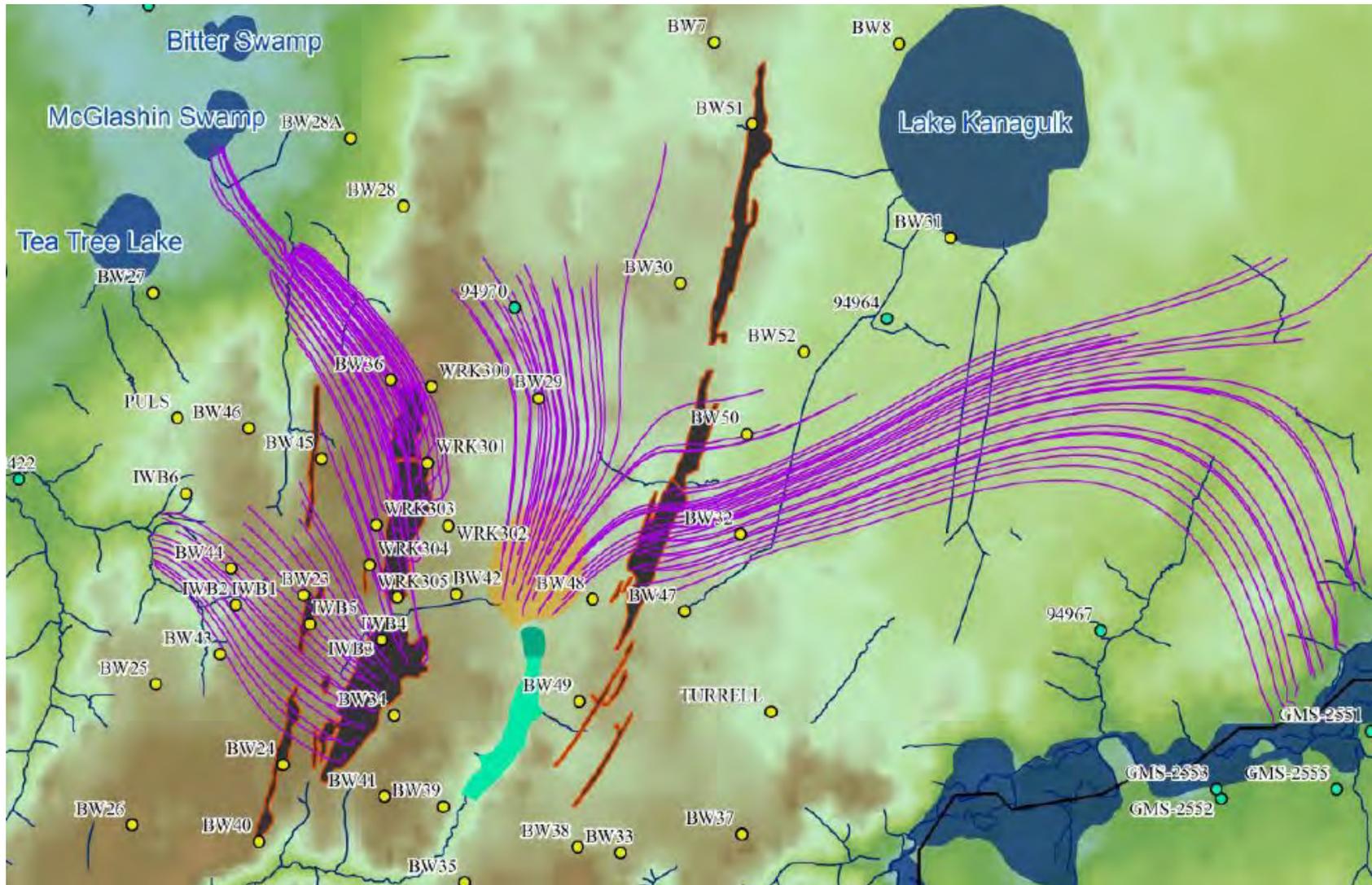


Figure 3.1 Particles originating from Pit 5, Pit 19, Pit 22, Pit 23 and the TSF tracked across the Douglas mine site (CDM Smith 2015)

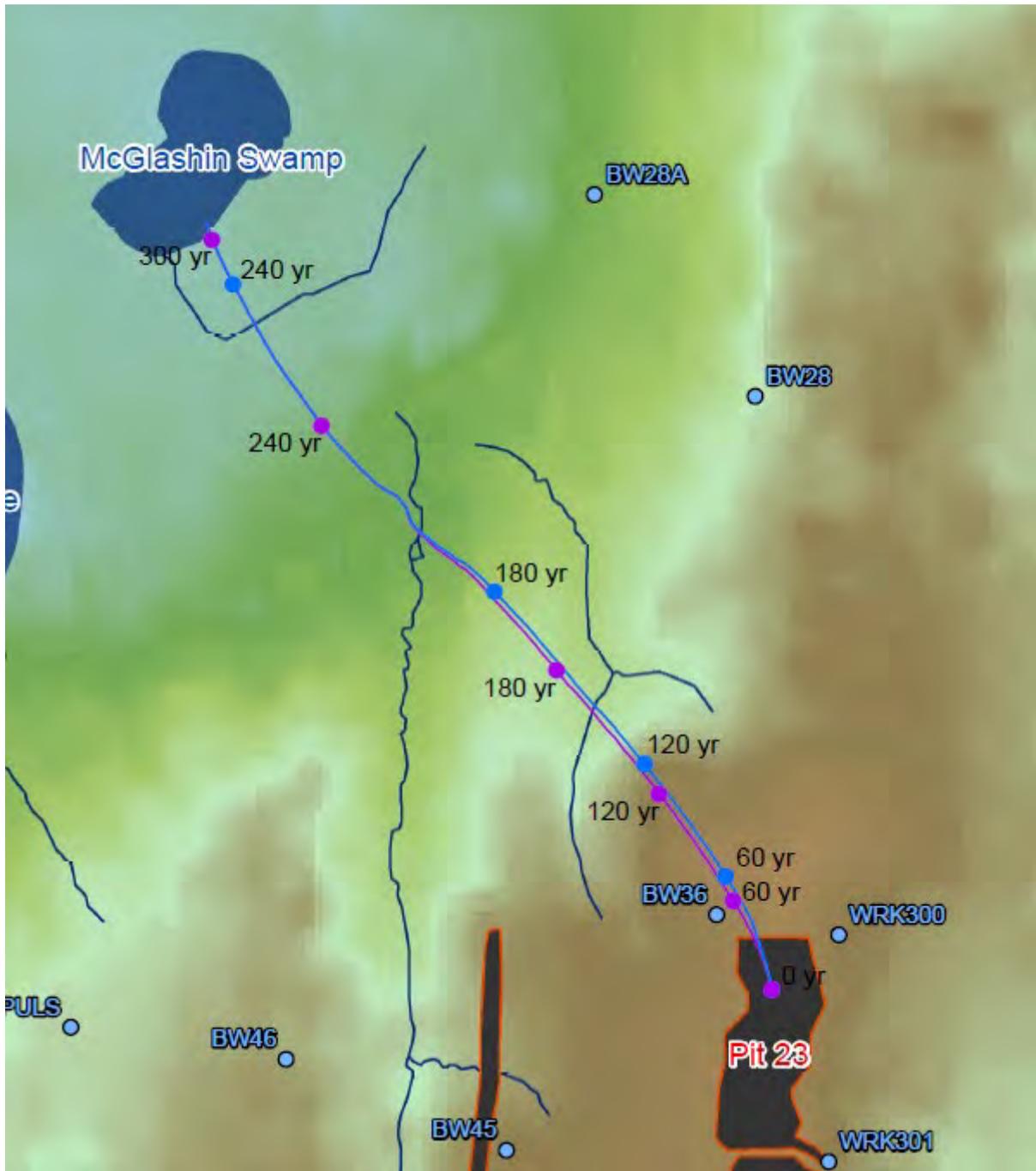


Figure 3.2 Pit 23 seepage particle tracking. Purple and blue represent the base and future disposal cases respectively (CDM Smith 2014)

3.2 Trend Analysis

For the exceedances at McGlashin Swamp to be caused by groundwater seepage from Pit 23, then the contaminated groundwater plume showing high pH and electrical conductivity levels, as well as low Cl:SO₄, would need to be visible at bores along the flow path between Pit 23 and McGlashin Swamp.

Figure 3.1 shows that particles that reach McGlashin Swamp from Pit 23 first pass through monitoring bores WRK301 and BW36. Therefore, by comparing the water quality data of these bores to historical data and to surrounding bores, it can be determined if they have experienced any negative trends associated with groundwater seepage as detailed below.

3.2.1 Electrical conductivity

To determine if the elevated electrical conductivity measurements observed at McGlashin Swamp could have been caused by groundwater seepage from Pit 23, measurements from nearby bores and other groundwater-influenced surface water locations were also assessed.

Figure 3.3 and Figure 3.4 show the locations and historical electrical conductivity measurements of the bores immediately surrounding Pit 23, while Figure 3.5 and Figure 3.6 show the same information for bores that are on or near the flow path of groundwater originating from Pit 23. Figure 3.7 is a time-series plot which compares the electrical conductivity measurements observed at McGlashin Swamp to other groundwater-influenced surface water bodies across the Douglas mine. From these figures the following is observed:

- apart from WRK305 exhibiting a downward trend, the bores surrounding Pit 23 show no clear electrical conductivity trends and have remained relatively stable since 2016, suggesting that they have not been influenced by high-salinity groundwater seepage;
- bores that are in the groundwater flow path (BW36 and WRK300) have electrical conductivity measurements ranging from 6,200–7,200 $\mu\text{S}/\text{cm}$ in August 2018. These levels are not elevated over the other bores adjacent to Pit 23;
- the highest electrical conductivity observed in the bores surrounding Pit 23 is seen in WRK302, which had a reading of 21,000 $\mu\text{S}/\text{cm}$ in August 2018;
- BW28A is located outside of the Pit 23 groundwater flow path but has consistently exhibited electrical conductivity levels of more than 15,000 $\mu\text{S}/\text{cm}$ from 2016 onward. Similarly, WRK301 is upstream of the flow path and has shown consistently elevated levels of more than 8,500 $\mu\text{S}/\text{cm}$. The electrical conductivity levels seen in these bores are higher than those in the flow path; and
- electrical conductivity measurements at McGlashin Swamp follow similar trends to other groundwater-influenced surface water locations. Each of the locations show a decrease in conductivity toward the end of 2017, before increasing in 2018, suggesting that this trend could be due to environmental factors and/or other related geochemical phenomena (see Section 4.2).



Figure 3.3 Locations and latest (2018) electrical conductivity measurements ($\mu\text{S}/\text{cm}$) of bores surrounding Pit 23

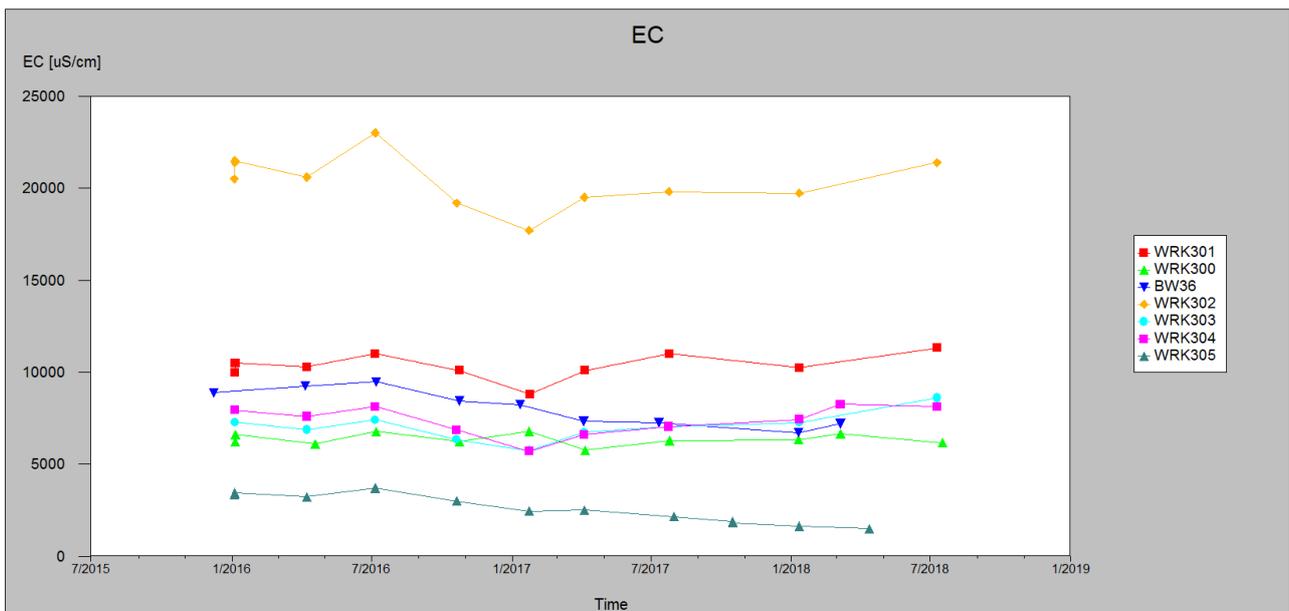


Figure 3.4 Time-series plot of electrical conductivity ($\mu\text{S}/\text{cm}$) measured in bores surrounding Pit 23



Figure 3.5 Locations and latest (2018) electrical conductivity measurements ($\mu\text{S}/\text{cm}$) of bores in or near the groundwater flow path from Pit 23 and at McGlashin Swamp (DUSW24)

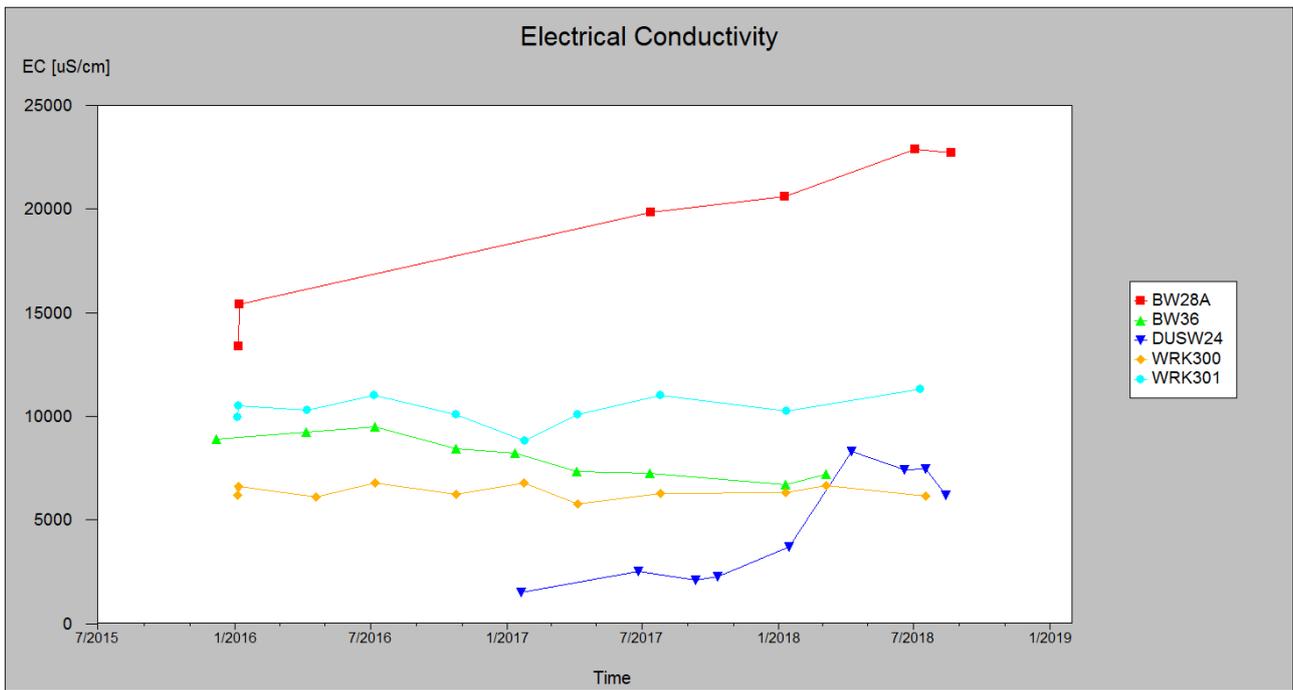


Figure 3.6 Electrical conductivity ($\mu\text{S}/\text{cm}$) measured at McGlashin Swamp (DUSW24) and bores located within the groundwater flow path from Pit 23

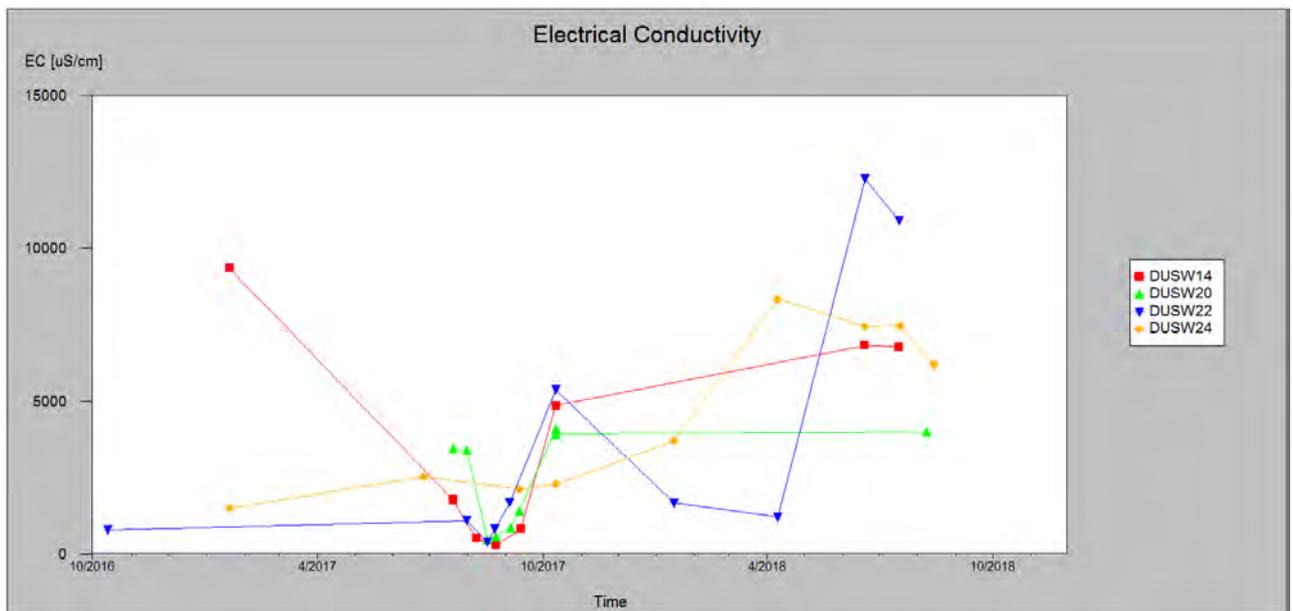


Figure 3.7 Comparison of electrical conductivity measurements ($\mu\text{S}/\text{cm}$) from groundwater-influenced surface water sites. DUSW14, DUSW20, DUSW22 and DUSW24 correspond to Costello's Creek, Northern Drainage Line, Shaw's Gully Creek and McGlashin Swamp respectively.

3.2.2 pH

To determine if the elevated pH measurements observed at McGlashin Swamp could have been caused by groundwater seepage from Pit 23, they were compared to measurements from nearby bores and other groundwater-influenced surface water locations.

Figure 3.8 and Figure 3.9 show the locations and historical pH measurements of the bores immediately surrounding Pit 23, while Figure 3.10 and Figure 3.11 show the same information for bores that are in or near the flow path of groundwater from Pit 23. Figure 3.12 is a time-series plot which compares the pH measurements observed at McGlashin Swamp to other groundwater-influenced surface water bodies across the Douglas mine. From these figures the following is observed:

- bores surrounding Pit 23 all show increasing pH levels up to the start of 2017. pH levels in each then decrease over 2017 and start to recover in 2018. As all bores are showing the same trend, even if they are not in the groundwater flow path, this suggests that natural factors are causing the change rather than groundwater seepage;
- WRK300, which is in the groundwater flow path, shows pH measurements that are higher than other bores surrounding Pit 23 (7.1 in August 2018), but BW36, which is also in the flow path, has one of the lowest pH levels (5.6 in March 2018). This suggests that if high pH groundwater was seeping from Pit 23, it has only reached WRK300 and not BW36. This is unlikely though, as these bores have had consistently high/low pH levels in relation to the other bores since 2014;
- the highest pH reading observed in the bores surrounding Pit 23 between 2014 and 2018 was 7.7 in WRK301. This reading is lower than all of the readings taken at McGlashin Swamp, which range from 8.6 to 10.4;
- BW28A is located outside of the Pit 23 groundwater flow path towards McGlashin Swamp, but has consistently exhibited pH levels similar to those in the flow path from 2016 onward, suggesting that these bores have not been affected by seepage and instead reflect natural processes;
- the pH levels of the groundwater-connected surface water systems all decrease at the end of 2017 before recovering in 2018. All of these water bodies exhibit similar trends, suggesting that they are influenced by environmental factors;
- pH measurements at McGlashin Swamp have been consistently higher than other groundwater-influenced surface water bodies since monitoring began in 2017, and unlike the other bodies, the pH is trending upward. This suggests that a process is occurring exclusively in McGlashin Swamp (and possibly at other swamps located outside of the study area) which is leading to alkalinisation of the system; and
- other groundwater-influenced surface water bodies including Costello's Creek, the Northern Drainage Line and Shaw's Gully, exhibit pH levels averaging around 7.5, which matches the groundwater pH levels observed in BW28A and the bores surrounding Pit 23.



Figure 3.8 Locations and latest (2018) pH measurements of bores surrounding Pit 23

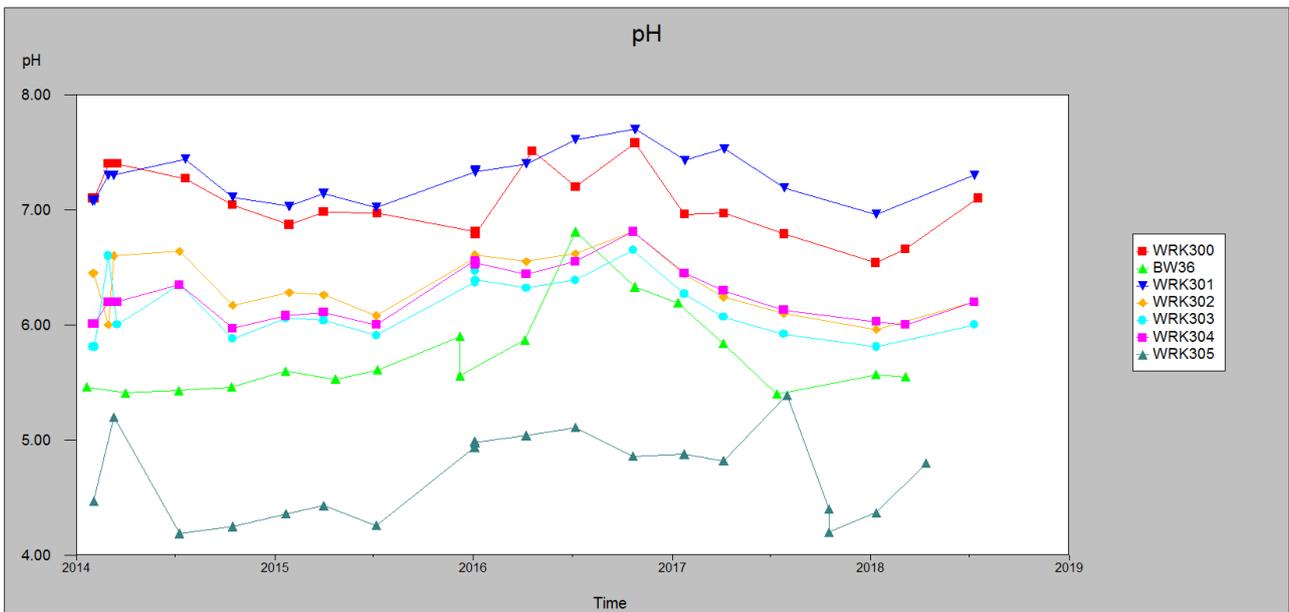


Figure 3.9 Time-series plot of pH measured in bores surrounding Pit 23



Figure 3.10 Locations and latest (2018) pH measurements of bores in or near the groundwater flow path from Pit 23 and at McGlashin Swamp (DUSW24)

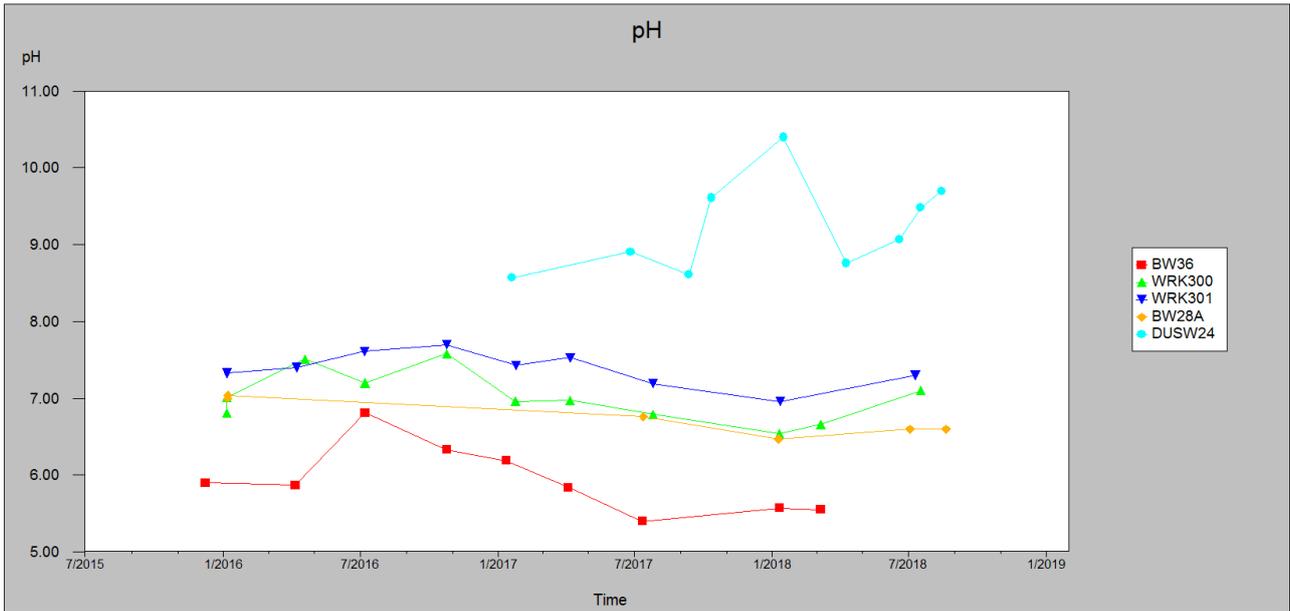


Figure 3.11 pH measured at McGlashin Swamp (DUSW24) and bores located within the groundwater flow path from Pit 23

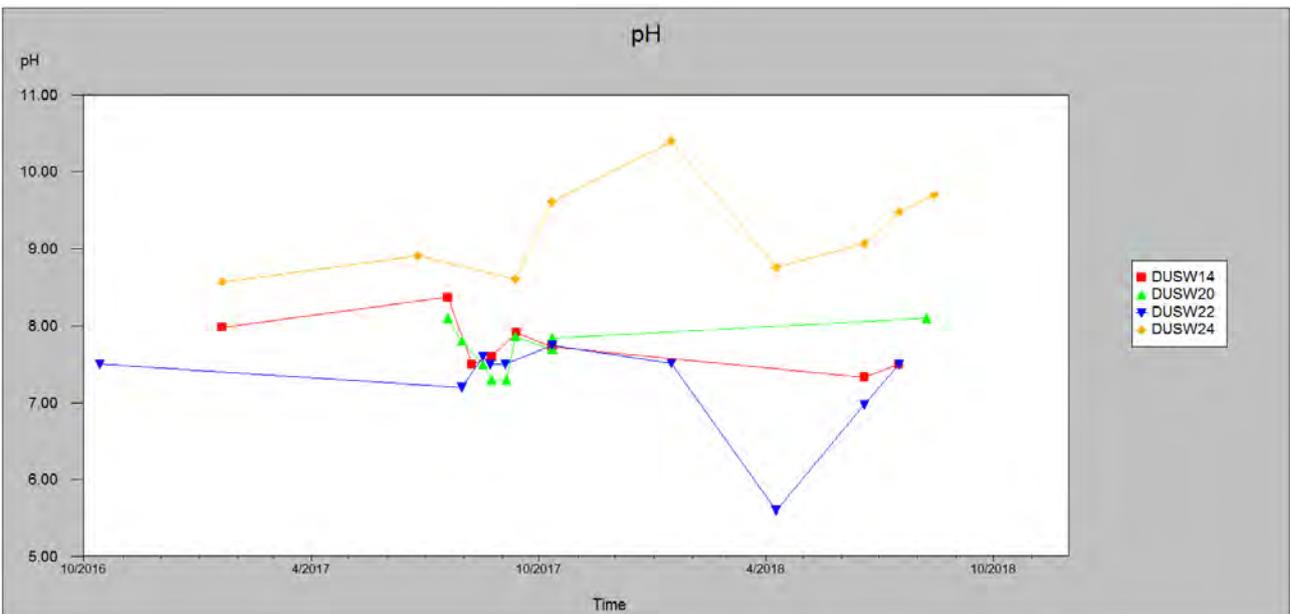


Figure 3.12 Comparison of pH measurements from groundwater-influenced surface water sites. DUSW14, DUSW20, DUSW22 and DUSW24 correspond to Costello's Creek, Northern Drainage Line, Shaw's Gully Creek and McGlashin Swamp respectively.

3.2.3 Chloride to sulphate ratio

To determine if the decreasing Cl:SO₄ observed at McGlashin Swamp could have been caused by groundwater seepage from Pit 23, measurements from bores in the vicinity of Pit 23, bores located along the Pit 23 groundwater flow path and other groundwater-influenced surface water locations were assessed.

Figure 3.13 and Figure 3.14 show the locations and historical Cl:SO₄ values of the bores immediately surrounding Pit 23, while Figure 3.15 and Figure 3.16 show the same information for bores that are in or near the flow path of groundwater from Pit 23. Figure 3.18 is a time-series plot which compares the Cl:SO₄ values observed at McGlashin Swamp to other groundwater-influenced surface water bodies across the Douglas mine. Figure 3.17 and Figure 3.19 compare the sulphate levels at McGlashin Swamp to nearby bores and surface water sites. From these figures the following is observed:

- bores surrounding Pit 23 all show relatively stable Cl:SO₄ from the start of 2016, except for WRK301 and WRK305;
- WRK301 shows a sudden Cl:SO₄ increase in August 2018 from 6.4 to 8.7, while WRK305 has shown a steady decrease since 2016.
- leachate from Pit 23 was determined to have a Cl:SO₄ of approximately 0.008 (Iluka 2017), and therefore any bores affected by groundwater seepage would be expected to show declining Cl:SO₄ levels. WRK305 is the only bore where Cl:SO₄ is decreasing, but it is outside of the groundwater flow path from Pit 23 and hence this change must be due to other factors. As Cl:SO₄ levels have remained steady in other bores, this suggests that no groundwater seepage from Pit 23 has occurred;
- WRK300 and BW36, which are in the Pit 23 groundwater flow path, both show higher Cl:SO₄ values than the other bores. This suggests that they have not been affected by low Cl:SO₄ seepage from Pit 23;
- Cl:SO₄ measurements at McGlashin Swamp are much higher than those seen in the Pit 23 groundwater flow path or in BW28A, which is outside of the flow path. The high Cl:SO₄ values observed suggest that McGlashin Swamp has not been strongly affected by groundwater as this would lead to much lower Cl:SO₄ levels, as seen in the other groundwater-influenced surface water bodies;
- BW28A is located outside of the Pit 23 groundwater flow path, but has consistently exhibited Cl:SO₄ levels similar to those in the flow path from 2016 onward, suggesting that these bores are showing natural levels and have not been affected by seepage;
- the Cl:SO₄ levels of the groundwater-connected surface water systems do not show any common trends and appear to vary independently, contrary to other water quality analytes;
- Cl:SO₄ measurements at McGlashin Swamp have been consistently higher than other groundwater-influenced surface water bodies since monitoring began in 2017. The high Cl:SO₄ is due to lower sulphate concentrations at McGlashin Swamp (1–72 mg/L) than other locations, suggesting that the water signature is not strongly affected by groundwater mixing which shows sulphate concentrations of 290–940 mg/L in the Pit 23 groundwater flow path; and
- Costello's Creek and the Northern Drainage Line exhibit much lower Cl:SO₄ levels around 10, which is similar to what is observed in groundwater.



Figure 3.13 Locations and latest (2018) Cl:SO₄ measurements of bores surrounding Pit 23

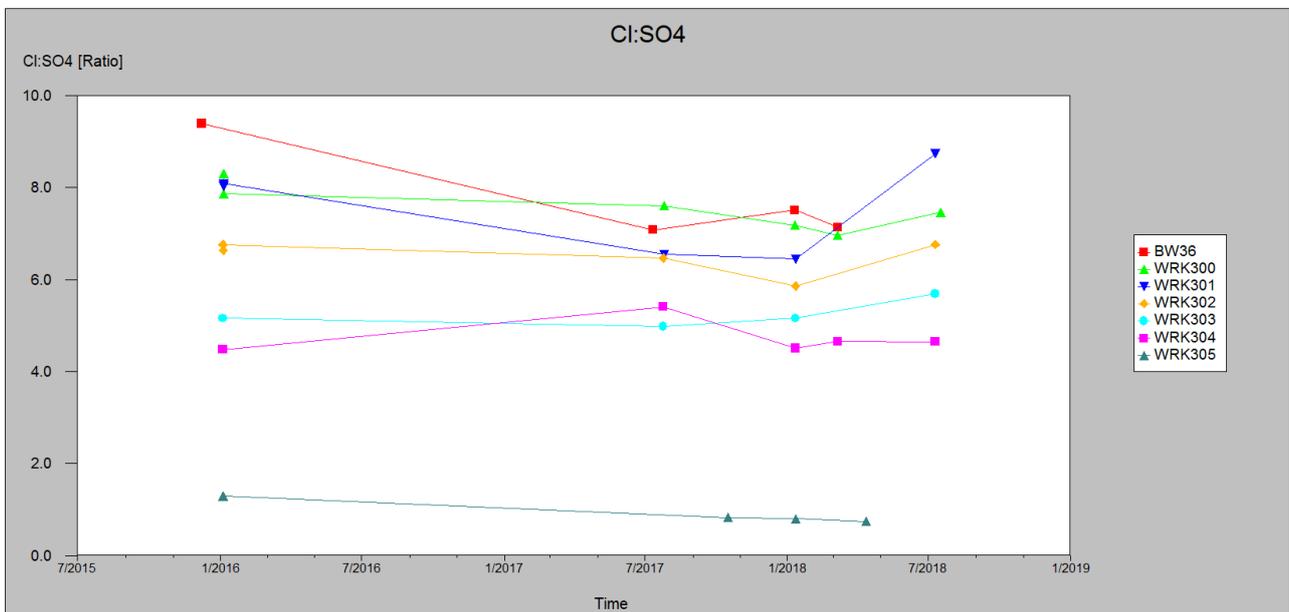


Figure 3.14 Time-series plot of Cl:SO₄ values measured in bores surrounding Pit 23



Figure 3.15 Locations and latest (2018) Cl:SO₄ measurements of bores in or near the groundwater flow path from Pit 23 and at McGlashin Swamp (DUSW24)

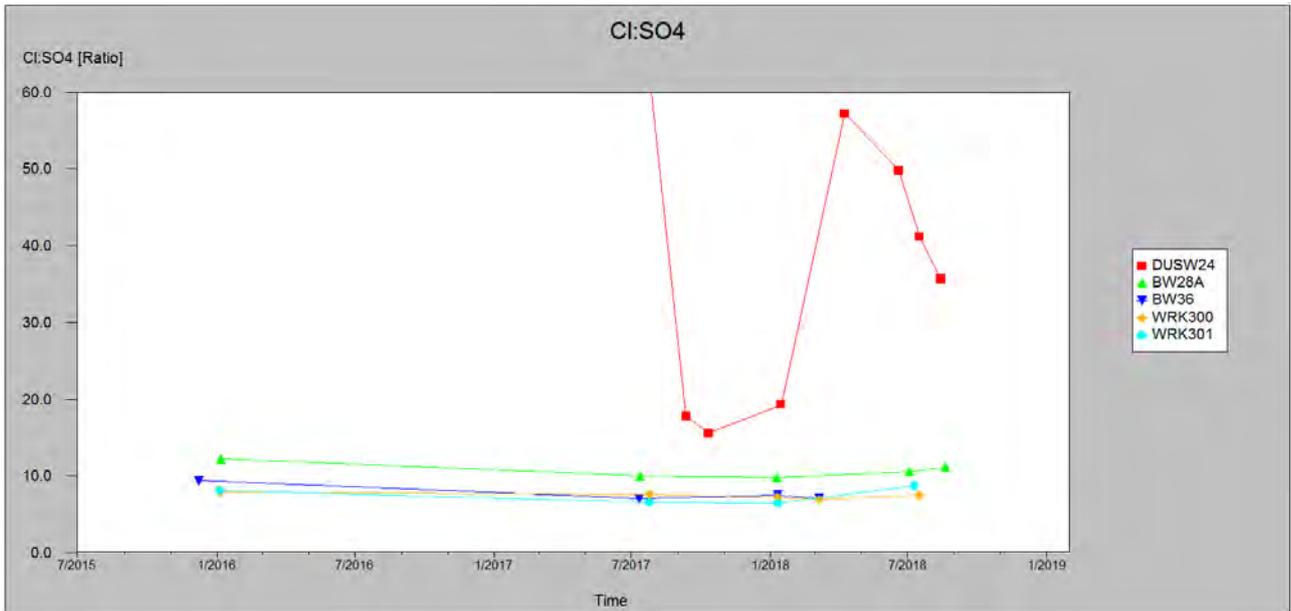


Figure 3.16 Cl:SO₄ levels measured at McGlashin Swamp (DUSW24) and bores located within the groundwater flow path from Pit 23

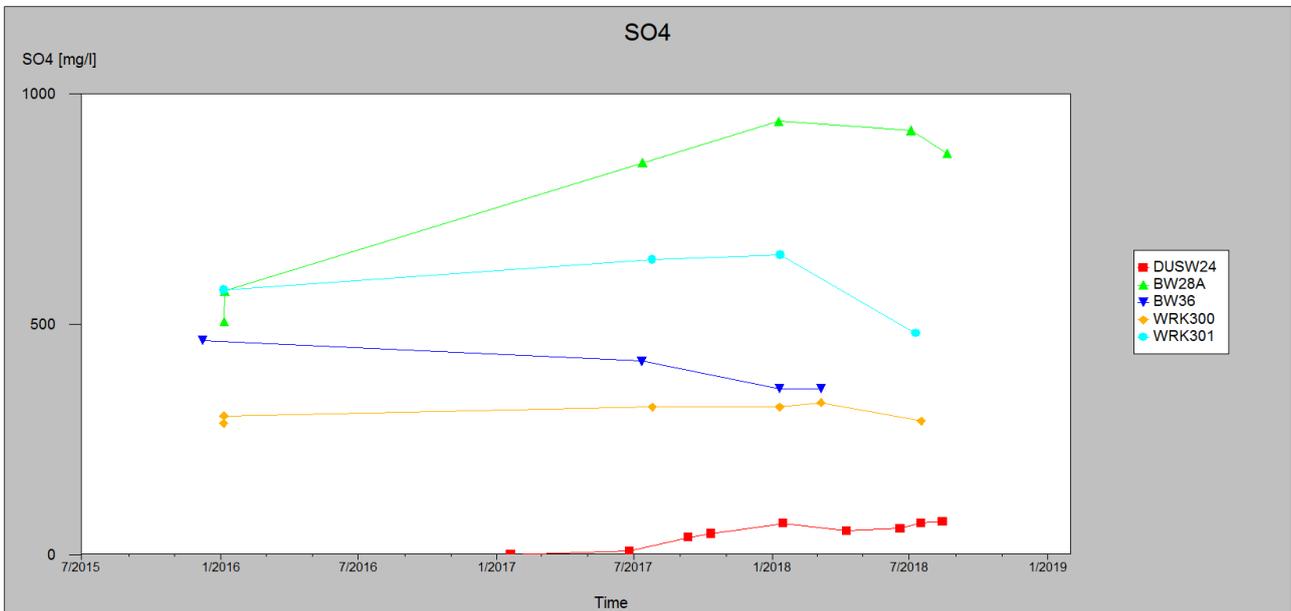


Figure 3.17 Sulphate levels (mg/L) measured at McGlashin Swamp (DUSW24) and bores located within the groundwater flow path from Pit 23

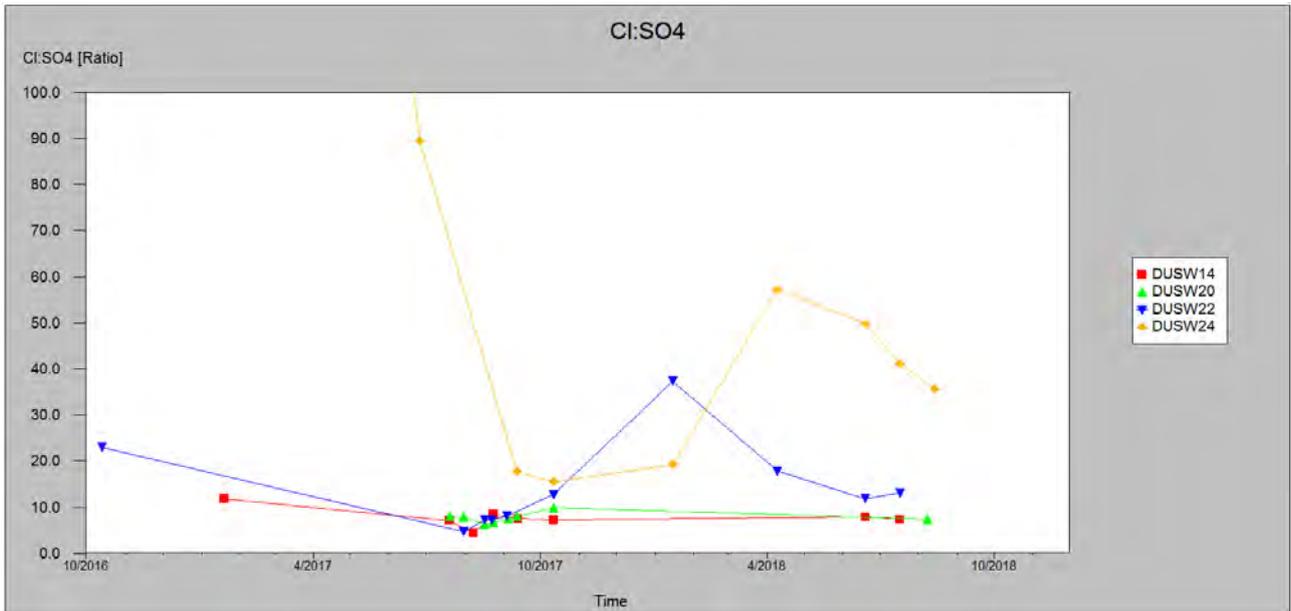


Figure 3.18 Comparison of Cl:SO₄ measurements from groundwater-influenced surface water sites. DUSW14, DUSW20, DUSW22 and DUSW24 correspond to Costello’s Creek, Northern Drainage Line, Shaw’s Gully Creek and McGlashin Swamp respectively.

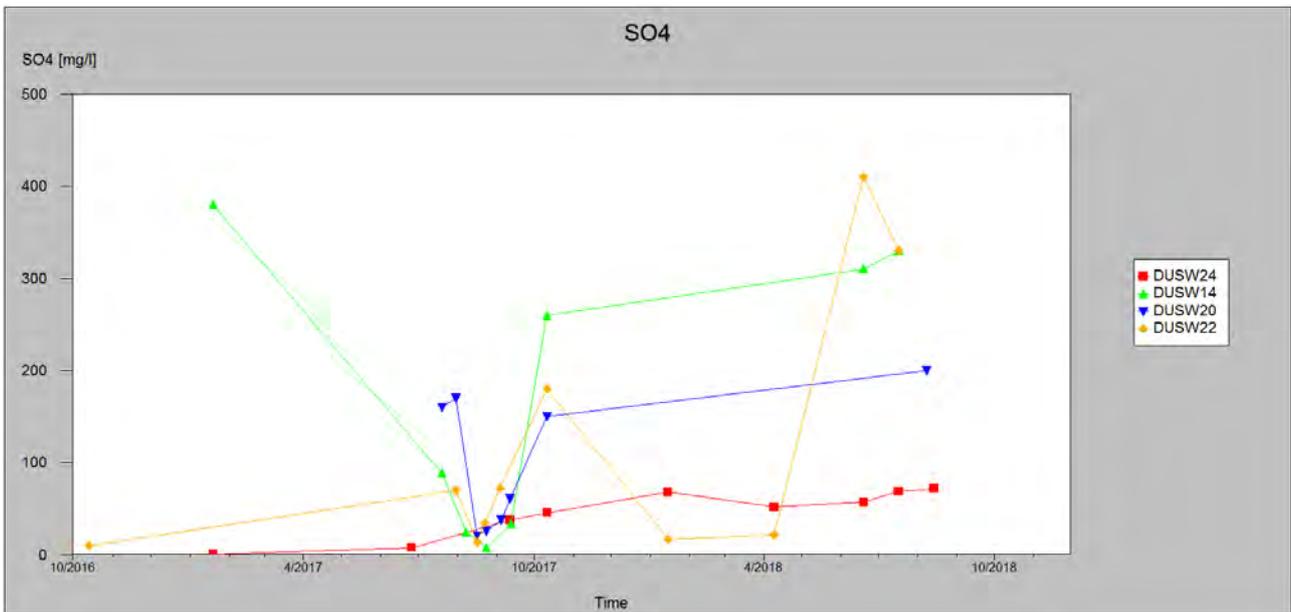


Figure 3.19 Comparison of sulphate measurements (mg/L) from groundwater-influenced surface water sites. DUSW14, DUSW20, DUSW22 and DUSW24 correspond to Costello’s Creek, Northern Drainage Line, Shaw’s Gully Creek and McGlashin Swamp respectively.

3.3 Groundwater Seepage Summary

Modelling by CDM Smith (2014, 2015) found that groundwater seepage from Pit 23 would flow to the north-west and eventually discharge to the surface at McGlashin Swamp, the North-West Drainage Line or through evapotranspiration. Modelled particles from Pit 22/23 were predicted to arrive at McGlashin Swamp between the years of 2140 and 2160, after passing through monitoring bores WRK300 and BW36. To determine if groundwater seepage was responsible for the exceedances seen in McGlashin Swamp, electrical conductivity, pH and Cl:SO₄ trends in upstream bores were assessed.

Electrical conductivity levels measured in bores located within the groundwater flow path showed stable trends and water quality values similar to or better than the bores surrounding Pit 23 and near the flow path. pH trends of bores within the flow path matched those seen in surrounding bores, suggesting that pH levels had not been affected by seepage. Cl:SO₄ values were found to be similar for bores in and near the groundwater flow path, indicating that they had not been affected by seepage, which would cause a drop in Cl:SO₄.

For each bore analysed within the groundwater flow path, as well as in the surrounding area, the increasing electrical conductivity, increasing pH, or decreasing Cl:SO₄ seen at McGlashin Swamp was not replicated. This indicates that groundwater seepage is not the cause for the exceedances at McGlashin Swamp, as the negative water quality trends would also have been observed in bores along the flow path emanating from Pit 23.

4 Surface Water Assessment

4.1 Surface Water Pathway Assessment

The water quality parameter exceedances described in this report were observed at the background water quality monitoring point DUSW24 at McGlashin Swamp.

McGlashin Swamp is one of a number of swamps located in the White Lake depression with its water quality parameters currently monitored by Iluka at monitoring point DUSW24 (Figure 2.1). North of McGlashin Swamp lie White Lake and Bitter Swamp with Ti Tree Swamp located to the south west. Over a dozen smaller unnamed swamps/depressions which may temporarily hold water are located in the vicinity, within 1 km of McGlashin Swamp.

McGlashin Swamp has a 900-ha surface water catchment (Figure 4.1). Approximately 300 ha of this catchment is forested, while the remainder (600 ha) is cropped. The North West drainage line and Red Hill drainage line south of Harrow-Kanagulk Rd receive surface water runoff from the catchment and convey it north towards the swamp. Prior to entering McGlashin Swamp, runoff from these creeks is captured by an unnamed depression (area approximately 7 ha) to the south east of McGlashin Swamp, which discharges water to McGlashin Swamp when filled. The volume required to fill the unnamed depression to the south east of McGlashin Swamp has not been assessed.

Pit 23 is located on a ridge at the eastern extent of the McGlashin Swamp surface water catchment. For material to be transported from Pit 23 to McGlashin Swamp via a surface water pathway, each of the following would need to occur:

1. Material would need to be released from Pit 23 into the upper reaches of the McGlashin Swamp catchment;
2. Rainfall with sufficient intensity to cause runoff and material transport would need to occur. This would involve completely filling Pit 23 and causing it to overflow; by-products disposed in Pit 23 are located approximately 15 m below the natural ground level; and
3. Runoff volume during and prior the transport event would need to be of sufficient volume to fill the unnamed depression to the south east of McGlashin swamp, such that it overflowed to McGlashin Swamp.

In addition, it is likely transport of material from Pit 23 to McGlashin Swamp via a surface water pathway would have water quality impacts at monitoring points upstream of McGlashin Swamp, i.e. DUSW25 on the Red Hill drainage line and DUSW20 on the North West drainage line.

There are currently no records that suggest that material has been released from Pit 23 into the McGlashin Swamp catchment.

The likelihood that rainfall sufficient to fill the depression south east of McGlashin Swamp and cause transport of material occurred prior to / in conjunction with the occurrence of water quality parameter exceedances discussed in this report was assessed using the Bureau of Meteorology's Australian Landscape Water Balance Model (the AWRA-L model). The AWRA-L model is a daily 0.05° grid-based, distributed water balance model. It simulates the flow of water through the landscape from the rainfall entering the grid cell, through vegetation and soil moisture stores, and then out of the grid cell through evapotranspiration, runoff or deep drainage to the groundwater. Daily and monthly runoff estimates from the catchment were obtained from the AWRA-L model. Peak daily runoff rates during 2017 were predicted to be 0.14 mm/day (16/9/17), and 0.05 mm/day during 2018 (12/5/18). Monthly runoff rates are plotted in Figure 4.2 together with 90th, 70th and 30th percentile monthly runoff rates, and indicators of dates that water quality parameter exceedances were measured in McGlashin Swamp.

From Figure 4.2, it can be seen that there may have been a large runoff event during September 2016, however runoff rates were lower than 2 mm/month during the period of water quality monitoring. There does not appear to be a correlation between rainfall runoff events and the occurrence of water quality parameter exceedances in McGlashin Swamp.

Figure 4.3 illustrates monthly potential evaporation, and the results of a simple water balance on the 7-ha depression upstream of McGlashin Swamp. This plot shows that the September 2016 rainfall runoff event would likely have been sufficient to fill the unnamed depression such that it discharged to McGlashin Swamp, but that following this event any captured runoff would have evaporated from the depression and not made it to McGlashin Swamp.

Background water quality sampling has been undertaken upstream of McGlashin Swamp at DUSW20 and DUSW25 during 2017-2018. During each sampling round, DUSW25 was found to be dry and no samples have been taken from that site. DUSW20 was found to be dry on 5 out of 8 sampling rounds. Samples were taken from DUSW20 on 20 July 2017, 12 Sept 2017 and 11 Oct 2017, with water quality parameters reported in Table 4.1 with the following observed:

- pH, total nitrogen and total phosphorus levels in each of the DUSW20 samples (Table 4.1) were lower than levels recorded in McGlashin Swamp DUSW24 (Table 2.6), and were below trigger levels; and
- Salinity (EC) was variable at DUSW20, and of a similar magnitude to McGlashin Swamp (DUSW24). This result is not an indication of transport of material from Pit 23 as the landscape naturally receives discharge of saline groundwater.

Table 4.1 DUSW20 observed water quality parameters

Date	EC	pH	DO	ORP	TO2N	Total P	TSS	Turbidity
	µs/cm@25C	@25C	mg/L	mV	mg/L	mg/L	mg/L	NTU
20-Jul-17	3600	8.1	8.9	302	1.8	0.073	6	72
12-Sep-17	1500	7.9	9.2	331	2.4	0.08	9	61
11-Oct-17	4100	7.8	6.5	-	2	0.04	8	22.1

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- KEY**
- Surface Contours (5 m)
 - Pre-mine drainage
 - ▭ McGlashin Swamp Catchment
 - Pit
 - Swamps and wetland

Figure 4.1
McGlashin Swamp surface
water catchment
Iluka Resources
Douglas pit 23

Source: EMM (2018); CDMSmith (2015); GA (2015)



GDA 1994 MGA Zone 54



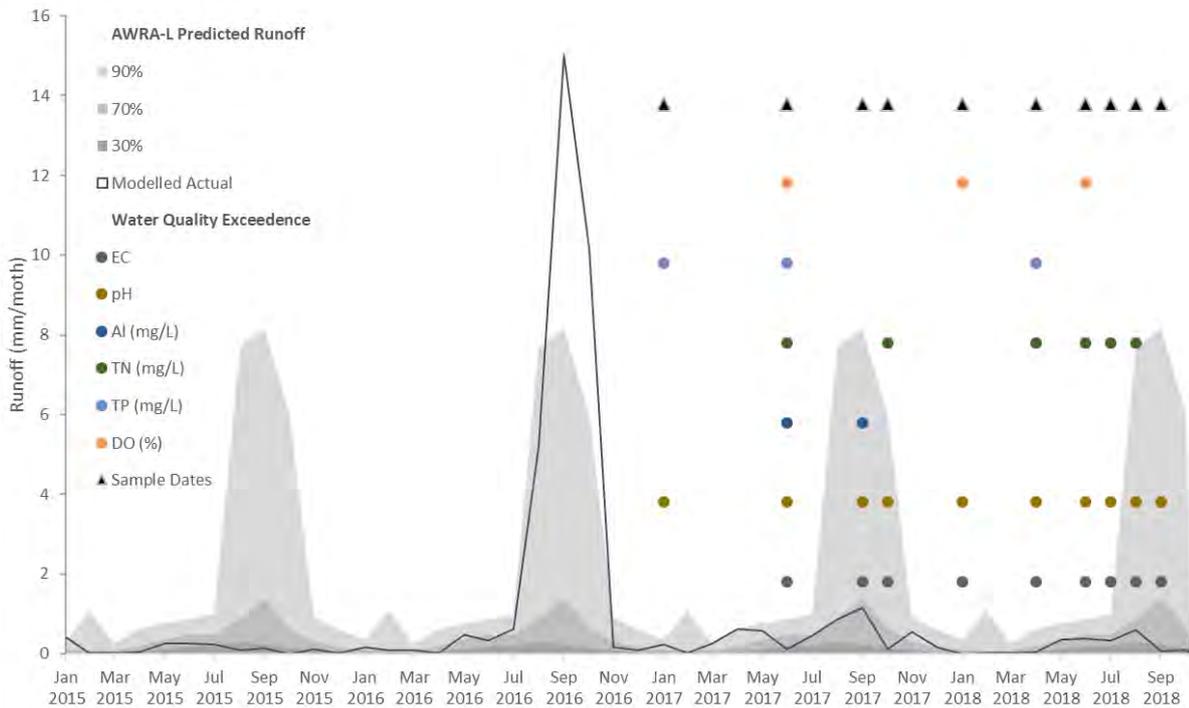


Figure 4.2 AWRA-L modelled monthly runoff in McGlashin Swamp catchment, and sample dates

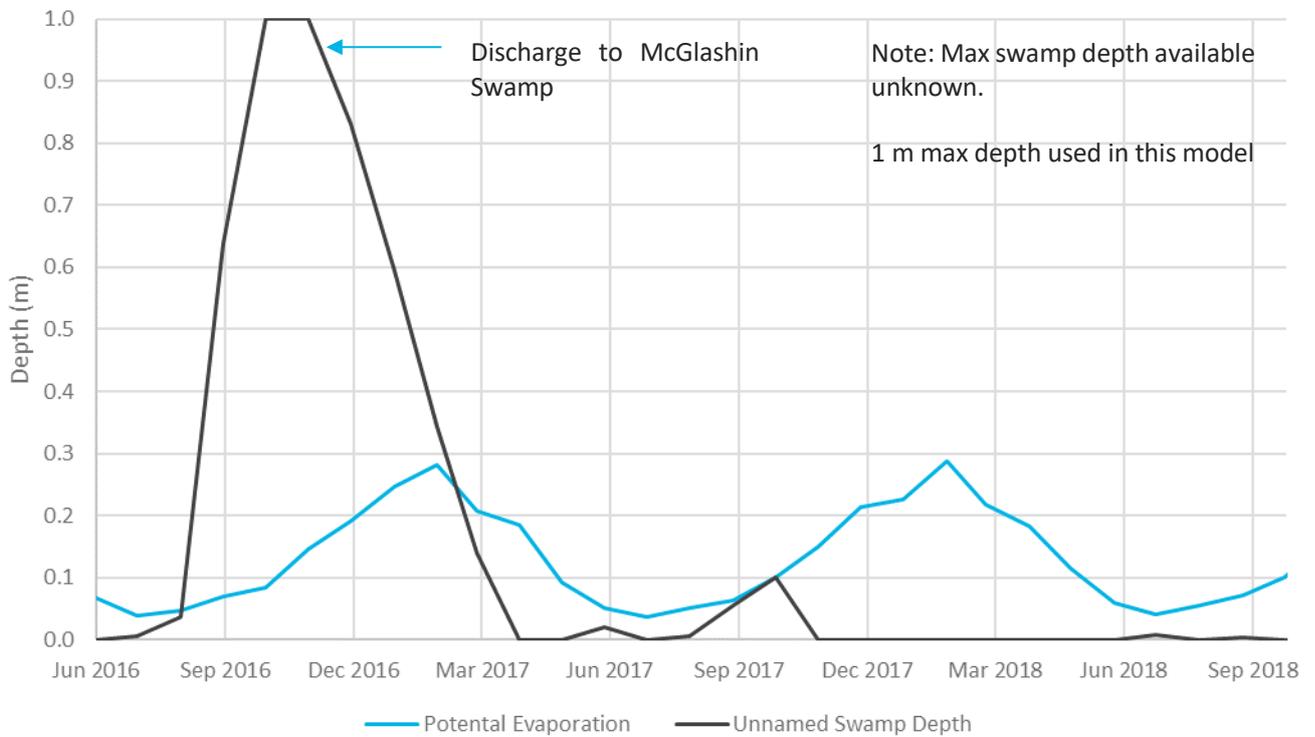


Figure 4.3 AWRA-L modelled monthly potential evaporation in McGlashin Swamp catchment, and simple water balance on unnamed 7 ha swamp upstream of McGlashin Swamp

This high-level assessment of a surface water pathway between Pit 23 and McGlashin Swamp has concluded that:

1. There are no recorded releases of material from Pit 23 into the McGlashin Swamp surface water catchment;
2. Water quality parameter exceedances do not appear to be associated with catchment runoff events;
3. Catchment runoff during the period of recorded water quality parameter exceedances would likely have been captured by an unnamed swamp upstream of McGlashin Swamp, and not arrived at McGlashin Swamp; and
4. Water quality parameter exceedances were not observed in DUSW20 and DUSW25 upstream of McGlashin Swamp.

Given the above, it appears unlikely that the water quality parameter exceedances recorded at McGlashin Swamp were caused by transport of material from Pit 23 via a surface water pathway.

4.2 Evapoconcentration and eutrophication at McGlashin Swamp

Reid & Mosley (2015) from the Goyder Institute, recently investigated different causes of increasing pH and salinity levels in lakes and wetlands. It was found that evapoconcentration and plant growth could cause the pH of these water bodies to increase, with pH levels of 9 to 10.5 being commonly seen.

McGlashin Swamp has been steadily drying out in recent times consistent with emerging drought conditions. When water is removed via evaporation, the concentrations of dissolved ions such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and carbonate (CO_3^{2-}) increase, explaining the increase in electrical conductivity observed over time at McGlashin Swamp. If the concentrations of these ions increase enough, the water will become saturated with them (contain the maximum possible dissolved concentration) and they will begin to precipitate as various compounds. Depending on the concentrations and ratios of each ion, different species will precipitate. Therefore, the precipitating compounds, and hence a change in water quality, can be predicted by knowing the ratios of different ions.

Reid & Mosley (2015) found that the ratio between ($\text{Ca}^{2+} + \text{Mg}^{2+}$) and ($\text{HCO}_3^- + \text{CO}_3^{2-}$) concentrations was the best indicator for high pH conditions forming during evapoconcentration. Lower calcium and magnesium levels relative to carbonate and bicarbonate (lower ratios) was associated with higher pH levels. Figure 4.4 shows the correlation between this ratio and pH for wetland water samples within the study.

Figure 4.4 shows that ratios lower than approximately 10 will result in pH levels ranging roughly between 7.5 and 11.0, with most being in the 8.0 to 9.0 range. Table 4.2 shows the ratios calculated when considering McGlashin Swamp data collected in 2017 with ratios range from 0.64 to 2.97. This is considered very low, indicating that McGlashin Swamp would be expected to increase in pH caused by evapoconcentration.

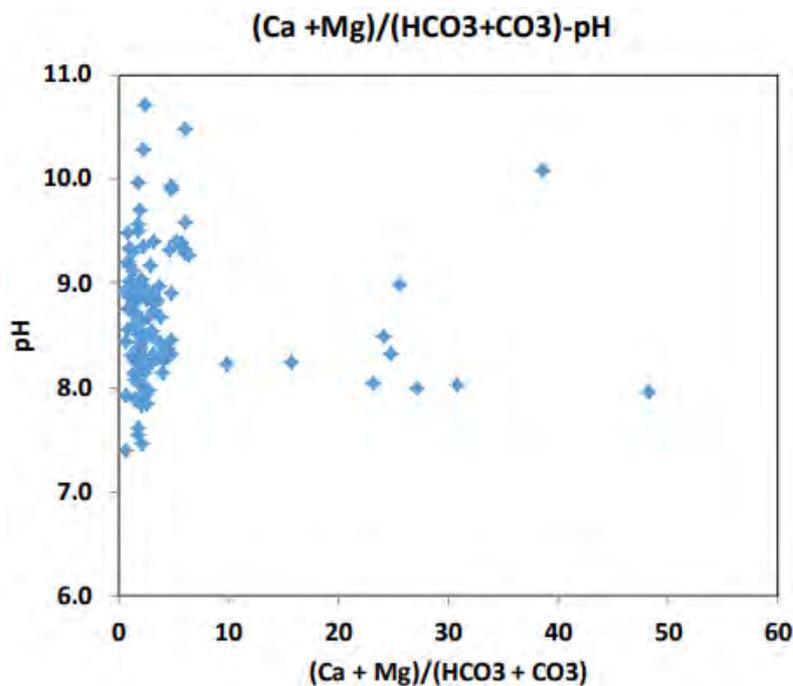


Figure 4.4 Sum of calcium and magnesium divided by the sum of carbonate and bicarbonate concentrations (meq/L) versus pH in wetlands (Reid & Mosley 2015)

Table 4.2 Ionic ratios calculated for 2017 McGlashin Swamp surface water samples

Sample Date	Total alkalinity (meq/L)	Ca ²⁺ + Mg ²⁺ (meq/L)	(Ca ²⁺ +Mg ²⁺)/Alkalinity
19/01/2017	7.39	4.70	0.64
26/06/2017	2.60	7.72	2.97
12/09/2017	6.19	5.73	0.92
11/10/2017	6.39	6.41	1.00

Besides evapoconcentration, the other explanation for increasing pH levels given by Reid & Mosley (2015) is photosynthesis and plant growth. Eutrophication (excessive growth of plants and algae in the water body due to high levels of nutrients) could explain the increasing pH and dissolved oxygen measurements seen at McGlashin Swamp. Yang et al. (2008) suggest that total phosphorus levels of more than 0.1 mg/L and total nitrogen levels of more than 2 mg/L indicate a hyper-eutrophic water body. The 2017–2018 background levels of total nitrogen and phosphorus found at McGlashin Swamp are 6.1 and 1.66 mg/L respectively, putting it far above the levels necessary for eutrophication to occur. This theory is supported by recent observations of algae at McGlashin Swamp during water quality sampling rounds.

Large amounts of algae growing due to high nutrient levels would lead to increased rates of photosynthesis in McGlashin Swamp. Part of this process involves inorganic carbon being removed from the water; carbon dioxide is the preferred source, but aquatic plants are also able to use bicarbonate. When plants utilise bicarbonate, hydroxyl ions are produced which lead to increased pH levels – this reaction is shown in Equation 1. Oxygen is produced as a result of photosynthesis, which can lead to high levels of dissolved oxygen in the water, such as the measurements of over 200% saturation measured in January and June 2018 at McGlashin Swamp.



bicarbonate ion → carbon dioxide + hydroxyl ion

Equation 1 Bicarbonate utilisation for photosynthesis

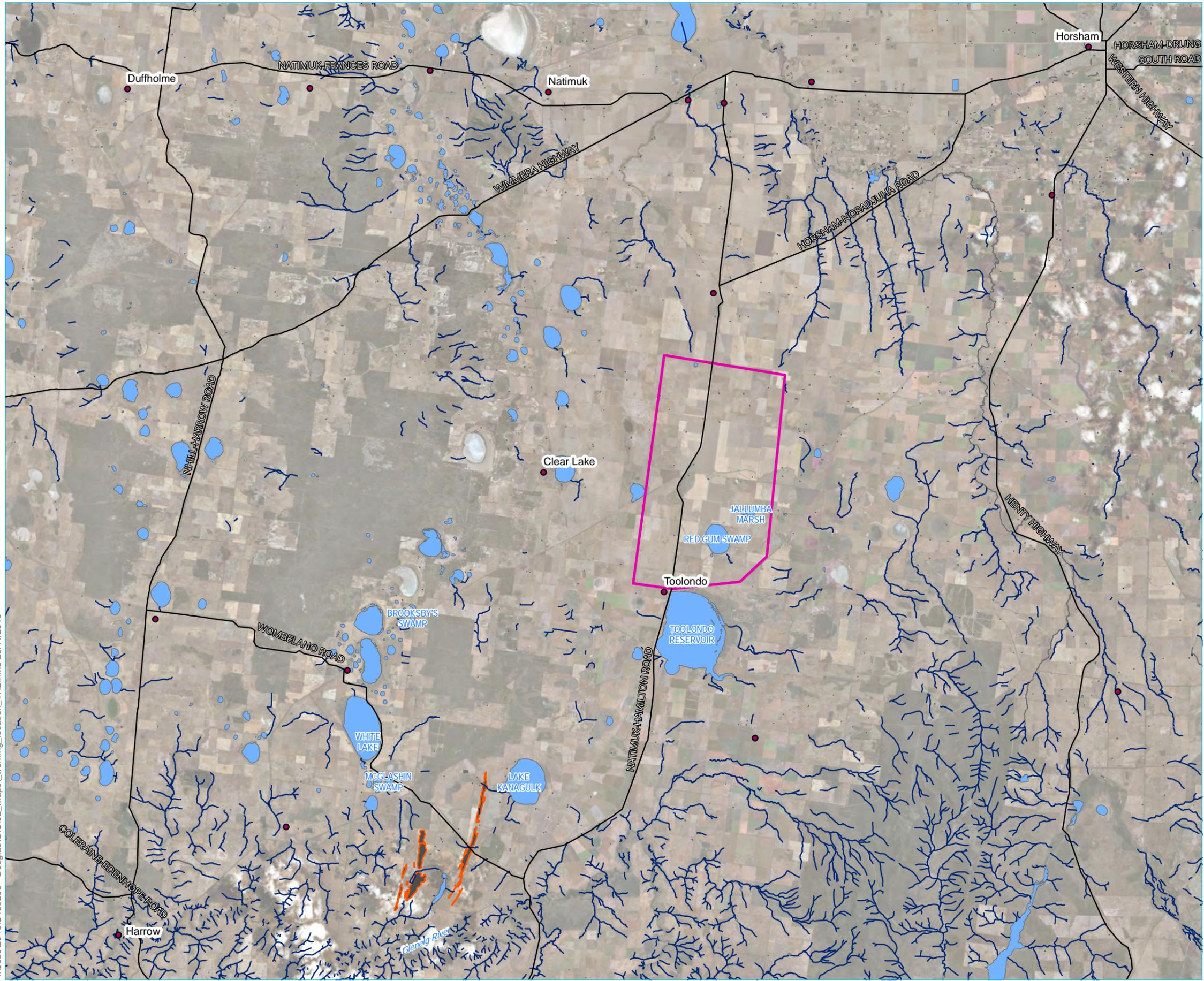
In addition to the effects from photosynthesis, plant growth itself can also cause alkalisng effects. Calcium and magnesium ions are sequestered during plant growth, which reduces the concentrations of these ions available in the water. As discussed previously in regard to evapoconcentration, reducing the concentrations of these ions prevents the precipitation of species like calcium and magnesium carbonates which would cause the pH of the water to decrease. Evidence for this is observed at McGlashin Swamp as calcium and magnesium levels have remained relatively constant from January 2017 to August 2018, while other ions have increased dramatically. Sodium, for example, has increased approximately 300 % from 330 to 1100 mg/L over the same period.

4.2.1 Jallumba Marsh and Redgum Swamp

To determine whether high pH levels are being recorded at other similar wetland/swamp environments in the region, Iluka supplied EMM with the baseline surface water monitoring data currently being collected to support Iluka's WIM100 Fine Minerals Project. Currently, two wetlands are being sampled as part of this project including Redgum Swamp and Jallumba Marsh. The location of these two wetlands in relation to McGlashin Swamp and the Douglas Mine is shown in Figure 4.5. The recorded pH values over the last three recordings for McGlashin Swamp, Redgum Swamp and Jallumba Marsh is shown in Figure 4.6. The following is observed:

- minimum pH recorded over the period was 8.6 across all sites;
- all surface water is alkaline;
- over the last two monitoring events, the Jallumba Marsh pH has increased dramatically (from September to October), similar to the increase seen at McGlashin between June and September; and
- it appears similar geochemical processes are occurring across numerous wetland/swamp environments in the region, although some variability is expected due to local geomorphic, hydrogeological and soil chemical variability.

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- KEY**
- Towns
 - Roads
 - Watercourses
 - Waterbodies
 - ▭ WIM100 site location
 - Douglas mine

Figure 4.5
WIM100 site location and
surface water monitoring

Iluka Resources
Fines mineral project



Source: EMM (2018); CDMSmith (2015); GA (2015)



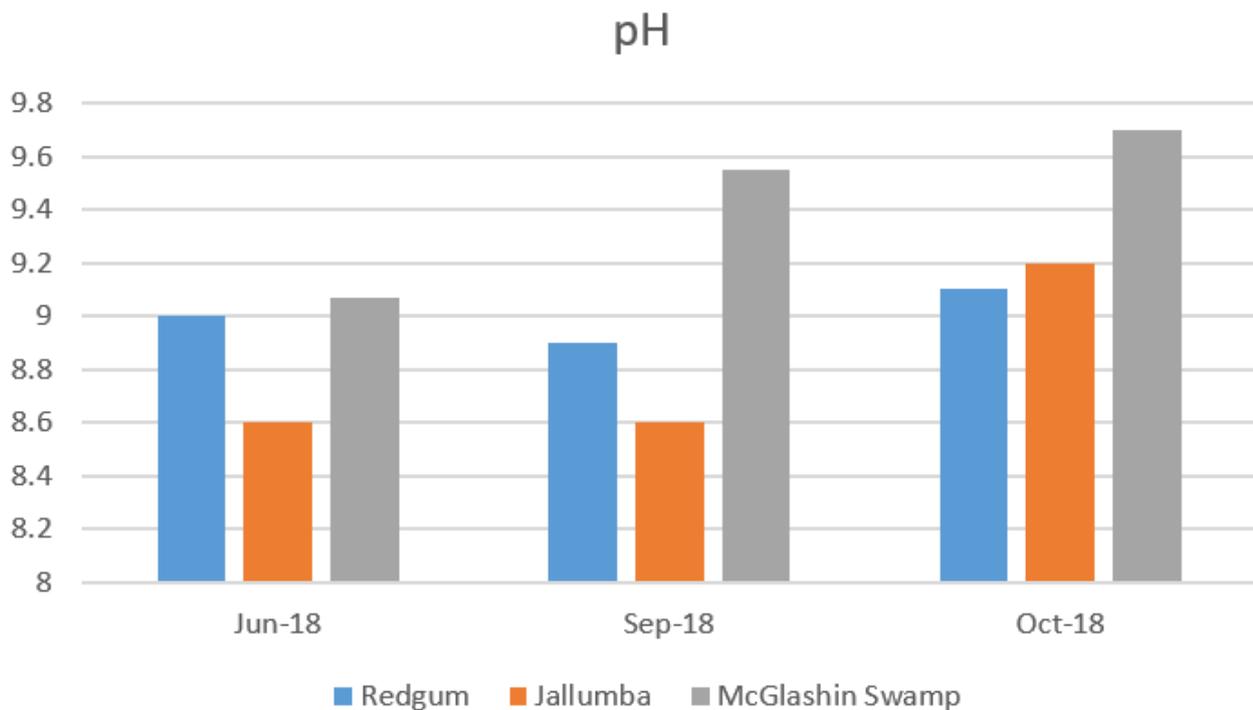


Figure 4.6 Recent pH recordings at McGlashin Swamp, Redgum Swamp and Jallumba Marsh.

4.2.2 Analogous surface water monitoring recommendation

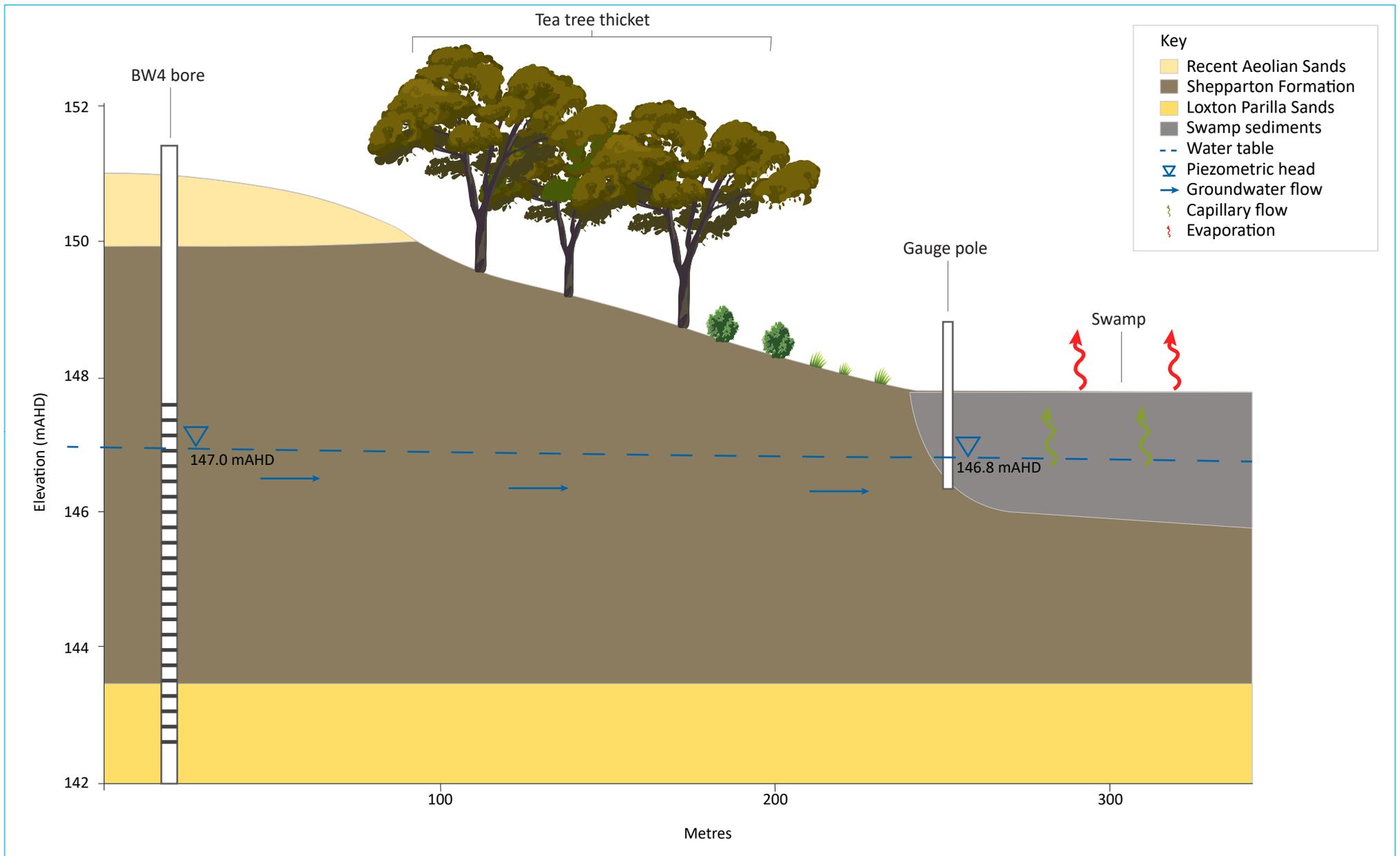
To assist Iluka with their regulatory obligation going forward and to minimise future exceedance triggers that may occur due to natural phenomena rather than disposal activities at Pit 23, analogous surface water monitoring locations are recommended in addition to the existing monitoring points DUSW24 (McGlashin Swamp) and DUSW5B (White Lake). These additional locations will need to meet the following criteria:

- be outside of any influence from groundwater flows from Pit 23;
- be classified as a saline lake or swamp, which receives groundwater discharge;
- have similar hydrogeological profiles and soil types; and
- support similar ecological vegetation communities (for assessing similarities in environmental attributes).

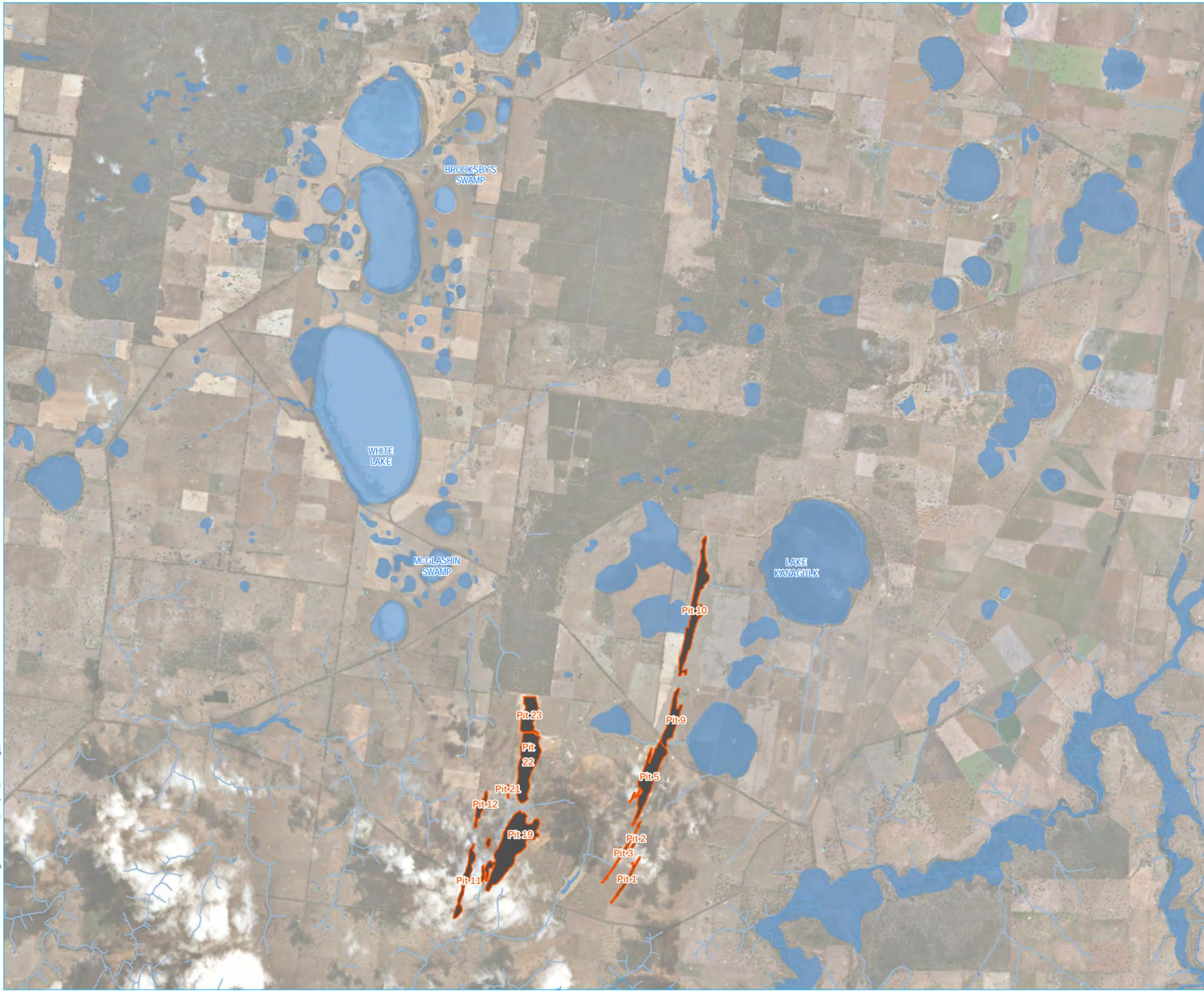
A brief review of the lakes and swamps in the Douglas region undertaken by Goldfields Revegetation (Smart 2001) as part of the Murray Basin Stage 1 Environmental Effects Statement (EES), identified Brooksby's Swamp to have similar characteristics to White Lake and Tea Tree Lakes, while being outside of any groundwater influence from Pit 23. White Lake and Tea Tree Lakes are located closer to the Douglas mine and are potential receptors to Pit 23 discharge. Brooksby's Swamp is located about 4 km northwest of Douglas and is typical of the saline swamps found within the Douglas Depression. Figure 4.7 shows a basic hydrogeological conceptual model of Brooksby's Swamp based on the Smart 2001 study, and Figure 4.8 shows the location of Brooksby's Swamp in relation to Pit 23. From Figure 4.7 and Figure 4.8, the following is noted:

- Brooksby's Swamp is located outside of any discharge zone associated with Pit 23;
- hydrogeological sequence is typical of the area and includes surficial aeolian sands, underlain by the sandy-clays of the Shepparton Formation, which is then underlain by the Loxton Parilla Sands. Typical clayey sediment dominates the top couple of meters within the swamp extent. This lithological structure is consistent with that found across the Douglas Mine/Pit 23 area;
- during the dry period of 2001, groundwater levels measured at the BW4 monitoring bore were 147 mAHD, with groundwater levels measured beneath the swamp at 146.8 mAHD;
- conceptually, groundwater flows towards the swamp during the dry period, and discharges to the surface through capillary action, making Brooksby's Swamp a groundwater discharge zone, at least during parts of the year during low rainfall; and
- the biodiversity mapping tool of Victoria (<http://maps.biodiversity.vic.gov.au>) highlights the Ecological Vegetation Community (EVC) to be 'Plains Woodlands or Forests' type for both McGlashin Swamp and Brooksby's Swamp. Smart (2001) noted that a stand of Yellow Gums (*E.leucoxydon*) existed on the sandy lunette section of the swamp and is recognised to be part of the 'Plains Woodlands or Forests' community. However, paperbark thicket was also mapped surrounding the swamp, which is a common species found within the 'Swamp Scrub' EVC. In summary, the saline lakes and swamps within the Douglas depression region support similar ecological communities and thus similar soil, climatic and geomorphologic conditions are assumed to prevail in the absence of a detailed site survey.

It is recommended that Iluka include Brooksby's Swamp as part of their ongoing surface water monitoring plan. However, it was noted that the swamp was dry during the millennium drought (groundwater levels were approximately 1 m below swamp surface) and thus other sites may also need to be included to ensure a surface water sample is obtainable. In addition, Redgum Swamp and Jallumba Marsh are currently being monitored as part of Iluka's WIM100 Fine Minerals Project. Given the monitoring results already show similar high pH values to McGlashin Swamp, Iluka may consider including these sites as part of the Douglas Environmental Management Plan (EMP). It is envisioned that monitoring these analogous swamps in parallel with the current surface water monitoring points will show the water quality variability is a natural phenomenon rather than a result of groundwater seepage and subsequent transport emanating from Pit 23.



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KEY

- Pre-mine drainage
- Pit
- Swamps and wetland

Figure 4.8
Douglas mine site and
surrounding environment

Iluka Resources
Douglas pit 23

Source: EMM (2018); CDMSmith (2015); GA (2015)



GDA 1994 MGA Zone 54



5 Risk Assessment Validation

Jacobs (2014) investigated the risk that continued by-product disposal to Pit 23 posed to groundwater accessibility, groundwater quality and groundwater dependent ecosystems in the surrounding environment. In each case, the risk was found to be low. To validate these findings, the conclusions made by Jacobs will be reassessed in this section to determine if they are still applicable.

5.1 Groundwater Accessibility

The overall risk to groundwater accessibility caused by continued by-product disposal to Pit 23 was rated as Low. Table 5.1 adapted from the Jacobs 2014 report explains that the reason for this conclusion is that the groundwater levels around Pit 23 are predicted to undergo only minor changes. To verify this claim, the standing water level (mBGL) of bores surrounding Pit 23, as well as bores in the flow path between Pit 23 and McGlashin Swamp are shown in Figure 5.1 and Figure 5.2 respectively. The change in water level between January 2014 and the last measurement in August 2018 for each bore is shown in Table 5.2. From these results, the following is observed:

- the water level in each bore has steadily changed over time. Three of the analysed bores showed a decrease in water level, while the other five showed a slight increase;
- the bores immediately surrounding Pit 23 showed no definite trends, with three bores showing increasing water levels and two showing decreasing water levels; and
- two of the bores located within the Pit 23 groundwater flow path (WRK300 and BW36) showed water level increases of 1.22 and 0.30 m respectively. Ordinarily, this could be perceived to be mound migration due to groundwater seepage, however a 0.44 m increase in water level was also observed in BW28A, which is nearby but not located within the flow path. Also, groundwater levels at Pit 23 have not risen enough over the reporting period to create a large enough groundwater gradient to induce such flow. This would therefore suggest that the increased water levels are due to natural processes.

This assessment suggests that while groundwater levels have slightly changed across the site between 2014 and 2018, the changes are small, appear random and cannot be linked to the disposal activities undertaken at Pit 23. Therefore, the overall risk to groundwater accessibility remains as Low.

Table 5.1 Risk to groundwater accessibility for current and future groundwater users (after Jacobs 2014)

Risk component	Ranking	Reason	Overall risk rating
Likelihood	Unlikely	<ul style="list-style-type: none"> predicted changes to groundwater levels are minor and result in very minor changes to travel times between the source and receptor 	
Consequence	Low	<ul style="list-style-type: none"> negligible to minor short-term stress on groundwater environment with rapid recovery no change in aquifer yield impacts within the range of natural variability inter-connected systems, including adjacent and overlying aquifers, hydraulically connected surface water systems and groundwater dependent ecosystems are unaffected groundwater environment is resilient to impacts and only simple, low cost rehabilitation works are required, if any 	Low

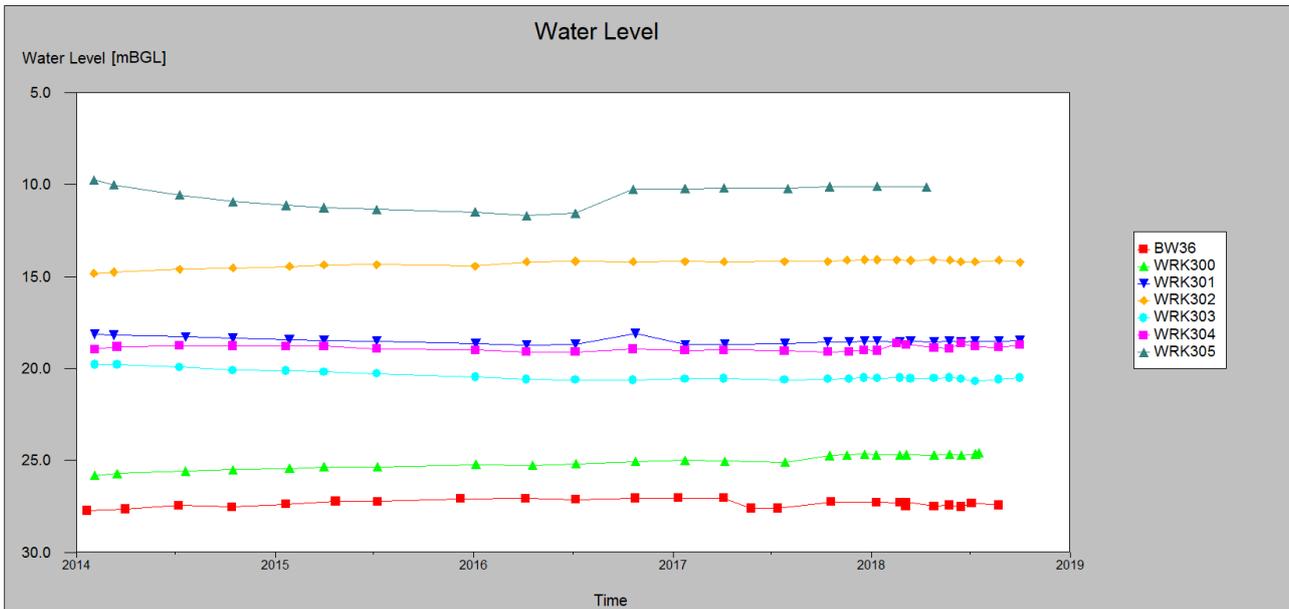


Figure 5.1 Standing water level (mBGL) of the bores surrounding Pit 23

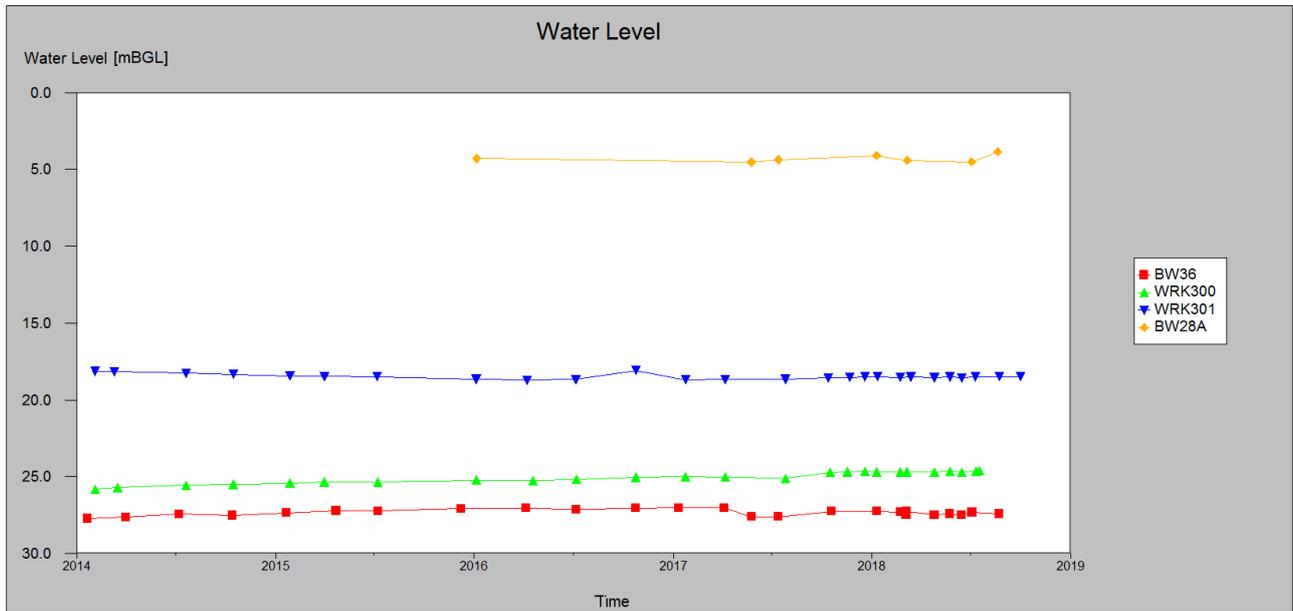


Figure 5.2 Standing water level (mBGL) of the bores in the groundwater flow path between Pit 23 and McGlashin Swamp

Table 5.2 Change in water level across the Douglas groundwater monitoring network (positive values indicate an increase in water level)

Bore	Change in water level (m)
WRK300	1.22
WRK301	-0.34
WRK302	0.61
WRK303	-0.70
WRK304	0.24
WRK305	-0.38
BW36	0.30
BW28A	0.44

5.2 Groundwater Quality

The overall risk to groundwater quality impacts caused by continued by-product disposal to Pit 23 was originally rated as Low by Jacobs (2014). Table 5.3 adapted from Jacobs 2014 report shows that the reasons for this rating are that the identified contaminants are not readily soluble or leachable, and that no impacts have been observed from historical disposal activities.

To verify Jacobs rationale and overall risk rating, reference will be made to Section 3 where some aspects of the groundwater quality surrounding Pit 23 were investigated. In addition, Figure 5.3 through to Figure 5.6 show time-series plots of various contaminants identified in the disposed by-products (radium-226, radium-228, chromium and arsenic) to determine if the concentrations of these analytes are increasing over recent time. With reference to these figures, along with those shown in Section 3, the following is noted:

- radium-226 concentrations have a large variance, but there are no clear increasing trends in any of the bores around Pit 23, or within the flow path between Pit 23 and McGlashin Swamp;
- radium-228 concentrations also show some variance between measurements, but again no clear increasing trends are observed;
- chromium concentrations in these bores are relatively stable, except in WRK301 which shows large fluctuations in measured values;
- arsenic concentrations are similarly stable except for WRK301. The spikes in chromium and arsenic concentrations in WRK301 occurred during the same monitoring rounds, suggesting that they may be due to sampling errors, or natural quality fluctuations;
- BW28A (not shown) showed very high arsenic levels ranging 0.5–1.1 mg/L between 2016 and 2018, suggesting that there is a source for this contaminant in the local environment. However, this bore is not located within the Pit 23 groundwater flow, thus these levels are unlikely to be caused by Pit 23 disposal activities; and
- investigations into the quality of the groundwater surrounding Pit 23 undertaken in Section 3 found that bores located within the flow path between Pit 23 and McGlashin Swamp showed similar or better quality than other bores in the vicinity of Pit 23.

From this analysis, contaminant concentrations are not increasing in the area surrounding Pit 23, or within the groundwater flow path from Pit 23, suggesting that these contaminants are not readily soluble in groundwater nor being transported via the aquifer. Additionally, from consideration of other water quality parameters in Section 3 (electrical conductivity, pH and Cl:SO₄), it is also noted that there has been no measurable impact of any disposal activities during recent time on the quality of the receiving groundwater environment.

Table 5.3 Risk to groundwater quality (after Jacobs 2014)

Risk component	Ranking	Reason	Overall risk rating
Likelihood	Unlikely	<ul style="list-style-type: none"> contaminants within by-products shown to be not readily soluble in groundwater no impact of current disposal activities measurable in existing groundwater effects of dilution in regional groundwater system would reduce potential source concentrations to negligible 	
Consequence	Low	<ul style="list-style-type: none"> no change in aquifer quality impacts within the range of natural variability inter-connected systems, including adjacent and overlying aquifers, hydraulically connected surface water systems and groundwater dependent ecosystems are unaffected groundwater environment is resilient to impacts and only simple, low cost rehabilitation works are required, if any 	Low

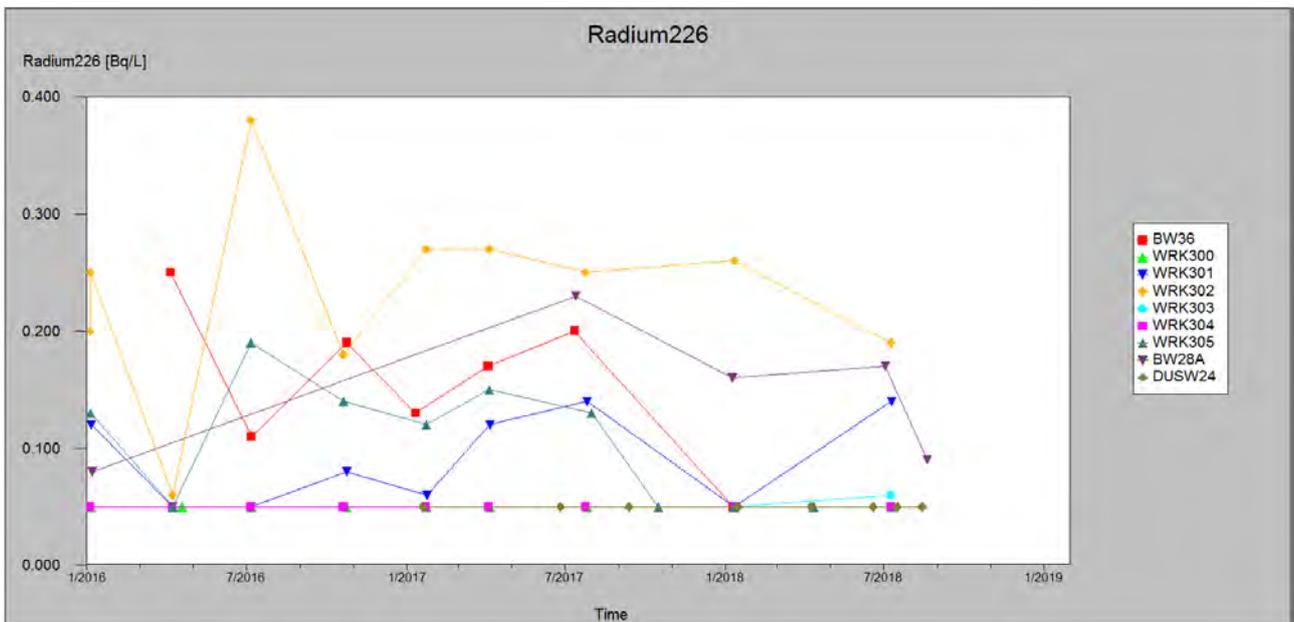


Figure 5.3 Radium-226 concentration (Bq/L) in bores surrounding Pit 23 and within/near the groundwater flow path between Pit 23 and McGlashin Swamp

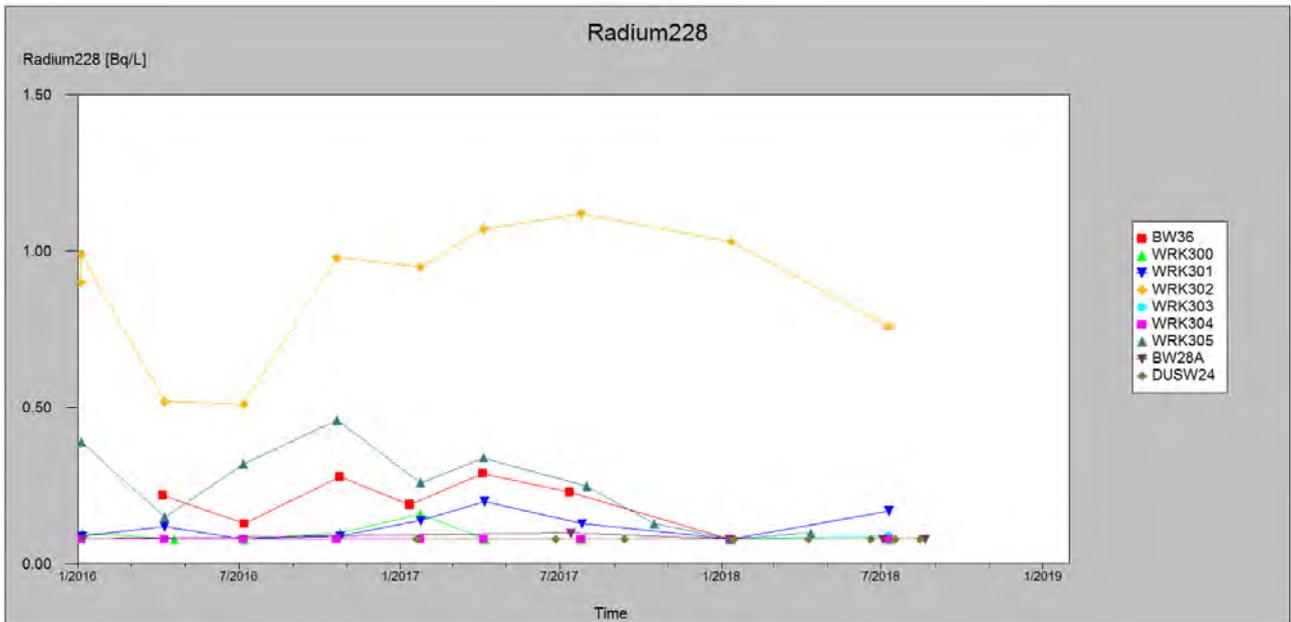


Figure 5.4 Radium-228 concentration (Bq/L) in bores surrounding Pit 23 and within/near the groundwater flow path between Pit 23 and McGlashin Swamp

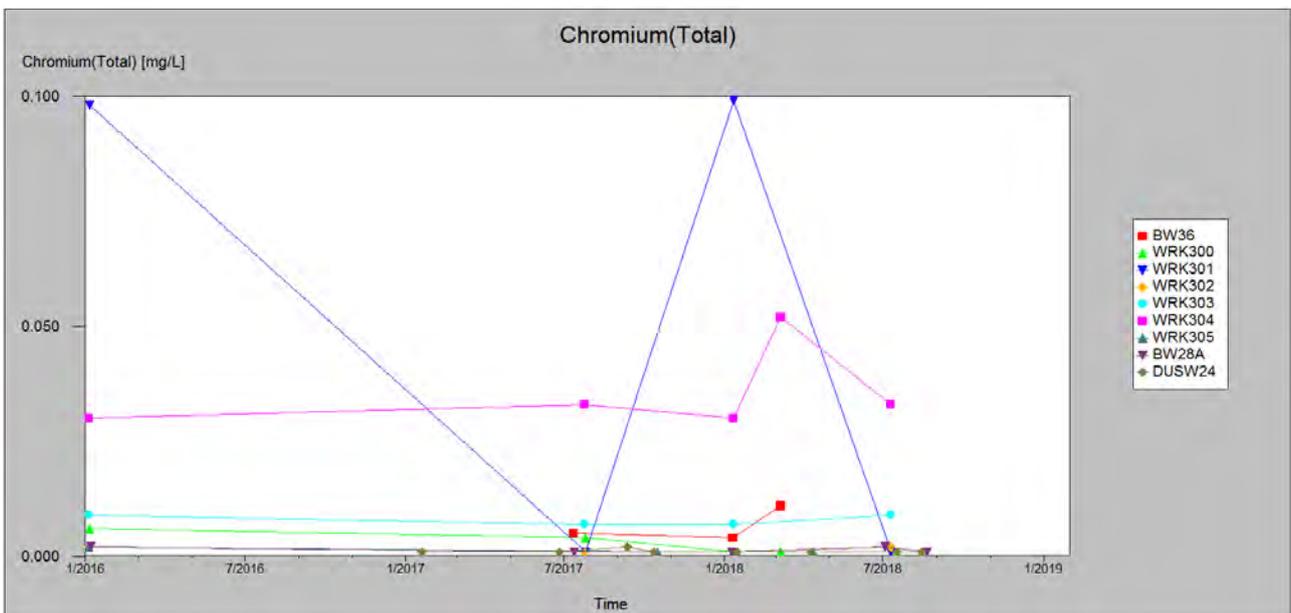


Figure 5.5 Chromium concentration (mg/L) in bores surrounding Pit 23 and within/near the groundwater flow path between Pit 23 and McGlashin Swamp

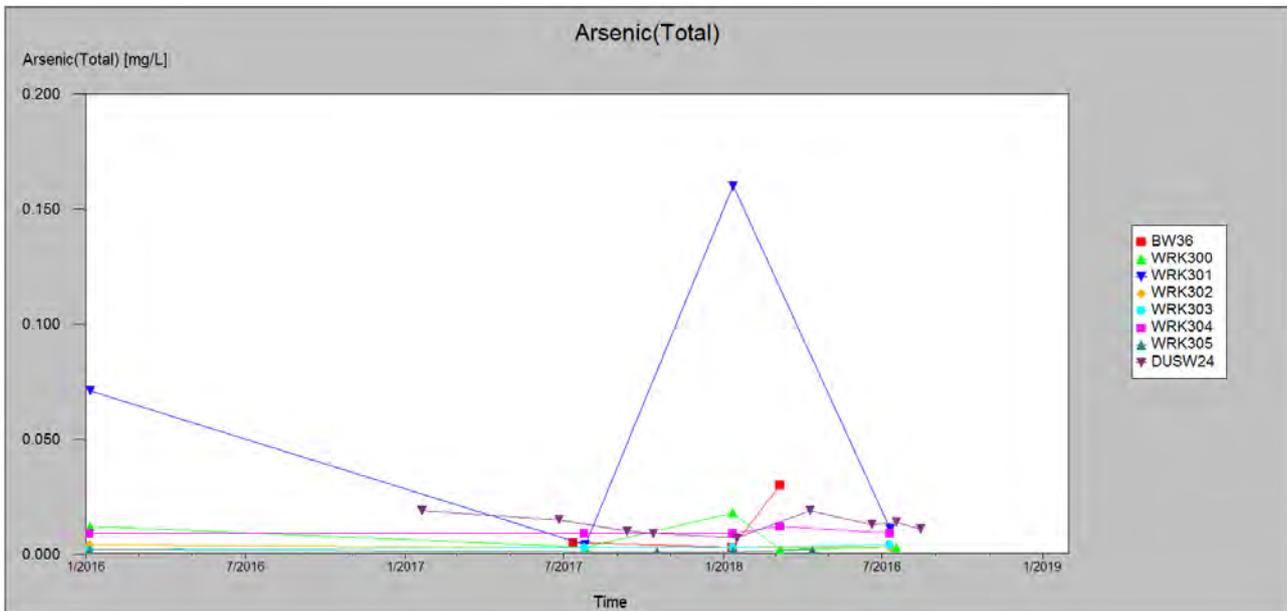


Figure 5.6 Arsenic concentration (mg/L) in bores surrounding Pit 23 and within/near the groundwater flow path between Pit 23 and McGlashin Swamp

5.3 Groundwater Dependent Ecosystems

The overall risk to Groundwater Dependent Ecosystems (GDEs), which are mainly concerned with the groundwater fed wetlands and swamps in the region, caused by continued by-product disposal to Pit 23 was rated as Low. Table 5.4 adapted from Jacobs (2014) shows that the reason for this rating is that groundwater quality and accessibility is unlikely to be affected by continual Pit 23 disposal. In addition, historical data collected up until 2014 were deemed to fall within natural variability.

The risks to groundwater accessibility and groundwater quality were reassessed in Section 5.1 and Section 5.2 respectively. By comparing these previous risk assessments by Jacobs (2014) to current site-based data evaluated in Section 3 along with the assessment of receiving bodies in Section 4, it is concluded that the original Low risk ratings are still valid and thus impacts to any GDEs remains Low, including McGlashin Swamp.

Table 5.4 Risk to groundwater dependent ecosystems (after Jacobs 2014)

Risk component	Ranking	Reason	Overall risk rating
Likelihood	Unlikely	<ul style="list-style-type: none"> given impacts to groundwater accessibility and quality immediately beneath Pit 23 is considered to be unlikely, the likelihood of impacting McGlashin Swamp and White Lake is considered unlikely 	Low
Consequence	Low	<ul style="list-style-type: none"> impacts are within the range of natural variability inter-connected systems, including adjacent and overlying aquifers, hydraulically connected surface water systems and groundwater dependent ecosystems are unaffected 	

6 Trigger Level Review

The trigger levels used to determine exceedances at McGlashin Swamp, and the process for deriving them, have been discussed in detail in Sections 2.1 and 2.2. Table 6.1 summarises the current water quality trigger levels again for completeness and the historical water quality measurements collected at McGlashin Swamp are shown in Table 6.2 with exceeding values highlighted.

As the groundwater seepage and surface water assessments undertaken in Section 3 and Section 4 respectively determined that seepage did not cause these exceedances at McGlashin Swamp, but rather they were caused by natural processes, these triggers should be reviewed so that they are less sensitive to natural variation. This can be achieved through a number of ways including amending how the background concentrations of the water quality analytes are determined, by assessing how the ionic ratios are treated and considering other similar wetland environments within the overall assessment.

Table 6.1 Current water quality trigger values for McGlashin Swamp

Trigger Type	pH (upper)	Electrical Conductivity (µS/cm)	Aluminium (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Dissolved Oxygen (upper) (% saturation)
Precautionary Trigger (2017 data)	8.0	2,125	0.39	3.0	1.44	110
Upper Trigger (2017 data)	9.09	2,500	0.46	3.5	1.70	130
Precautionary Trigger (all data)	8.0	5,759	0.26	5.2	1.41	162
Upper Trigger (all data)	9.68	6,775	0.30	6.1	1.66	191

Table 6.2 Water quality exceedances measured at McGlashin Swamp (based on triggers using all data)

Measurement Date	Cl:SO ₄	Reduction in Ratio	Electrical Conductivity (µS/cm)	pH	Aluminium (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Dissolved Oxygen (% saturation)
19/01/2017	312		1,500	8.57	0.3	1.2	1.66	-
26/06/2017	66.25	79%	2,530	8.91	0.47	5	1.8	110
12/09/2017	13.16	80%	2,120	8.61	0.45	2.8	0.92	82
11/10/2017	11.52	12%	2,290	9.61	0.09	3	0.69	85
15/01/2018	14.26	-24%	3,710	10.4	0.04	4.6	0.35	236
9/04/2018	42.31	-197%	8,336	8.76	0.09	11	1.9	64
19/06/2018	36.84	13%	6,900	9.07	0.17	6.1	0.76	218
17/07/2018	30.43	17%	6,800	9.4	0.12	6.1	0.73	-
14/08/2018	26.39	13%	6,200	9.7	0.12	5.6	0.60	-
12/09/2018	22.47	15%	6,700	9.7	-	-	-	-

Notes: Highlighted values exceeded precautionary (yellow) and Upper (red) triggers, and/or Cl:SO₄ reductions greater than 10%

6.1 Determination of Background Concentrations

Background concentrations of water quality parameters that naturally exceed the guidelines set in SEPP (Waters; EPA Victoria 2018) are currently set as the 75th percentile of the background data collected. The precautionary and upper triggers are then calculated to be 85% and 100% respectively of the background concentrations. Currently, this system struggles at identifying exceedances in cases where the concentrations of analytes have a large variance (e.g. due to seasonal variations), or when considering logarithmic values like pH. The reason for this is likely due to attempting to classify a system with insufficient background data that has not been collected across sufficient climatic variability (such as periods of severe drought).

The effects of variance can be seen in all the water quality parameters in Table 6.2, but it is most apparent when looking at the electrical conductivity measurements. In 2017, these measurements were relatively low at less than 3,000 $\mu\text{S}/\text{cm}$, but in 2018 they rose to an average greater than 6,000 $\mu\text{S}/\text{cm}$, presumably due to the emerging drought conditions. Due to the large difference in measurements in both years, nearly every sample was classified as an exceedance. Jacobs (2014) found that the electrical conductivity at McGlashin Swamp in December 2013 was approximately 18,000 $\mu\text{S}/\text{cm}$, showing that a large variability exists in the system and these swamp/wetland environments are highly sensitive to the prevailing climate at the time.

6.1.1 Trigger levels based on insufficient background data

The Pit 23 EMP defines the interim precautionary and upper trigger levels, to be used when insufficient background data is available, as 1.25 and 1.5 times the calculated background concentrations.

Calculating the trigger levels for pH follow the same process as set out for other water quality analytes, but with special consideration given to the logarithmic nature of this parameter. Instead of multiplying the pH by 1.25 or 1.5, the following equations are used, where pH indicates the background pH concentration:

$$\text{Precautionary Trigger} = \text{LOG}_{10}(10^{pH} \times 1.25)$$

$$\text{Upper Trigger} = \text{LOG}_{10}(10^{pH} \times 1.5)$$

Equation 2 Trigger level calculations for pH

Trigger levels based on the 2017 dataset calculated using this method are shown in Table 6.3, and Table 6.4 shows the exceedances for the last two years when this method is applied. As observed in Table 6.4 and discussed previously in Section 2, this method still highlights exceedances.

Table 6.3 Proposed McGlashin Swamp water quality trigger levels calculated from 2017 data

	pH (upper)	Electrical Conductivity ($\mu\text{S}/\text{cm}$)	Aluminium (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Dissolved Oxygen (upper) (% saturation)
Precautionary trigger (1.25x background level)	9.19	2,940	0.57	4.4	2.12	122
Upper trigger (1.5x background level)	9.27	3,530	0.68	5.3	2.54	146

Table 6.4 Water quality exceedances measured at McGlashin Swamp (based on ‘insufficient data triggers levels’)

Measurement Date	Cl:SO ₄	Reduction in Ratio	Electrical Conductivity (µS/cm)	pH	Aluminium (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Dissolved Oxygen (% saturation)
19/01/2017	312		1,500	8.57	0.3	1.2	1.66	-
26/06/2017	66.25	79%	2,530	8.91	0.47	5	1.8	110
12/09/2017	13.16	80%	2,120	8.61	0.45	2.8	0.92	82
11/10/2017	11.52	12%	2,290	9.61	0.09	3	0.69	85
15/01/2018	14.26	-24%	3,710	10.4	0.04	4.6	0.35	236
9/04/2018	42.31	-197%	8,336	8.76	0.09	11	1.9	64
19/06/2018	36.84	13%	6,900	9.07	0.17	6.1	0.76	218
17/07/2018	30.43	17%	6,800	9.4	0.12	6.1	0.73	-
14/08/2018	26.39	13%	6,200	9.7	0.12	5.6	0.60	-
12/09/2018	22.47	15%	6,700	9.7	-	-	-	-

Notes: Highlighted values exceeded precautionary (yellow) and Upper (red) triggers, and/or Cl:SO₄ reductions greater than 10%

6.2 Ionic Ratios

Currently, Cl:SO₄ and sodium calcium ionic ratios are monitored; an exceedance is said to have occurred when repeated measurements show that one of these ratios has decreased by more than 10%. This system of determining exceedances faces problems in locations that show seasonal changes, especially for surface water locations that are highly sensitive to the prevailing climate, such as McGlashin Swamp.

All of the groundwater-connected surface water bodies showed similar trends of increasing and decreasing Cl:SO₄ values around the same time of the year. Therefore, this makes it very likely that this trigger value will be regularly breached just through natural variation. This effect can be seen in Table 6.2, where Cl:SO₄ was found to decrease by more than 10% in most measurements. In reality, the Cl:SO₄ at McGlashin Swamp was always higher than other surface water bodies and not indicative of groundwater seepage, more so a result of ongoing drought conditions and ongoing evapoconcentration.

To make this parameter less sensitive to natural variation, it is proposed that the trigger level be changed to the actual ratio value, rather than the reduction in ratio percentage, with the latter still assessed as perhaps a leading indicator. As lower Cl:SO₄ values can indicate seepage from Pit 23, the trigger level set will be a minimum; values that are lower than the trigger level are considered to be exceeding.

The precautionary and minimum Cl:SO₄ trigger values can be derived from background data, as is done with the other analytes. The 25th percentile is used to calculate the background concentration instead of the 75th percentile, as a lower Cl:SO₄ value suggests seepage. Additionally, instead of multiplying by 1.25 and 1.5 to find the precautionary and upper triggers, the background level is divided by these values. Based on the 2017 dataset, the precautionary and minimum trigger values for Cl:SO₄ would be 10.2 and 8.5 respectively. Note, that it is common that Cl:SO₄ values of less than 4 are generally considered acid producing environments thus the suggested updates to the Cl:SO₄ triggers are still considered conservative from this perspective.

6.3 Suggested updates to trigger level values

At this point in time, there does not appear to be enough data available to properly characterise the background chemistry and thus set valid trigger levels for McGlashin Swamp. It is recommended that Iluka include Brooksby's Swamp as part of their ongoing surface water monitoring plan, and perhaps also include Redgum Swamp and Jallumba Marsh to allow a more statistically valid approach for calculating trigger levels. As discussed earlier, the recent millennium drought may be causing exacerbation of some of these leading indicators through natural processes including evapoconcentration, eutrophication and photosynthesis. It is envisioned that monitoring these analogous swamps in parallel with the current surface water monitoring points will show the water quality variability is a natural phenomenon rather than a result of groundwater seepage and subsequent transport emanating from Pit 23. Ongoing monitoring for up to two years should be considered, allowing for enough climatic variability to exist in the system and the corresponding monitoring dataset.

As discussed in Section 6.2, Iluka may also want to consider using the actual Cl:SO₄ values as the trigger levels, rather than the reduction in ratio percentage, with the latter still assessed as perhaps a leading indicator. Until more data is collected at the wetland/swamp sites, interim triggers for Cl:SO₄ could be set at 10.2 and 8.5 for the precautionary and minimum trigger values respectively. Note that Cl:SO₄ trigger levels are lower boundaries; Cl:SO₄ measurements below these triggers are considered to be breaching.

7 Conclusions

Based on the findings of this report, the following conclusions and recommendations are made:

- manually calculated ion balance errors closely matched values provided by the laboratory, suggesting that the water quality results provided are valid;
- exceedances of the precautionary trigger values for electrical conductivity and pH are observed in the 2017 reporting period only if the four samples taken that year are considered to be representative of all background data. Measurements taken before and after 2017 suggest that these samples are not representative;
- no evidence was found that suggests groundwater seepage or material transport from Pit 23 via a surface water pathway contributed to the exceedances observed at McGlashin Swamp, or that groundwater seepage into the environment surrounding Pit 23 has occurred;
- the exceedances were likely caused by a combination of natural evapoconcentration and photosynthesis processes;
- the groundwater risk assessment of continued by-product disposal into Pit 23 produced by Jacobs (2014) which stated that there was a low risk of impact to groundwater accessibility, groundwater quality and groundwater dependent ecosystems was found to still be valid. Only small changes were observed to groundwater levels and no evidence of contaminants leaching into the groundwater was found;
- Sites analogous to McGlashin Swamp, but outside of any influence from Pit 23 groundwater, including: Brooksby's Swamp, Redgum Swamp and Jallumba Marsh, should be included in the surface water monitoring program from this point on to demonstrate water quality variations due to natural phenomena;
- Once enough data across varying climatic seasons is collected, surface water quality triggers can be recalculated for groundwater fed wetlands and swamp environments such as McGlashin Swamp; and
- to make the ionic ratio triggers less sensitive to natural variation, it is recommended that precautionary and minimum trigger levels are implemented and applied to the ratio value, rather than the current system which uses the percentage decrease between samples as the trigger.

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