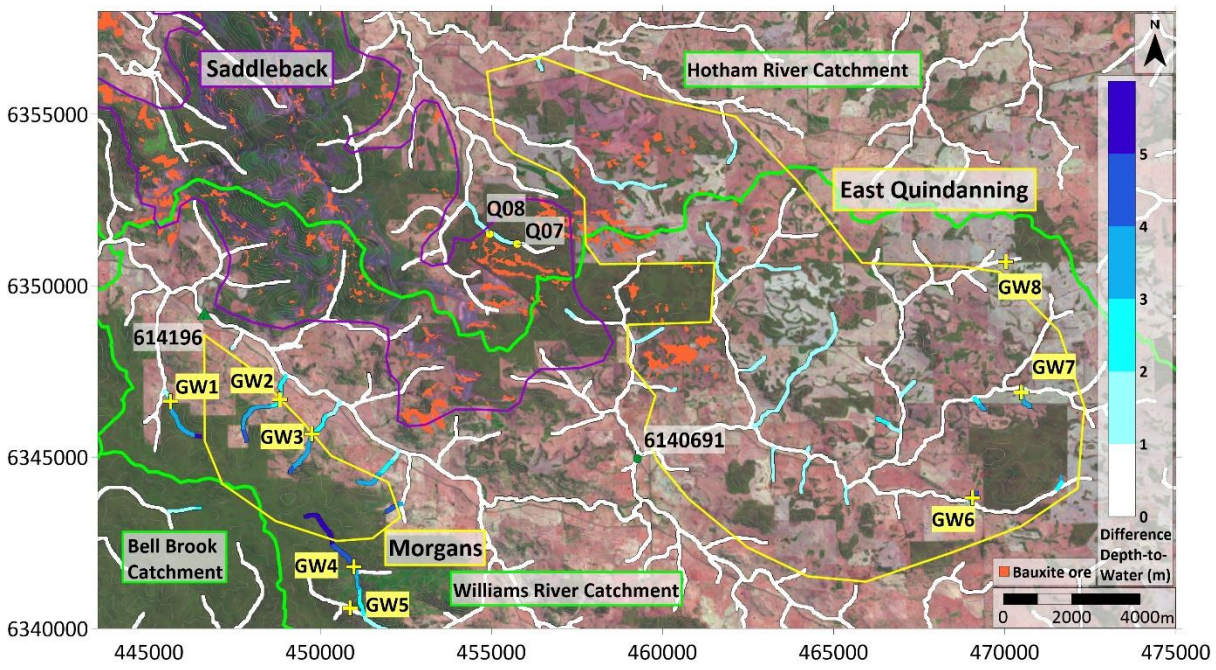
REPORT
TO
SOUTH 32 WORSLEY ALUMINA PTY LTD

SALINITY RISK ASSESSMENT FOR THE EAST QUINDANNING & MORGANS MINING AREAS USING FLUX DENSITY ANALYSIS



K.A. Green, G.T. Dalton, J.T. Croton, and J.A. Dalton
Water & Environmental Consultants
July 2023

Contents

LIST OF FIGURES ii
SUMMARY iii
1. INTRODUCTION 4
1.1 Bauxite Mining and Salinity Risk 4
1.2 Climate 5
1.3 Hydrogeology 5
1.4 Soil-Salt Storage 6
2. LAND & WATER USE 6
3. GROUNDWATER REVIEW 7
4. SURFACE WATER REVIEW 10
5. FLUX DENSITY ANALYSIS & RECOMMENDATIONS 12
6. CONCLUSIONS 15
References 16
Appendix 17

LIST OF FIGURES

Figure 1: Location of current and extended mining areas within Worsley's ML258SA.....4
Figure 2: Annual rainfall for Marradong rain gauge 9575. 5
Figure 3: Map of bedrock geology of East Quindanning and Morgans mining areas. 6
Figure 4: Land use and water catchments of EQMA, MMA, and surrounds. 7
Figure 5: Groundwater-monitoring locations in the EQMA and surrounds. 8
Figure 6: Groundwater level and salinity for Q07 and Q08 groundwater monitoring bores. 9
Figure 7: Groundwater-monitoring locations in the MMA and surrounds. 9
Figure 8: Surface-water monitoring locations in MMA, EQMA and surrounds. 10
Figure 9: Streamflow and salinity for Williams River 614196 stream-gauge. 11
Figure 10: A theoretical landscape with two minepits illustrating the application of FDA. ...12
Figure 11: Map of the FDA-estimated changes in valley-floor groundwater levels due to existing agricultural clearing.....13
Figure 12: Map of FDA-estimated change in groundwater-level along the valley floor due to an estimated 40% of forested land cleared for mining activities in EQMA and MMA. 14
Figure 13: Map of FDA-estimated change in groundwater-level along the valley floor due to 80% of forested land cleared for mining activities in EQMA and MMA; with relevant existing ground and surface monitoring locations, and proposed groundwater monitoring locations (+). 15

SUMMARY

South32 Worsley Alumina Pty Ltd (Worsley) proposes to extend their bauxite-mining activities to five mining envelopes: Brookton, Central, Hotham North Extension, East Quindanning and Morgans. Due to known issues associated with salinity and agricultural clearing in the south-west of W.A., Worsley has commissioned Water & Environmental Consultants (WEC) to conduct salinity-risk assessments for the extended mining areas. This report focuses on the East Quindanning Mining Area (EQMA) and Morgans Mining Area (MMA), it evaluates available information on the climate, hydrogeology, soil-salt storage, groundwater and surface-water level/flow and quality to develop an understanding of the current state of the groundwater and surface-water systems. Flux Density Analysis (FDA) is then used to assess the potential salinity-risk and identify potential salinity-hotspots.

Rainfall has been declining since 1975, with rainfall over the recent period on average fifteen-percent lower than pre-1975 rainfall. This has led to associated declines in the groundwater-table under the forested areas of Boddington Bauxite Mine (BBM). Rainfall is a significant unknown in estimating the salinity-risk, given the high inter-annual variability, and its direct role in water-table rises and declines.

The hydrogeology at EQMA and MMA is equivalent to that of BBM; with up to three aquifers, a small, shallow, superficial aquifer that is usually not connected to the deeper aquifers in the saprolite and fractured rock (which are connected). The soils are highly permeable with little runoff, so streamflow is generated through interflow in the upper layers and by a seasonal perched aquifer. The main groundwater aquifer tends to be saline and disconnected from the surface water in forested areas, but is often connected to the stream in agricultural areas.

Groundwater monitoring of the EQMA and MMA catchments is limited and dated with the most recent measurement occurring in 1986. Two nearby BBM monitoring bores suggest the groundwater is deep and saline in forested areas. It is difficult to develop an understanding of the groundwater level and salinity in agricultural areas due to the lack of recent data and deep monitoring bores. However, there appears to be, at least historically, areas of surface expression of groundwater within and downslope of the planned mining areas.

The EQMA and MMA lie predominantly within Williams River catchment, with the northern area of EQMA draining to Hotham River and a small south-western part of MMA in the forested Bell Brook catchment. Williams River catchment is predominantly cleared for agriculture and has high salinity in the main river and several tributaries, suggesting that there is saline-groundwater discharge. The streamflow and salinity of Williams River has not changed significantly since the mid-1970's.

A Flux Density Analysis (FDA) was conducted, to assess the potential water-table rise from bauxite-mining activities and to identify hotspots where we expect a greater groundwater-flux due to the local topography and mine-plan. Surveying for bauxite has not been conducted in MMA or most of EQMA so two mining-scenarios were developed, with 40% and 80% clearing of forested areas for mining respectively, excluding riparian zones. The 40% scenario is a conservative estimate of the overall clearing, and the 80% is an upper limit of expected clearing within a valley. The groundwater fluxes are greatest in MMA, where the valley heads are forested, and in small tributaries draining the main forested area of EQMA. There may be some increase in salinity and surface-water expression on agricultural land downslope of the mining areas, and it is recommended that groundwater monitoring bores are installed at eight locations to develop an understanding of the current groundwater situation and monitor any changes. The effects are expected to be localised with no significant effect on the main river flows and salinity.

1. INTRODUCTION

South32 Worsley Alumina Pty Ltd (Worsley) proposes to extend their bauxite mining activities to five mining envelopes: Brookton, Central, Hotham North Extension, East Quindanning and Morgans. These mining envelopes are in Worsley's mining lease 258SA in the northern jarrah forest on the Darling Plateau, both north and south of existing mining activities (see Figure 1). The focus of this review is the two southern mining envelopes, East Quindanning Mining Area (EQMA) and Morgans Mining Area (MMA). Due to known issues associated with salinity and agricultural clearing in the south-west of W.A., Worsley has commissioned Water & Environmental Consultants (WEC) to conduct a salinity-risk assessment for the extended mining areas. This report evaluates available information on the climate, hydrogeology, soil-salt storage, groundwater and surface-water level/flow and quality for the EQMA and MMA, to develop an understanding of the current state of the groundwater and surface-water systems. Flux Density Analysis (FDA) is then used to assess the potential salinity-risk and identify potential salinity-hotspots.

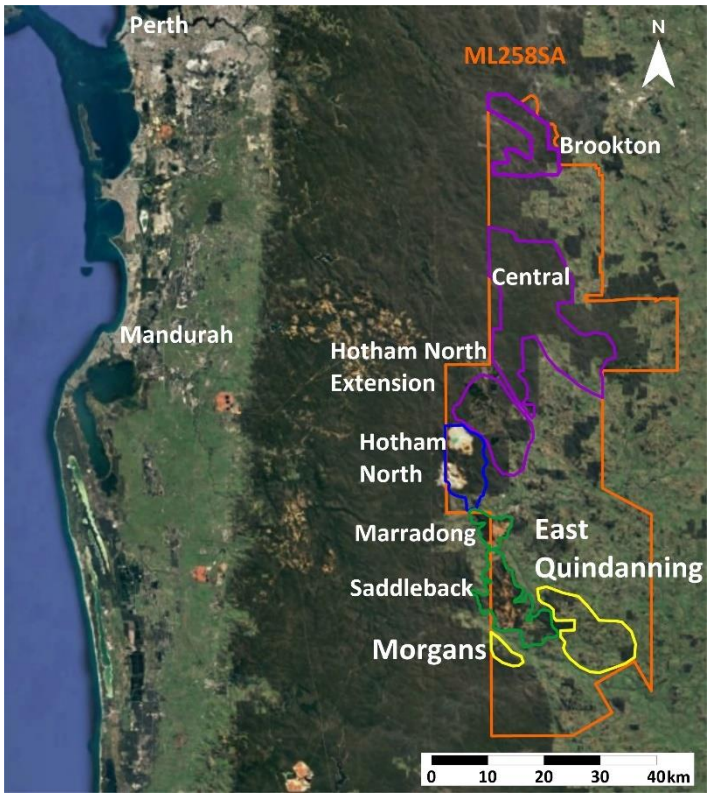


Figure 1: Location of current and extended mining areas within Worsley's ML258SA.

1.1 Bauxite Mining and Salinity Risk

Bauxite mining has the potential to affect the groundwater-table due to changes in recharge caused by vegetation clearing. In the Low Rainfall Zone (LRZ) of the northern jarrah forest evapotranspiration normally accounts for the vast majority of rainfall; when this forest is cleared the bare-soil evaporation rate is significantly lower resulting in higher infiltration, some of which can increase the groundwater-table level, particularly in the lower-slope and valley-floor areas. Clearing for bauxite is transient in nature, with land being promptly revegetated after mining except for areas of haul roads and infrastructure. If this revegetation is hydrologically equivalent to what is cleared, then the rise in the groundwater will be temporary. The potential salinity-risk of bauxite-mining depends on the initial groundwater-depth, the potential for the groundwater to rise, the salinity of the groundwater, the soil salt-storage profile of the valley floor, and the initial stream-salinity. To give an initial assessment of the salinity-risk potential of bauxite-mining in EQMA and MMA this report assesses these factors, using available data.

1.2 Climate

The East Quindanning Mining Area (EQMA) and Morgans Mining Area (MMA) are located in the Low Rainfall Zone (LRZ, <900 mm/annum rainfall) of the northern jarrah forest, with a Mediterranean climate of hot dry summers and wet winters. The rainfall in the area has been declining, with the annual rainfall at Marradong gauging station shown in Figure 2. This gauging station is located between the Marradong and Saddleback mining areas (see Figure 1) The average rainfall since 1975 (642 mm/yr) is fifteen percent (117 mm) lower than the pre-1974 average (759 mm/yr). The rainfall decline has led to associated declines in the groundwater-table under forested areas of the Boddington Bauxite Mine area (BBM) (Green *et al* 2021). These declines in the groundwater-table reduce the salinity- risk of mining activities as the gap between the groundwater-table and valley-floor soil-surface increases. Rainfall is a significant unknown in estimating the salinity-risk, given the high inter-annual variability, and its direct role in water-table rises and declines.

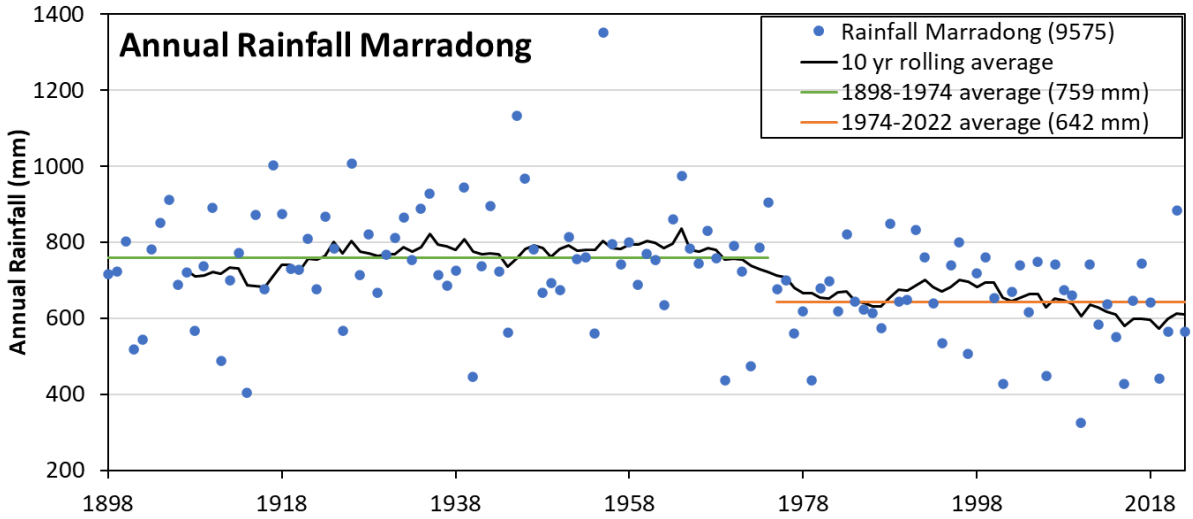


Figure 2: Annual rainfall for Marradong rain gauge 9575.

1.3 Hydrogeology

The hydrogeology of EQMA and MMA is similar to that at Worsley BBM operations which lies between and to the north of these areas, with no significant differences in the overall structure. There are up to three aquifer-layers: a shallow seasonal-aquifer, a deep weathered-zone aquifer, and a fractured-bedrock aquifer. The existence and extent of these three aquifers varies across the region. The soil profile typically varies from 10 m to over 50 m but averages around 25 m. The typical soil-profile involves: a shallow top-layer of gravelly sand (0-2 m), in which can form a superficial aquifer; a low-permeability duricrust underlies this layer (0-3 m thick) and forms the upper section of a bauxite layer (0-10 m thick); next come the mottled and pallid zones; followed by a saprolite layer, which forms the second aquifer; below this is the fractured-rock aquifer within the bedrock. The saprolite and fractured-rock aquifers are in hydraulic-continuity and are distinguished from each other by their material properties. The near-surface soils are highly permeable, so streamflow is usually generated from lateral flows in the upper layer and the superficial aquifer. The salinity is usually low in these upper layers and the low volume and high permeability of the superficial aquifer generally results in ephemeral streams, with flow periods dependent on the catchment area and superficial-aquifer thickness. As well as generating streamflow some water penetrates to the connected saprolite and fractured-rock aquifers. These aquifers are usually disconnected from surface water in forested areas with their water-table remaining at depth, even in the stream zone. Rises of this water-table can result in discharge of saline groundwater to streams, significantly affecting the stream and riparian ecosystems, as has been observed following historical clearing for agriculture in the region.

1.4 Soil-Salt Storage

Croton and Dalton have conducted a number of studies into the soil-salt storage in the Boddington Bauxite Mine (BBM) areas (2000, 2001, 2004 & 2007). Given the similarities in the hydrogeology of EQMA and MMA to these areas it is expected that the findings from these studies will provide insight to the EQMA and MMA. The underlying bedrock in EQMA is predominantly Yilgarn Craton granites, with a small area of South-West Terrane greenstones along the western edge. The underlying bedrock in MMA is predominantly greenstones, with granite bedrock over a third of the area in the south-west, there is also a small area of Widgiemooltha Dolerite in the eastern edge. The 2007 study found that mean volumetric total soluble salts (VTSS) was statistically higher over granite bedrock (1.29 kg/m^3) compared to greenstone bedrock (0.97 kg/m^3). These studies also found the VTSS to be significantly lower than other literature values of 1.78 kg/m^3 (Stokes *et al* 1980) and 1.94 kg/m^3 (Tsykin & Croton 1988); the underlying cause of this difference is not clear, however it was suggested that it may be due to the high porosity of soils associated with bauxite (Croton & Dalton 2007).

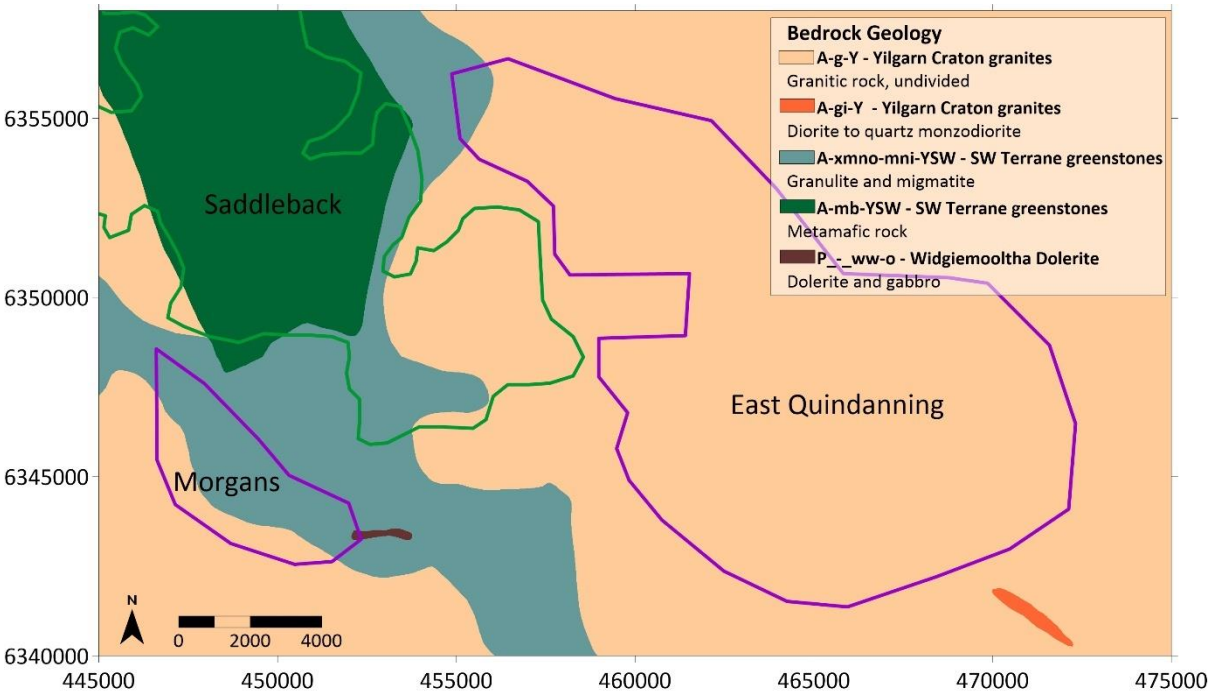


Figure 3: Map of bedrock geology of East Quindanning and Morgans mining areas.

2. LAND & WATER USE

Land use in EQMA and MMA is a mixture of cleared agricultural land and forested areas, with the main timber reserves and water catchment areas shown in Figure 4. The majority of forested areas in MMA are part of the Morgan Timber Reserve (MTR), which covers approximately half of MMA. Forested areas in the EQMA are privately owned, and the majority of the land is cleared for agriculture. The majority of both the EQMA and MMA are within the Williams River catchment, which is mostly cleared agricultural land. The northern part of the EQMA flows into the Hotham River catchment, which is also predominantly cleared agricultural land and BBM operations, and merges with Williams River to the west of the study area forming the Murray River. A small portion of MMA drains to Bell Brook catchment which is predominantly forested and joins the Murray River further downstream.

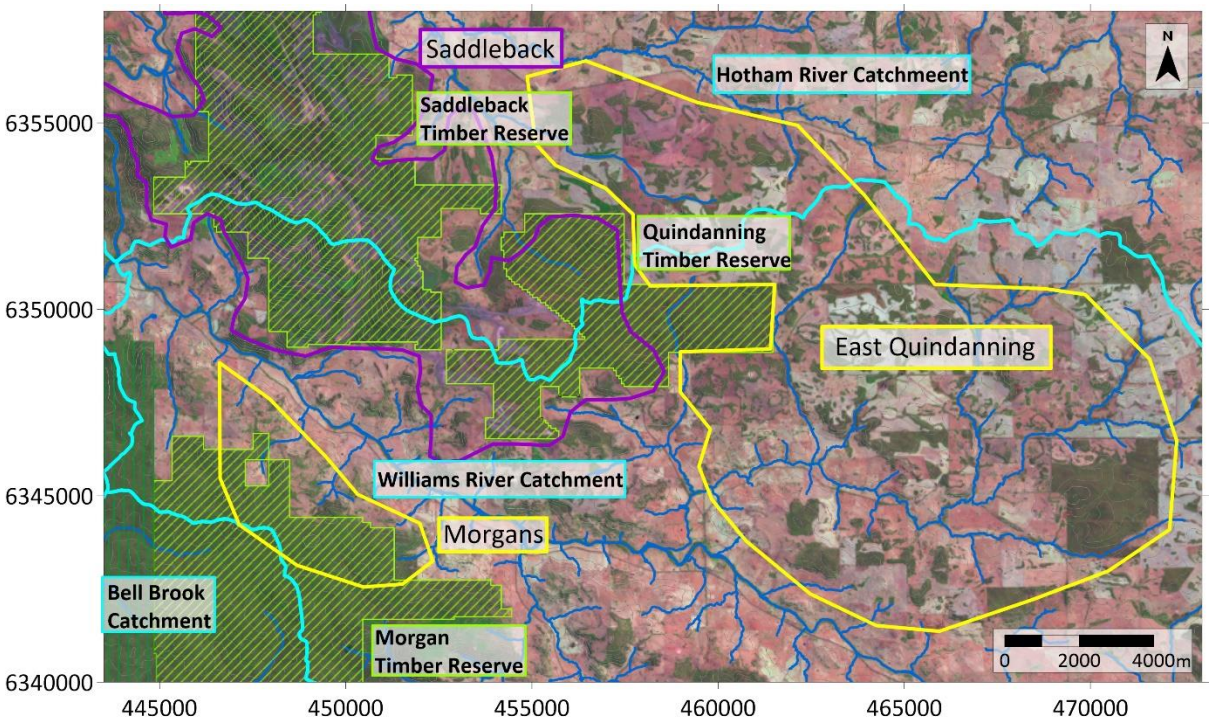


Figure 4: Land use and water catchments of EQMA, MMA, and surrounds.

3. GROUNDWATER REVIEW

There are several groundwater monitoring locations within and downslope of EQMA. The locations are shown in Figure 5 and the data is summarised in Table 1. The majority of these are surface expression of groundwater (soaks and springs). There are two Worsley monitoring bores in the forested area adjacent to EQMA, Q07 and Q08. Plots of the groundwater level and salinity of these two bores is shown in Figure 6. The groundwater level at these forested bores is deep and has been declining over the monitoring period due to the declining rainfall. The two bores in agricultural areas with depths greater than five metres (61405778 and 61405786) have groundwater levels significantly deeper than nearby shallow bores (6140907 and 6145787). The salinity of the shallow bores is significantly lower than the deep bores of these pairs, suggesting that there is a lower salinity perched-aquifer and higher salinity main-aquifer. Some of the shallow and surface-level monitoring locations have high salinity, most notably 61406091 with a salinity of 2,300 mg/L, suggesting that there is some surface discharge of high-salinity groundwater. The date of sampling is unknown for most monitoring locations, so it is unclear if the saline-water discharge is localised temporally and/or spatially. The salinity of groundwater at or close-to the surface is likely to vary significantly depending on the recent rainfall. The salinity at Q07 and Q08 increased in the first years of monitoring, there is no significant change in salinity for other monitoring-points with multiple measurements. The most recent dated monitoring in agricultural areas occurred thirty-seven years ago so it is unclear what the current depth and salinity of the groundwater is in EQMA.

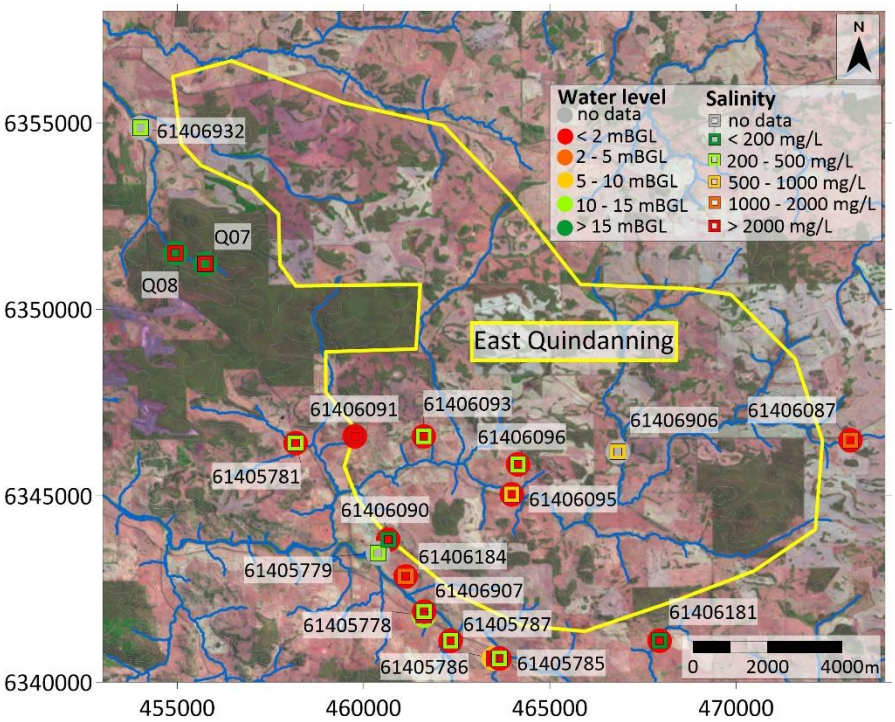


Figure 5: Groundwater-monitoring locations in the EQMA and surrounds.

Table 1: Groundwater monitoring data for EQMA and surrounds.

Bore	Easting	Northing	Date	Level (mBGL)	TDS (mg/L)
61405778	461619	6341790	30-Jun-1978	10.7	4004
61405779	460383	6343463	30-Jun-1970 8-Aug-1986	- -	420 490
61405781	458179	6346415	-	0	360
61405785	463650	6340639	-	0	205
61405786	463501	6340632	30-Jun-1974 7-Aug-1986	7.2 -	2650 2560
61405787	462340	6341108	-	0.7	210
61406087	473072	6346491	-	0	1080
61406090	460663	6343821	-	0	155
61406091	459768	6346591	-	0	2300
61406093	461619	6346593	-	0	410
61406095	463971	6345038	-	0	620
61406096	464144	6345847	-	0	320
61406181	467950	6341115	30-Jun-1963	0	155
61406184	461128	6342835	-	0	1050
61406906	466819	6346181	- 13-Aug-1986	- -	820 820
61406907	461623	6341899	-	1	205
61406932	454014	6354868	-	-	460
Q07	455750	6351213	2005 – 2019	24.3 – 26.4	2100 – 3060
Q08	454949	6351498	2005 – 2019	19.4 – 23.9	2900 – 4290

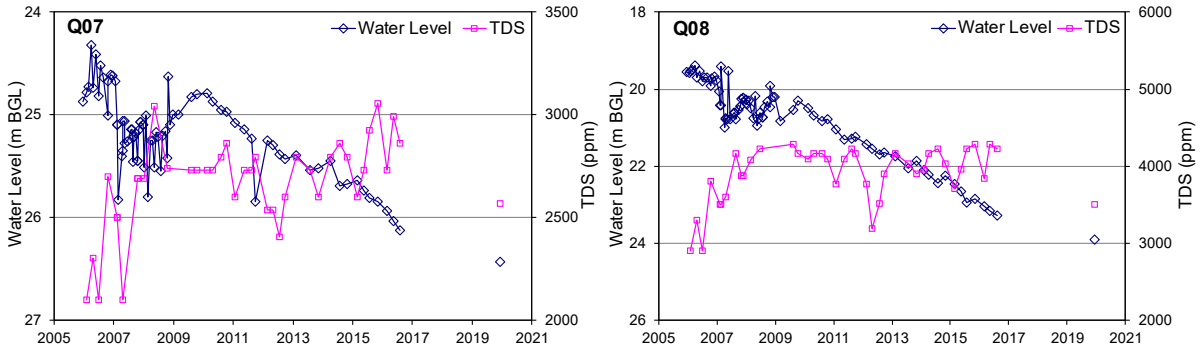


Figure 6: Groundwater level and salinity for Q07 and Q08 groundwater monitoring bores.

The groundwater monitoring locations within and downslope of MMA are shown in Figure 7 and the data is summarised in Table 2. There is only one bore with a depth greater than five metres (61406047), with the remainder being surface or near-surface groundwater expressions (soaks and springs). Similar to EQMA the salinity varies significantly between monitoring locations, and most monitoring dates are unknown. The only dated monitoring is thirty-nine years ago so again, the current depth and salinity of the groundwater is unknown.

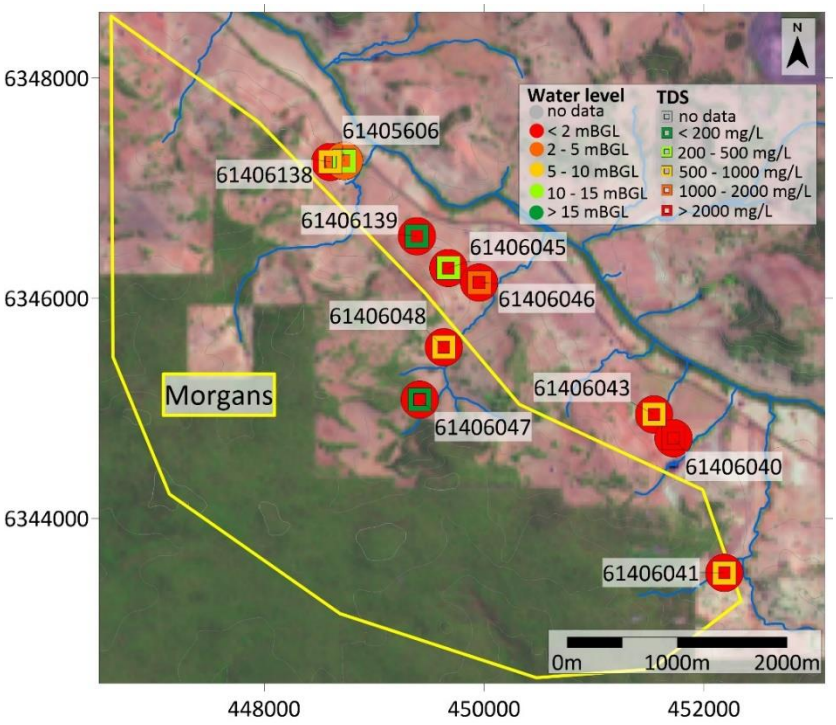


Figure 7: Groundwater-monitoring locations in the MMA and surrounds.

Table 2: Groundwater monitoring data for MMA and surrounds.

Bore	Easting	Northing	Date	Level (mBGL)	TDS (mg/L)
61405606	448726	6347248	-	4.5	260
61406040	451722	6344729	-	0	2120
61406041	452184	6343505	-	0	890
61406043	451546	6344944	-	0	760
61406045	449674	6346274	- 17-May-1984	1.2 -	190 286
61406046	449955	6346143	-	0	1730
61406047	449413	6345080	-	0	190
61406048	449633	6345553	-	0	800
61406138	448602	6347238	-	0	610
61406139	449389	6346563	-	0	195

It is difficult to develop a clear picture of the groundwater situation in EQMA and MMA based on the data available due to the lack of deep bores, and lack of recent measurements, with the date unknown for most measurements. There appears to be, at least historically, surface expression of groundwater within and downslope of the mining areas. The surface-level groundwater is mostly of low to moderate salinity suggesting that it may be from the shallow superficial aquifer, however there are some high-salinity shallow-groundwater measurements suggesting that the main aquifer may have been connected to the surface-water at the time of measurement. In forested catchments the groundwater appears to be deep and disconnected from the surface-water. It is unclear what the current groundwater levels and salinity are in agricultural areas, given the dated measurements are nearly 40 years old. Additional deep groundwater-monitoring bores, and further monitoring of existing locations would be necessary to obtain a better understanding of the current groundwater situation in these areas.

4. SURFACE WATER REVIEW

There are several surface-water monitoring locations within and around EQMA and MMA which are shown in Figure 8 with the relevant data summarised in Table 3 (plots are included in the Appendix). The salinity measured at most locations is high, with measurements over 10,000 mg/L at several locations. The high salinity at most monitoring locations suggests that there is saline-groundwater discharging into the waterways.

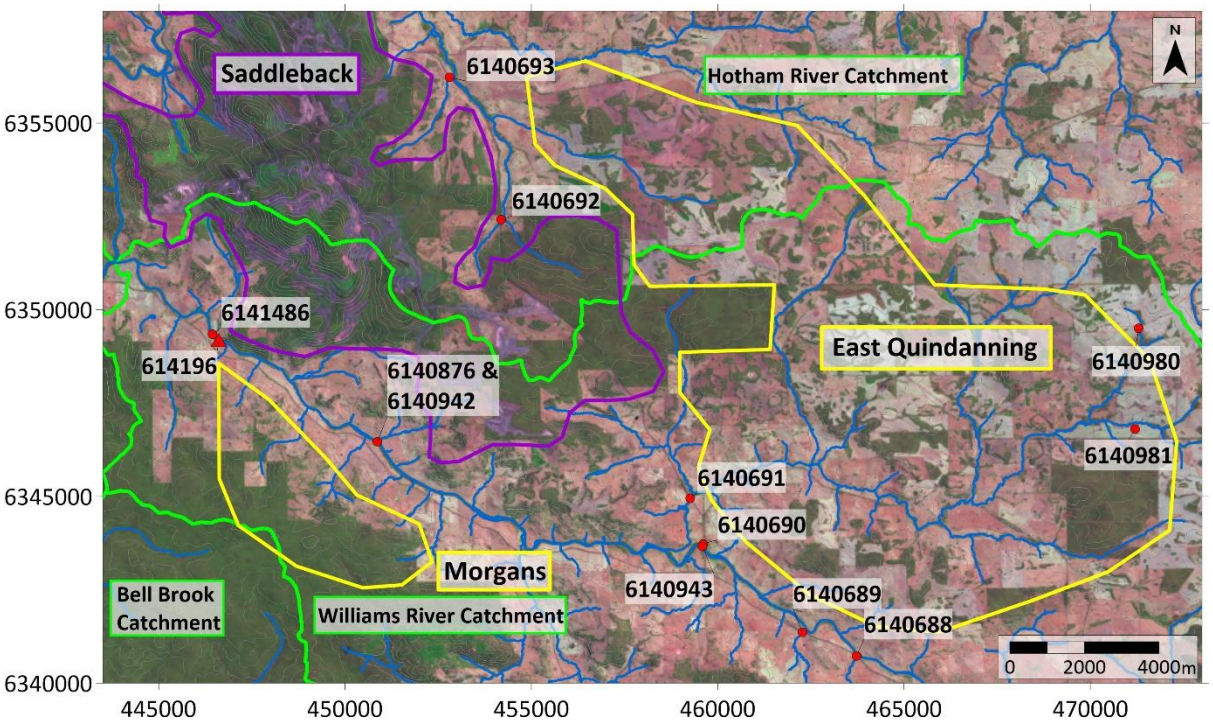


Figure 8: Surface-water monitoring locations in MMA, EQMA and surrounds.

Table 3: Summary of relevant surface water monitoring data in BMA, EQMA, and surrounds.

Site	Easting	Northing	Date Range	TDS Range (mg/L)
6140688	463730	6340731	2004 – 2009	760 – 8870
6140689	462278	6341363	2004 – 2009	1,770 – 6,430
6140690	459605	6343726	2004 – 2009	1,360 – 11,200
6140691	459263	6344954	2004 – 2009	3,400 – 10,800
6140692	454188	6352419	2004 – 2009	1,880 – 8,990
6140693	452799	6356225	2004 – 2009	1,550 – 6,320
6140943	459585	6343667	Aug & Nov 2002	9,800 – 11,200
6140980	471301	6349502	Oct 2004	10,410 – 11,110
6140981	471201	6346802	Oct 2004	15,180 – 16,800
6140876 & 6140942	450868	6346469	2002 – 2010	4,920 – 8,600
6141486	446440	6349350	Oct 1975	660
614196	446615	6349182	1966 – 2023	400 – 11,250

There is a surface-water gauging-station with in-situ conductivity and flow monitoring on Williams River located downstream of EQMA and most of MMA (614196), the salinity and streamflow is plotted in Figure 9. The streamflow and salinity have been reasonably steady over the monitoring period with no significant change in streamflow and salinity since the mid-1970's. The salinity declines during peak flow periods but has rarely dropped below 2,000 mg/L over the past two decades when there has been continuous in-situ monitoring.

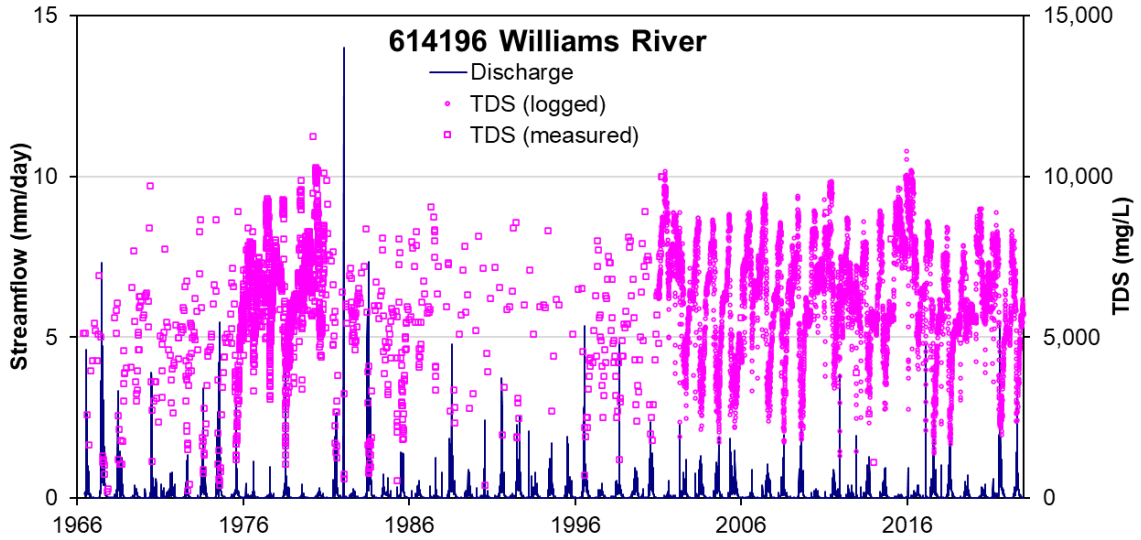


Figure 9: Streamflow and salinity for Williams River 614196 stream-gauge.

Overall, the stream salinity is high at most monitoring locations, suggesting that the ground and surface-water systems are connected in these agricultural catchments. This is consistent with other waterways in the region with a high percentage of land cleared for agriculture, and the high-salinity near-surface groundwater at some monitoring locations.

5. FLUX DENSITY ANALYSIS & RECOMMENDATIONS

Flux Density Analysis (FDA) is based on the concept of tracing possible groundwater flow-pathways across the landscape to calculate their catchment area, and on the concept of weighting areas of different land-use to account for differences in potential groundwater-recharge due to differences in vegetation-cover. The method factors in the effects of topography and vegetation cover on groundwater flux-densities. The significance of flux density is illustrated by Figure 10, which shows two theoretical minepits, the one on the west has convergent drainage to the valley head, whereas the northern one has divergent drainage dispersed along the stream flank. While both minepits are the same size, the one with convergent drainage has a narrowing flow path and therefore a much higher flux-density where the flowpath meets the stream, all the flux is focused on the valley head. The northern minepit with its divergent drainage has a distributed flux as it meets the stream along its length and thereby has a much lower flux-density. The net result is that the western pit has a greater potential to cause groundwater rise at the stream contact-point compared to the northern minepit. A limitation of FDA is that it is driven just by surface-topography and vegetation-cover as these are the only two parameters readily available; the complexities of local hydrogeology are lacking. However, given that it is a first-pass tool designed to identify areas that may require further investigation and the possible installation of monitoring (piezometers), this limitation is acceptable.

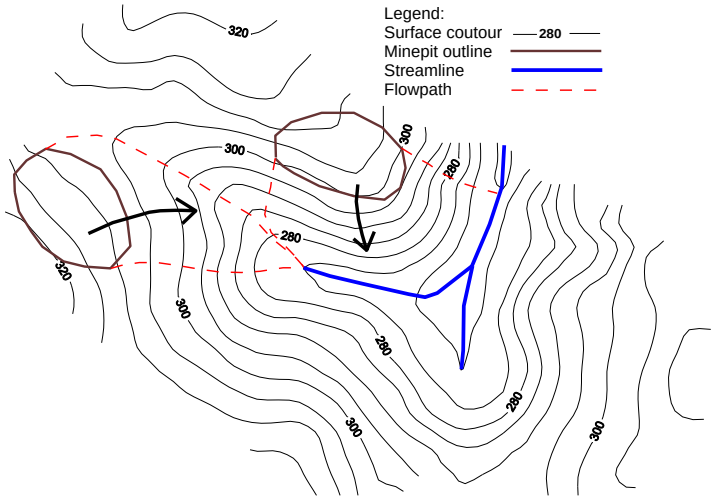


Figure 10: A theoretical landscape with two minepits illustrating the application of FDA.

The FDA concept discussed above is applied to the EQMA and MMA through computational analysis of a digital elevation model (DEM). The DEM is created with a 25 m square grid-cell, consisting of 1,800,000 cells for the EQMA and MMA study areas. Weighting layers are then created for different land-use scenarios with cleared areas given a weighting of five, and forested areas a weighting of one: that is the assumption that groundwater recharge beneath cleared areas is five times that under forested areas. This weighting is the same as has been used in previous studies (Croton & Dalton 2003, Green *et al* 2023) which was developed based on observed-data to model-fit. The weighting layers were combined with the DEM to create weighted catchment layers. Previous studies have developed estimates of the relationship between catchment area and groundwater depth. A relationship was developed for the intermediate rainfall zone (IRZ) by Croton (1991) analysing 24 valley floor piezometers, with the depth-to-water (DTW) = 30.15 - 4.76*ln(Area) where DTW is in metres and Area is in hectares. This relationship was adapted for the BBM LRZ to 30.0 - 3.95*ln(Area) (Croton & Dalton 2003), and later for the Hotham North area to 25.2 - 3.32*ln(Area) (Green *et al* 2023). The relationship from the BBM area will be used to estimate the flux density in the EQMA and MMA as there is insufficient data to develop a local relationship and BBM is between and to

the north of these two areas. The EQMA and MMA have similar hydrogeology, rainfall, and forest density to BBM. As FDA is a tool for identifying hotspots where larger groundwater fluxes may occur to guide further monitoring and investigations, the analysis should be sufficient to locate these areas even if the magnitude of change is uncertain.

The effects of prior clearing in the study area were first reviewed, to understand the current level of disturbance. Land currently cleared for agriculture activities was identified by analysing satellite imagery with cleared land given a 5:1 weighting to the forested areas. There are some small plantation areas in EQMA; these were left with the standard forest weighting of 1. Plantation areas are likely to have an oscillating water-table, with rises occurring after harvest followed by falls as the dense revegetation becomes established. The net effect is likely to be a water-level decline; accurate modelling of these plantations would require annual land-use mapping. Given that the plantation areas are small it was decided that treatment of these areas as equivalent to other forested areas, as a conservative approximation, would be sufficient. The estimated valley-floor groundwater-level rise due to current land-use is shown in Figure 11. There are significant rises in Williams and Hotham River catchments due to agricultural clearing.

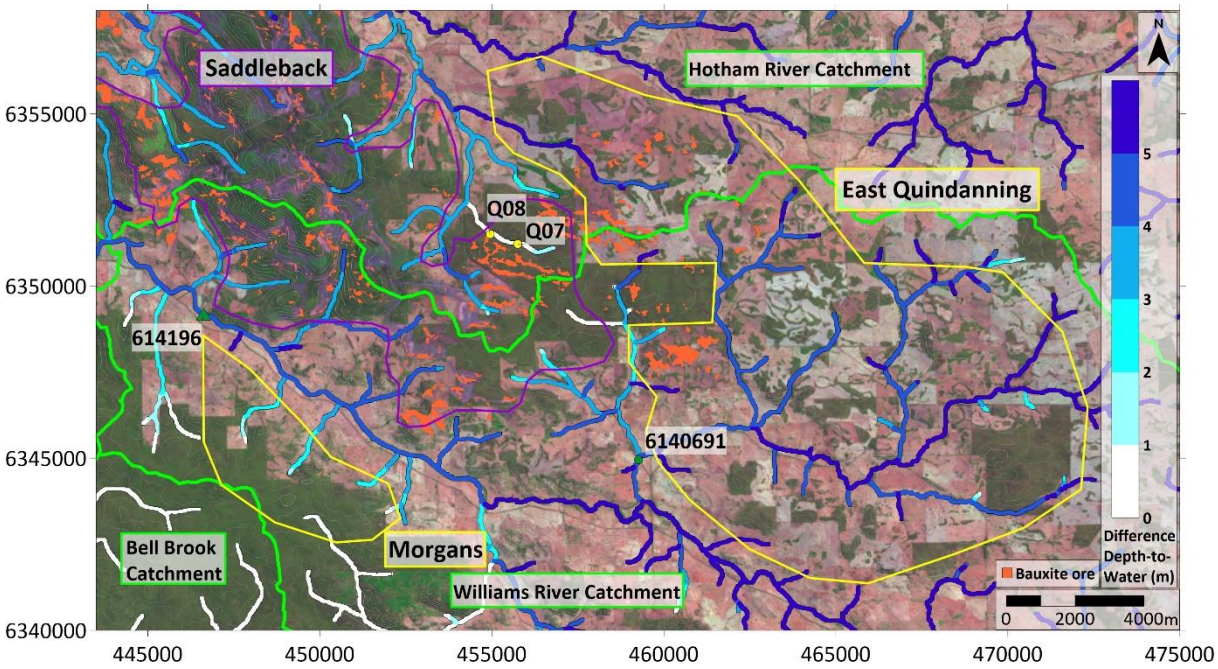


Figure 11: Map of the FDA-estimated changes in valley-floor groundwater levels due to existing agricultural clearing.

The potential effect of bauxite-mining activities on the groundwater table was analysed using FDA. Bauxite bodies have not been identified in MMA and most of EQMA, so an estimate was used for non-surveyed areas. Land clearing for bauxite mining was conservatively estimated to be 40% of forested land within each mining area, excluding the riparian zone, giving these areas a weighting of 2.6. For comparison in the Brookton Mining Area (BMA), where surveying is completed, the planned land clearing for mining and roads is 25% of the area. The resulting groundwater change along the valley floor compared to the current land-use is shown in Figure 12. In both mining areas there are small rises in the groundwater level (>4 m) along the valley-floor of minor tributaries, with no significant changes in the water-table along the main channel of Williams River. The rises are greater in MMA than EQMA due the larger area of forested land at the head of the tributaries.

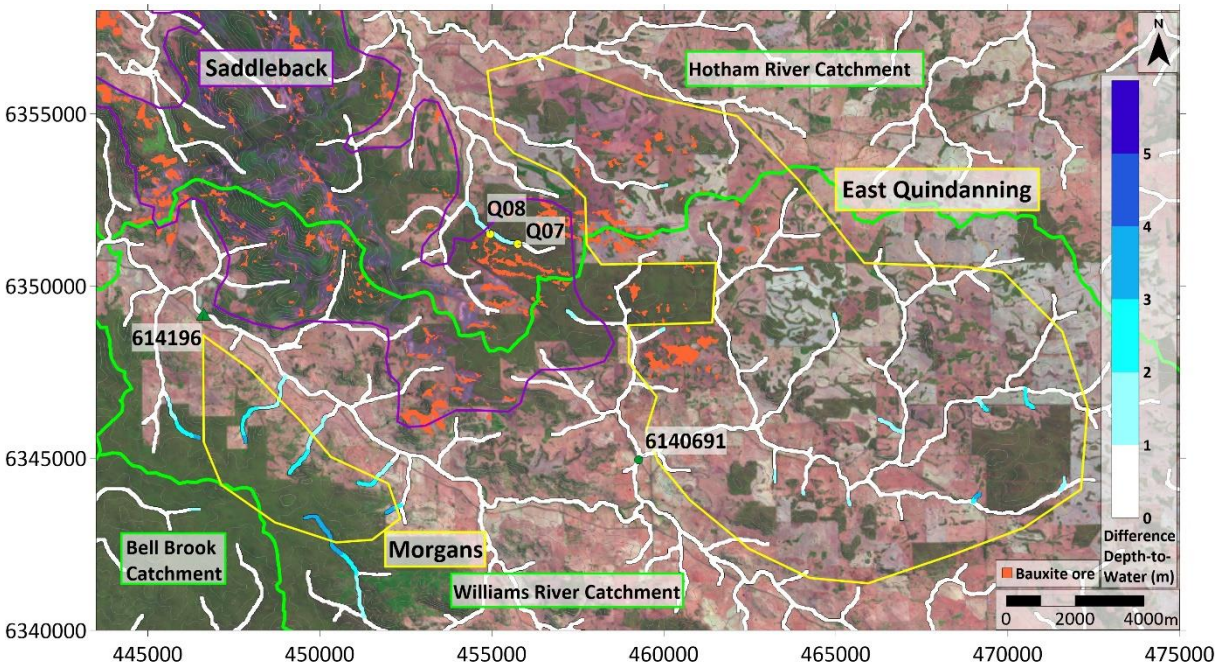


Figure 12: Map of FDA-estimated change in groundwater-level along the valley floor due to an estimated 40% of forested land cleared for mining activities in EQMA and MMA.

A second flux-density analysis was completed on the mining areas assuming that there was 80% clearing of forested land for bauxite (excluding riparian zones). This analysis, shown in Figure 13, is expected to show the upper-limit of clearing within any given valley. The expected groundwater rises from this analysis are again limited to the minor tributaries. In EQMA, the largest forested area in the south-east has dispersed drainage to valleys north and south of the area, which have mostly cleared catchments, so the rises are limited to short minor tributaries. In MMA the rises are more significant because the forested areas are the upper reaches of the valleys, with rises over five metres in the southern tributary. In agricultural valleys where the anticipated rise is greater than one metre there may be some localised effect on the utility of the land along the valley floor due to increased surface expression of groundwater, depending on the rainfall over the mining activity period. This groundwater may be from the shallow superficial-aquifer and have low salinity, or from the main saprolite-aquifer with high salinity. It is recommended that four groundwater monitoring bores are installed along the main valleys in MMA, GW1 to GW4 in Figure 13, and a control bore GW5 in a similar tributary outside the mining area. Groundwater monitoring bores are also recommended on the two minor tributaries with the highest expected flux in EQMA, GW6 and GW7, and a control monitoring bore, GW8 in a similar catchment outside the mining area. There should be two nested bores at each location screening the shallow superficial-aquifer, and the saprolite aquifer. Quarterly monitoring of the water-level and salinity of these bores is recommended along with continued monitoring of Q07 and Q08. This monitoring will help to establish the current groundwater level and salinity as well as allowing monitoring of any changes that may occur during mining activities. Surface water monitoring at 6140691 which is downstream of most of EQMA is recommended to establish the current salinity and seasonal flow; and monitor any changes. Monitoring should occur annually in late winter, if accessible. To monitor any changes in surface-water flow and quality; initial quarterly monitoring would be desirable to establish current seasonal trends. Regular review of flow and salinity data from gauging station 614196 is also recommended during mining and rehabilitation activities as this gauge is downstream of EQMA and most of MMA.

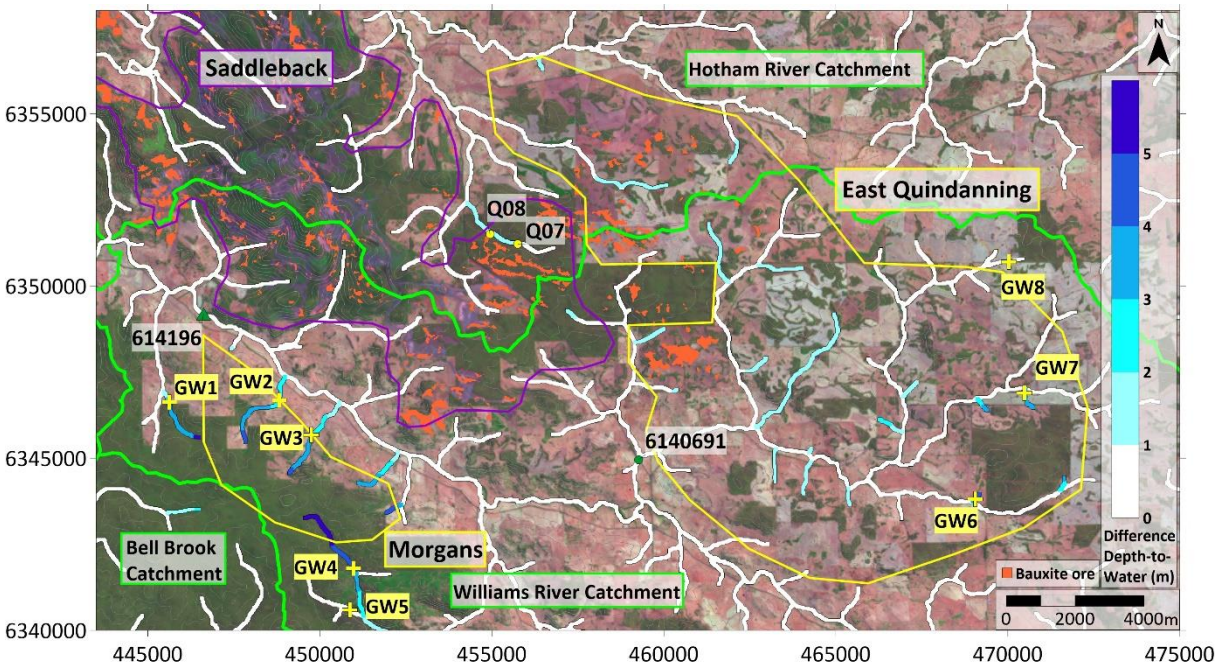


Figure 13: Map of FDA-estimated change in groundwater-level along the valley floor due to 80% of forested land cleared for mining activities in EQMA and MMA; with relevant existing ground and surface monitoring locations, and proposed groundwater monitoring locations (+).

6. CONCLUSIONS

The majority of EQMA and MMA are within the Williams River catchment, which is largely cleared for agriculture. While there is very limited information on the groundwater level and salinity in these areas, the high surface-water salinity suggests that there is significant saline-groundwater discharge in this catchment. The clearing of vegetation for mining activities will be small compared to the existing cleared agricultural land so it is unlikely to have a significant effect on the flow and salinity of Williams River. There may be some increase in salinity and surface-water expression on agricultural valleys downslope of forested mining areas. The extent of this will depend on the current groundwater level and salinity and the rainfall over the mining period and will be temporary if hydrologically equivalent vegetation is restored.

The FDA method is expected to be useful in identifying areas of greatest flux, however, the estimated magnitude of this flux is not expected to have a high degree of accuracy, so caution should be applied to interpreting the results. While the overall salinity-risk of bauxite mining in the EQMA and MMA is expected to be low, the groundwater monitoring data in the area is limited. Further monitoring is recommended before mining activities, to develop a better understanding of the current hydrology. An additional eight groundwater monitoring locations are recommended, as well as monitoring at surface-water monitoring site 6140691 and ongoing review of data from government-monitored stream-gauge 614196.

References

Croton, J.T., 1991. *Relationships of Groundwater Levels and Salt Storages to the Geomorphology of the Intermediate Rainfall Zone of the Northern Jarrah Forest.* Alcoa Environmental Research Bulletin No. 24.

Croton, J.T. & Dalton, J.A. 2000. *Review of the Salinity Research and Development Programme for the Boddington Bauxite Mine*. Water & Environmental Consultants Report to Worsley Alumina Pty. Ltd.

Croton, J.T. & Dalton, J.A. 2001. *Review of the Soil Salinity Database for the Boddington Bauxite Mine*. Water & Environmental Consultants Report to Worsley Alumina Pty. Ltd.

Croton, J.T. and Dalton, J.A., 2003. *Salinity Risk Assessment for the Boddington Bauxite Mine using FDA*. Water & Environmental Consultants Report to Worsley Alumina Pty. Ltd.

Croton, J.T. & Dalton, J.A. 2004. *Soil Salt Storages and Salinity Risk Assessment for the Boddington Bauxite Mine*. Water & Environmental Consultants Report to Worsley Alumina Pty. Ltd.

Croton, J.T. & Dalton, J.A., 2007. *Summary of Soil Salt Storages for the Boddington Bauxite Mine*. Water & Environmental Consultants Report to Worsley Alumina Pty. Ltd.

Green, K.A., Croton, J.T., & Dalton, J.A., 2021. *Boddington Bauxite Mine Triennial Aquifer Review July 2017 – June 2020*. Water & Environmental Consultants Report to South32 Worsley Alumina Pty. Ltd.

Green, K.A., Croton, J.T., G.T. Dalton, & Dalton, J.A., 2023. *Salinity Risk Assessment for the Hotham North Mining Area Using Flux Density Analysis*. Water & Environmental Consultants Report to South32 Worsley Alumina Pty. Ltd.

Stokes, R.A., Stone, K.A. & Loh, I.C. 1980. *Summary of soil salt storage characteristics in the northern Darling Range*. Water Resources Branch, Public Works Depart. W.A., Tech. Rep. No. WRB 94.

Tsykin, E.N. & Croton, J.T. 1988. *General salt storage-terrain relationships for the Darling Range, W.A.* Alcoa Environmental Research Note No. 14.

Appendix

Surface-water monitoring plots (see Figure 8 for locations).

