TRONOX FAIRBREEZE: SURFACE AND GROUNDWATER HYDROLOGY – HELEZA MOYA

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Executive Summary

The Fairbreeze Mine has completed mining the FBC and FBCx areas. The mine is now engaged in the process of backfilling and rehabilitation. The mining of the FBB has started with plans to expand into the Heleza Moya (HM) section thereafter. Both of these mining sections are located upstream of the Amanzimnyama River. Authorisation is required for the HM section. The following concerns require assessment to inform impact assessment and future mining design:

- Estimate groundwater fluxes and changes to the groundwater head related to the Heleza Moya pit.
- Model post-pit backfill scenario, to ascertain the re-establishment of water table.
- Estimate baseflow changes to the Amanzimnyama stream for mining and post-mining scenarios.
- Compute loss of run-off yield as the mine block plan progresses.
- Evaluate and assess perturbations to the Amanzimnyama flow regime due to Heleza Moya impacts on surface and sub-surface water fluxes.
- Review and update mitigation measures in the current EMP, based on recent hydrological studies and findings related to Heleza Moya.
- Review and recommend appropriate additions to the current water monitoring programme, as defined in the EMP, with respect to Heleza Moya.

Using previously developed numerical models, the impacts from the proposed mining were assessed.

A comprehensive upgrade of the flow record has been achieved to include observed (DWS) and manually measured flows in the Amanzimnyama and Siyaya catchments.

During this focus on the Heleza Moya mining development, the ACRU model has been updated to include a system of cascading hillslope responses to allow build-up of subsurface water in riparian and wetland zones, and thus increase evapotranspiration in these areas. Simulations of runoff for recent periods in the Siyaya and Amanzimnyama catchments are accurate, compared to the revised observed runoff at the gauge stations (W1H019 and W1H018). Using the model settings and the land use distribution for proposed mining at Heleza Moya and post mining scenarios, a long- term record of daily average flows was generated for the Amanzimnyama weir and the Siyaya Estuary.

Surface runoff is insignificantly reduced at the Amanzimnyama weir and at the estuary during mining at Heleza Moya, and closure scenario simulations reflect a return to an improved flow regime at the Siyaya estuary.

No human drinking water occurs in the Amanzimnyama or Siyaya systems and any perturbations to the reserve (anticipated to be established in April 2024), caused by the Heleza Moya mining, are considered inconsequential in either of these systems.

The surface water model development will continue in future years, particularly with respect to compatibility with the groundwater simulations and anticipated rehabilitation of soils and land use conditions.

The mining activities at FBB and HM will extend below the water table, causing seepage and inflows into both pits. As FBB is backfilled, seepage into HM will occur. Inflows at FBB are anticipated to be 30 to 35 L/s and at HM at most 19 L/s. However, the inflow should be considered preliminary as the discretisation at HM is course and the model needs to be updated with revised lithologies. The inflows could be directed to the in-pit sump for use in mining operation or more active dewatering considered using in-pit trenches or ex-pit dewatering boreholes.

Dewatering at the pits will cause a drawdown around the pits but is unlikely to significantly impact neighbouring water supply boreholes due to its limited extent. The Shepley Farm borehole is located outside the significant zone of drawdown of 3 m, but monitoring should continue as it is located close

to the simulated zone of drawdown. Throughout mining FBB and HM, the baseflow to the Amanzimnyama River may decline by approximately 18%, but compared to streamflow variation this is a small change and is not expected to have a significant impact on the river system.

The induce a zone of drawdown in the groundwater will recover once rehabilitation is complete and the baseflow Amanzimnyama River to the after mining will increase to around 120 m^3/d.

To better estimate the impact on the hydrological system, it is advisable to further enhance the understanding of the hydrological processes taking place in the FBB and HM regions, as well as to conduct additional surface water and groundwater simulations.

Key improvements can be made by:

- Assessment of the impacts of the flow regime perturbations against the Reserve Determination, when this becomes available (anticipated for April 2024),
- Adoption of stable isotopes analysis to enhance the simulation of surface water and groundwater interaction,
- Updating the current numerical groundwater model with the current geological model, and
- Review the monitoring program to considering changes in mining, infrastructure, and observed groundwater changes.

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1 Introduction

Fairbreeze Mine has completed mining the FBC and FBCx areas and is currently working on backfilling and rehabilitation. The mining of the FBB has commenced and expansion to the Heleza Moya (HM) section is planned. Both mining sections are located upstream of the Amanzimnyama River, as shown in Figure 1-1. Authorisation is required for the HM section. The following concerns require assessment to inform impact assessment and future mining design:

- Estimate groundwater fluxes and changes to the groundwater head related to the Heleza Moya pit.
- Model post-pit backfill scenario (Figure 1-2), to ascertain the re-establishment of water table.
- Estimate baseflow changes to the Amanzimnyama stream for mining and post-mining scenarios.
- Compute loss of run-off yield as the mine block plan progresses.
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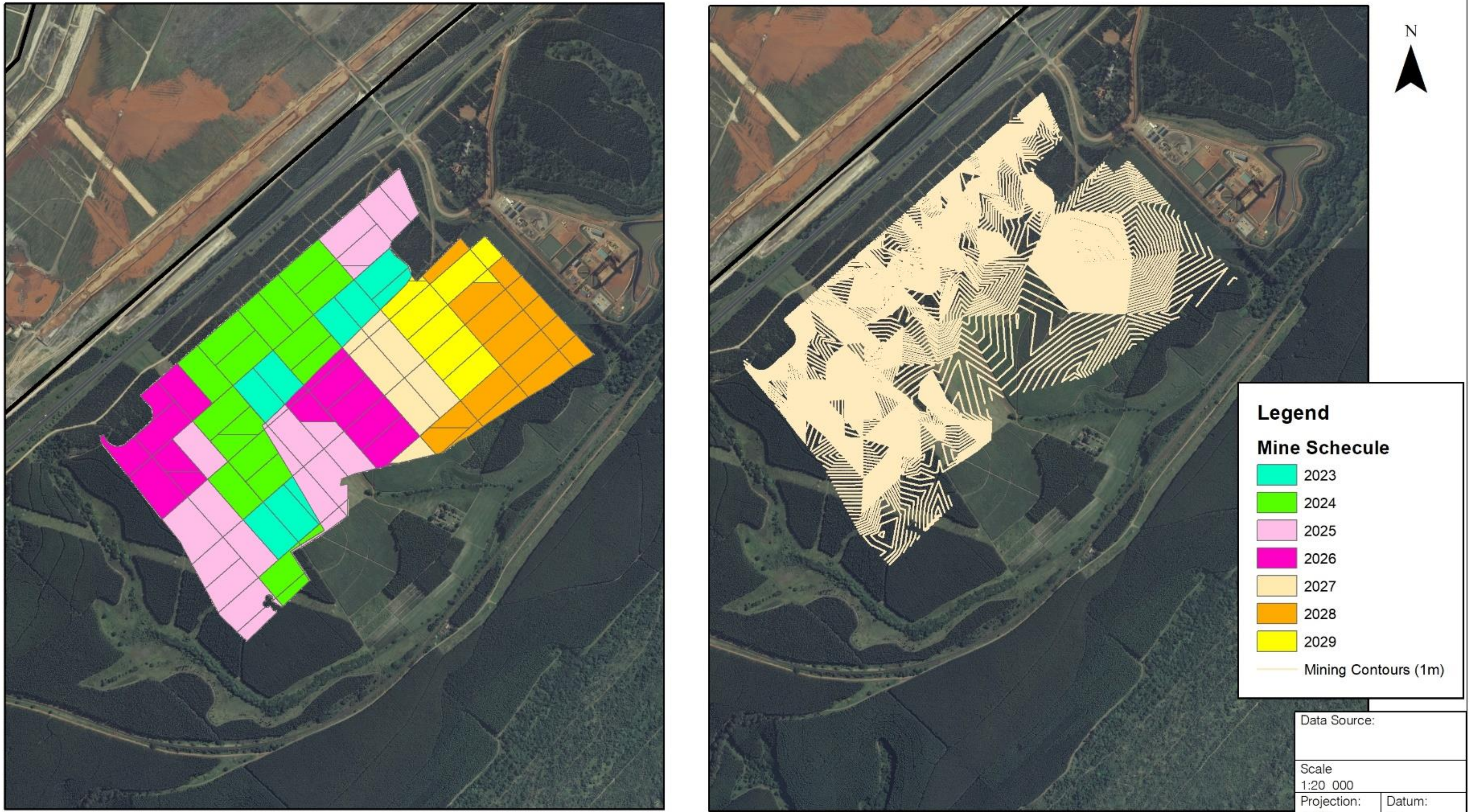

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FAIRBREEZE MINE

MINING SCHEDULE AND FLOOR CONTOURS

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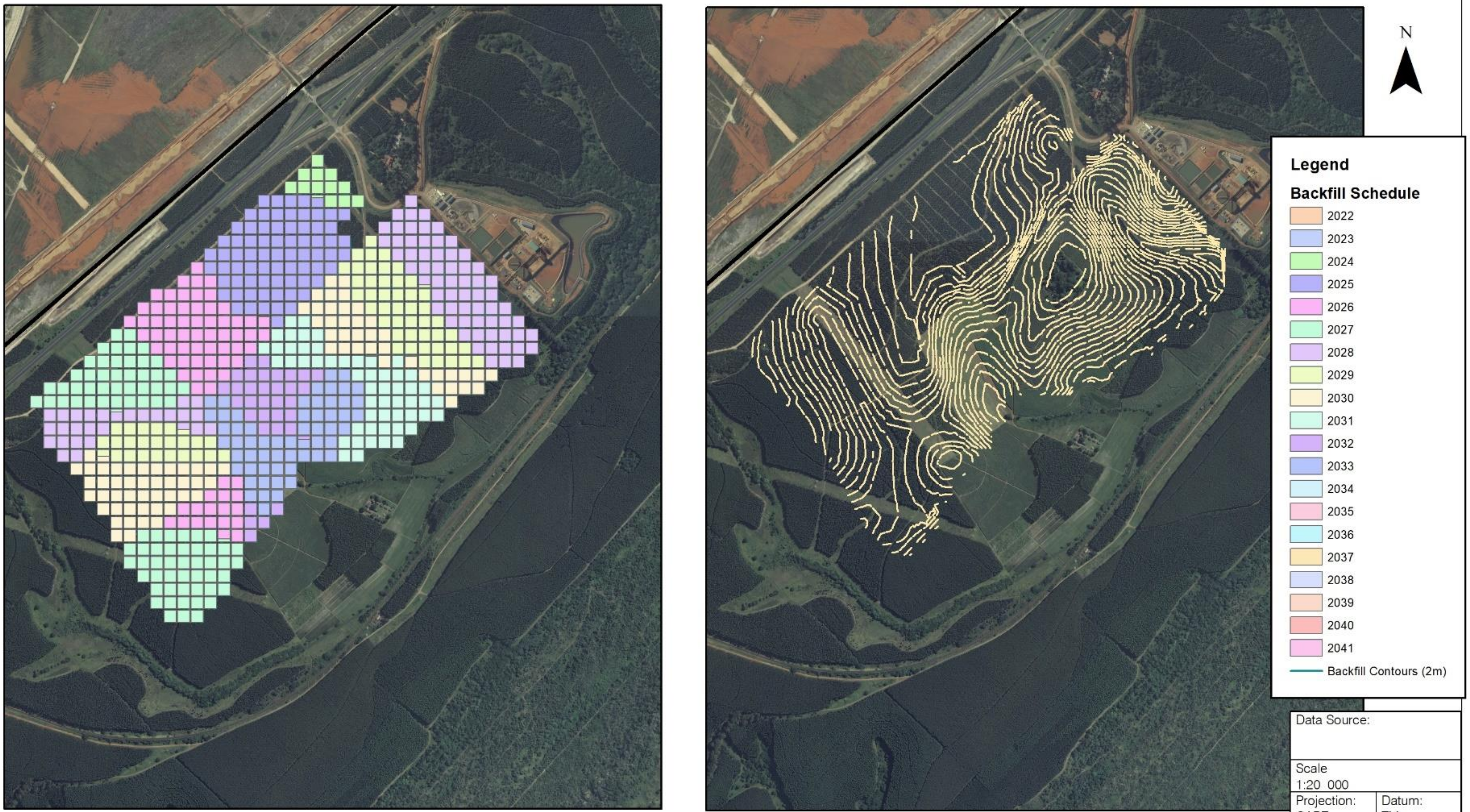

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FAIRBREEZE MINE

BACKFILL SCHEDULE AND BACKFILL CONTOURS

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2 Catchment Characteristics

2.1 Climate

The climate in the region is one of high rainfall and high evaporation where the annual evaporation is not always higher than the annual rainfall. The area is humid and hot in the summer and relatively warm in the winter.

2.1.1 Rain

The Mtunzini area receives a high amount of rainfall with a Mean Annual Precipitation of 1 146 mm. The maximum monthly rainfalls are exceptionally high compared to the 10% rainfall. This is mainly due to the fact that the area falls within a cyclone area, which can result in heavy rainfall events (for example, Cyclone Demoina in 1984). Additionally, cut-off low pressure systems (such as the September 1987 floods) can cause heavy rainfall in the region.

The rainfall record used in the simulations of current catchment status was taken primarily from records of the Mtunzini station and patched using local rainfall station data. A daily record of rainfall from 1 January 1970 to 31 August 2023 was compiled as shown in Figure 2-1. The rainfall record is deemed to be sufficient for future scenario modelling.

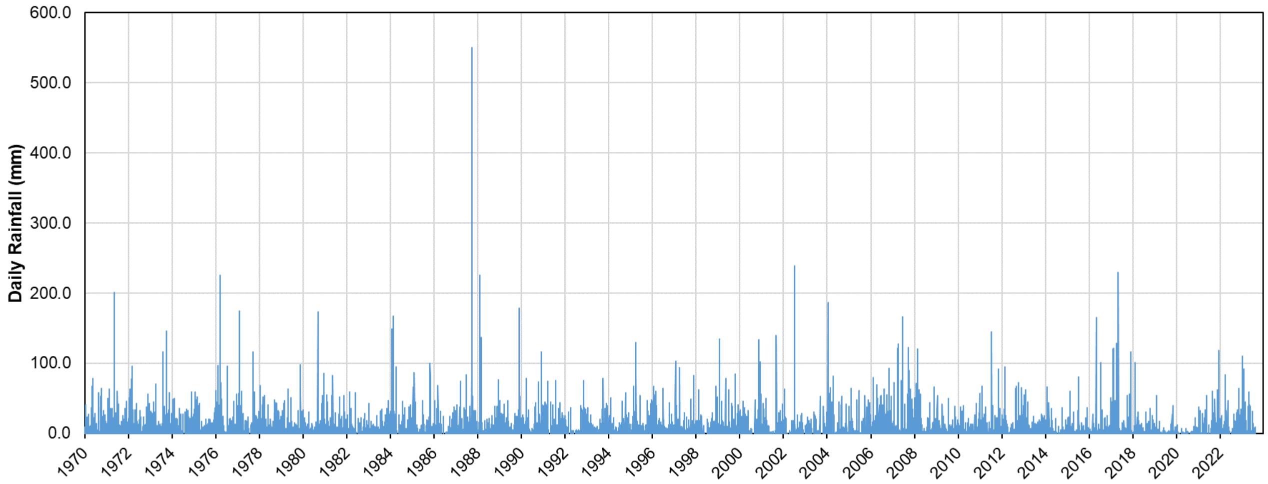


Figure 2-1: Daily rainfall record used in runoff simulations (Jan 1970 –Aug 2023).

2.1.2 Evapotranspiration

Potential evapotranspiration values were derived from observed A-Pan data at Hillendale. The monthly A-Pan potential evaporation data are shown in Figure 2-2. These range from 82 mm to 214 mm per month. The monthly A-Pan evaporation data are disaggregated into daily potential evapotranspiration values in the model, using Fourier transforms.

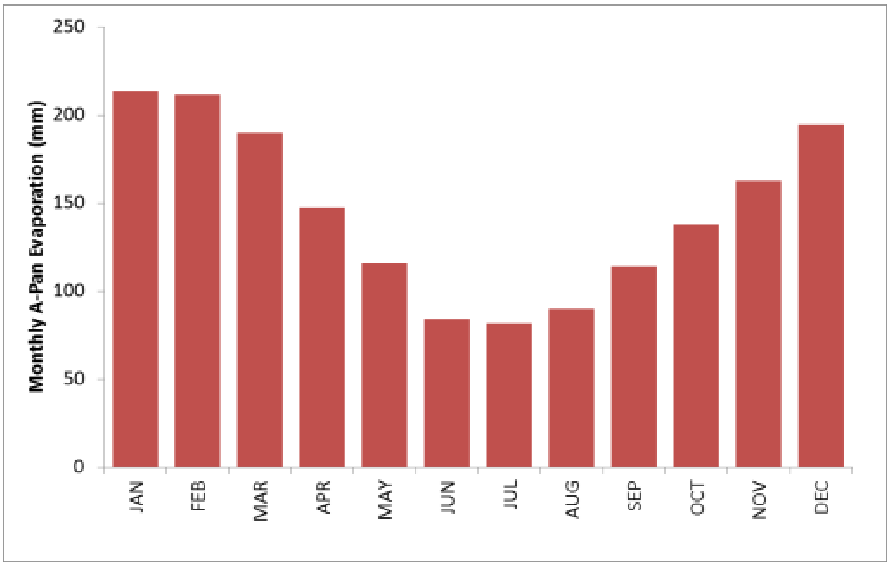


Figure 2-2: Monthly A-Pan Potential Evaporation used in the runoff simulations.

2.2 Topography

The area comprises a series of palaeodunes that are orientated parallel to the coastline, i.e., in a northeast-southwest direction. Inland of the dune belt are a number of valleys that have incised into the underlying unconsolidated material. To the northwest, the topography is relatively flat and the land slopes gently to the north-west. The terrain slopes steeply from the palaeodunes down to the present-day shoreline to the east of the site.

2.3 Geology

Unconsolidated sediments cover much of the area inland of the present coastline. These deposits consist of planar and trough cross-bedded coarse sands often with conglomerate beds and representing various aeolian sand, beach and littoral marine deposits. The unconsolidated sediments are known as the Maputaland Group. The group comprises of recent dune and beach cover sands underlain by the Berea Formation, the KwaMbonambi Formation, the Port Durnford Formation, the Uloa Formation and Richards Bay Formation (Worthington, 1978). The Berea type sediment is found in this area.

The Berea Formation consists of unconsolidated red dune ridges, which can extend in some places inland for up to 80 km. These can be placed in general sequence of increasing age away from the coast on the basis of colouring and pedogenesis, the oldest having the deepest red colour and the highest clay content. The formation is derived from calcarenites and progressive leaching of the underlying calcarenites which produced or produces the capping sands of the formation and can often exhibit a collapsible fabric. Their properties can vary laterally and vertically, usually in relation to their clay content and moisture status.

The unconsolidated material was deposited unconformably on the eroded surface of the Karoo and Natal Supergroup sediments. The Dwyka Group, Pietermaritzburg, Vryheid and Volkrust Formations of the Karoo Supergroup all sub-outcrop in the area. These sediments have been block-faulted resulting in the repetition of the geological sequence from Amatikulu north to Mtunzini. The Dwyka Group comprises of tillites. Mudstone, shale and sandstone units make up the Pietermaritzburg, Vryheid and Volkrust Formations of the Karoo Supergroup.

Dolerite dykes or sills have intruded the Karoo Supergroup, with sills mapped to the west of Mtunzini. A geophysical survey using electrical resistivity imaging (ERI) and frequency domain electromagnetics (EM) has mapped several possible geological structures but no dykes (ASST, 2019).

2.4 Soils and Land Use

Soils comprise mostly recent red and grey sands including dolerite derived soils, wetland soils and dune sands. Soil hydrological types have been derived for hydrological simulation (SRK, 2015).

The land use changed dramatically in the early 1990s when forestry replaced the dominant sugar cane practice, particularly in the Amanzimnyama catchment. The land uses are listed for revised sub-catchments in Table 4-1.

2.5 Runoff

A runoff divide runs parallel with the coast some 2.5 km off-shore (Figure 2-3). From here, drainage occurs towards the coast in an easterly direction, but in the proximity of the coastal dunes, rivers are diverted northwards by the marine sediments, where they emerge in estuaries (e.g., Siyaya estuary). West of the divide, drainage occurs in a north westerly direction. Similar drainage patterns occur in the groundwater, where the groundwater mound is highest at the catchment divide.

The sub-catchments have been delineated according to topography and the land use areas provided by EcoPulse. The hydrological modelling has proceeded with these land uses, distributed as indicated in Table 4-1.

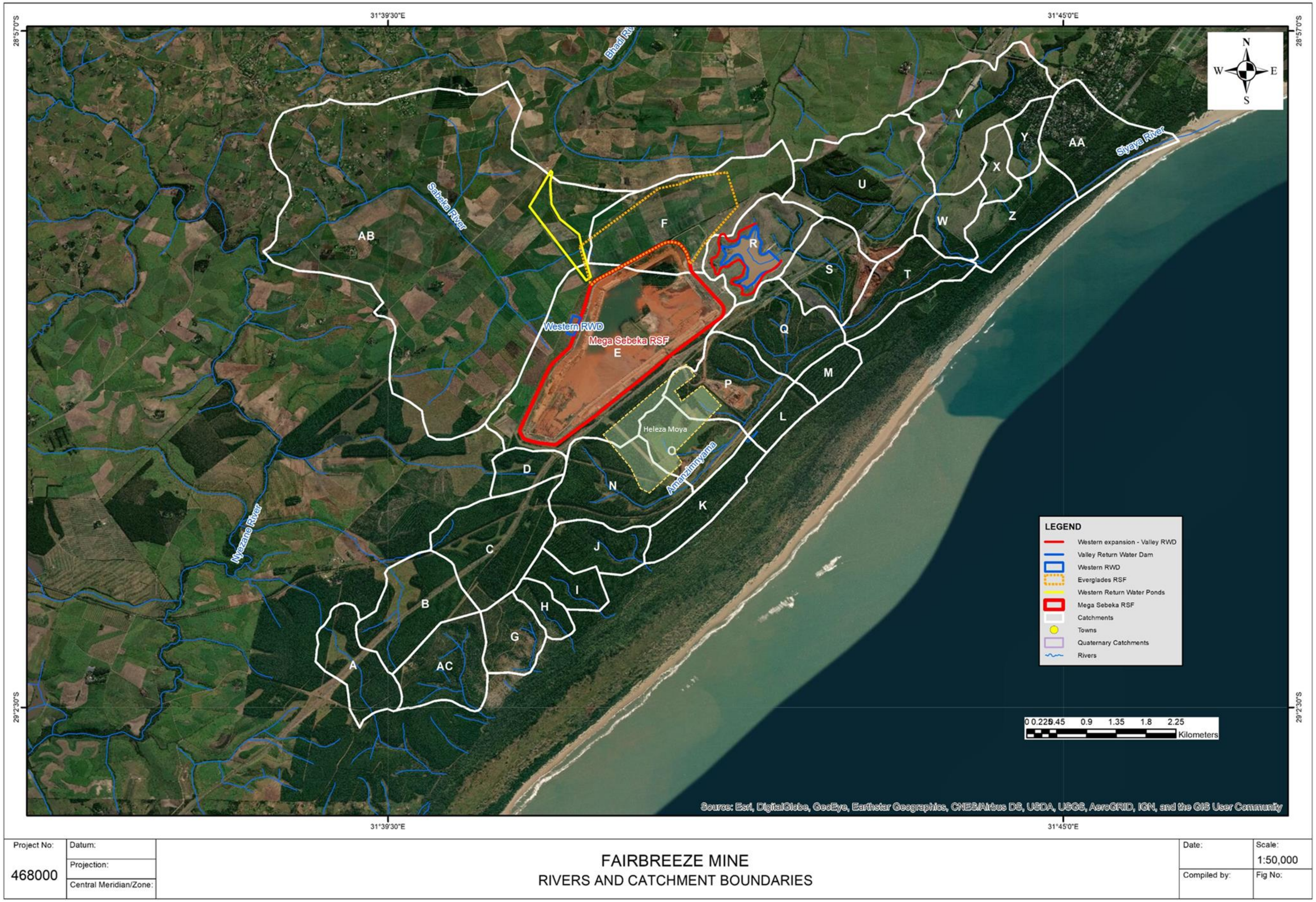


Figure 2-3: Drainage sub-catchment delineation (A-AB), showing the outline of the Heleza Moya mining area (yellow dashed line)

2.5.1 Gauging weirs

Two gauging stations occur below the mining site, the Amanzimnyama weir (W1H018) and the Siyaya weir (W1H019) as shown in Figure 2-4. Records are available for an early period, from 1983 to 1989 for the Siyaya and 1983 to 1987 for the Amanzimnyama weirs. However, the weirs were entirely silted up during 1990 and abandoned. Recent records for the Siyaya weir (2005 to 2013) appear usable, but the Amanzimnyama weir record shows mostly levels below the lowest sharp crested weir invert due to zero flows in the catchment. However, on occasions of flow onset, the weir basin first fills, after which discharge over the weir may reflect flows. This means that many low flow events are not recorded. Since August 2013, the Siyaya weir is deemed to be faulty. Indeed, a visit to the weir on 15 December 2015 revealed an overflow of 50 mm, but the recorded depth of flow on that date was negative.

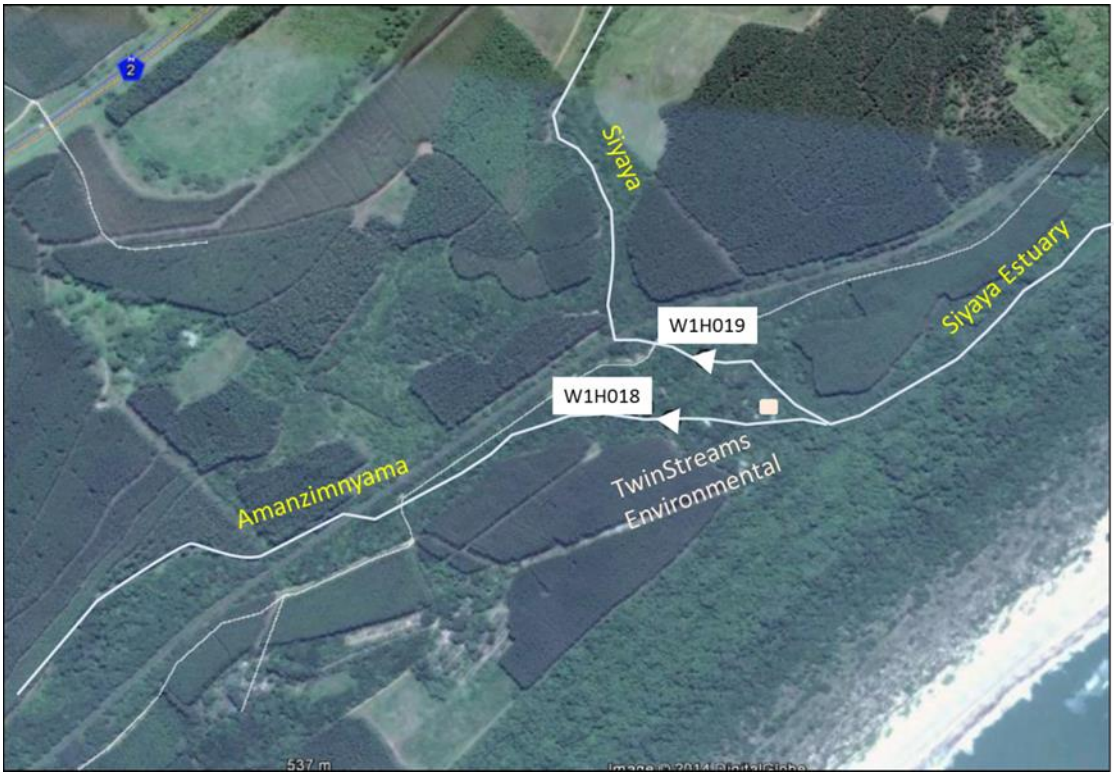


Figure 2-4: Location of gauging weirs Amanzimnyama (W1H018) and Siyaya (W1H019).

The primary (flow depth) data for both weirs were retrieved from the DWS site and an assessment was made of the rating curve. During December 2015, a survey was performed of the Siyaya weir, taking out upstream and downstream sections using a Trimble Differential GPS and correcting to the Richards Bay base station. The Siyaya curve was modified to include discharge levels which exceeded the weir capacity by deriving depth-discharge relationships through the sections using HEC hydraulic modelling software. The resultant rating curve allowed for estimating discharge at depth of flow over the weir exceeding 0.75 m, where the DWS rating curve reports a constant value of 3.09 m^3/s. There were 32 occasions where the Siyaya weir capacity was exceeded during the five-year record between 1984 and 1989, whereas there were 18 such occasions during the eight-year record from 2006 to 2013. The DWS daily average discharge records were updated using the integrated discharges based on the primary data for those days in which the weir capacity was exceeded.

However, the Siyaya weir has not operated correctly since August 2013.

3 Conceptual Model

Surface water and groundwater sources mix to form observed stream flow. The groundwater mound, in the vicinity of the catchment divide, yields baseflow towards the coastal streams as well as towards streams flowing inland (Figure 3-1). Where the groundwater intersects the land surface in topographical depressions between the coastal dunes, wetlands are likely to occur as shown in the sections through the Siyaya catchment in Figure 3-1. Significant interflow is likely to contribute to stream flow from sloped land surfaces. Overland flow is likely to contribute to surface runoff during extreme rainfall events. Access to surface water, and in some places to groundwater, by vegetation is likely to result in high evapotranspiration fluxes.

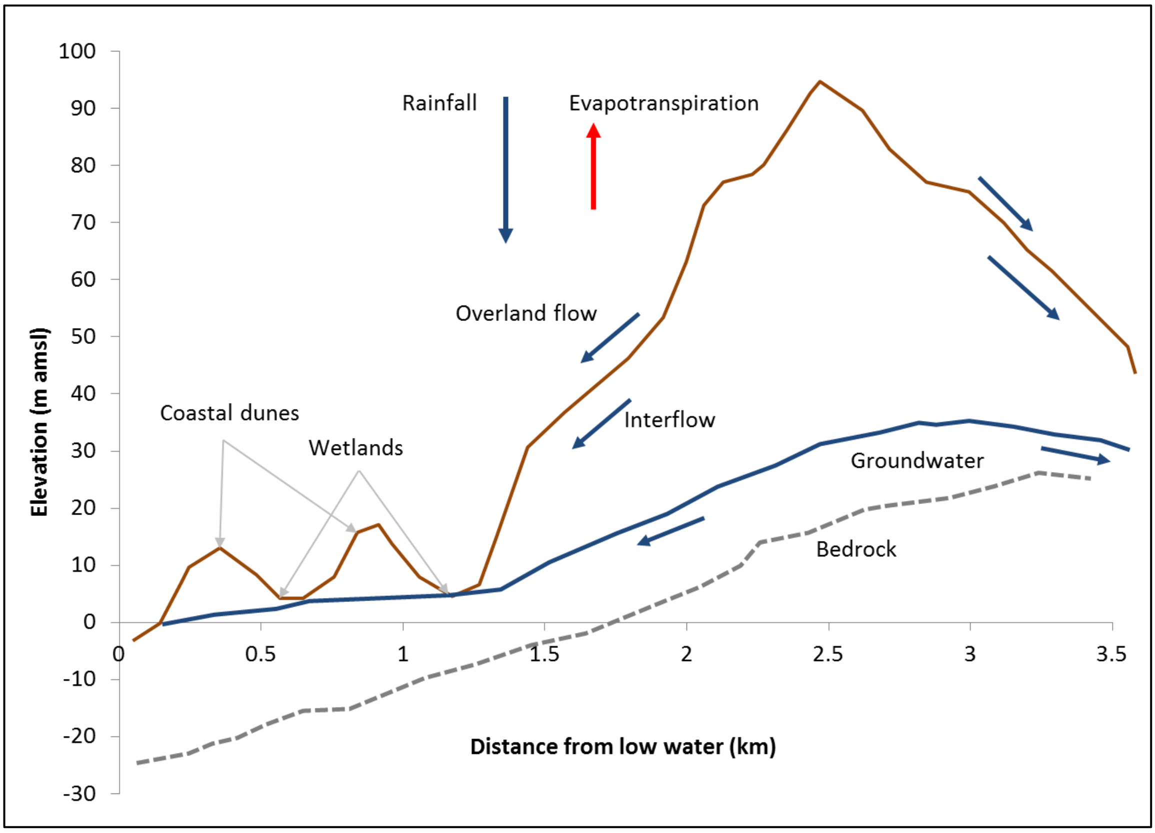


Figure 3-1: Section through the Siyaya catchment (after Kelbe and Germishuyse, 2010), showing the dominant hydrological processes.

4 Surface Water Hydrology

4.1 Catchment Delineation

Twenty--five sub catchments have been delineated within the Amanzimnyama and Siyaya basins to simulate the Siyaya estuary outflows. The catchment delineation was based on flow directions and catchment divides as well as the twenty-four land use zones (Table 4-1). Current and proposed rehabilitated land uses are used for current and closure scenarios (Scenario 5 in Table 4-1) simulations.

4.2 Model Parameterisation

The ACRU, agrohydrological model was parameterised with soil, topographical and vegetation characteristics based on land uses as listed in SRK 2015. Runoff (including quickflow and baseflow), evapotranspiration and recharge fluxes and soil water and groundwater storage states are simulated for each land use in each sub catchment on a daily basis for the record, 1970 to 2023.

4.3 Fairbreeze Mine Runoff Simulation

Runoff simulations are initially tested against observed data from the Amanzimnyama and Siyaya weirs. Daily runoff simulations of all the catchments in the Fairbreeze boundary are driven by daily rainfall and atmospheric evapotranspiration demand inputs. Controlling these are the soil water, groundwater and vegetation characteristics. The soil water and groundwater storage states are updated daily, defining the volume of runoff response, infiltration to groundwater and baseflow releases. When the soil profile is dry, evapotranspiration is reduced below the potential atmospheric demand and water distribution to groundwater is low. Again, the model has been set up to allow for the accumulation of surface and subsurface water in the riparian and wetland zones, resulting in enhanced evapotranspiration responses in vegetation adjacent to streams and in wetlands.

The recharge to groundwater is simulated as the daily fluxes leaving the soil profile. These have been simulated for the different land uses in the study area and used in the groundwater model to estimate baseflow, while concurrently matching observed groundwater levels (Section 5).

Flow exceedance plots for the observed flow records and the simulated runoff for the pre- and post-commercial forestry periods are shown for the model setup of the Siyaya River in Figure 4-1. The calibration focused on the Siyaya River weir (W1H019), having the best flow records with the fewest data gaps and errors. The data are plotted on an exceedance diagram, which shows the percent of the time that any discharge is equalled or exceeded. The flow regimes for the post-commercial afforestation period, (2005–2014) are illustrated with the modelled and observed daily runoff. The simulated flows closely reflect the observed flows and can thus be used to predict flow regimes for periods during mining and closure.

The simulated flow regime in the Amanzimnyama catchment, based on calibration against the 2005 to 2014 record, yields flows higher than those observed (Figure 4-2). However, the gauging record in the Amanzimnyama catchment during this period is deemed unreliable and has many interrupted periods which may have produced high flows. Also, discharges are predominantly lower than 0.1 m^3/s and measurements here are considered inaccurate. Nevertheless, the simulations reflect the hydrological response to the changed land use and the model is deemed adequate for continued predictions.

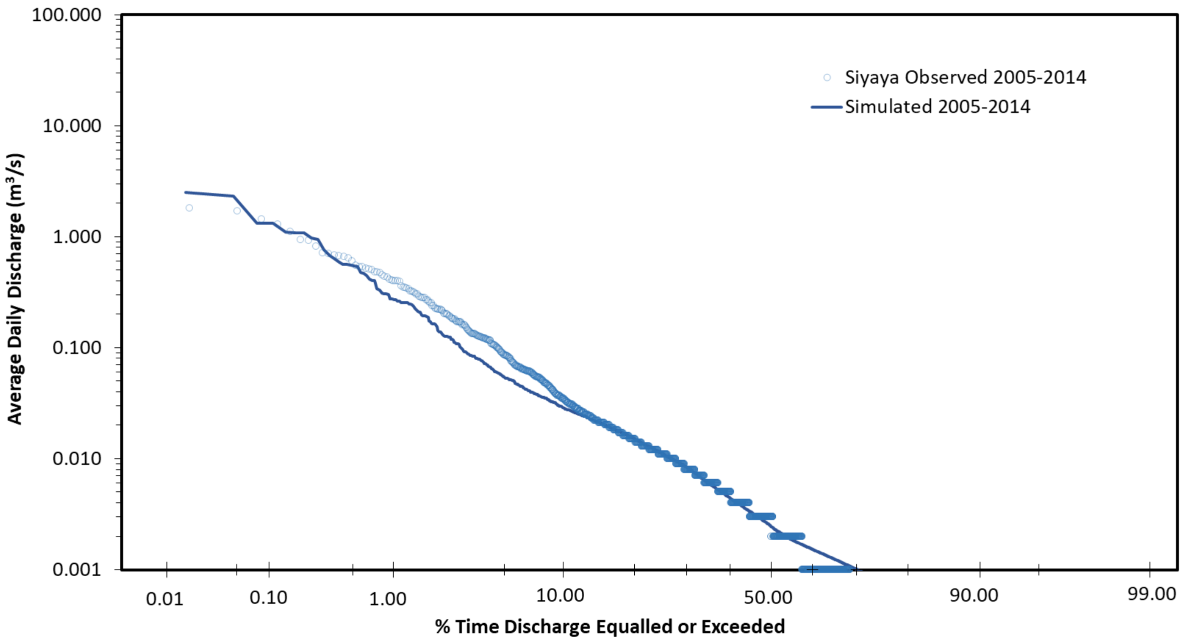


Figure 4-1: Flow exceedance of observed and simulated daily flows for the Siyaya weir for 2005-2014.

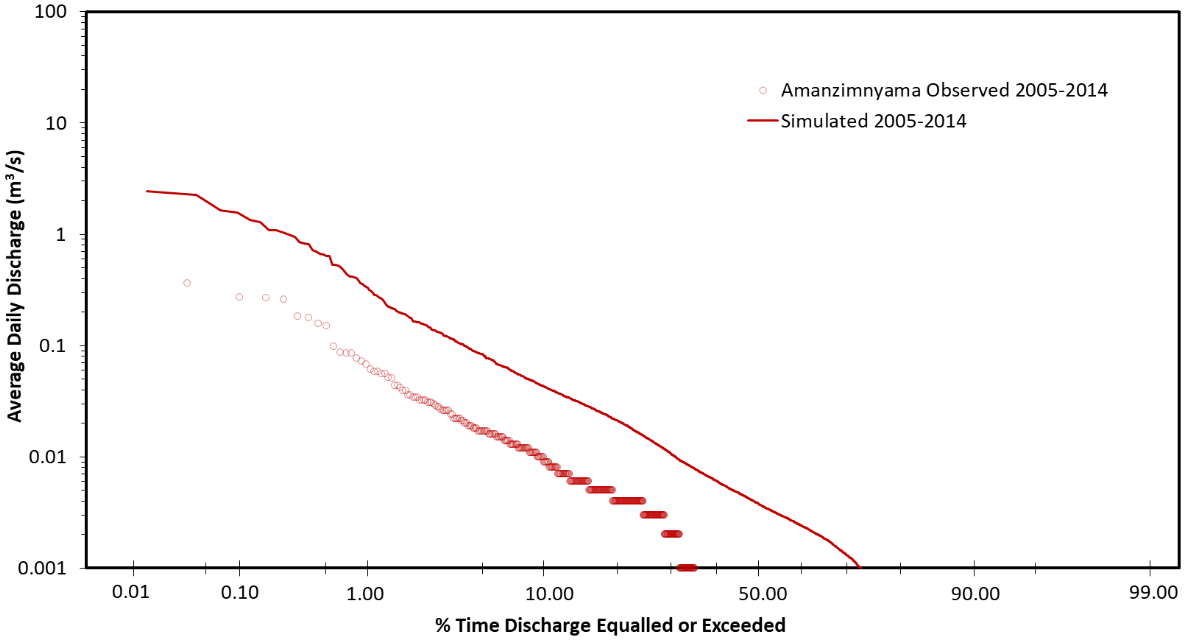


Figure 4-2: Flow exceedance of observed and simulated daily flows for the Amanzimnyama weir for 2005-2014.

The time series of simulated and observed flows for the Amanzimnyama and Siyaya are illustrated in Figures 4-3 and 4-4 respectively. The erratic observed flow record is easily discerned, while the simulations reveal extended baseflow reduction beyond the capacity of the weirs to measure (below 0.001 m^3/s). Periodic manual flow measurements have been performed using velocity cross-section analysis (ENVASS, 2022). These are shown together with DWS observed flow for the Amanzimnyama (Figure 4-5) and Siyaya (Figure 4-6) weirs, from 2016 to August 2023.

The simulations of the Amanzimnyama River have been extended to 2023, for the purposes of evaluating the impact of the Heleza Moya mining on the discharge in this catchment (next section).

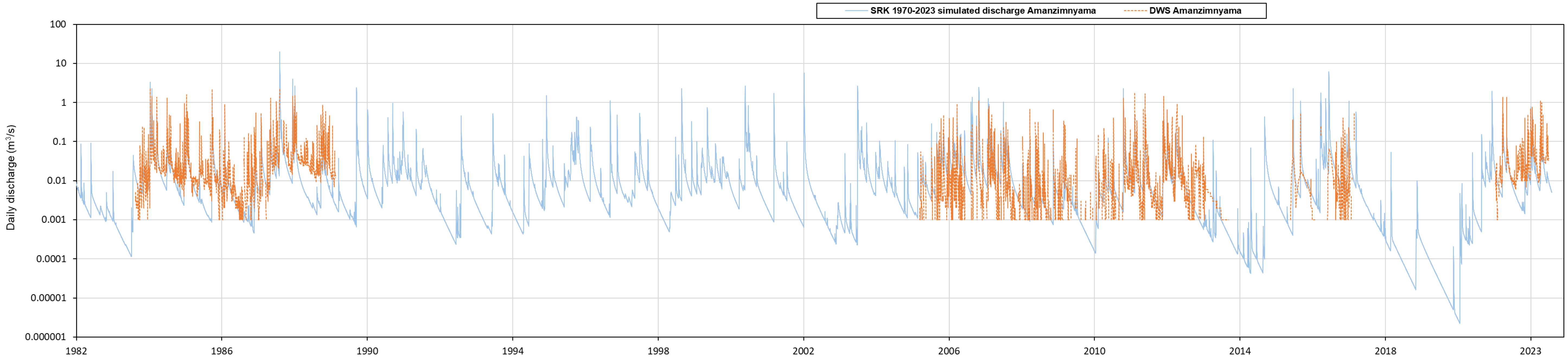


Figure 4-3: Log scale time series of daily simulated and observed (DWS) flows at the Amanzimnyama weir (1982 – 2023)

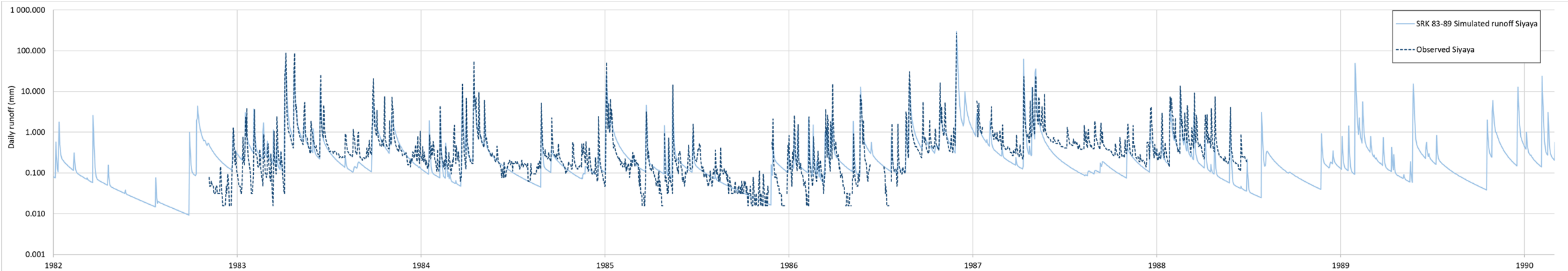


Figure 4-4: Log scale time series of daily simulated and observed (DWS) flows at the Siyaya weir (1982 – 1990)

Table 4-1: Summary of the percentage land use in each catchment of the Siyaya and Amanzimnyama rivers and Siyaya Estuary

Land Use	Siyaya 83-89	Siyaya Current	Siyaya Scenario 5	Amanzimnyama 83-89	Amanzimnyama Current	Amanzimnyama Scenario 5	Estuary 83-89	Estuary Current	Estuary Scenario 5
Indigenous Forest	11.0	10.4	10.4	15.7	15.9	19.3	38.2	38.9	38.9
Plantation Forest	0	29.3	3.2	0	65.6	16.6	0	17.9	6.2
Built Up	3.8	1.0	7.7	1.0	1.9	2.1	12.3	24.7	24.7
Maintained	0.6	0.6	0	0.8	0.9	0.7	0.8	0.8	0
Grassland	37.2	3.2	43.6	68.3	1.5	47.2	31.9	1.7	21.4
Sugar Cane	46.0	47.3	29.3	9.6	9.7	10.3	10.0	9.4	0
Wetland	1.0	1.0	5.8	4.6	4.6	0	3.4	3.3	5.7
Water Bodies	0	0	0	0	0	3.7	3.3	3.3	3.3
Dense Alien	0.4	0.4	0	0	0	0	0	0	0

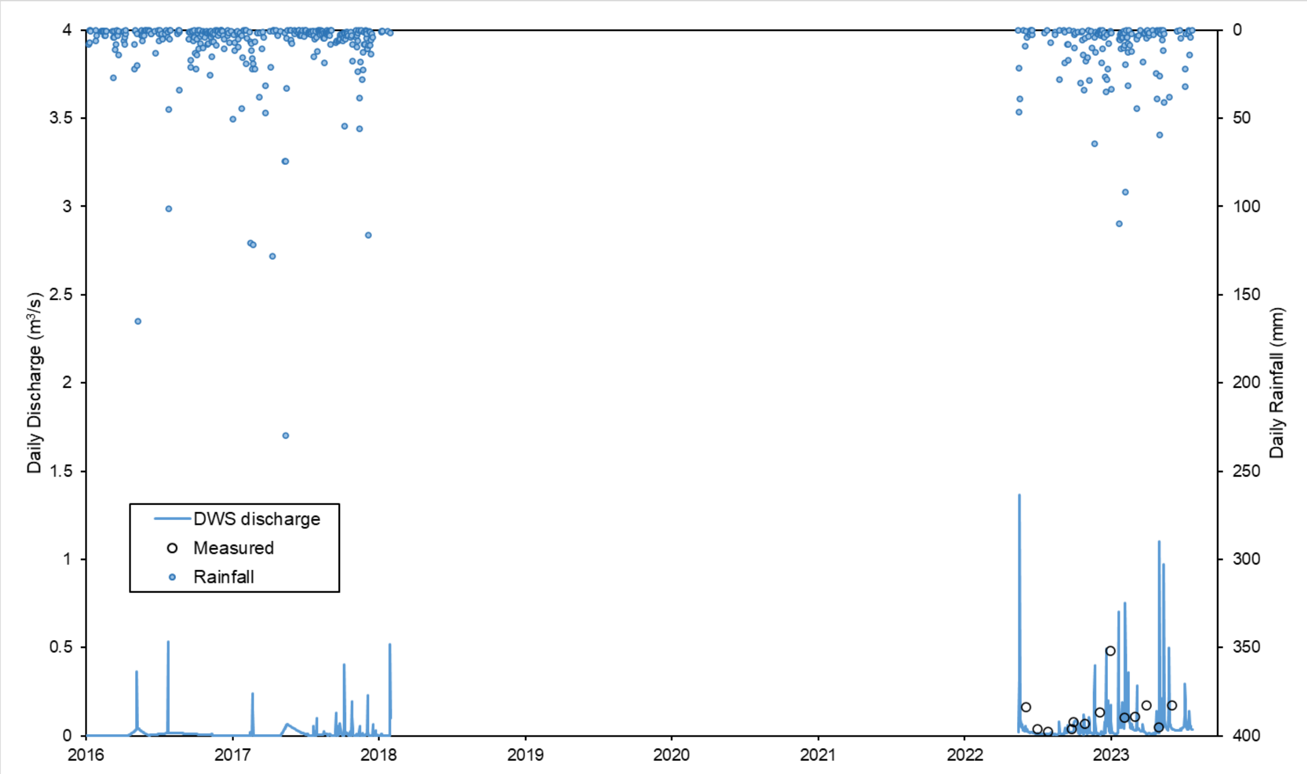


Figure 4-5: Amanzimnyama observed flows (DWS) and manual measurements (open circles).

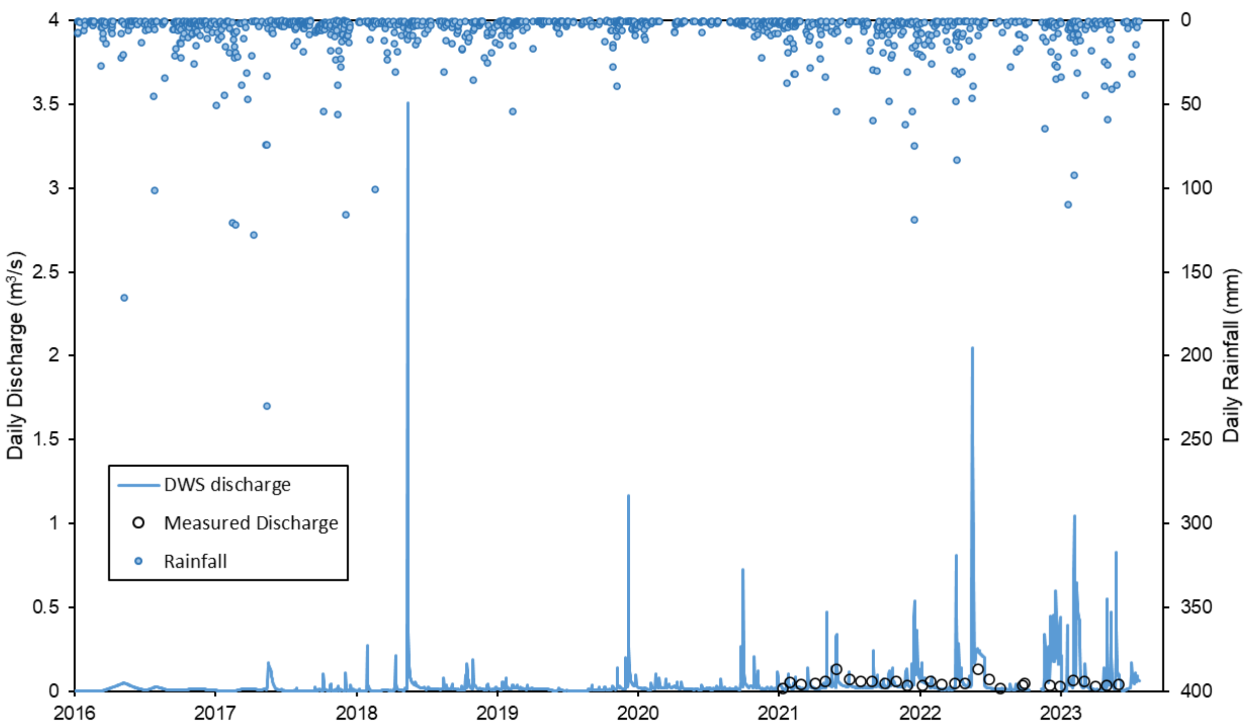


Figure 4-6: Siyaya observed flows (DWS) and manual measurements (open circles).

4.4 Heleza Moya Surface Water Simulation

Four scenarios were simulated to represent the Heleza Moya mining development. The first comprised current land use, the second Year 2025, the third Year 2027 and the final scenario comprised closure land use. The progression of mining development is illustrated in Figure 4-8, while the land uses in catchments O and P (Figure 2-3) are summarised in Table 4-2. Where mining void, stripping ahead of the void and backfilled void occur in a catchment, the current land use area is reduced accordingly.

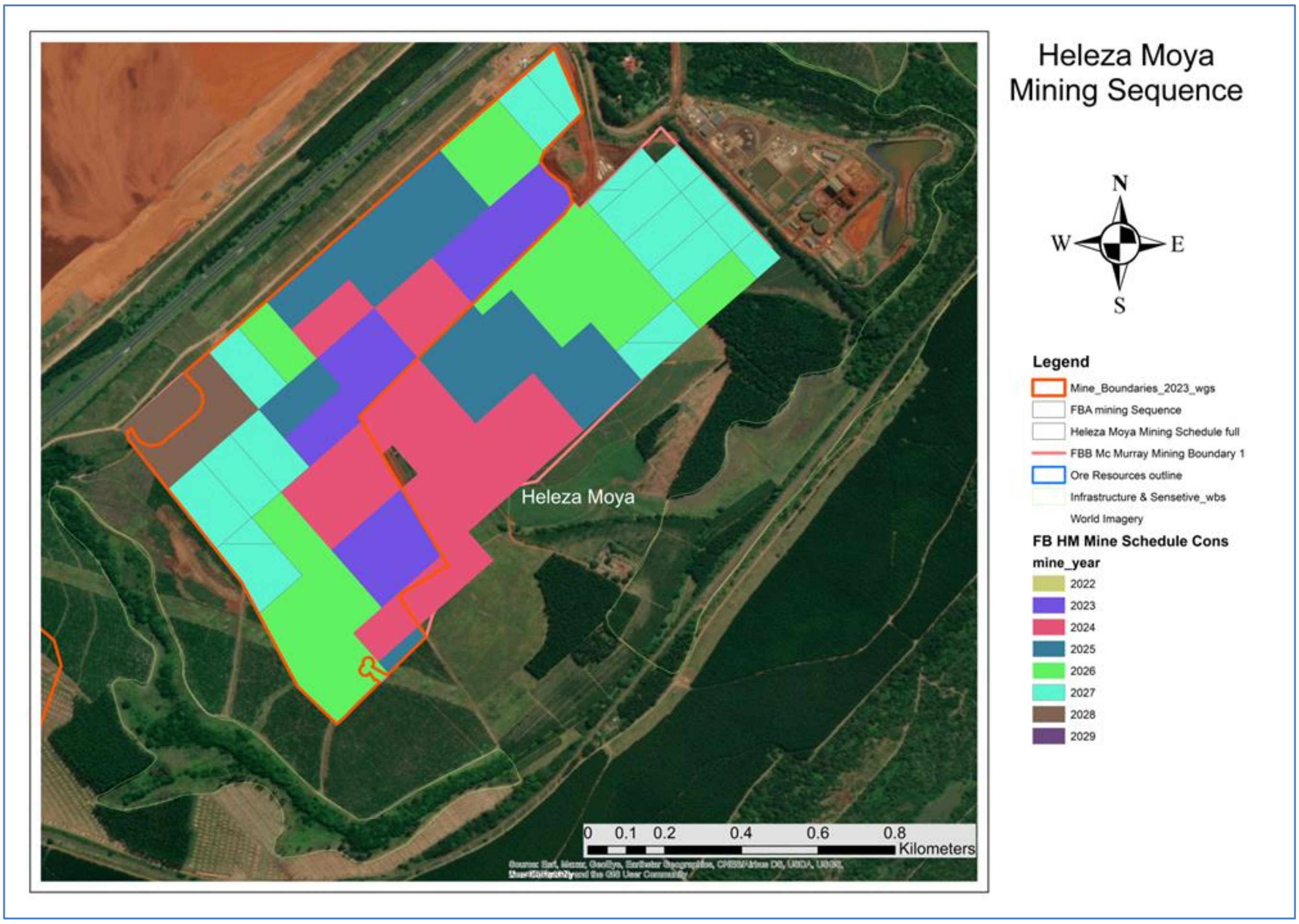


Figure 4-7: Sequencing of mining at Heleza Moya and FBB.

Table 4-2: Summary of Land-use Areas in Heleza Moya simulation

Land use	AREA (Km^2)					
	Amanzimnyama current	Amanzimnyama 2025-Scenario		Amanzimnyama 2027-Scenario		Amanzimnyama Closure
	Catchment P+O	Catchment O	Catchment P	Catchment O	Catchment P	Catchment P+O
Total catchment area	2.595	1.111	1.484	1.111	1.484	2.595
Grasslands	0.062	0.001	0.060	0.001	0.049	0.030
Plantations	1.406	0.429	0.937	0.469	0.922	1.916
Forestry	0.045	-	0.045	-	0.045	0.045
Surgarcane	0.625	0.356	0.199	0.426	0.105	0.146
Infrastructure	0.036	0.021	0.014	0.021	0.014	0.036
Wetland	0.422	0.193	0.229	0.193	0.229	0.422
Stripped (10%) (mining)	-	0.011	-	-	0.012	-
Open Void (60%) (mining)	-	0.066	-	-	0.072	-
Backfilled (30%) (mining)	-	0.033	-	-	0.036	-

Where a mining void exists during the 2025 or 2027 scenario, the model has been set up to neglect any runoff generated from the open void. The rain falling directly into the void is assumed to either report to the groundwater or be returned to the Valley Return Water Dam (VRWD). The open void is assumed to comprise 60% of the area designated for mining at the particular time. Further, an area of stripped vegetation, ahead of the mine void is assumed to comprise 10% of the designated mine area and an area of backfill assumed to comprise 30% of the mining limit for the year under simulation. The current land uses of either catchment O or P are reduced by the amount taken up by the mining area.

The runoff results for each scenario are reported at the Amanzimnyama weir and for the Siyaya estuary in order to estimate the perturbations to the flow regimes effected by the Heleza Moya development. These results are presented in the form of flow exceedance plots, as shown in Figure 4-9 (Amanzimnyama weir) and Figure 4-10 (Siyaya Estuary).

The Amanzimnyama weir flow exceedance demonstrates a very slight reduction in the high and low flows during the 2025 scenario (mostly O catchment). The 2027 scenario flows are slightly increased compared to the 2025 scenario, while the closure flows are very close to the current runoff in the Amanzimnyama catchment over the entire flow regime. Over the range of flows, the 2025 discharges vary from 0.6% to 1.3% lower than current flows, while the 2027 scenario flows are similarly lower than current. The DWS observed flows lie below the 2025 simulated flow regime. However, the observed record is far shorter than the simulated and much of the high and very low flows are not observed. Nevertheless, the data are reassuring, since an improvement in flow regime is predicted for closure.

These flow regime reductions are repeated at the Siyaya weir, (Figure 4-10), but, due to the unimpacted Siyaya flows, the reductions are lower. Over the range of flows, the 2025 discharges vary from 0.6% to 0.7% lower than current flows, while the 2027 scenario flows are similarly lower than current, except at low flows, where the 2027 flows are some 6% lower than current.

The simulated closure flow regime is practically identical to the current flows, as assessed at the Amaminzimnyama weir and at the Siyaya estuary. The closure flows are marginally (1.6%) lower than current for flows for flows lower than the 80% exceedance flow, probably due to the deep infiltration assumed in the backfill. These low flows are deemed to improve with time.

Impact of these minor perturbations to the flow regime at the Siyaya estuary can only be assessed against recent estuary studies and regional DWS classifications. DWS is currently undertaking the classification of significant water resources and determination of the resource quality objectives for water resources in the Usuthu and Mhlathuze catchments and these are due for completion in May 2024. The Basic Human Needs Reserve in the W13B quaternary (which includes the uMlalazi and Siyaya systems) is currently estimated at 0.099 Mm^3/annum and projected at 0.115 Mm^3/annum in 2030. However, no water in the Manazimnyama and Siyaya rivers are used for drinking purposes.

Using previously developed flow and water quality criteria for current and closure scenarios, the impact on the estuary ecology have been assessed to be inconsequential (CRUZ Environmental, 2020; Anchor Environmental, 2023) and the minor perturbations to the flow regimes due to the Heleza Moya mining are unlikely to affect this assessment.

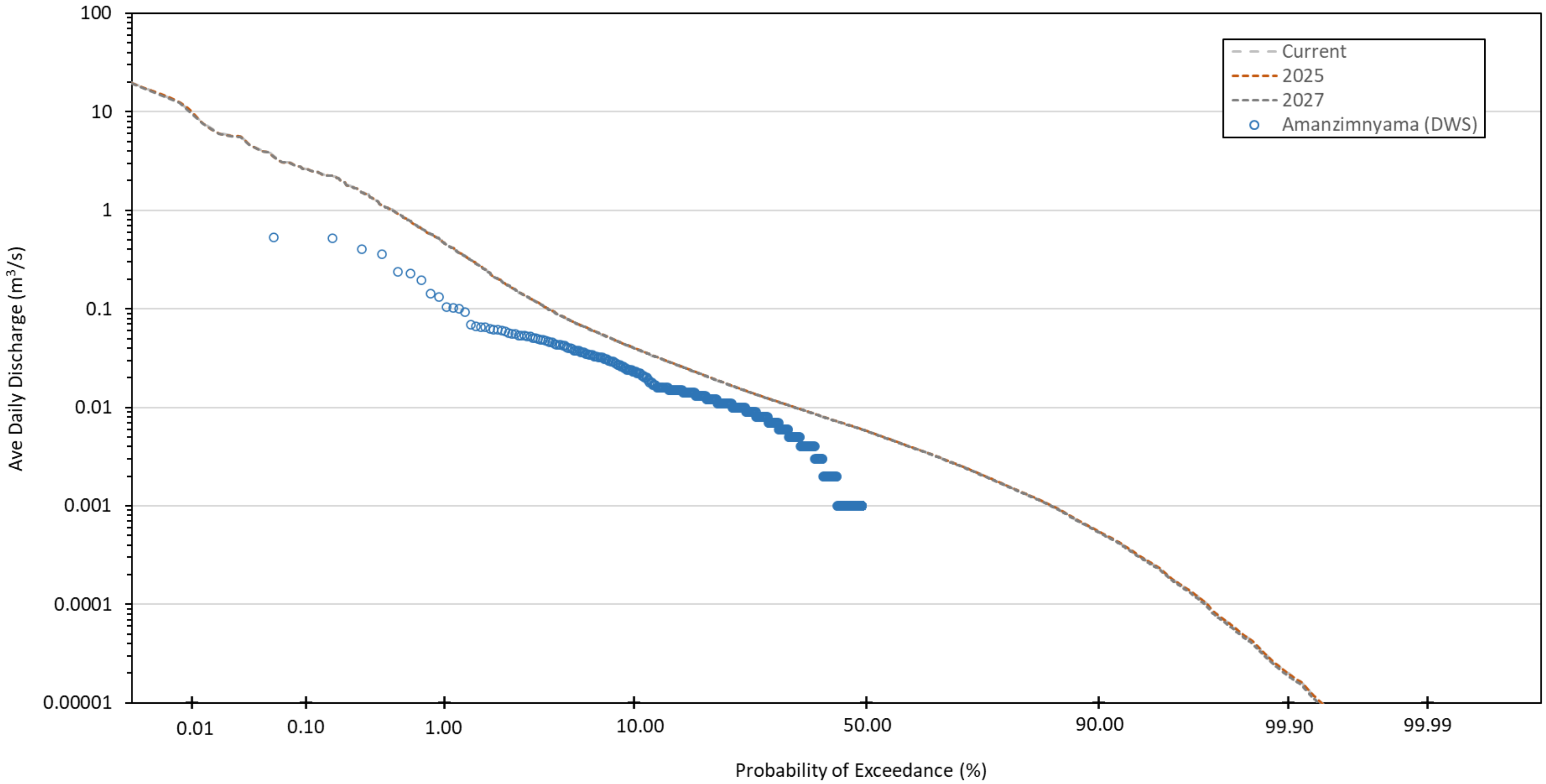


Figure 4-8: Flow exceedance at the Amanzimnyama weir for selected simulated scenarios and the DWS observed flows.

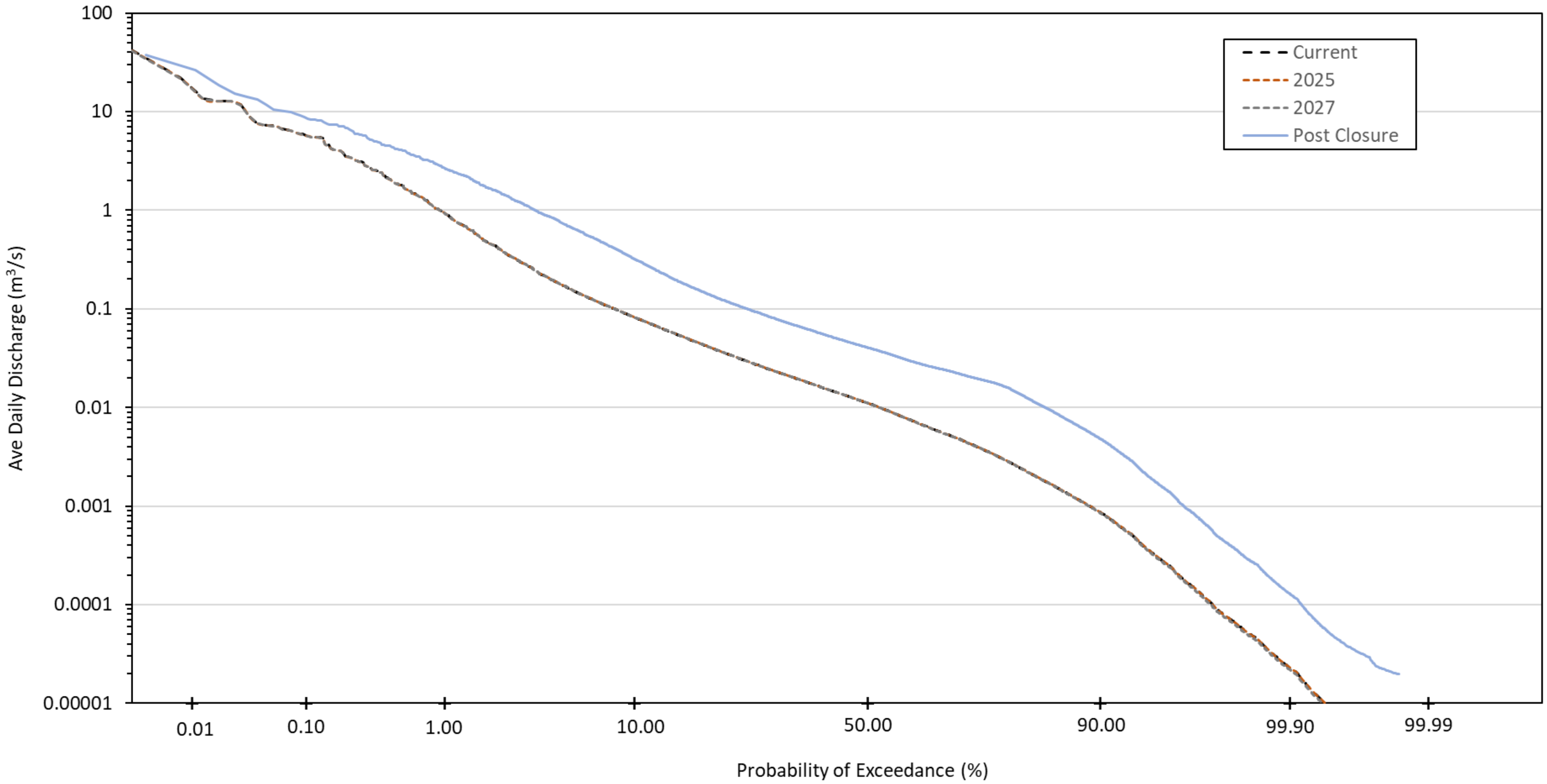


Figure 4-9: Flow exceedance at the Siyaya Estuary for selected simulated scenarios and closure (closure flows from SRK 2021, Scenario 5).

4.5 Surface Water Quality

The surface water quality has been examined in relation to the simulated and observed flow regimes, with a focus on the Amanzimnyama river, leading into the Siyaya estuary, and addressing sediment and salinity aspects of water quality.

4.5.1 Sediments

Sediments in the estuary have been noted as a concern through visual observation of local residents. An analysis of the suspended solids (SS) is thus warranted. In the Amanzimyama catchment, only FS08 and FS09 are sampled regularly. The SS at these stations have been correlated against prevailing observed (DWS) flows (at the Amanzimnyama weir), as illustrated in Figure 4-10. Similar plots have been developed for all Amanazimnyama and Siyaya sampling stations (figure 4-11 shows a data for a typical Siyaya station) and all show similar trends.

Typically, these data reveal that the high SS concentrations are associated with low flows, (perhaps even stagnant water) while high flows have low SS concentrations. This is true for both the Amanimnyama and Siyaya catchments Appendix A. This demonstrates that high rainfall-runoff events do not result in excessive sediment loads, but rather serve to dilute the SS concentrations.

While stripping ahead of the mining void may generate some additional sediments, the data demonstrates that this has been carefully controlled in the past and sediment loss from the Heleza Moya development is likely to be controlled within the mining area.

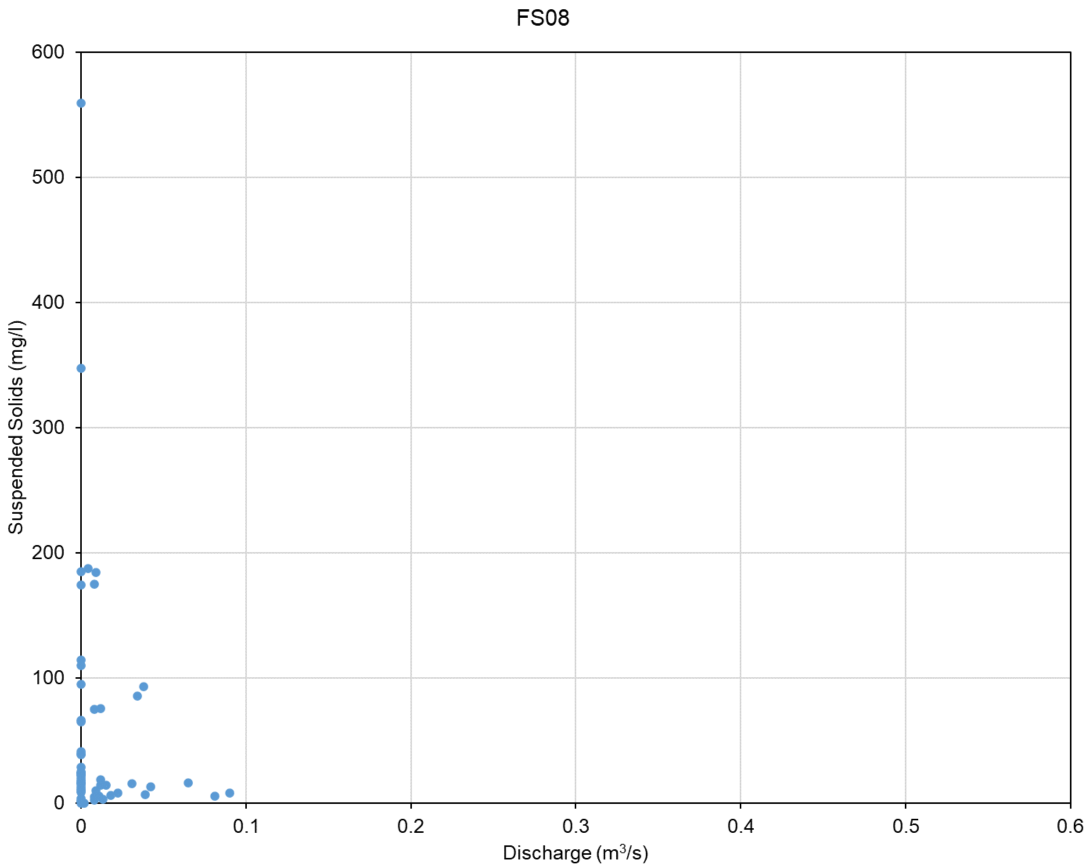


Figure 4-10: Discharge versus Suspended Solids concentrations on the Amanzimnyama river.

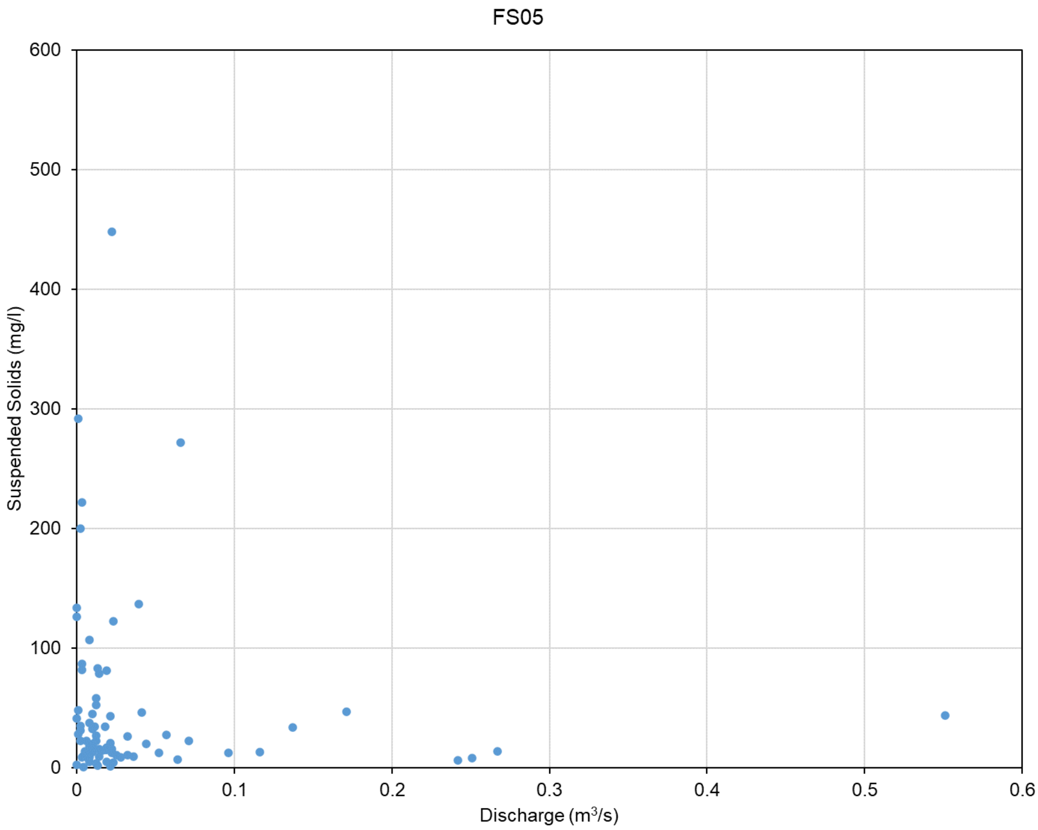


Figure 4-11: Discharge versus Suspended Solids concentrations on the Siyaya river.

An orange floc has been noted in the Amanzimnyama during the assessment of backfill seepage in the C and C-ext blocks. This may be what has been observed in the estuary. While analysis of this almost jelly-like substance has revealed it comprises predominantly Iron 55.24% g/g and Silica 7.06% g/g . Other constituents comprised: Strontium <0.003 %g/g; Barium 0.04 %g/g; Vanadium <0.02 %g/g; Zirconium <0.005 g/g; Titanium 0.08 g/g; Aluminium 0.50 g/g; Manganese 0.24 %g/g; Manganese Oxide 0.26 %; Magnesium 0.40 g%/g; Calcium 0.31 %g/g; Potassium <0.02 %g/g; Phosphorus 0.42 %g/g; Chromium <0.02 %g/g; Loss on Ignition (1000 °C) 34.96 g%/g.

This same suspension has been noted on the west side of the N2 highway and is considered a natural suspension of subsurface seepage of in-situ soils in the area.

4.5.2 Salinity

Surface water quality sample results were assessed from sites FB1 to FB18. None of the water quality variables pose a health risk (DWAF, 1996) except for high iron concentrations at FB7 and FB18. Elevated salinity values (Figure 4-12) are assumed to be sodium (Na) and chloride (Cl) associated with deposition from coastal rainfall. This phenomenon is illustrated in the relationship between Na and Cl in Figure 4-13, which shows a regression slope similar to that found in sea water.

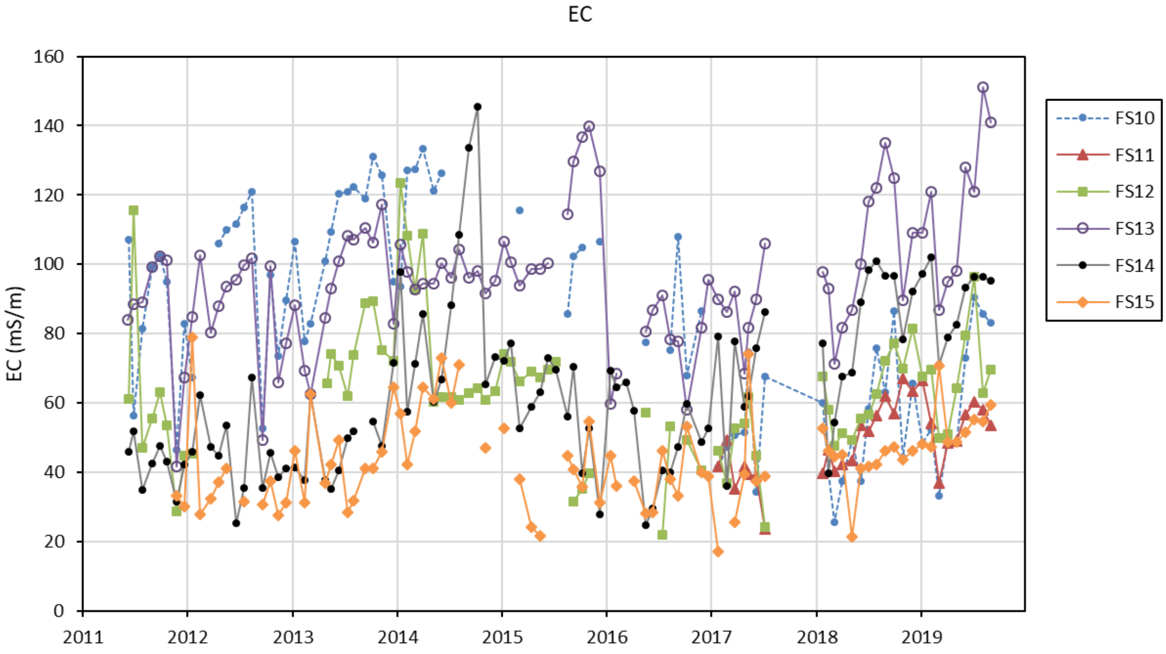


Figure 4-12: EC of surface water observation sites for 2011 and 2019.

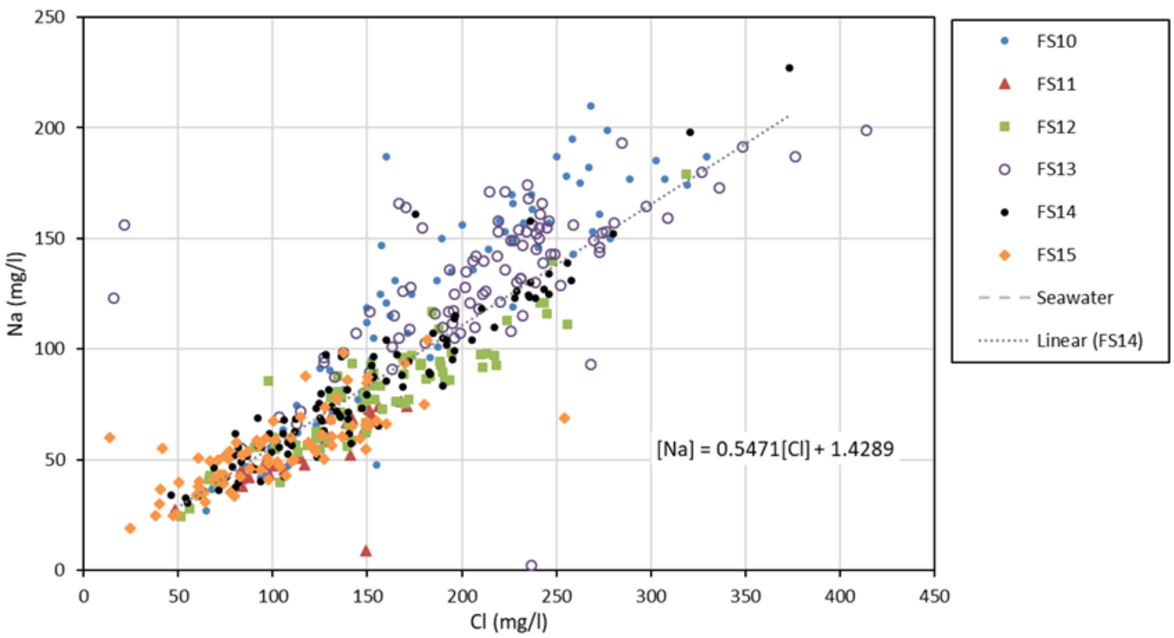


Figure 4-13: Sodium-Chloride relationship of surface water samples.

4.6 Conclusions

A comprehensive upgrade of the flow record has been achieved to include observed (DWS) and manually measured flows in the Amanzimnyama and Siyaya catchments.

During this focus on the Heleza Moya mining development, the ACRU model has been updated to include a system of cascading hillslope responses to allow build-up of subsurface water in riparian and wetland zones, and thus increase evapotranspiration in these areas. Simulations of runoff for recent periods in the Siyaya and Amanzimnyama catchments are accurate, compared to the revised observed runoff at the gauge stations (W1H019 and W1H018). Using the model settings and the land use distribution for proposed mining at Heleza Moya and post mining scenarios, a long- term record of daily average flows was generated for the Amanzimnyama weir and the Siyaya Estuary.

Surface runoff is insignificant reduced at the Amanzimnyama weir and at the estuary during mining at Heleza Moya, and closure scenario simulations reflect a return to an improved flow regime at the Siyaya estuary.

No human drinking water occurs in the Amanzimnyama or Siyaya systems and any perturbations to the reserve (anticipated to be established in April 2024), caused by the Heleza Moya mining, are considered inconsequential in either of these systems.

The surface water model development will continue in future years, particularly with respect to compatibility with the groundwater simulations and anticipated rehabilitation of soils and land use conditions.

5 Groundwater Hydrology

5.1 Numerical Groundwater Model

A three-dimensional, numerical groundwater flow model was constructed during 2011 using the finite element code *MINEDW* (Azrag et al., 1998) to simulate the effects on groundwater during mining.

The reports completed for the construction of the model as well as subsequent updates are as follows:

- A detail description of the numerical model setup - SRK hydrogeological report for the 2011 EIA (SRK, 423506);
- Re-calibration of numerical model using most recent water level monitoring data in 2014 (SRK, February 2015); and
- The numerical groundwater model calibration was checked and updated annually since 2016 using the most recent groundwater level monitoring data and estimates of measured baseflows in the Siyaya and Amanzimnyama Streams.

During the annual update the model was refined and principally the boundary conditions that define the streams within the catchment and land-use based recharge rates were refined using the latest topographical survey, rainfall data and ACRU model results. Faults, as mapped by geophysical survey and regional mapping, were included as preferential flow pathways.

The latest FBB and Heleza Moya (HM) annual mine plans and a backfill strategy was included in the predictive simulation, which covered the period from 2023 to 2030. The Hydrus model RSFs seepage rates were applied to the *MINEDW* model. The numerical model domain boundary conditions and hydraulic parameters were left unchanged from the original model.

5.2 Hydrologic Study Area and Boundary Conditions

The Fairbreeze mining area is drained by a number of streams both ephemeral and non-perennial that flow into the Mlalazi River to the north, the Matigulu River to the south or directly to the ocean. To the west the land surface rises to form a ridge which is assumed to correspond to the groundwater divide. These physical boundaries were used to define the Hydrological Study Area (HSA).

All selected rivers including the Siyaya and Amanzinyama River within the HSA were simulated as drainnode boundaries within the first model layer, with the specified heads varying along the river course. Gaining streams are thus simulated when the groundwater heads are higher than the stream stage.

For predictive simulation, a variable-flux boundary condition which allows flow across the model boundary was applied. The variable-flux boundary condition that is incorporated into *MINEDW* uses a linked analytical solution to simulate infinite continuity of the hydrogeologic units at the boundary. The same hydraulic properties of the units at the boundary are assigned to the analytical “extension” of the units. The variable-flux boundary condition calculates the flows across the boundaries as a function of the calculated changes in groundwater levels (heads) at the boundaries.

The ocean was assigned a fixed head of zero. The upper boundary of the model is the phreatic surface, which is calculated by the model during both steady-state and transient simulations.

5.3 Mesh

The finite-element grid of the HSA used for the Fairbreeze model is shown in map view in Figure 5-1. The mesh is more finely discretised in the vicinity of the pits, where the horizontal dimensions of the elements are about 30 to 60 m. The finer discretisation enables better numerical resolution where the hydraulic gradients are the greatest and also allows the geometry of the pits and surrounding hydrogeologic units to be represented at a reasonable level of detail. Heleza Moya is a new orebody and lies within a zone of coarser discretisation region and will be refined in future updates. The elements forming the mesh depict the top (or bottom) of triangular prisms, with the points at the corners of the prisms constituting the finite-element “nodes.” The model comprises 486 100 elements and has 270 380 nodes.

The mesh was divided into eleven layers vertically, each with an average thickness of 10 m. These layers represented the Quaternary sands, Maputuland Group, and bedrock. The Quaternary sands were present only in the topmost layer of the model. It is assumed that the hydraulic conductivity decreases with depth, which is why the bedrock was divided into an upper and lower zone. The bottom of the model was set arbitrarily at -80m below sea level. The most recent FFB and HM pits exceed the assumed depth of the Maputuland Group in the model. Therefore, future updates will need to incorporate the revised geology.

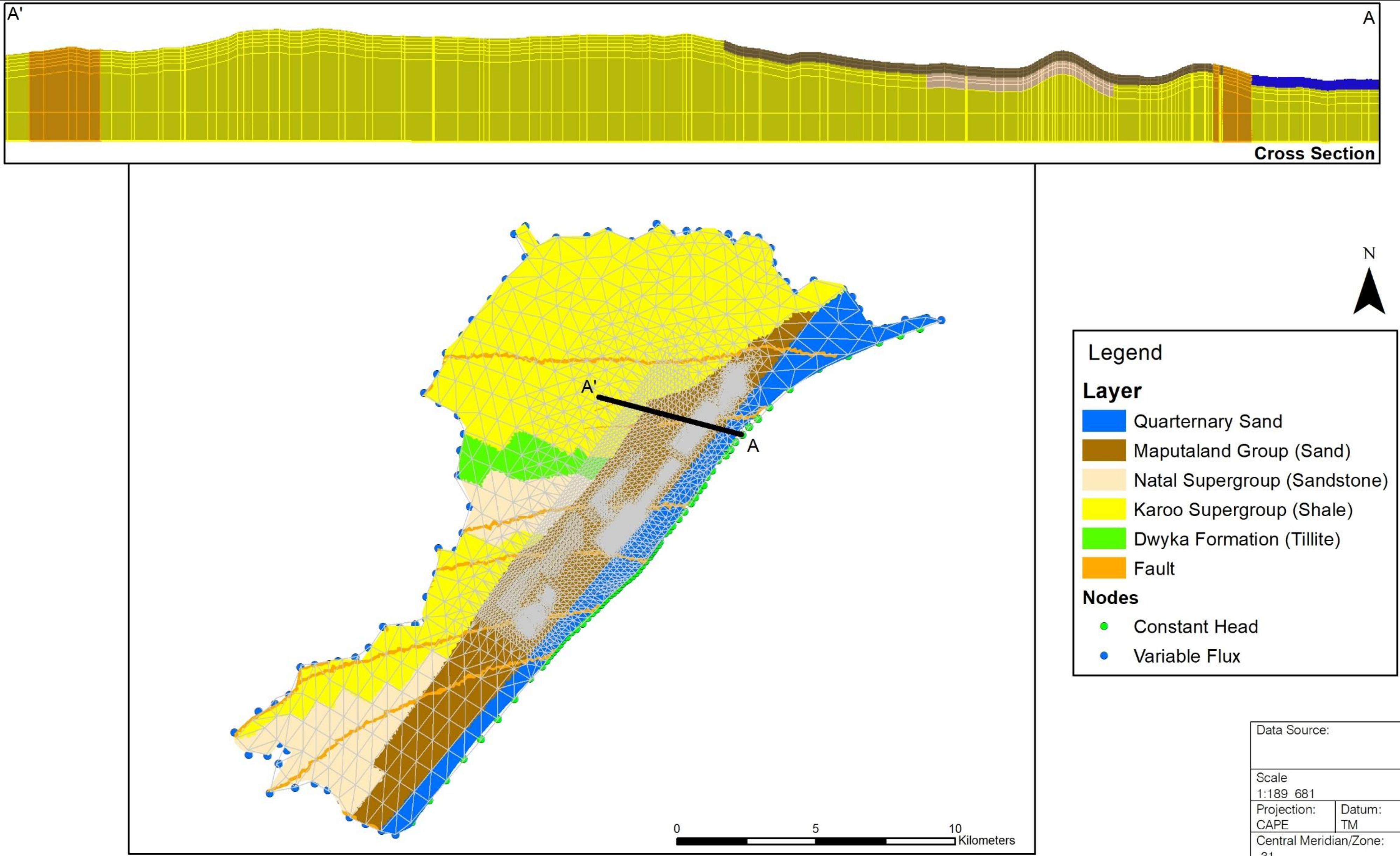
5.4 Model Parameterisation

5.4.1 Hydraulic Parameters

The geological units incorporated in the model are represented by individual layers and zones within the model mesh. The hydraulic parameters of importance in investigation groundwater flow are hydraulic conductivity, specific storage and specific yield. These parameters control the ease with which groundwater can move through the subsurface and how much water can be released from the system. This is important to estimate inflow if any into the mine voids, drawdown and pore pressure distribution. The hydraulic properties used to calibrate the model are summarised in Table 5-1, and based on limited historical data collected pre-mining and during the Mega Sebeka RSF design.

Table 5-1: Hydraulic Properties of Units Used in the Numerical Model

Unit	Hydraulic Conductivity K [m/day]		Storage Parameters	
	$K_{x,y}$	K_z	Specific Storage S_s [m^{-1}]	Specific Yield S_y [-]
Sandstone (Upper Layer)	0.5	0.5	5 $x10^{-06}$	0.005
Sandstone (Lower Layer)	0.4	0.4	5 $x10^{-06}$	0.005
Tillite (Upper Layer)	0.3	0.3	5 $x10^{-05}$	0.05
Tillite (Lower Layer)	0.25	0.25	5 $x10^{-06}$	0.005
Shale (Upper Layer)	0.2	0.2	5 $x10^{-05}$	0.05
Shale (Lower Layer)	0.17	0.17	5 $x10^{-06}$	0.005
Maputaland Group Sands	10	10	5 $x10^{-05}$	0.05
Quarternary Sands	20	10	5 $x10^{-05}$	0.05
Faults	1	1	5 $x10^{-06}$	0.005



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FAIRBREEZE MINE

MESH AND SIMULATED HYDROGEOLOGICAL UNITS

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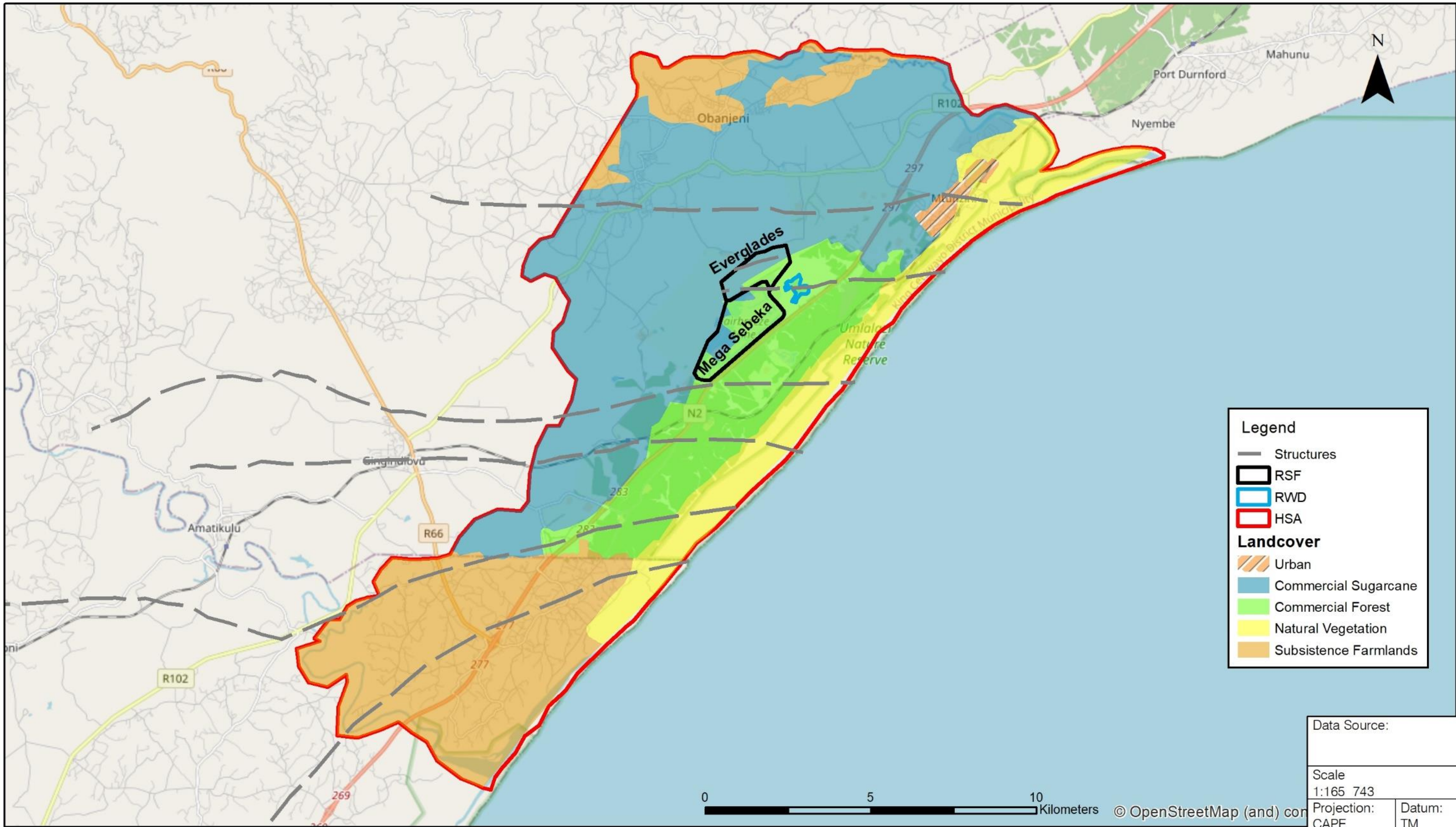
5.4.2 Recharge

Rainfall recharge varies over the area due to varying rates of evapotranspiration from the natural vegetation, commercial forest and sugar cane plantations. Previous estimates put recharge at between 5% and 8% of rainfall (Rison, 2004) and a recharge model (Kelbe *et. al.*, 2001) suggests that the maximum recharge from individual rainfall events is 50 mm with a threshold of 10 mm before recharge occurs. Recharge for the current model was varied according to land use shown in Figure 5-2 and assigned values as in Table 5-2.

These recharge factors were applied to the actual monthly precipitation for the period 2003 to 2022 and the average monthly precipitation values for predictive simulation. The recharge rates used allowed for the best calibration of the numerically simulated water levels to the observed water levels.

Table 5-2: Recharge Percentage

Land Use	Percentage Recharge
Sugarcane	6%
Farmlands	6%
Forest	5%
Natural	7%
Urban	10%



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FAIRBREEZE MINE
GROUNDWATER RECHARGE ZONES

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5.5 Model Calibration and Validation

The model was calibrated to the observed groundwater conditions between 2013 and 2021. The latest data, 2022 and 2023, is compared to the model computed values as a validation of the model. Details of model calibration to groundwater levels and stream baseflows are provided below.

5.5.1 Water Level Calibration

The numerical model was calibrated to the regular and routine groundwater level monitoring data collected by TRONOX since February 2013.

The recharge and hydraulic parameters were varied, through trial and error, until a reasonable match was obtained between the observed and simulated water levels. The simulated water levels, up to 2021, have a normalised mean residual error of 9.7 % across the HSA. On average, the difference between simulated water levels and observed water levels is 2.05 m and overall only 8 of the 94 monitoring points have a difference of greater than 10 m (Figure 5-3).

Monitoring points with long records are compared to the simulated results in Figure 5-4. The location of all boreholes is shown in Figure 5-5. Over the past two years, fewer water levels have been collected and therefore only a few boreholes are available for validation. Historically the simulated heads in many of the boreholes and piezometers do accurately mimic the observed values. Where poor calibration exists, this is attributed to:

- Simplification of the geological units which affects the hydraulic parameters; and
- A generalisation of the land use zones within the study area which would affect the recharge to these areas.
- Inaccuracy in the borehole elevation, as accurate surveyed collar elevations are not available.

Overall, the model accurately reflects the observed water level trends. The increasing trend of water levels at FBMW 6, suggests that there may be influence from the plant and the water storage pond may be a source. This needs to be investigated. To reflect the observed water level increases, additional changes need to be made in future model updates once the likely source is identified. The current piezometric surface, from the calibrated model, is shown in Figure 5-6 and reasonably mimics the expected groundwater table conditions.

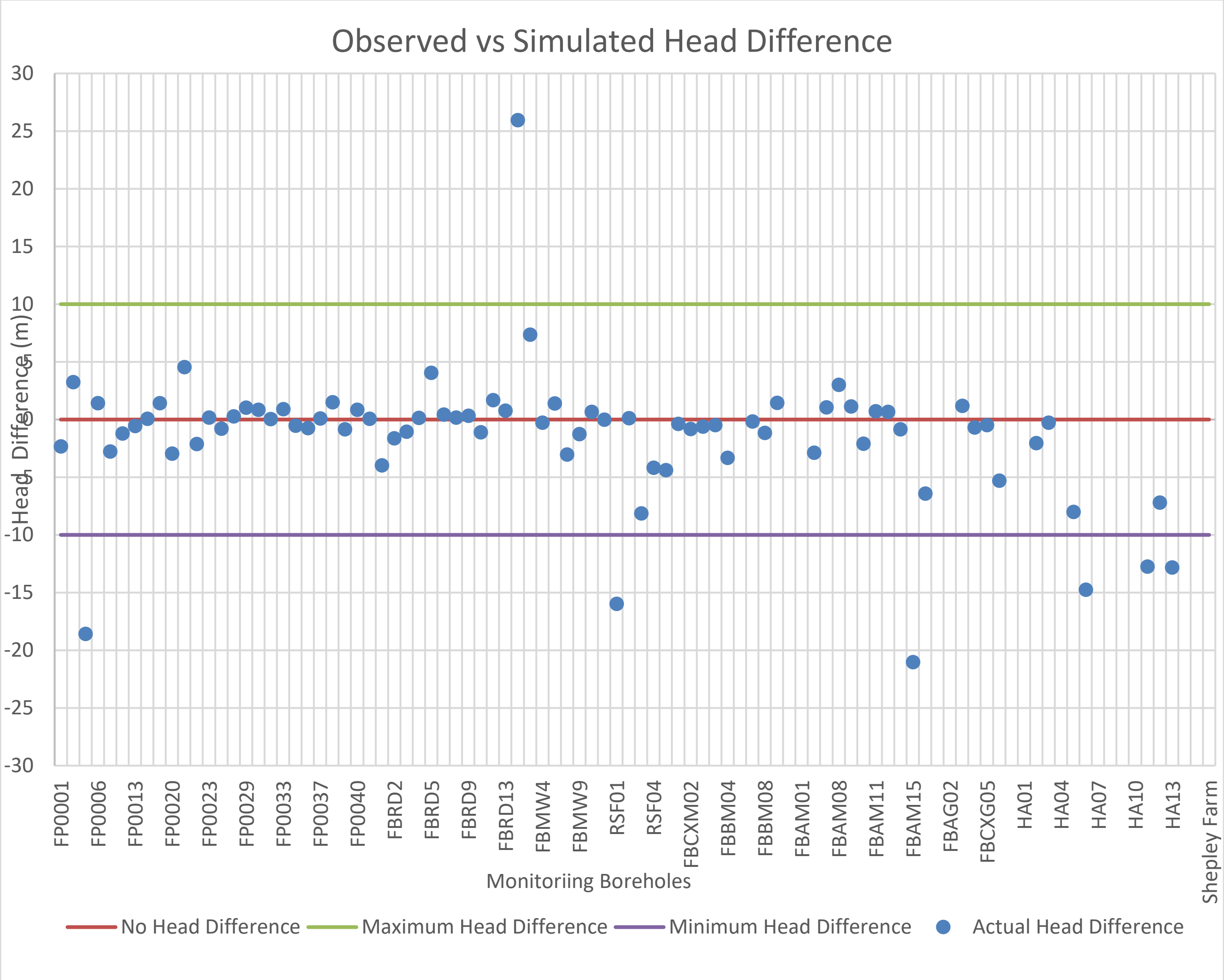


Figure 5-3: Observed-Simulated Head Differences for the various boreholes (horizontal axis) within the simulation boundary.

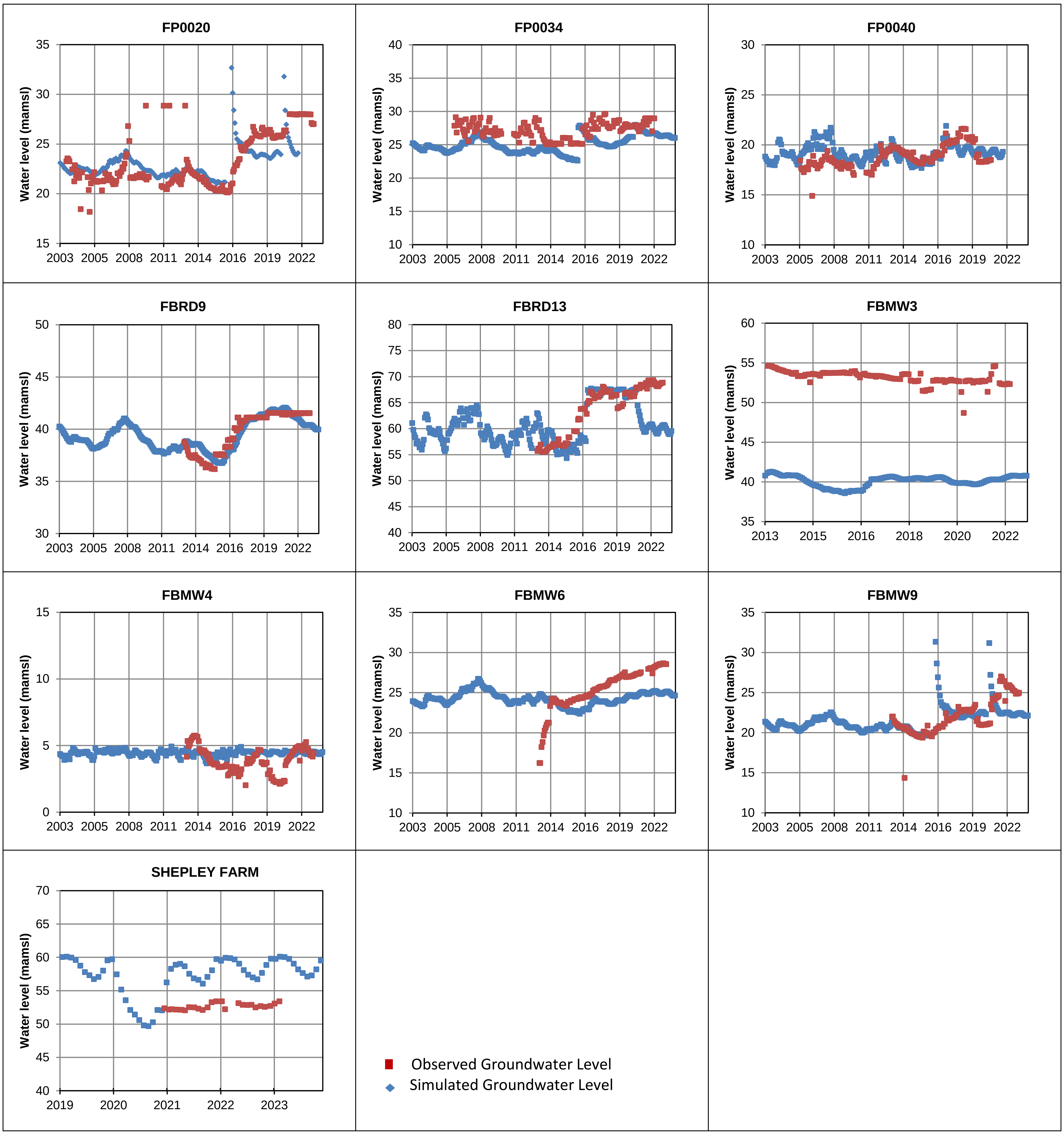
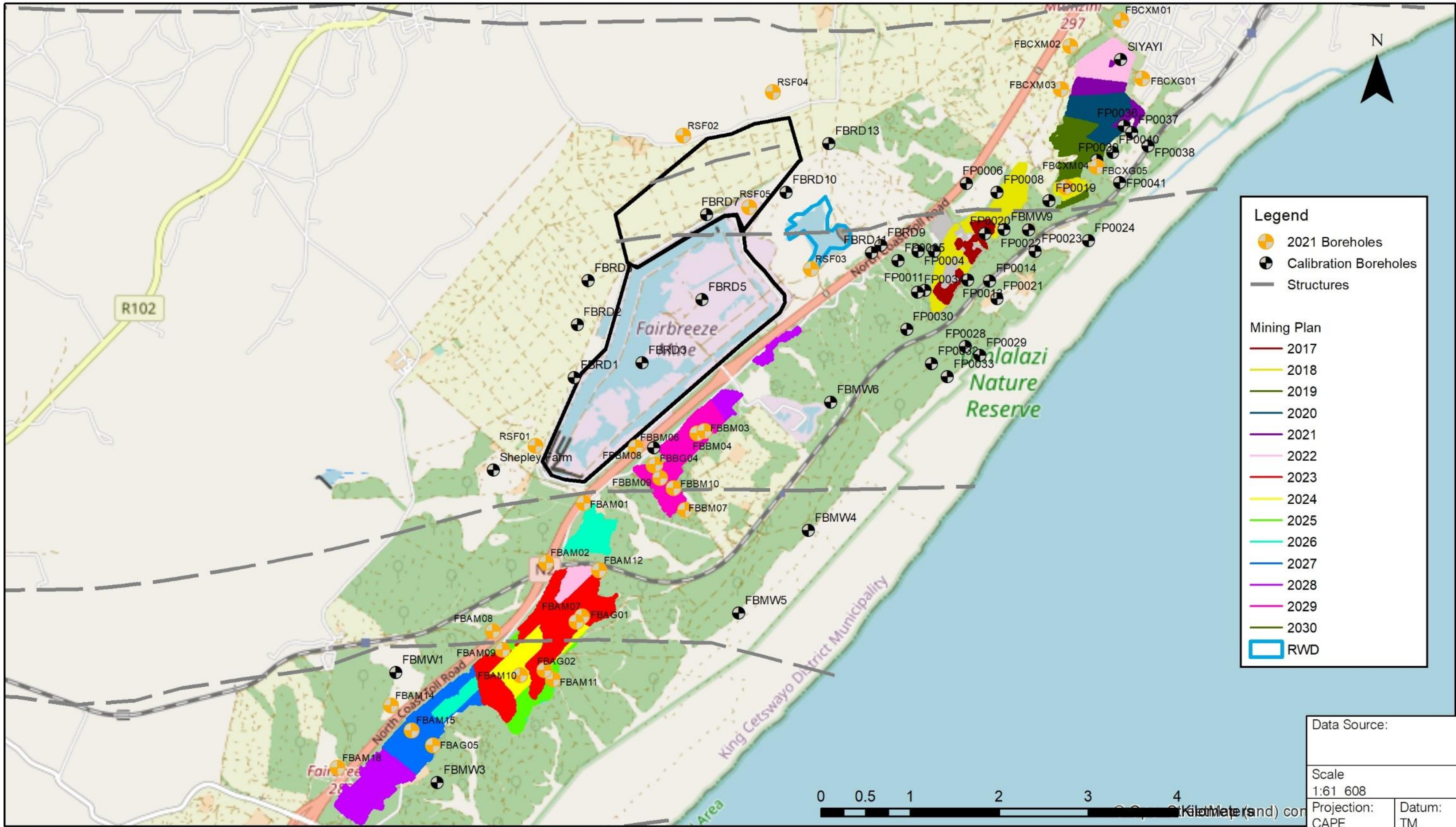


Figure 5-4: Observed versus Simulated Water Levels (2003-2023)



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CALIBRATION BOREHOLES

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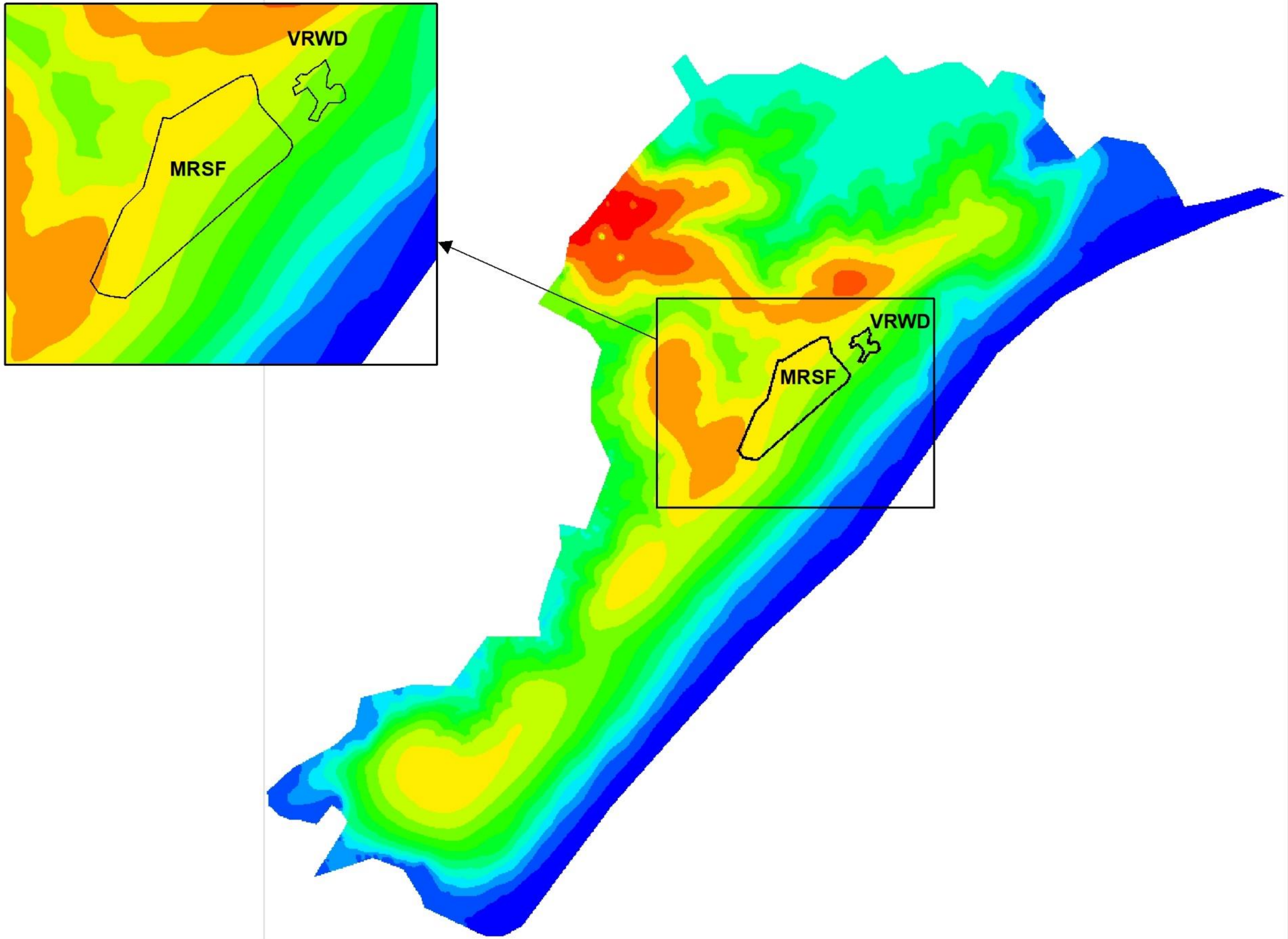

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2022 PIEZOMETRIC SURFACE

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5.5.2 Baseflow Calibration

The simulated groundwater baseflow to the Amanzimnyama and Siyaya (up to the confluence with the Amanzimnyama) Streams is low and is in broad agreement with the baseflow derived from the surface water model (Figure 5-7). The simulated baseflow represents the total groundwater seepage for the entire length of the stream considered. In reality, groundwater seepage will occur only along selected portions of the streams, where it either evaporates or seeps back into the streambed alluvium and flow may not be visible long the entire length. The amount of baseflow is intermittently linked to rainfall.

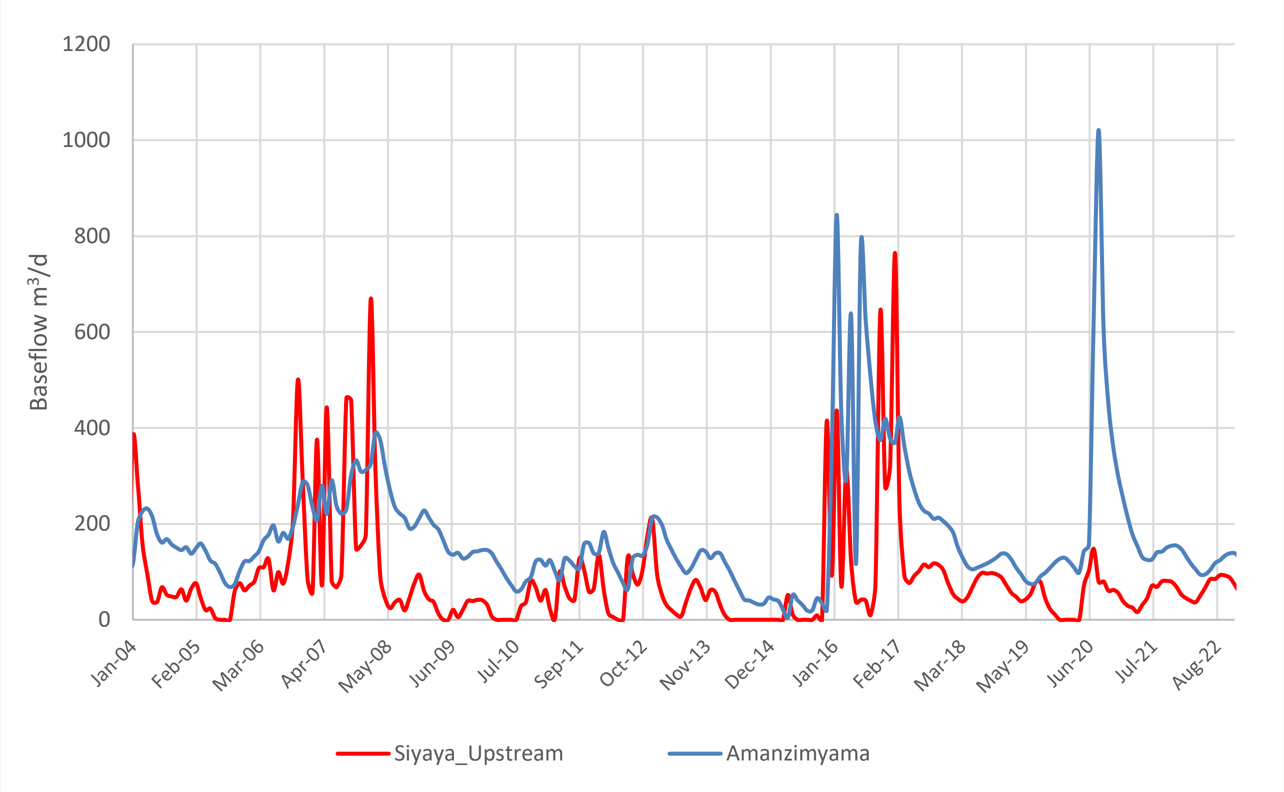


Figure 5-7: Groundwater Numerical Model Simulated Baseflow for the Siyaya and Amanzimnyama Streams (Jan 2003 – Dec 2022)

5.6 Simulation of Residue Storage Facility

Based on the recent HYDRUS 2D model the percolation flux through the foundation RSF materials to the groundwater phreatic surface was calculated to be 0.36 mm/d. This seepage rate was applied over the entire footprint of the MRSF.

5.7 Simulation of Mining and Rehabilitation

The annual, 2023 to 2030, configurations for the FBB and Heleza Moya mining voids were included in the model. The mine plans and actual mine voids as per the 2021 annual model update were left unchanged for FBC and FBC Ext.

The recharge applied to the mining voids, during the period of mining and the subsequent year, is 12% of the mean monthly precipitation. Backfilling of mining voids at FBC ext has begun. Backfilled areas will be grassed and as such, the recharge applied for the rehabilitated areas was assumed to be the same as that assigned to grasslands, that is 7% of the mean monthly precipitation.

5.8 Predictive Simulation of Mining and Rehabilitation

5.8.1 Groundwater at Mining Voids

Mining started in 2016 at FBC and both the FBC and FBC ext orebodies are mined out. Mining operations have recently commenced at FBB and will be followed by the HM pit which is expected to be continue until 2030. The FBB and HM pits are predicted to extend to below the current water table, which ranges from 30 to 40 mamsl at present. Based on the model outcomes:

- Inflows into FBB will range from approximately 3 000 (35 L/s) to 2 500 m^3/d (30 L/s) (Figure 5-8) at the end of mining in 2026. Steady increase in inflows at the HM pit will begin as FBB is backfilled, peaking at approximately 1 644 m^3/d (19 L/s) in 2029.
- The inflow is due to the pit extending well below the water table. The amount of seepage into the pit will be dependent on actual rainfall. Inflow into HM may also be due to seepage from the backfilled FBB.
- Cross-sections through the FBB and HM orebodies showing the water table position relative to the void (Figure 5-9), illustrated that as the pits develop seepage is likely to occur along the up-gradient pitwalls and from the base of the pit. Seepage is predicted to begin seven months into mining. During the first few months of mining at HM, it is unlikely ingress will occur since mining will take place above the water table.
- The drawdown associated with the mining will expand as the mine fully develops (Figure 5-10). The Shepley Farm borehole is just within the significant zone of drawdown of 3m, and monitoring of this borehole should continue and if required any adverse impacts mitigated.
- Just two years after rehabilitation (Figure 5-11), the water levels would be largely recover to close to pre mining.

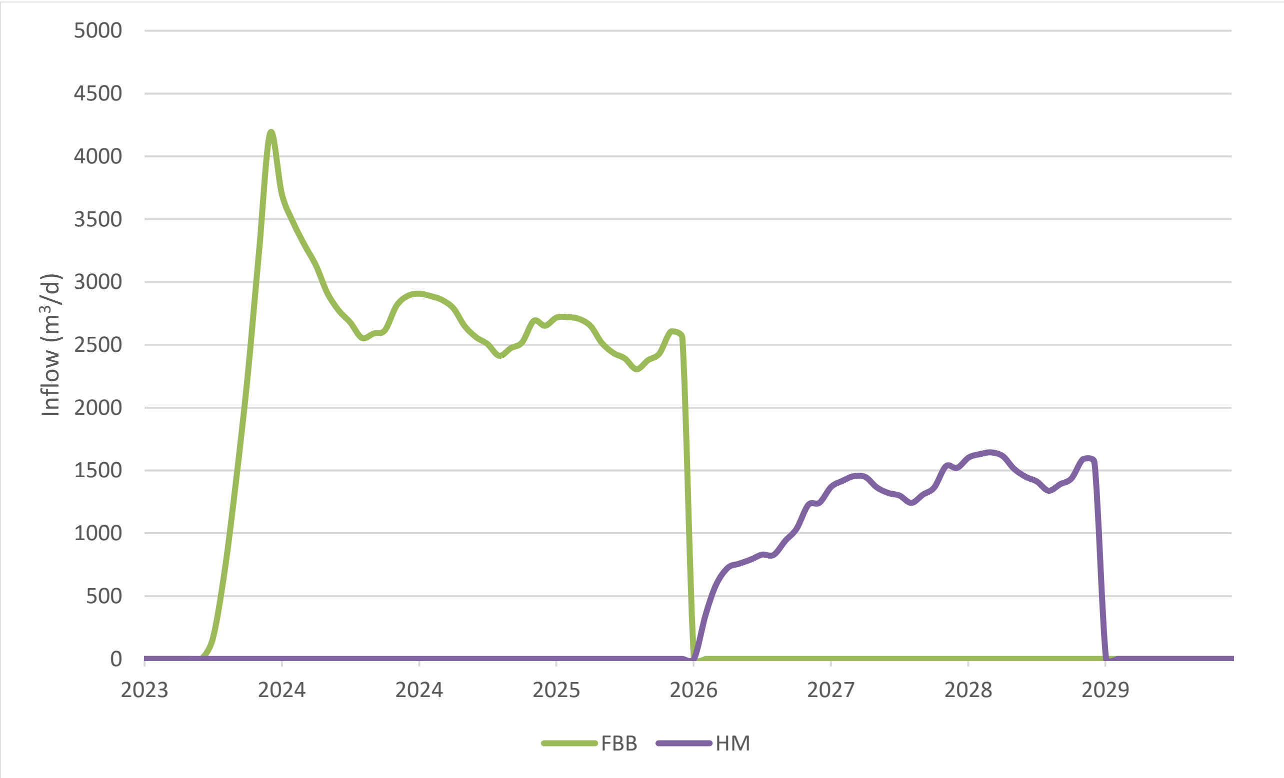
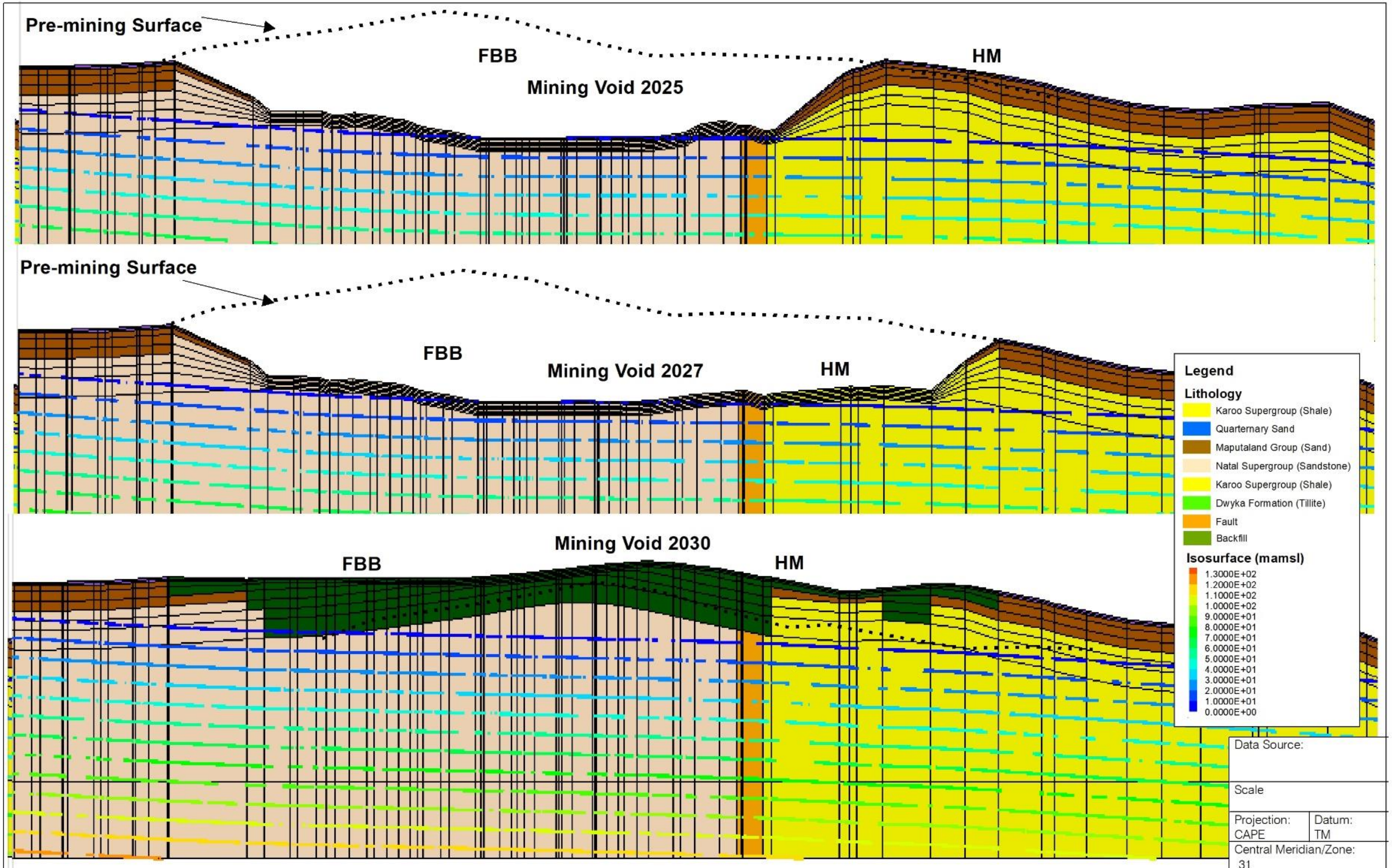


Figure 5-8: Predicted Inflows into FBB and Heleza Moya (HM)



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FAIRBREEZE MINE

CROSS SECTION MINING VOIDS - FBB AND HELEZA MOYA (HM)

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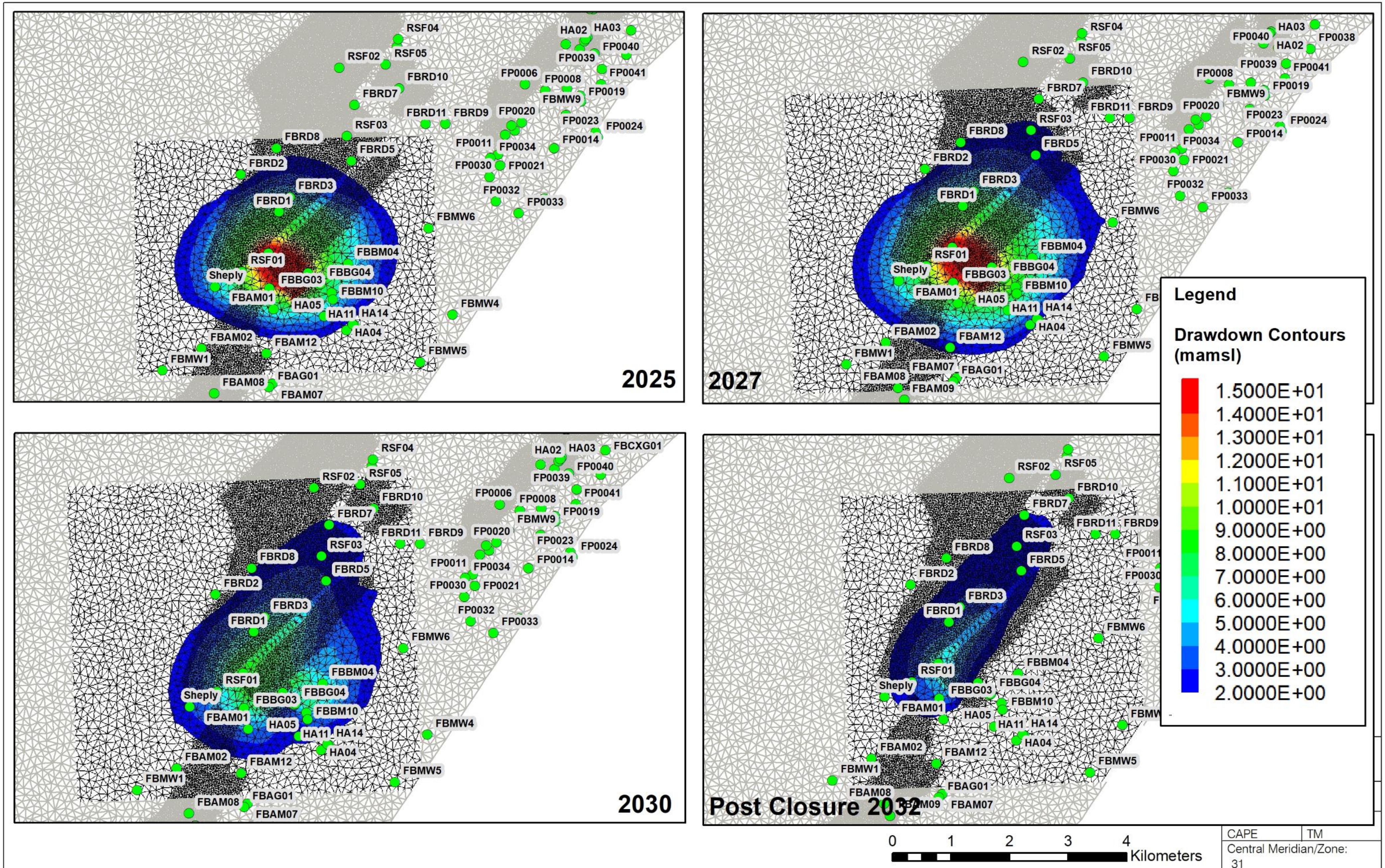

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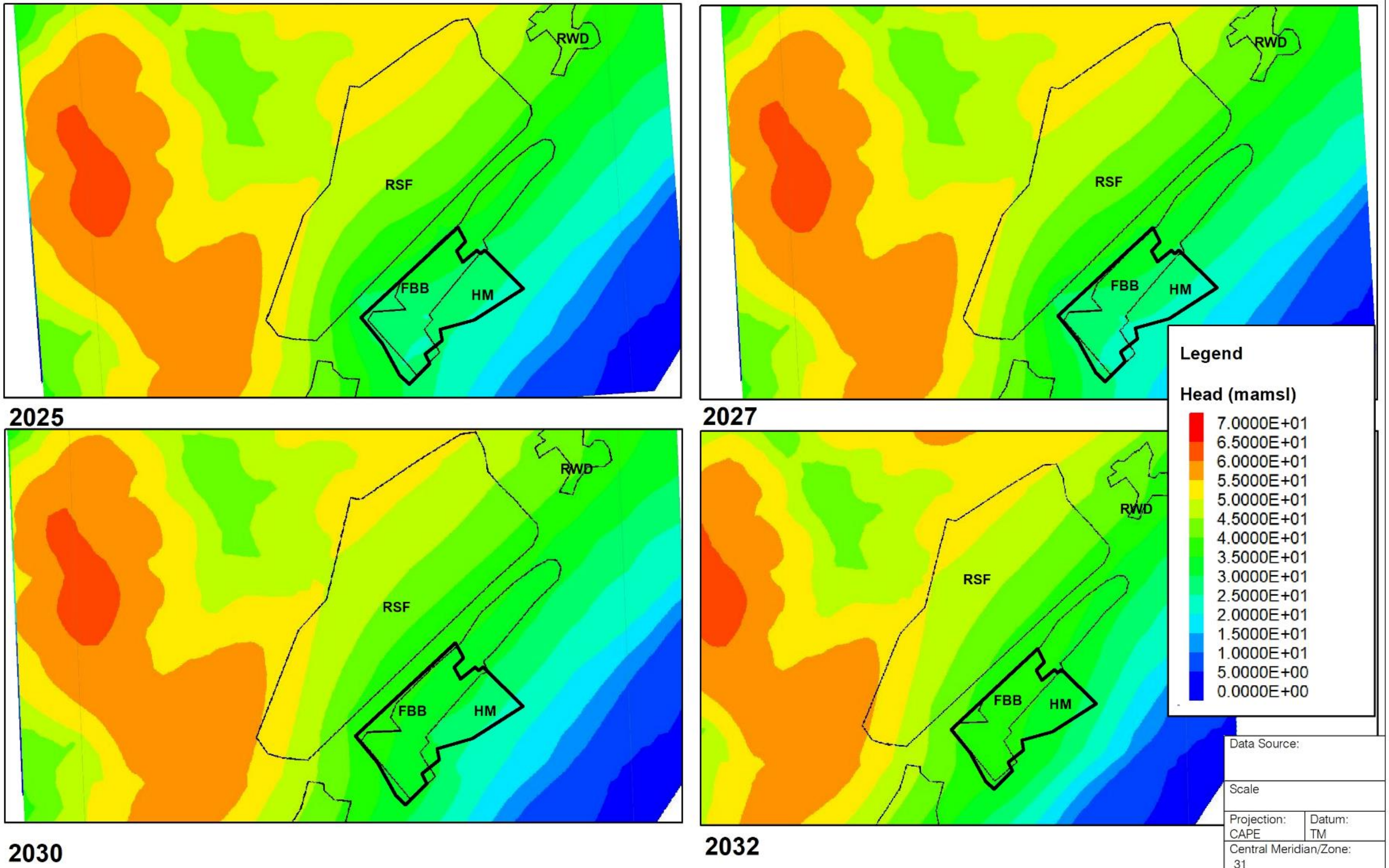
FAIRBREEZE MINE

DRAWDOWN OVER LoM - FBB & HELEZA MOYA (HM)



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FAIRBREEZE MINE

PIEZOMETRIC SURFACE OVER LoM - FBB & HELEZA MOYA (HM)

5.8.2 Changes to Baseflow Conditions

Recharge was assumed to be 12% of the mean monthly precipitation during mining and one subsequent year thereafter. During the rehabilitation phase and once grasslands are established the recharge is assumed to decrease to 7% of the mean monthly precipitation. Baseflow which will vary with seasonal rainfall (Figure 5-12) is predicted to change during mining as follows:

- Siyaya will remain low at less than 100 m³/d, however not drying up totally. This is mainly due to higher recharged associated with the rehabilitated FBC and FBCext.
- Amanzimyama will experience about a 25 m³/d decrease in baseflow during the mining of the FBB and HM orebodies. This is a relatively small decrease compared to the overall streamflow. It is noteworthy that the stream does not go dry i.e., there is always some baseflow under average rainfall conditions.
- Post mining baseflows will increase to approximately 120 m³/d. The baseflow contributions will be proportionally to the recharge. Recharge over the rehabilitated area is assumed to be 7% of MAP, a 5% decrease from the mining period, hence the baseflow will re-establish as lower levels than during the mining period. The baseflow post rehabilitation is similar to the pre-mining simulated levels and corresponds with the hydrology analysis.

These estimates are based on best approximations of recharge and thus could change with improved recharge estimates. Low rainfall season will exacerbate the baseflow decreases and the converse will occur under higher rainfall seasons. Monitoring of the weir along these streams will be important to confirm decreases and if required initiate mitigation.

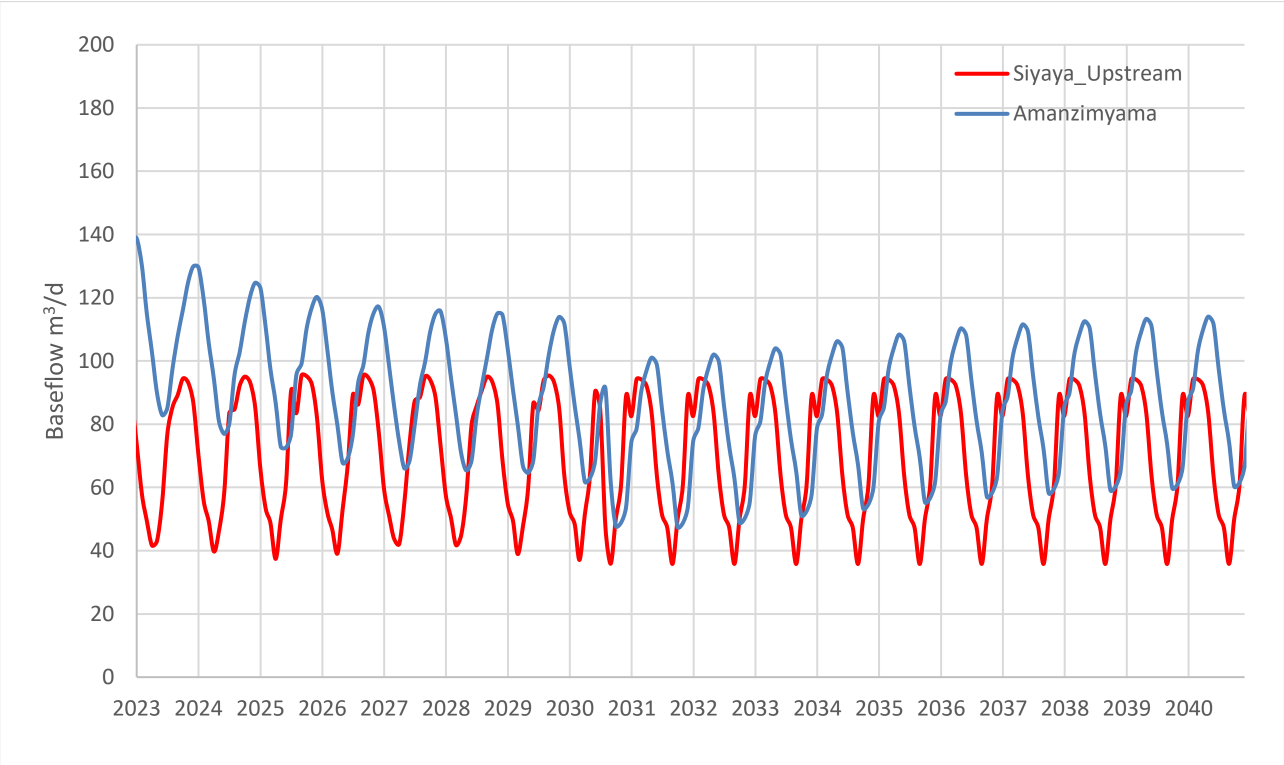

Figure 5-12: Baseflow predictions into the Siyaya and Amanzimyama River

5.9 Limitations of Current Numerical Model

The current numerical flow model has some limitations as the lithological thickness of the Maputaland Group was assumed, base on information at the time of constructing the original model. The Maputaland Group seems to be thicker, at least at the FBB and HM orebodies, than previously modelled. Improvements will need to be made to the current numerical model to more accurately simulate the extent of the Maputaland Group.

The recharge applied to the mining pits and rehabilitated areas are assumed and based on judgement and as such incorporates some uncertainty. Improved estimates of recharge and seepage from mine water storage ponds can be made, based on the now available water level data, during future updates.

5.10 Groundwater Quality

Regular, quarterly, monitoring of surface and groundwater has taken place since 2013, when mining began. The groundwater monitoring results provide a general overview of water quality. The average concentrations of a groundwater sample point for the various monitored parameters were calculated and compared to the domestic water quality guideline values. The average groundwater quality is generally within the guideline values as illustrated by selected ions in Figure 5-13 to Figure 5-17.

The following exceptions are noted:

- Boreholes - Bonakala 1 and TEC have elevated concentrations of chloride and sodium. All other sample points have less than 200 mg/l chloride and sodium. The Na and Cl levels at Bonakala 2 has remained fairly constant since 2020.
- The borehole TEC continues to have elevated concentrations of sulfate in comparison to the other monitoring boreholes.
- The average Electrical Conductivity (EC) has remained below the SANS 241:2015 guideline limits. The Bonokala and TEC boreholes historically have elevated levels relative to the other sampling points and at the guideline limit for drinking water. The elevate levels are natural and unlikely to be related to mining.
- Average pH is generally between 6 and 9 in all monitoring boreholes.

The seepage observed and previously reported from the VRWD has no significant impact on the water quality at monitoring boreholes FBRD9 and 13 and similarly there is no significant impact on water quality at FBMW6.

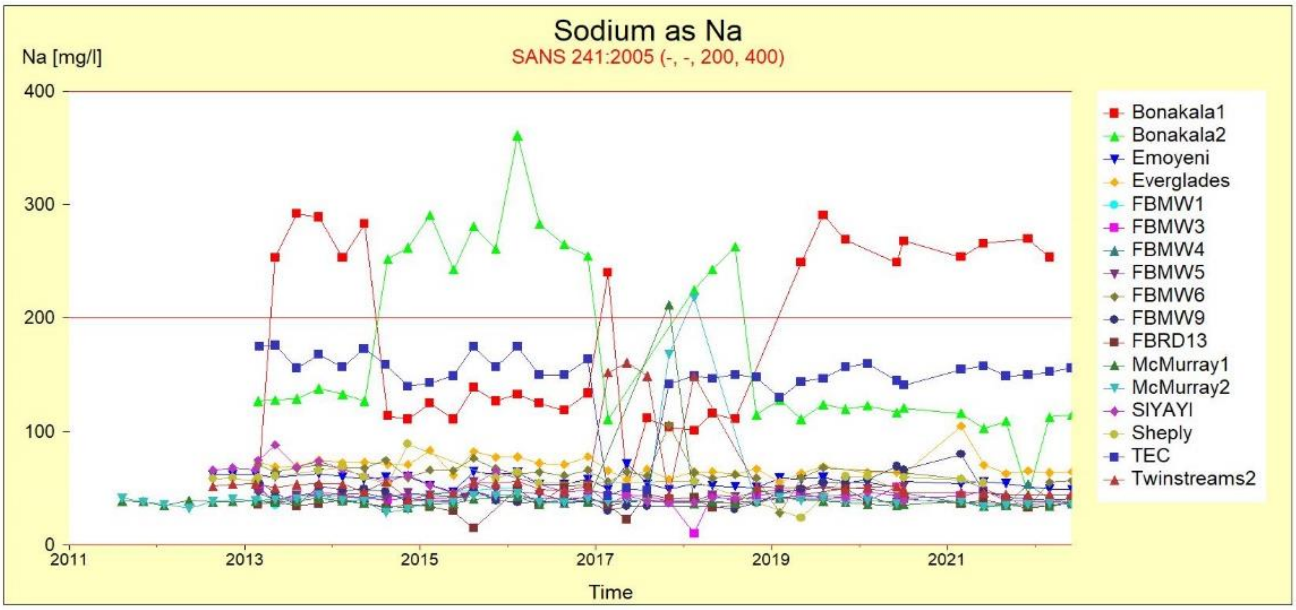

Figure 5-13: Sodium Concentrations at Monitoring Boreholes

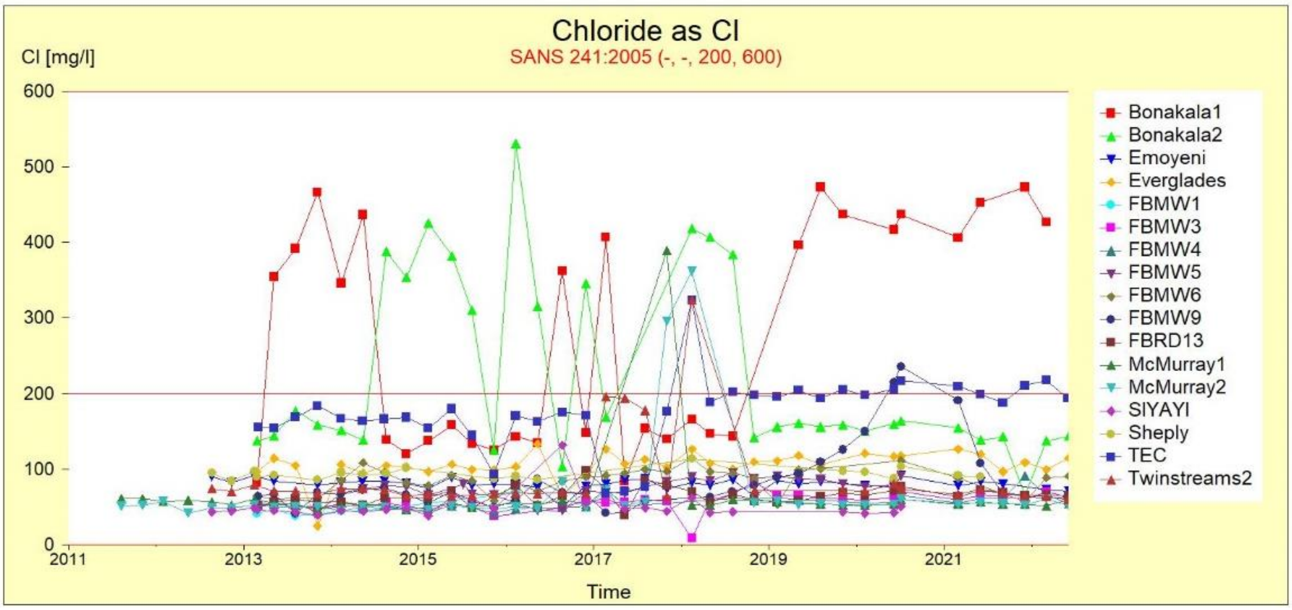

Figure 5-14: Chloride Concentrations at Monitoring Boreholes

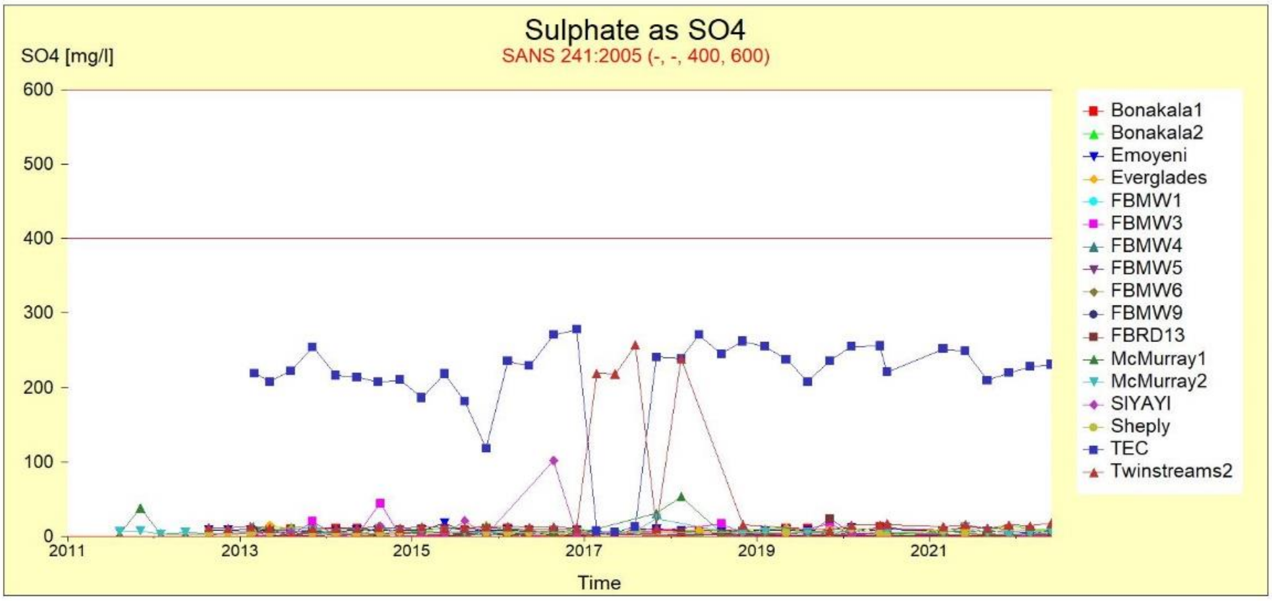

Figure 5-15: Sulfate Concentrations at Monitoring Boreholes

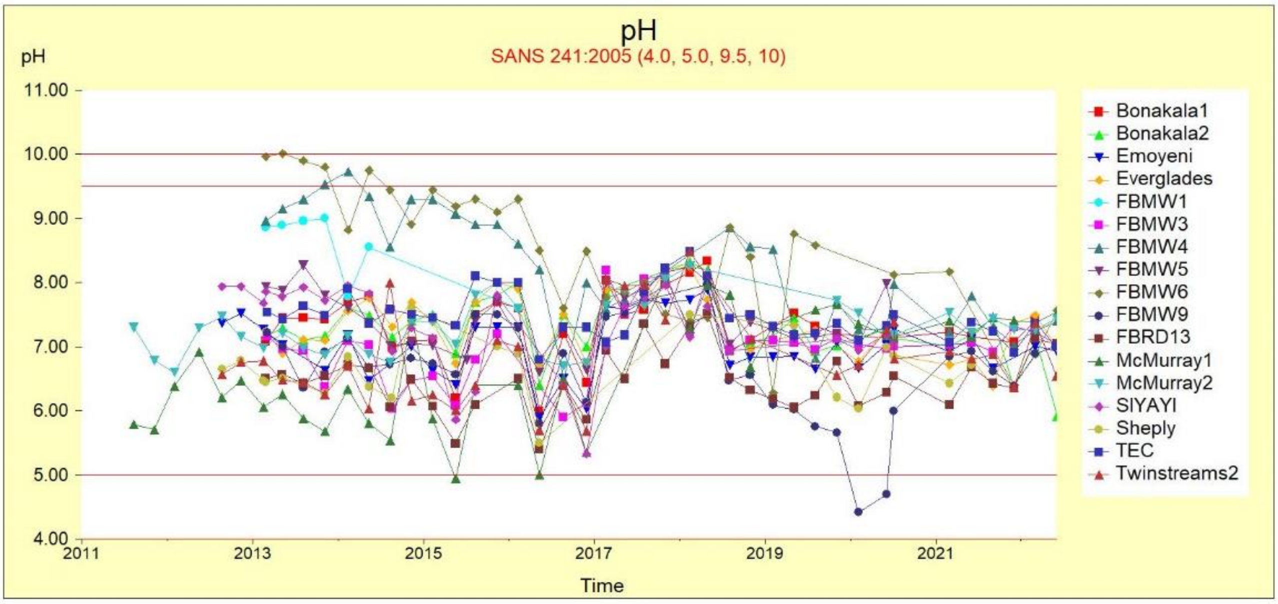

Figure 5-16: pH at Monitoring Boreholes

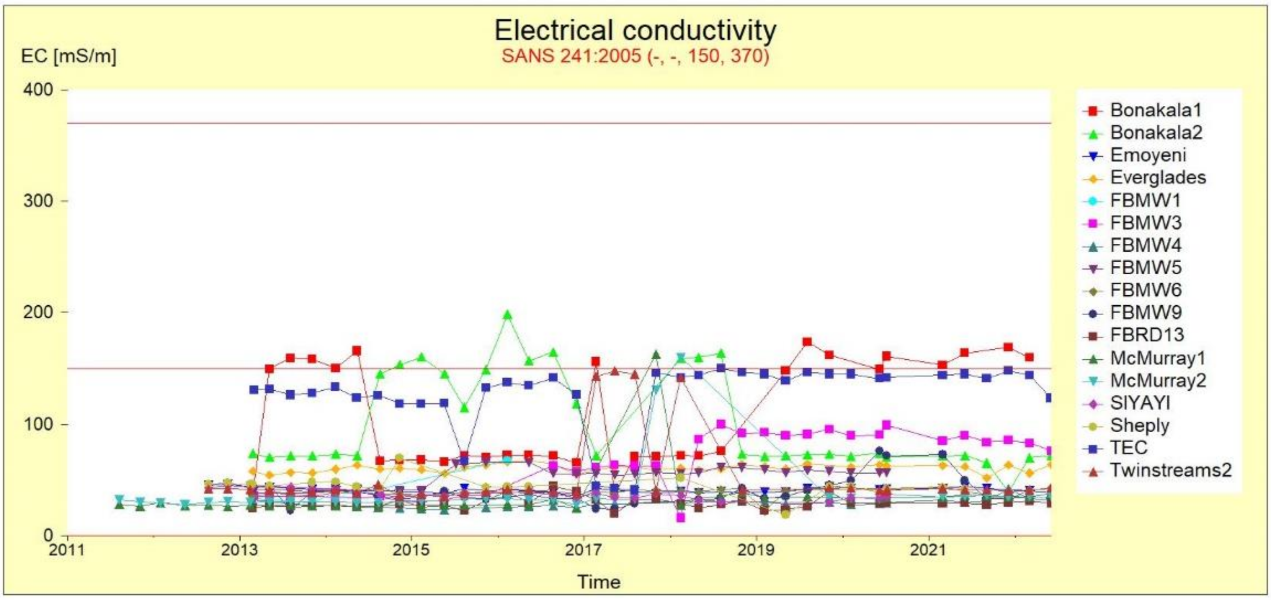

Figure 5-17: Electrical Conductivity at Monitoring Boreholes

5.11 Conclusions

- FBB and HM will extend to below the water table resulting in seepage and inflows into both pits. As FBB is backfilled seepage from there will report to HM. The inflows should be considered preliminary as the discretisation at HM is course and the model needs to be update with the latest lithological model. Inflows at FBB is anticipated to be 30 to 35 L/s and at HM at most 19 L/s.
- The inflows could be directed to the in-pit sump for use in mining operation or more active dewatering considered using in-pit trenches or ex-pit dewatering boreholes. However, at this stage further investigation and confirmation of model simulations is required before selecting an appropriate approach.
- Dewatering at the pits will result in drawdown around the pits but, is unlikely to impact significantly on neighbouring water supply boreholes. The Shepley Farm borehole is outside the significant zone of drawdown of 3 m, however monitoring of this borehole should continue as it is located close to the simulated zone of drawdown.
- Baseflow to the Amanzimyama could decline by approximately 25 m^3/d during the period when FBB and HM will be mined. The reduction in the groundwater baseflow, is relatively small in comparison to stormflow.
- Post rehabilitation the baseflow and the water levels will recover. Baseflow contributions is expect to be *c.* 120 m^3/d post closure and will be a function of recharge rates dictated in part by the final land use.
- Seepage seems to be contributing to an increased in water level at FBMW6, and is likely to be related to infrastructure at the plant, but needs to be investigation. No impact on the groundwater quality is noted and this is probably because the water quality within the PCD is of good quality and similar to the groundwater.

6 Monitoring

6.1 Monitoring in the Amanzimnyama and Siyaya Catchments

The gauging structures at the Amanzimnyama and Siyaya rivers have provided reasonable data, when properly maintained in the past (SRK discussions with DWS). In order to refine the understanding of surface water and groundwater interactions in the catchment, it is recommended that observations at these gauges be continued. It is advised that:

- The Siyaya and Amanzimnyama weirs have been surveyed in order to establish discharges during over-topping of the rectangular weirs. The resultant overtopping estimates have been concluded and added value to the record. However, since August 2013, the water level observations at the Siyaya weir have been deemed faulty.
- An independent pressure transducer logger could be established upstream of the weirs to provide an automated depth of flow measurement to estimate low flows which do not result in discharge through the weir (to be included with further discussion with DWS).
- Samples of rainfall, stream flow at the gauges as well as near-surface water and groundwater in the catchment be collected and analysed for stable isotopes of water (^{2}H and ^{18}O) and selected cations and anions in the UKZN Soil and Water laboratory. A time series of isotope samples will allow for distinction of groundwater (baseflow), interflow and event water contributions to the streamflow. This will enable an accurate representation of the surface water and groundwater interactions to be derived and simulated. This understanding will improve the prediction of the water balance and identification of ecologically sensitive areas during mining.

6.2 Groundwater Monitoring

6.2.1 Groundwater Level Monitoring

It is crucial to monitor water levels monthly, especially around the RSF and future mining area, ensuring good spatial and temporal coverage. Some piezometers located near the mining area are damaged, so it is necessary to protect the remaining ones that are situated outside of the mine. As several newer boreholes have been installed in recent years, a review and update of the monitoring program is required.

6.2.2 Groundwater Quality Monitoring

The program should continue on a quarterly basis so that any impacts form the mining can be detected and quantified. Given the Everglades RSF is in construction, seepage has occurred from various control dams and changes to mine plans were made, we recommend that a thorough review is done of the monitoring network and historical data. Dashboards to display and interpret data may also be useful.

7 Surface and Groundwater Interaction

While the surface water and groundwater models are independent simulations, each includes processes used in the other. The surface water model includes a detailed water balance of the runoff, vegetation and soil water dynamics but also includes a crude estimate of the release of accumulated water from a groundwater storage volume, in the form of baseflow to a stream. The groundwater model, on the other hand, includes an estimate of recharge fluxes from the surface, but simulates the groundwater flows below the phreatic surface in detailed response to geological materials and hydraulic gradients. The groundwater model also reports fluxes reaching a stream and these fluxes are also referred to as baseflow. Both models are corrected against observed data. In the case of the surface water model, simulated flows are compared to observed weir discharges, and in the case of the groundwater model, simulations are compared to observed groundwater levels in boreholes.

The lateral flow and groundwater processes in the Zululand coast have been the subject of much research (Kelbe and Germihuyse, 2010; Gundling *et al*., 2014). These processes have been considered in the set-up of each model (Chapter 3). It is therefore worth comparing the baseflows simulated by each of the models, to provide further confidence in the accuracy and robustness of the simulations.

The results of this comparison are shown in Figure 8-1. The groundwater generated baseflow, for the most part, reflects the low flows of the surface water simulation. The correlation of these low flows is considered adequate, considering the significant differences in the two models.

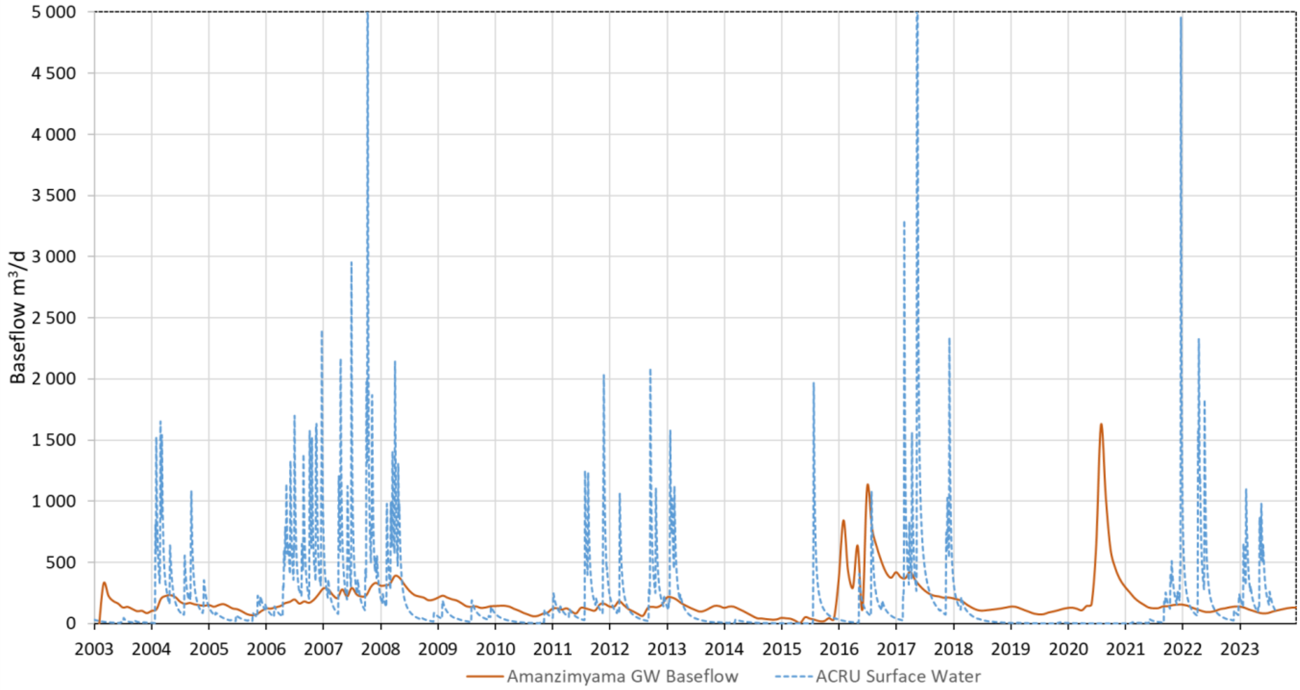

Figure 7-1: Groundwater baseflows compared to surface water simulation (2003-2023).

8 Recommendations

The mining of FBB and HM has a very minor effect on the streamflow of the Amanzimnyama and negligible effect at the Siyaya estuary. To better estimate the impact on the hydrological system, it is advisable to further enhance the understanding of the hydrological processes taking place in the FBB and HM regions, as well as to conduct additional surface water and groundwater simulations, after the suggested improvements.

Key improvement can be made by:

- Assessment of the impacts of the flow regime perturbations against the Reserve Determination, when this becomes available (anticipated for April 2024),
- Adoption of stable isotopes analysis to enhance the simulation of surface water and groundwater interaction,
- Updating the current numerical groundwater model with the current geological model, and
- Review the monitoring program to considering changes in mining, infrastructure, and observed groundwater changes.

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