V

McArthur River Mine

Overburden Management Project

Appendix V
Final Void Limnology Assessment Report

Draft Environmental Impact Statement

Report #3 to Glencore

MCARTHUR RIVER OPEN PIT: 3D HYDRODYNAMIC MODELING

RUN 04 – 20 YEARS ASSESSMENT

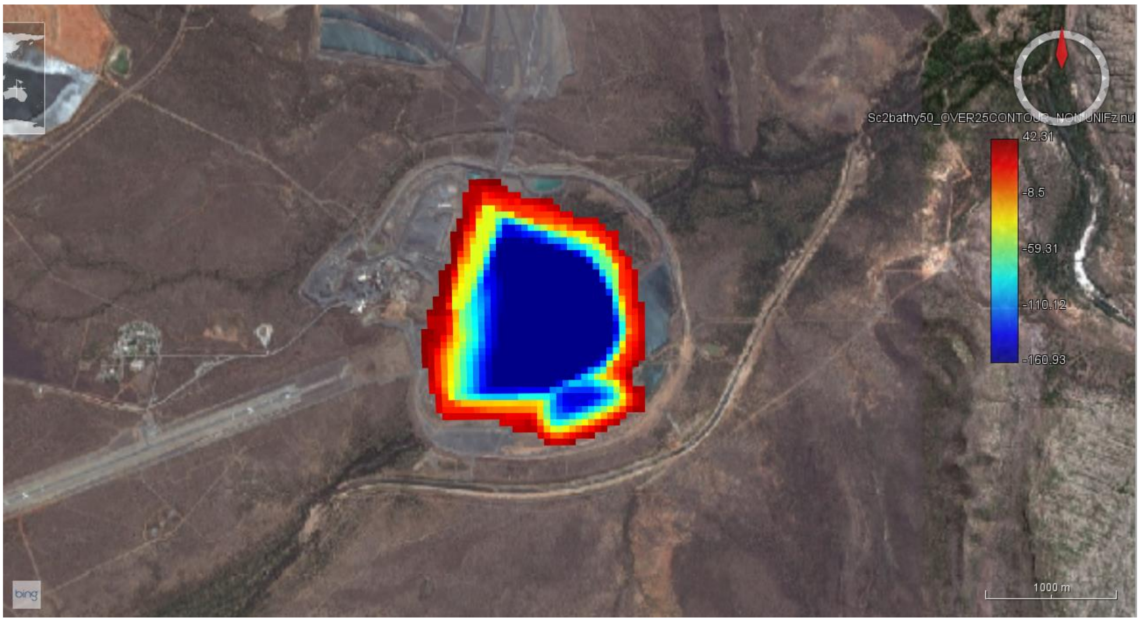

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Image on cover page: ELCOM bathymetry overlaid on Bing image in ARMS.

The authors would like to acknowledge Peter Yeates and Chris Dallimore from Hydronumerics for quality control of input data, assistance in water quality aspects of the model set up and providing computational capacity as well as discussion of results.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

AHD:	Australian Height Datum: reference datum for elevation, measured in metres
AREMI:	Australian Renewable Energy Mapping Infrastructure
BOM:	Bureau of Meteorology
EC:	Electrical Conductivity
GHI:	Global Horizontal Irradiance
NIR:	Near Infrared Radiation
PAR:	Photosynthetic Active Radiation
RPAF:	Reactive Potential Acid Forming
TWS:	Tropical Water Solutions Pty. Ltd.
MRM:	Mc Arthur River Mine
NT:	Northern Territory
SEA:	System Engineer Australia Pty. Ltd.
UVA, UVB:	Ultraviolet A and B Radiation

1. INTRODUCTION

The purpose of this study is to analyse McArthur River Mine (MRM) pit processes in the long term after closure.

The project consists of the development of a hydrodynamic pit lake model of the McArthur River Mine open cut pit. The aim is to investigate relevant hydrodynamic processes that would affect the long-term performance of the water quality such as stratification, vertical mixing and turbulence. For such purpose, a long-term simulation of 20 years was run starting from a filled void after operation ceased.

MATERIAL AND METHODS

A three-dimensional hydrodynamic model was built for the McArthur River open pit on the estimated shape expected after the closure stage. The focus of this modeling exercise is the temporal and spatial behaviour of temperature within the water body and understanding of dilution and concentration of proxy tracers over time.

The numerical model tool chosen was ELCOM (Estuary, Lake and Coastal Ocean Model). ELCOM applies hydrodynamic and thermodynamic models to simulate the temporal behaviour of stratifying water bodies with environmental forcing. The hydrodynamic simulation method solves the unsteady, viscous Navier-Stokes equations for incompressible flow using the hydrostatic assumption for pressure (Hodges B.R. & Dallimore C, 2015 a, b). ELCOM was developed by the Centre for Water Research (CWR) at The University of Western Australia, and has been applied globally in numerous and varied aquatic and coastal environments.

1.1 Input data

Meteorological data to force hydrodynamics is best ideally in time steps of one hour or less. The Input data used to force ELCOM are summarised in Table 1.

Table 1: Summary of the data used to force ELCOM.

Location	Data type	Time Step	Data Source	Period	Units
Bathymetry					
Mc Arthur River Mine	xyz	-	Glencore	-	m (AHD)
Meteorological Data					
Mc Arthur River Airport Station	Air Temperature	9 am and 3 pm	BOM	1976-1996	°C
Mc Arthur River Airport Station	Rainfall	daily	BOM	1976-1996	m
Mc Arthur River Airport Station	Wind Speed	9 am and 3 pm	BOM	1976-1996	m/s
Cyclone Modelled data	Wind Speed	30 min average	SEA	March 1984	m/s
Mc Arthur River Airport Station	Wind Direction	9 am and 3 pm	BOM	1976-1996	degrees true north
Cyclone Modelled data	Wind Direction	30 min average	SEA	March 1984	degrees true north
Mc Arthur River Airport Station	Relative Humidity	9 am and 3 pm	BOM	1976-1996	-
Mc Arthur River Airport Station	Cloud Cover	9 am and 3 pm	BOM	1976-1996	-
Darwin Airport Station	GHI	1 hour average	AREMI	2014-2015 looped	Wm^{-2}
Boundary Conditions					
MRM modelled surface water	Local catchment	daily	WRM	1950-1970	m^3s^{-1}
MRM modelled surface water	McArthur River flow	daily	WRM	1960-1970	m^3s^{-1}

1.1.1 Configuration and initial conditions

The Model was run for 20 years, starting in April 2050. The simulation includes three tracers, one for each of the inflows (local catchment and river inflows) and one that represents a proxy (in this case Zn and SO4) that is release from the tailing (Table 2). No tracer was assigned to the receiving water at the start of the simulation.

Table 2: Summary of ELCOM configuration

Description	Setting
Simulation period	April 2050 – Dec 2069
Computational time step	60 seconds
Albedo	0.08
PAR extinction coefficient	0.4
NIR extinction coefficient	1.0
UVA extinction coefficient	1.0
UVB extinction coefficient	1.0
Sediment release tracer	0.5 mg/m2/day
River Inflow tracer	1 mg/L
Local Catchment tracer	1 mg/L
Initial water level	15m AHD
Initial salinity	0.33 PSU

Initial conditions of the thermal structure in the void were extracted from previos ELCOM hindcasted result run by TWS for MRM. Extraction point was (21,21) of the grid (located within the deepest area) and the extraction date was 01/04/1984.

Figure 1 displays the initial water temperature profile with which the simulation was started.

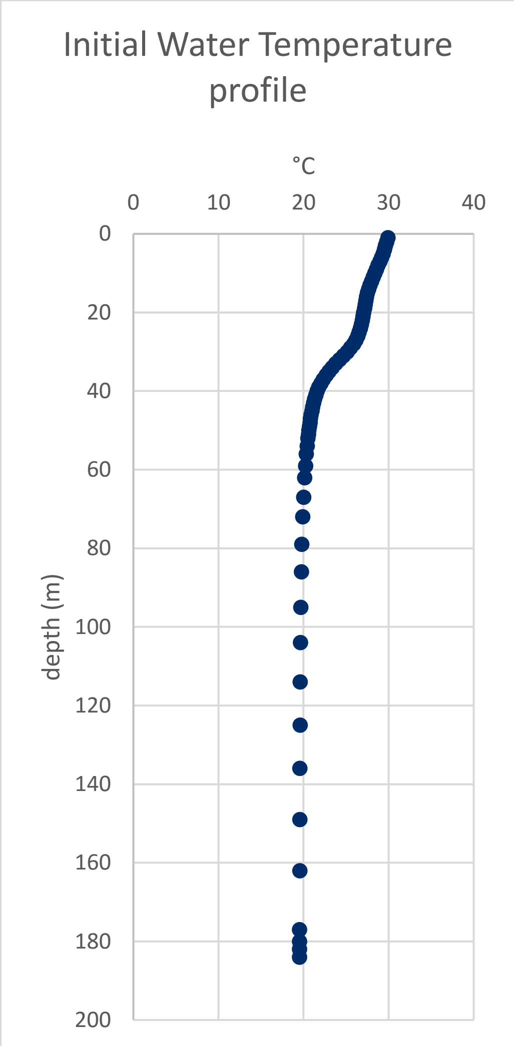

Figure 1: Initial Water Temperature profile.

1.1.2 Bathymetry

Bathymetric data was provided by Tyson Lavender (Glencore) in the form of a 'xyz' topography file of the estimated pit contours by the closure time. The provided topography was modified to define the tailing at approximately a maximum height of -167 m AHD, giving a maximum depth of 209.77 m. A three-dimensional computational domain was set-up with the above-mentioned bathymetric data set. The grid has a lateral resolution of 100 x 100 m and a non-uniform vertical resolution that varies progressively with depth, forming a total of 73 layers.

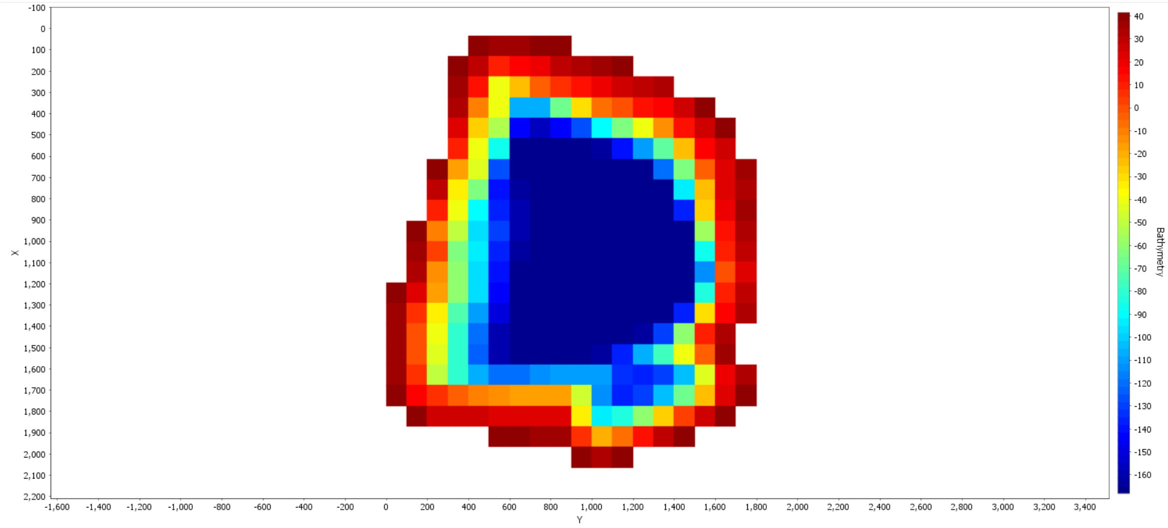

Figure 2: Final Bathymetry for MRM. Horizontal resolution is 100 m * 100 m. Legend in m (AHD).

1.1.3 Meteorological data

The closest meteorological station to the study area was Mc Arthur River Airport Station (BoM station 014704) where the following environmental forces were extracted: Air Temperature, Cloud Cover, Humidity fraction, Wind Speed, Wind Direction and Rainfall for the period 1976 to 2006. All variables were available in a frequency of two measurements per day (9am and 3 pm) except for Rainfall which had been recorded in the 24 hours before 9 am. Global Horizontal Irradiance (GHI) was obtained from Darwin Airport Station (014015), as station 014704 did not have suitable GHI data to force ELCOM. Measured solar data has been reported only from 2003. Since this data is known for having several gaps and needing extensive processing, due to the time restraints a decision was made to extract and process years 2013-2014 and loop it to cover the 10 years run.

An extreme weather event took place during the data period used for this simulation. In 1984 Tropical Cyclone Kathy passed Borroloola on March 23rd. Higher resolution modelled wind data of 30 minute time steps was inserted into the twice daily BoM data to better represent the atmospheric situation from 21/03/1984 to 23/03/1984 (included). This cyclone model data was provided by System Engineer Australia Pty. Ltd (Bruce Harper). In order to maximise the extremity of the event, wind data used to represent the cyclone was the one calculated for Borroloola, instead of the intensity at MRM. In this way, the simulation represents a cyclone blowing right over the surface of the void.

The input data described above, period 1973 to 2006, is displayed in Figure 3 with the dates converted to the modelled period, 2050-2070. Note that after converting dates, Cyclone Kathy drops in March 2058, which is easily identifiable by the approx. 29 m/s peak shown in the wind data on the 23/03/2058.

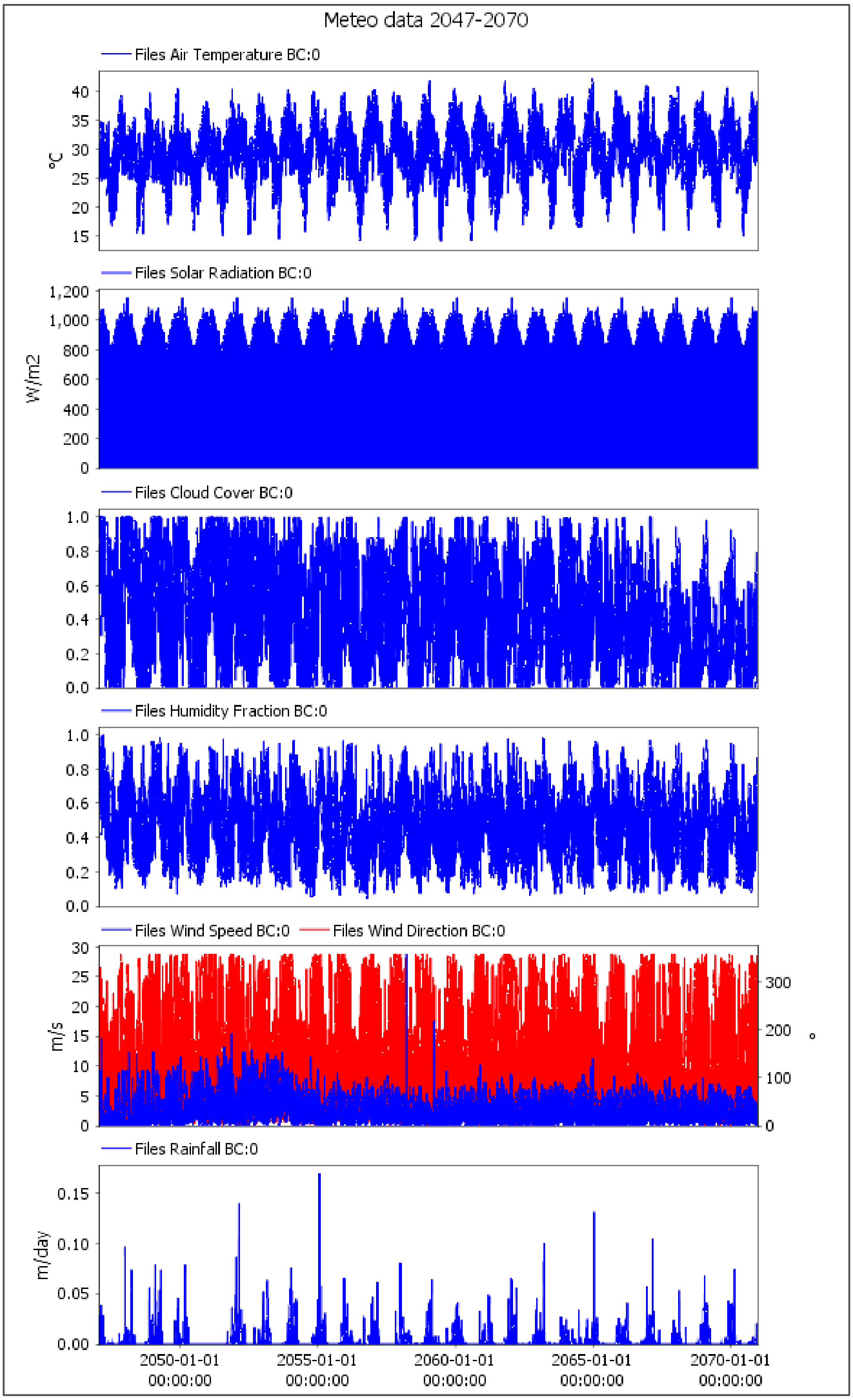

Figure 3: Input meteorological data for ELCOM model of McArthur River open pit run 04. From top to bottom: Air Temperature, Solar Radiation, Cloud Cover, Humidity Fraction, Wind Speed, Wind Direction and Rainfall.

1.1.4 Boundary conditions

Flow forces consisted of modelled flow rate data provided by WRN which were based on the same data period used for the weather data detailed in section 1.1.3.

Inflow water temperature was estimated from air temperature data obtained from BoM. Water temperature is expected to be on average lower and less variable than air temperature (specific heat). Based on this, a moving average was applied to air temperature records with the purpose of smoothing and lowering the profile.

As for inflow salinity, it was defined as constant at 0.33 PSU, based on an average calculated on 2014 McArthur river water quality data obtained from the NT Government website for MRM Upstream Gauging Station. EC was provided by Klohn, but conversion to PSU was not done due to the fact that such conversion depends on temperature and ion species present in the water, information we don't have. Since in the studied ecosystem, density is believed to be driven mainly by temperature, assuming a constant salinity in the inflowing water is considered an acceptable assumption.

Figure 4 displays the modelled inflow input data used for run 04.

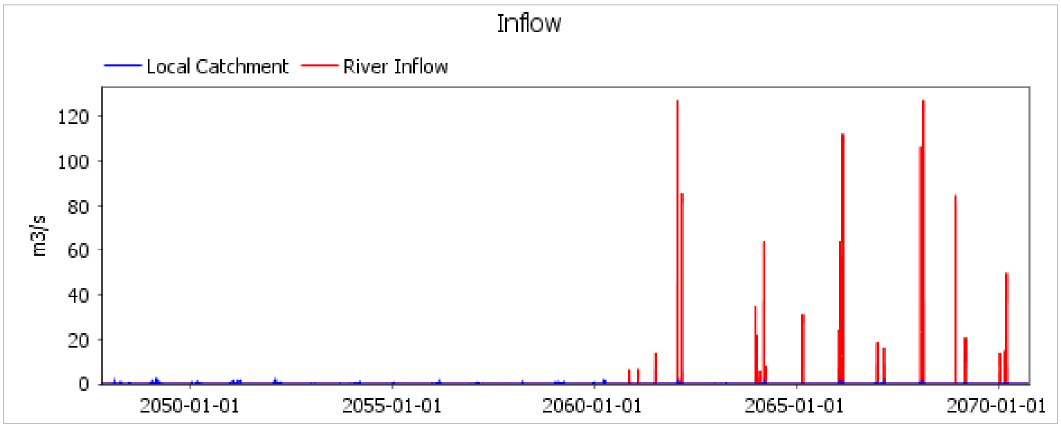

Figure 4: Modelled Inflow data input to ELCOM. Local catchment (blue line). River inflow (red line). Source: WRM.

The inflows include separate tracers added to the catchment, and river surface flows with an arbitrary concentration of 1 mg/L. This gives an indication of the portion of water in the void that comes from each of the different sources.

Sediment tracer release from the bottom of all cells beneath – 30 m AHD at an arbitrary rate of 0.5 mg/m2/day (a cumulative rate of 0.864 kg/day) was defined to represent the evolution of pollutant concentration in the water body.

2. MODEL OUTPUTS

2.1 Overview

The variables selected as Output of the 3D ELCOM configuration were:

- Water temperature
- Water age
- Sediment release tracer
- River tracer
- Local Catchment tracer

Figure 5 shows locations of 1D (grey dot) and 2D (red line) output locations in the ELCOM bathymetry map. 2D-Outputs are in the form of a Curtain that extends from the upstream to downstream levees.

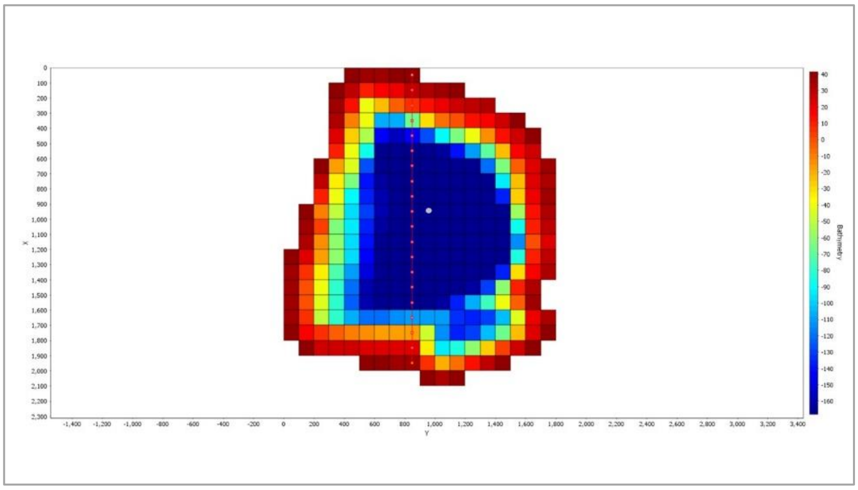

Figure 5: Bathymetry showing output locations exported as ELCOM results for run 04. The red line shows the location of the 2D Curtain and the grey dot indicates the location of the 1D profile extraction. Bathymetry legend in m (AHD).

2.2 Results

For the purpose of interpretation of these results, it is important to understand that the concentration of tracers have no 'real-world' meaning. i.e. they provide information about dilutions of different inputs but the absolute numbers are meaningless unless they have been assigned known concentration of a selected conservative input scalar at the boundaries. For this study a constant tracer value of 1 has been used, so that the simulated concentration of the tracer is equal to dilution of water volume. The tracer results can then be scaled to represent the concentration of any conservative scalar that is entering the water body.

Notice that an inflow tracer concentration of 0.1 means that 10% of the water is sourced from the traced inflow (or alternatively a dilution of the inflow of 1:10) at any time during the simulation (i.e. the tracer is cumulative unless flushed from the void during outflow). The tracer concentrations therefore need to be considered in the context of the water age to interpret the effects of the inflows on the chemistry of the release water (which will change over time as the water sits in the void). For example, prior to the large flow event of 2066 there is a standing stock of surface water with a river tracer concentration of 0.4 that is attributable to previous river inflows. The average age of this water is 4000 days; therefore, despite that 40% of the surface water was originally derived from the river, it has on average been in-situ for a period of time that would allow significant chemical change. Immediately after the event the concentration of river water tracer in the surface increases quickly to 0.9 due to the inflow of new river water. This is equivalent to mixing 4 parts new river water to 1 part of standing surface water. As result, the age of the surface water reduced from 4000 days to 1000 days. As time passed after the event, overall increase in water age and mixing with older bottom waters corrects the average water age.

In summary, tracer on inflows (referred as *Local catchment* and *River inflow* in Figure 6) are to be use as an indication of the portion of water in the void that comes from different sources and not as a measure of concentration of a contaminant. Conversely, the tracer released from the wells and tailing (referred as *Sediment Release* in figure 6 and as *Tracer 4* in figure 7) indicates the concentration of a proxy (in this case Zn and SO4) in the water.

Figure 6 below provides summary of results over time from a profile point in the centre of the void.

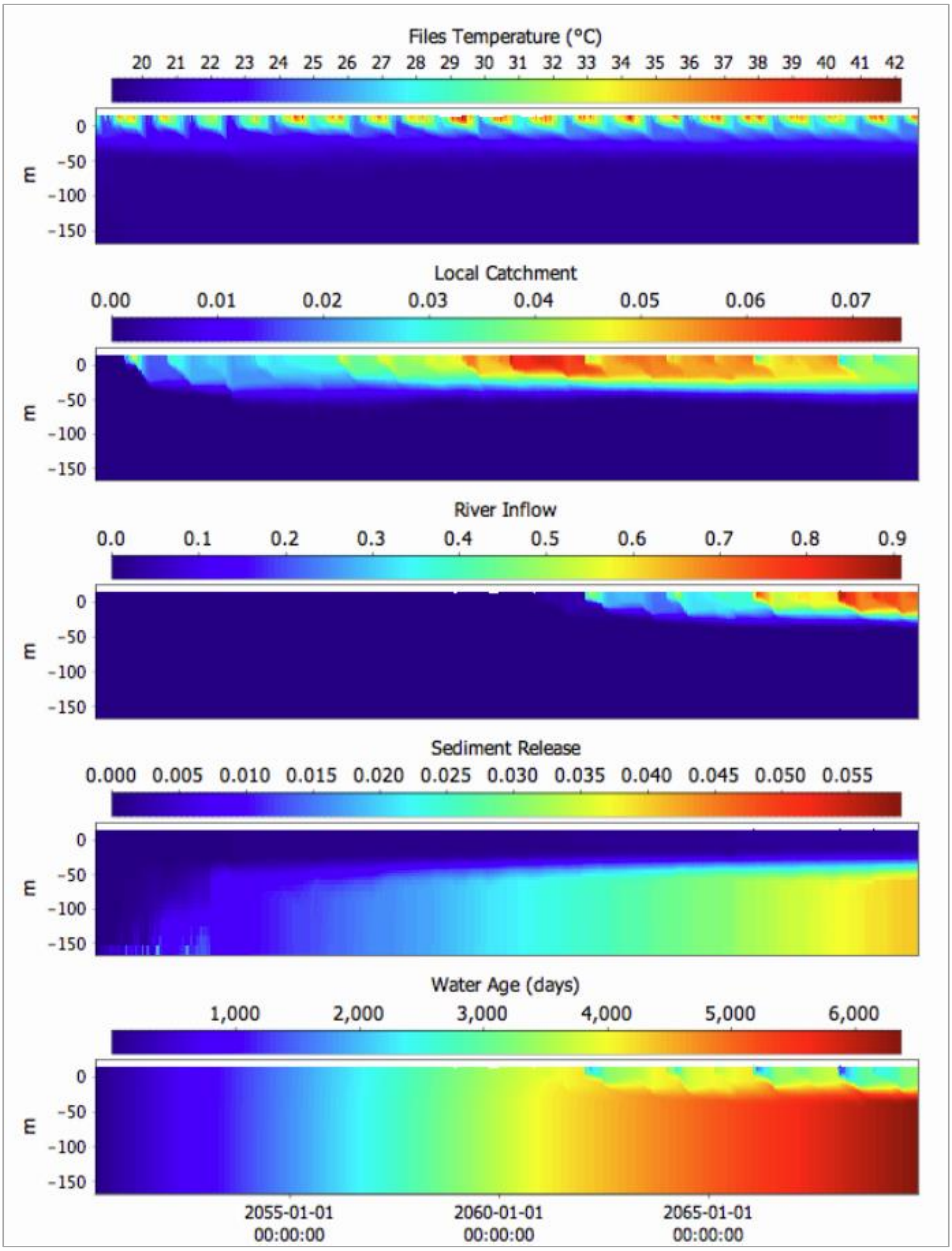

Figure 6: Simulation results from the middle of the void; (in the order) temperature, tracer from local catchment flow, tracer from river inflow, tracer from sediment release and water age.

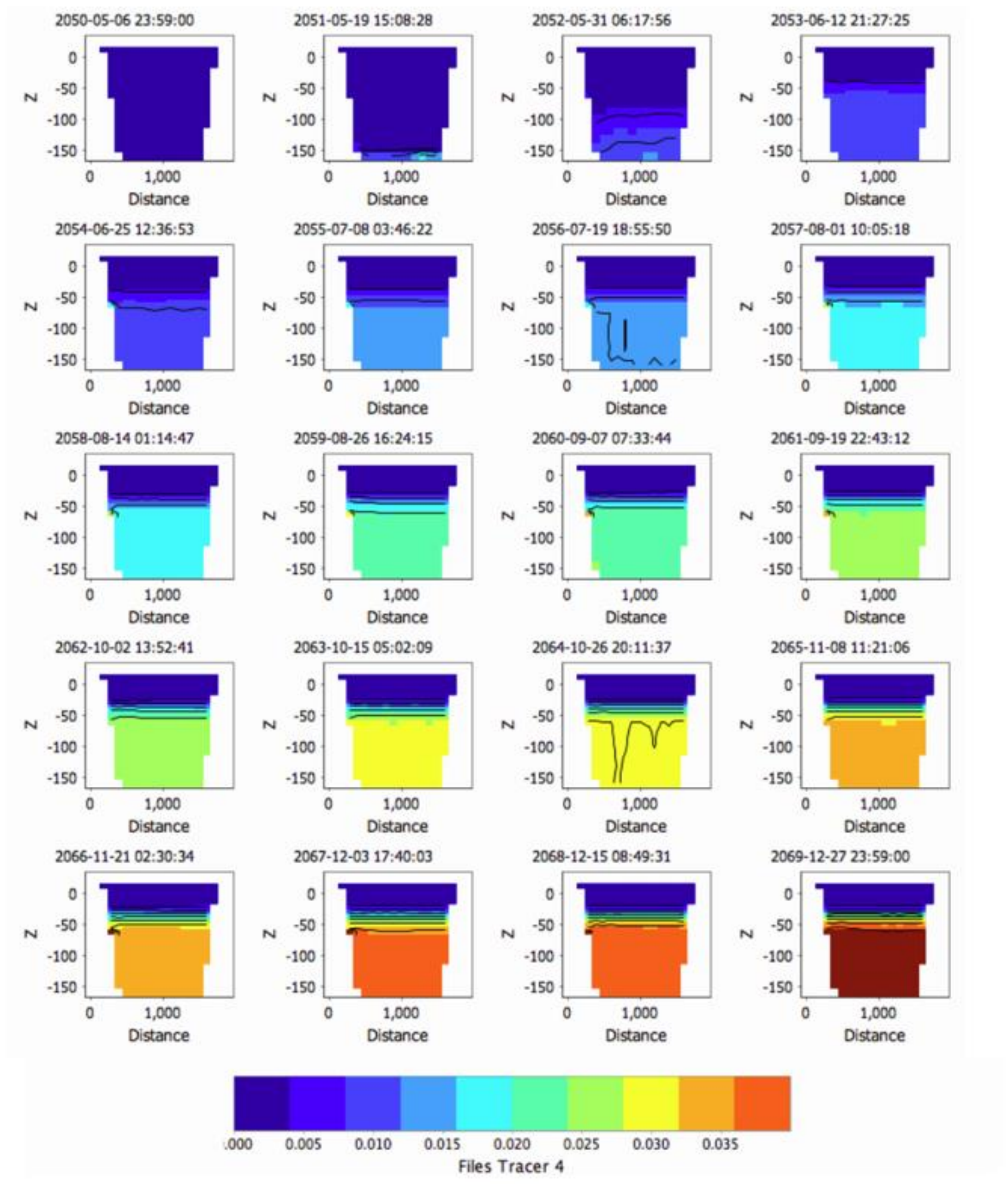

Figure 7: Evolution of the chemocline (illustrated using the sediment release tracer – Tracer 4) over the 20-year simulation period.

Figure 8 provides a summary of the surface and outlet release tracer concentrations.

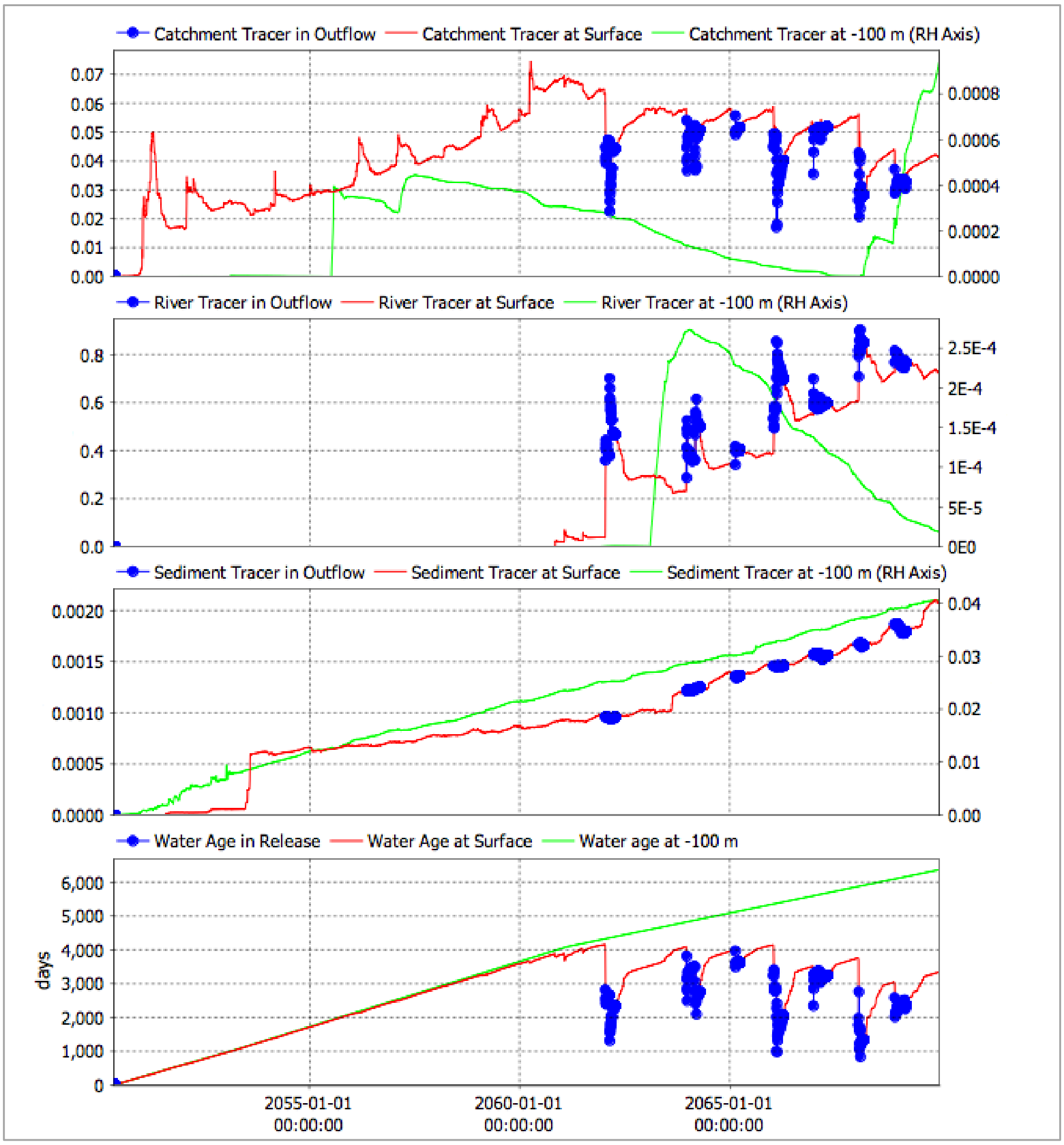

Figure 8: Dilution of each tracer and the water age at the surface, in the release water and at -100 m AHD.

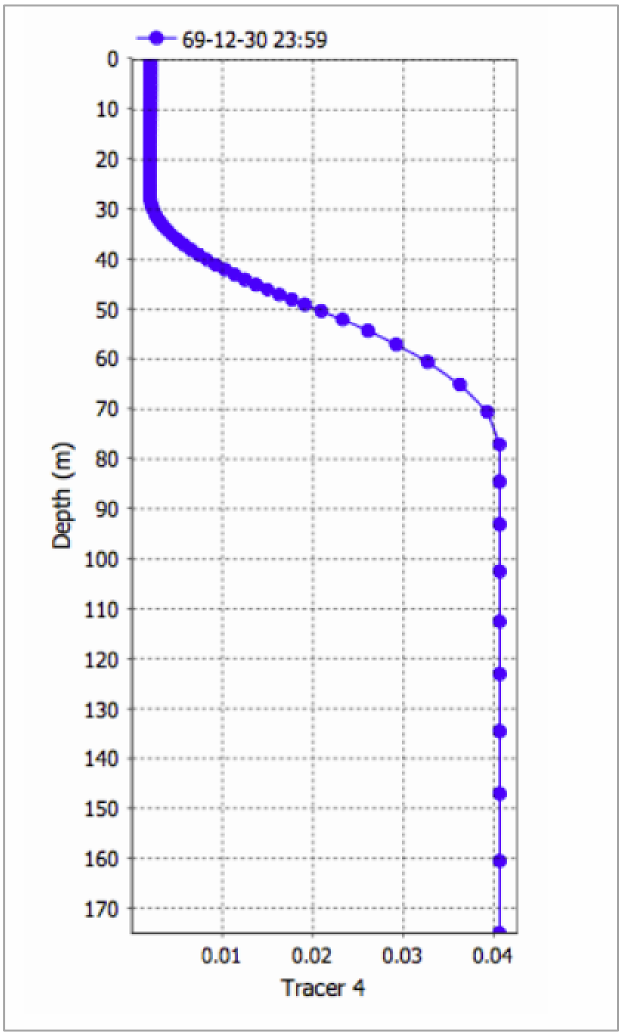

Figure 9: Profile of sediment release tracer at the end of the simulation period.

2.3 Discussion

The results presented in this report give an overview of the hydrodynamic forces, dilutions and proxy tracer concentration processes that take place over a period of 20 (twenty) years in an open pit subjected to the climate forces recorded in MRM and Darwin Airport (Solar Radiation only) after operations have ceased and the void has been filled with water up to 15 m (AHD).

In summary, the results show that there is very limited mixing below 50 m depth and therefore the sediment release tracer (a proxy for SO4 and Zn released from the inundated tailings) continues to fill the lower waters of the void without any significant periods of flushing. In contrast when the river flows begin, the epilimnion is readily flushed by the river waters as shown in the last panel (Water Age) of Figure 6. Looking closely at the sediment release tracer in the epilimnion it is notable that whilst there is a gradual increase in concentration over time (caused by constant but low level release and mixing and being about one order of magnitude less in concentration compared to the hypolimnion) there are also periods of more intense mixing that bring the sediment release material into the surface waters.

3. REFERENCES

Hodges BR & Dallimore C (2015a): Estuary, Lake and Coastal Ocean Model: ELCOM, v3.0 User Manual.

Hodges BR & Dallimore C (2015b): Estuary, Lake and Coastal Ocean Model: ELCOM, v2.2 Science Manual.