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Seven Mile Creek 2-D Modelling

1 Background

As part of the proposed expansion of the 4 East Pit (4E Expansion -4EE), an additional ~160m of the orebody needs to be dewatered. Dewatering of the Wittenoom formation will also be required to as part of depressurisation of the Mount McRae shale. Drawdown from the dewatering is expected to potentially impact riparian vegetation located along Seven Mile Creek (SMC) and has been identified as a risk. Ecohydrogeological studies are required to further investigate and quantify the potential impacts to the riparian vegetation.

The purpose of this modelling is to estimate the extent of drawdown within the Shallow Alluvial aquifer which will inform water levels for subsequent ecohydrogeological studies.

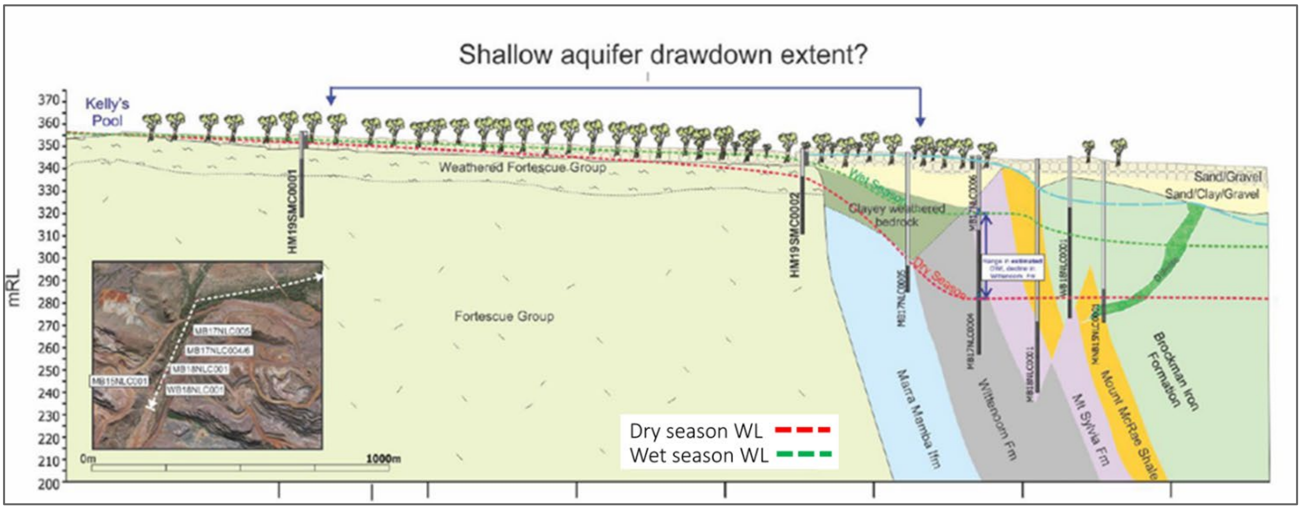

Figure 1 Hydrogeological cross section along Seven Mile Creek, illustrating wet and dry season groundwater levels. Hydrographs illustrating the influence of low permeability layers creating “buckets” which fill and over top during the wet season

2 Hydrogeology

The interaction between surface water in Seven Mile Creek and the underlying and adjacent groundwater hosted within fractured bedrock has an important bearing on the water balance of the riparian vegetation.

The groundwater area to be modelled area is defined by where the Seven Mile Creek approaches and passes through a narrow (200m wide) gorge incised through the Paraburdoo Range adjacent to the 4 East mining area. Leakage from the creek alluvial aquifer to the underlying and adjacent fractured rock aquifers occurs, before the creek exits on the opposite side of the range.

Groundwater abstraction from the mineralised Brockman Iron Formation orebody aquifer (FRA/MIN BRK aquifer) to enable below water table (BWT) mining of the current 4East mining pit has occurred since 2001. Abstraction from the Wittenoom formation will be required as part of depressurisation of the Mount McRae shale. Varied groundwater level response has been observed across different stratigraphic units enabling the development of a hydrogeological conceptual model, including the identification of aquifers and aquitards, as detailed below:

Table 1 Summary of hydrogeological characteristics.

Geology	Hydrogeology Reference	Hydrogeology Characteristics	Description
Seven Mile Creek alluvial aquifer	***SMC Aquifer***	Shallow aquifer	A thin (up to 30m thick) sedimentary aquifer comprising varying sands, gravels and clays located within the active channel and flood plain of Seven Mile Creek. Overlies and is in hydraulic connection with bedrock fractured rock aquifers.
Weeli Wolli Formation	***WW***	Low permeability Low storage	A succession of jasperlite, shale and dolerite sills, that lie to the south of the study area. The jasperlite is more resistant than the shale and dolerite, resulting in a series of parallel ridges and troughs. Although not tested within the Paraburdoo region, the Weeli Wolli Formation is known to have relatively low permeability with low groundwater storage.
Brockman Iron Formation	***FRA/MIN BRK aquifer***	Fractured and mineralised rock aquifer	The 4 East deposit is hosted within the Brockman Iron Formation. Groundwater is predominantly associated with secondary porosity developed through mineralisation within the Joffre and Dales Gorge Members.
Mount McRae Shale/Mount Sylvia Formation	**MCS/MTS**	Aquitard	South of the FRA WF aquifer lies the Mount McRae Shale and the Mount Sylvia Formation. The shale bands are characteristically ***low*** permeability and often act as an aquitard. Abstraction within the FRA/MIN BRK aquifer has had minimal drawdown within the FRA WF aquifer.
Wittenoom Formation	***FRA WF aquifer***	Fractured rock aquifer	A thick succession of chert, shale and dolomite that lies to the north of the 4 East deposit. Groundwater is associated with secondary porosity associated with

Geology	Hydrogeology Reference	Hydrogeology Characteristics	Description
			faulting/fractures and subsequent karstic dissolution predominantly within the Paraburdoo Member.
Marra Mamba Iron Formation	***MMIF***	Low permeability	A low permeability thickness of un-mineralised Banded Iron Formation, limited hydrogeological information exists for this formation in the Paraburdoo area.
		Low storage	
Fortescue Group	***FOR***	Low permeability	The Jeerinah Formation hosts interbedded chert, shale, dolomite and a high density of intruded dolerite sills (up to 50% of the formation). It lies both conformably to the north of 4 East underlying Seven Mile Creek, and on the east of the deposit where the 18-East fault brings it into contact with the Brockman Iron Formation. The formation is characteristically very low in permeability and storage.

Low permeability shale bands and weathered dolerite sills and dykes result in aquifer compartmentalisation resulting in discrete units of high permeability separated by hydraulic barriers. This is most evident beneath Seven Mile Creek, where each discrete unit acts as “buckets” which successively fill and overflow into the next bucket (Figure 1), during creek flooding events. These buckets then recede as groundwater seeps into adjacent aquifers.

3 Model setup

2D (cross-section) numerical simulations were conducted using the HYDRUS (2D/3D) software to examine the extent of drawdown propagation within the alluvial aquifer along the SMC as a result of dewatering in the Wittenoom Formation. The HYDRUS (2D/3D) software package (Šimůnek et al., 2011) was used to allow the simulation of water level dynamics in the vadose and groundwater zones, by numerically solving the Richards equation. Figure 2 shows a schematic of the simulation domain and boundary conditions. This 2D cross-sectional domain was adapted to be consistent with the current conceptualisation of the site. The model extends 2km covering the area where the SMC approaches and passes through a narrow (200 m wide) gorge incised through the Paraburdoo Range adjacent to the 4 East mining area (Figure 1).

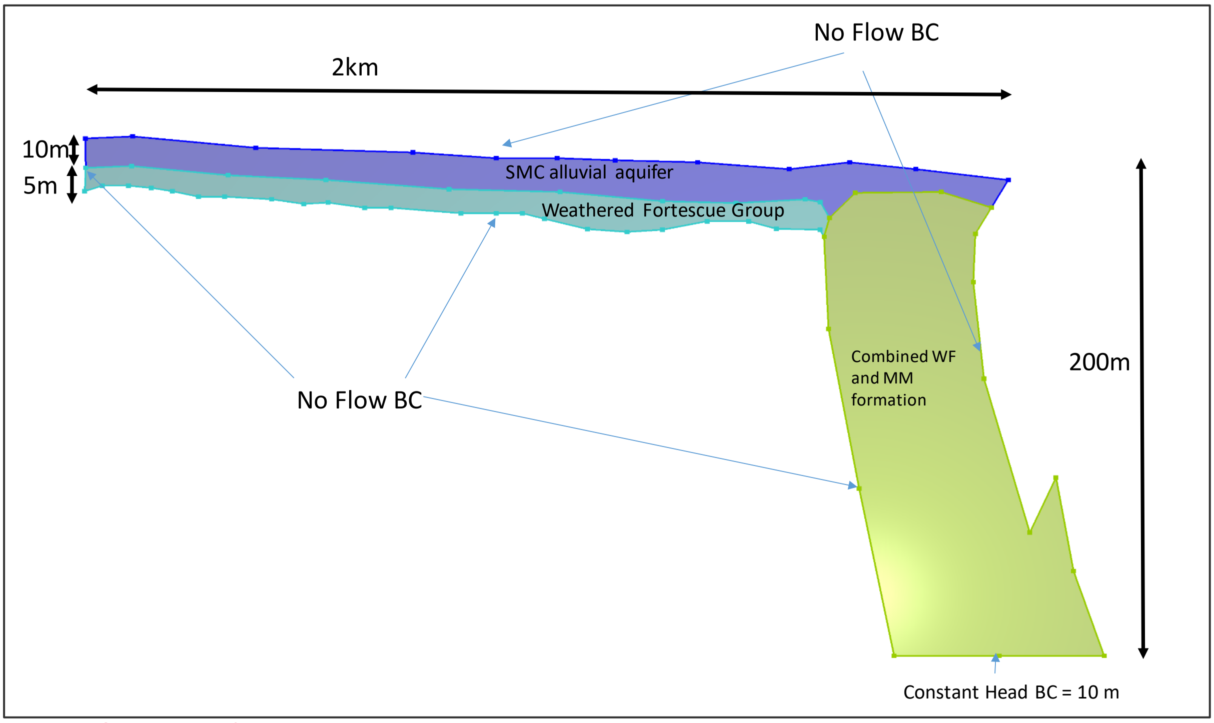

Figure 2 Schematic of the simulation domain and boundary conditions

3.1 Model Initial and Boundary Conditions

The initial condition was specified in terms of the water pressure and was set to a constant pressure of −0.05 m for the entire flow domain. This pressure head was lower than the air-entry value of the soils considered in the simulations as such the flow domain was initially fully saturated. The nodes along the bottom boundary (at the deepest part of the Wittenoom formation) were assigned a constant pressure boundary condition of 10 m which represented a total drawdown of 190 m within the Wittenoom Formation. A no-flux boundary condition was assigned to all other boundaries (e.g. upper, right, left and bottom right sides) of the flow domain. Therefore, the simulations considered that the domain was initially fully saturated, and then allowed for the water level at the Wittenoom Formation to fall over time to a selected depth (10 m above the boundary) as a result of dewatering. It should be noted that these boundary conditions were selected to represent a worst-case scenario for the evaluation of dewatering impact on the water-level along the SMC. The simulations were run for a period of 365 days which was found to be sufficient for the water level in the system to reach steady-state conditions.

The simulation domain was discretised into a two dimensional triangular finite element mesh (76,000 elements) using the MESHGEN tool available within HYDRUS (2D/3D). To reduce the mass balance error, the finite element mesh was adjusted such that the size of elements was smaller than 0.1 m. The optimal mesh resolution was determined by starting from a smaller number of elements and doubling the number until the water content changes from two consecutive meshes were found to be within a few percent (1-3%).

3.2 Scenarios

The model domain was divided into the following three zones where soil hydraulic parameters in each zone were constant:

- Shallow Aquifer (alluvial) along the SMC
- Underlying weathered Fortescue bedrock
- Combined Wittenoom Formation and Marra Mamba Iron Formation

Key parameter values for soil properties (e.g., saturated hydraulic conductivity, Ks; saturated water content or porosity, θs; the pore-size distribution parameter in the soil-water retention function, n) were taken from the HYDRUS (2D/3D) Soil Catalog. The van Genuchten hydraulic parameters for selected soil textures were also taken from the HYDRUS (2D/3D) soil Catalog. The soil hydraulic parameters of each zone were assigned different values as summarised in Table 1. Sequential numerical experiments (4 Scenarios) were then conducted to examine the effect of various hydraulic properties of each formation on the propagation of dewatering along the SMC aquifer.

Table 2 Parameters assigned for the modelling scenarios

Scenario	Formation	Hydraulic Properties				Sediment textural Description
		Porosity	A (1/m)	n	Ks (1/m)	
1	SMC	0.35	1.5	1.5	0.2	Loamy Sand, low Ks
	Weathered FOR	0.35	7.5	1.89	7.5	Fractured aquifer represented as coarse sand
	WF-MMIF	0.35	1.5	1.5	0.2	Loamy Sand
2	SMC	0.35	7.5	1.89	1	Sand, higher Ks
	Weathered FOR	0.35	14.5	2.68	7	Fractured aquifer represented as coarse sand
	WF-MMIF	0.35	0.5	5	0.5	Silty Clay Loam, fine sediment, higher Ks
3	SMC	0.35	7.5	1.89	1	Sand, higher Ks
	Weathered FOR	0.35	14.5	2.68	7	Fractured aquifer represented as coarse sand
	WF-MMIF	0.35	0.9	3.5	0.5	Silty Clay Loam, coarser sediment, higher Ks
4	SMC	0.35	7.5	1.89	1	Sand, higher Ks
	Weathered FOR	0.35	14.5	2.68	7	Fractured aquifer represented as coarse sand
	WF-MMIF	0.35	2.6	1.89	0.25	Loam, fine sediment, Lower Ks

4 Results

To assess the extent of drawdown within the SMC Aquifer induced by dewatering in the Wittenoom Formation, four numerical simulations were conducted in which the soil physical properties of each formation were systematically varied. Figure 3 shows the drawdown evolution for select time periods obtained from the simulation conducted for the Scenario 1. The saturated zone is indicated with red colour in this figure. It is observed that initially the two aquifers were hydraulically connected and the water level drawdown was proportionally propagated within the SMC Aquifer. However, the relationship between the SMC and Wittenoom Formation evolved from hydraulically connected to disconnected when dewatering in the Wittenoom Formation progressed creating an unsaturated condition in soils near the intersection of SMC and Wittenoom Formation. It is illustrated that the SMC aquifer started to hydraulically separate from the Wittenoom Formation Aquifer toward the end of simulation period. Therefore, when the SMC aquifer was disconnected from the adjacent aquifer, the rate of water level decline within the alluvial aquifer along the SMC decreased and finally reached a steady state condition (Figure 4).

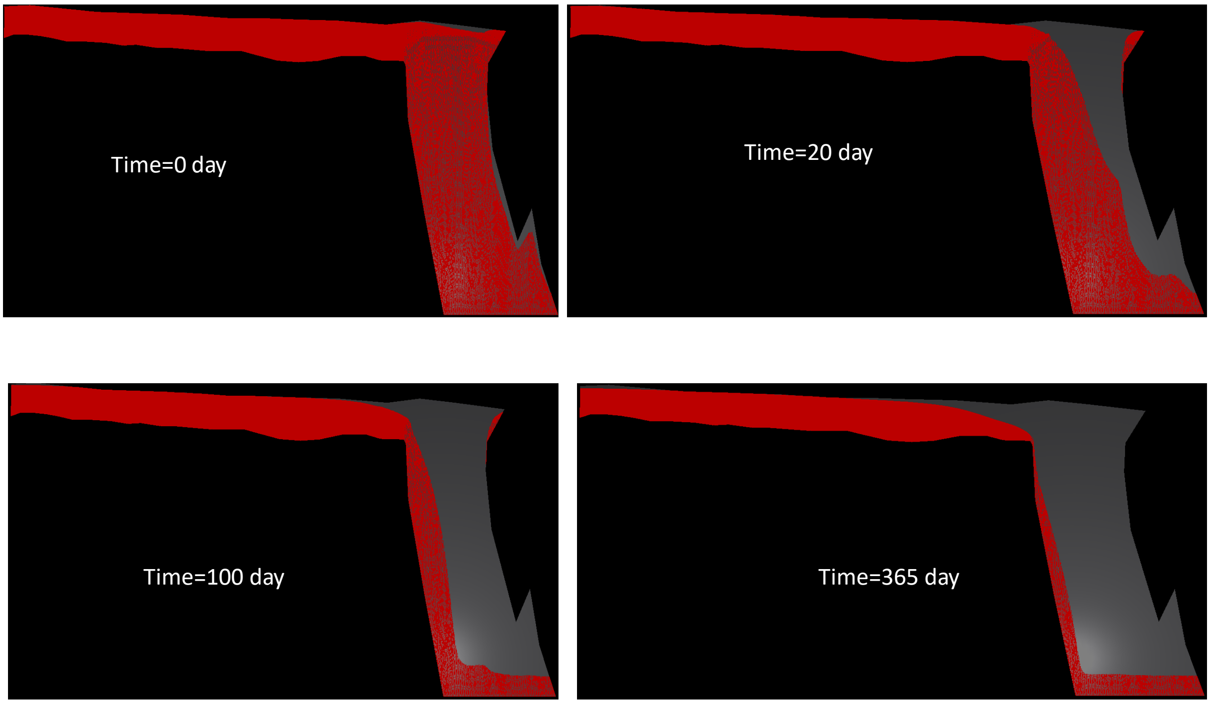

Figure 3 Response of groundwater level to dewatering in the Wittenoom Formation, Red colour indicates the saturated zone.

Figure 4 shows that the magnitude of drawdown along the SMC Aquifer for Scenario 1 at various simulation times. It is observed that the extent of water-level decline within the SMC aquifer as a result of dewatering in the Wittenoom formation is limited to a few hundred metres upstream of the gorge incised through the Paraburdoo Range adjacent to the 4 East mining area. Note that zero distance in this figure and subsequent figures refers to the location of the monitoring bore of HM19SMC0002 which is located approximately 200m upstream of the 4 East mining area (see Figure 1). For Scenario 1, predicted drawdown greater than 2m extended only about 500 m to the north of reference point (HM19SMC0002) at the end of simulation period of1 year (Figure 4 and Figure 5)

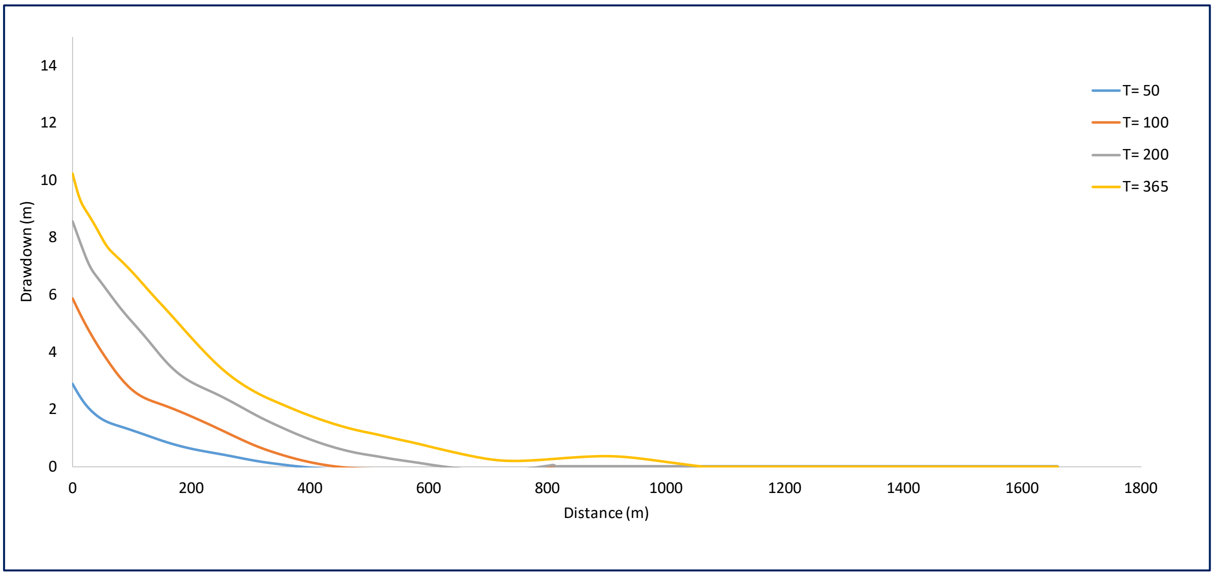

Figure 4 Drawdown (m) along the SMC at various simulation times (in days) obtained from simulation of scenario 1, note zero distance refers to the location of the monitoring bore of HM19SMC0002.

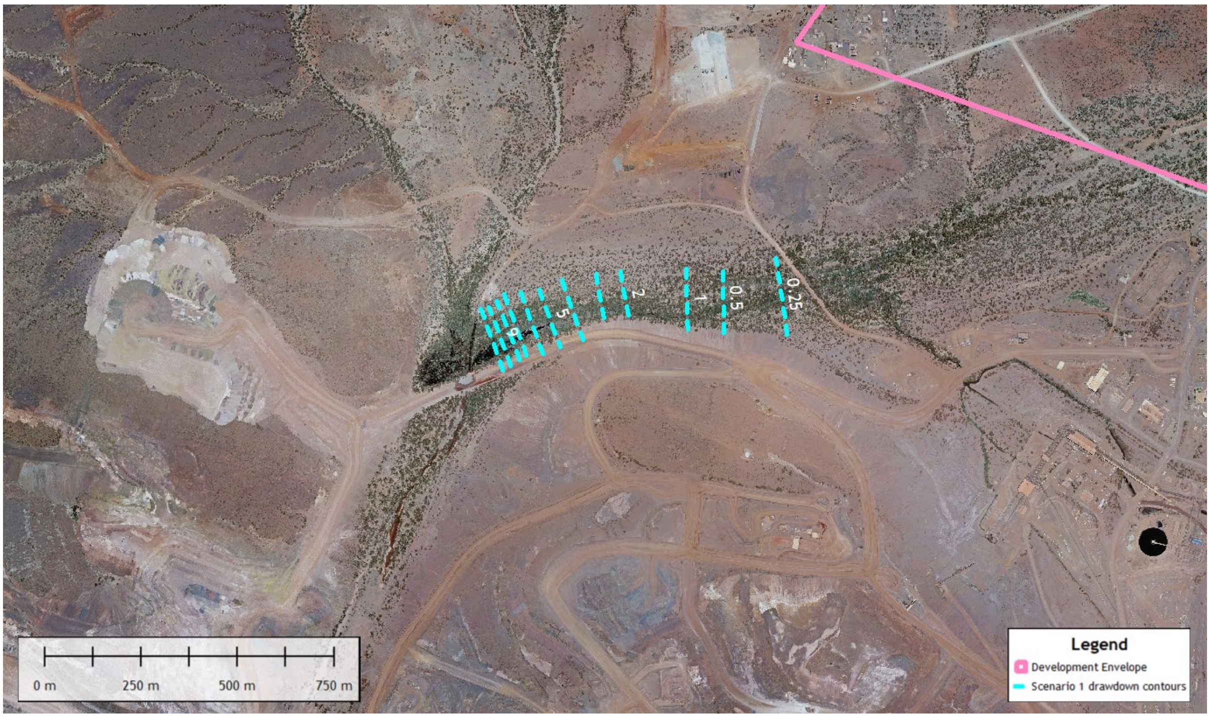

Figure 5 Scenario 1 drawdown contours

An explanation for the above predictions (i.e. limited drawdown along the SMC) can be obtained from inspection of the unsaturated hydraulic conductivity as a function of pressure head (capillary head) for Wittenoom Formation (Figure 6). It is observed that the unsaturated hydraulic conductivity is significantly reduced when the soil becomes unsaturated during the dewatering. As can be seen from Figure 6, the relative hydraulic conductivity starts out with a zero slope at pressure head values near zero, but then falls off increasingly rapid as h (capillary pressure) increases. Therefore, when an unsaturated zone is developed between the alluvial aquifer along the SMC and Wittenoom formation, the relationship between the two aquifers is evolved from the hydraulic connection to disconnection (Wang et al., 2016).

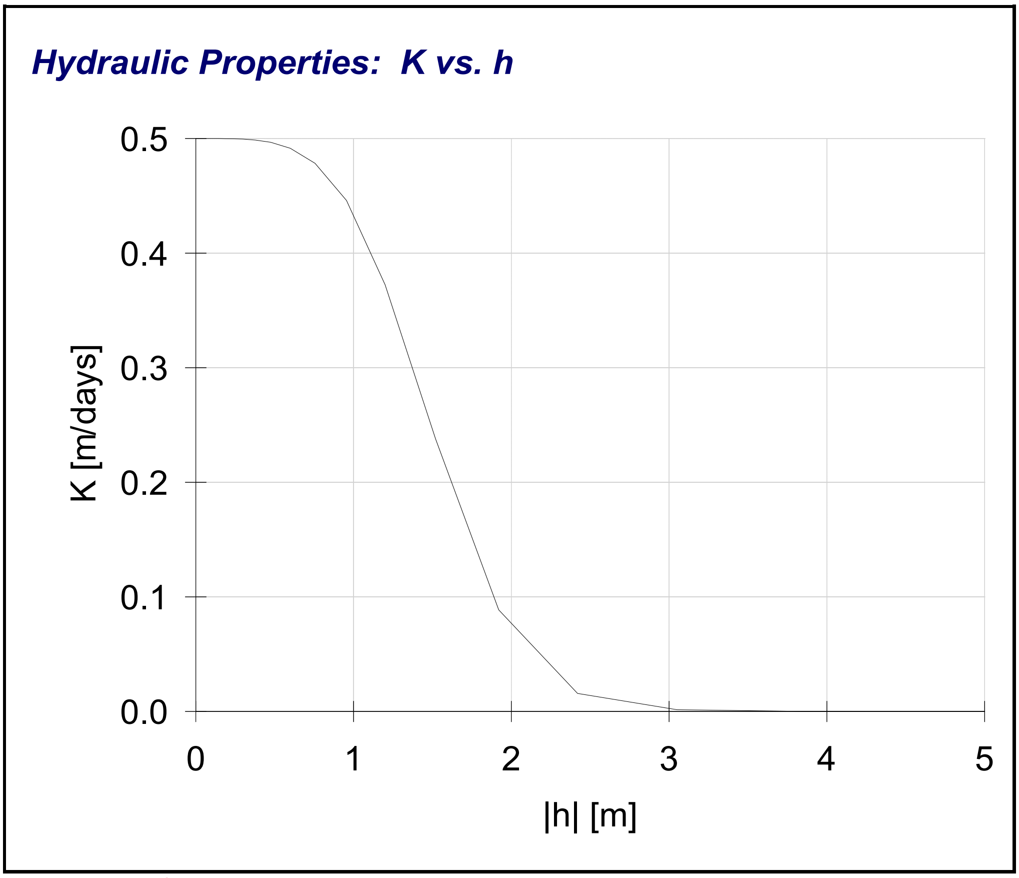

Figure 6 Plot of the relative hydraulic conductivity vs. pressure head based on the soil hydraulic properties of Wittenoom Formation used in Scenario 1 summarized in Table 1.

Similar to Scenario 1, the extent of water-level decline within the SMC aquifer for other Scenarios (i.e. 2, 3, and 4) was found to be limited to a few hundred metres upstream of the monitoring bore of HM19SMC0002 (Figure 7 to Figure 12). Especially for Scenario 2, predicted drawdown greater than 2m extended only about 400 m to the north of reference point (HM19SMC0002) at the end of simulation period (1 year). In this Scenario, the soil properties for the Wittenoom Formation employed in the numerical simulation had a rather narrow pore-size distribution (high value of *n*), causing the soil-water retention curve to become very steep when the soil becomes unsaturated. Therefore, the unsaturated hydraulic conductivity would have significantly reduced as the soil become unsaturated. When the Wittenoom Formation is dewatered, the hydraulic conductivity of the unsaturated zone is significantly reduced as such the flow of water from the alluvial aquifer into the Wittenoom Formation is greatly restricted.

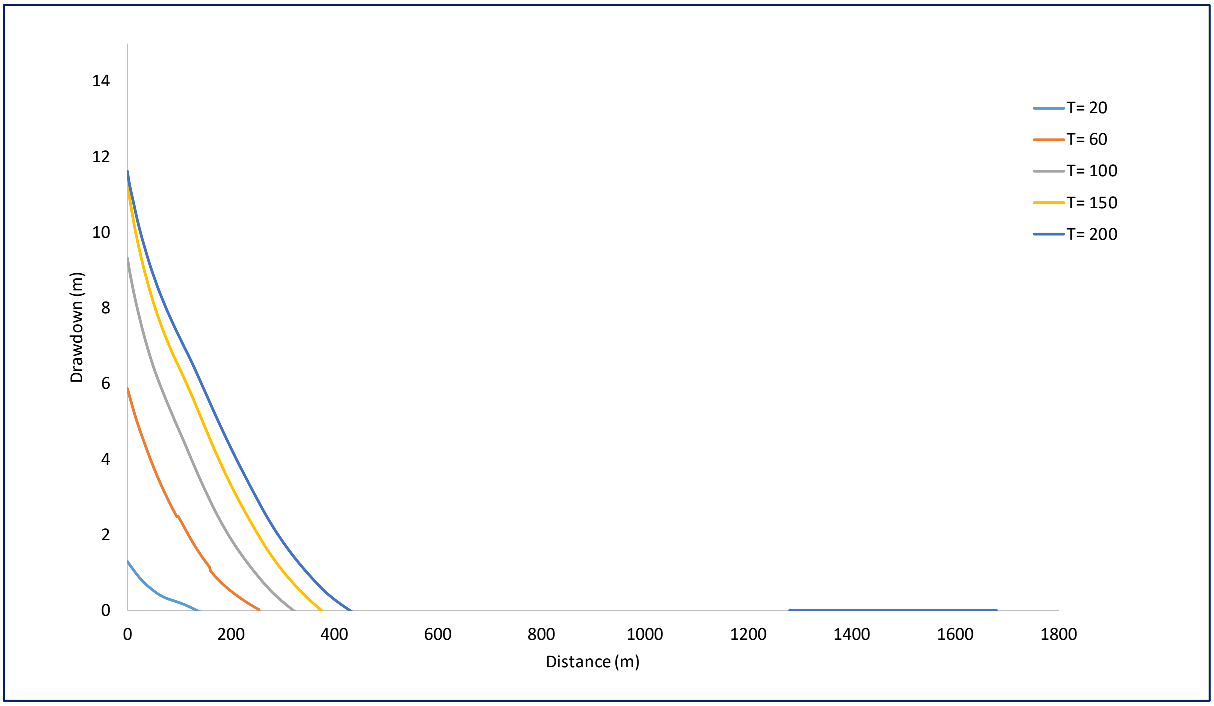

Figure 7 Drawdown (m) along the SMC at various simulation times (in days) obtained from simulation of scenario 2, note zero distance refers to the location of the monitoring bore of HM19SMC0002.

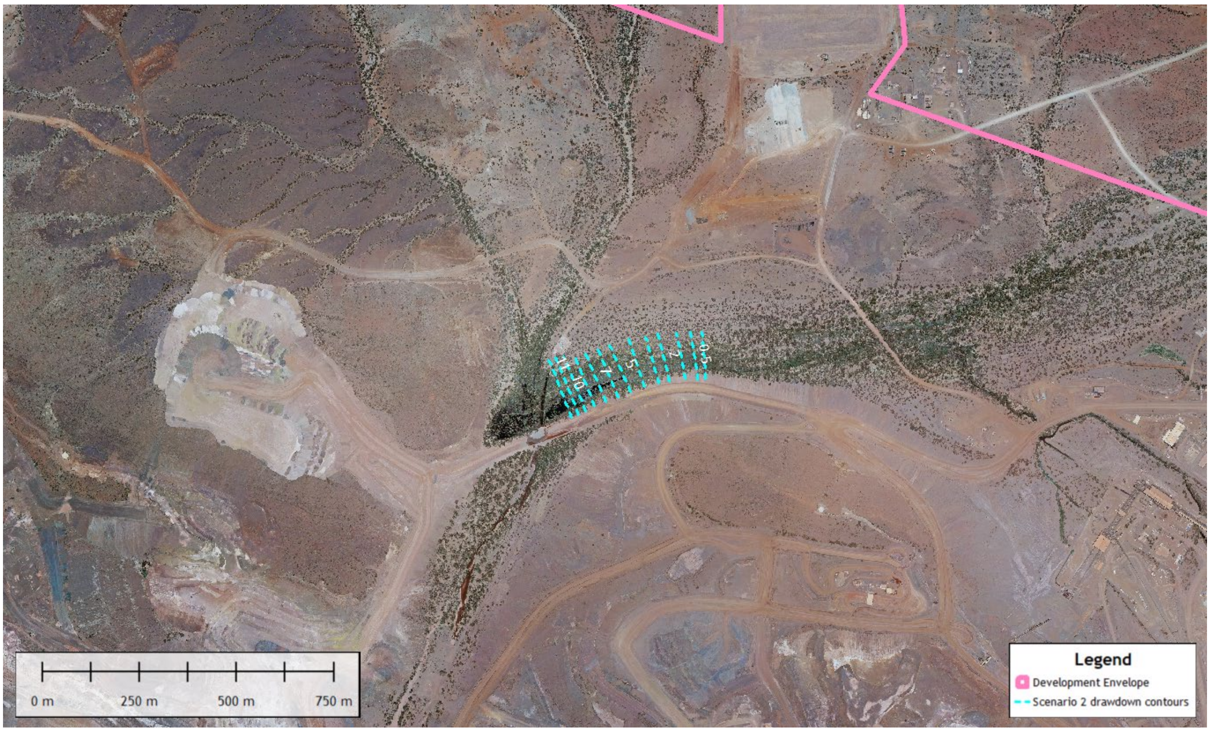

Figure 8 Scenario 2 drawdown contours

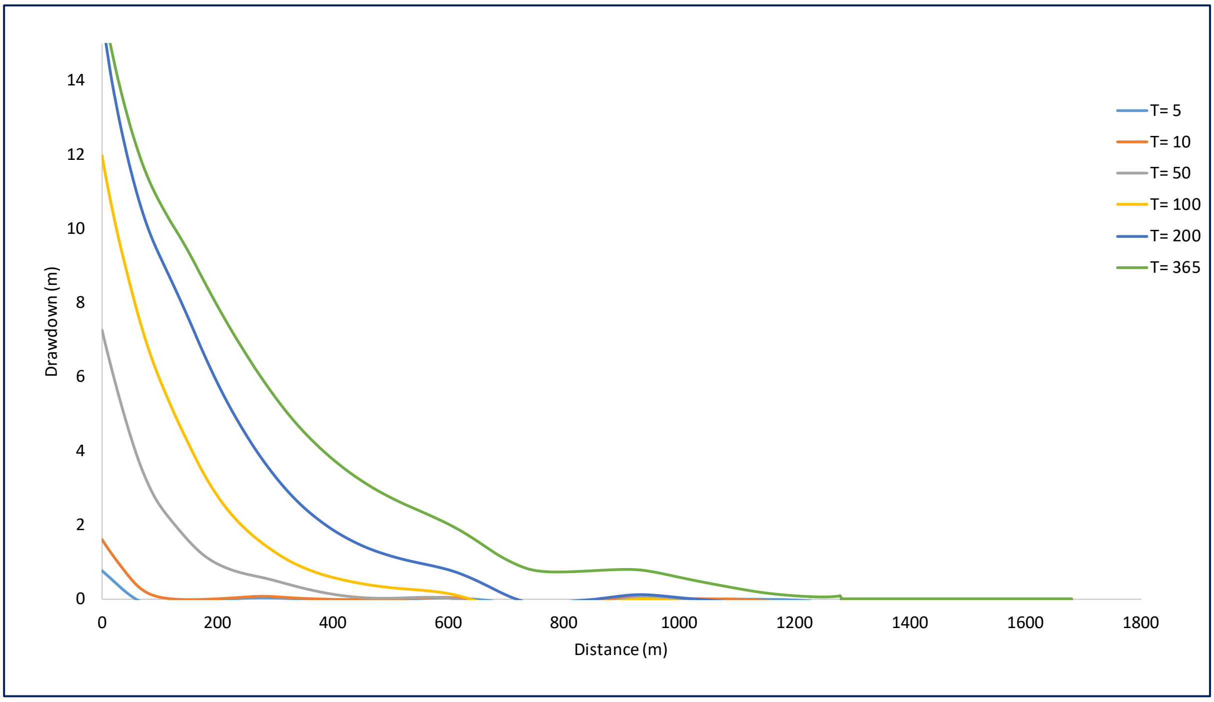

Figure 9 Drawdown (m) along the SMC at various simulation times (in days) obtained from simulation of scenario 3, note zero distance refers to the location of the monitoring bore of HM19SMC0002.

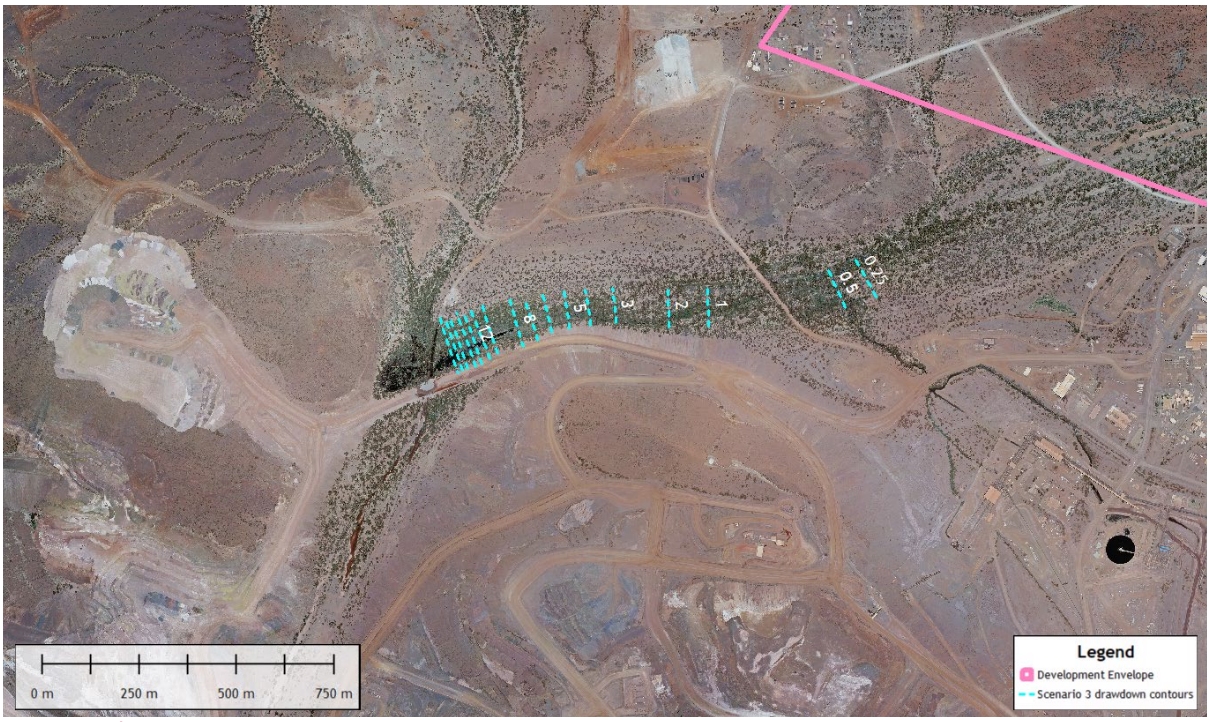

Figure 10 Scenario 3 drawdown contours

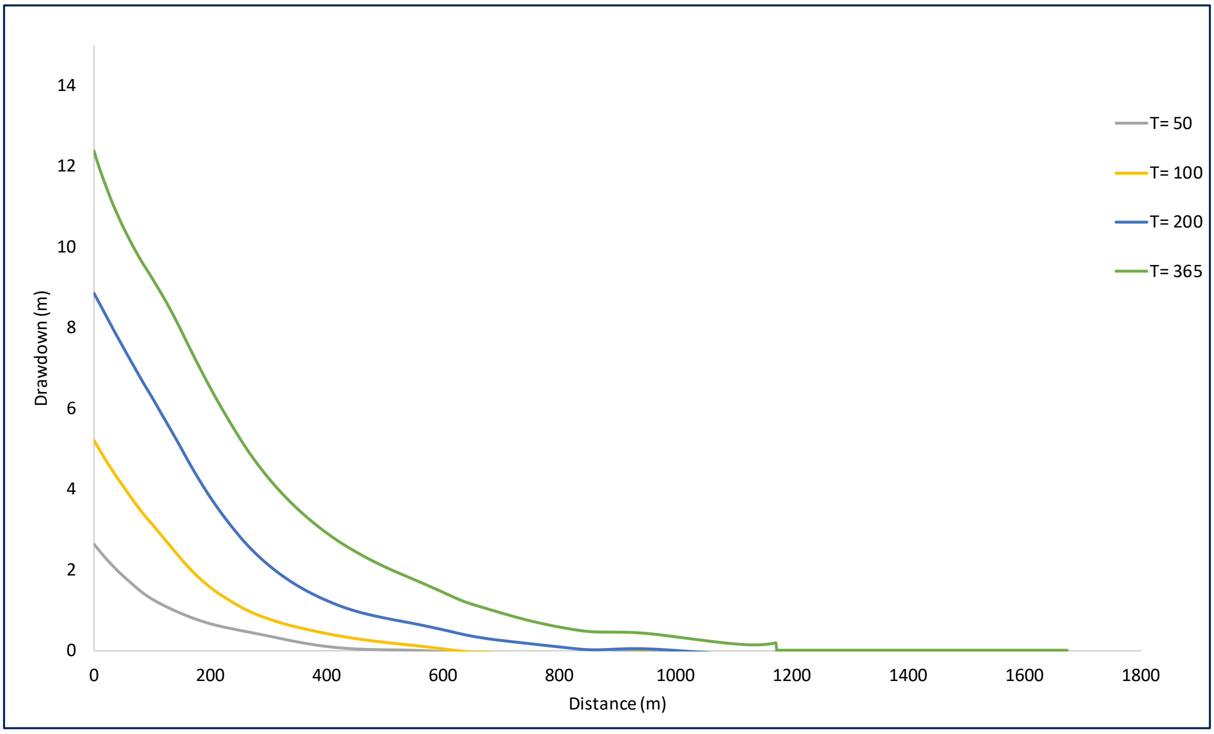

Figure 11 Drawdown (m) along the SMC at various simulation times (in days) obtained from simulation of scenario 4, note zero distance refers to the location of the monitoring bore of HM19SMC0002.

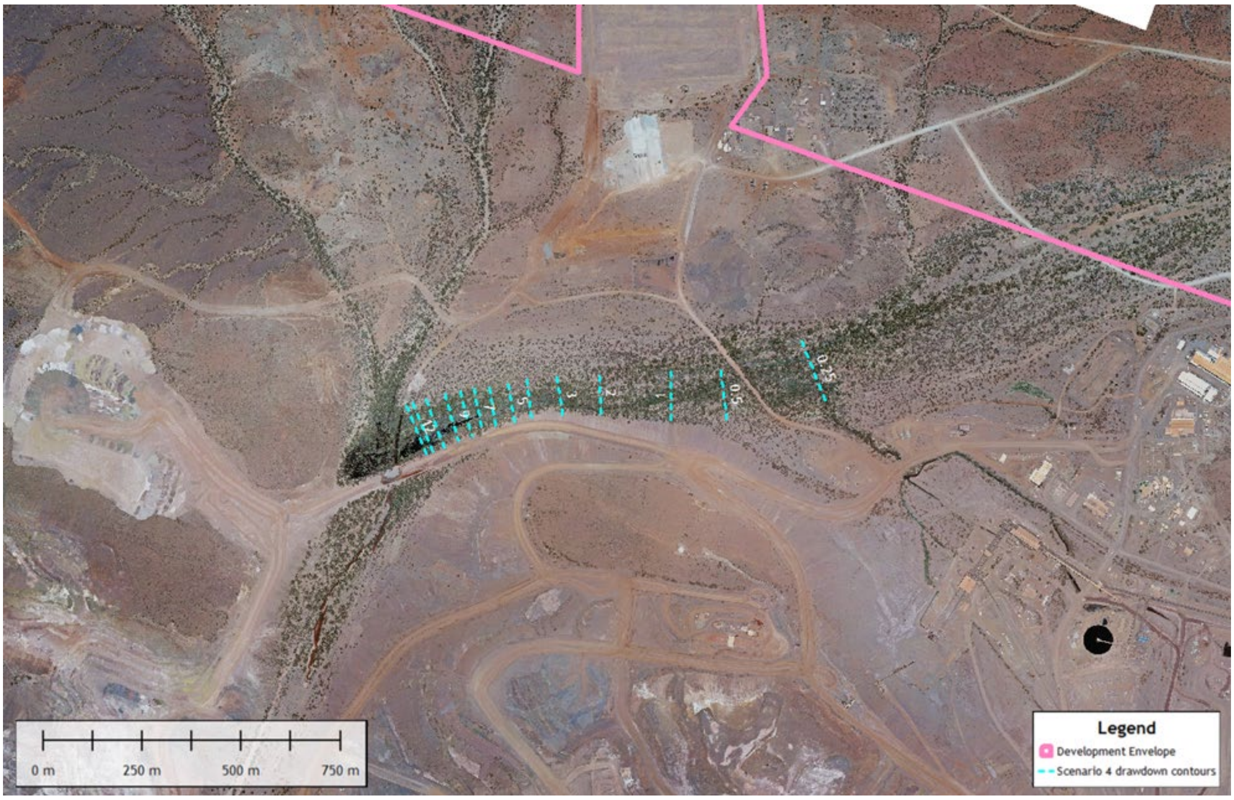

Figure 12 Scenario 4 drawdown contours

5 Conclusions and Recommendations

2-D numerical simulations were conducted to assess the influence of soil properties on water-level decline within the alluvial aquifer along the SMC as a result of dewatering in the Wittenoom Formation. Specifically, the work examined the processes of the hydraulic connectedness of the aquifers along the SMC and in the Wittenoom Formation from connection to disconnection due to groundwater pumping (dewatering) in the Wittenoom formation. The numerical simulation results computed from the saturated-unsaturated flow model collectively show that when the water level in the Wittenoom Formation was lowered significantly due to dewatering, the relationship between the creek and aquifer evolved from connection to disconnection. Therefore, the drawdown propagation along the SMC Aquifer was limited to a few hundred metres upstream of the dewatered formation. In particular, the extent of drawdown was decreased when the soil properties of the Wittenoom formation had a narrow pore-size distribution (Scenario 2).

The above simulations are considered highly idealized scenarios, whereas the natural subsurface is inherently highly heterogeneous. Specifically, the exact level of connection with adjacent formations is unknown.

Yours sincerely

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