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MEMO

TO:	Neil Dixon	COMPANY:	BCI MINERALS LIMITED	
FROM:	Adam Pratt	PROJECT TITLE:	MARDIE SALT AND SOP PROJECT	
DATE:	29 November 2019	PROJECT & DOCUMENT NO:	BCI-001-1-1	004
SUBJECT:	Mardie Salt and SOP Project - Seepage Model Results and Potential Environmental Impacts			

1 INTRODUCTION

Soilwater Consultants (SWC) were engaged by BCI Minerals Limited (BCI) to undertake unsaturated zone seepage modelling of the proposed Evaporation and Crystalliser Ponds to be constructed and operated as part of the Mardie Salt and Sulphate of Potash (SOP) Project (the ‘Project’). The primary objectives of this study were to:

- Quantify predicted seepage losses from both the Evaporation and Crystalliser Ponds during normal operations, and
- Establish the potential environmental impacts of this seepage, paying particular attention to the water quality of the underlying Calcarenite Aquifer and of Mardie Pool.

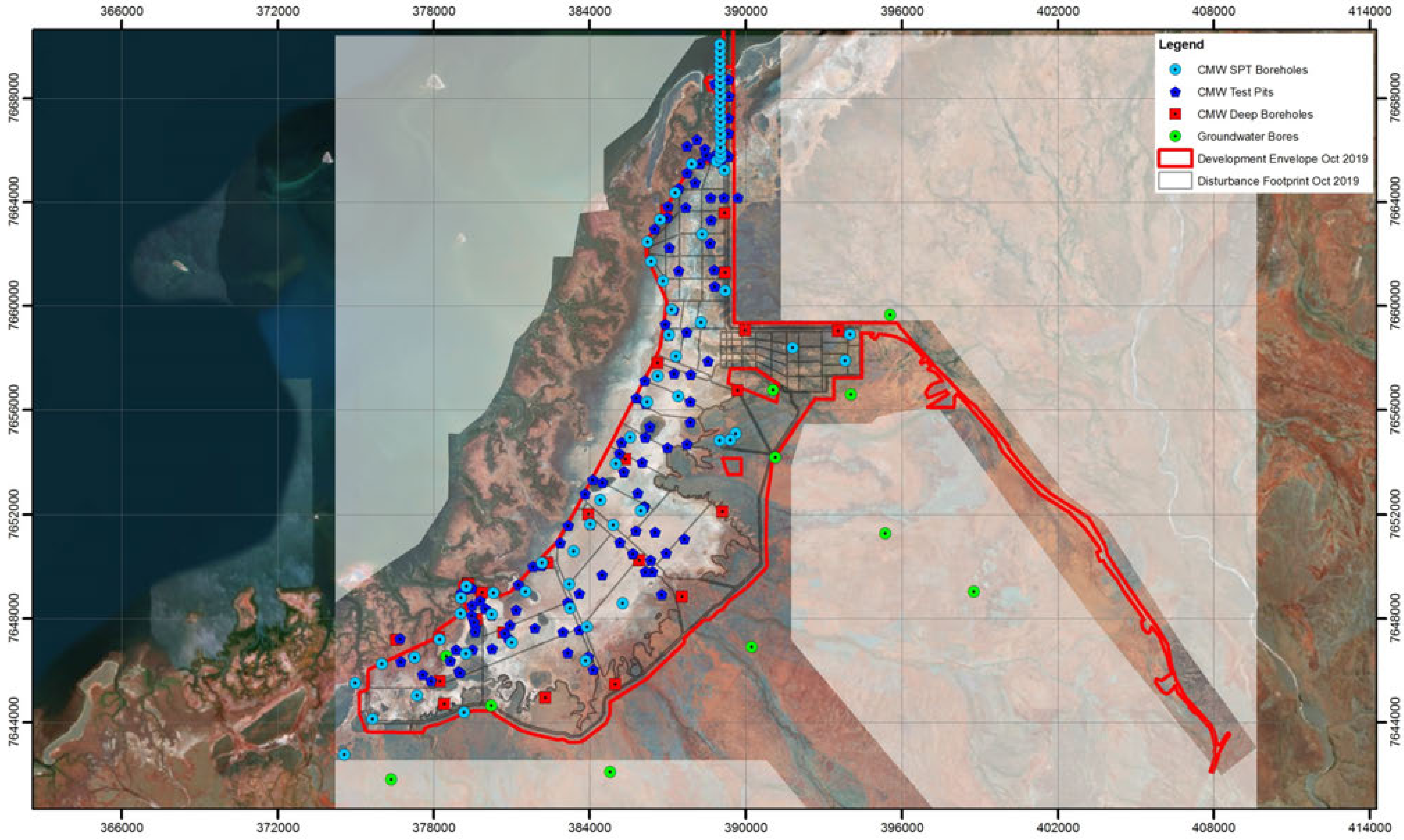
This memo summarises the modelling undertaken and discusses the results obtained and their implications for the environmental management of the Project.

2 CONCEPTUAL HYDROGEOLOGICAL SITE MODEL (CHGSM)

A Conceptual Hydrogeological Site Model (CHGSM) was developed for the Mardie Salt and SOP Project, based on a review of the following information:

- Published regional hydrogeological reports (Haig, 2009; Fugro, 2011)
- CMW (2019) Geotechnical Drilling Program
- CMW (2019) Deep Borehole Drilling Program
- CMW (2019) Supratidal Flats Test Pit Program
- Stantec (2017) Acid Sulphate Soil Investigation – Mardie Salt Project

A map showing the location of all soil, geotechnical and geological sampling sites that were used to construct the CHGSM is shown in Figure 1.



BCI MINERALS LIMITED	Figure 1: Sampling sites used to constructed the CHGSM	soilwater GROUP
MARDIE SALT AND SOP PROJECT		

The Project is located on the northern portion of the Peedamullah Shelf, which forms the southeastern-most division of the Northern Carnarvon Basin, fringing the western margin of the Pilbara Craton. Sediments in the Peedamullah Shelf range in age from Ordovician to Pleistocene, with a total basin depth up to 5 km.

The Project Area is generally underlain by a moderately to highly calcreted shelly calcarenite layer (Plate 1), likely equivalent to the regionally extensive Quaternary Bibra Limestone and older Tertiary Bundera Calcarenite. On the eastern side of the Supratidal Flats, the calcarenite is unconformably overlain by Pleistocene to Holocene aeolian, alluvial and colluvial sediments forming the current surface of the Onslow Land System. The calcarenite layer dips westerly under the Supratidal Flats (corresponding to the Littoral Land System), creating an undulating surface onto which the mudflats were deposited. In areas where the calcarenite layer outcrops the mudflat surface, or where significant secondary agglomeration of calcirudite and / or calcisiltite occurs, it anchors a thin veneer of eolian (dunal) sand (Plate 2).

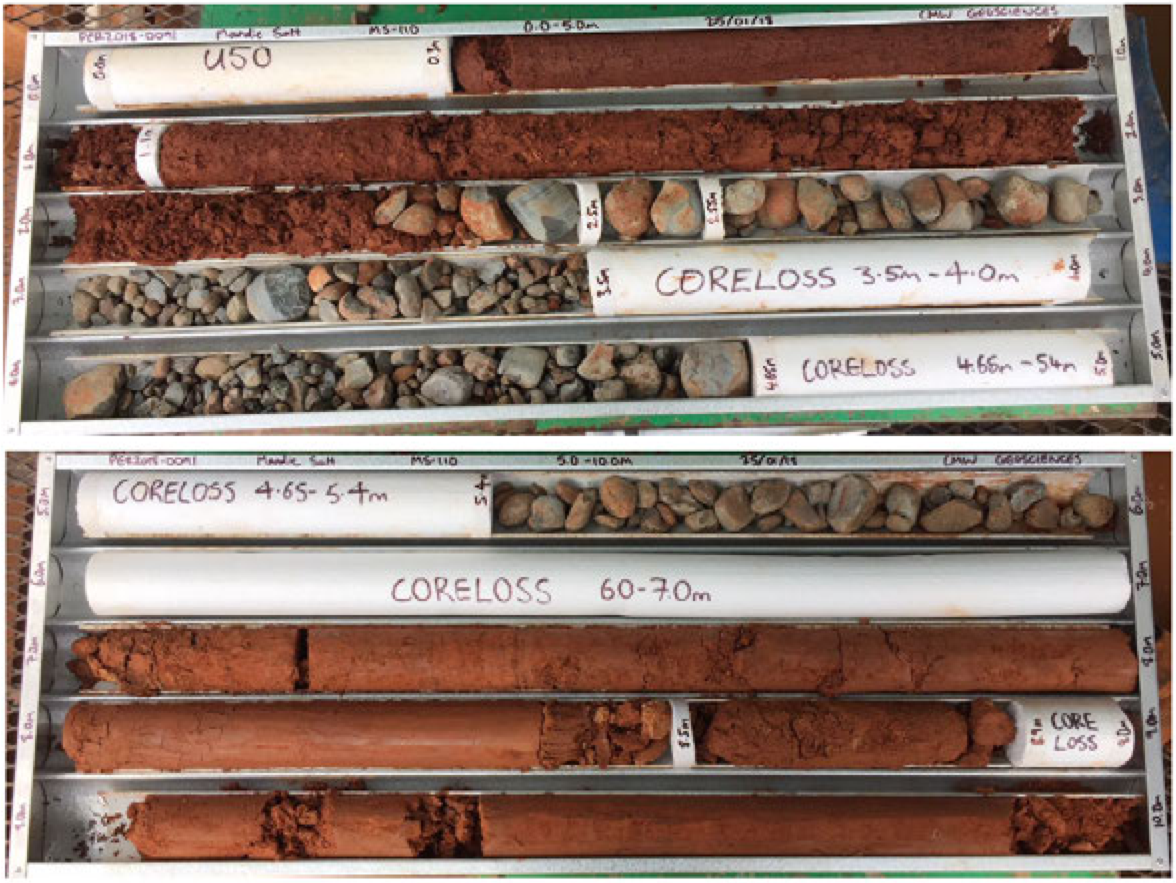
The Supratidal Flats that occur extensively across the Project Area, on top of the calcarenite layer, have formed by prolonged deposition of terrestrial and marine sediments. Several large creek systems, including Peter Creek (catchment area 422 km^2), Gerald Creek (catchment area 153 km^2), Trevarton Creek (catchment area 172 km^2) and 6 Mile Creek (catchment area 164 km^2), discharge directly into the Supratidal Flats. Depending on the rainfall intensity within the various creek catchments, and the distance from the discharge point, the sediments making-up the Supratidal Flats will vary from heavy clays to sands to gravels, with each deposition event interfingering with the last deposition event (Plate 3).

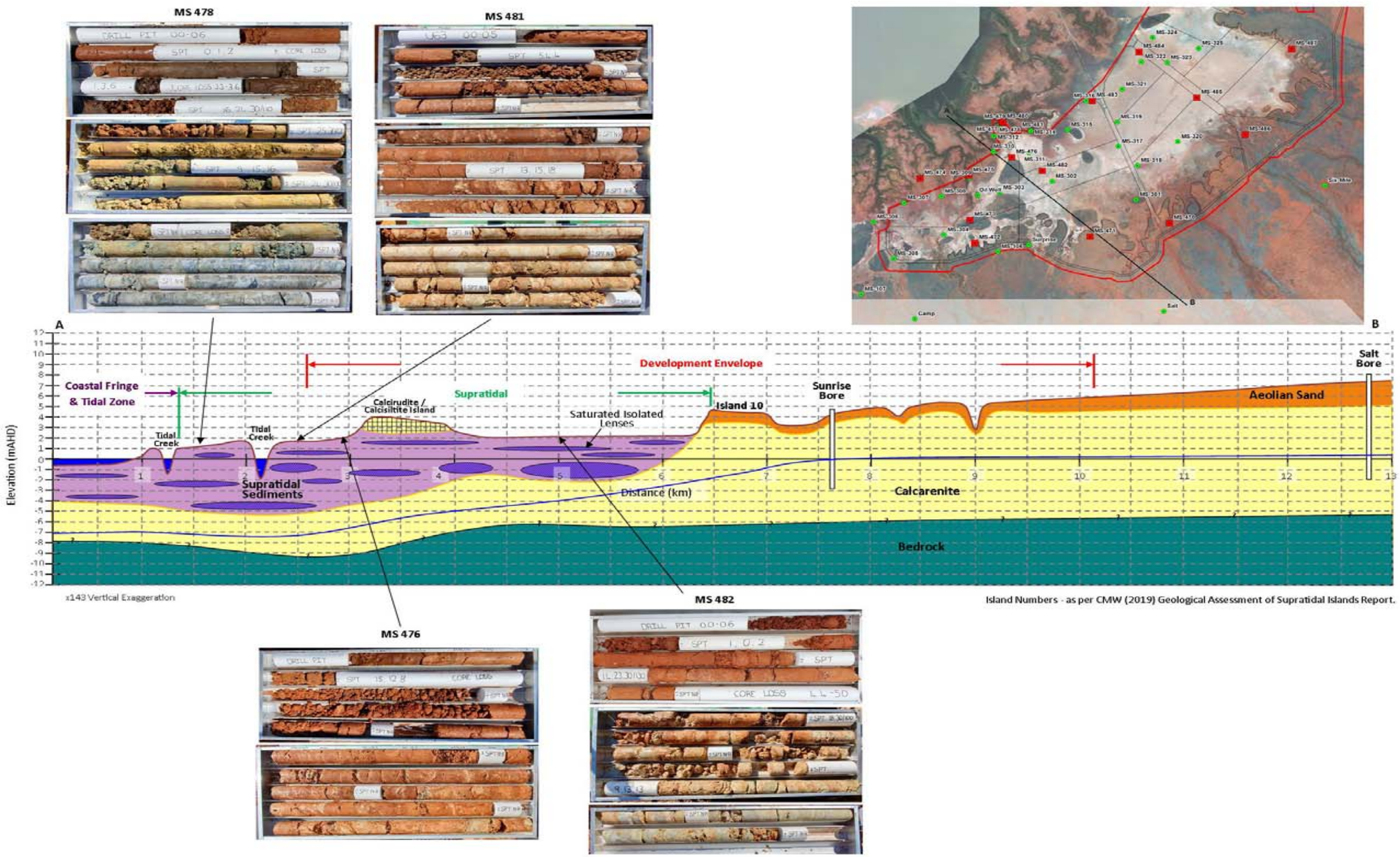
Schematic cross-sections through the Project Area are provided in Figure 2 and Figure 3.

Plate 1: Outcrop of calcarenite on the eastern side of the Supratidal Flats within the Project Area (surface of the calcarenite dips below the mudflats)

Plate 2: Outcropping calcarenite layer within the Supratidal Flats

Plate 3: Core photo showing the interfingering of the clay and gravel layers within the Supratidal Flats





BCI MINERALS LIMITED	Figure 2: Schematic cross-section in the north of the Project Area showing the CHGSM
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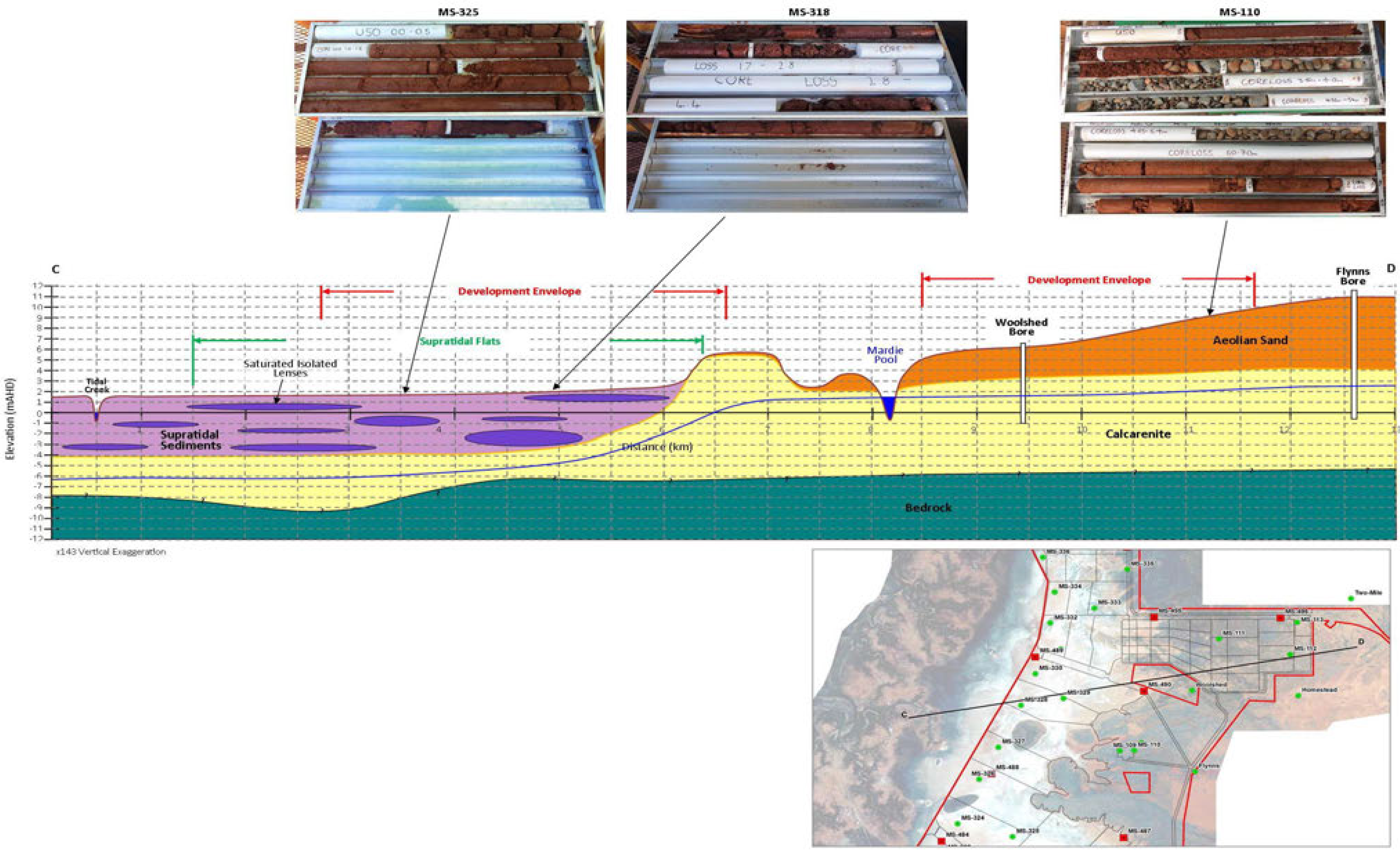
soilwater GROUP



BCI MINERALS LIMITED	Figure 3: Schematic cross-section in the north of the Project Area showing the CHGSM	soilwater GROUP
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3 UNSATURATED ZONE SEEPAGE MODELLING

Unsaturated zone seepage modelling was undertaken using HYDRUS 2D/3D, which is considered industry best-practice for seepage modelling because it explicitly solves the Richard's Equation when calculating water movement. Seepage modelling was undertaken for both the Evaporation and Crystallisation Ponds to quantitatively assess seepage and to determine potential impacts on the underlying Calcarenite aquifer (Figure 2 and Figure 3) and Mardie Pool (Figure 3). The results obtained are discussed below.

3.1 HYPERSALINE SEEPAGE FROM EVAPORATION PONDS ON THE SUPRATIDAL FLATS

3.1.1 POTENTIAL FOR GROUNDWATER MOUNDING

3.1.1.1 Model Setup

As shown in the CHGSM (Figure 2 and Figure 3) and in Plate 4, saturated groundwater lenses often occur within 1-2 m of the surface in the Supratidal Flats. These saturated groundwater lenses may impede the dissipation of seepage from the Evaporation Ponds and result in seepage or groundwater mounding beneath the Evaporation Ponds. Unsaturated zone modelling was therefore undertaken to establish whether this mounding will likely occur and how it will likely spread away from the Evaporation Ponds (i.e. what is its area of influence).

Plate 4: Interception of a shallow saturated groundwater lense within the Supratidal Flats

This model assumes a very sluggish groundwater system within the Supratidal Flats, which is expected given the very low hydraulic gradients across the site and the predominately clay matrix; hence Free Drainage boundary conditions were used on the sides to control lateral movement of seepage water and exacerbate the potential rise of the water table. The top of the water table was also set as a No Flux boundary so that the degree of saturation of the *in-situ* clays, and the rise of the water table, could easily be seen.

For this scenario two *in-situ* clay depths below the evaporation ponds were modelled: 1) 1 m clay depth and 2) 2 m clay depth (Figure 4). The model was only run for a one year period (365 days).

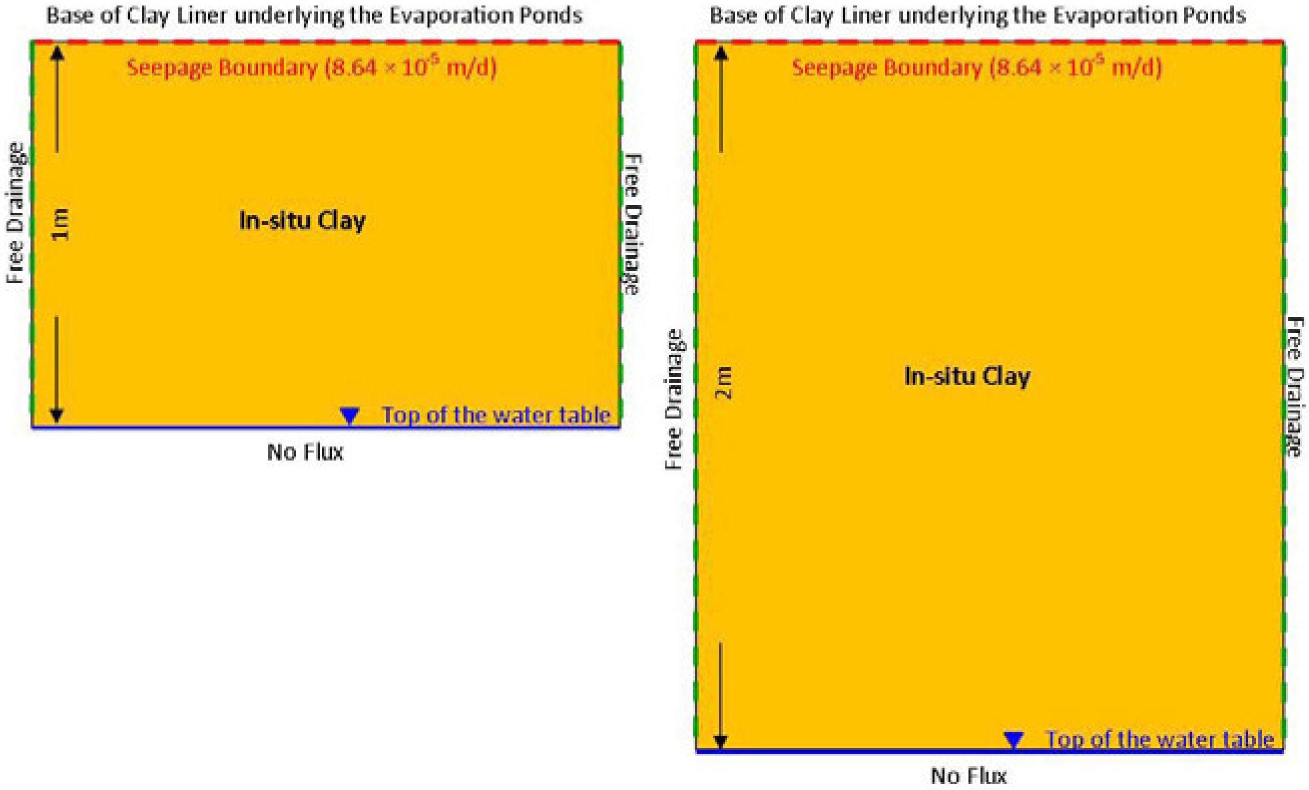


Figure 4: Model setup to determine the potential for groundwater mounding to occur below the Evaporation Ponds

3.1.1.2 Input Parameters

The key parameters used in the setup of the above models are provided in Table 1 (SWC, 2019). All parameters highlight the clayey nature of the *in-situ* soils underlying the proposed evaporation ponds.

Table 1: Key input parameters

Parameter	Value Used	Comments
Initial moisture content of in-situ clay underlying the evaporation ponds (%; v/v)	29.7	Determined in the laboratory from *in-situ* cores collected in the field
Bulk density of *in-situ* clay (t/m^3)	1.31	Average bulk density of intact cores collected in the field
Water retention properties (%; m^3/m^3)		Laboratory determined from samples collected in the field
- 0 kPa	0.51	
- 10 kPa	0.47	
- 33 kPa	0.36	
- 100 kPa	0.34	
- 1,500 kPa	0.23	
van Genuchten parameters		Derived from above water retention properties

- α (1/m)	0.00996	
- n (-)	1.393	
l (-)	0.5	
Saturated hydraulic conductivity (m/d)	0.015	Average saturated hydraulic conductivity measured on samples collected in the field

3.1.1.3 Model Results

The predicted matric potential below the proposed evaporation ponds is shown in Figure 5 and Figure 6. The -100 m matric potential starting point represents the likely moisture content at the beginning of the operation, but once it is in use the starting matric potential will be around -10 m (or less). As it can be seen in Figure 5 and Figure 6, the shallow (1 m) soil profile wets up rapidly as a result of seepage below the evaporation ponds, even with a clay liner with a 10^{-9} m/s saturated permeability, such that it only takes 42 days to saturate if the clays below the liner are at -10 m matric potential.

If the depth of the clay or to the water table below the proposed evaporation ponds is 2 m, then the profile is unlikely to become saturated and will remain in a semi-wet, unsaturated condition for at least one year after operations commence (Figure 7).

Based on the results presented in Figure 5 to Figure 7, and discussed above, groundwater mounding will likely occur below the proposed evaporation ponds, even when a 10^{-9} m/s clay liner is installed. The degree of mounding is influenced by the initial depth to groundwater and the starting matric potential of the clays, and saturated conditions are expected below the evaporation ponds if the depth to groundwater is 1 m below the pond floor and the *in situ* clays are relatively ‘wet’; hence it doesn’t take much seepage to fully saturate the small macro- and meso-porosity of the clays.

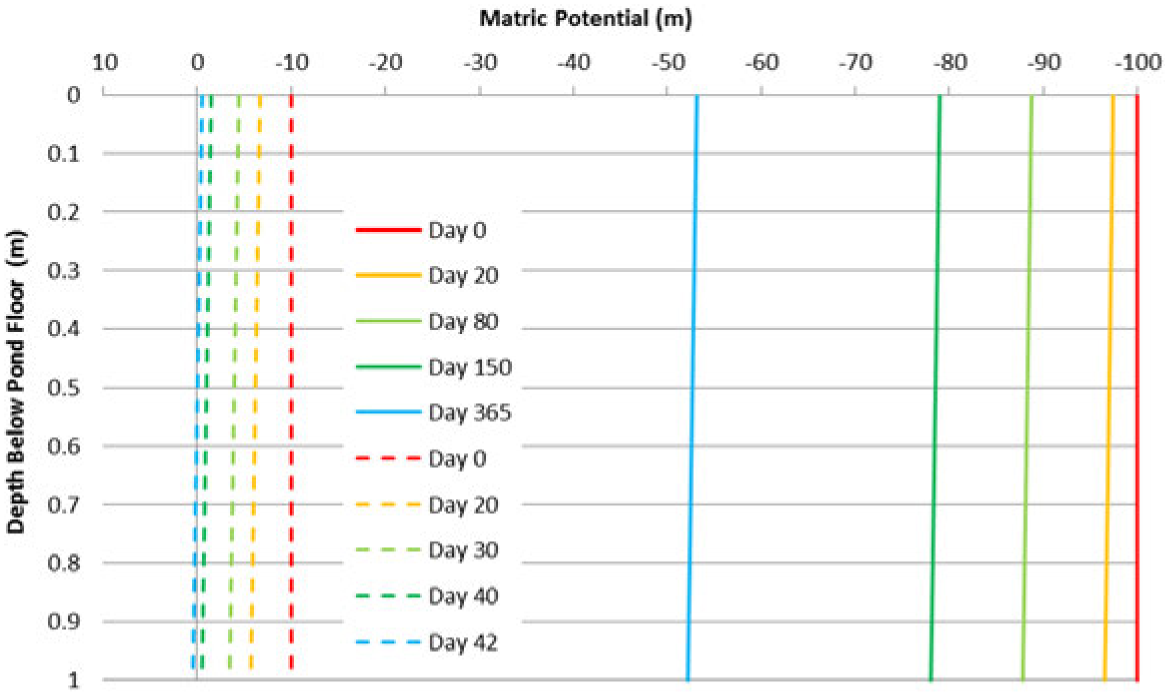


Figure 5: Predicted soil matric potential under the proposed evaporation ponds (Dashed line predicts degree of saturation with a -10 m starting matric potential, whilst the solid line is for a -100 m starting potential)

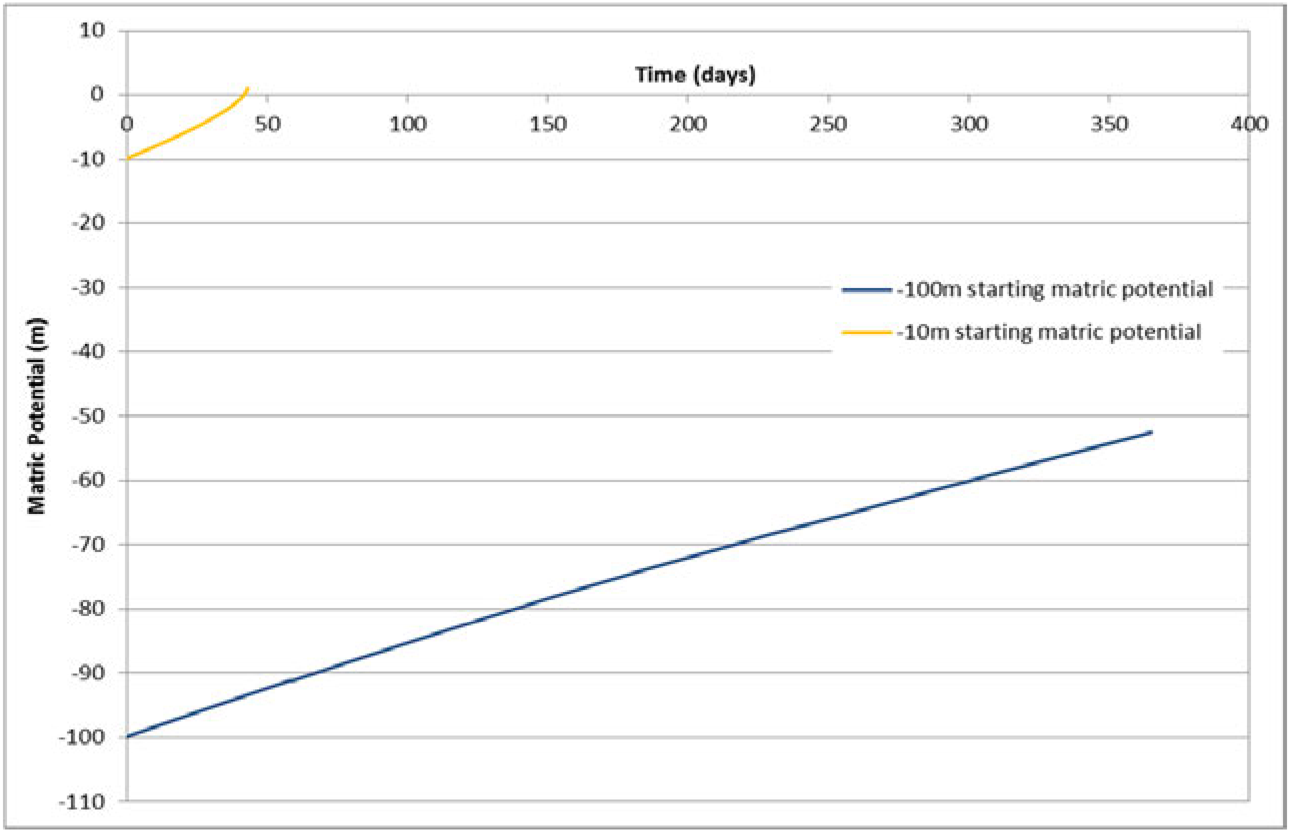


Figure 6: Predicted matric potential below the proposed evaporation ponds based on a -10 m and –100 m starting matric potential

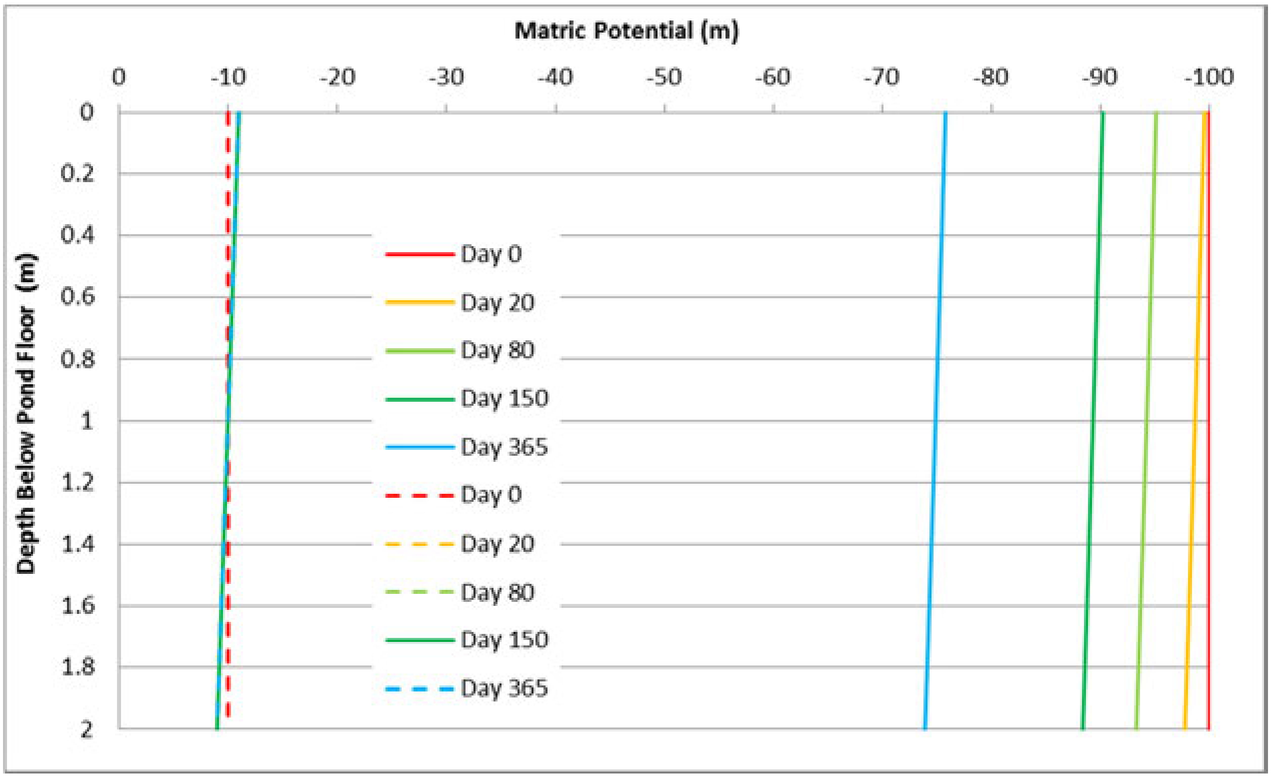


Figure 7: Predicted matric suction below the proposed evaporation ponds, assuming the depth to groundwater is 2 m

3.1.2 POTENTIAL IMPACT OF GROUNDWATER MOUNDING ON THE SURROUNDING ENVIRONMENT

To establish the potential impact of seepage on the surrounding environment, a scaled-down cross-section of the proposed evaporation ponds was modelled. The setup of the model is shown in Figure 8. The primary aim of this model was to determine the distance that seepage from the evaporation ponds might reach (and thus potentially impact) during the normal operations. This model was run for ten years (3,650 days) to allow sufficient time for the seepage front to move downstream.

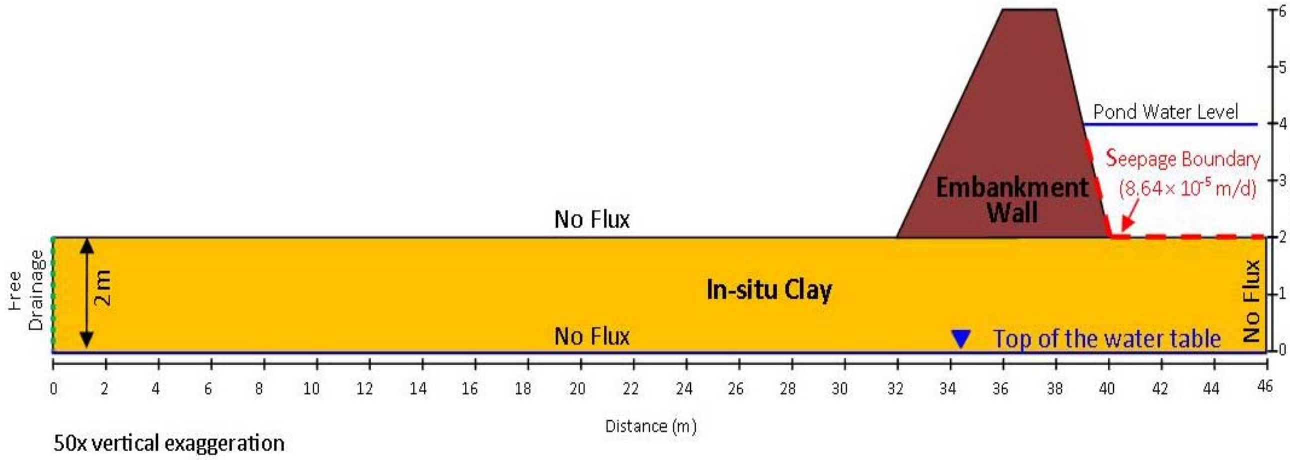


Figure 8: Model setup to establish potential downstream impacts from groundwater mounding

3.1.2.1 Modell Results

The predicted matric suctions modelled in this scenario are presented in Figure 9 to Figure 11. These results assume a 2 m depth to groundwater and a starting matric potential of -100 m. The results show that surface evaporation of the Supratidal mudflats surrounding the Evaporation Ponds will play a significant role in determining the extent to which groundwater mounding under the Ponds is likely to impact on the downstream soils. It is important to recognise that although the pan evaporation rate for the Pilbara Region is around 3,100 mm per year, the actual evaporation from the surface of the mudflats will be appreciably lower as the dry soil conditions at the surface will effectively impede the upward movement of water from the soil; hence the permeability of the dry soils at the surface become rate-limiting.

If no evaporation is considered, then groundwater mounding will spread downstream, such that at Day 640 the entire surficial soil profile, to at least 30 - 40 m from the embankment wall toe, will become saturated (Figure 9). If a realistic (actual) evaporation rate of 1,000 mm per year is considered, then the spread of the groundwater mound is reduced such that at after two years of continuous operation (i.e. Day 730) the surface soils downstream of the embankment wall remain unsaturated (Figure 10). Under this evaporation scenario, the surface soils at distances greater than 10 m from the embankment wall, only become saturated after 10 years of continuous operation.

If an actual surface evaporation rate of 2,000 mm per year is used, then the surface soil profile will remain unsaturated, likely over the life of the operation (Figure 11).

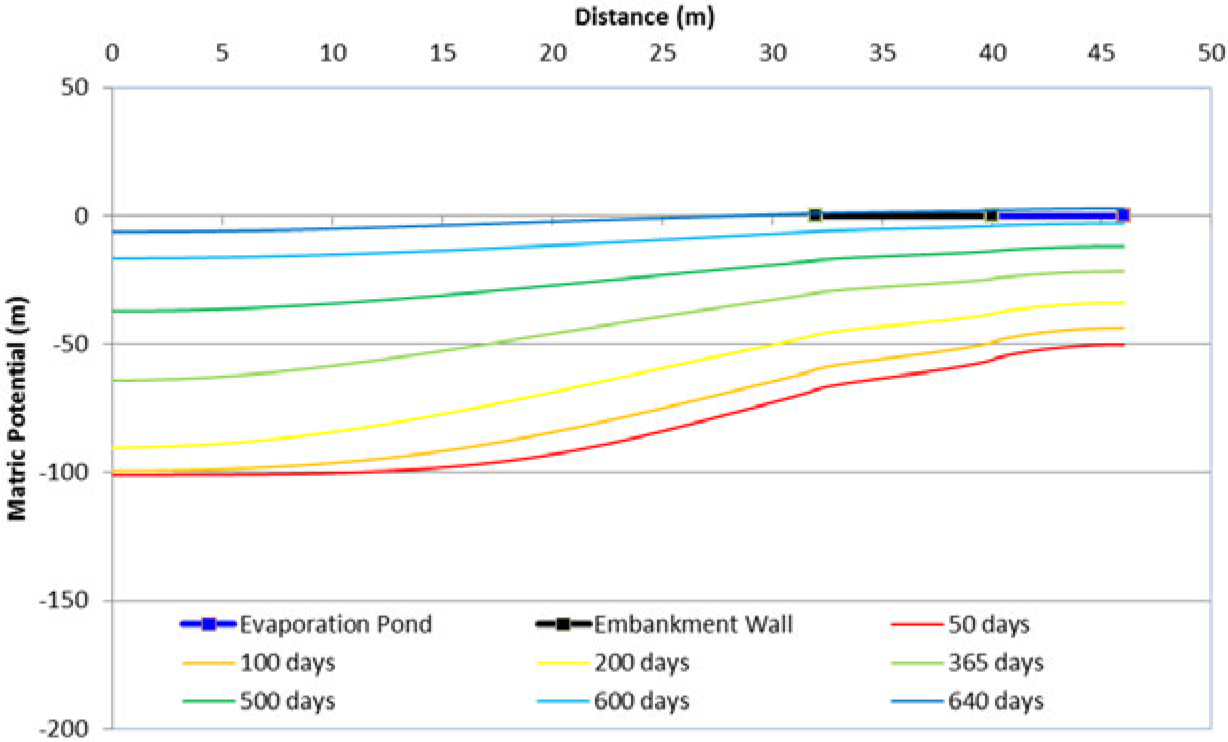


Figure 9: Predicted matric suction of the *in situ* soils (at 5 cm below the surface) under the evaporation ponds, embankment walls and adjacent areas, assuming no surface evaporation

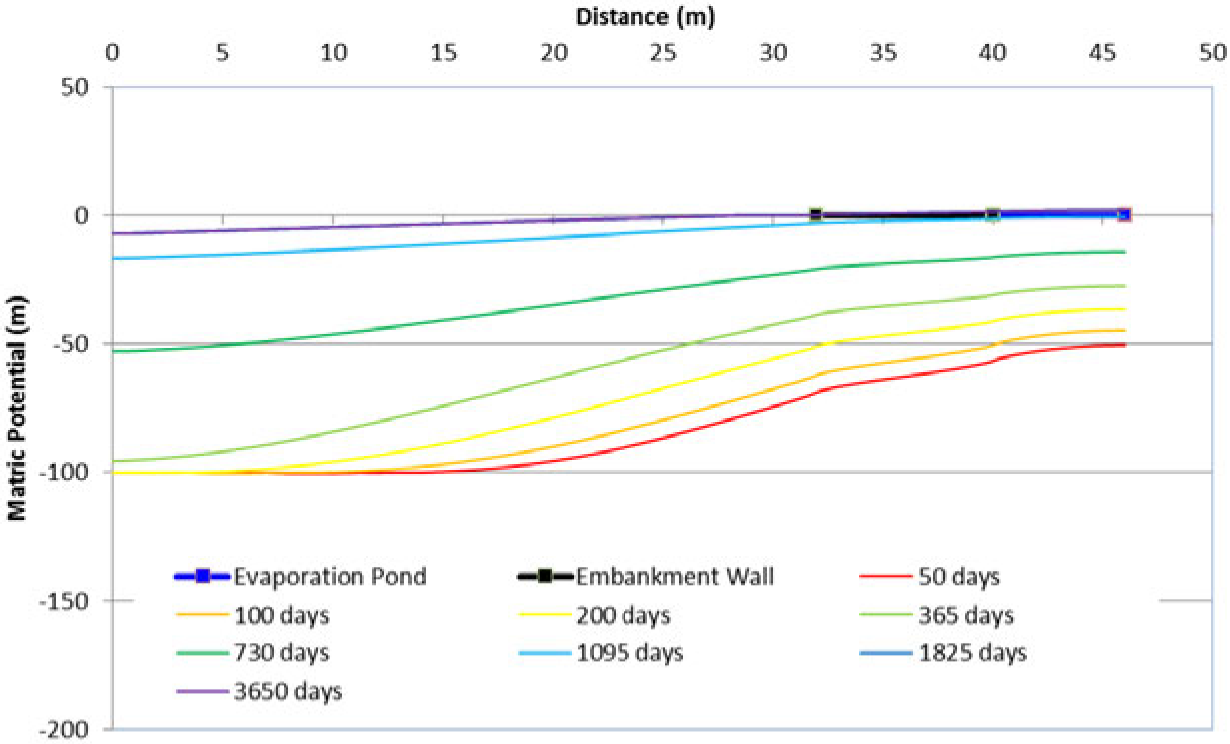


Figure 10: Predicted matric suction of the *in situ* soils (at 5 cm below the surface) under the evaporation ponds, embankment walls and adjacent areas, assuming actual evaporation rates from the surface

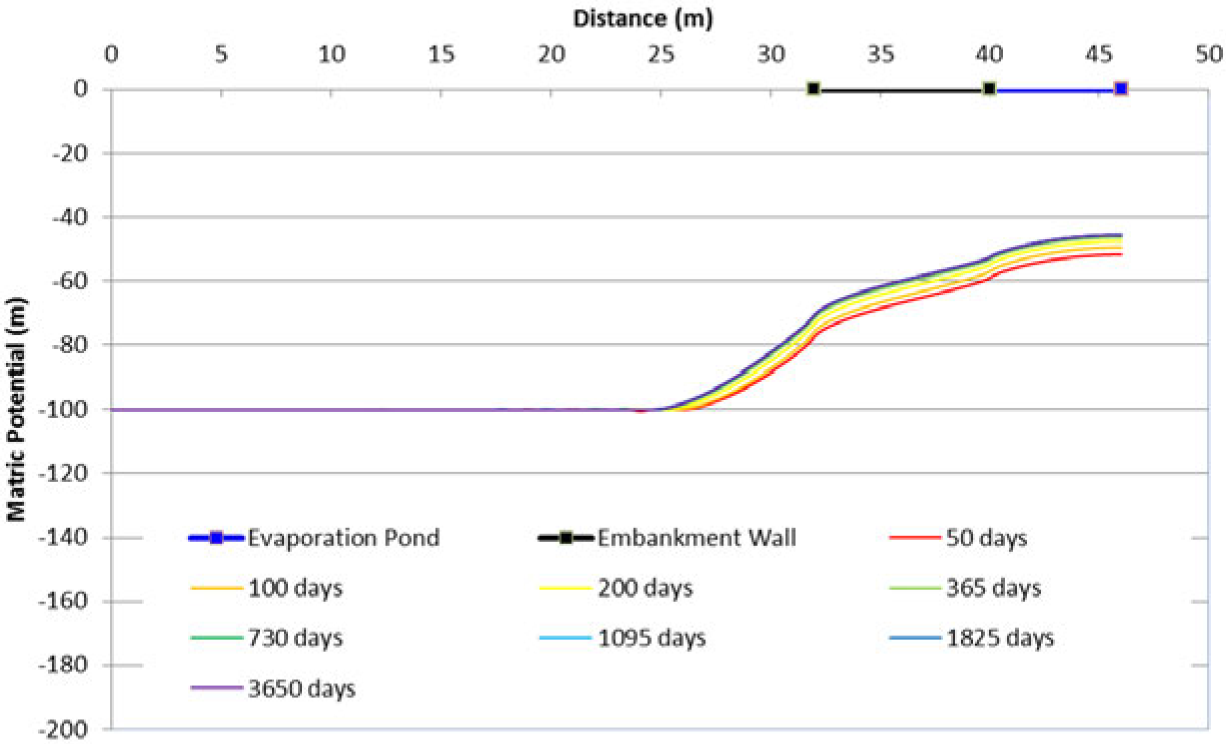


Figure 11: Predicted matric suction of the *in situ* soils (at 5 cm below the surface) under the evaporation ponds, embankment walls and adjacent areas, assuming high surface evaporation rates

Given the importance of actual evaporation from the surface soils in the Supratidal Flats, on the spread of groundwater mounding and likely impact on the surrounding soils, it would be beneficial to accurately measure these rates to constrain the model results. If lower than expected surface evaporation rates are identified, which may result in the downstream spread of the groundwater mound, then seepage capture bores or trenches may be considered to help restrict the this spread. The likely efficacy of using this management strategy is shown in Figure 12 and Figure 13, assuming a seepage capture rate of 3 and 30 L/day/m^2, respectively.

3.1.2.2 Summary of Results

The pertinent findings from this investigation are:

- The groundwater system within the Supratidal Flats is effectively a closed system, which has experienced prolonged evaporative concentration of salts resulting in hypersaline conditions. This system is not connected to the marine environment or the underlying calcarenite aquifer.
- The elevated ‘natural’ salinities within the Supratidal Flats restrict the landward extension of mangroves, and thus the impacts from the Mardie Salt and SOP Project are expected to be minimal.
- The predicted process water quality, and hence potential seepage water quality, from the Brine Concentration Ponds, which represents the largest footprint area, is similar to the existing groundwater quality, and thus negligible impacts on groundwater quality in the Supratidal Flats is expected.
- Process water quality within the Crystallisers does exceed the surrounding natural environment, but the extent of seepage from these areas is significantly reduced by the precipitation of salts.
- Based on the data presented, the Mardie Salt and SOP Project is not expected to alter the local or regional groundwater quality.

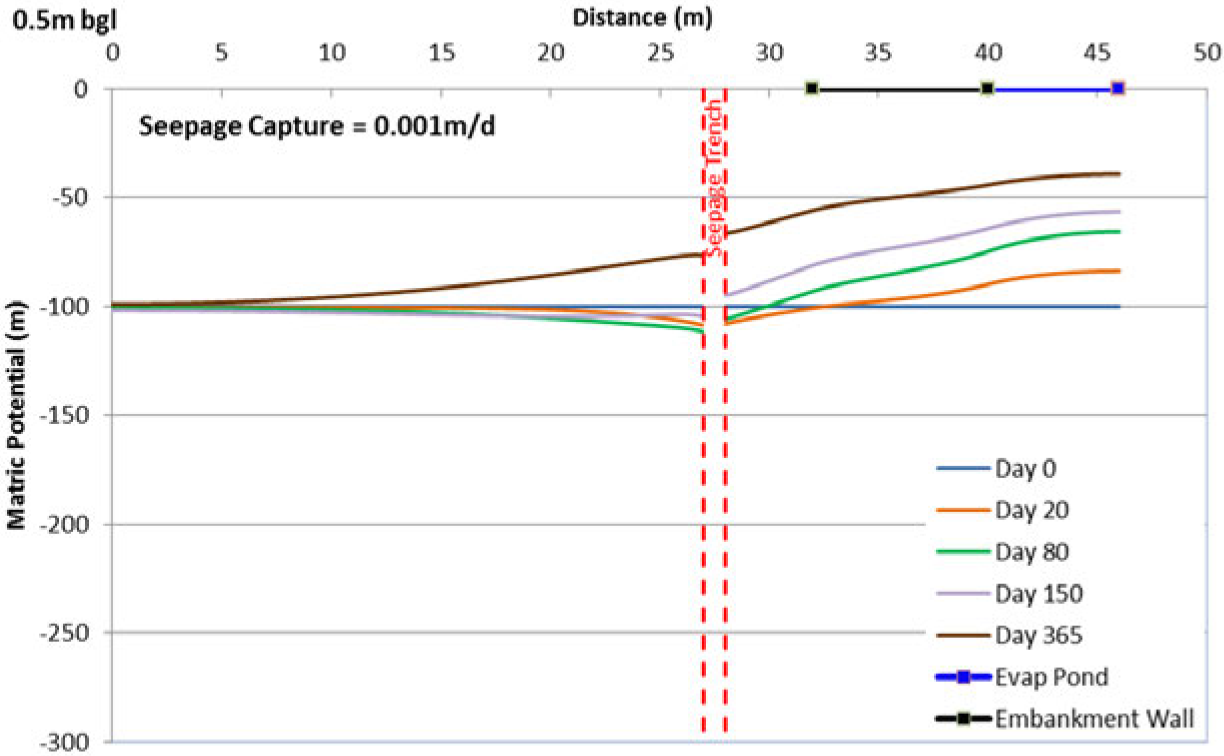


Figure 12: Predicted matric potential of *in situ* soils (at a depth of 0.5 m bgl), with a seepage capture trench installed, dewatering at a rate of 3 L/day per linear metre of trench

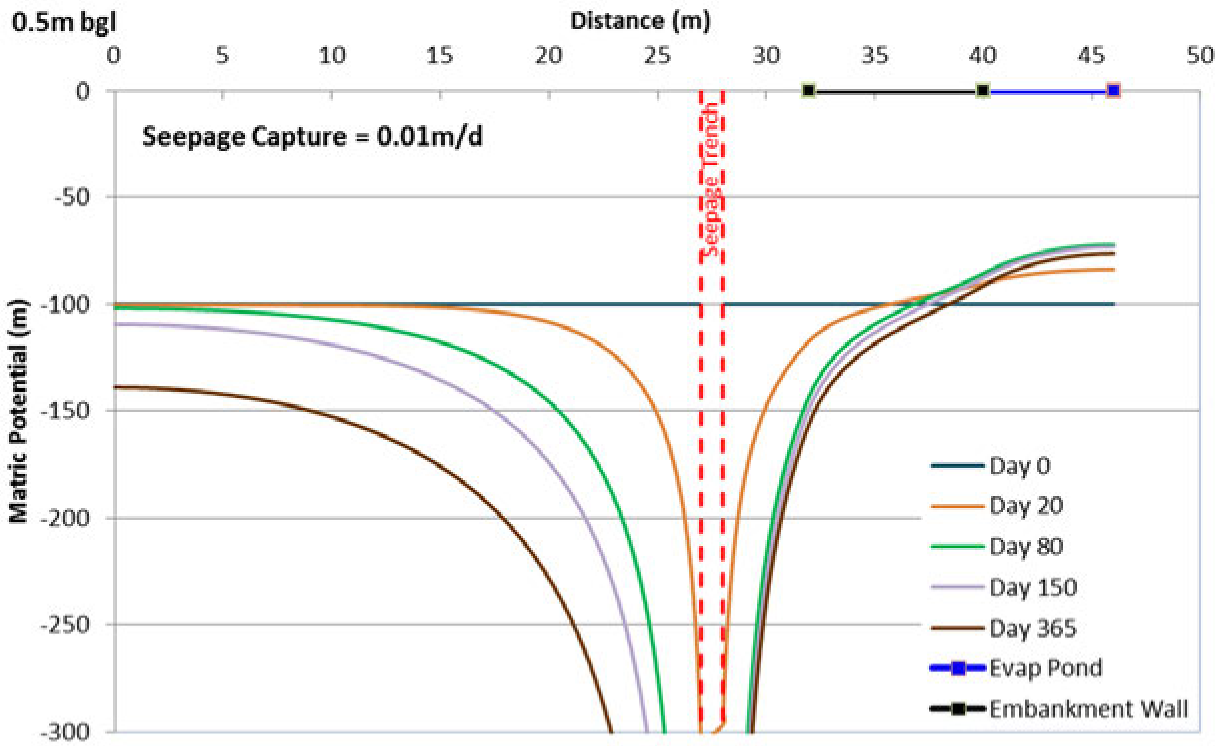


Figure 13: Predicted matric potential of *in situ* soils (at a depth of 0.5 m bgl), with a seepage capture trench installed, dewatering at a rate of 30 L/day per linear metre of trench

- Under realistic actual evaporation conditions, the spread of the groundwater mound under the Evaporation Ponds will not interact with the algal mats that occur downstream of the Evaporation Ponds, and no change in soil water dynamics is expected in the top 2 cm of the soil profile, which is the depth of soil that the algal mats depend on (Paling, 1990).
- If evaporation rates are lower than expected, resulting in a greater spread of the groundwater mound, then modelling has shown that seepage capture bores or trenches could be used, with potential extraction rates of up to 30 L/s/m^2 significantly reducing any downstream impacts.

3.1.3 Potential Impact of Seepage from Evaporation Ponds on Calcarenite Aquifer

As shown in the CHSM (Figure 14 and Figure 3), and discussed in more detail in SWC (2019), the Supratidal Flats are composed of a spatially complex array of alluvial, fluvial and tidal sediments that have an average depth of around 6 m. The properties of the various sedimentary layers or lenses can vary from heavy clays to clayey gravels based on the conditions of the depositional event. Geotechnical (SPT and Deep Borehole) drilling clearly shows that the gravelly clay lenses contain a sluggish, isolated hypersaline groundwater system, with a salinity equivalent to that likely to be achieved in the crystalliser ponds (i.e. EC up to 210,000 μS/cm or a TDS up to 147,000 mg/L). These groundwater lenses are likely to be isolated and separated by heavy, compact clayey soils that exist at field capacity (i.e. 10 kPa matric suction; around 40 – 45 % moisture by volume).

Concerns were raised in the ESD that the hydraulic head generated in the evaporation ponds may ‘push’ the hypersaline groundwater in the Supratidal Flats downwards into the ‘fresher’ calcarenite aquifer, impacting on its water quality and potential downstream receptors (if any). Unsaturated zone modelling was therefore undertaken to confirm if this interaction is likely to occur during the operation of the evaporation ponds.

3.1.3.1 Model Setup

The model setup for the Supratidal Flats is shown in Figure 14. Seepage from the Evaporation Pond was varied from 1.0 x 10^{-9}m/s (to reflect the seepage through the constructed clay liner) to 1.0 x 10^{-8}m/s (to reflect the potential increased seepage in response to osmotic suction). The model was run initial for 2 years to capture an operational period of 730 days, and then extended to the 80 years (29,200 days) to cover the proposed Life of Mine (LoM) of the operation. The additional input parameters and model conditions are specified in Table 2.

Table 2: Supratidal model input parameters and model conditions

Parameter	Value			Justification
Initial moisture content				These starting moisture values were
- Clay	-100 kPa (field capacity ~ 45 %; v/v)			laboratory determined from samples
- Gravelly Loam	-0.01kPa (saturation ~ 43 %; v/v)			collected in the field.
- Calcarenite	-330 kPa (~ 8 %; v/v)			
Water Retention Properties (v/v)	Clay	Gravelly Loam	Calcarenite	
- 0 kPa	0.51	0.43	0.40	Laboratory data was obtained on samples
- 10 kPa	0.47	0.37	0.10	of Clay and Gravelly Loam collected in the
- 33 kPa	0.36	0.28	0.07	field. Water retention properties of
- 100 kPa	0.34	0.25	0.05	calcarenite was set to reflect its
- 1,500 kPa	0.23	0.17	0.02	macroporosity.

van Genucthen parameters	Clay	Gravelly Loam	Calcarenite	
- Alpha (α; 1/cm)	0.011	0.016	0.882	van Genuchten parameters derived directly from the above water retention properties.
- n (-)	1.348	1.334	1.310	
- θ_s (cm^3/cm^3)	0.51	0.43	0.404	
- θ_r (cm^3/cm^3)	0.18	0.12	0	
Saturated Hydraulic Conductivity (mm/day)				These permeability values for the Clay and Gravelly Loam materials were determined on undisturbed cores collected in the field, whilst the value for the calcarenite was set to reflect its macroporosity
- Clay	1			
- Gravelly Loam	10			
- Calcarenite	1000			

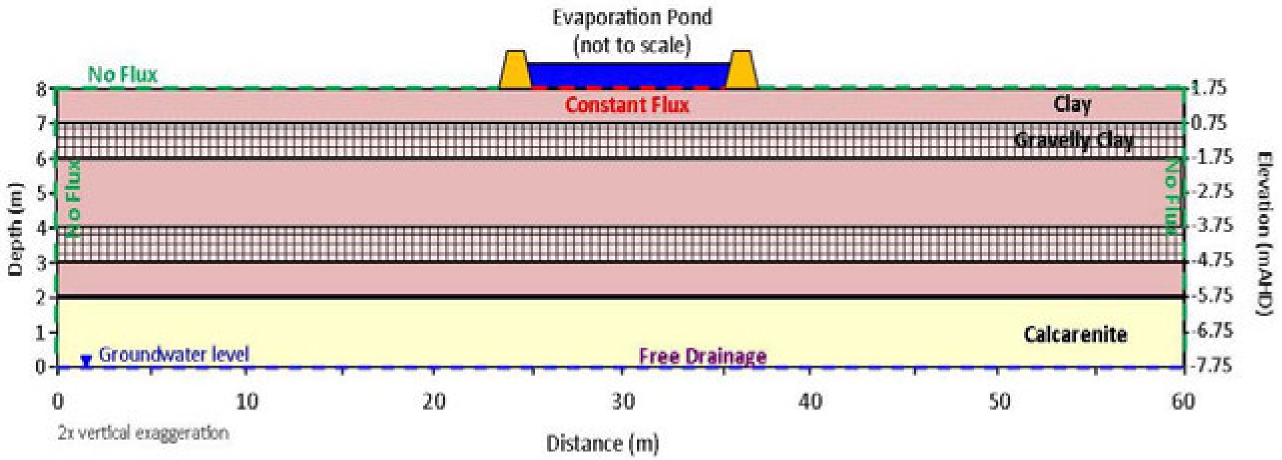


Figure 14: Model setup for the Supratidal Flats

The derived Soil Water Characteristic Curve and Hydraulic Conductivity Function (HCF) for the three soil materials are presented in Figure 15 and Figure 16.

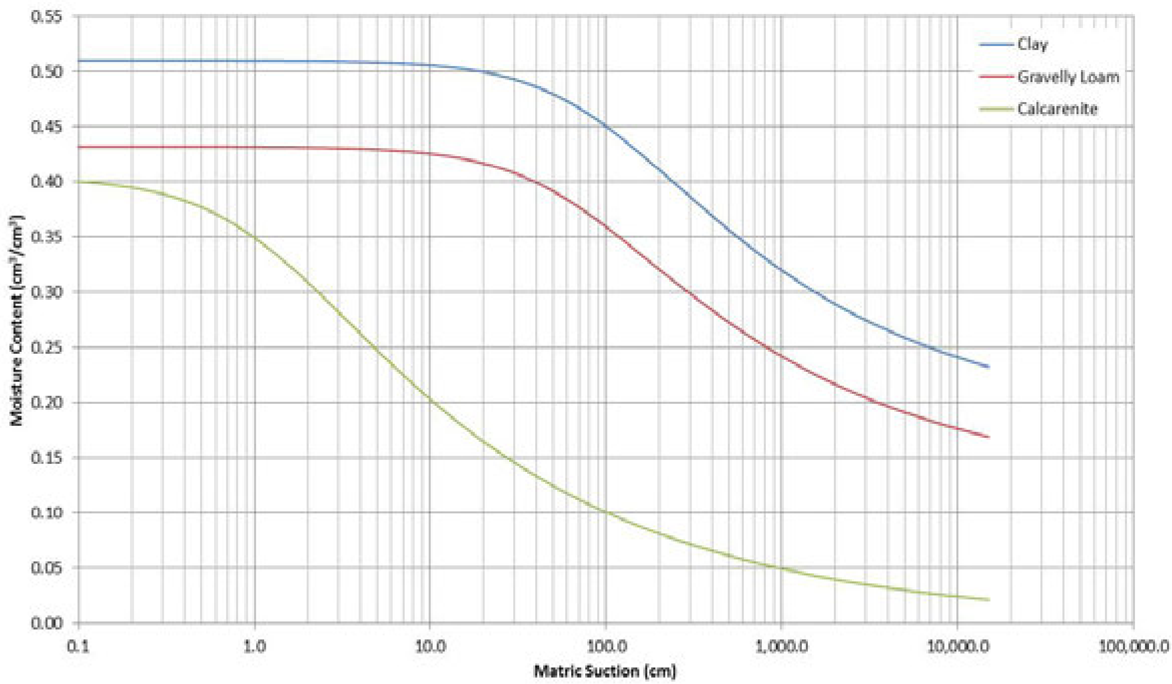
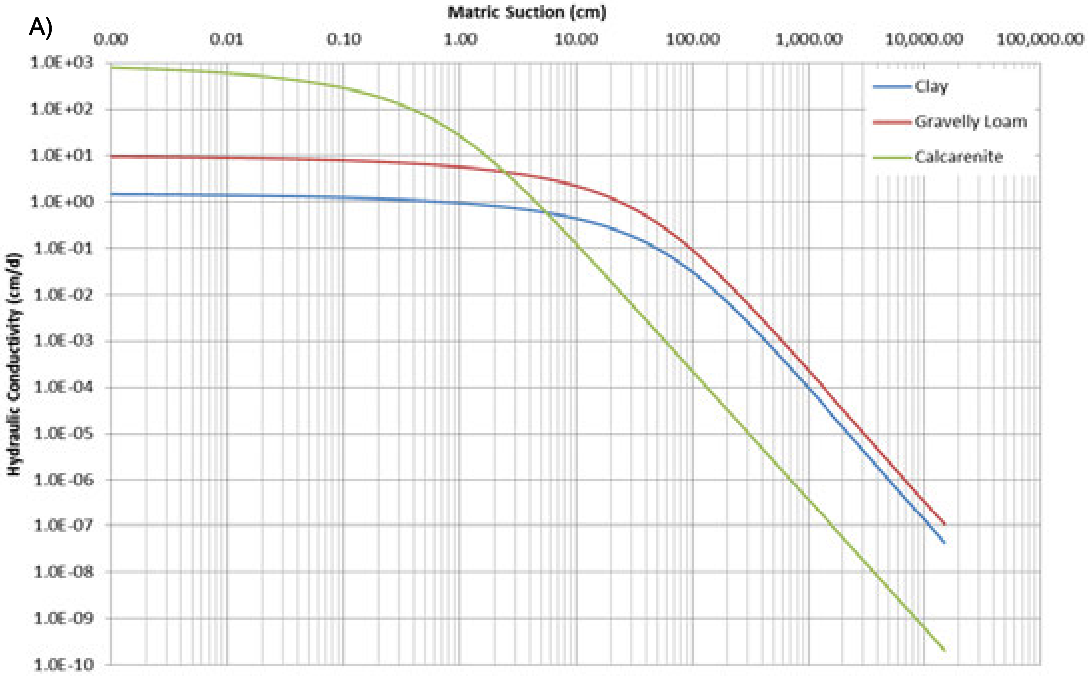


Figure 15: SWCC for the three materials modelled

A)



B)

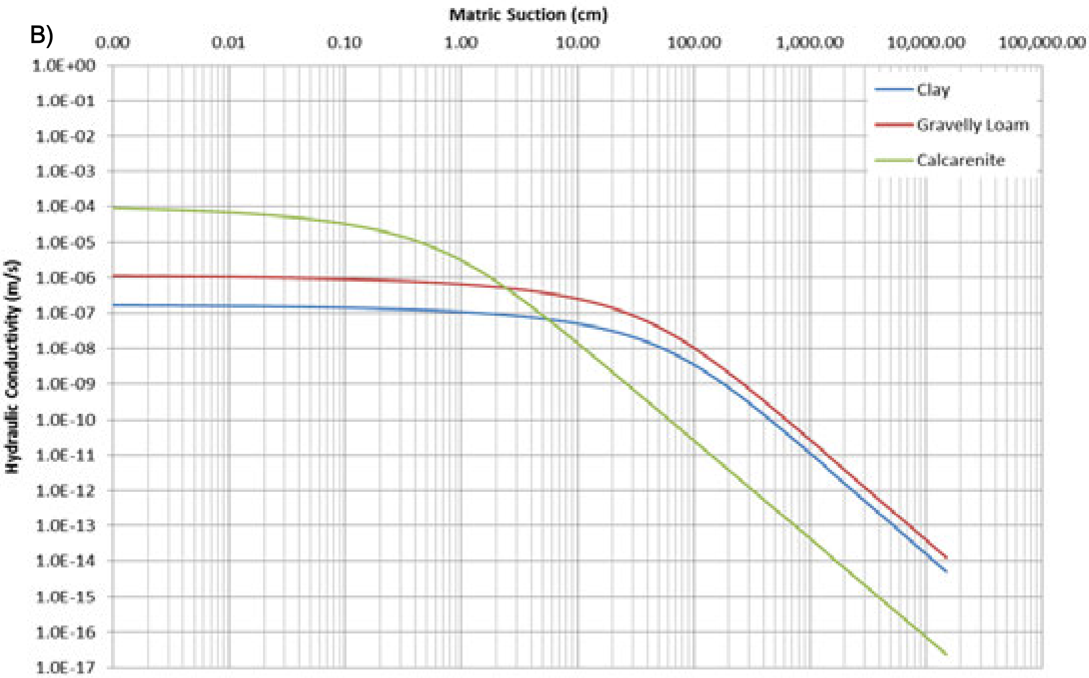


Figure 16: Derived Hydraulic Conductivity Function (HCF) for the three materials modelled A) Data expressed in cm/d, whilst B) Data expressed in m/s.

The HCF data presented in Figure 16 helps to explain the function of the Supratidal Flats. This data shows that at field capacity (i.e. 10 to 33 kPa) the clayey sediments, which separate the saturated gravelly loam lenses, have a permeability of around 10^{-8} or 10^{-9} m/s, and therefore they act as a natural clay liner or aquitard separating the saturated groundwater lenses and preventing groundwater in the Supratidal Flats from seeping into the underlying Calcarenite sediments.

In addition, the appreciably higher matric suctions occurring in the Supratidal Flats, due to its clayey nature, means that the majority of the stored moisture will not be released into the underlying Calcarenite sediments, until the overlying clays become fully saturated; which based on their very low permeability is unlikely to occur.

Furthermore, using the HCF data presented in Figure 16, an assumed seepage rate through the constructed clay liner of around 10^{-9} m/s equates to a matric suction of around 200 kPa, which is lower than the *in situ* field capacity of the clayey soils; hence the expected seepage from the evaporation ponds is likely to be slower than the *in situ* permeability of the soils.

All of the above information provides the reasoning behind the very low likelihood of any hypersaline seepage from the evaporation ponds reaching and interacting with the underlying Calcarenite aquifer.

3.1.3.2 Model Results

The model results for the initial two years of operation, assuming a 10^{-9} m/s seepage rate, are presented in Figure 17 and Figure 18, whilst the model results for a 10^{-8} m/s seepage rate, for the same time period, are shown in Figure 19. The results show that overtime the seepage from the Evaporation Pond/s slowly displaces the stored moisture in the underlying sediments, resulting in the downward movement of the wetting front.

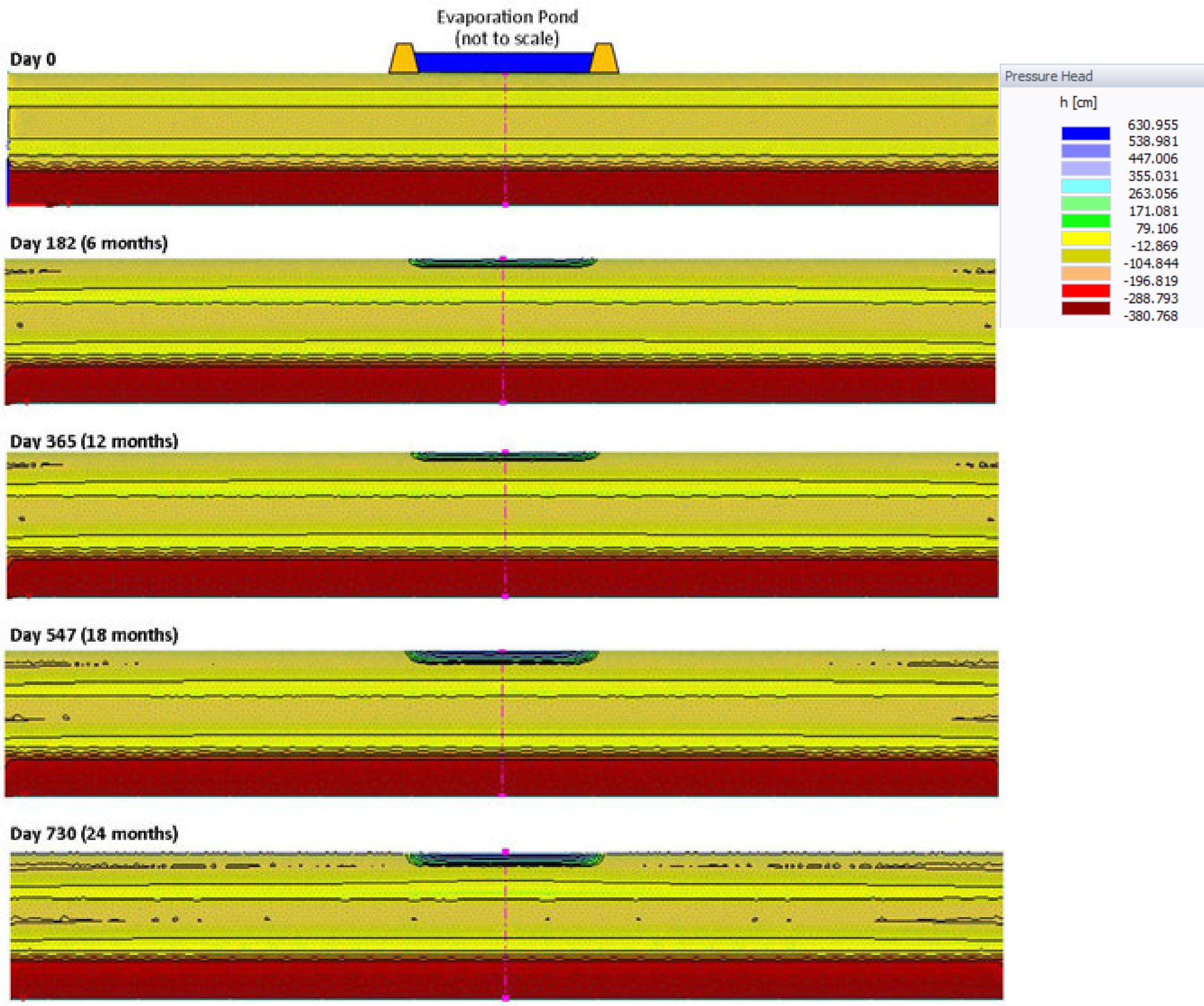


Figure 17: Evaporation pond model results

For the 10^{-9} m/s seepage rate, positive matric potentials (i.e. > 0 kPa) will likely develop to around 25 cm depth over the entire evaporation pond floor after 6 months of operation. After one year, fully saturated conditions will extend to 50 cm depth, whereas at one and a half years it will reach 75 cm depth, where it will remain.

Although seepage from the evaporation ponds will likely cause a redistribution of stored soil moisture in the Supratidal Flats, a total of only 2 mm of seepage is expected to reach the Calcarenite Aquifer, which equates to a seepage rate of 0.003 mm/day (Figure 18).

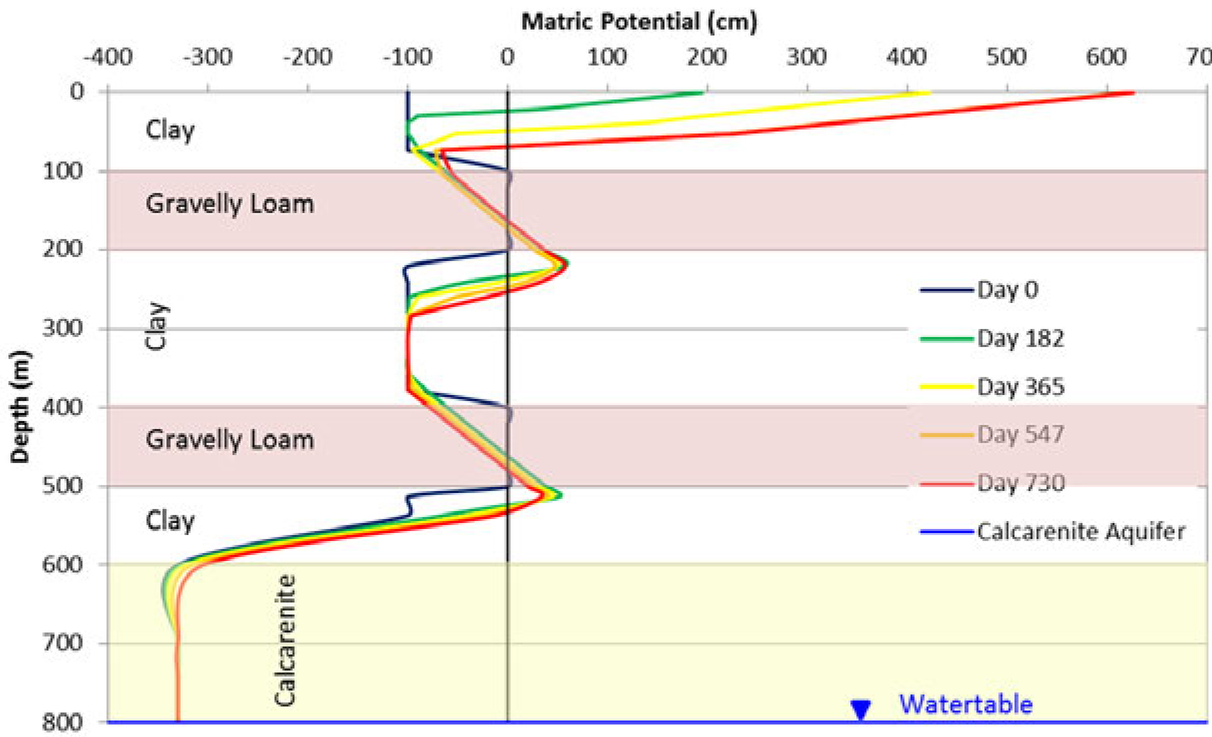


Figure 18: Predicted pressure head depth profiles below the proposed Evaporation Ponds for 10^{-9} m/s seepage rate

Even if the potential seepage from the Evaporation Ponds is increased by an order of magnitude, to 10^{-8} m/s, resulting in a significant saturation of the Supratidal Flats to a depth of over 3 m (after two years; Figure 19), negligible seepage reaches the Calcarenite sediments and very little actually interacts with the Calcarenite Aquifer (6.8 mm after two years; or 0.009 mm/day).

The modelling results for the 80 year (i.e. LoM) period, assuming a 10^{-9} and 10^{-8} m/s seepage rate, are provided in Figure 20 and Figure 21. The results show that it takes approximately 20 years for the seepage front from the Evaporation Ponds to reach the calcarenite aquifer, and that after 80 years only 25 cm of seepage into the watertable has occurred. When this rate (i.e. 25 cm seepage over 80 years) is expressed in m/s, it equates to 9.91×10^{-11} m/s, which is two orders of magnitude lower than the accepted 10^{-9} m/s seepage rate for clay liners (DoW, 2013).

3.1.3.3 Summary of Results

The above modelling results clearly show that the proposed Evaporation Ponds, and generation of positive pressure heads at the surface during operations, will not result in an appreciable interaction with the Calcarenite Aquifer and the water quality of this aquifer is expected to remain unimpacted.

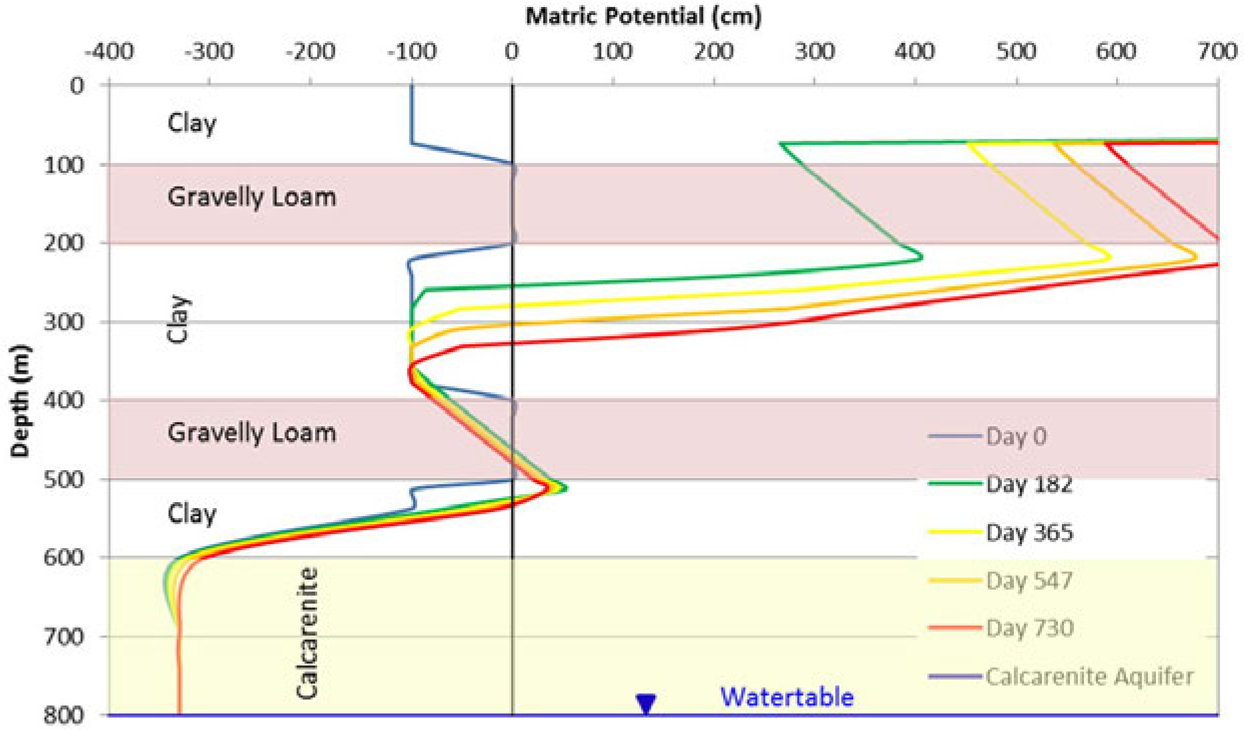


Figure 19: Predicted pressure head depth profiles below the proposed Evaporation Ponds for 10^{-8} m/s seepage rate

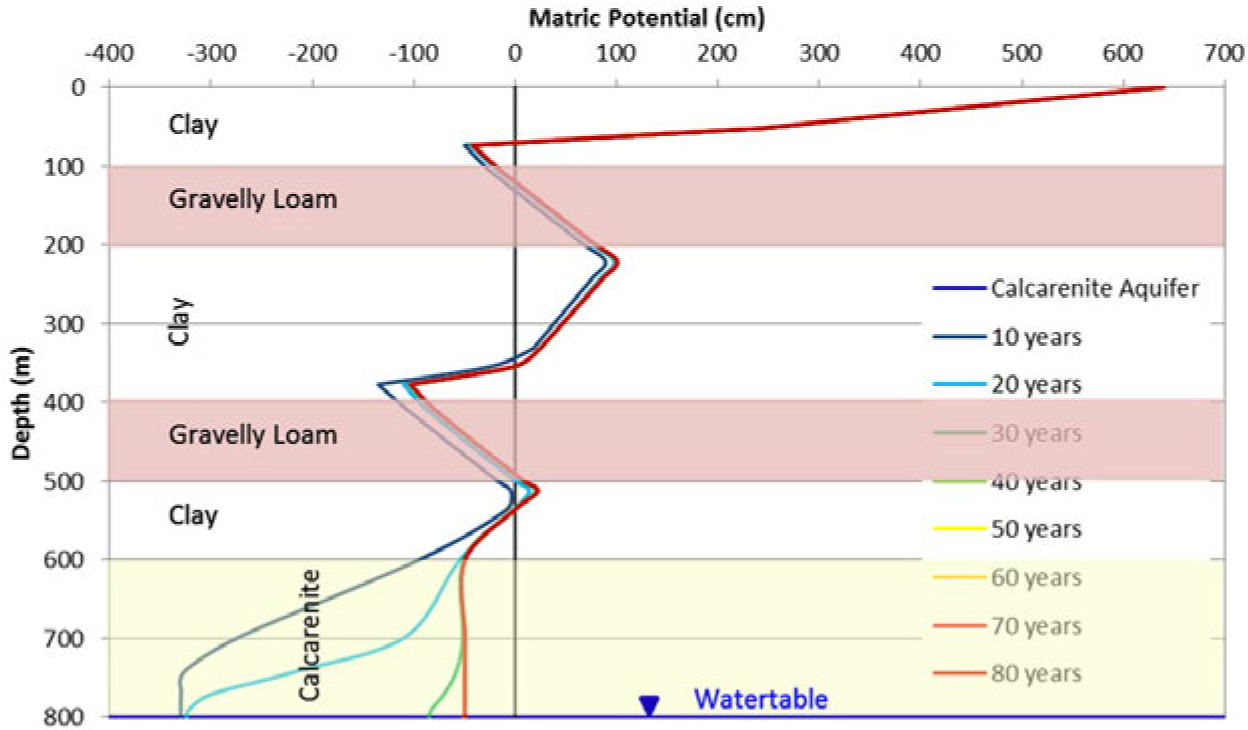


Figure 20: Predicted pressure head depth profiles below the proposed Evaporation Ponds for 10^{-9} m/s seepage rate for the 80 year LoM

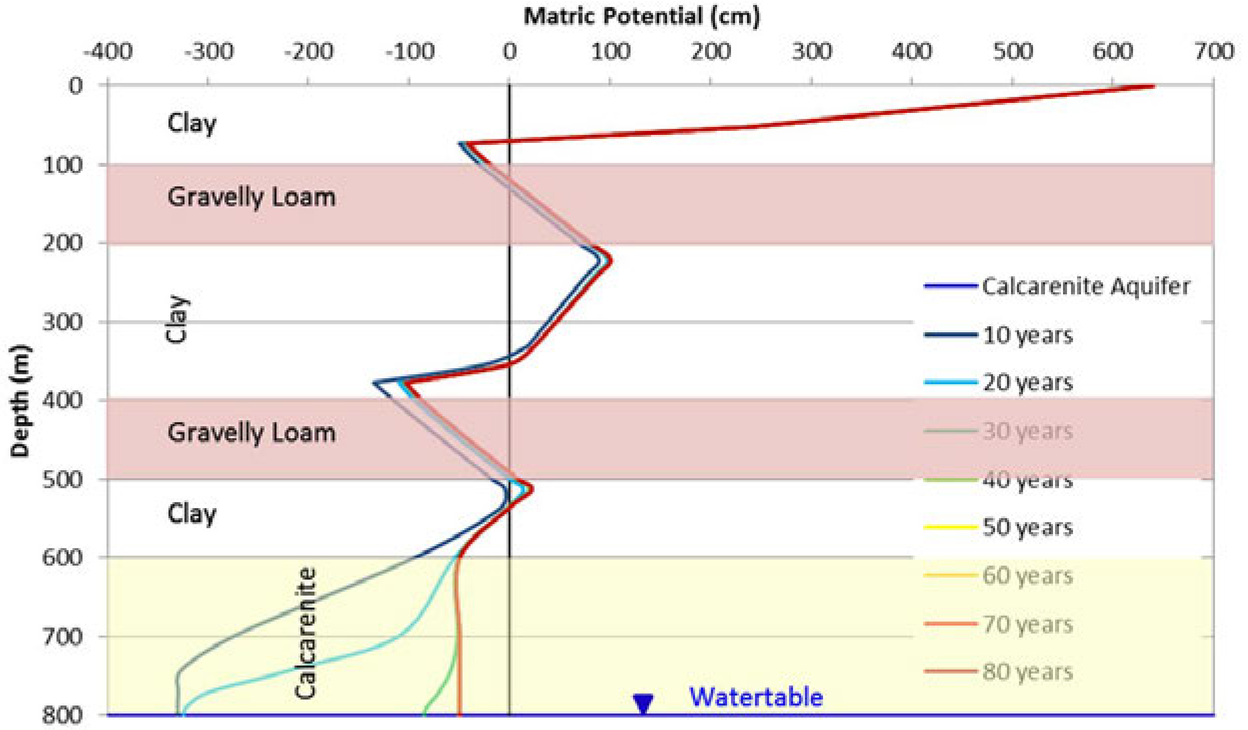


Figure 21: Predicted pressure head depth profiles below the proposed Evaporation Ponds for 10^{-8} m/s seepage rate for the 80 year LoM

3.1.4 Potential for Preferential Flows to Occur Through the Calcarenite Islands

During the construction and operation of the Evaporation Ponds there is a possibility that outcropping Calcarenite within the Supratidal Flats will be truncated at the surrounding clay surface to form part of the Pond Floor. Given the coarse textured nature of the Calcarenite there is a risk that they may result in preferential or bypass flow of seepage through the Supratidal Flats resulting in an interaction with the underlying Calcarenite Aquifer.

3.1.4.1 Model Setup

To model the above scenario and establish whether preferential flows may occur through the truncated Calcarenite Islands the model setup shown in Figure 22. The model was run for a two year period (730 operational days) using a 10^{-9}m/s and 10^{-8}m/s seepage rate.

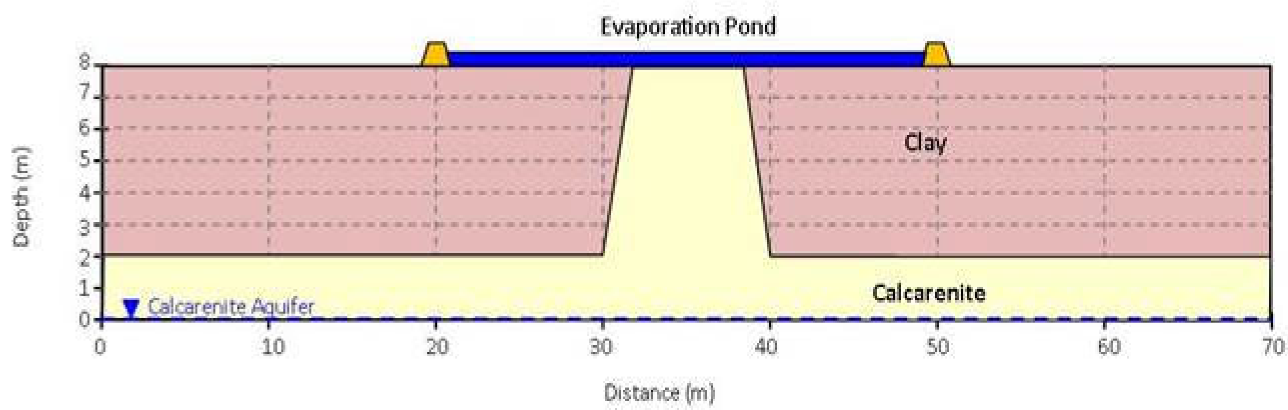


Figure 22: Model setup to assess the potential for preferential flows to occur through the Calcarenite Islands

3.1.4.2 Model Results

The model results for the 10^{-9}m/s seepage rate after 2 years of operation are shown in Figure 23. The results show that limited seepage occurs into the Calcarenite material, with seepage only down to approximately 1m depth. Significant seepage only occurs in the clays due to the continuity of small pores; hence the wetting front is 'sucked' downwards.

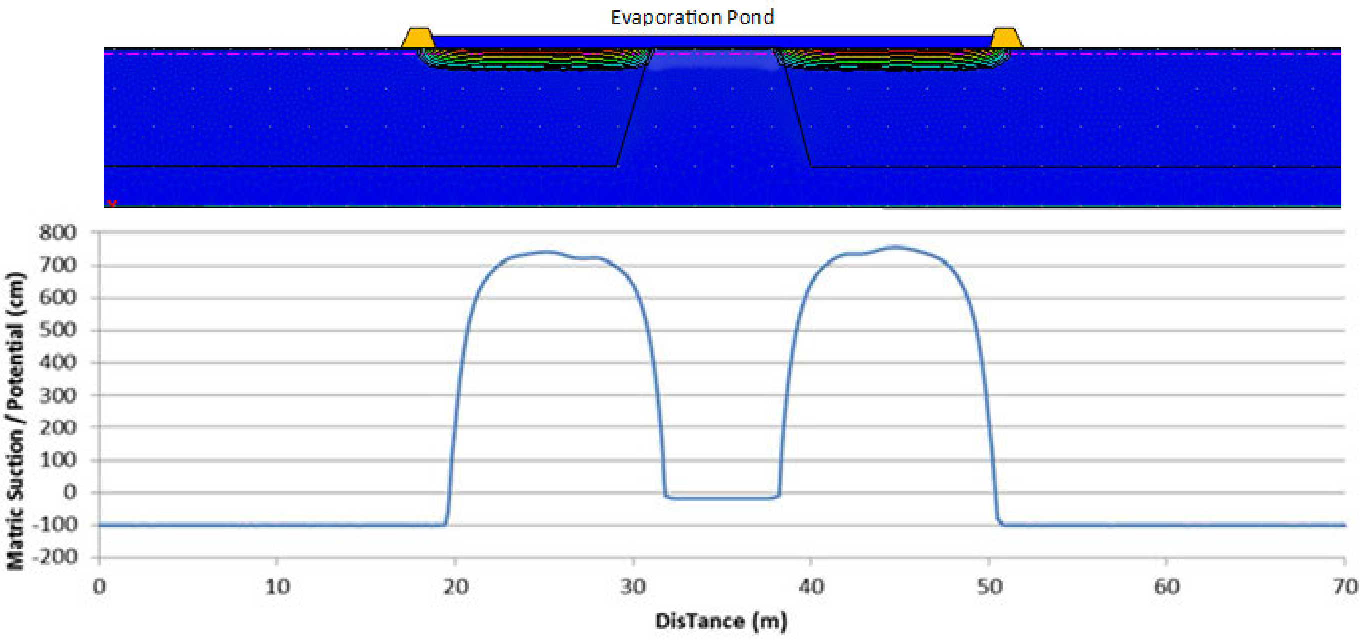


Figure 23: Model results for a 10^{-9}m/s seepage rate after 2 years of operation

Results for 10^{-8}m/s seepage rate after 2 years of operation are shown in Figure 24. Even under an order of magnitude increase in seepage rate, seepage will not preferentially flow down the macroporous Calcarenite material due to the discontinuity in pore size.

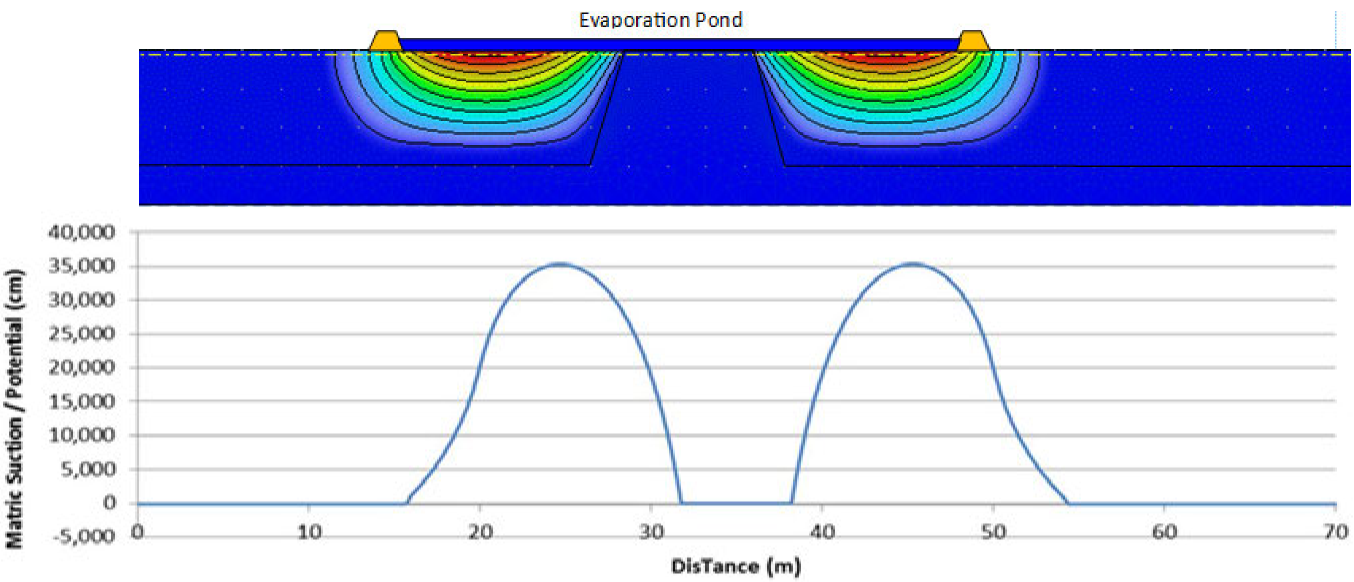


Figure 24: Model results for a 10^{-8}m/s seepage rate after 2 years of operation

3.1.4.3 Summary of Model Results

Based on the above results, as long as there is a compacted clay liner on the floor of the evaporation ponds, preferential seepage will not occur down the Calcarenite Islands and thus there is no increased risk of impact to the Calcarenite Aquifer. The reason preferential or bypass flow doesn't occur is due to the pore size discontinuity between the compacted clay liner and the macroporous Calcarenite; hence the compacted clay liner will not release water into the underlying Calcarenite material.

3.1.5 Brine Seepage from Crystalliser Ponds and the Potential Impacts on Mardie Pool

The Crystalliser Ponds on the eastern side of the Project Area are located within the Cane River Zone Regional Land System, which consists of 3 – 6 m of Aeolian sands and sandy loam soils overlying the Calcarenite material which dips below the western Supratidal Flats (Figure 2 and Figure 3). The southern margin of the Crystalliser Ponds is located approximately 250 m north of Mardie Pool (Figure 25 and Figure 26), which is considered an important environmental receptor as it represents a permanent 'fresh to brackish' surface water body.

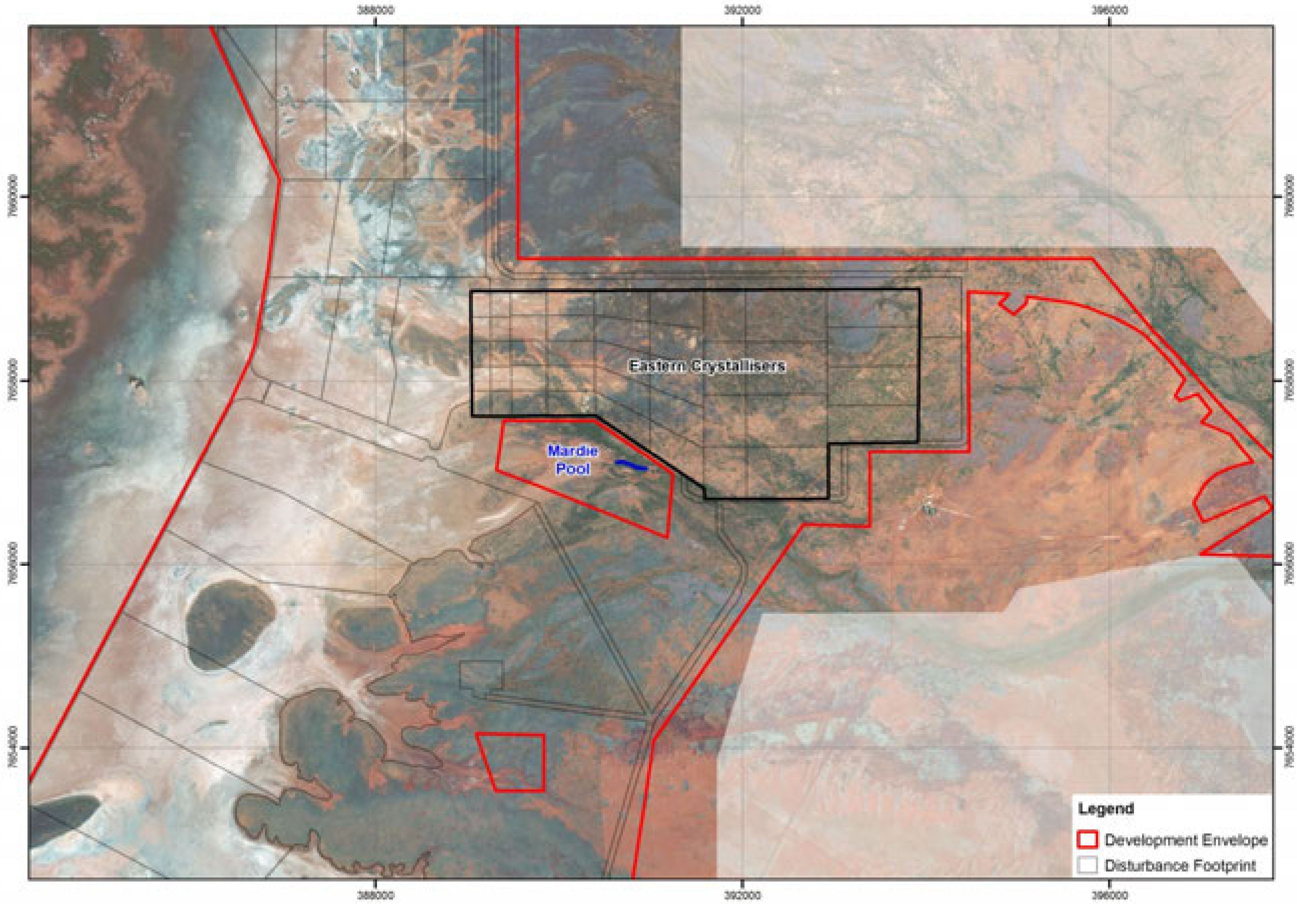


Figure 25: Location of the Eastern Crystallisers and Mardie Pool

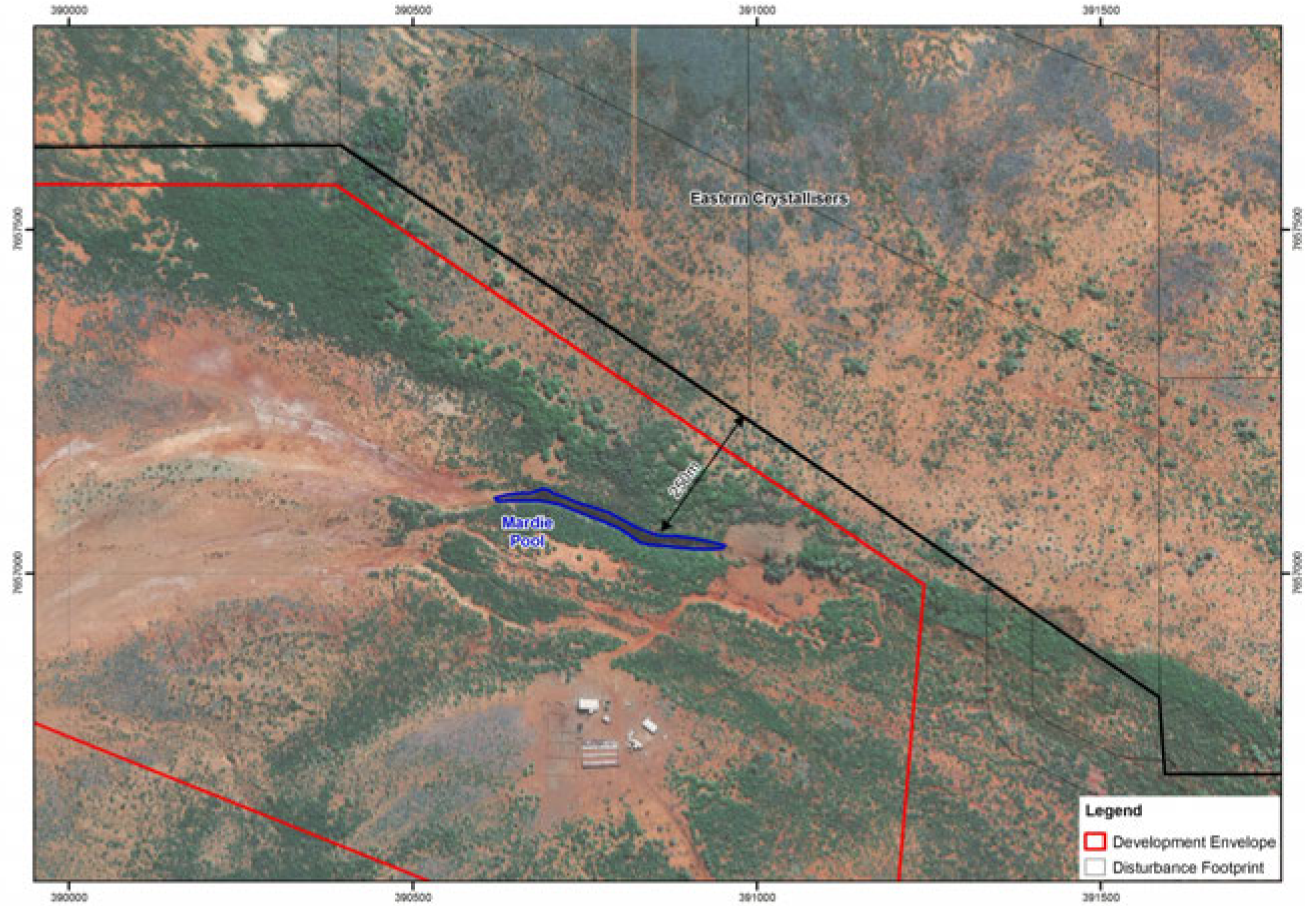


Figure 26: Distance of the Eastern Crystallisers from Mardie Pool

3.1.5.1 Model Setup

To establish whether hypersaline seepage from the eastern Crystalliser Ponds will impact on the water quality of Mardie Pool, the model setup shown in Figure 27 was used.

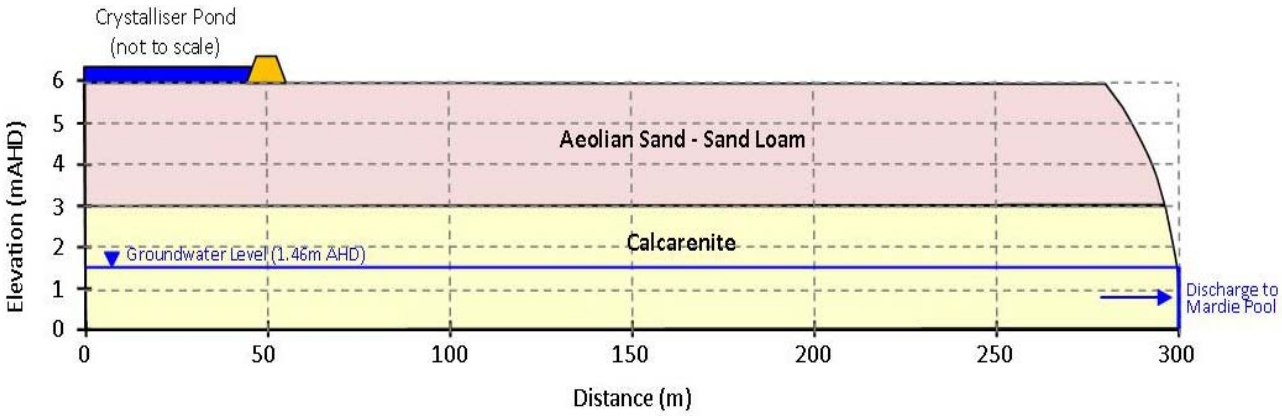


Figure 27: Stratigraphic profile underlying the eastern Crystalliser Ponds

Seepage from the Crystalliser Ponds is expected to have a salinity of around 230,000 µS/cm (or 160,000 mg/L TDS). For this modelling the seepage rate was varied from -10^{-9} m/s (to reflect initial seepage through the constructed clay liner) to 10^{-7} m/s (to reflect potential increased seepage as function of osmotic suction). The hydraulic properties of the Calcarenite material was the same as that used in the Evaporation Model (Table 2), whilst the hydraulic properties of the Aeolian sand are provided in Table 3. The starting moisture content for all materials was set at field capacity (10 kPa).

Table 3: Hydraulic properties of the Aeolian sand

Parameter	Value	Justification
Water Retention Properties (v/v)		
- 0 kPa	0.41	Data obtained from laboratory measurements on Aeolian sand collected in the field.
- 10 kPa	0.36	
- 33 kPa	0.32	
- 100 kPa	0.22	
- 1,500 kPa	0.12	
van Genuchten parameters		
- Alpha (α; 1/cm)	0.005	van Genuchten parameters derived directly from the above water retention properties.
- n (-)	1.451	
- θ_s (cm^3/cm^3)	0.404	
- θ_r (cm^3/cm^3)	0.070	
Saturated Hydraulic Conductivity (mm/day)	1.061	Data obtained from laboratory measurements on Aeolian sand collected in the field.

The derived Soil Water Characteristic Curve and Hydraulic Conductivity Function (HCF) for the Aeolian Sand are presented Figure 28 and Figure 29.

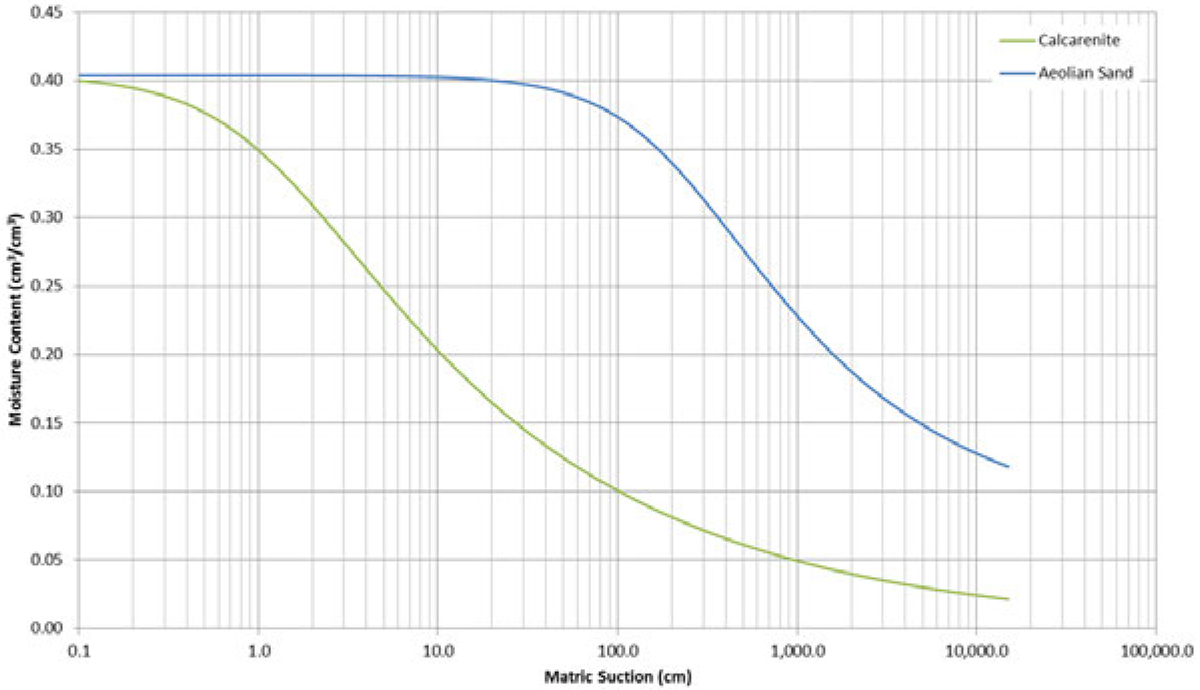


Figure 28: SWCC for the two materials modelled

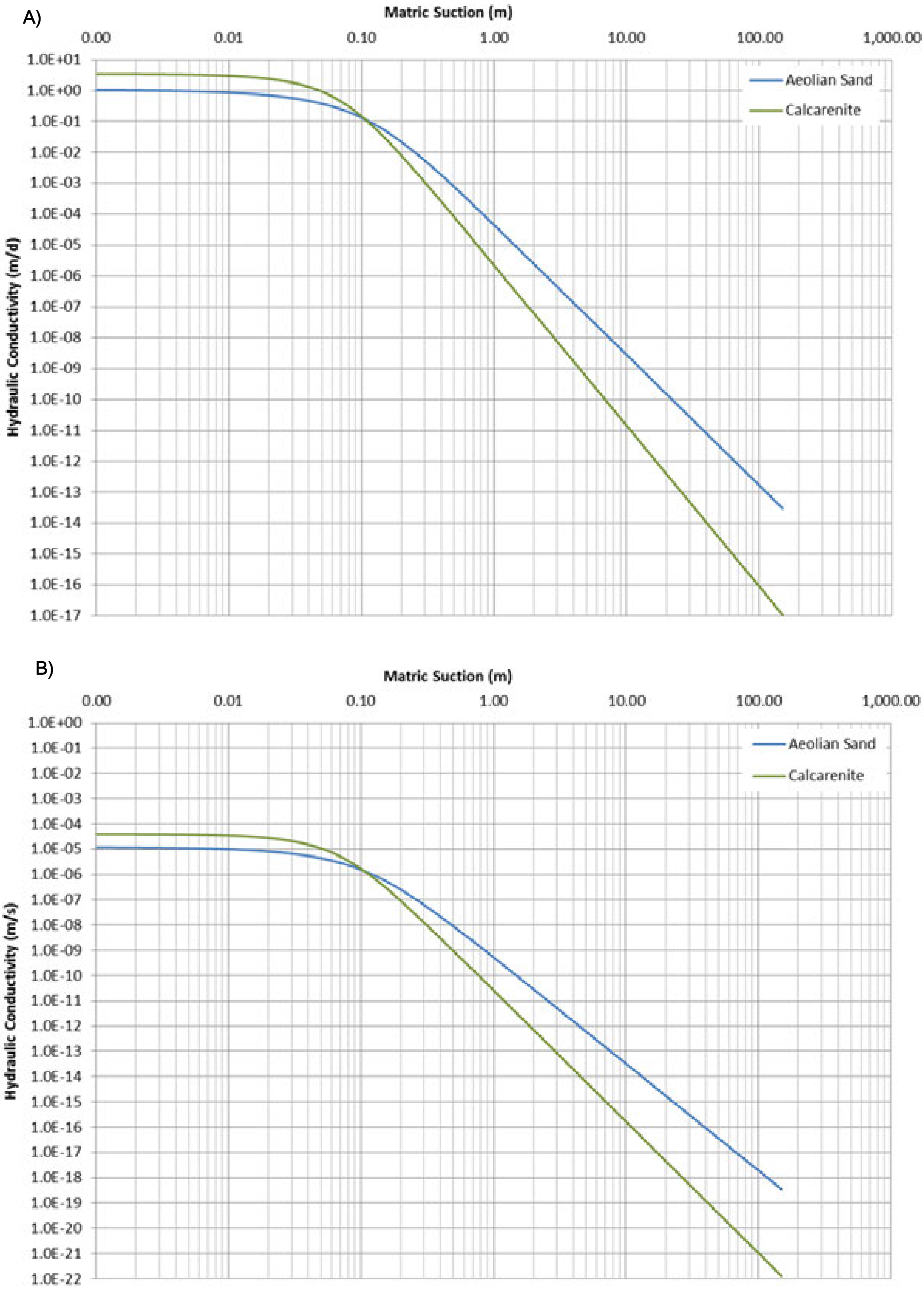


Figure 29: Derived Hydraulic Conductivity Function (HCF) for the two materials modelled A) Data expressed in m/d, whilst B) Data expressed in m/s.

3.1.5.2 Model Results

The model results for the 10^{-9}, 10^{-8} and 10^{-7} m/s seepage rates are provided in Figure 30 to Figure 32. The results show the Chloride (Cl^-) concentration (in mmol/m^3), such that 5,600 mmol/m3 is equivalent to a Cl^- concentration of 200,000 mg/L. It was assumed that the Cl^- was an inert trace and did not undergo chemical reaction or retardation during transport.

If the seepage below the Crystalliser Ponds remains at 10^{-9} m/s, then after two years of operation the salinity / seepage front has only moved approximately 1 m below the pond floor (Figure 30). The reason for this negligible transport is that according to the HCF (Figure 29) the permeability of the Aeolian Sand at field capacity (i.e. 10 kPa or 1 m matric suction) is itself around 10^{-9} m/s and thus as the wetting front moves through the Aeolian Sand it continually encounters dry, low permeability soil which impedes its downward movement.

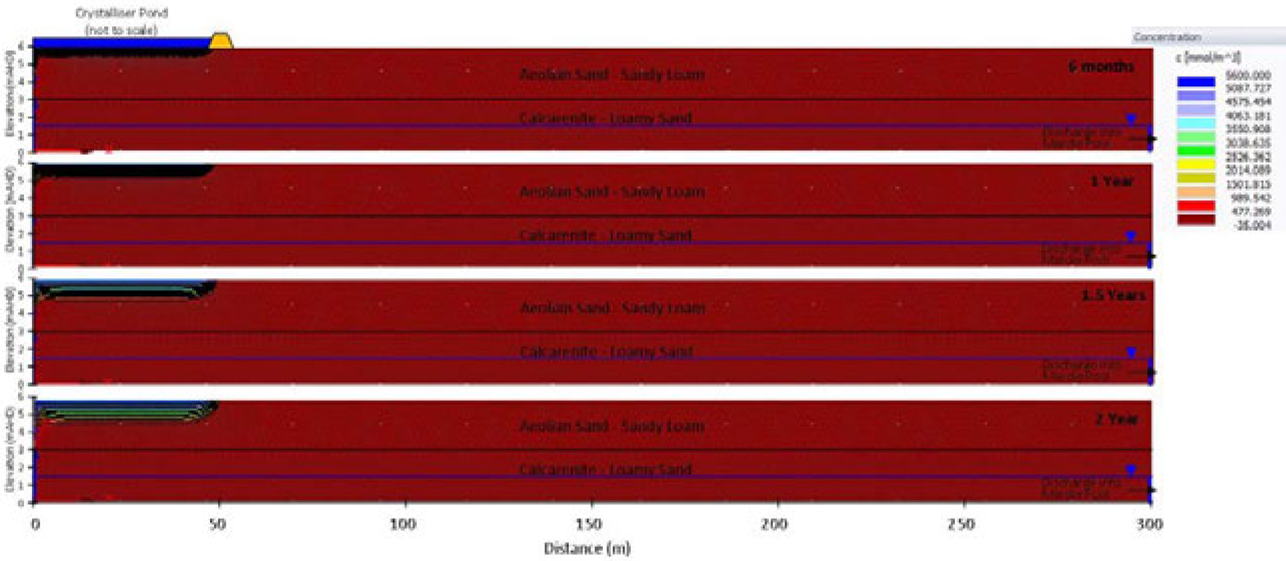


Figure 30: Salt seepage below the Crystalliser Pond/s assuming a seepage rate of 10^{-9} m/s

If the seepage rate below the Crystalliser Ponds increases to 10^{-8} m/s, possibly in response to osmotic suction 'pulling' seepage water downward, then the salinity front is expected to reach the underlying Calcarenite Aquifer in around 1.5 years (Figure 31), after which time it will rapidly move towards Mardie Pool at a rate of around 1 m/day. It is expected that the salinity front from the Crystalliser Ponds would reach Mardie Pool by Year 3.

If in the unlikely event that the seepage rate below the Crystalliser Ponds is around to 10^{-7} m/s, then the salinity front will reach the Calcarenite Aquifer in 6 months and by 1.2 years it has reached Mardie Pool (Figure 32).

3.1.5.3 Summary of the Model Results

Based on the above model results, there is a potential that saline seepage from the eastern Crystalliser Ponds may intersect and impact Mardie Pool depending on the long-term seepage rates achieved. It would therefore be prudent to install groundwater monitoring bores along the southern margin of the Crystalliser Ponds to establish whether such seepage is occurring and to determine the rate at which it is moving towards Mardie Pool. If the salinity front is detected, and it is considered that there is a risk to the quality of Mardie Pool, then seepage capture bores may be required to halt the progress of the salinity front.

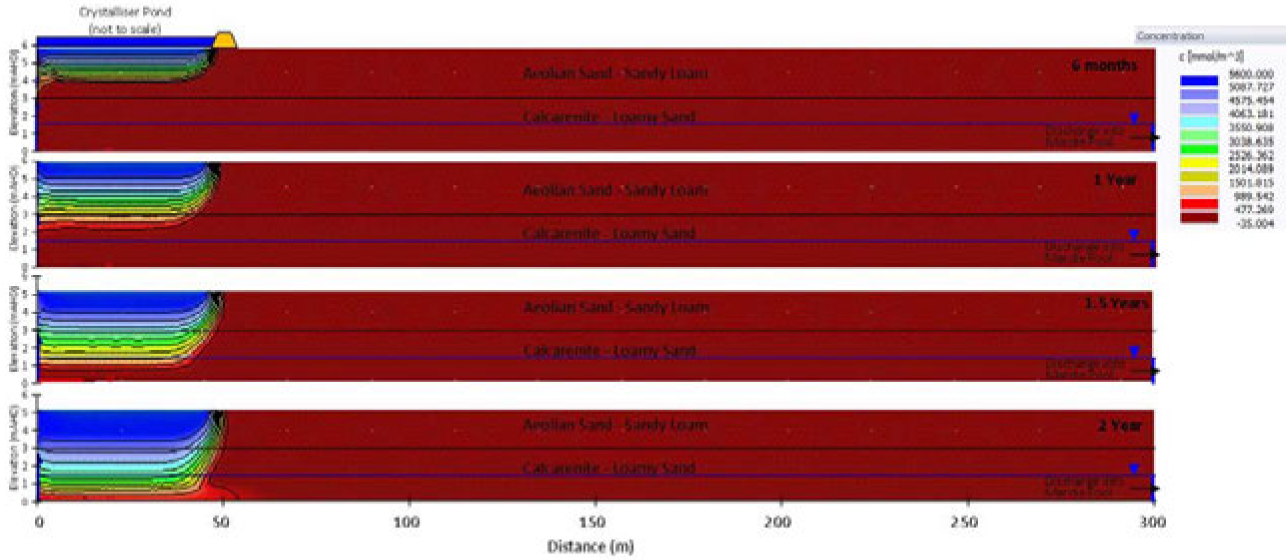


Figure 31: Salt seepage below the Crystalliser Pond/s assuming a seepage rate of 10^{-8} m/s

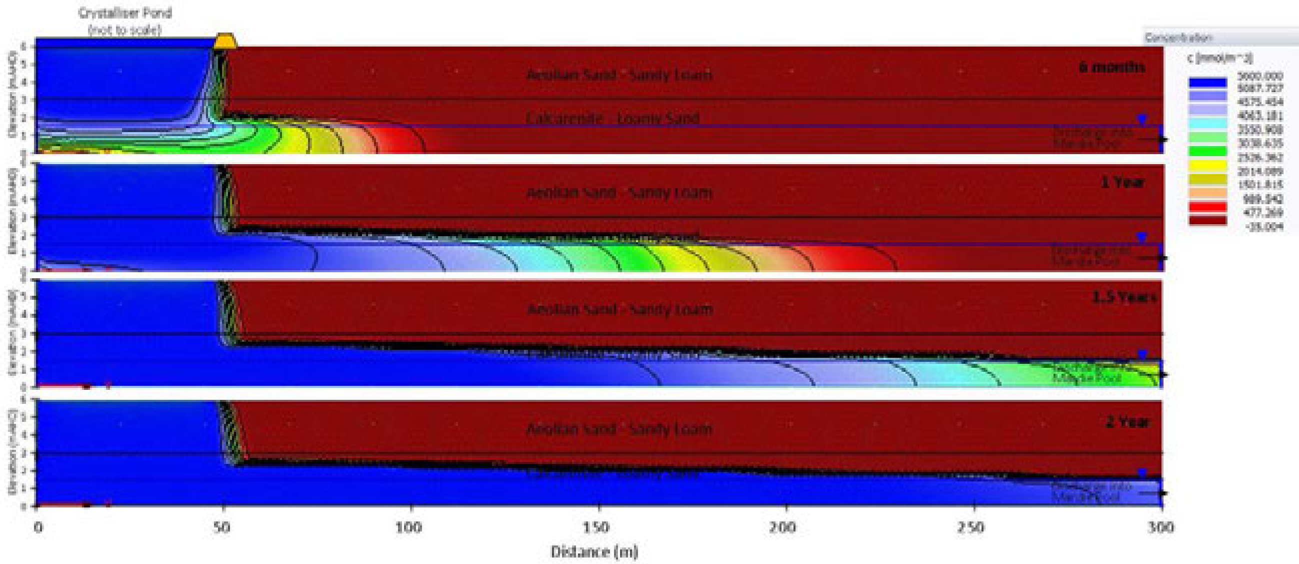


Figure 32: Salt seepage below the Crystalliser Pond/s assuming a seepage rate of 10^{-7} m/s

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Should you have any queries regarding this report, please do not hesitate to contact us.

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