Fingerboards Mineral Sands Project Inquiry and Advisory Committee Technical note

TN No: TN 026

Date: 24 May 2021

Subject: Further information relating to seepage rates

On 14 May, during the cross-examination of Mr Joel Georgiou, Counsel for the EPA called for copies of any documents seen by Mr Georgiou relating to seepage rates, regardless of whether they had formed part of the numerical groundwater modelling described in Appendix B to Groundwater and Surface Water Impact Assessment. This was qualified by the IAC's observation that any information provided should be in a form capable of being interpreted. In response to that call, the following documents are provided:

1. A moisture migration report prepared by the Centre for Bulk Solids and Particle Technologies at the University of Newcastle, NSW (**Attachment 1**). As indicated by Mr Georgiou in his presentation slide 32, the MODFLOW software used to undertake the groundwater modelling does not (because it cannot) consider 'specific retention' - that is, the percentage of water retained by rock or soil against the pull of gravity. In this regard, the modelling is conservative because it assumes all the water in the tailings can leave the tailings. What the soil moisture report indicates is that once the moisture content falls to approximately 23.1%, the sand tails will cease to drain.

2. A presentation prepared for the purposes of informing the development of the Work Plan post-EES describing the results of preliminary modelling undertaken using the SEEP/W software package (**Attachment 2**). As explained by Mr Georgiou, the groundwater modelling has assumed that the water in the tailings will travel immediately from tailings to the water table. In actual fact, the water will have to traverse the distance between the bottom of the pit and the water table and this will take time. MODFLOW is unable to model this process, so EMM undertook further modelling to establish a more realistic seepage rate for the purpose of preparing an updated Work Plan if the Project receives a favourable assessment. As set out in Attachment 2, the modelling suggested a seepage rate of between 0.3 and 7 L/s per pit through the Coongulmerang Formation is a more realistic estimate of seepage rates, with the lower figure regarded as more plausible on current information.

The information in the University of Newcastle report did not form part of the numerical groundwater modelling presented in the EES, because the MODFLOW software used for that modelling is unable to incorporate the seepage information presented in that document. Further, as indicated by the date, the SEEP/W modelling was undertaken after completion of the modelling for the EES.

In addition to the two documents described above, **Attachment 3** is an updated presentation, prepared by EMM following a review of the preliminary modelling. This attachment was not considered by Mr Georgiou but is included for fairness and completeness as it predicts a higher level of seepage than the preliminary modelling in Attachment 2, although still lower than the rate used in the EES. EMM advises that the higher seepage rate is a result of simulating tailings with a more accurate representation, post discussion with software developer.

Attachment 1

Centre for Bulk Solids and Particulate Technologies

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Research project to identify moisture migration and transportable moisture limit for a sand tailing

To:	Kalbar Resources	Date:	05/07/2019
Attention:	Neil O'Loughlin		
Email:	neil.oloughlin@kalbarresources.com.au	From:	Jian Chen, Jie Guo, Kenneth Williams

DISCLAIMER

For clarification, regarding any aspects contained within this report, please contact the Centre for Bulk Solids and Particulate Technologies (CBSPT), Newcastle Institute for Energy and Resources, The University of Newcastle, NSW, Australia. Should the properties of the materials handled in practice vary from those tested, the anticipated outcomes based on the conclusions specified in this report may differ. Any extrapolation of the data and/or recommendations to situations other than those intended may lead to erroneous conclusions. The contents of this report may not be reproduced without the consent of the client; and then only in full.

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TABLE OF CONTENTS

1 EXECUTIVE SUMMARY

This research project was commissioned by Kalbar Resources to investigate the moisture migration of a sand tail under static conditions for two different starting moisture contents. The two samples of sand tailing were compacted into separate columns and left to drain for a period of 20 days, after which the migration of moisture was assessed.

A summary of project findings include:

- Moisture migration towards the bottom of the stack occurred for the sand tailing prepared at an initial moisture of 20%, with minimal drainage out the porous base.
- Water drained out of the over saturated sample of sand tailing initially prepared at 27% until an average moisture content of approximately 23.1% was reached throughout the stack of material.
- The majority of water drainage out of the over saturated sample occurred in the first 30min of test time
- The wet bulk density was higher for the sand tailing with an initial moisture content of 27%, than the initial moisture content of 20%.
- During loading, a moisture content of approximately 16.8% will likely occur at the free surface of the stockpile or at the top of the ship hold with increasing moisture occurring through the pile to the base
- The upper moisture holding limit for the sand tailing will be approximately 23.6%, which will occur at the base of the stockpile or ship hold

The requirements of this study are encompassed by PO100778 dated 11th April 2019.

2 BULK MATERIAL SAMPLES TESTED

The project involved testing of the supplied sand tailing.

3 COMPACTION AND DRAINAGE METHOD

The experimental equipment used for this investigation is an oscillatory type drainage tester designed and built at the University of Newcastle. An overview of the system is shown in Figure 1. The experimental system is comprised of a drainage bench and an oscillatory frame. The drainage bench accommodates six material columns. For this project, two columns were used and each material column was stacked up with six Perspex cells. The inner diameter of each cell is 140 mm and the height of each cell is 80 mm. Under each material column, a steel mesh layer with aperture size of 45 μm is fitted, which allows water to drain. A load cell is placed under each water collector to monitor and record any water mass change over time.

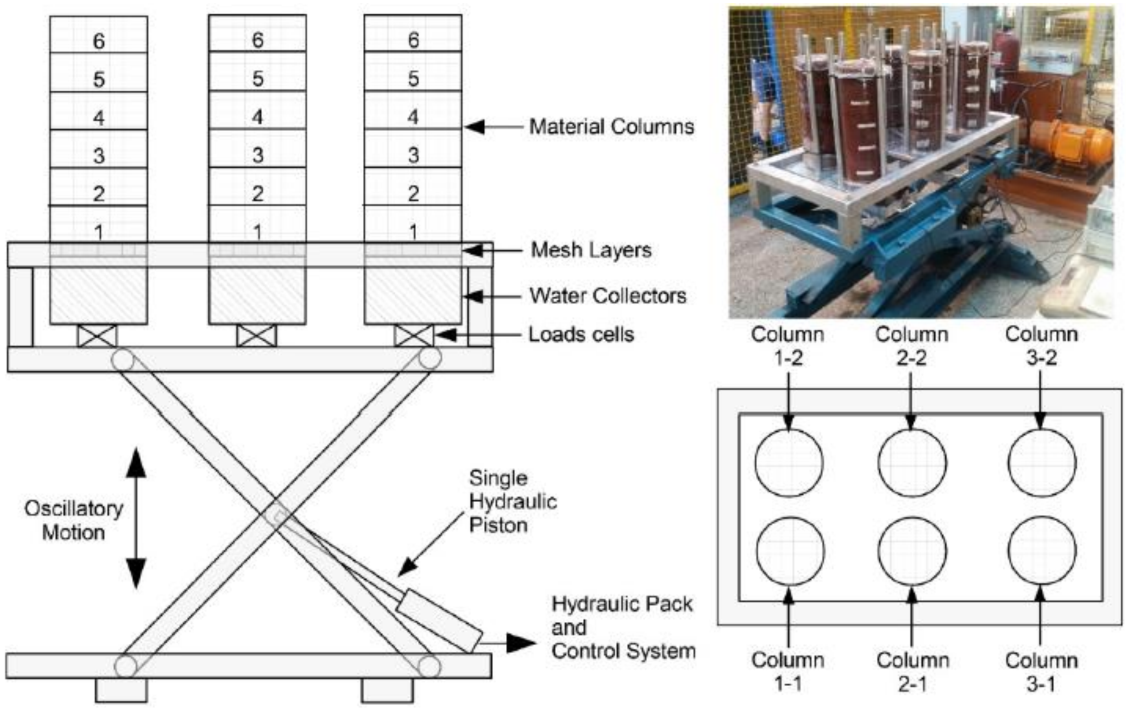


FIGURE 1. EXPERIMENTAL SET-UP FOR OSCILLATORY DRAINAGE TESTING SYSTEM.

Before commencement of the tests, the sample was separated into two batches. Batch one was mixed with 20% water and 80% solid and batch two was mixed with 27% water and 73% solid, calculated by mass on a wet sample basis.

Two separate columns made up of 6 stacked cells were packed with the two prepared batches of sand tailings. Latex membranes were fitted in the columns as linings to prevent the water from leaking through the clearance between the cells. Each cell in the columns were filled one by one with the sand tailing and compacted with a C type compaction hammer, as per the Proctor-Fagerberg TML test in the IMSBC code [1]. This was to reflect the compaction of the materials in a ship hold or stockpile.

After the material column preparation was completed, the top cell of each column was sealed to eliminate evaporation from the surface. The columns were left for a period of 20 days to drain under static conditions.

Once the 20 days of testing time was complete the cells in each column were carefully removed one by one and the bulk density and moisture content of the material in each cell was measured to identify if there was any significant moisture migration.

4 STATIC DRAINAGE RESULTS

4.1 MOISTURE MIGRATION

The variation of water through each column for the testing performed on the sand tailings with initial moisture contents of 20% and 27%, after 20 days of static drainage time, are shown in Figure 2.

The material in the batch mixed up to the initial moisture content of 27% was over saturated, being more representative of a dense slurry. As the column of material was filled cell by cell, the material was left to free drain, until it better represented the sand tailing in the fully saturated condition, before the compaction hammer was applied.

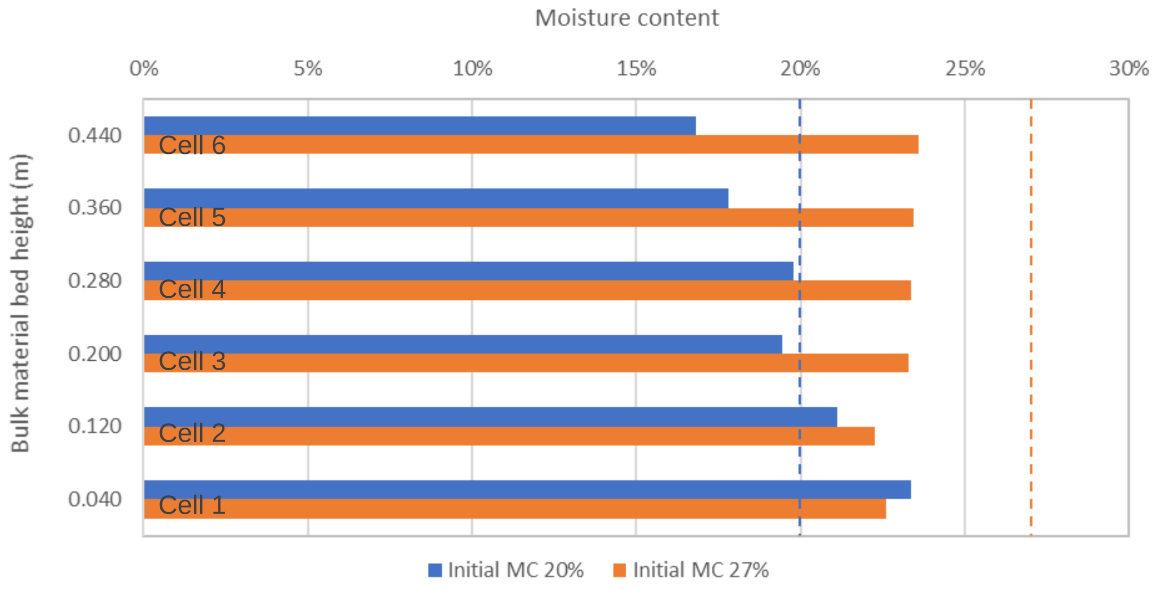


FIGURE 2 COMPARISON OF MOISTURE VARIATION THROUGH COLUMNS

The mass of the water collected in the tray underneath the columns is given in Figure 4 and Figure 4 for the first 5 hours of test time. After 5 hours there was evaporation of water in the collection tray.

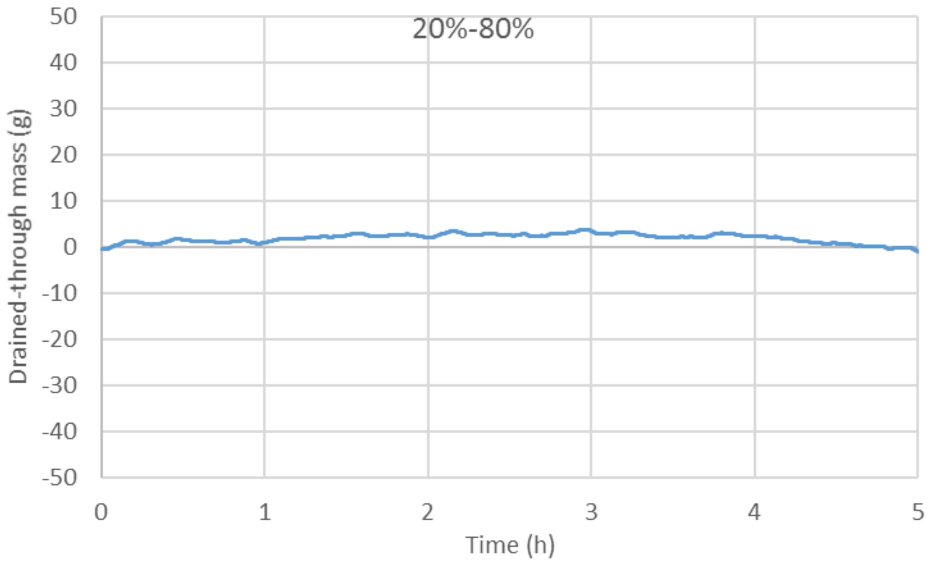


FIGURE 3 MASS OF DRAINED WATER COLLECTED UNDER THE SAND TAILINGS WITH AN INITIAL MOISTURE CONTENT OF 20%

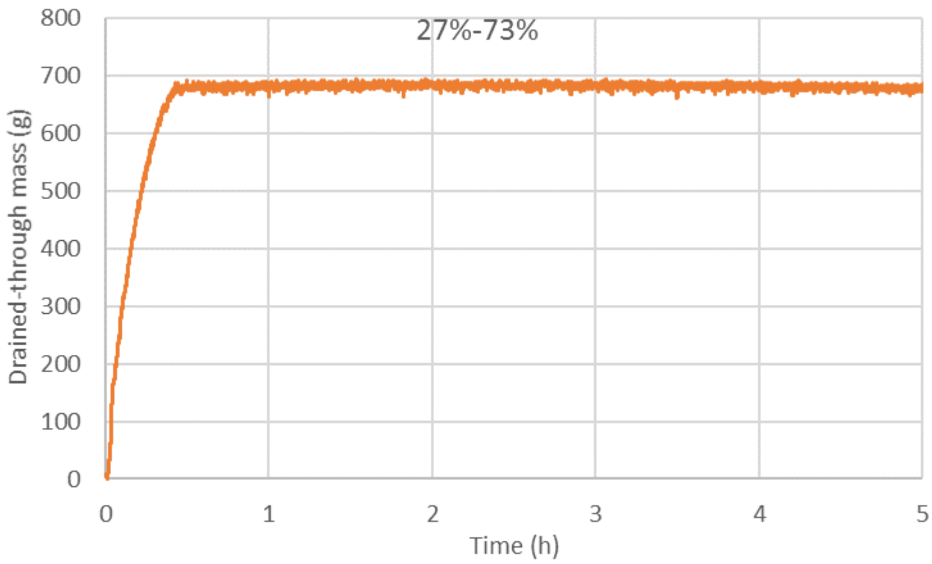


FIGURE 4 MASS OF DRAINED WATER COLLECTED UNDER THE SAND TAILINGS WITH AN INITIAL MOISTURE CONTENT OF 27%

The following points are the main findings from the moisture migration results:

- Moisture migration occurred in the cell stack with an initial moisture content of 20% over the time period tested, where water moved towards the bottom of the stack.
- There was no significant amount of water drained through the steel mesh at the bottom of the column for the sand tailings with an initial moisture content of 20%, as seen in Figure 3.
- The sand tailings with an initial moisture content of 27% drained until the material in each cell reached an average moisture content of approximately 23.1%.
- The recorded water drainage measurements shown in Figure 4 for the sand tailings with an initial moisture content of 27% shows that majority of drainage occurred in the first 30 minutes of testing.

4.2 Bulk Density

The wet bulk densities measured throughout the cell stacks are displayed in Figure 5 and the dry bulk densities are given in Figure 6. The following points are of note for the bulk density analysis:

- The bulk density was lower in the top cells due to lack of material compaction.
- The bulk density was higher for the sand tailing with an initial moisture content of 27%, than the initial moisture content of 20%. This will be due to the packing efficiency of the sand tailing being higher at the higher moisture tested.

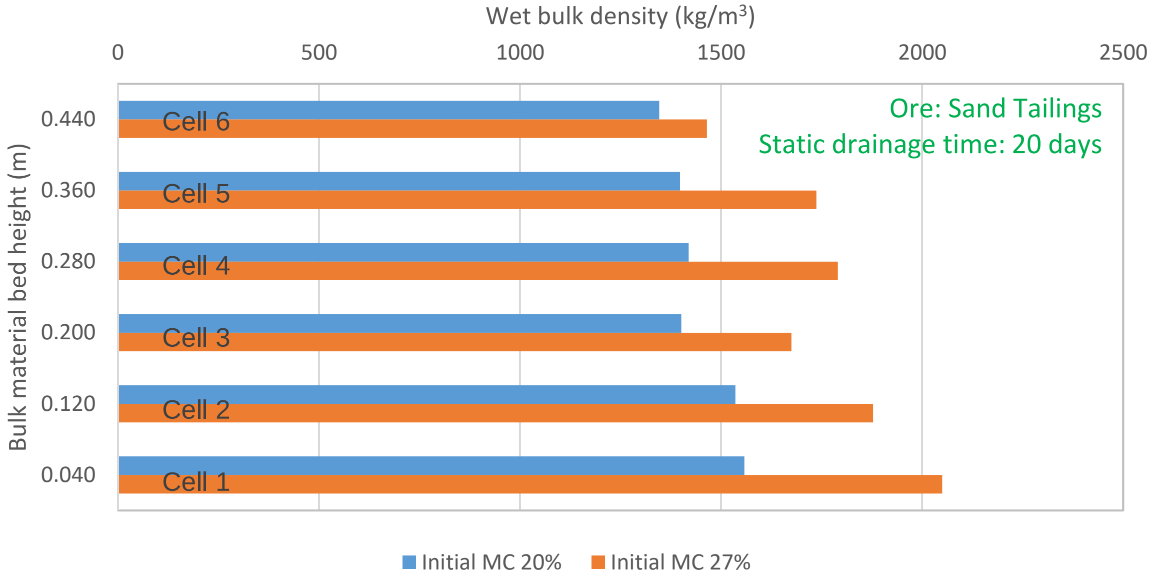


FIGURE 5 COMPARISON OF WET BULK DENSITY VARIATION THROUGH EACH COLUMN

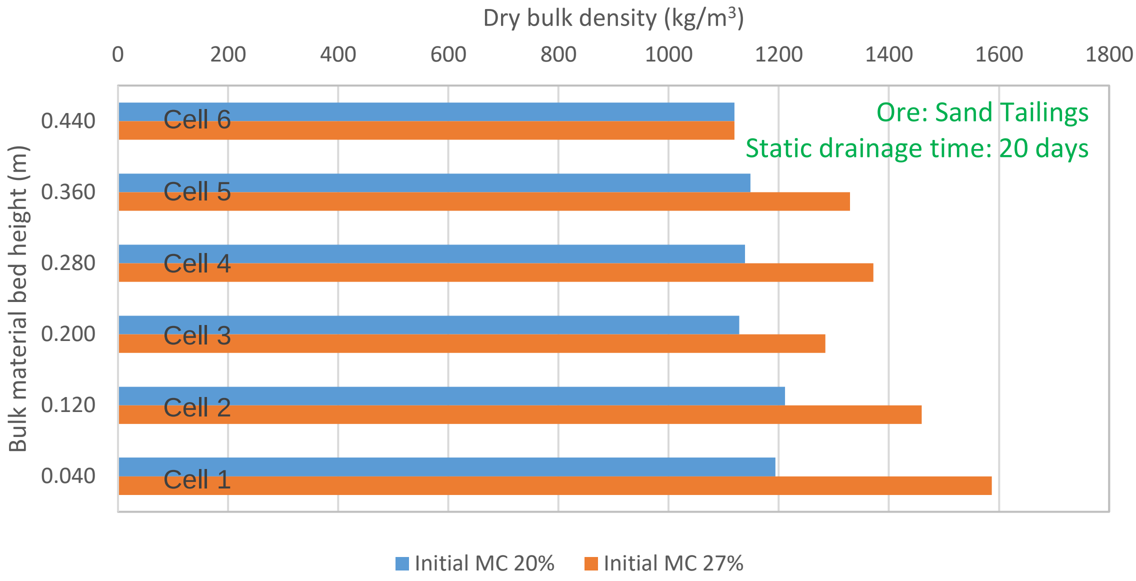


FIGURE 6 COMPARISON OF DRY BULK DENSITY VARIATION THROUGH EACH COLUMN

5 Conclusion

Moisture variation through material columns was assessed and presented for a sand tailing prepared at 2 initial moisture contents and left to drain under static conditions for 20 days. The following results are of note:

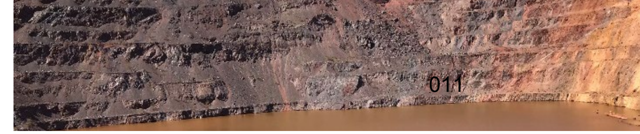
- Moisture migration towards the bottom of the stack occurred for the sand tailings prepared at an initial moisture of 20%, with minimal drainage out the porous base.
- For the sand tailings initially prepared at 27%, water drained out of the over saturated sample until an average moisture content of approximately 23.1% was reached throughout the stack of material.

- The bulk density was higher for the sand tailing with an initial moisture content of 27%, than the initial moisture content of 20%.
- During loading of the sand tailing, the lower limit moisture content will be approximately 16.8%
- The final moisture results show that a moisture content of 23.6% is the upper limit for this metal concentrate.

6 REFERENCE

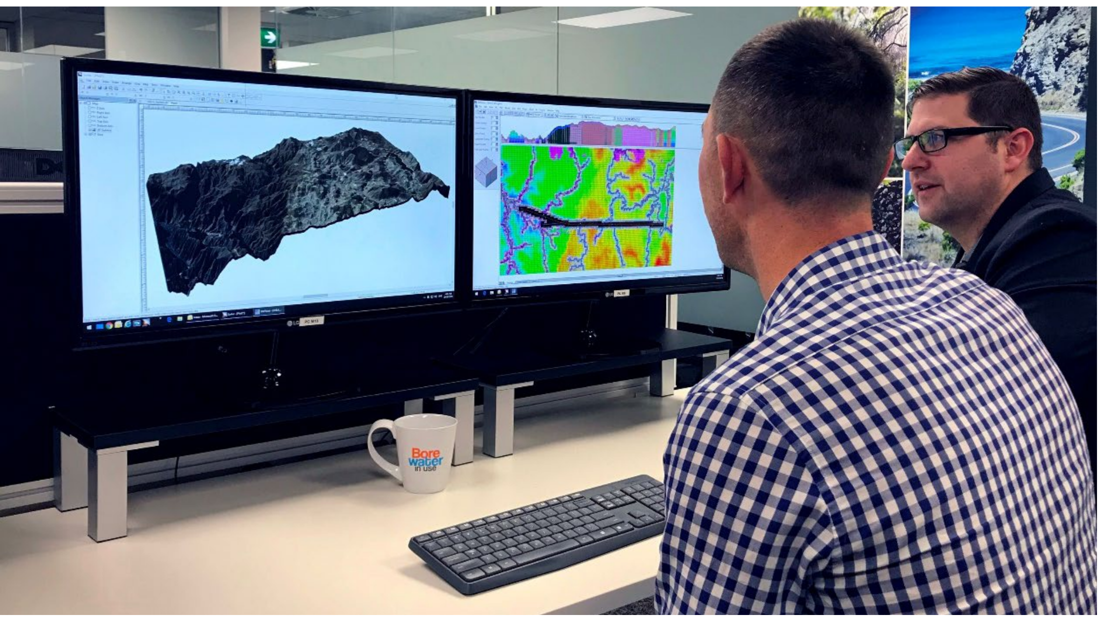
[1] *International Martime Solid Bulk Cargoes (IMSBC) Code,* Resolution MSC.268(85), 2019.

Attachment 2



Fingerboards mine tailings seepage assessment – unsaturated zone groundwater flow modelling

In support of the Work Plan
March 2021



Authors: Tom Neill and Joel Georgiou

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Background

- Mine seepage rates were assumed within the EES groundwater model to equal the total losses from sand tailings, as supplied initially by Kalbar
- Total loses were equivalent to ~53 L/s and were applied directly to the model as water table recharge
- High and steep groundwater mounds were simulated beneath the mine tailing cells
- Although no significant risk to GDEs and 3rd party bores were simulated, concerns were still raised by the TRG, Government and expert witnesses

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Objectives

- To simulate mine tailings cells on a finer resolution using the SEEPW software
- Based on various assumptions, simulate the seepage of tailings water through the unsaturated Coongulmerang Formation, to determine a more realistic loss from the base of these pits
- Test a range of Coongulmerang Formation properties (upper and lower) to determine a broad range of possible seepage rates
- Updated seepage rates will be used in the updated water balance model and Work Plan

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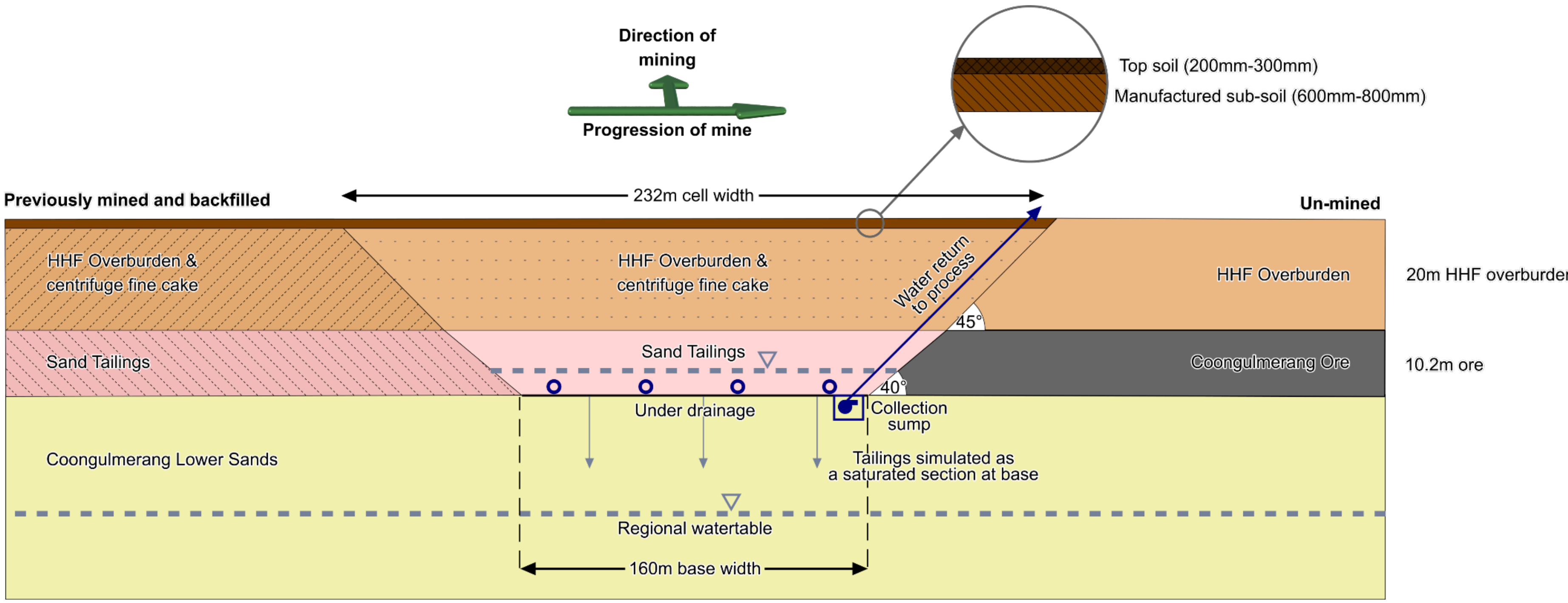
Conceptual model design



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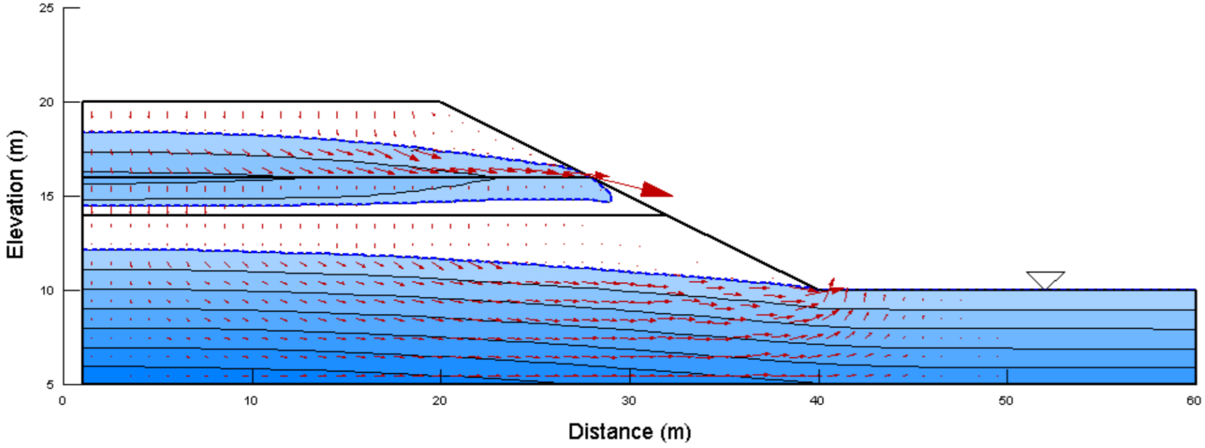
Modelling software

- SEEP/W by Geoslope (https://www.geoslope.com/products/seep-w)
- Finite element software for modelling variably saturated groundwater flow in porous media
- Base version simulates flow in 1 or 2 dimensions



Material properties

Material name	Equivalent media	a (Pa)	n	Sat. WC	Res. WC	Sat. Kx (m/s)	Kx:Kz
Coarse sand tailings	Sand	676.3	2.68	0.43	0.045	1×10^{-5}	1
Coongulmerang Upper Sands	Modified clay/silty clay	19,613.3	1.09	0.36	0.07	1×10^{-6} / 6×10^{-8}	1
Coongulmerang Lower Sands	Modified clay/silty clay	19,613.3	1.09	0.36	0.07	1×10^{-6} / 6×10^{-8}	1
HHF Overburden	Loam	2,724.1	1.56	0.43	0.078	2.9×10^{-6}	1
HHF Overburden & fines cake	Loam	2,724.1	1.56	0.43	0.078	2.9×10^{-6}	1

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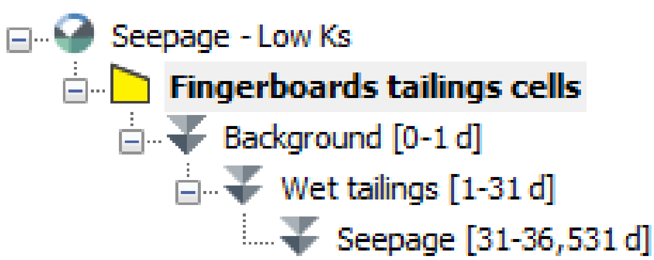
Model design

- 3 stress periods:
  - Steady state background flow, watertable at 30 mAHD
  - Wet tailings over bottom 3 m of cell for 30 days
  - Seepage simulated for 100 years (to look at long term wetting fronts and recharge lag-times)
- 2dimensional, 1.5 m mesh spacing
- 2 model scenarios:
  - High K Coongulmerang Fm (0.08 m/d)
  - Low K Coongulmerang Fm (0.005 m/d)



- Low K scenario is the most likely scenario based on knowledge to date
- Ksat values based on our current knowledge. Other properties based on “text book” values from available libraries, notably from the Hydrus software.

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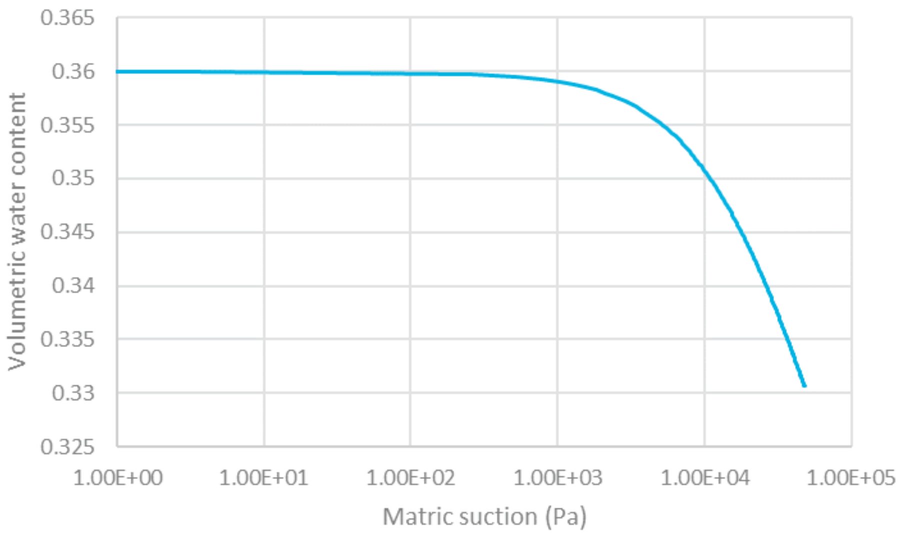
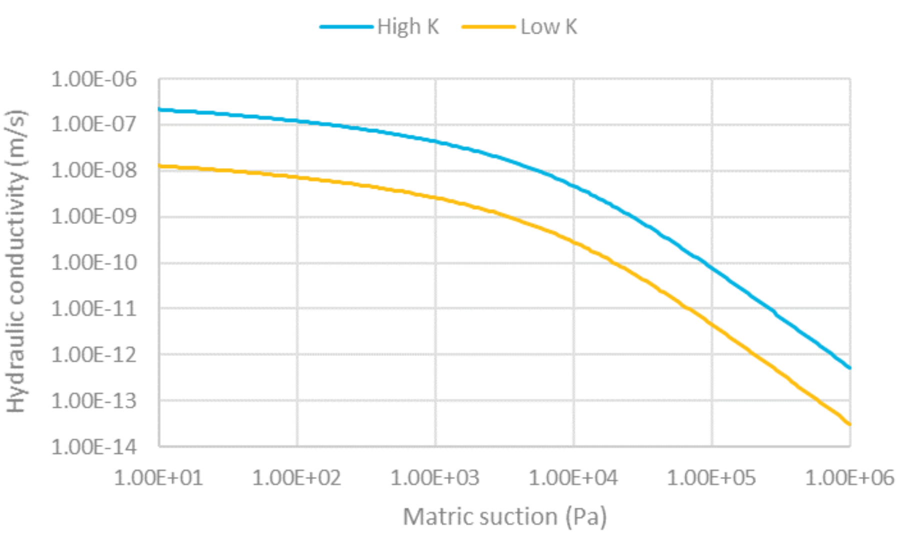
Example of Soil Moisture Curves (Coongulmerang Fm)





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Model elements

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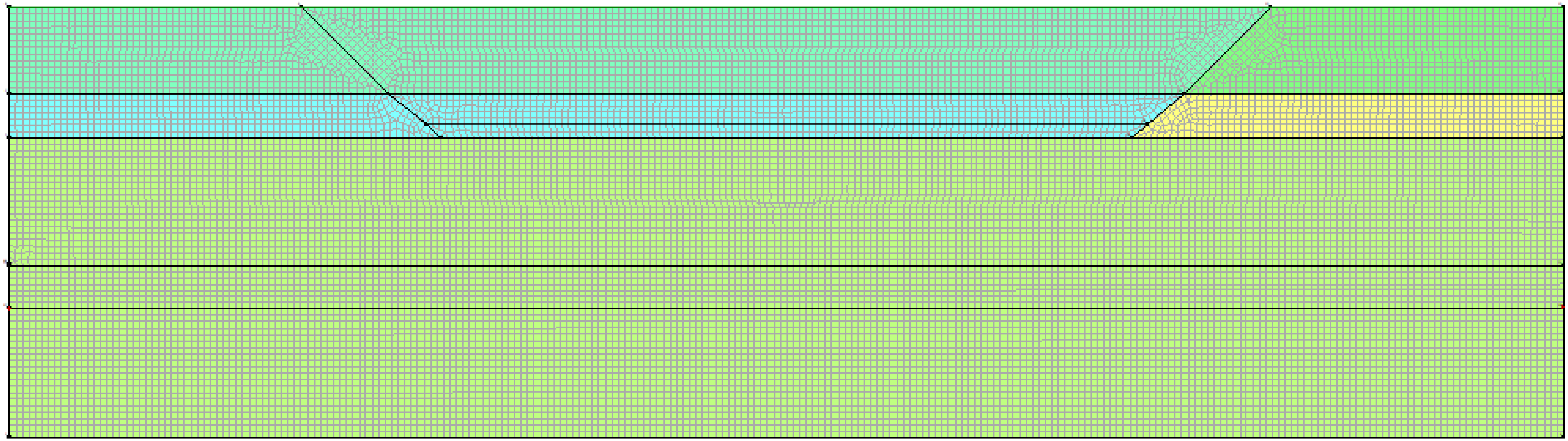
2D Finite element mesh



- 1.5m sized cells = very high 2D resolution modelling

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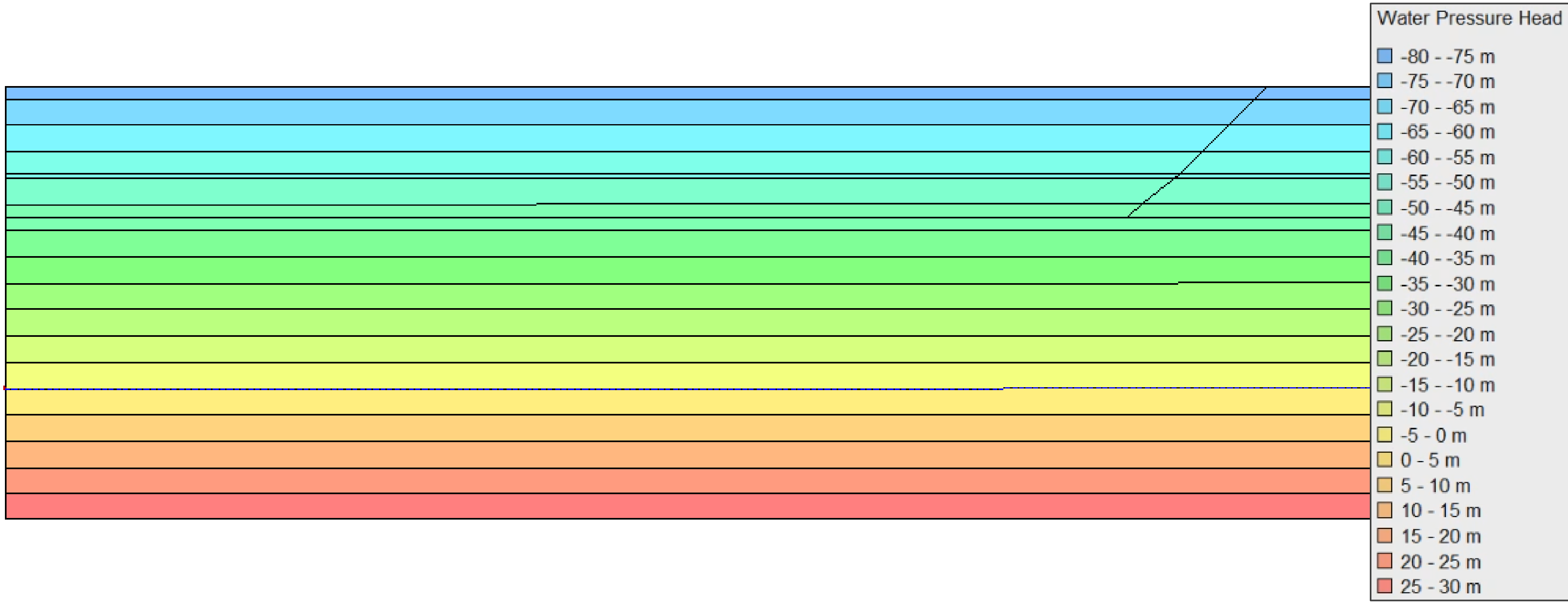
Steady-state background pressure profile



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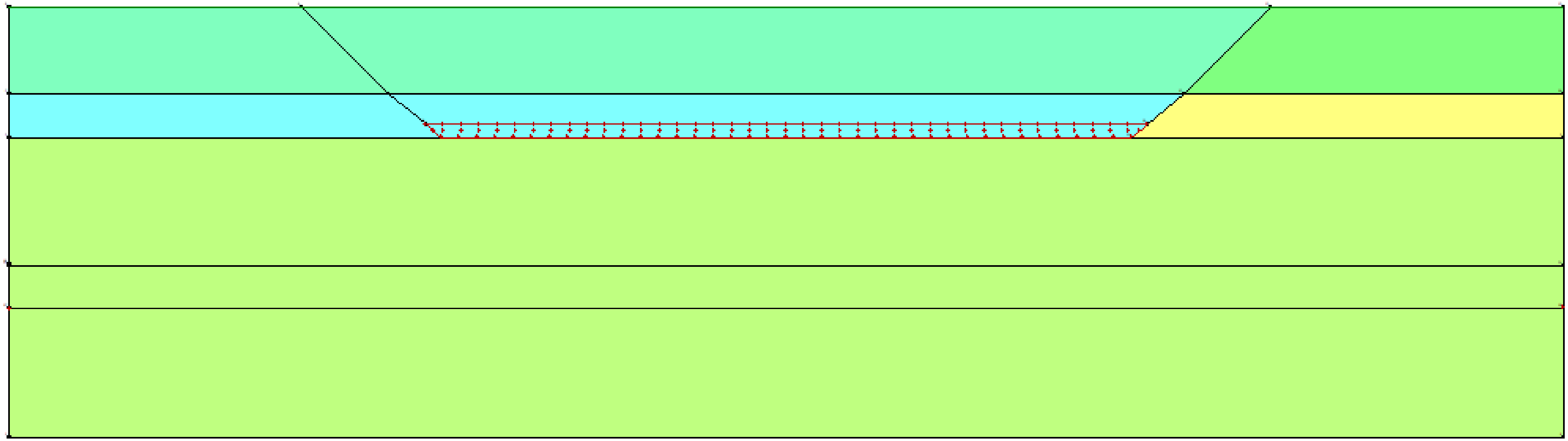
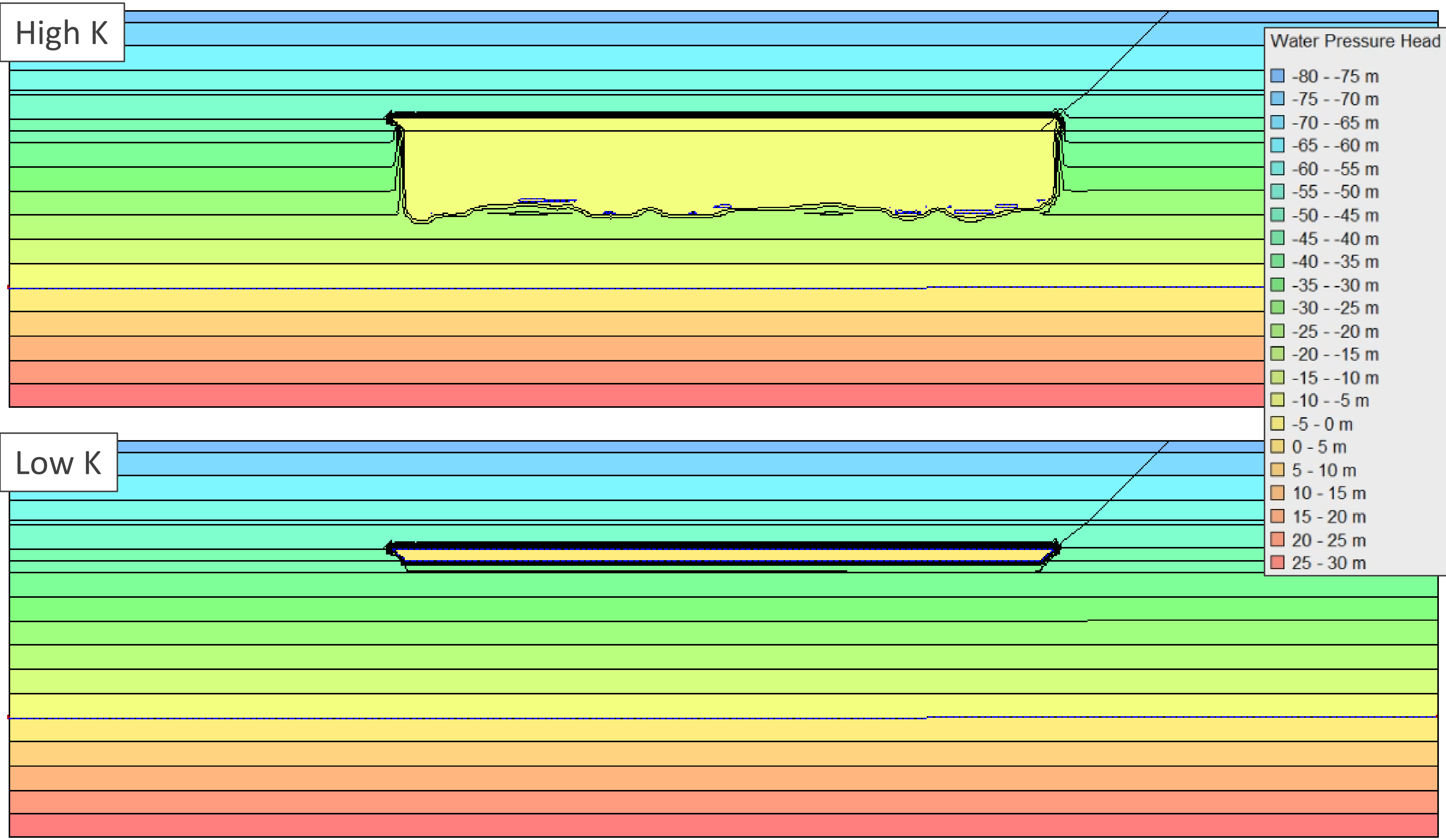
Wet tailings activation



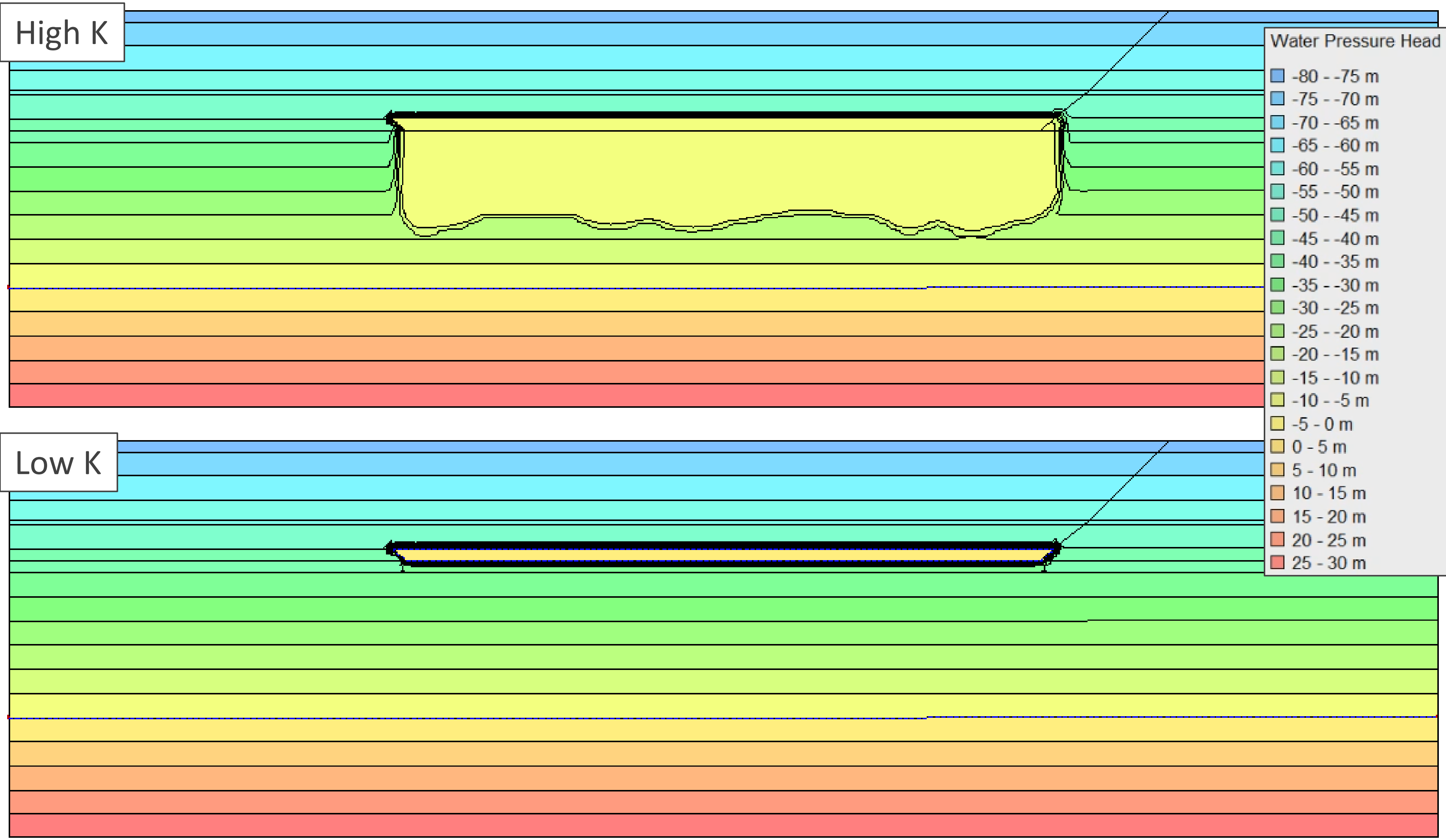
Seepage rate over time

- High conductivity Coongulmerang Formation
  - Tailings drains from full saturation to near field capacity within 150 days
  - Average seepage rate 7 L/s
- Low conductivity Coongulmerang Formation
  - Tailings drains from full saturation to near field capacity within 5 years
  - Average seepage rate 0.35 L/s

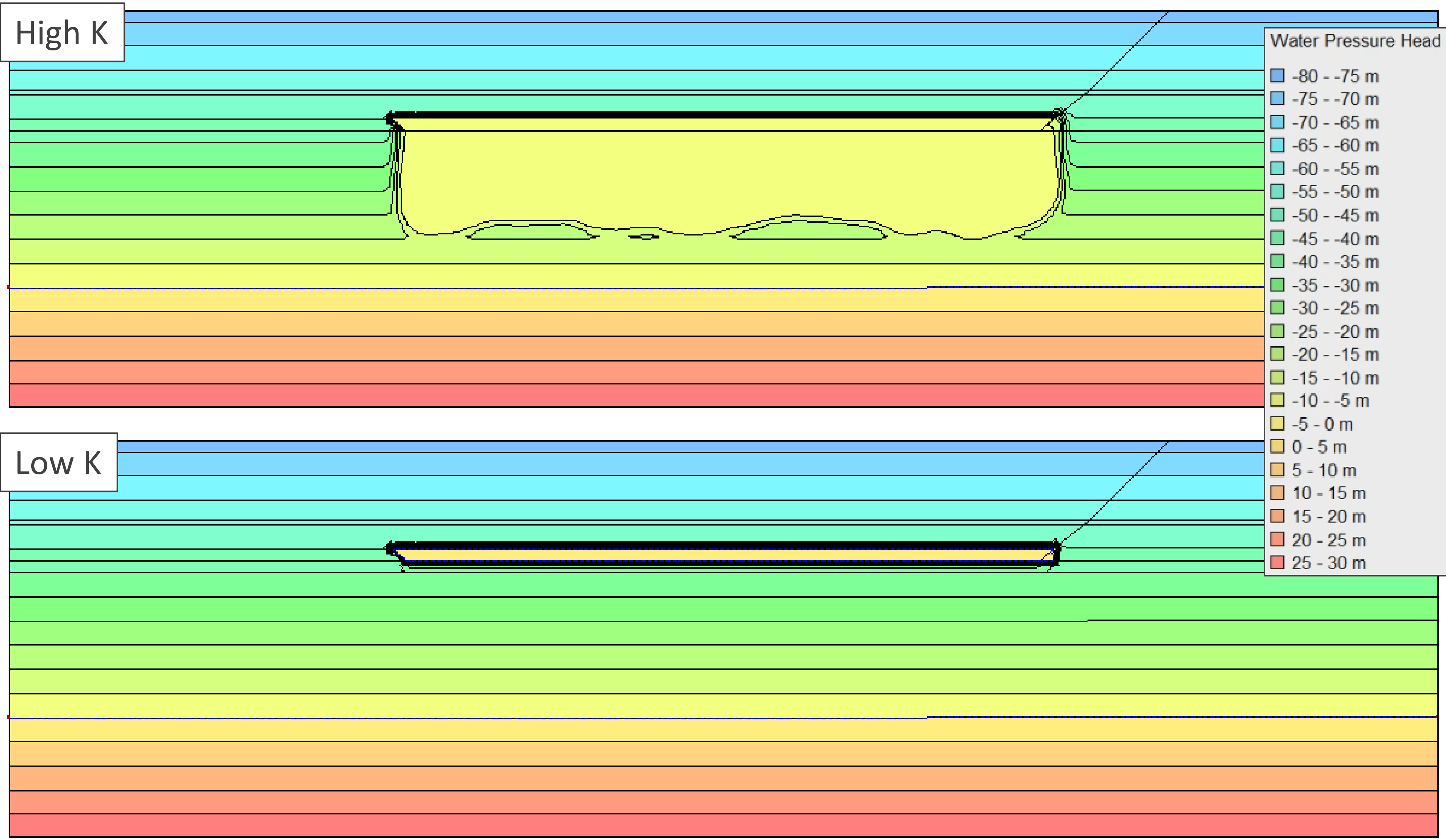
Seepage pressure profile – 0.5 years



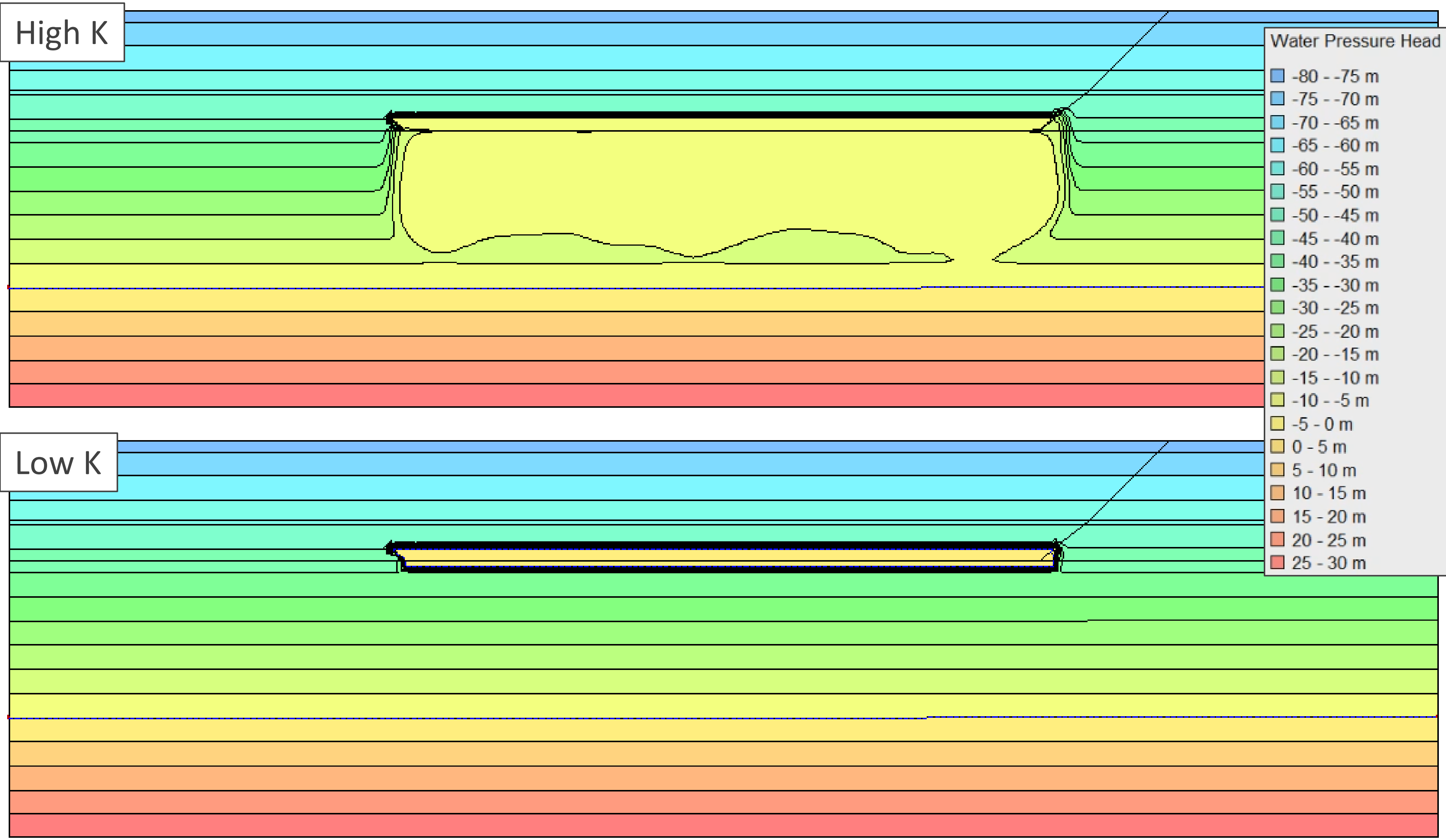
Seepage pressure profile – 1.0 years



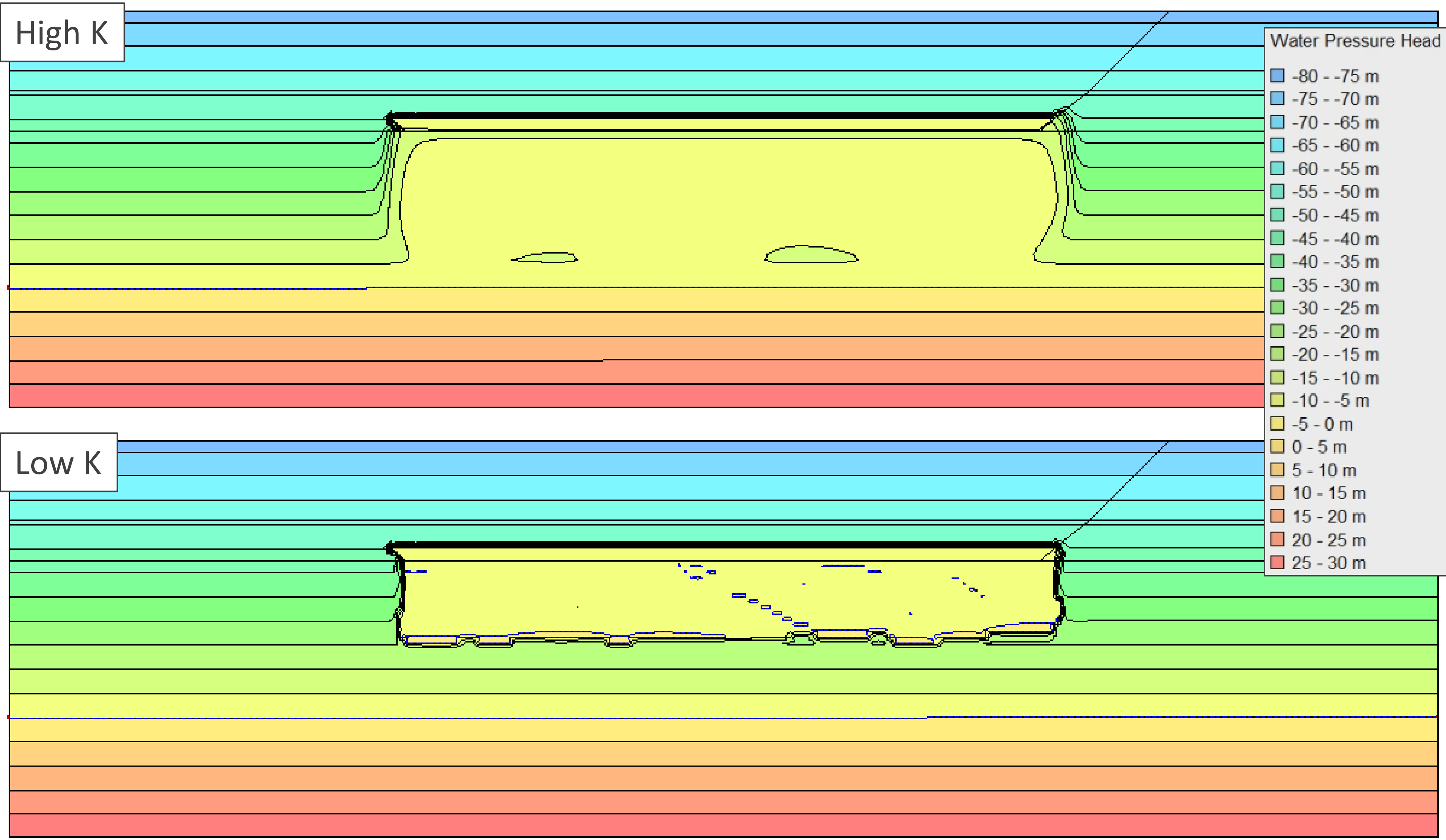
Seepage pressure profile – 1.5 years



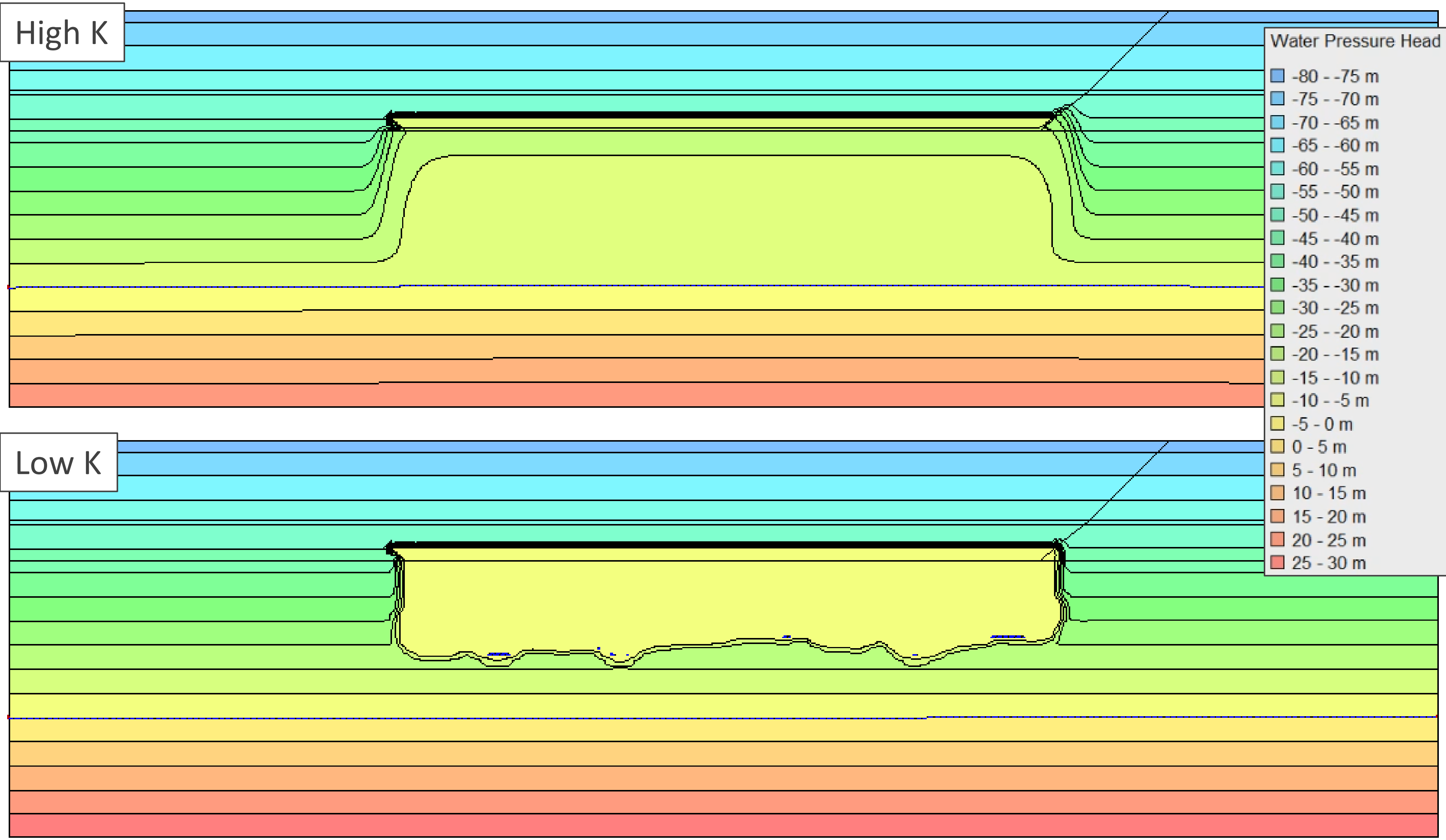
Seepage pressure profile – 3 years



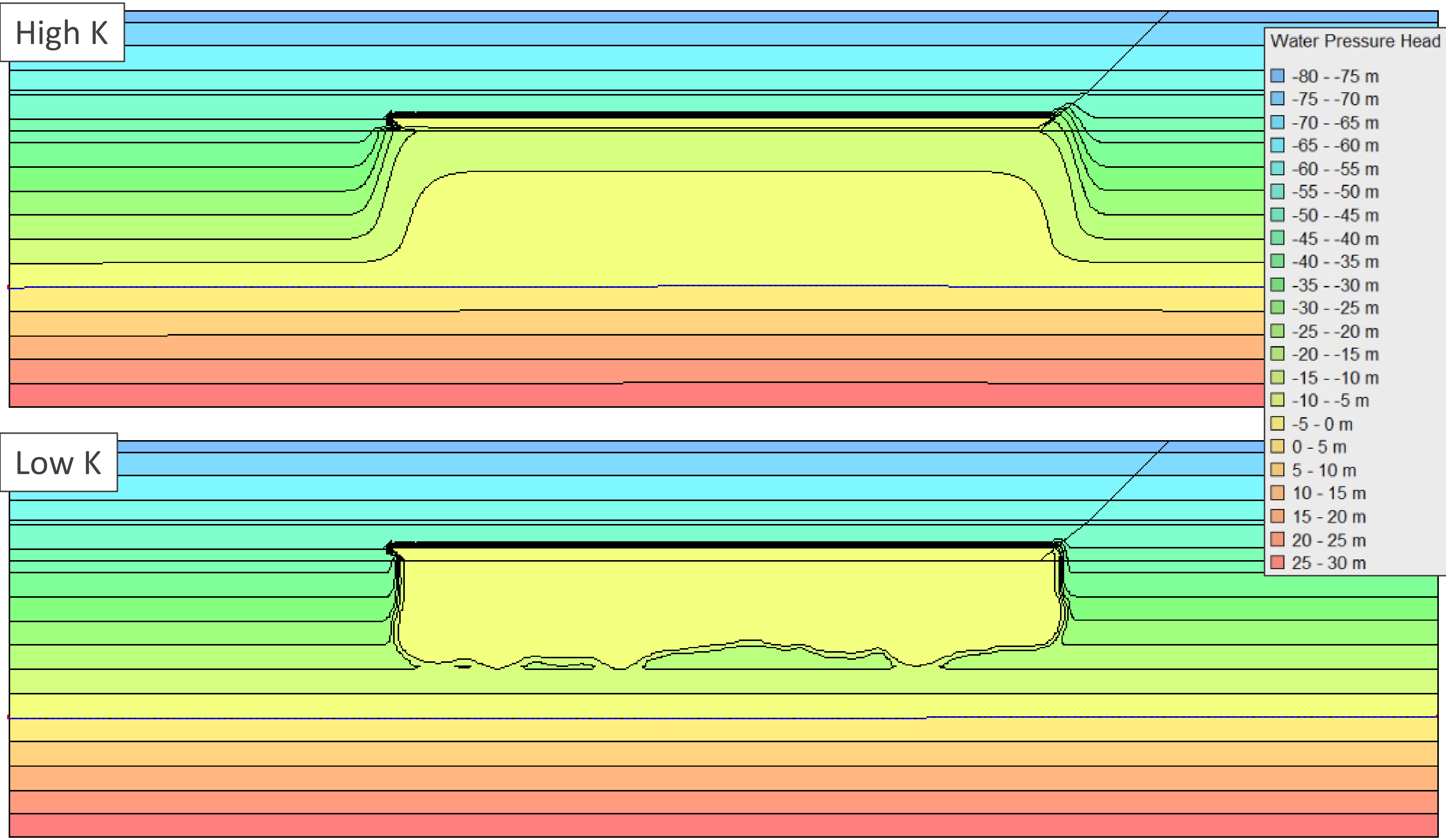
Seepage pressure profile – 5 years



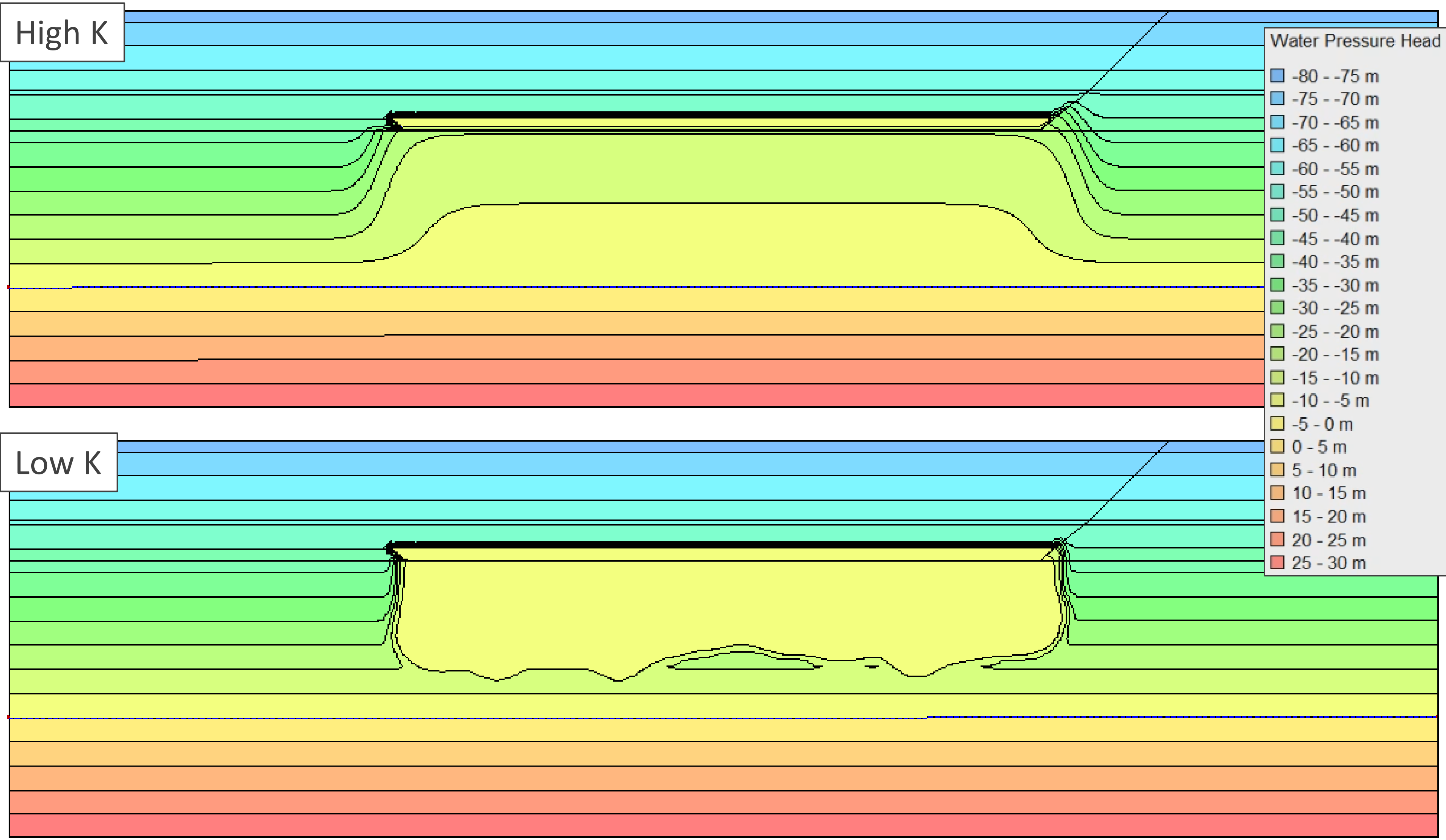
Seepage pressure profile – 10 years



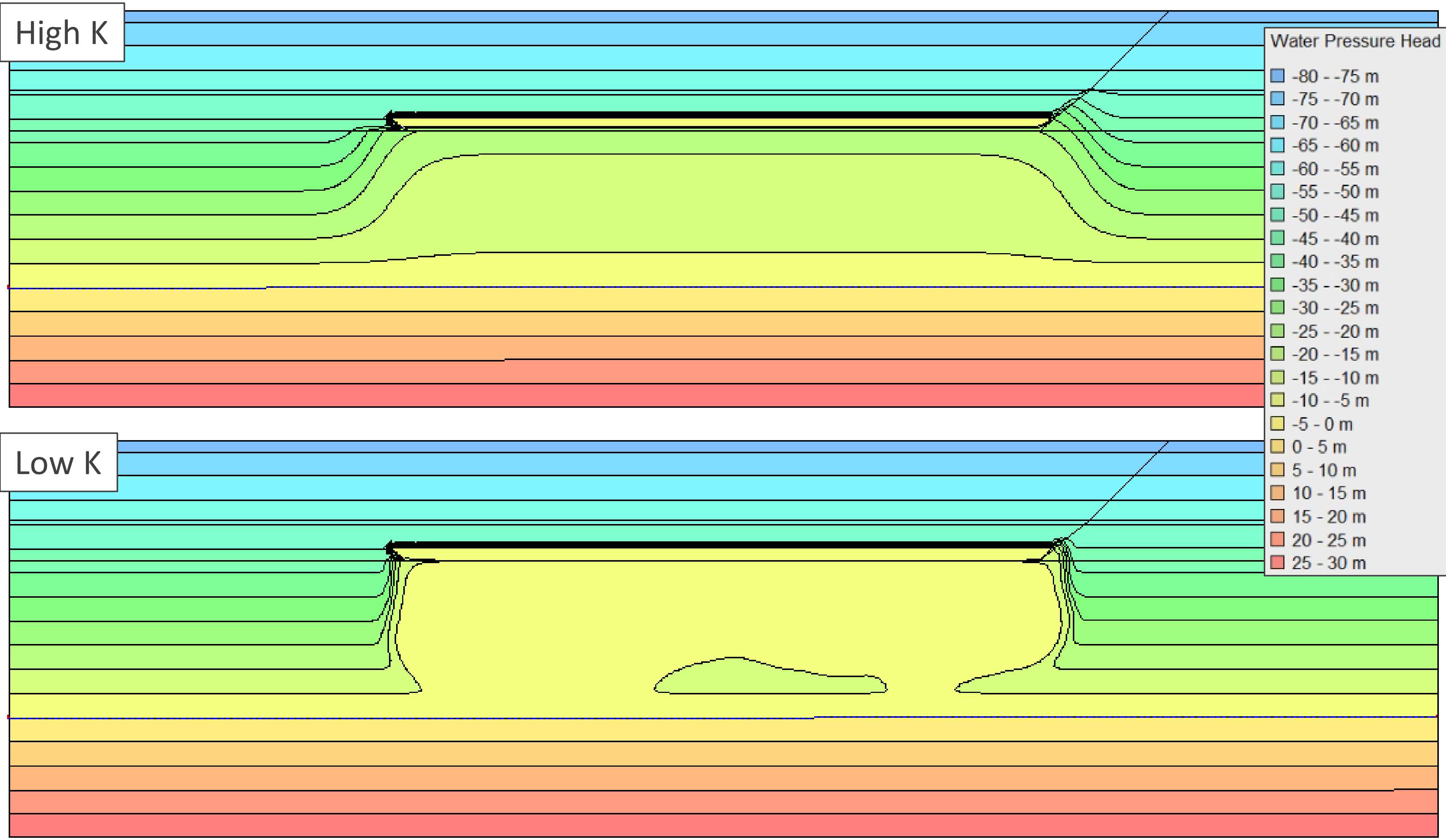
Seepage pressure profile – 15 years



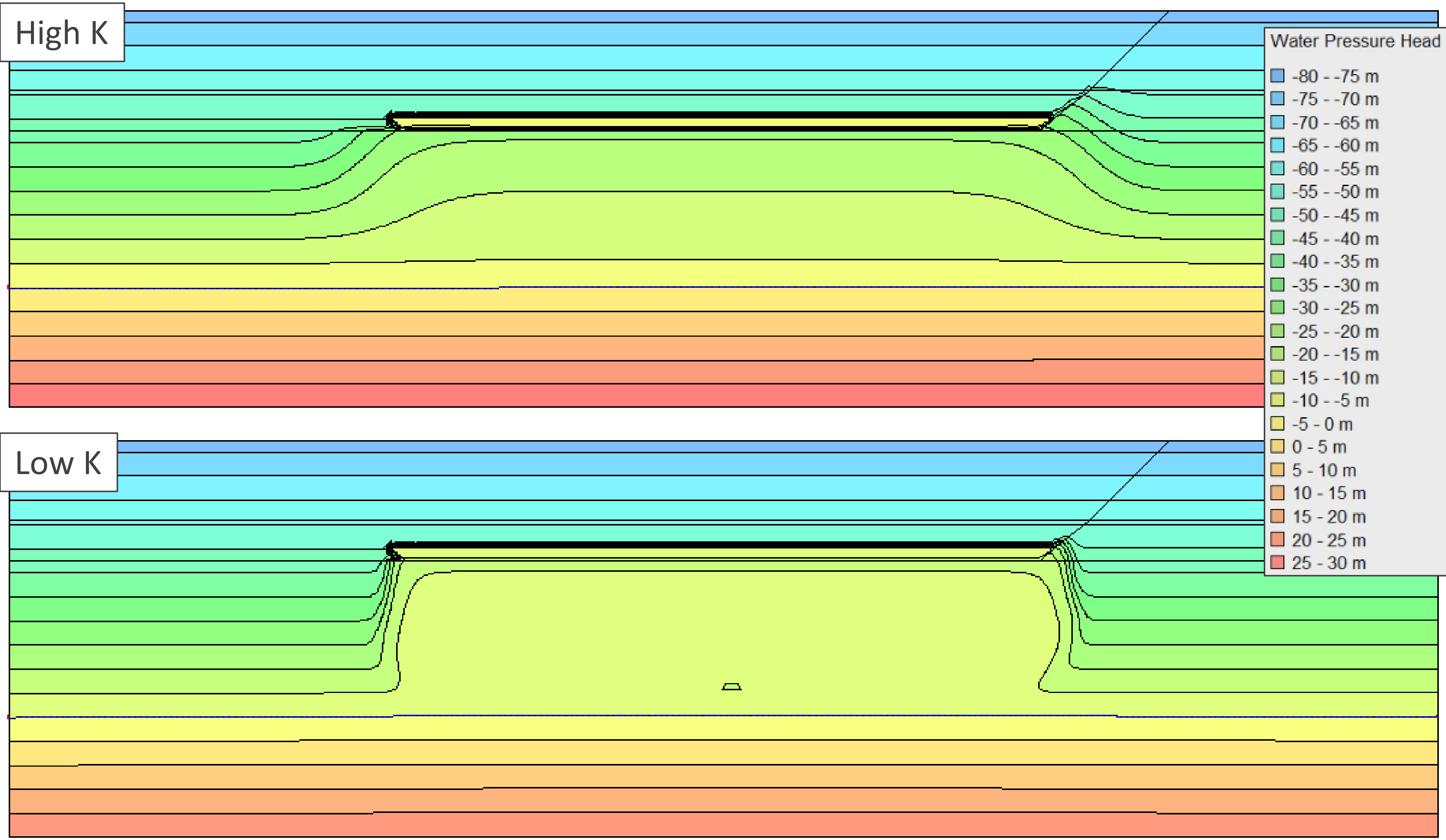
Seepage pressure profile – 25 years



Seepage pressure profile – 50 years



Seepage pressure profile – 100 years



Conclusion & Recommendations

- Tailings seepage is predicted to occur slowly through the vadose zone, without enough water to maintain full saturation
- Seepage rate from tailings materials is dependent on the unsaturated hydraulic parameters of the Coongulmerang Fm, with an average rate between 0.3 and 7 L/s per 160 x 300 m tailings cell. Note that several of these cells may be mined in any one year.
- The lower rate is the most likely, based on our knowledge to date
- Seepage to the watertable is more gradual, with a subset of the water from the tailings cells reaching the watertable
- Tailings materials are predicted to desaturate but hold on to water, with modelled matric suction pressure between 5 and 10 m

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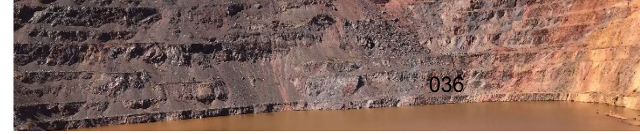
Conclusion & Recommendations

- Model implications include:
  - More tailings volume will exist within the pit. Does this affect the accommodation space?
  - May lead to an opportunity to dewatering sand tailings further
  - Significantly less seepage compared to the EIS model (for the ksat = 0.005 m/d case) reduces the development of any groundwater mounds. The environmental impact risks from tailings seepage may be greatly reduced compared to EES assessment.

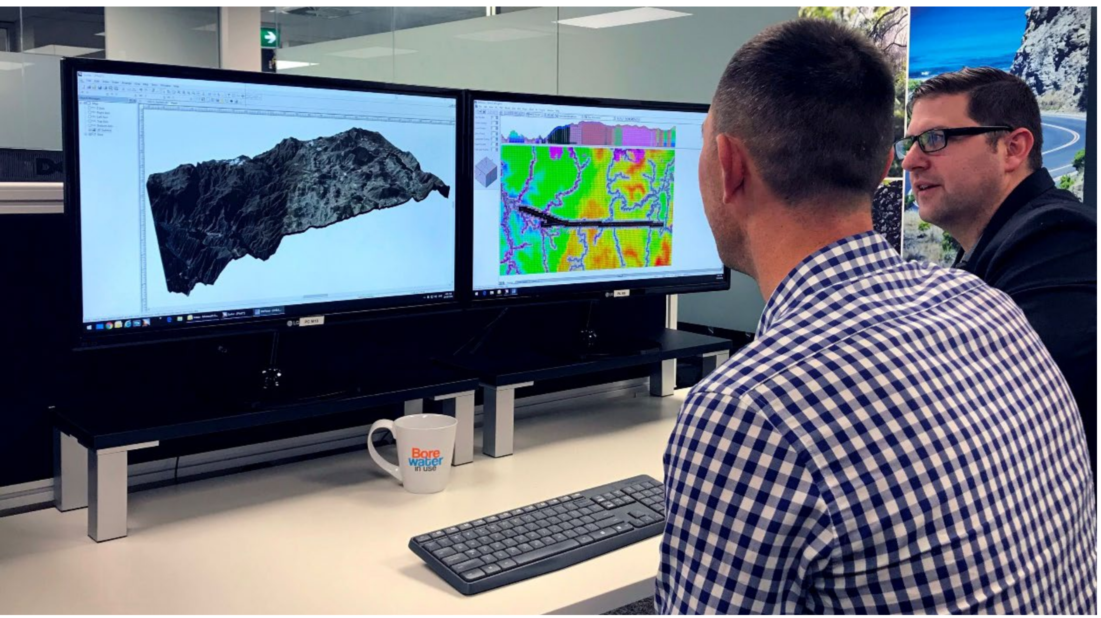
- Model based on generic soil curves with some control on Ksat values. Recommend using site-based data once information is received from the EAL labs. Kalbar are currently identifying suitable samples from the core shed.

Attachment 3



Fingerboards mine tailings seepage assessment – unsaturated zone groundwater flow modelling

In support of the Work Plan and Project Hearings
May 2021



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Background

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- Total loses were equivalent to ~53 L/s and were applied directly to the groundwater model as water table recharge
- High and steep groundwater mounds were predicted by the modelling beneath the mine tailing cells
- Although no significant risk to GDEs or 3rd party bores were simulated; TRG, Government and expert witnesses expressed an interest in additional modelling of seepage and mounding

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Objectives

- To simulate mine tailings cells on a finer resolution using the SEEP/W software
- Simulate the seepage of tailings water through the unsaturated Coongulmerang Formation, to estimate a more realistic rate of water seepage from the base of tails
- Test a range of possible Coongulmerang Formation properties (upper and lower) to estimate the related range of possible seepage rates

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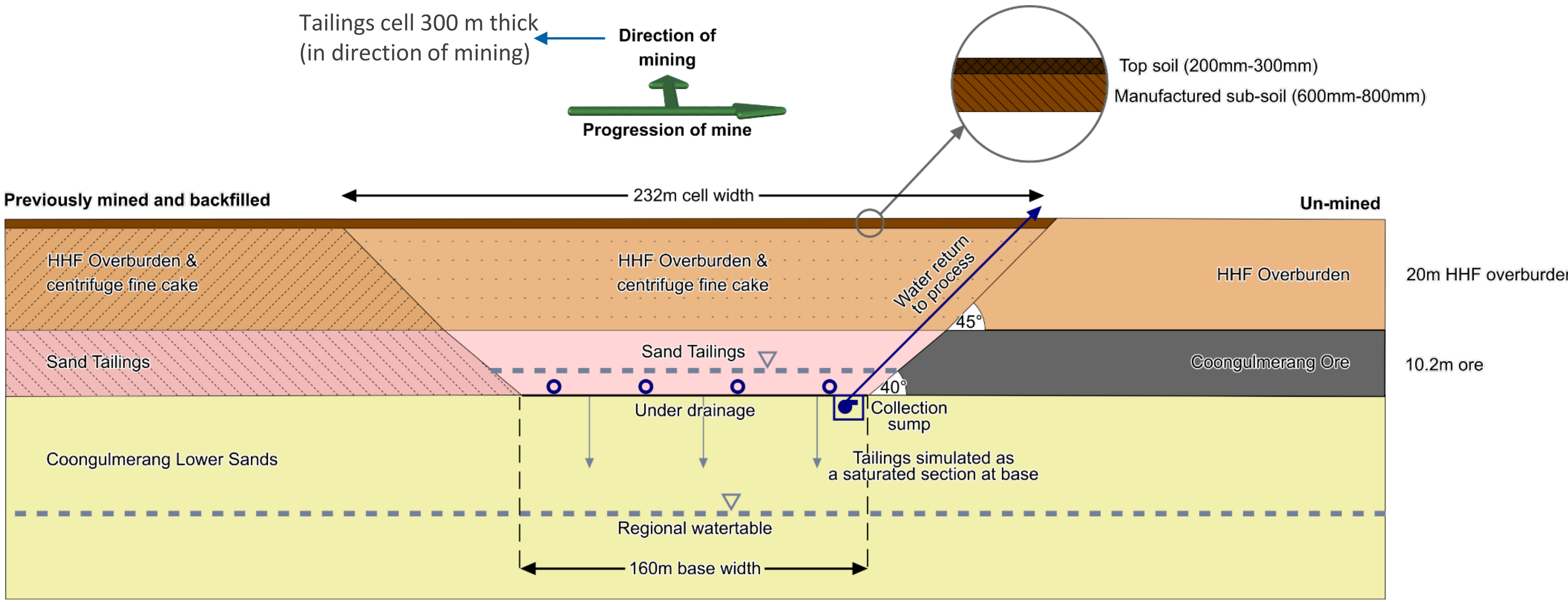
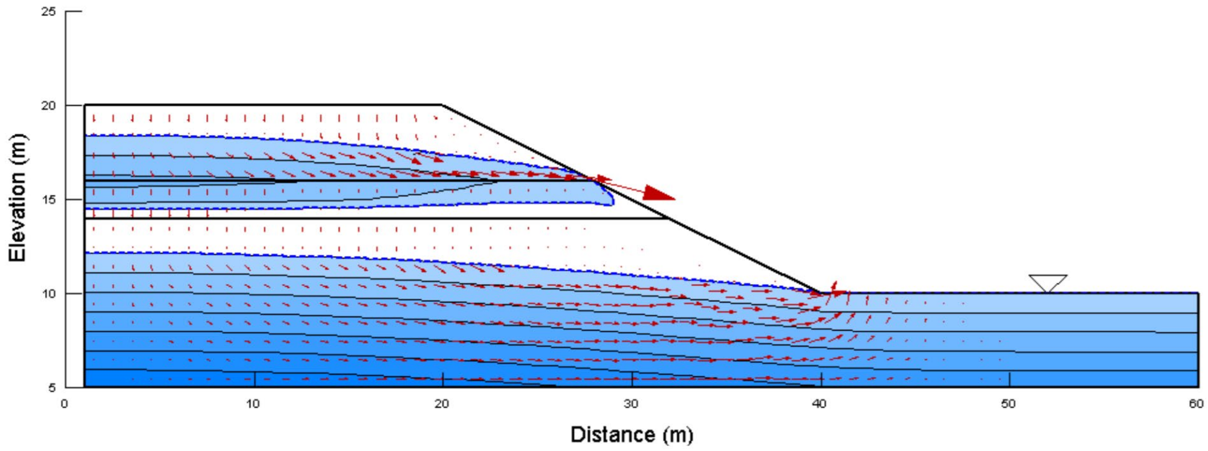
Conceptual model design



Modelling software

- SEEP/W by Geoslope (https://www.geoslope.com/products/seep-w)
- Finite element software for modelling saturated and unsaturated groundwater flow in 1 or 2 dimensions



Material properties

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Coongulmerang Lower Sands	Modified clay/silty clay	19,600	1.09	0.36	0.07	0.086 / 0.005	1
HHF Overburden	Loam	2,724.1	1.56	0.43	0.078	0.25	1
HHF Overburden & fines cake	Loam	2,724.1	1.56	0.43	0.078	0.25	1

- Ksat values based on our current knowledge. Other properties based on “text book” values from available libraries, notably from the Hydrus software.
- Laboratory derived data will used to update models when available

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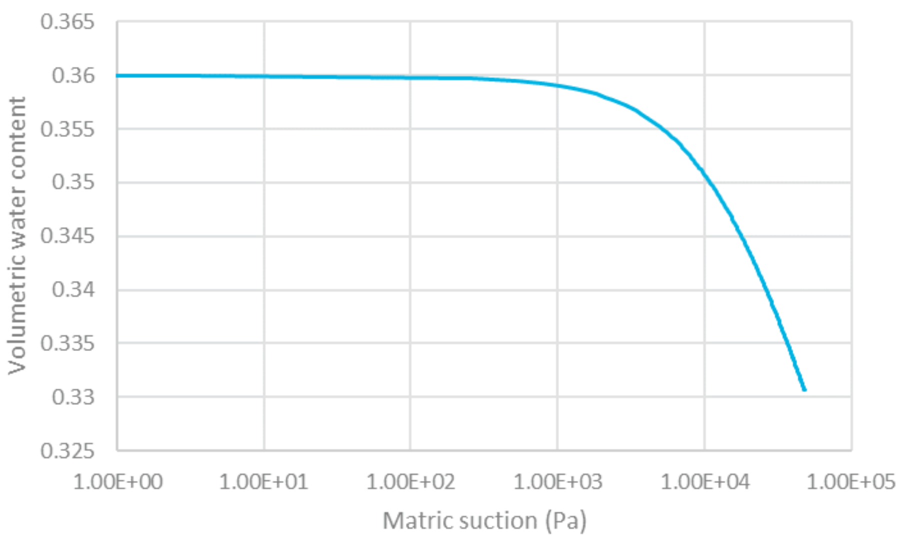
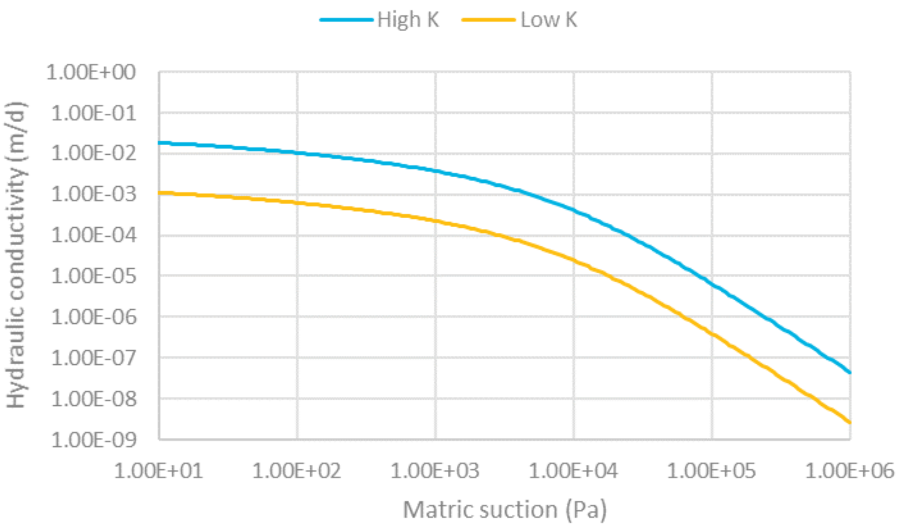
Model design

- 2 phase model; initial conditions and mining scenario:
  - Steady state background flow, watertable at 30 mAHD, seepage via rainfall at 25 mm/year, consistent with regional groundwater flow model
  - Activation of tailings cell, with seepage simulated for 100 years (to look at long term wetting fronts and recharge lag-times)
- 2-dimensional, variable mesh spacing from 0.5 m within and below tailings to 2 m above tailings
- Tailings cell conservatively estimated to be fully saturated over bottom 3 m, activated in model with water pressure of 0 m
- 2 model versions:
  - High K Coongulmerang Formation (0.086 m/d)
  - Low K Coongulmerang Formation (0.005 m/d)
- Low K value of Coongulmerang Formation is more likely than the high K value of Coongulmerang Formation based on current knowledge

Example of Soil Moisture Curves (Coongulmerang Fm)





- Volumetric water content and hydraulic conductivity curves retrieved from available soil database using 'modified clay/silty clay' as representative media and assigning saturated hydraulic conductivity values

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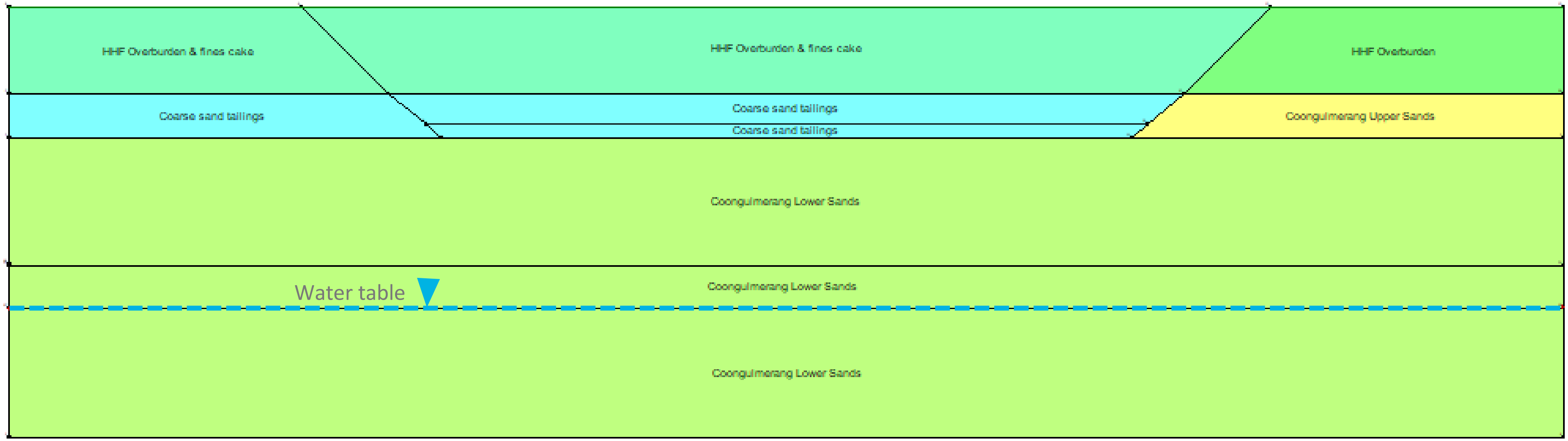
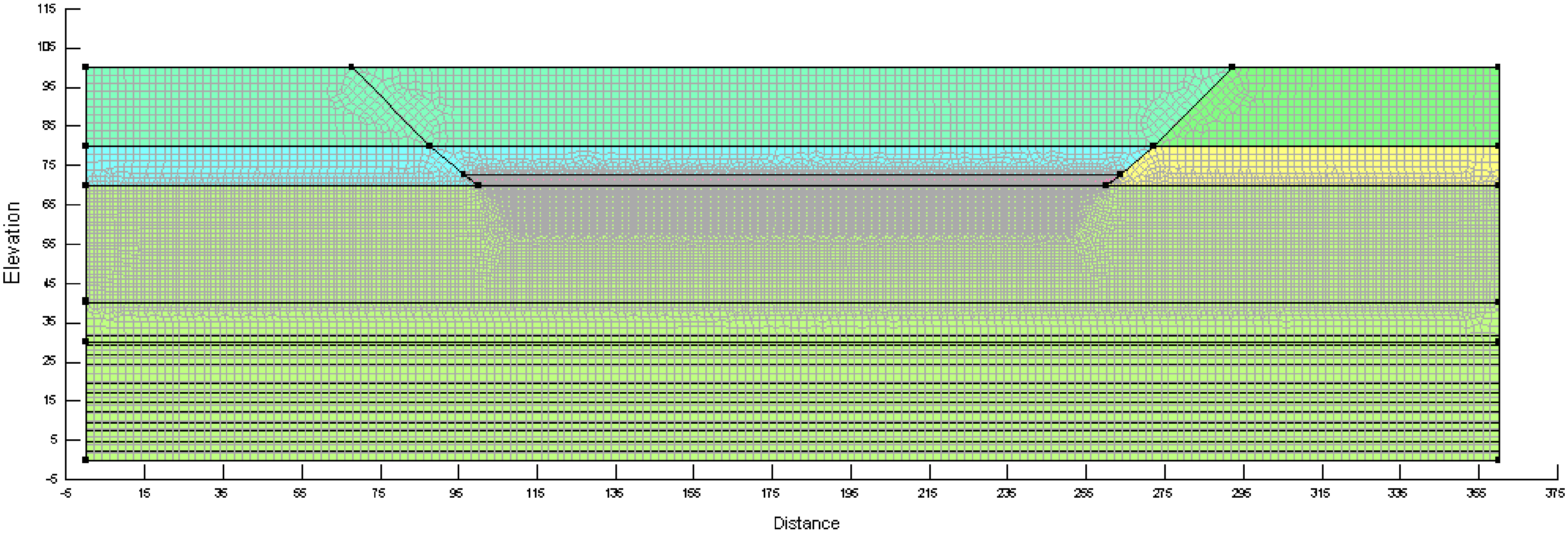
Model elements



2D Finite element mesh

Color	Name	Vol. W.C. Function	K-Function	Activation PWP(Pa)
	Coarse sand tailings	Sand (HYDRUS)	Sand (HYDRUS)	
	Coongimerang Lower Sands	Coongimerang Lower Sands	Coongimerang Lower Sands	
	Coongimerang Upper Sands	Coongimerang Upper Sands	Coongimerang Upper Sands	
	HHF Overburden	Loam (HYDRUS)	Loam (HYDRUS)	
	HHF Overburden & fines cake	Loam (HYDRUS)	Loam (HYDRUS)	
	Wet sand tailings	Sand (HYDRUS)	Sand (HYDRUS)	0



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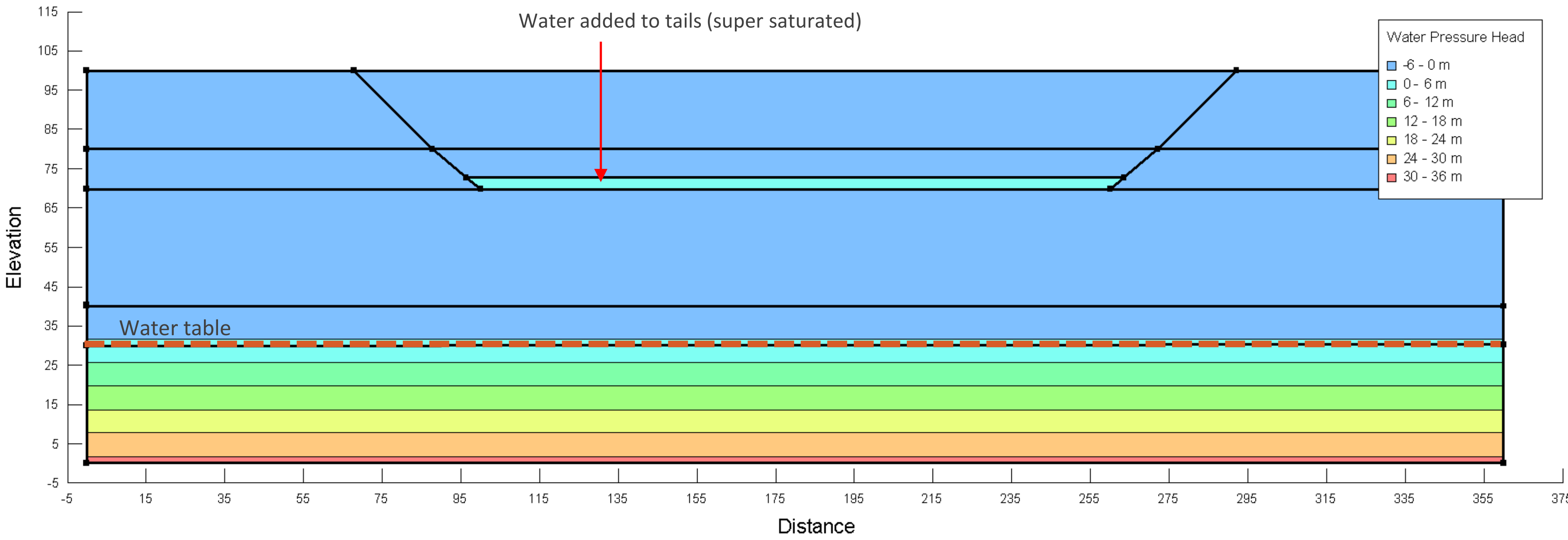
Pressure profile at the commencement of tailings seepage



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Results- Seepage rate over time

- High conductivity Coongulmerang Formation
  - Tailings drain from full saturation to near residual water content within 100 days
  - Average seepage rate 58 L/s for first 4 days, dropping to average of **15 L/s for the next 30 days**
- Low conductivity Coongulmerang Formation
  - Tailings drains from full saturation to near residual water content within 2.5 years
  - Average seepage rate 10.7 L/s for first day, dropping to average **of 3.5 L/s for first 80 days**

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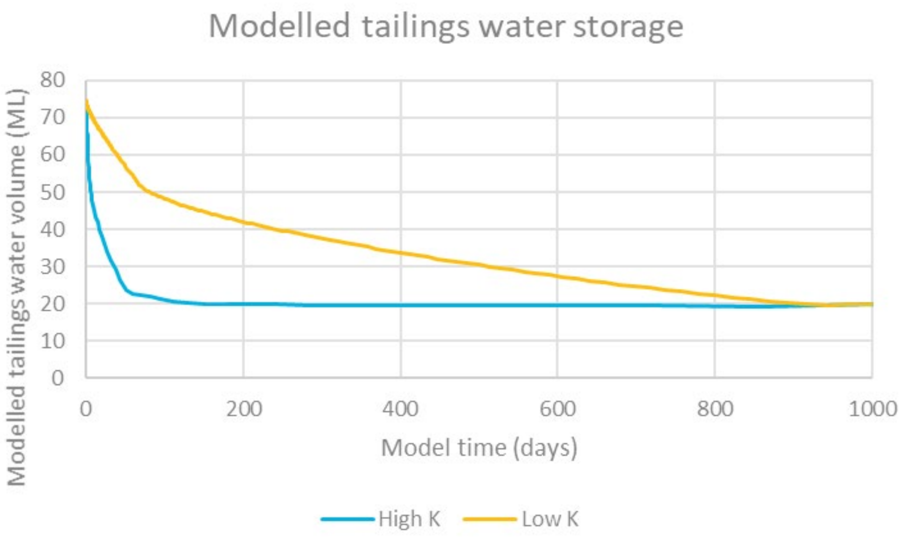
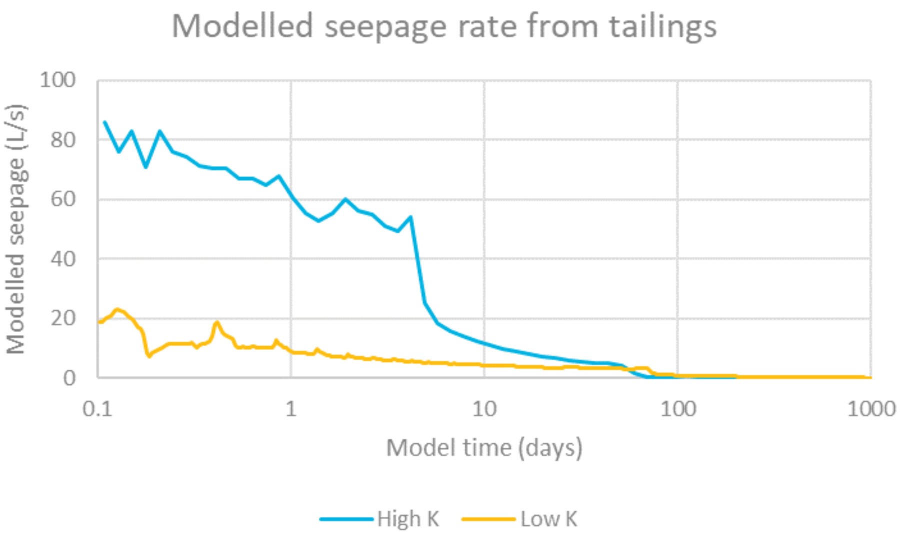
Results- Seepage rate over time





Comparison against seepage simulated in groundwater model

- EES groundwater model simulates 53 L/s (non Centrifuge scenario) total annual seepage to groundwater over multiple tailings cells
- SEEP/W models simulate tailings seepage over individual 160 m x 300 m tailings cells (floor space ~4.8 ha)
- Scaled to a vertical seepage rate, the EES groundwater model simulates average seepage of **2.55 m/year**
- In equivalent terms, the high K and low K scenarios simulate annual vertical seepage of **1.25** and **0.82 m/year** respectively
- Low K scenario equates to only **30% of EES model**

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Seepage rates vs Moisture Migration Study

- Resulting modelled seepage less than than EES model
- Results are consistent with the Moisture Migration Study
  - Results suggest that moisture content must be >20% to promote vertical moisture migration (ie seepage)
  - Sand tails drain to 23% (from a starting point of 27%) within 20 days, for the ‘saturated’ tailings case
  - Majority of seepage seems to occur within the first 30 minutes of tailings placement

1. Centre for Bulk Solids and Particulate Technologies (5 July 2019)

Moisture Migration Study results

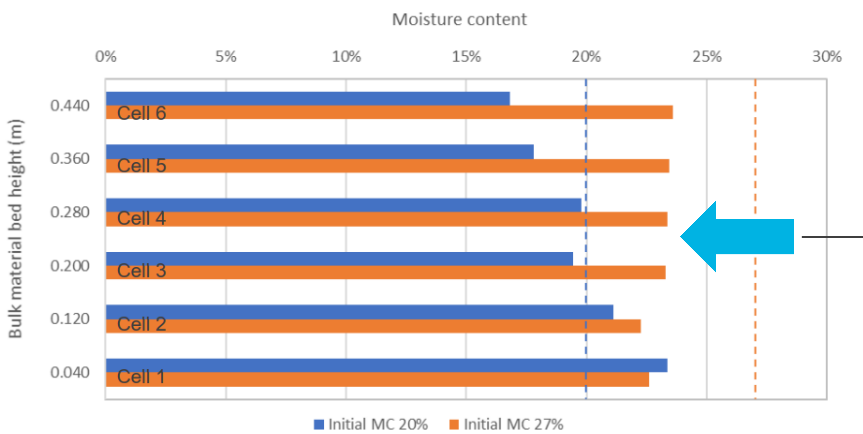

FIGURE 2 COMPARISON OF MOISTURE VARIATION THROUGH COLUMNS

Moisture % falls over time, as water drains from the bottom of the column cells (20-day results shown)

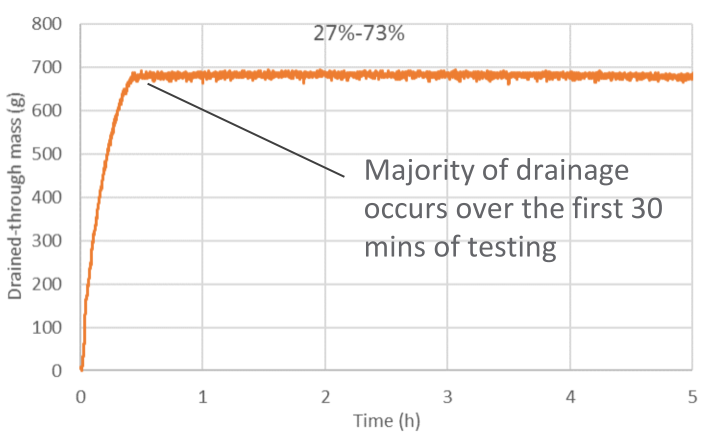

FIGURE 4 MASS OF DRAINED WATER COLLECTED UNDER THE SAND TAILINGS WITH AN INITIAL MOISTURE CONTENT OF 27%

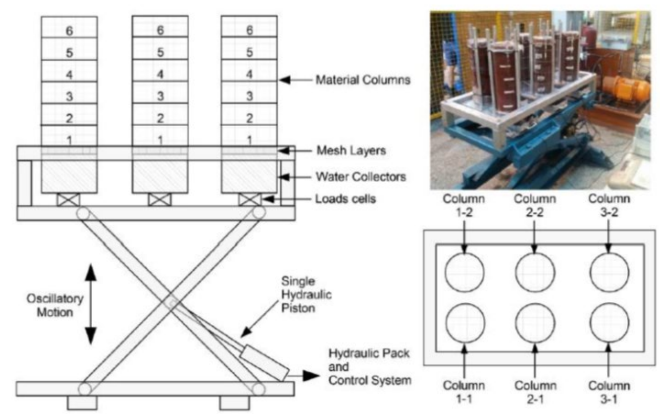

FIGURE 1. EXPERIMENTAL SET-UP FOR OSCILLATORY DRAINAGE TESTING SYSTEM.

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Conclusion & Recommendations

- Tailings seepage is predicted to occur slowly through the unsaturated zone, without enough water to maintain full saturation to the watertable
- Seepage rate from tailings materials is dependent on the unsaturated hydraulic parameters of the Coongulmerang Formation, with monthly average rate between 3 and 15 L/s per 160 x 300 m floor space of tailings cell. Note that several of these cells may be mined in any one year.
- The lower rate is the most likely, based on our knowledge to date
- Seepage to the watertable is more gradual, with only a portion of the water from the tailings cells reaching the watertable
- Tailings materials are predicted to desaturate but hold on to water, with approximately 20 ML of water entrained in each cell

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Conclusion & Recommendations

- The SEEP/W model loses more water from the tails than the moisture migration study suggests. However, even with this over-estimate of water loss, this model shows a significant decrease in the volumes of water reaching the water table when compared to the EES. This is due to the slow percolation rates through the Coongulmerang Formation, and also due to the moisture retention properties of the tails.
- The moisture migration study suggests:
  - Moisture contents must be >20 % to promote any seepage
  - Fully saturated tailings will only seep tailings water initially, until water content approaches 23%.

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Conclusion & Recommendations

- Model implications include:
  - More tailings volume will exist within the pit. Does this affect the accommodation space?
  - May lead to an opportunity to dewatering sand tailings further
  - Significantly less seepage compared to the EIS model (for the ksat = 0.005 m/d case) reduces the significance of groundwater mounds. The environmental impact risks from tailings seepage may be greatly reduced compared to EES assessment.
- Model based on generic soil curves with some control on Ksat values.
- Recommend using site-based data once information is received from the EAL labs.

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