Studies Related to Analysis of Seepage of Sea Water through the Dyke and from underneath the Flood Regulator

as part of

Development of Detailed Project Report of Kalpasar Dam Project

being undertaken by the
National Centre for Coastal Research, Ministry of Earth Sciences

Department of Civil Engineering, IIT Delhi

Preliminary Report

Dr. G.V. Ramana
Professor
Department of Civil Engineering
Indian Institute of Technology Delhi
Hauz Khas, New Delhi-110016

Outline

- ***Numerical model***
- ***Estimation of the hydraulic conductivity of soils***
- ***Identification of critical cross-sections for seepage analysis***
- ***Steady state seepage analysis***
- ***Seepage analysis with temporal variation of the sea level***
- ***Results of seepage analysis for -25 m cross-section***
- ***Summary***

Numerical model

- Based on **Biot's 3-phase mixture theory where the phases are soil, water, and air**
- Governing equation for the rate of change of pressure head of water is given by,

$$\frac{d^s h_l}{dt} = \frac{1}{\tilde{C}_{sr}} [\nabla . [k \nabla (h_l + y)]]$$

- Where $\tilde{C}_{sr} = C_l + C_s$. $C_l = \gamma_l n_l / K_l$ and $C_s = n dS_r / dh$ are the specific storage and specific moisture terms, respectively.
- h_l and y are the pressure and elevation heads.

- Degree of saturation & permeability are related to the suction head by the **van Genuchten model**,

$$S_r = S_{res} + (S_{sat} - S_{res})[1 + (g_a|-h|)^{g_n}]^{g_c}$$

$$k = k_{sat} S_e^{g_l} \left[1 - \left(1 - S_e^{-1/g_c}\right)^{-g_c}\right]^2$$

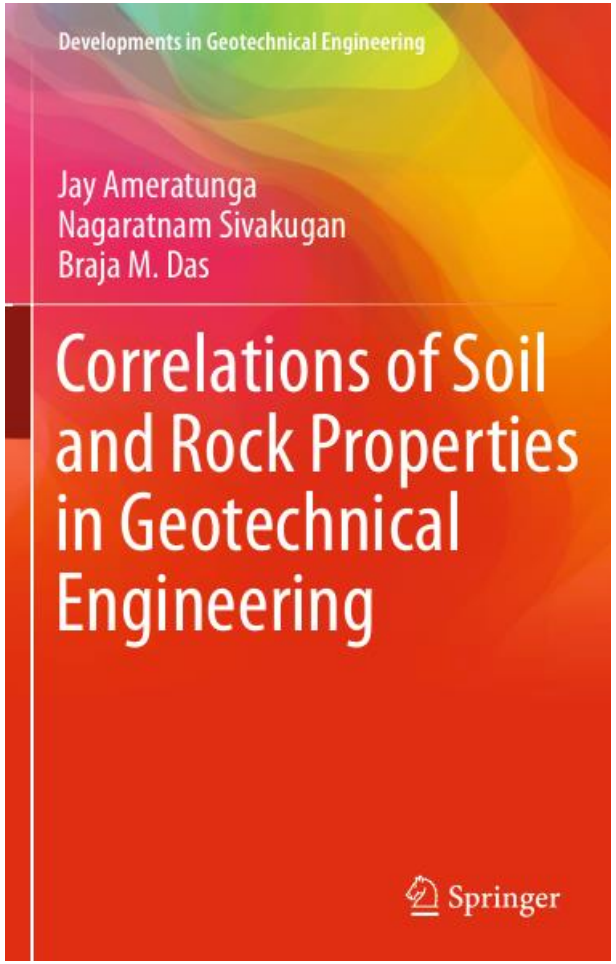
- Where, S_r is the degree of saturation, g_a, g_n and g_c are the model parameters, and k is the hydraulic conductivity of the soil.
- Assuming Darcy's law to be valid, the flow velocity is obtained by, $q = -k \nabla (h_l + y)$

Estimation of the hydraulic conductivity of soils

- The in-situ void ratio for the seabed calculated using the dry density provided in the marine geotechnical report.
- e, D_{10}, and D_{50} are used for estimating the hydraulic conductivity using the Chapuis & Kozeny-Carman equations.
- Average value of the hydraulic conductivity estimated from all boreholes is equal to 2.0×10^{-4} m/s and is adopted for the seepage analysis.

- The embankment (compacted) material is assumed to be silty sand (SM).
- Literature reported hydraulic conductivity for SM ranges between 1.0×10^{-6} to 1.0×10^{-5} m/s.
- Hence, average value of 5.0×10^{-5} m/s is adopted.

- Based on data in geotechnical investigation report, consistency index of clay estimated to be 78%, resulting in hydraulic conductivity of 1.0×10^{-11} m/s.
- However, due to chemistry of the seawater, the permeability is likely to be higher, and taken to be 1.0×10^{-6} m/s.



https://link.springer.com/book/10.1007/978-81-322-2629-1

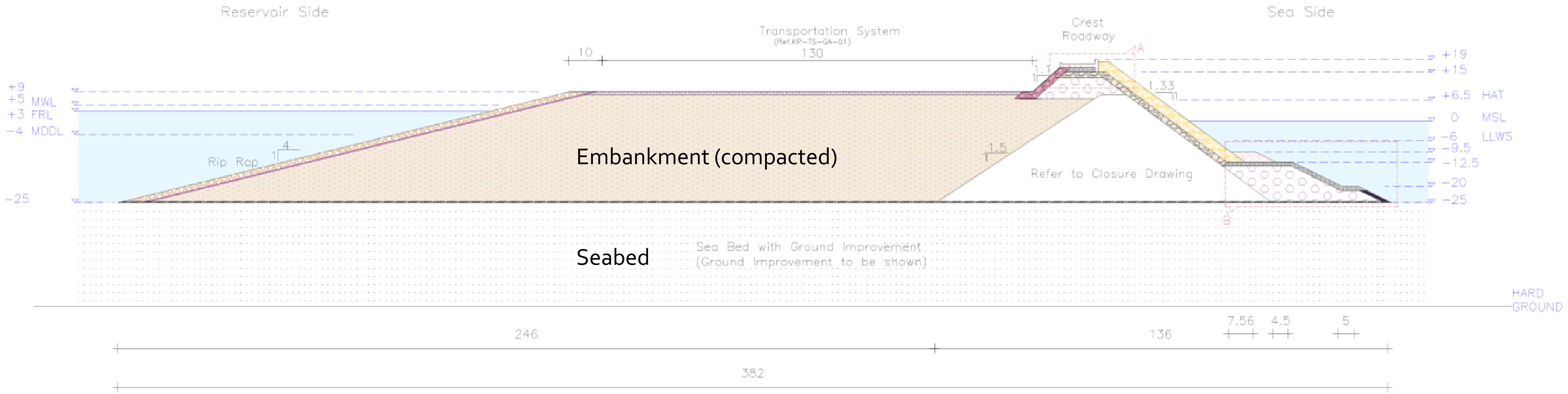
Estimation of the hydraulic conductivity of soils

- For considering the heterogeneity of hydraulic conductivity of the soils:
    - Analysis performed for μ, $\mu - 3\sigma$, and $\mu + 3\sigma$ values.
    - Hydraulic conductivity reported to follow the lognormal distribution with high coefficient of variation (~100%).

Material	Mean hydraulic conductivity (m/s)	$\mu - 3\sigma$ (m/s)	$\mu + 3\sigma$ (m/s)
Seabed	2.0×10^{-4}	1.2×10^{-5}	1.7×10^{-3}
Embankment (compacted)	5.0×10^{-5}	2.9×10^{-6}	4.3×10^{-4}
Clay	1.0×10^{-6}	5.8×10^{-8}	8.6×10^{-6}

Identification of critical cross-sections for seepage analysis

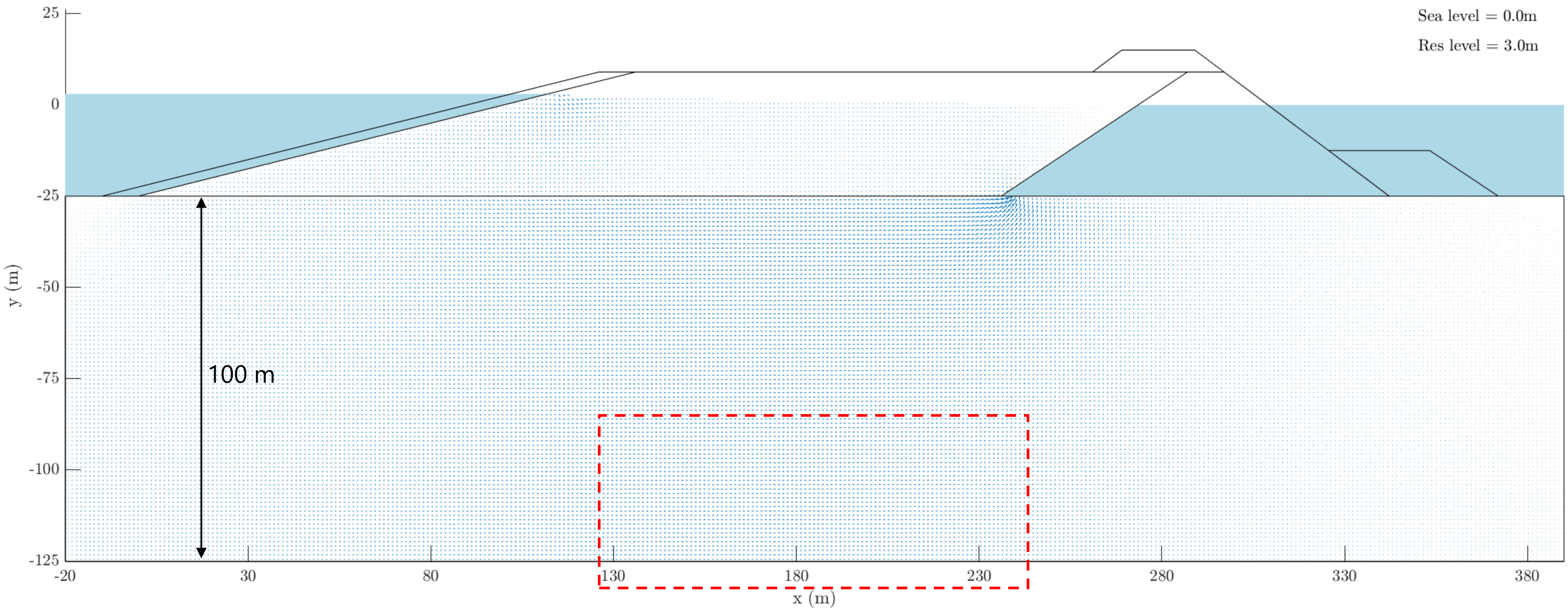
- Using bathometric survey data, the depth of seabed below each cross-section is determined.
- Deepest seabed levels corresponding to each dam cross-section are selected as the preliminary critical sections for performing the seepage analysis.
- Optimal seabed depth for seepage analysis identified by analysing the dyke cross-section at -25 m for increasing depths of the seabed.



Cross-section of dyke at -25 m depth

Identification of critical cross-sections for seepage analysis

- Parametric study on the seabed depth: beyond 100 m depth, the flow vectors become horizontal.



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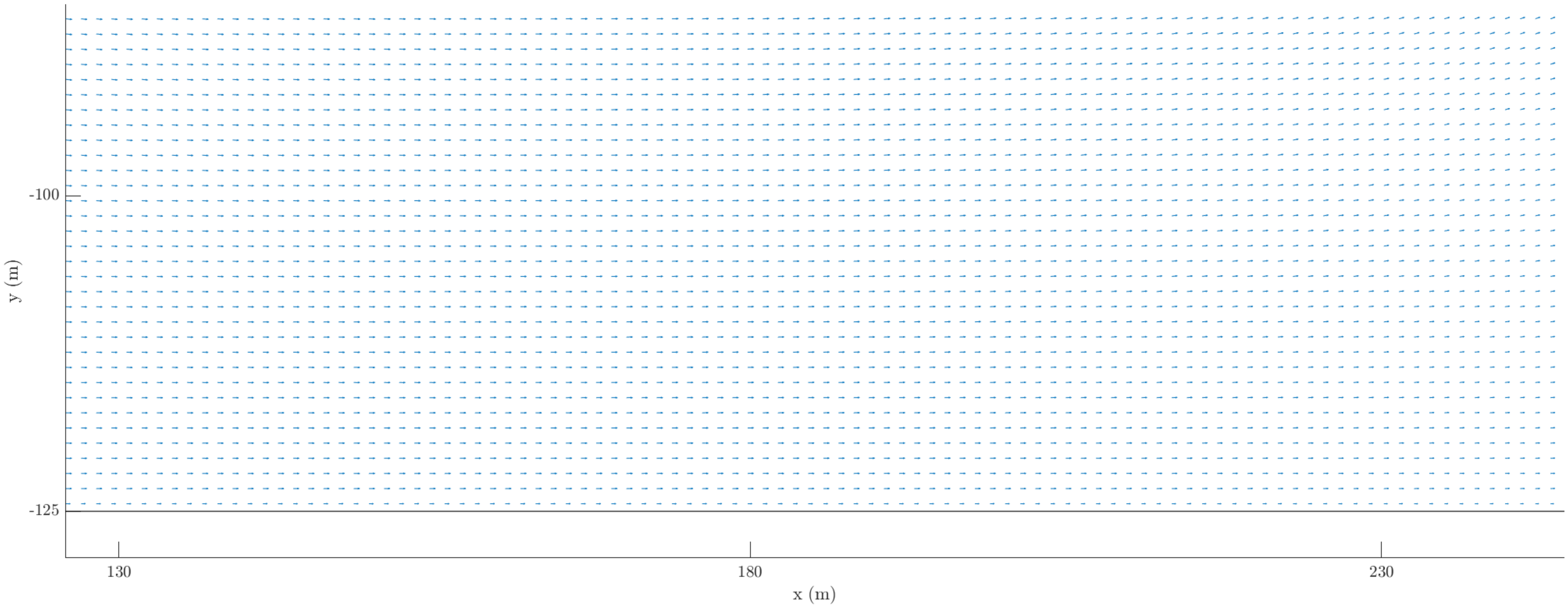
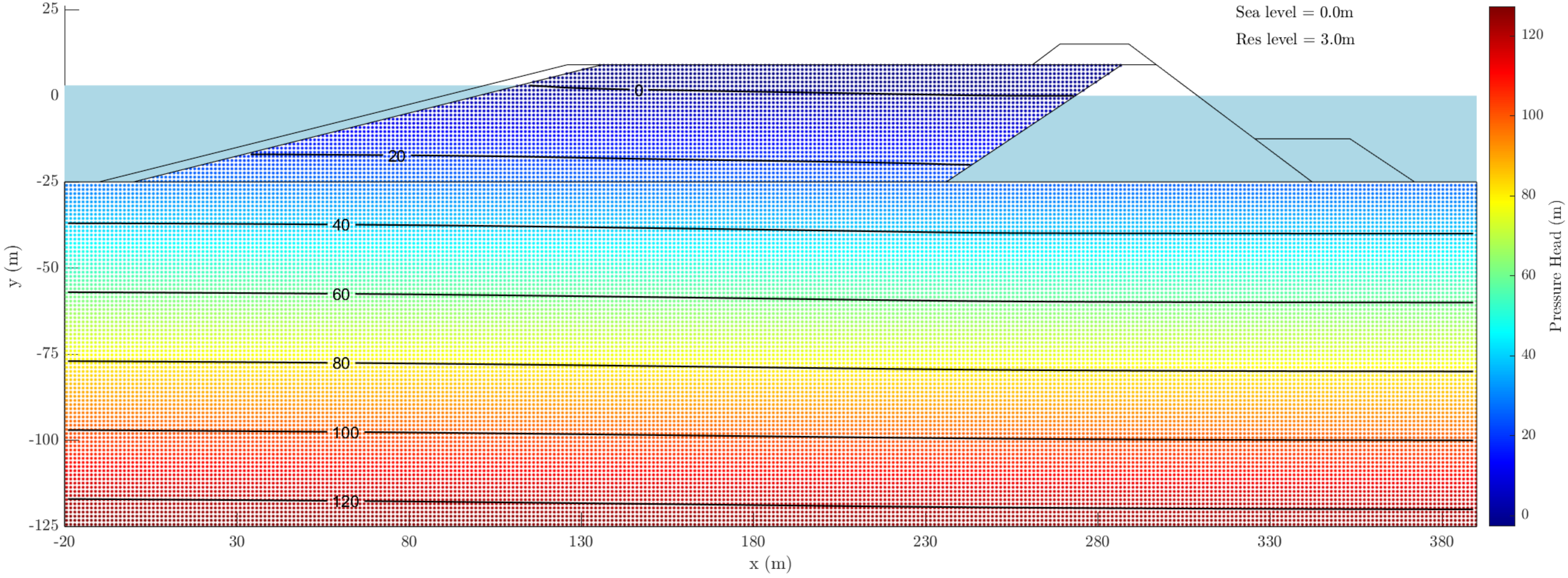


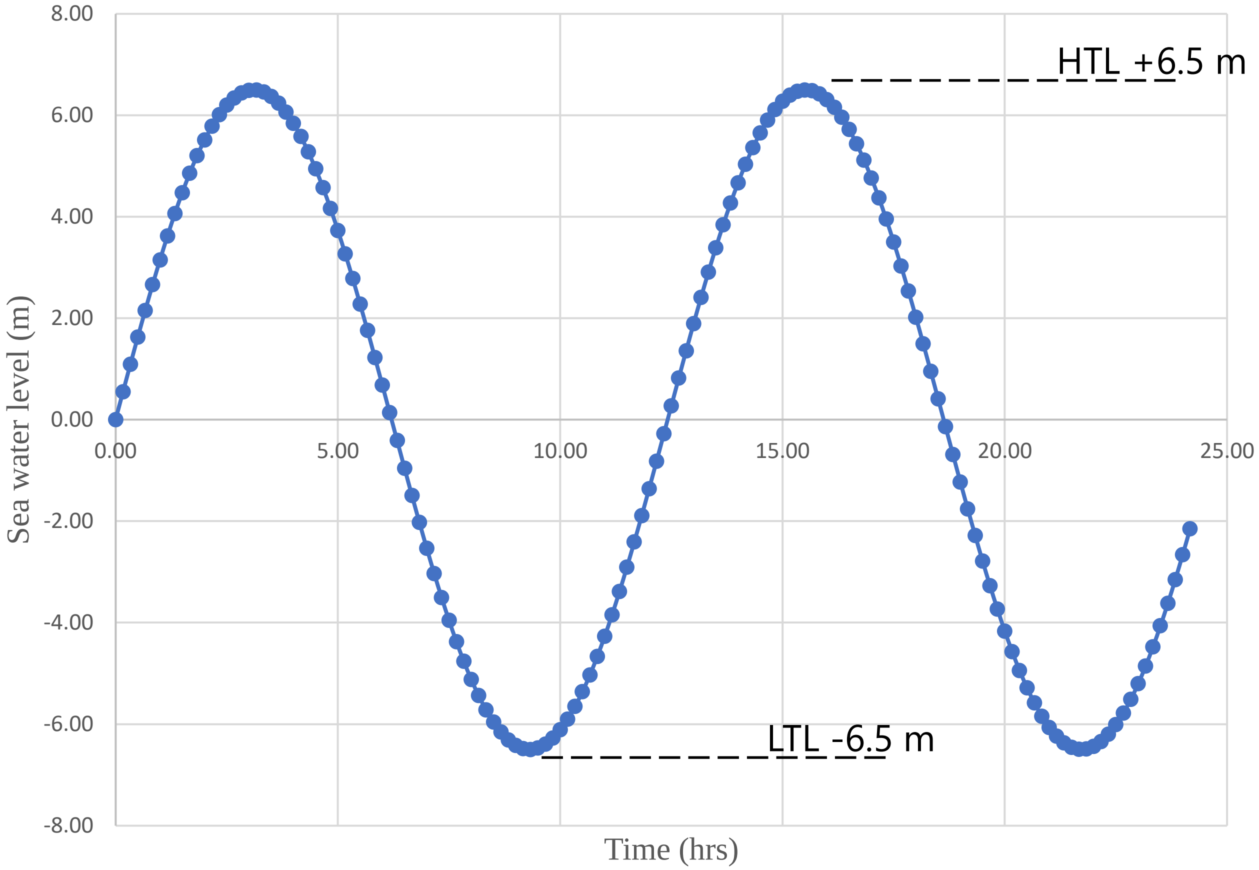
Steady state seepage analysis

- Steady state pressure head contours for sea at the MSL (0.0 m), and reservoir at FRL (+3.0 m)



Seepage analysis with temporal variation of the sea level

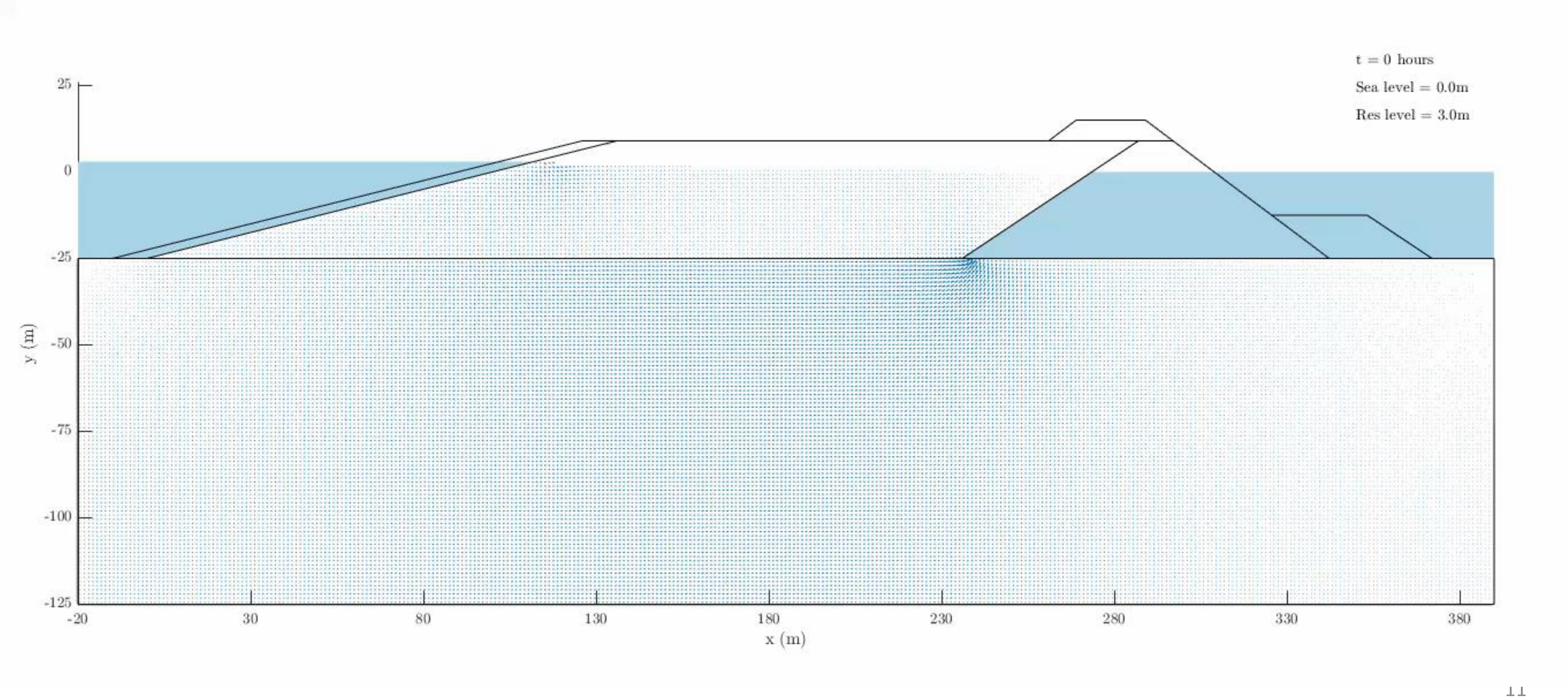
- 2 high and 2 low tides every 24 hr 50 minutes
- One cycle of sea water level variation is shown below.
- Simulations performed for 35 days of the sea level variation (currently).



https://oceanservice.noaa.gov/education/tutorial_tides/tides05_lunarday.html

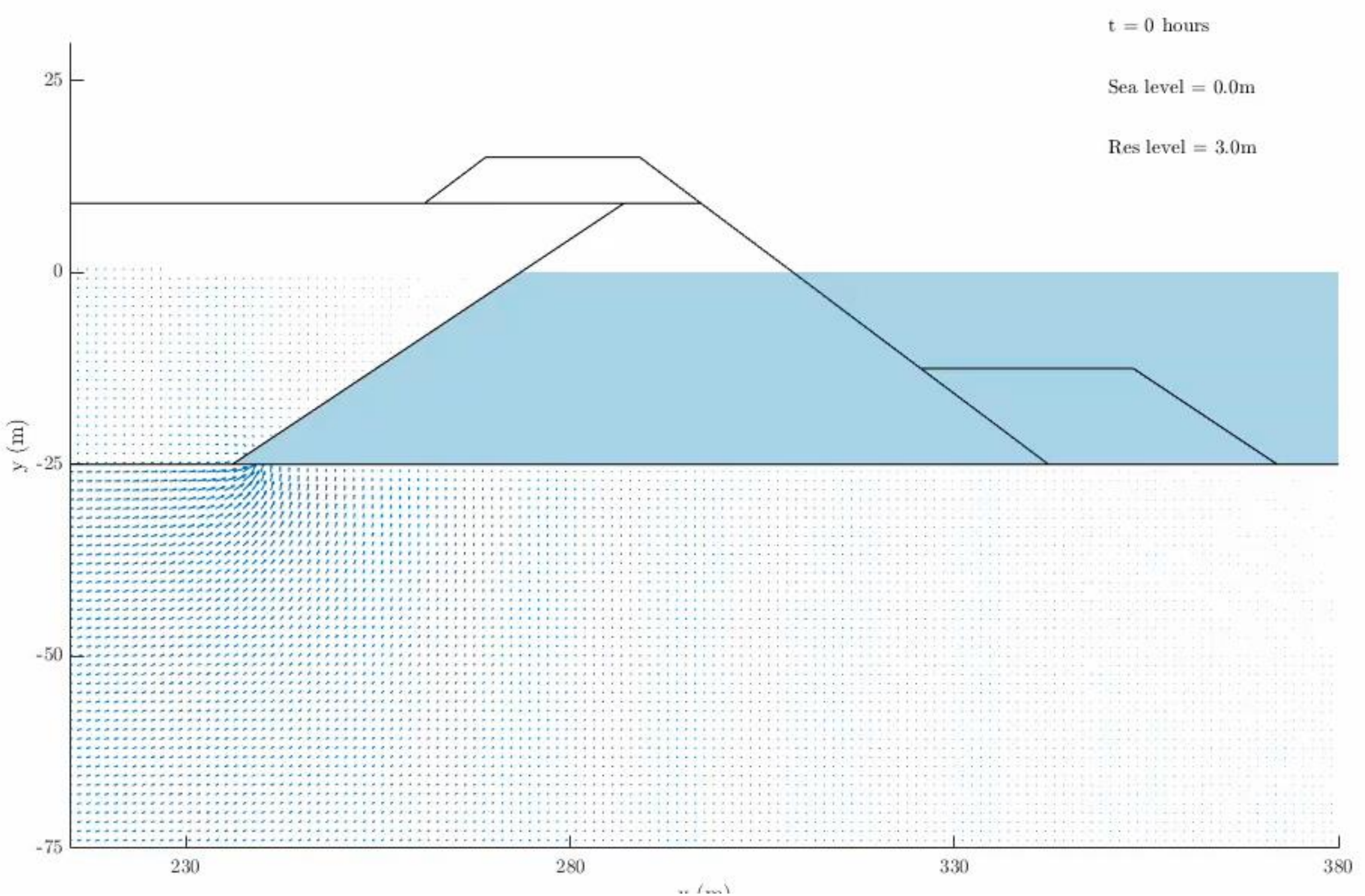
Results of seepage analysis for -25 m cross-section

- Velocity profile for one cycle of sea water variation



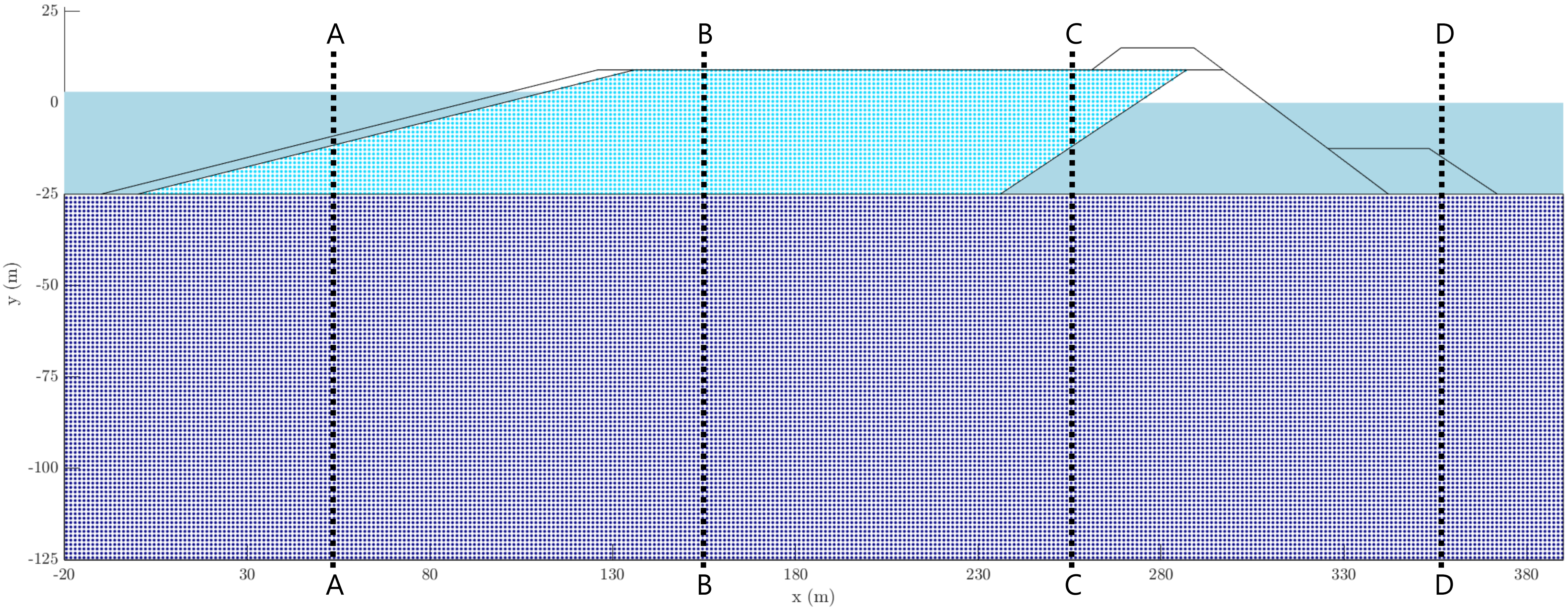
Results of seepage analysis for -25 m cross-section

- Closeup of the region near the sea



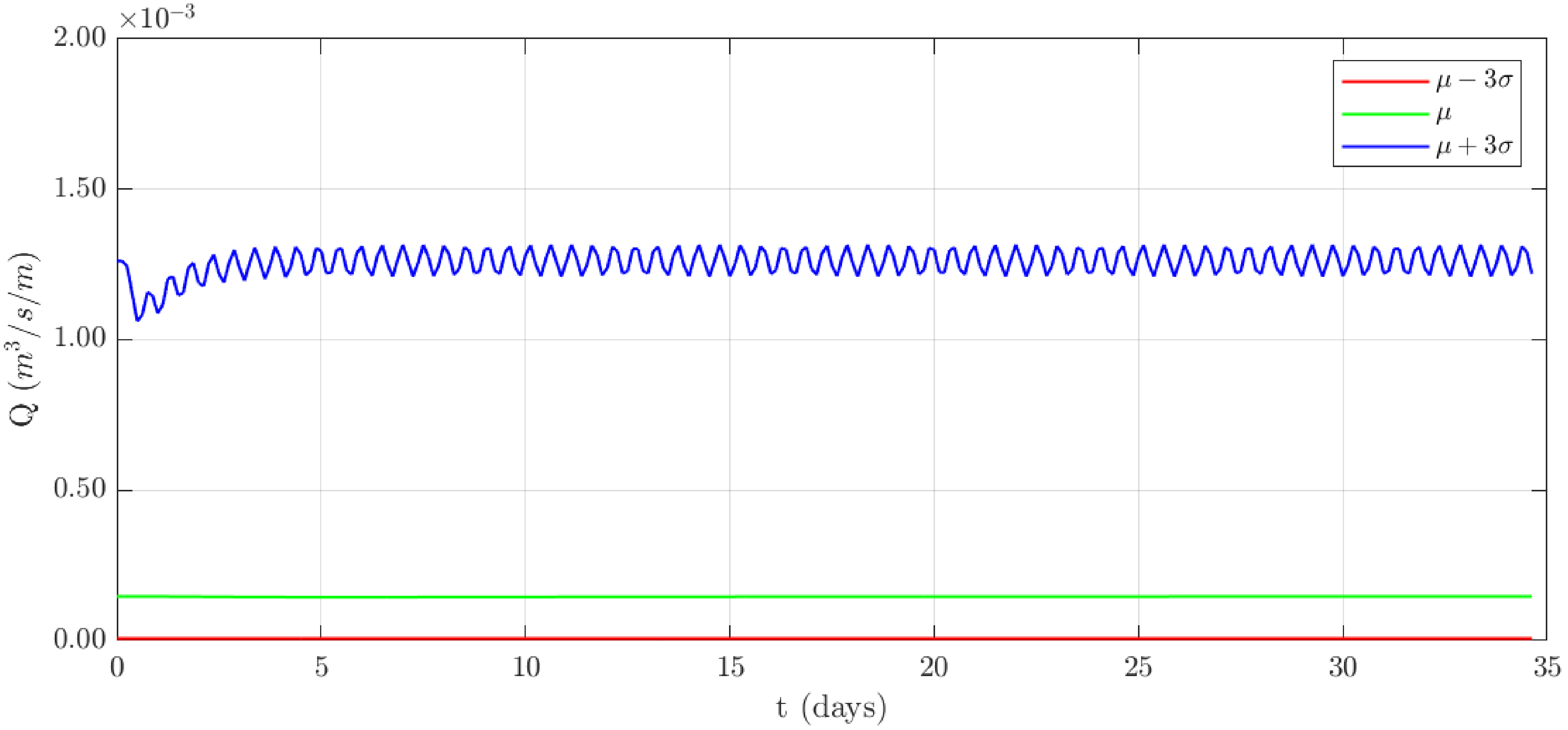
Results of seepage analysis for -25 m cross-section

- Flow rate and total quantity of flow in negative x direction calculated across 4 cross-sections as shown below.
- A (x = 50 m); B (x = 150 m); C (x = 250 m), and D (x = 350 m).



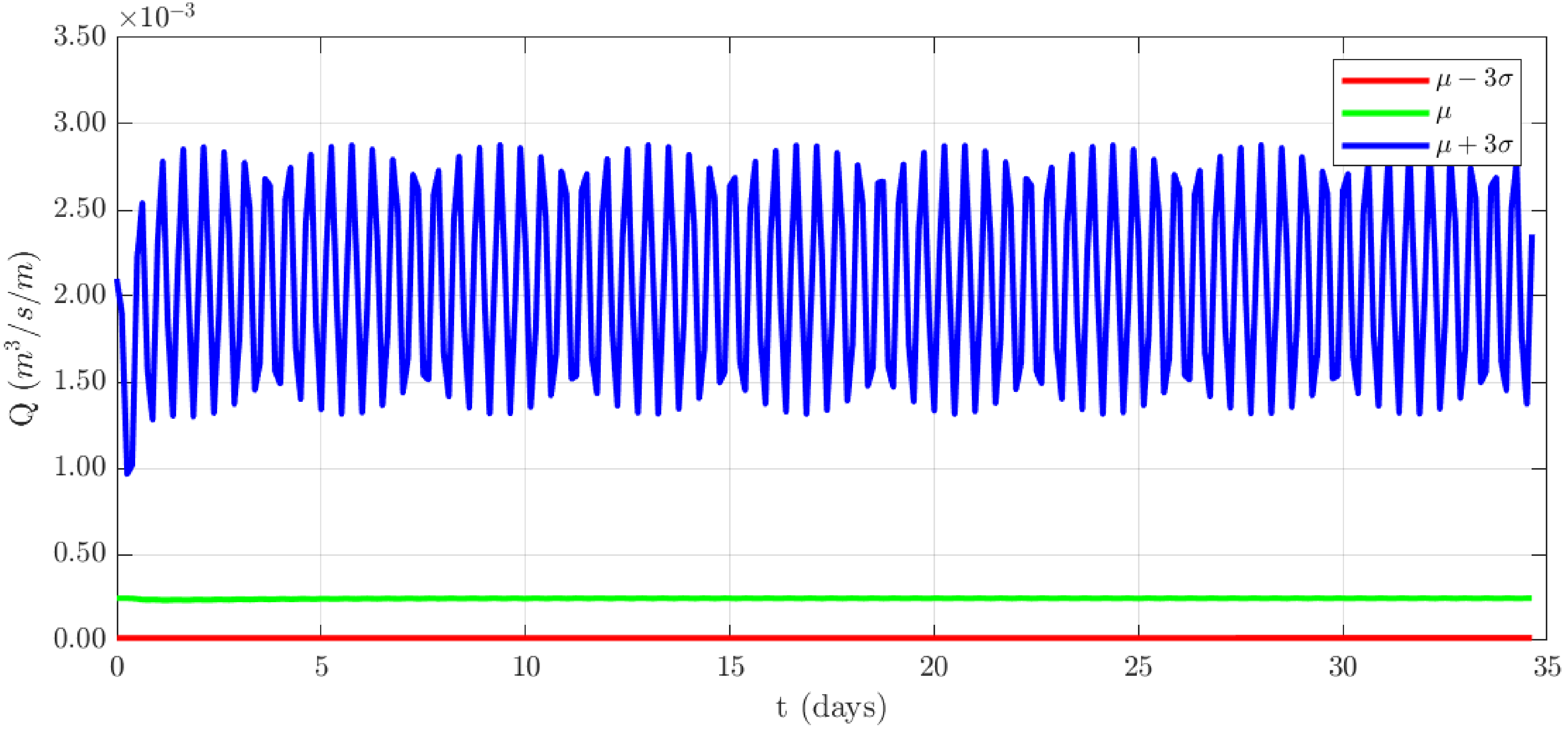
Results of seepage analysis for -25 m cross-section

Section A (x = 50 m) – flow rate through the seabed



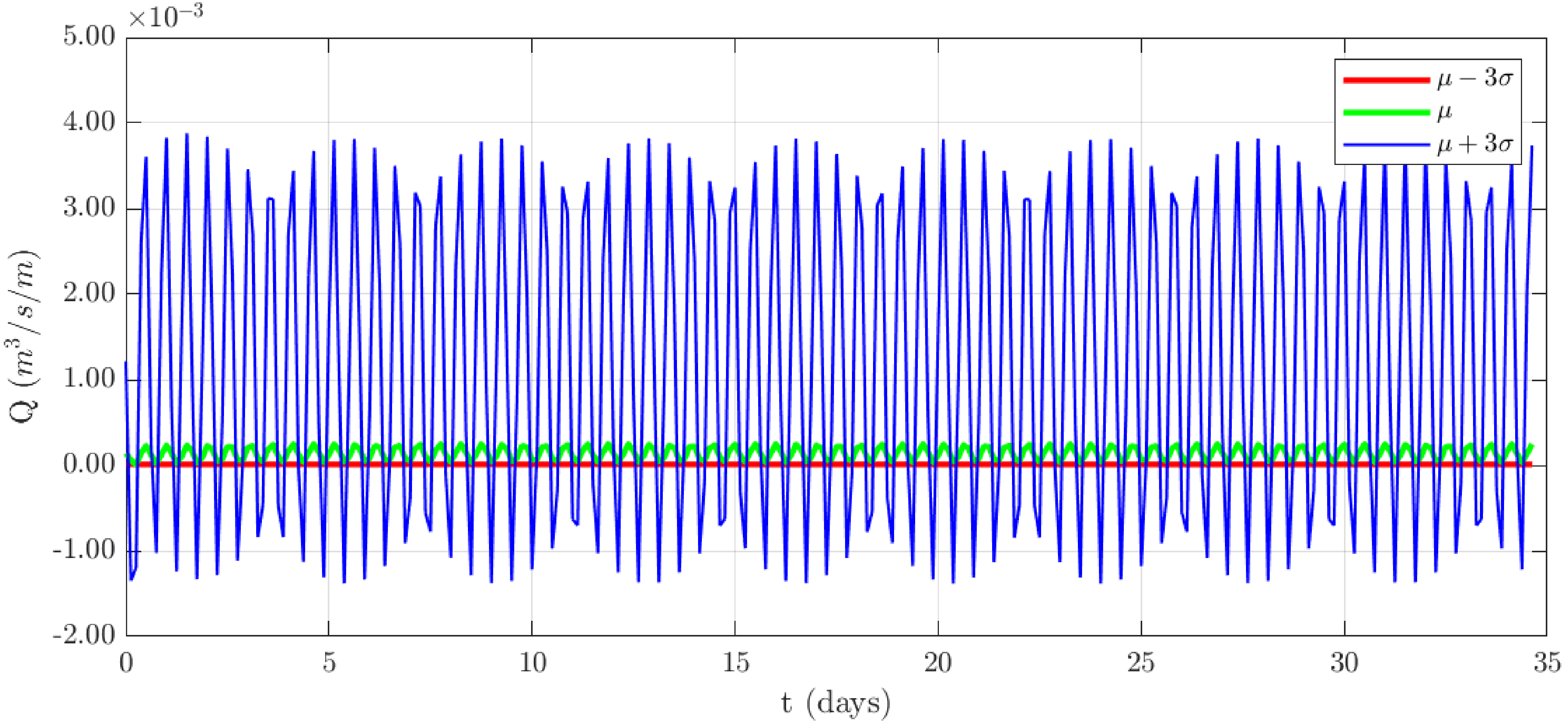
Results of seepage analysis for -25 m cross-section

Section B (x = 150 m) – flow rate through the seabed



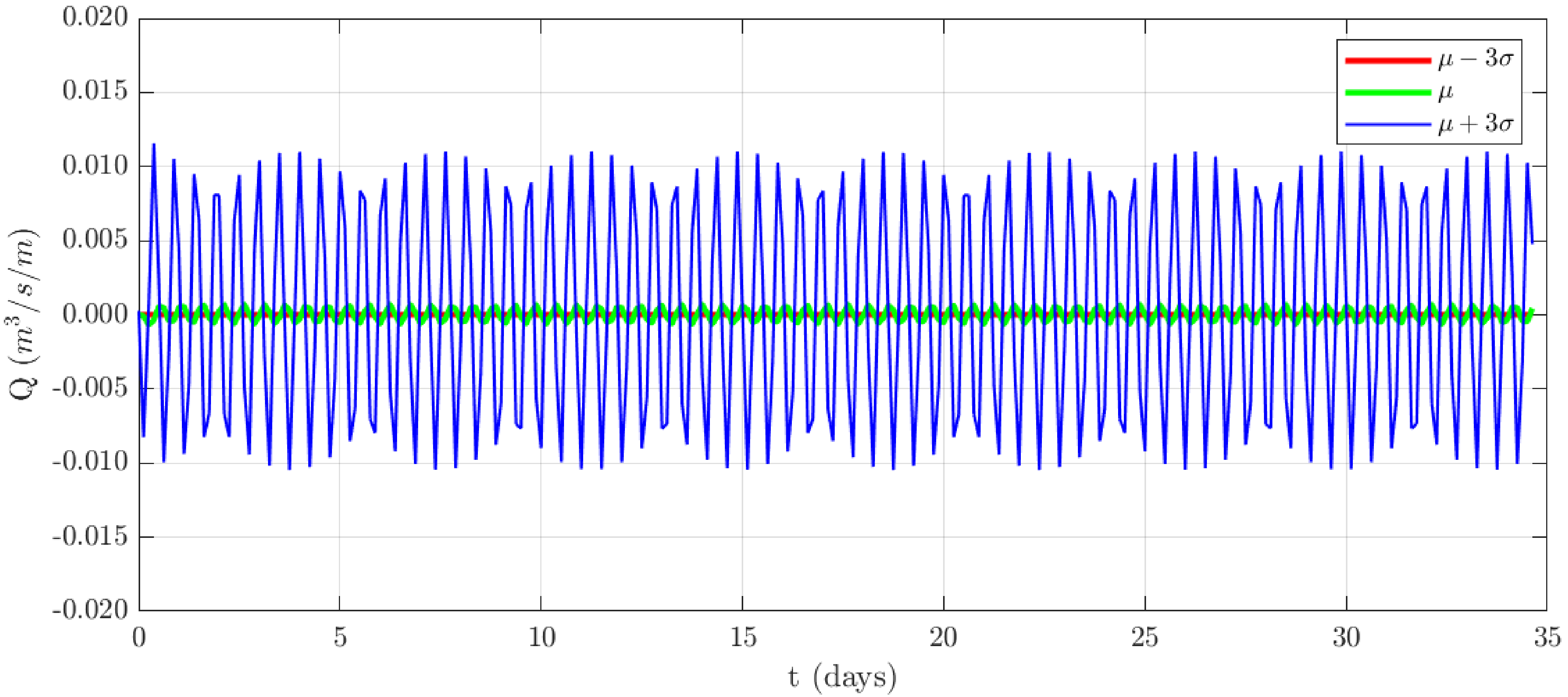
Results of seepage analysis for -25 m cross-section

Section C (x = 250 m) – flow rate through the seabed



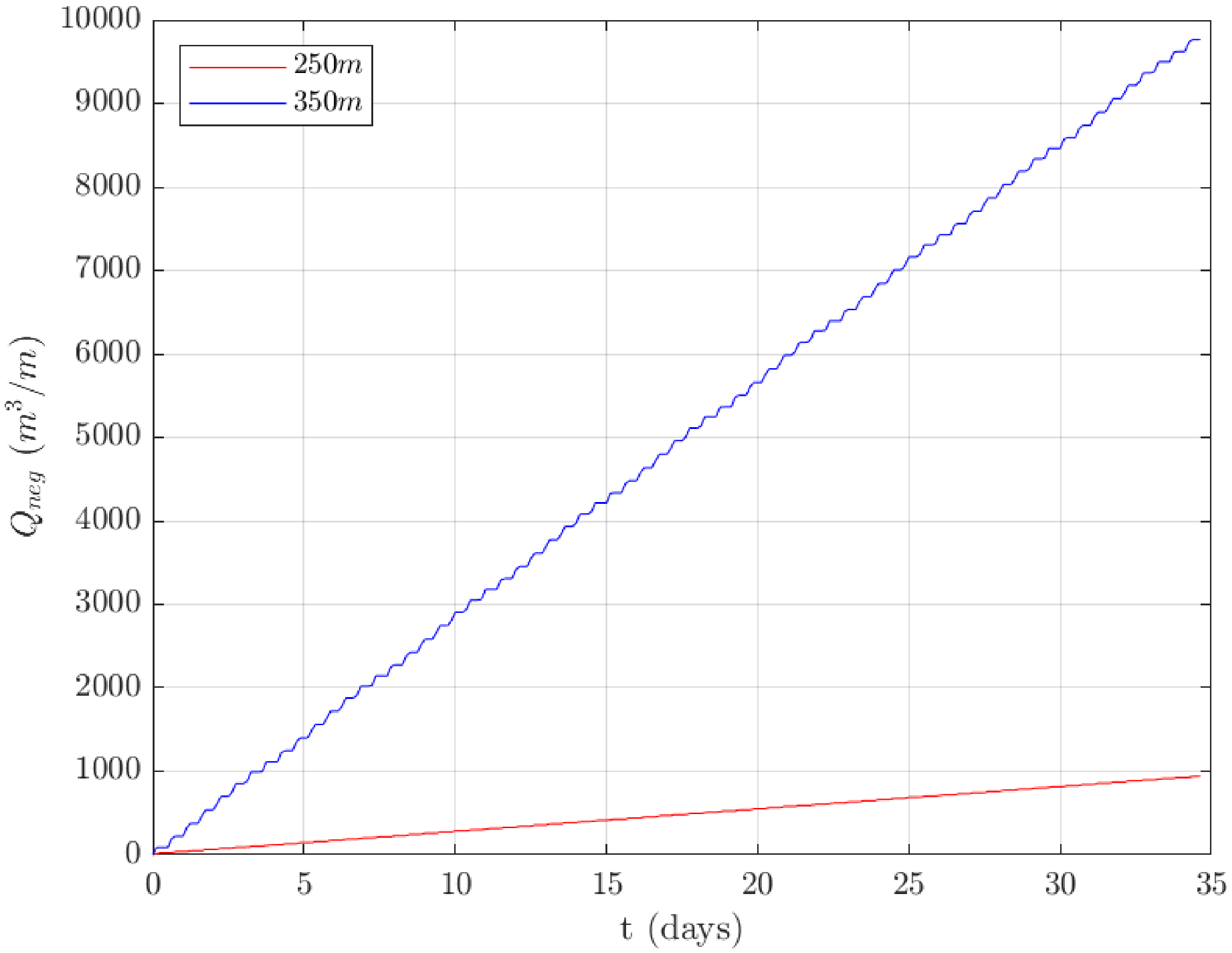
Results of seepage analysis for -25 m cross-section

Section D (x = 350 m) – flow rate through the seabed



Results of seepage analysis for -25 m cross-section

Total quantity of flow in negative x direction (through seabed) at sections C (x = 250 m) and D (x = 350 m)



Results of seepage analysis for -25 m cross-section

Influence of hydraulic conductivity on the total quantity of flow in the negative x direction

Flow through seabed (quantities in m^3/m)

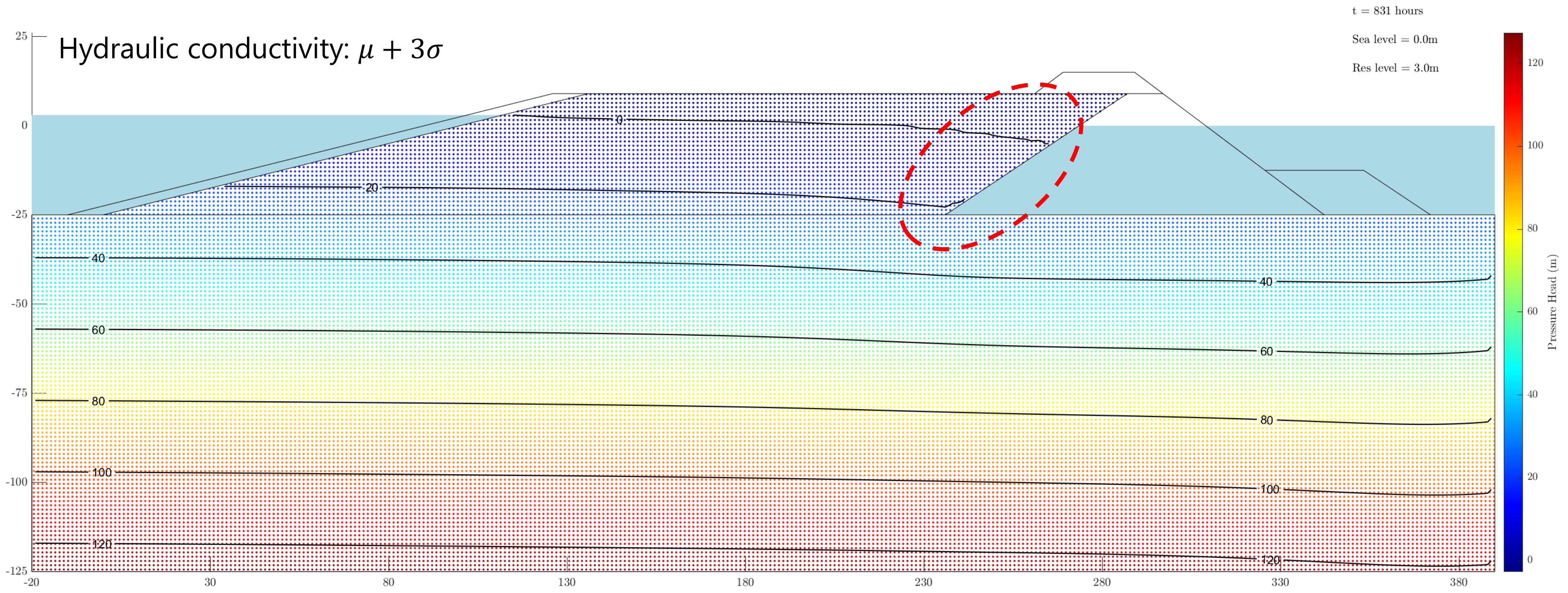
Section	x (m)	$\mu - 3\sigma$	μ	$\mu + 3\sigma$
A	50	0	0	0
B	150	0	0	0
C	250	0	0	939.2
D	350	0	570.3	9764.2

Flow through embankment (quantities in m^3/m)

Section	x (m)	$\mu - 3\sigma$	μ	$\mu + 3\sigma$
A	50	0	0	0
B	150	0	0	0
C	250	12.3	215.6	1252.1
D	350	NA	NA	NA

Results of seepage analysis for -25 m cross-section

Influence of hydraulic conductivity on the pore-water pressure (at 35 days):



Results of seepage analysis for -25 m cross-section

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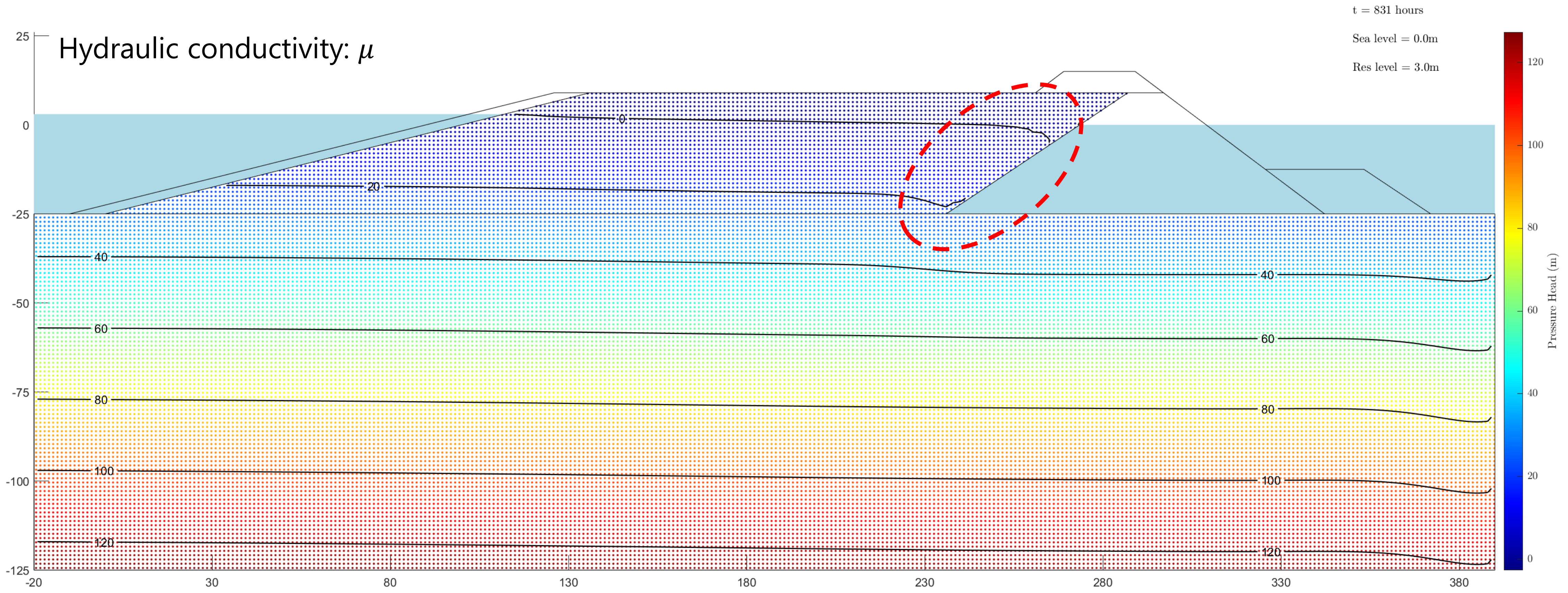
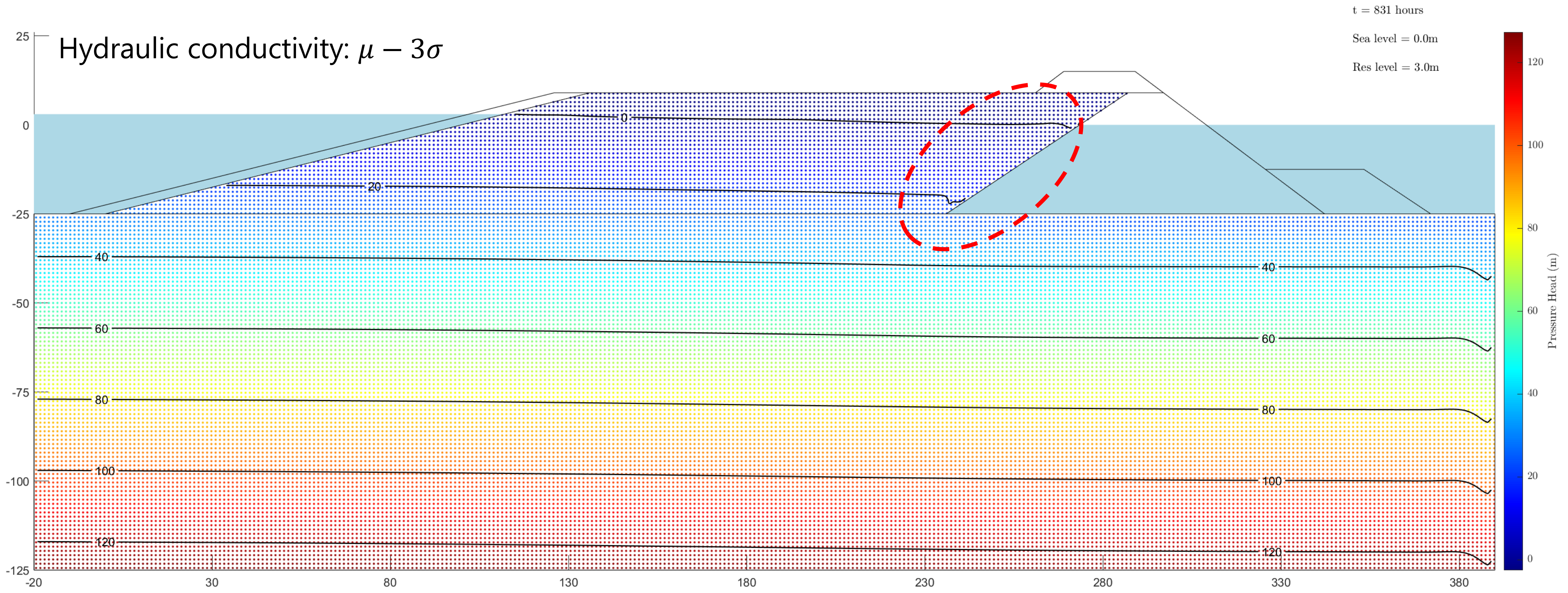


Results of seepage analysis for -25 m cross-section

Influence of hydraulic conductivity on the pore-water pressure (at 35 days):



- Hydraulic conductivity controls the rate of change of the pore-water pressure in the soil.

Summary

Work accomplished:

- Identified the critical cross-sections for the seepage analysis for different depths of the dyke.
- SPH models for various critical cross-sections (dyke and flood regulator) are ready for simulation.

Inputs to be finalized by NCCR:

- Soil properties: hydraulic conductivity and gradation.
- Depth of ground improvement.
- Hydraulic conductivity of seabed after ground improvement.

Thank You