EVALUATING REMEDIATION POTENTIAL OF A SALINIZED HETEROGENEOUS AQUIFER SYSTEM USING THREE-DIMENSIONAL, DENSITY-DEPENDENT GROUNDWATER MODELING

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TECHNISCHE UNIVERSITÄT DRESDEN

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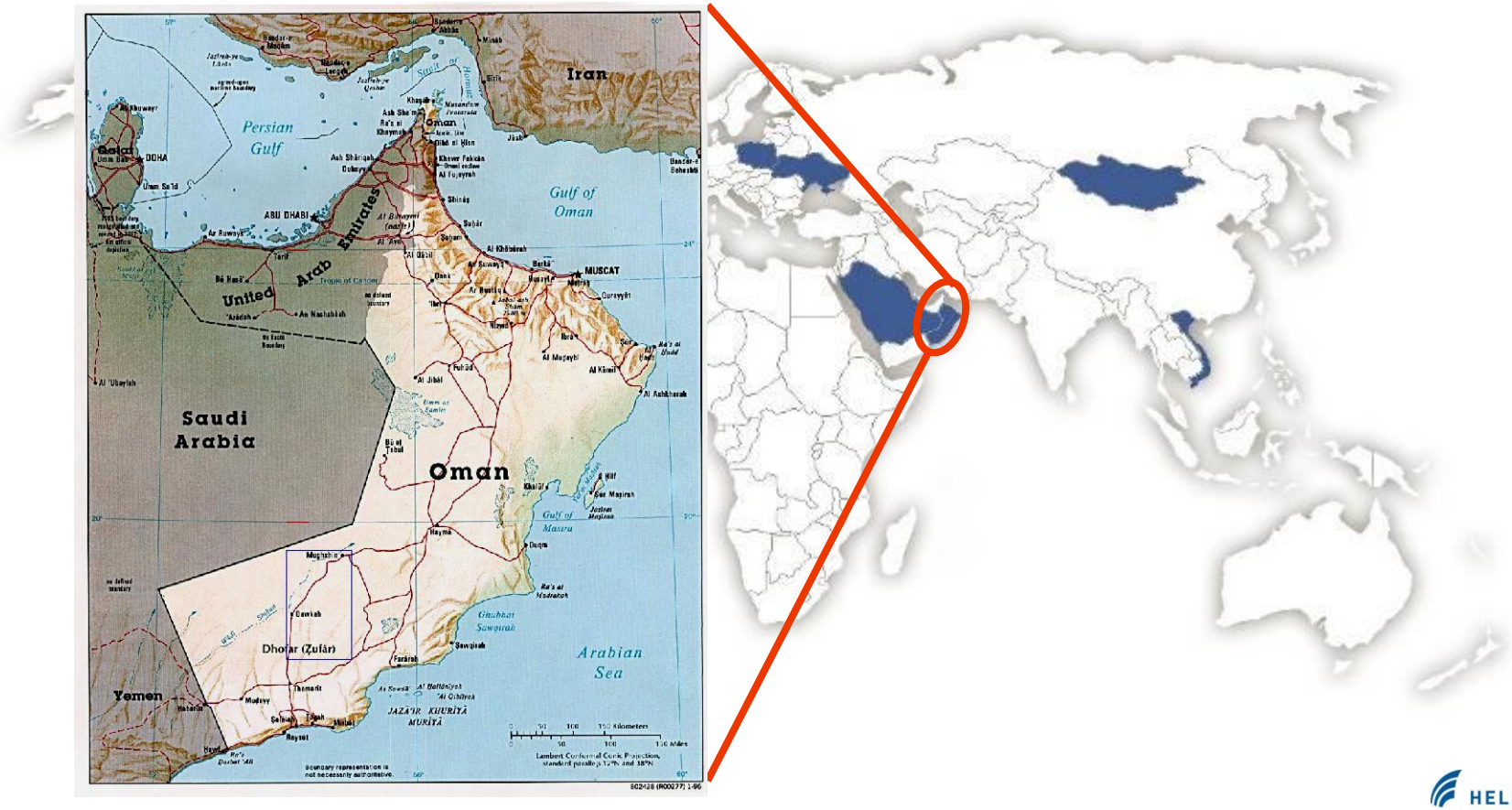
OpenGeoSys
www.opengeosys.org

IWAS PROJECT

International Water Research Alliance Saxony



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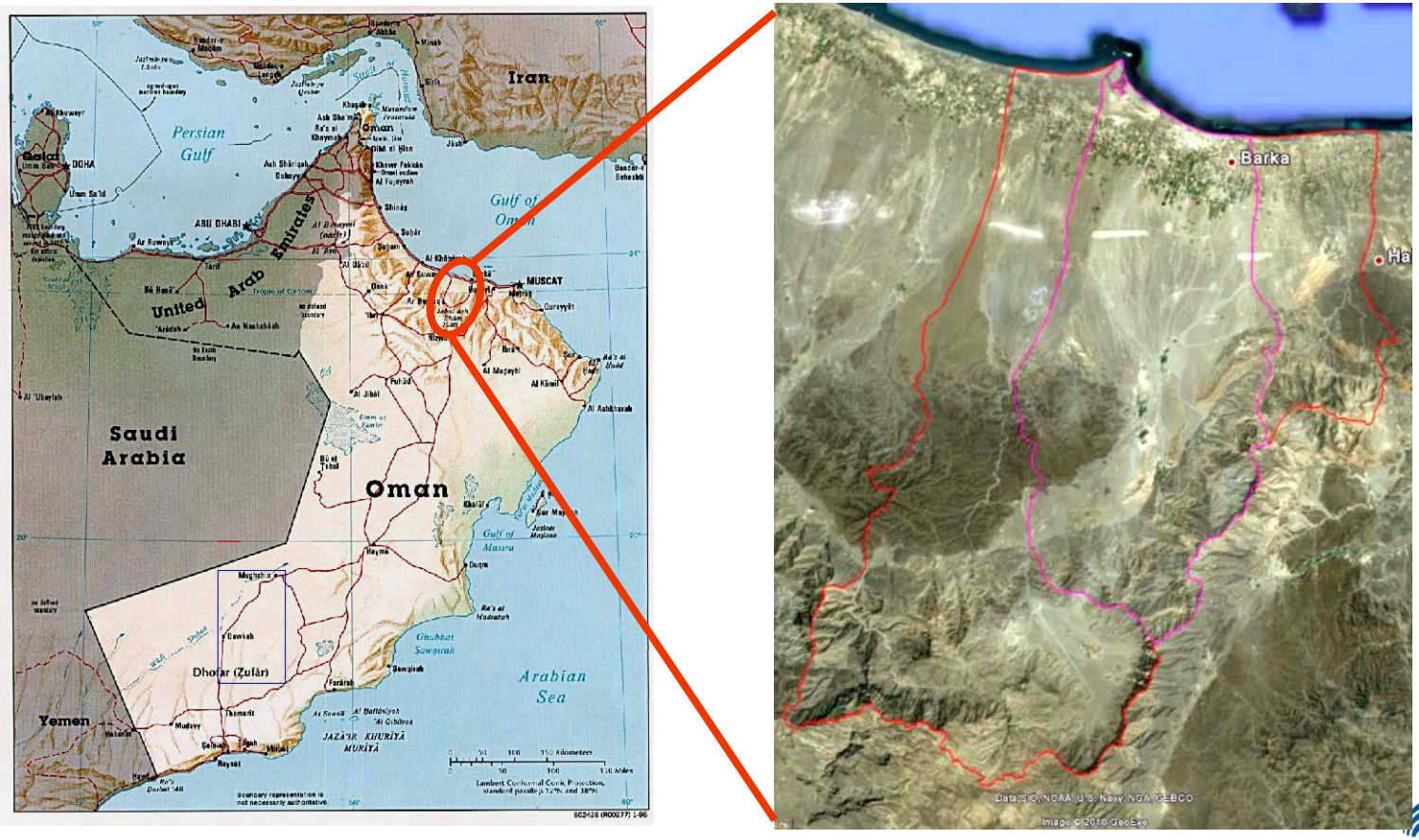
STUDY REGION

AL BATINAH COAST



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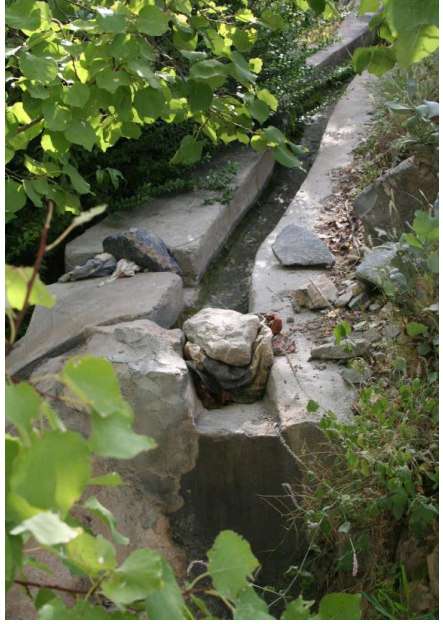
STUDY REGION

AL BATINAH COAST

- Highest population density of Oman, strong economical and population growth
- Highly productive soils
  → Large amount of agriculture
- Three wadis in northern coastal area along Gulf of Oman



CHALLENGES FOR GROUNDWATER MANAGEMENT

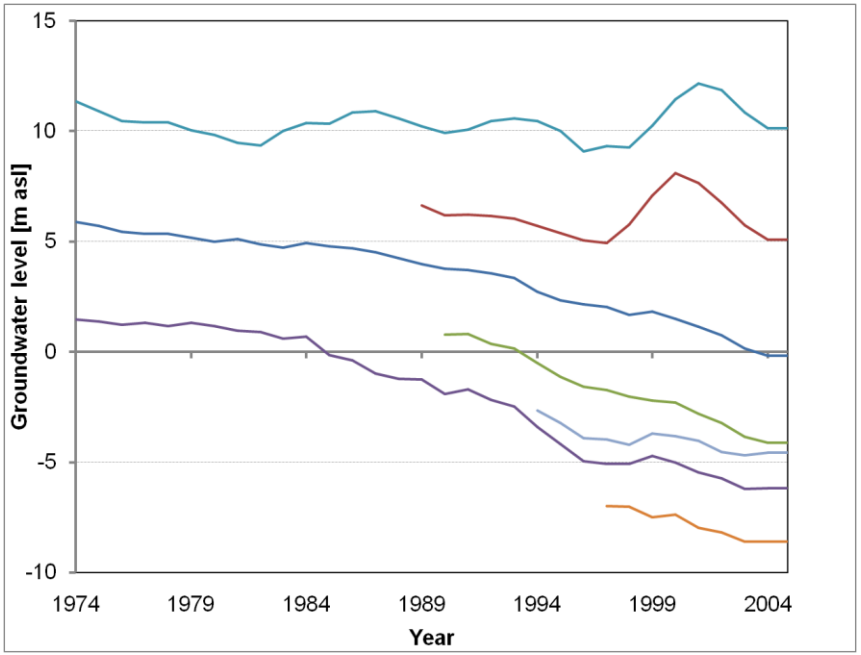
- Since 1970s,
  rapid decrease of GW-level
  due to overpumping

→ *quantitative* constraint

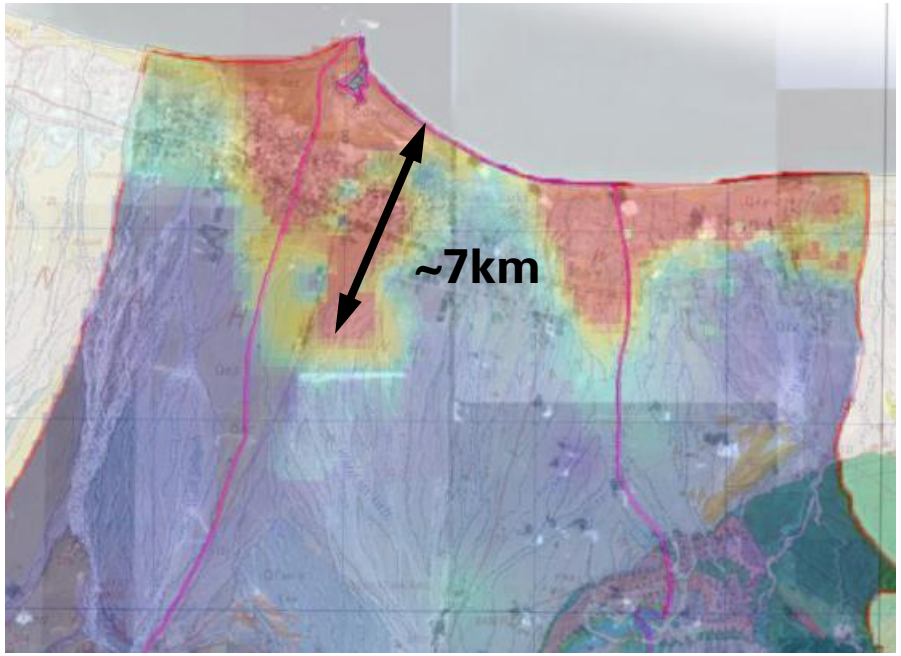
- Reversion of natural
  groundwater gradient,
  marine saltwater intrusion

→ *qualitative* constraint

CHALLENGES FOR GROUNDWATER MANAGEMENT

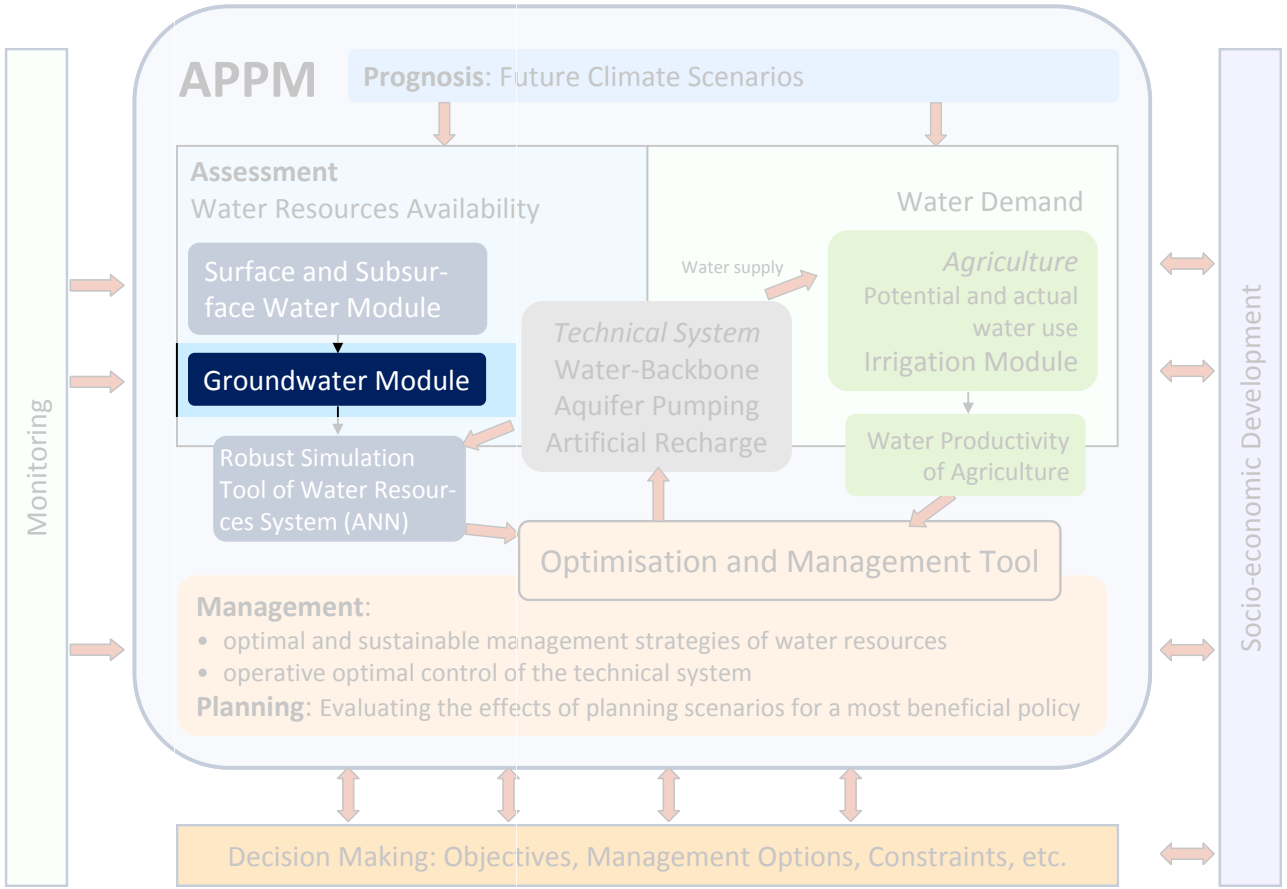


Decreasing Groundwater Level



Saltwater intrusion (2000)

IWRM FOR STUDY AREA



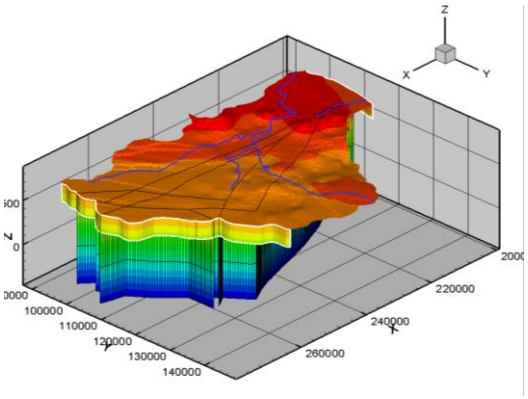
Grundmann, et al., 2011

OpenGeoSys
MODELLING SOFTWARE

- Open-source, scientific numerical modeling toolbox
- Coupled THM/C processes (thermo, hydraulic, mechanical, chemical)

→ Kolditz et al., 2012

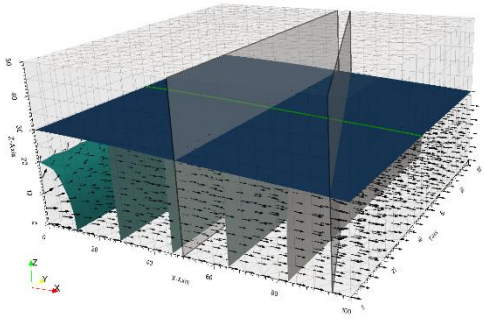
→ www.OpenGeoSys.org



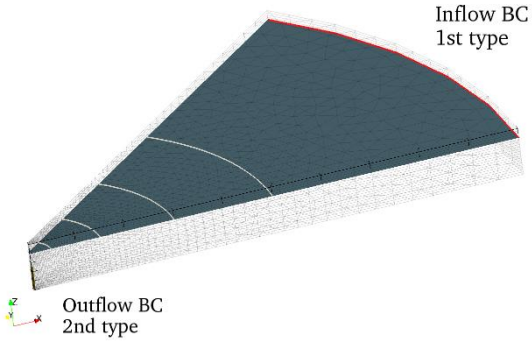
Kalbacher, Delfs, Watanabe, et al.

BENCHMARKS

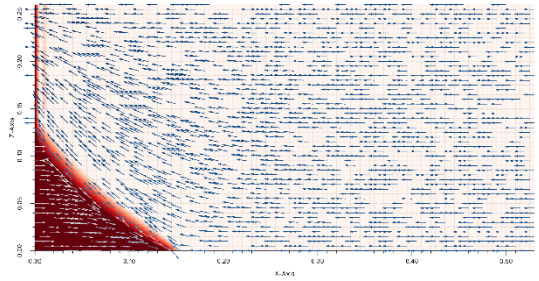
Unconfined GW Surface (DARCY)



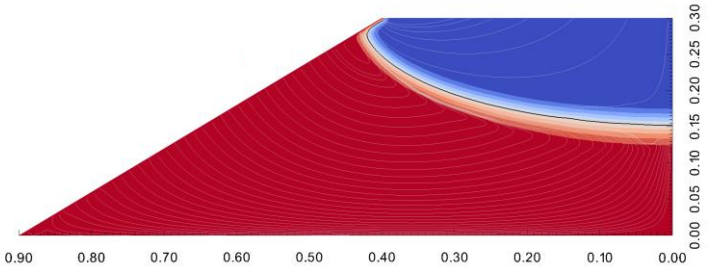
Transient Drawdown (THEIS)



Saltwater Intrusion (GOSWAMI-CLEMENT)



Freshwater Lens (STOECKL)



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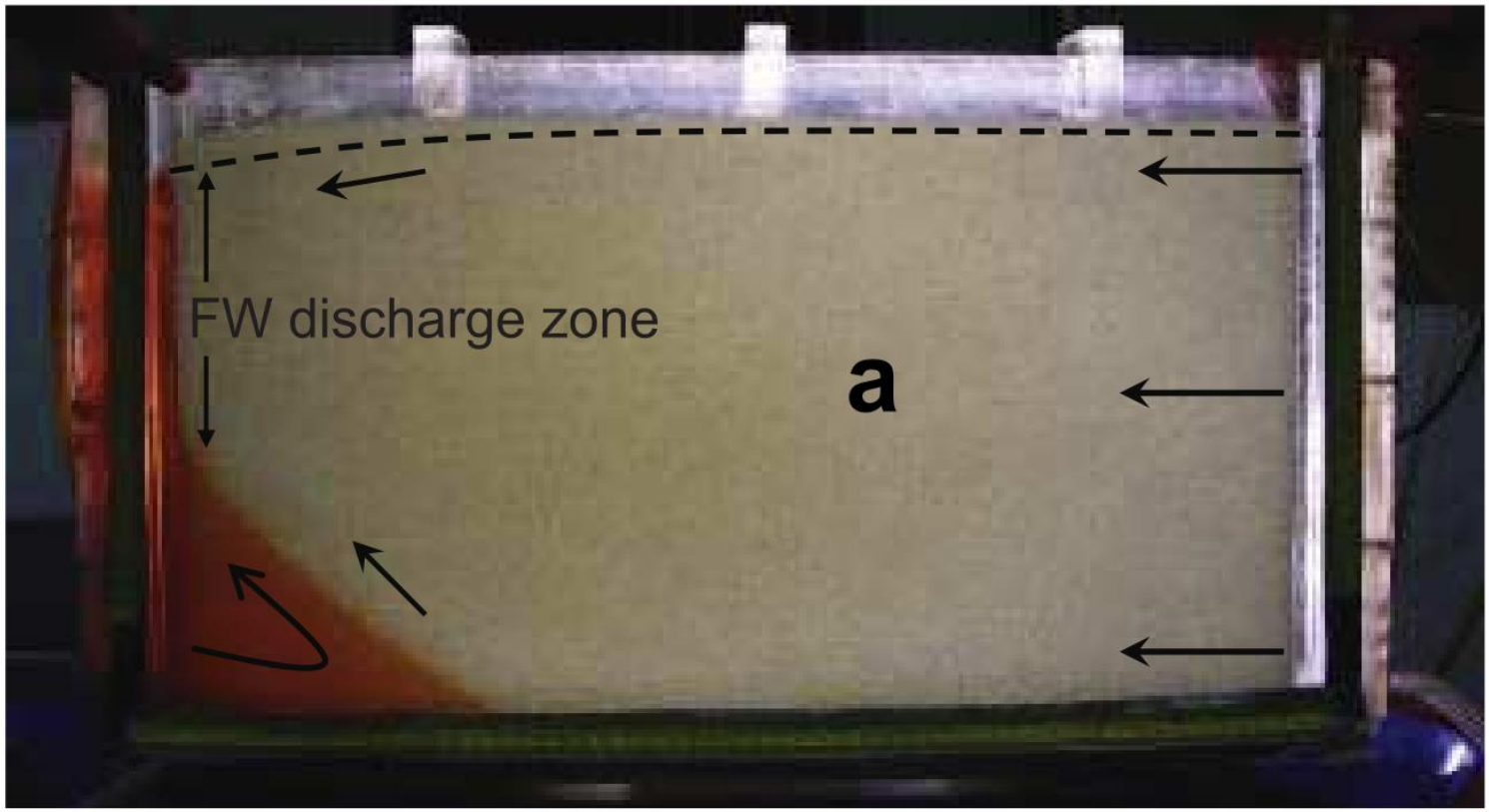
GOSWAMI-CLEMENT BENCHMARK

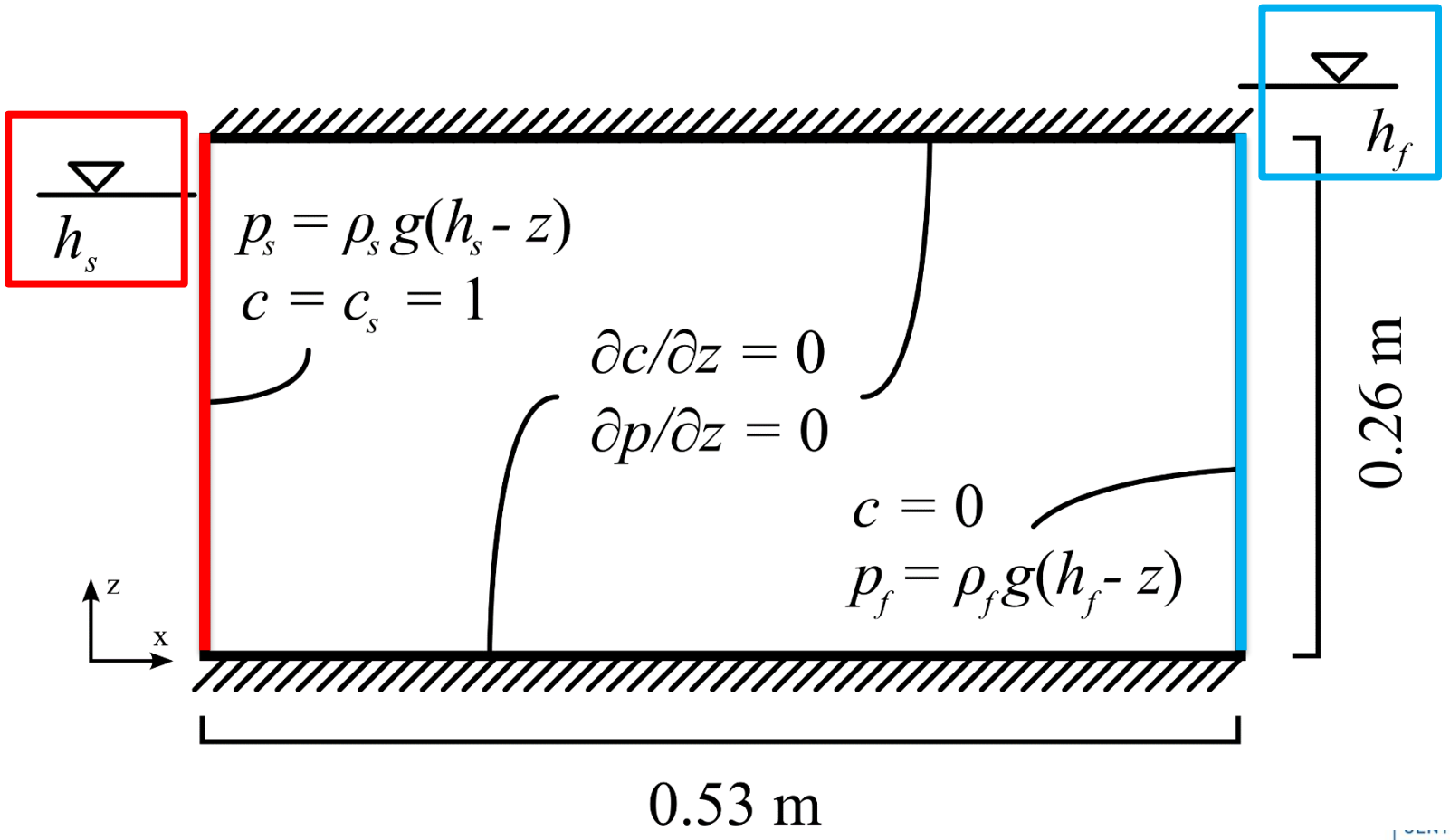
EXPERIMENT



Goswami, R.R., Clement, T.P., 2007. Laboratory-scale investigation of saltwater intrusion dynamics. Water Resour. Res. 43, 1–11.

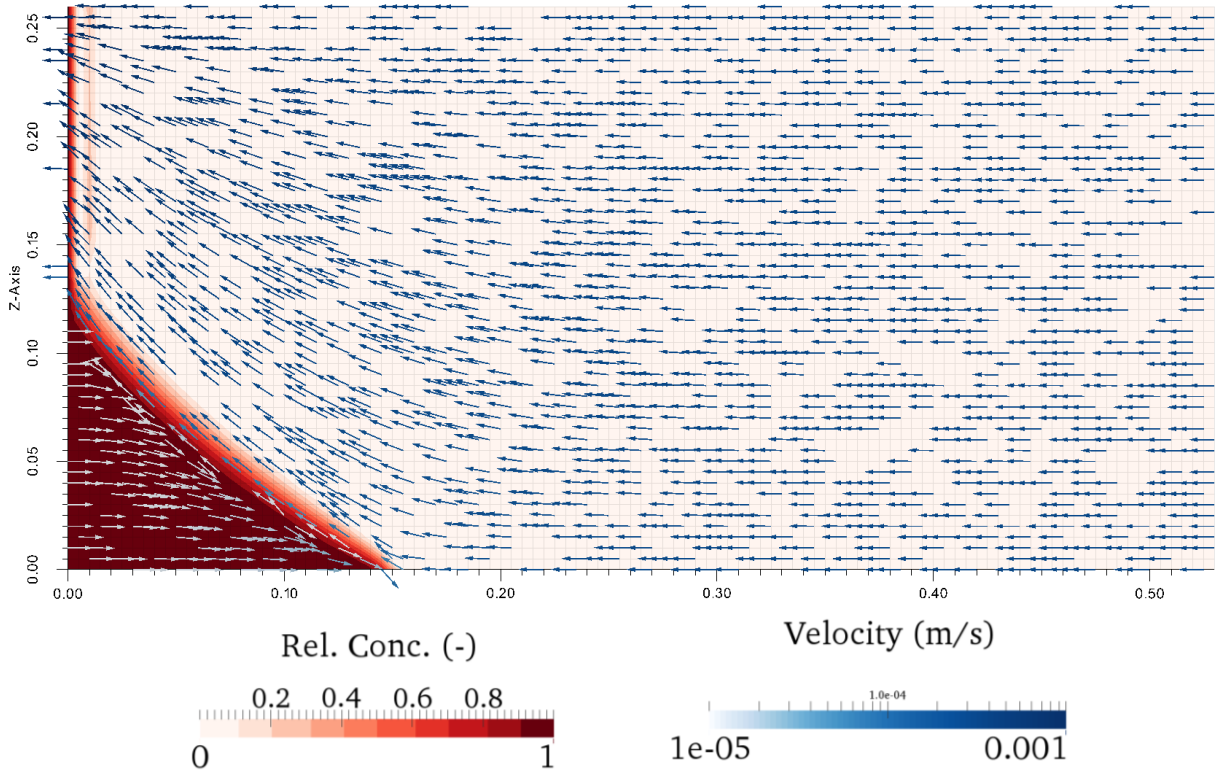
GOSWAMI-CLEMENT BENCHMARK

CONCEPTUAL MODEL



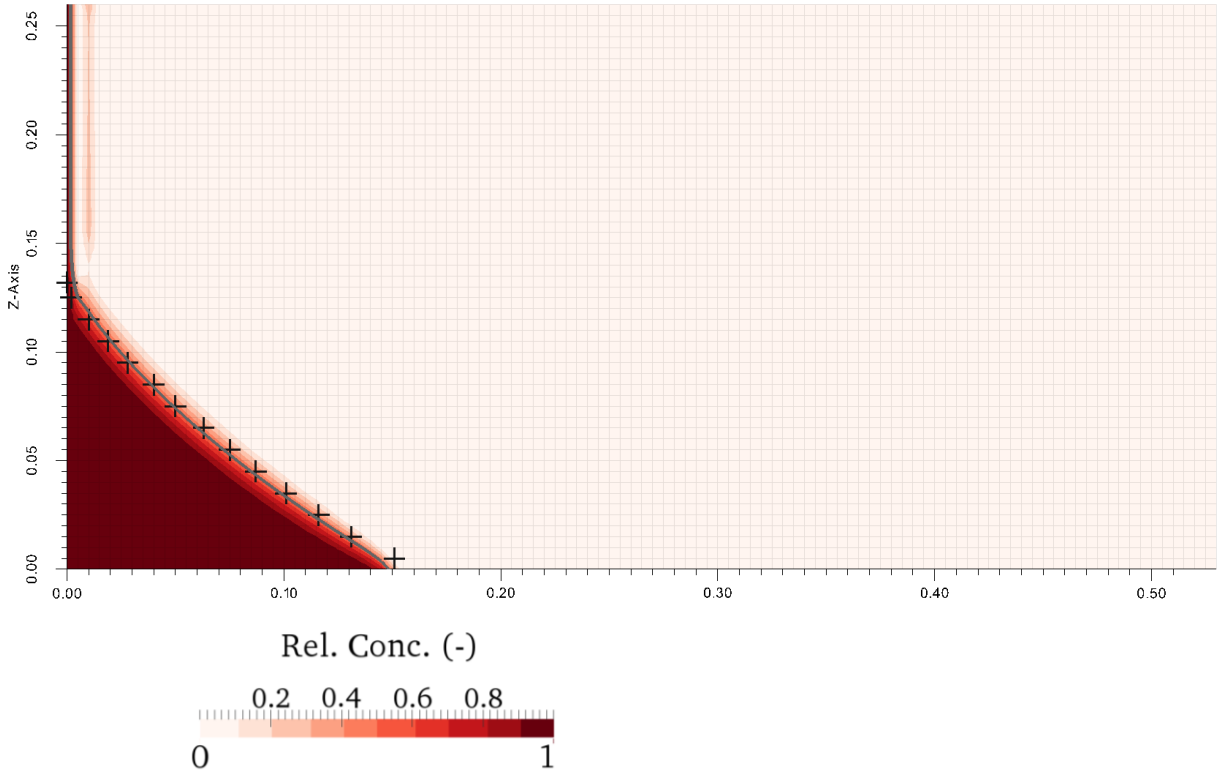
GOSWAMI-CLEMENT BENCHMARK

RESULTS STEADY STATE 1



GOSWAMI-CLEMENT BENCHMARK

RESULTS STEADY STATE 1



Rel. Conc. = 0.5

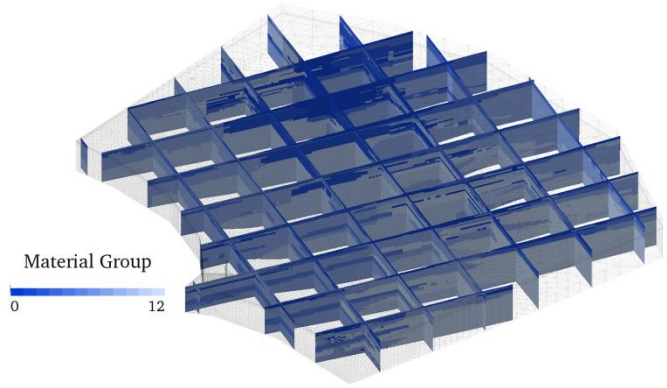
Experimental Observation

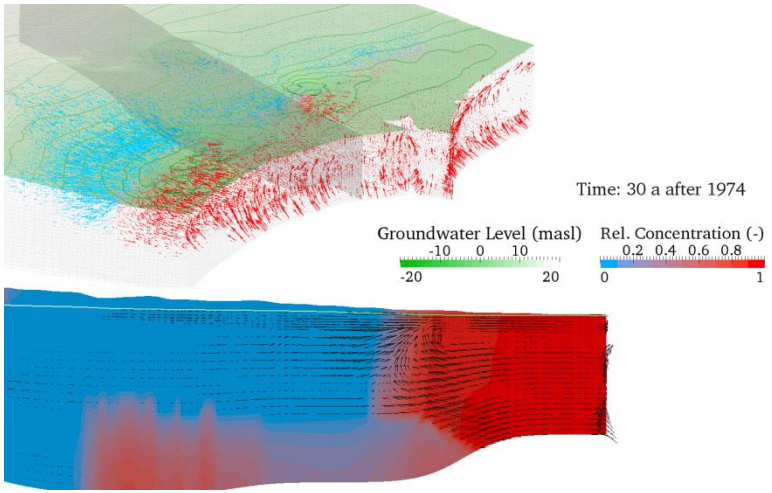
Simulation Result

VISUALIZATION TOOL

ParaView

- Open source scientific visualization tool www.paraview.org
- During model setup (hydrogeology)
- Model run / process verification
- Result visualization, data assimilation & processing
- Run parallel to reduce bandwidth traffic





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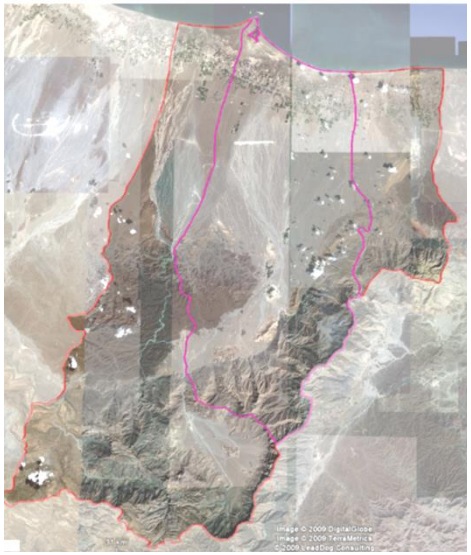
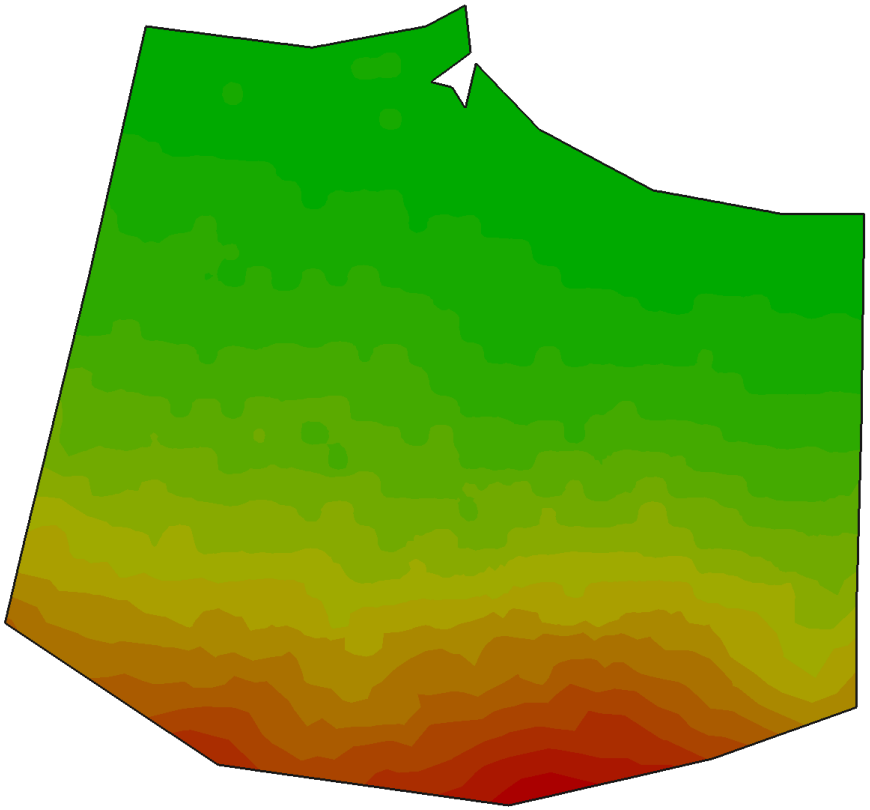
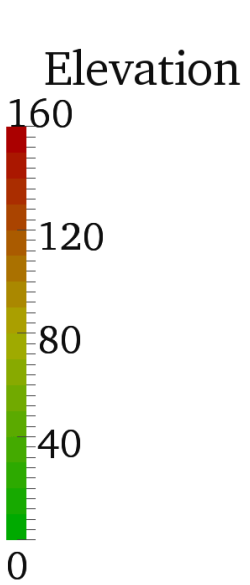


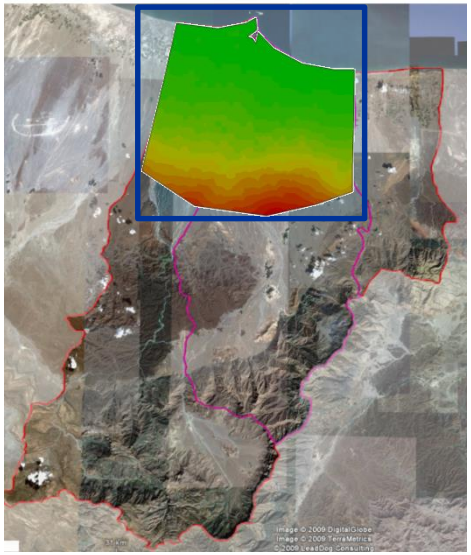
Regional Scale Application for Al Batinah

TARGET AREA MODEL

MODEL DOMAIN

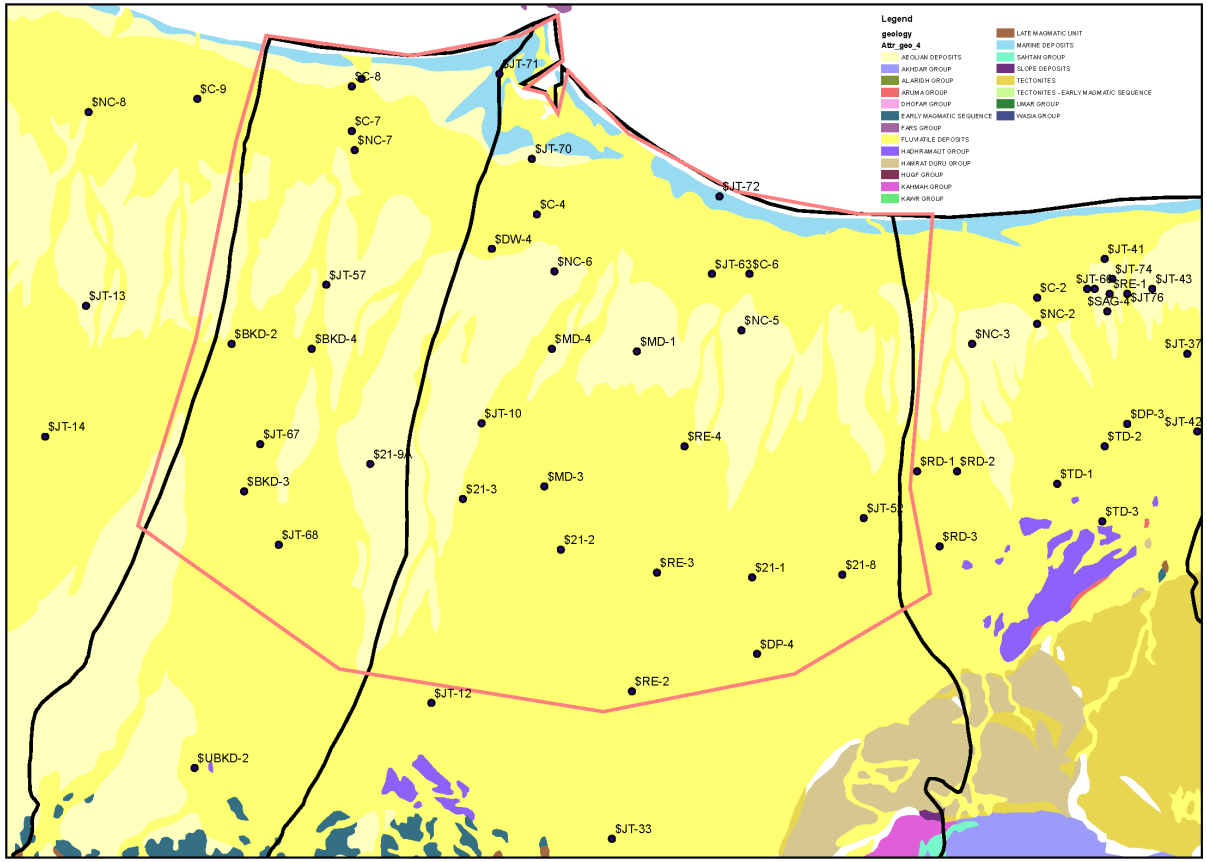






20x30km²,
400 m thickness
700‘000 Elements,
25 Layer

HYDROGEOLOGY IN COASTAL PLAINS

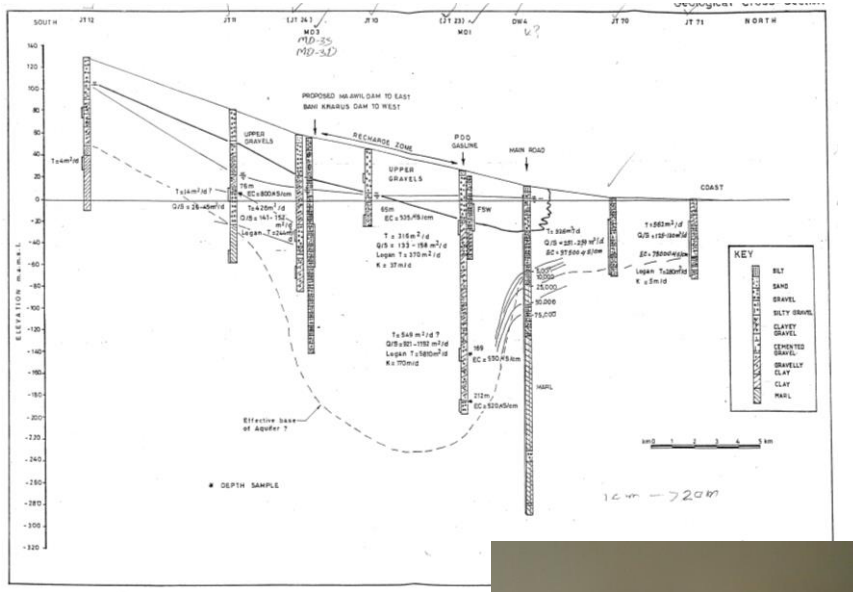


Fluviatile, Marine, Aeolian Deposits

HYDROGEOLOGY

DATA COLLECTION

- Data gathering from various sources: tables, figures, drilling logs…
- Meetings/Conversations with Omani hydrogeologists
- 12 major “materials” (e.g. gravel, silt, clay…)

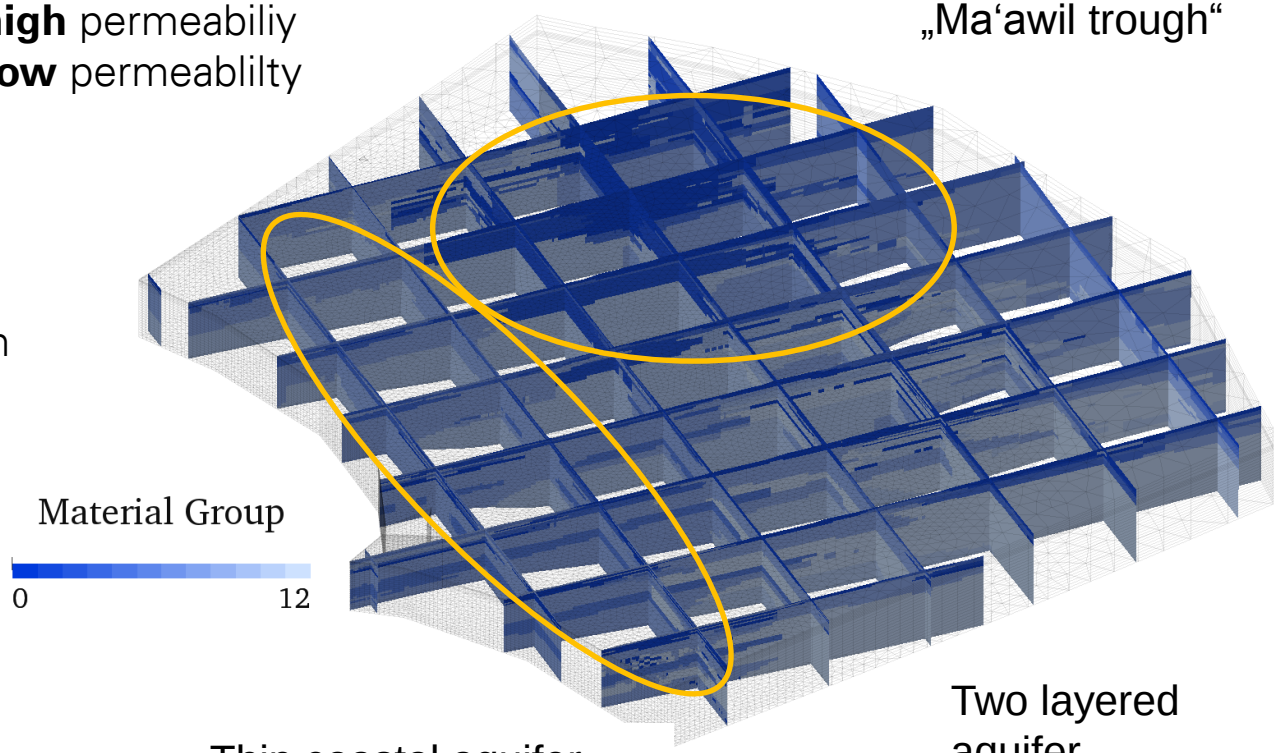


HYDROGEOLOGY

INTERPOLATION USING MODIFIED INVERSE DISTANCE WEIGHTING

Blue = **high** permeabiliy
Grey = **low** permeablilty

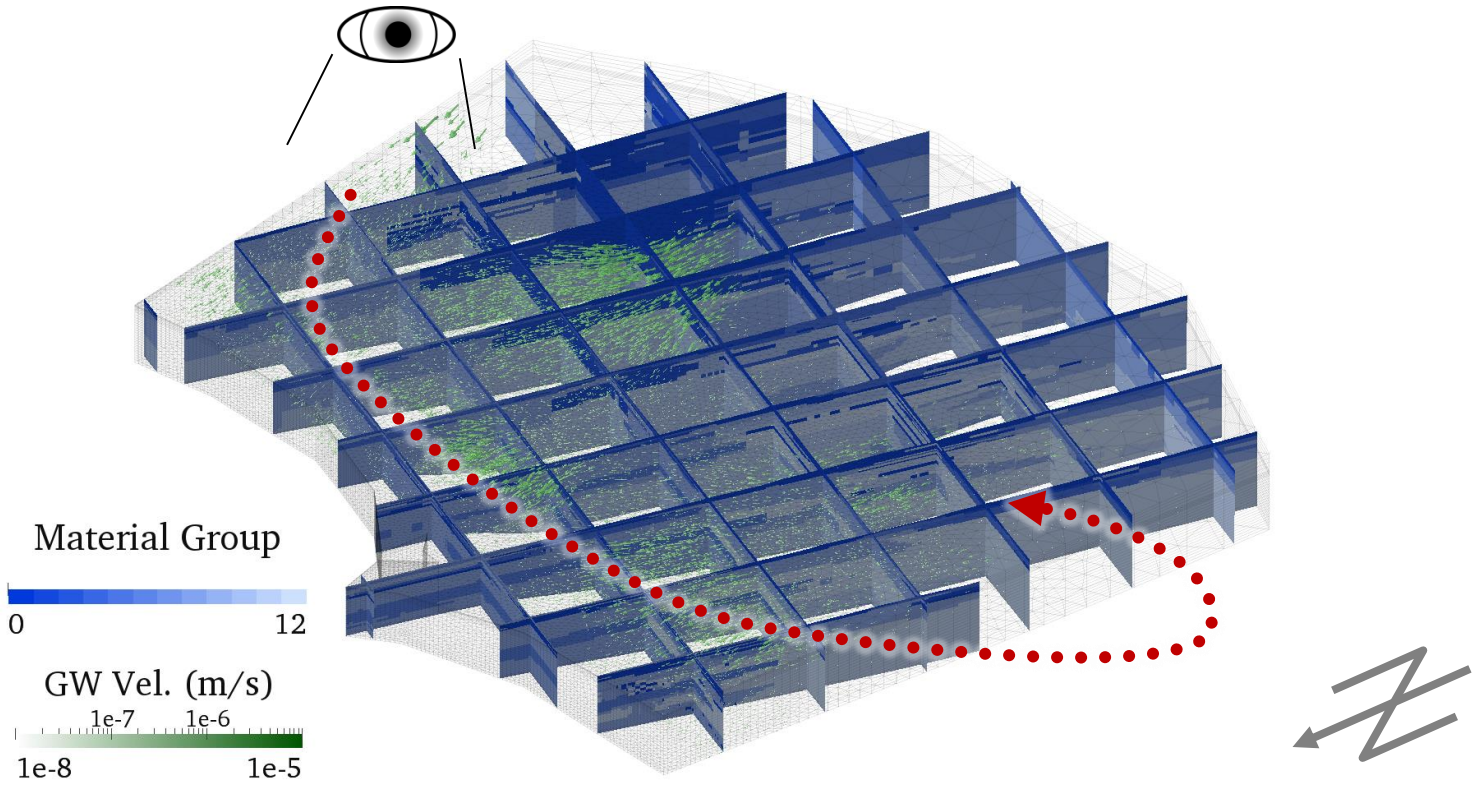
Thickness
Total ~400m
Coast ~50m
Trough ~250m

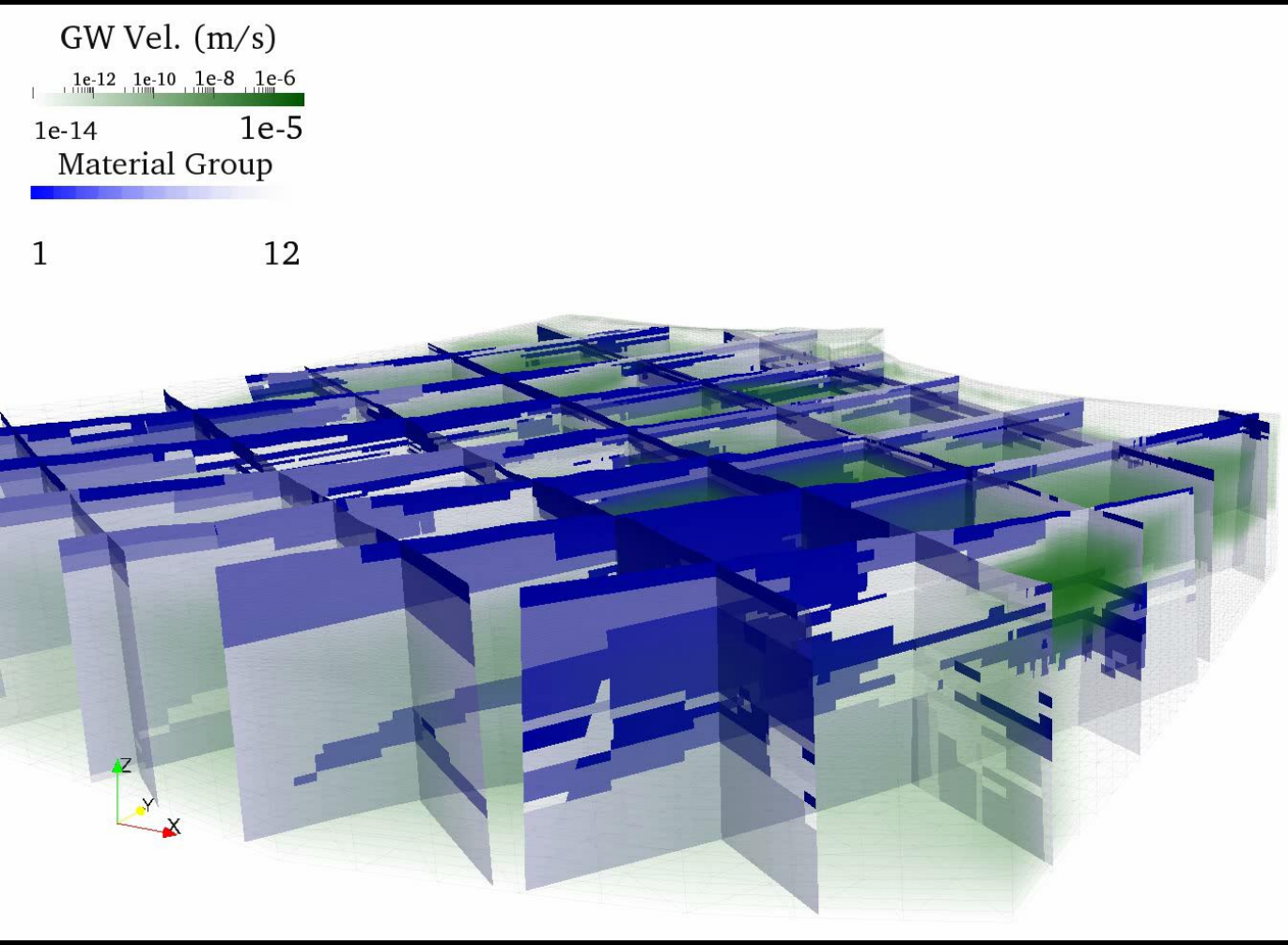


Walther, et al., 2012

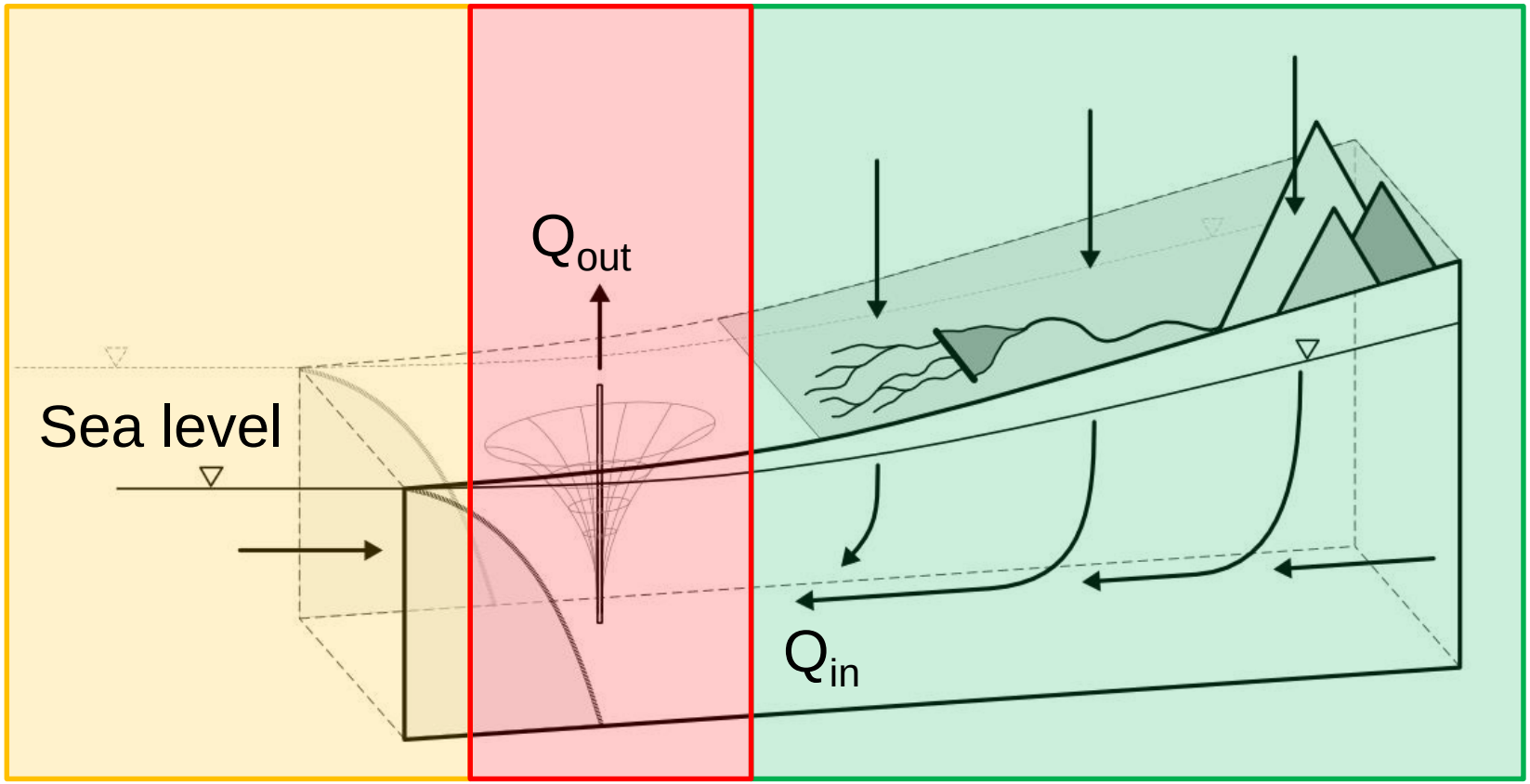
HYDROGEOLOGY

INTERPOLATION USING MODIFIED INVERSE DISTANCE WEIGHTING




GW Vel. (m/s)
1e-12 1e-10 1e-8 1e-6
1e-14
1e-5
Material Group
1
12
Z
Y
X

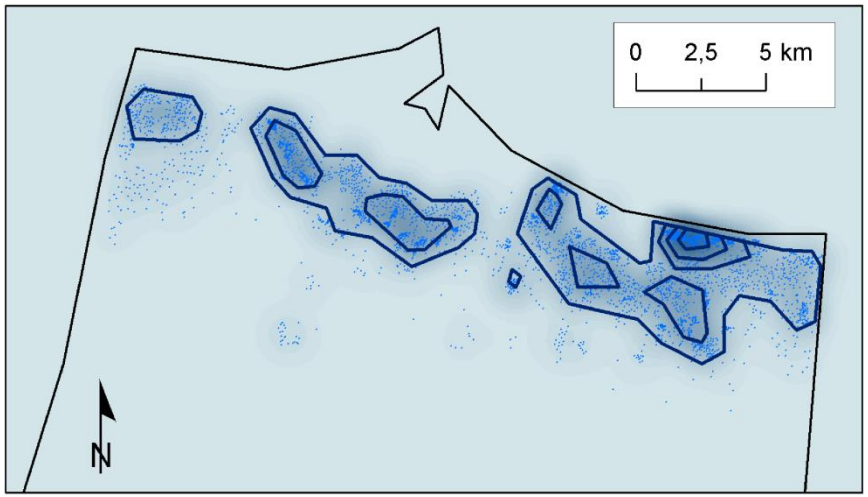
BOUNDARY CONDITIONS



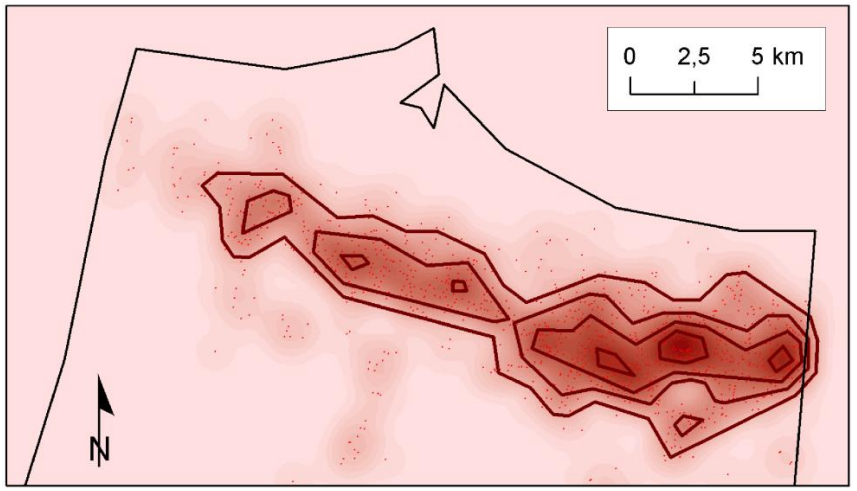
BOUNDARY CONDITIONS
ABSTRACTION THROUGH PUMPING

Estimate of total abstraction rates until 1970s Q~40 mio m^3/a

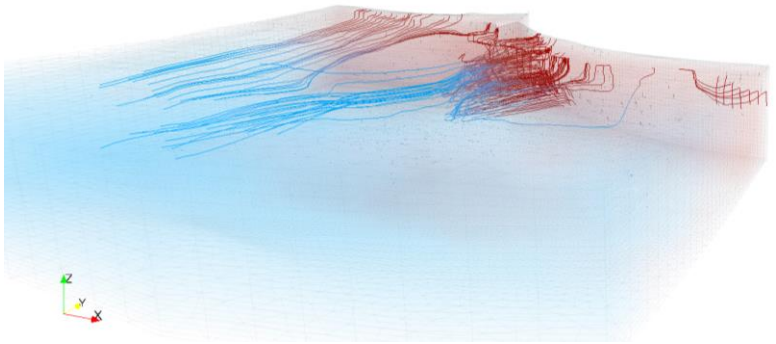
(Ministry of agriculture and fisheries, Technical Report, 1992; Al-Shoukri, 2008)



Dug wells



Borehole wells

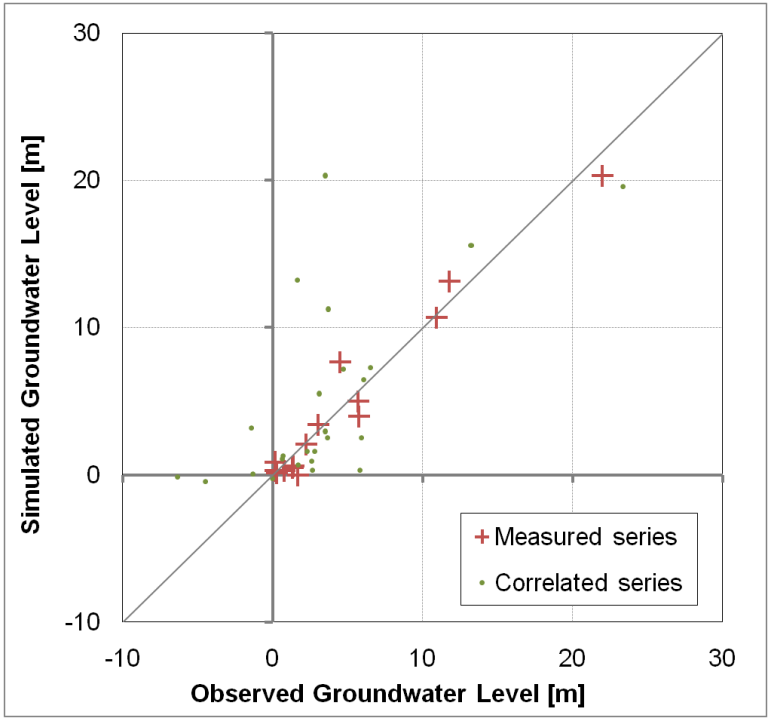


Calibration & Prediction

MODELING RESULTS

PEST CALIBRATION
STEADY-STATE (1974)

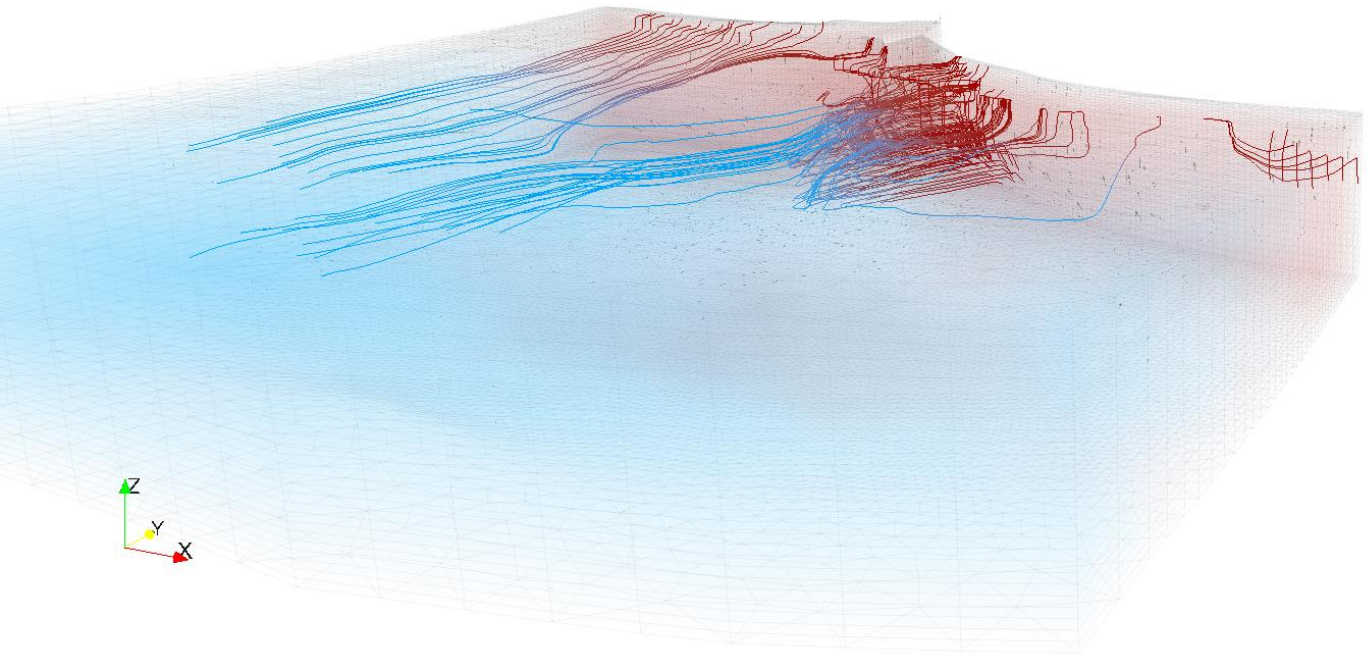
- PEST = Parameter Estimation Tool, widely used in groundwater applications
- PEST Results
  - Biased correl. coeff. > 0.9
  - Inflow ca 68 mio m³/a
    Extraction ca 37 mio m³/a
  - Material properties
    (ie hydraulic conductivity)
    „as expected“
- Reasonable results for transient calibration

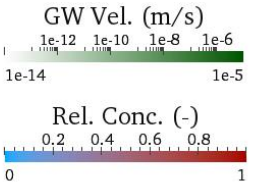


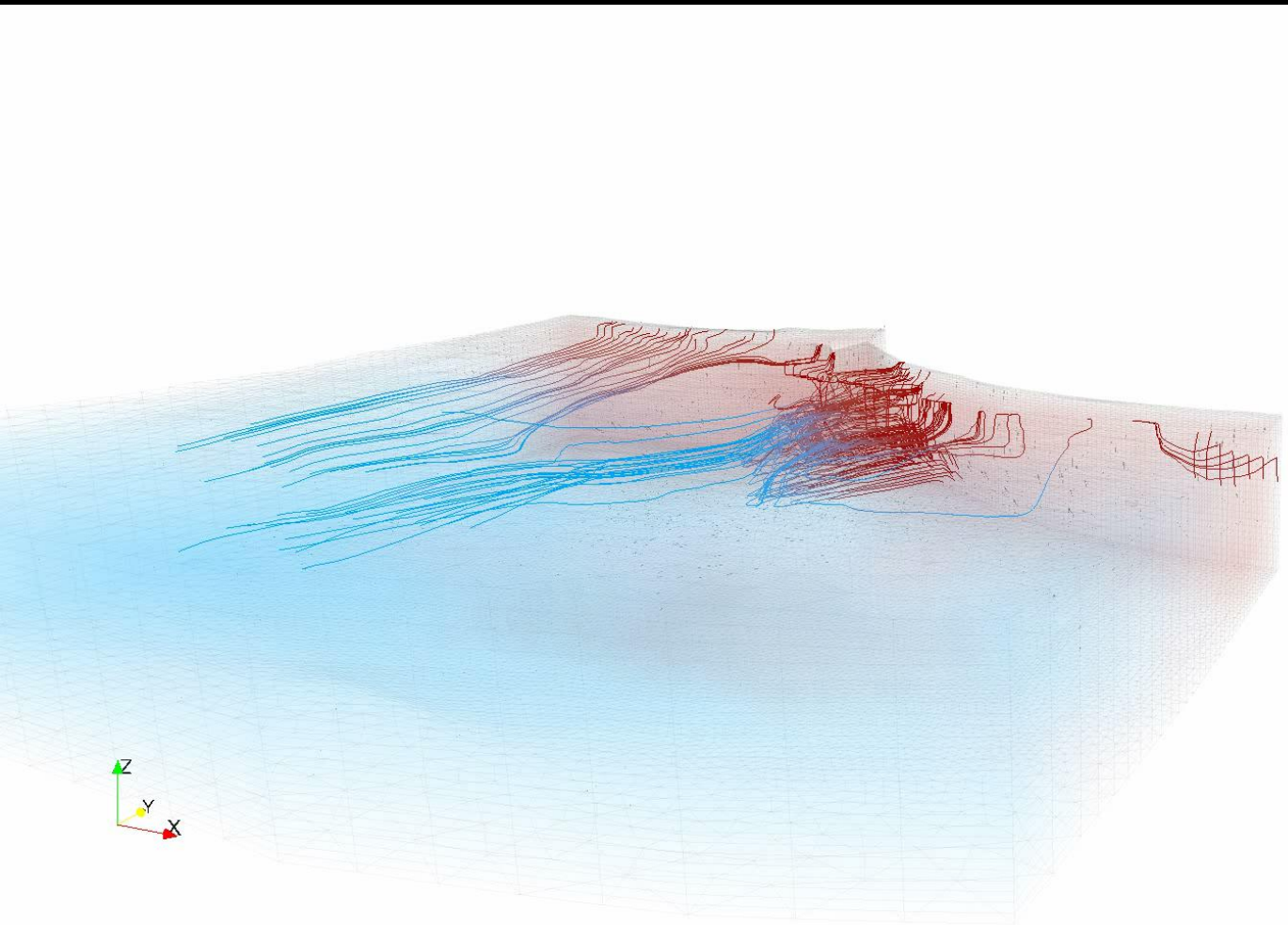
Scatter plot steady state calibration

DENSITY-DEPENDENT GW-FLOW

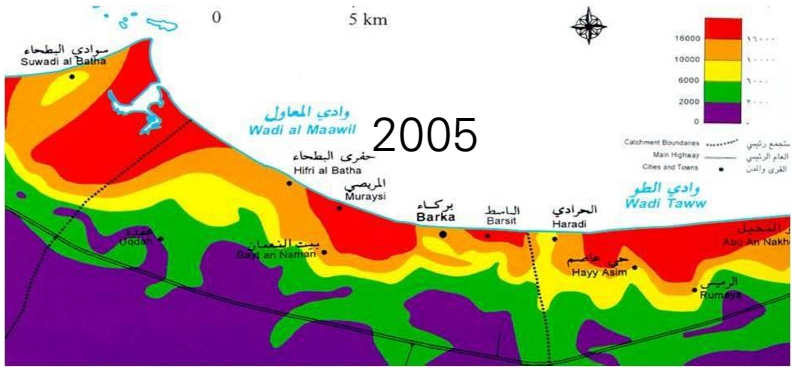
SUBSURFACE FLOW PATHS IN YEAR 1985

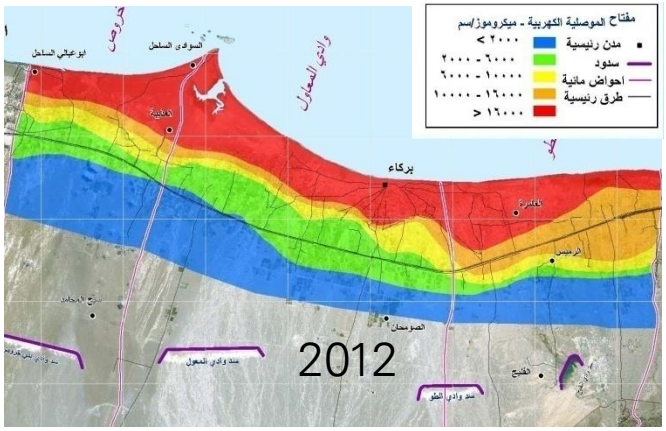


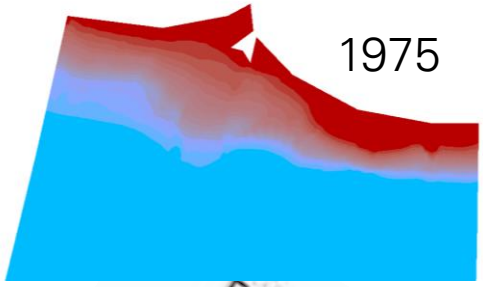


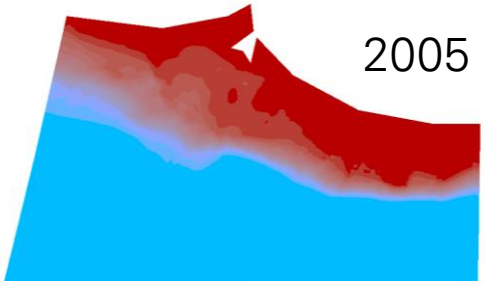

Z
Y
X
GW Vel. (m/s)
1e-12 1e-10 1e-8 1e-6
1e-14 1e-5
Rel. Conc. (-)
0.2 0.4 0.6 0.8
0 1

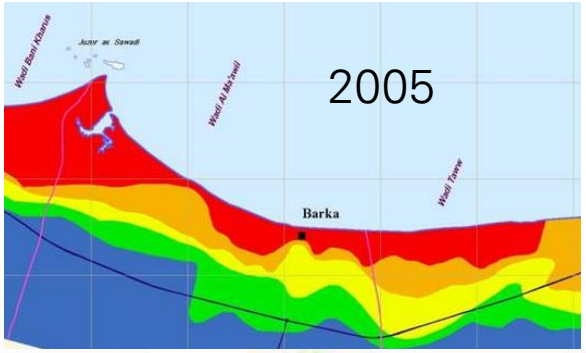
SALINITY MEASUREMENTS





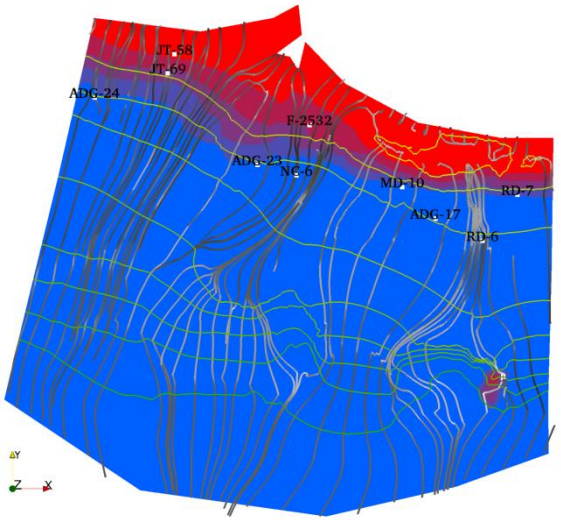




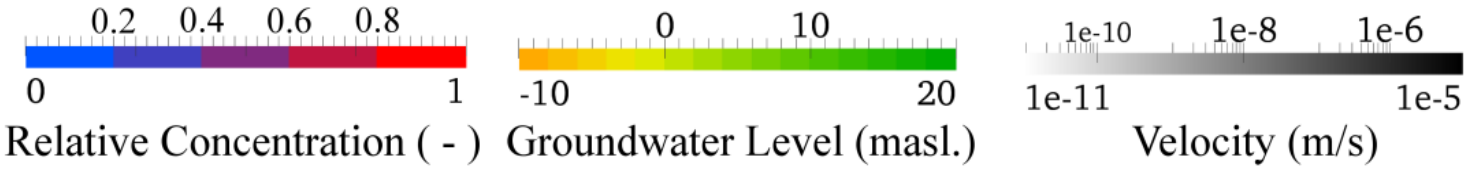


SCENARIO SIMULATION

"BEST CASE" – PUMP STOP IN 2005

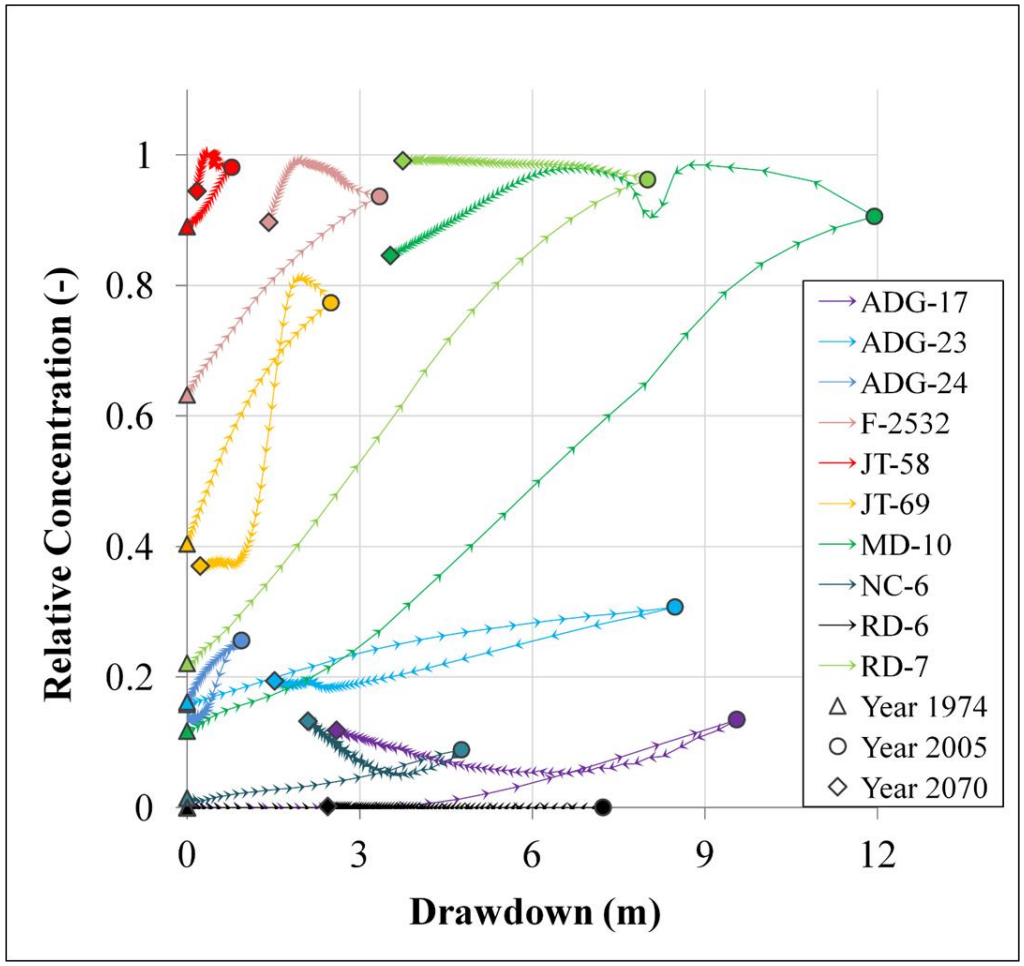


1974



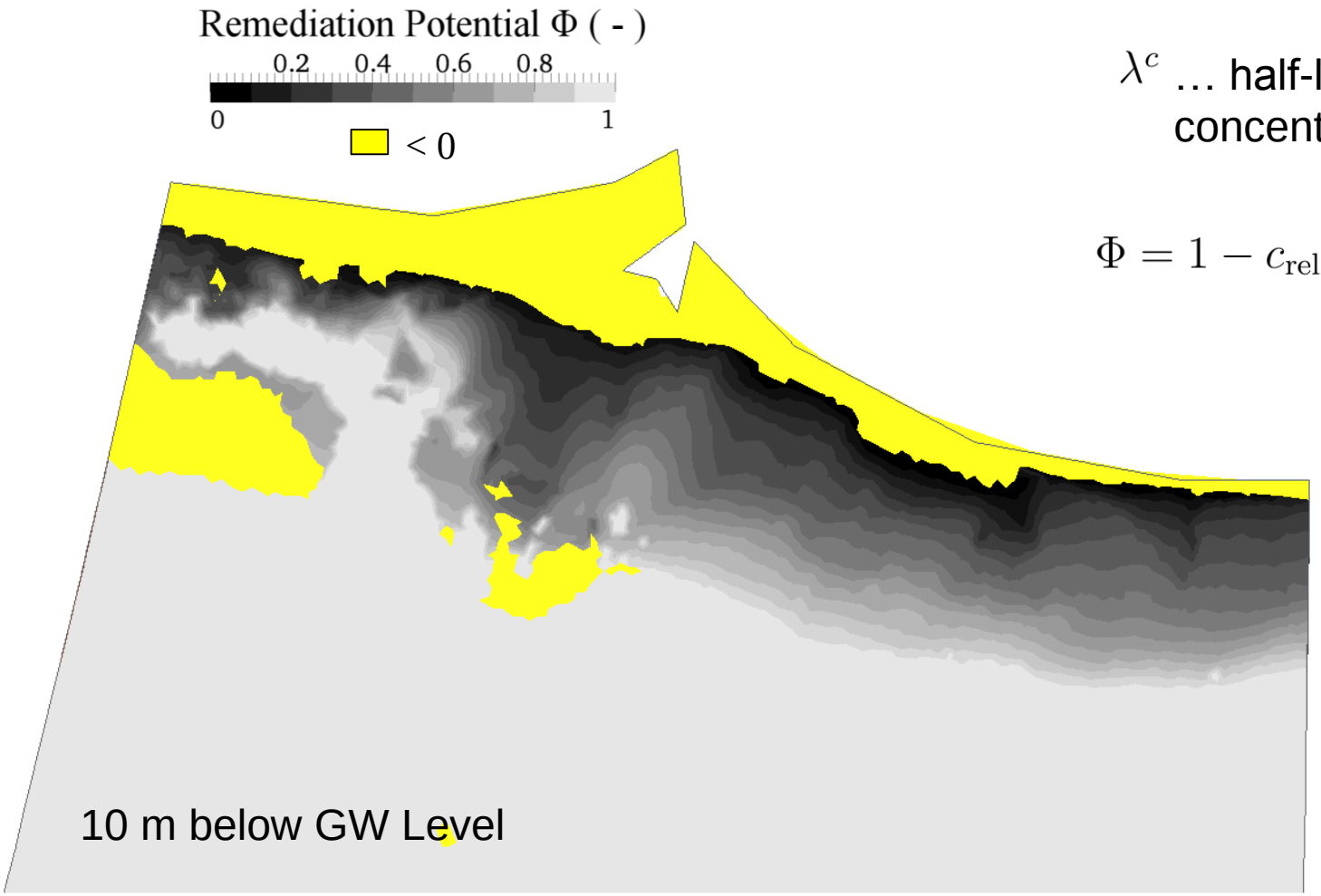
AQUIFER RECOVERY
SALINITY VS. GW-DRAWDOWN

"BEST CASE" – PUMP STOP IN 2005



HALF-LIFE OF SALINITY

„SALINIZATION RISK ASSESSMENT“
SIMULATION TIME 500 YEARS

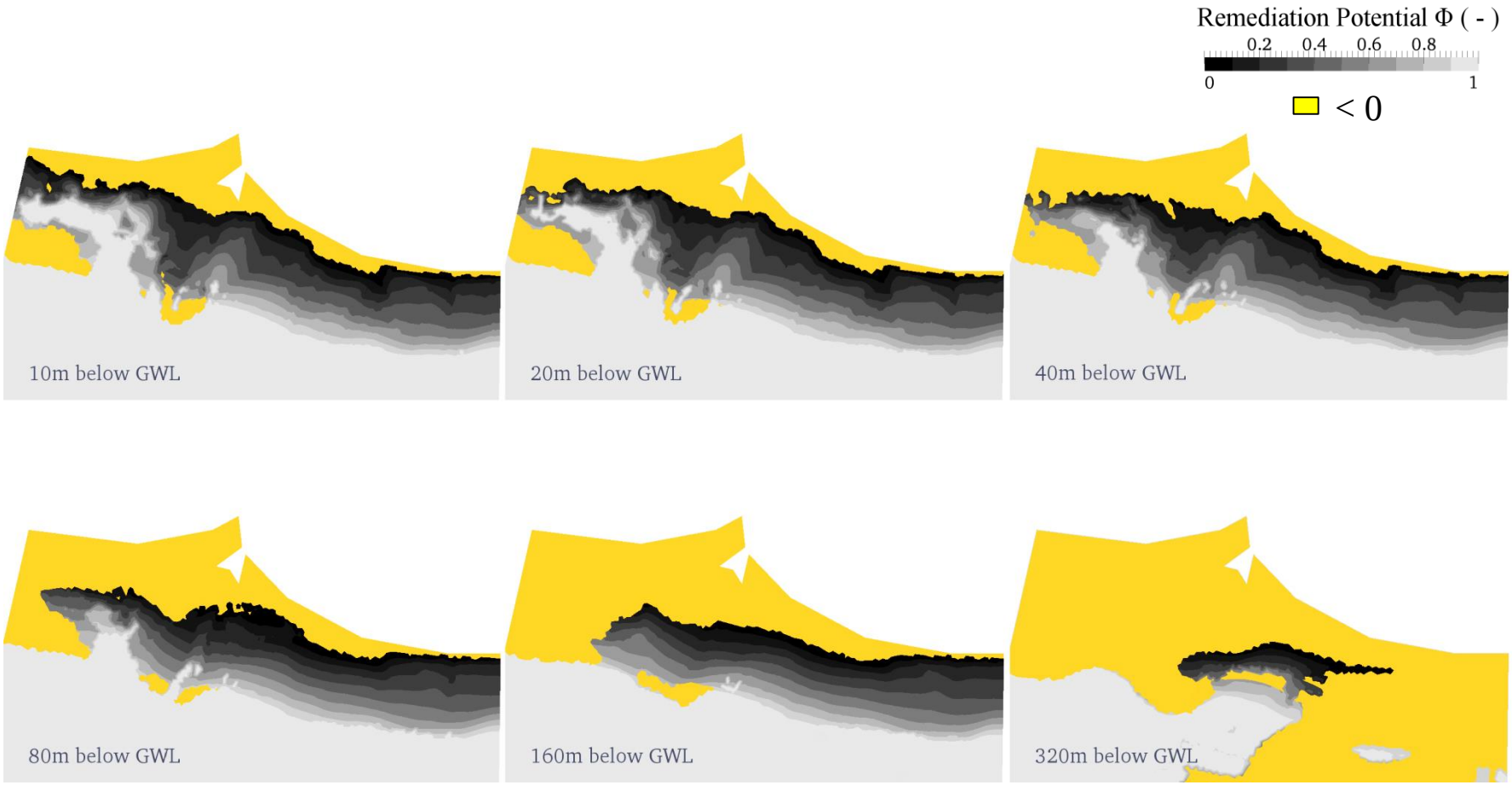


λ^c … half-live of concentration

$$\Phi = 1 - c_{\mathrm{rel}} \cdot \frac{\lambda^c}{\max\left(\lambda^c\right)}$$

HALF-LIFE OF SALINITY

„SALINIZATION RISK ASSESSMENT“



SUMMARY

- Setup and evaluation of hydrogeological model and conceptual model setup (VisLab@UFZ)
- Process verification and calibration of regional scale model
- Scenario simulations show possible future development
- Estimates on aquifers‘ remediation potential aid future management activities

OUTLOOK

- More data gathering
  - Continued GW level observation
  - Depth specific salinity measurements (time series)
  - Hydrogeological exploration (validation of current setup?)
- Decrease input data uncertainty
- Increase model robustness
- Measures to decrease water consumption & reduce marine saltwater intrusion

CONCLUSIONS & QUESTIONS

- Data shortage reduces prediction quality
  How to deal with data situation?
- Numerical modeling still a useful tool to assess management options
  How to increase model robustness?
- One of many possible futures
  How to transfer this knowledge to decision makers?

Thank you for your attention!

Walther, M., Bilke, L., Delfs, J.-O., Graf, T., Grundmann, J., Kolditz, O., & Liedl, R. (accepted). Visualizing Saline Intrusion in a Three-Dimensional, Heterogeneous, Coastal Aquifer. Workshop on Visualisation in Environmental Sciences (EnvirVis). Leipzig.

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Grundmann, J., Schütze, N., Schmitz, G.-H., & Al-Shaqsi, S. (2011). Towards an integrated arid zone water management using 10.1007/s12665-011-1253-z.

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Bundesministerium für Bildung und Forschung

SPITZENFORSCHUNG & INNOVATION IN DEN NEUEN LÄNDERN

IWAS

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