Groundwater Modeling in Mining:
A Case Study

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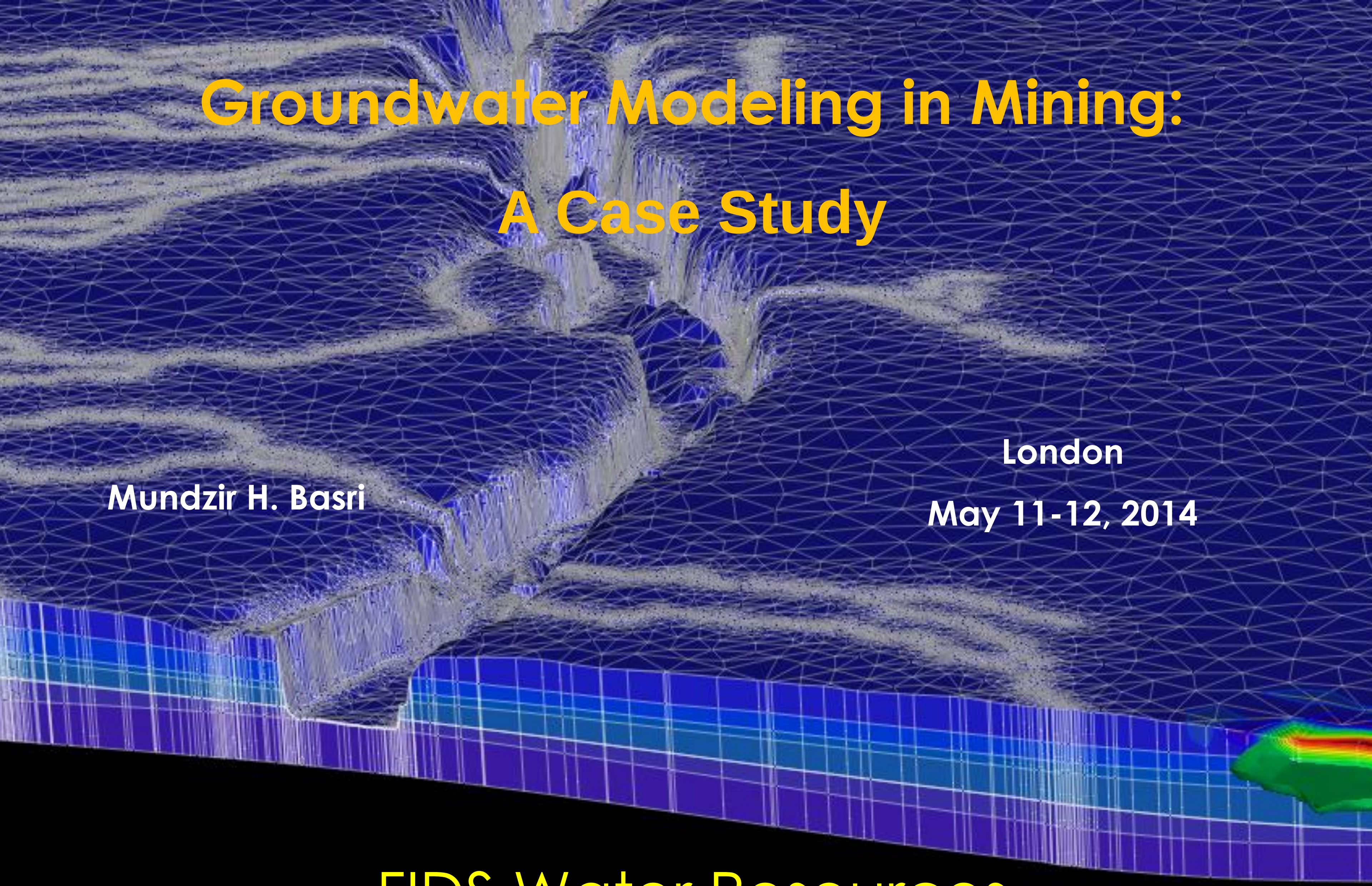

FIDS Water Resources Symposium

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Outline

INTRODUCTION

GUIDELINES AND OBJECTIVE

MODEL CONSTRUCTION AND CALIBRATION

SIMULATED EFFECTS OF BRINE TRANSPORT

RESULTS

CONCLUDING REMARKS

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INTRODUCTION

Groundwater modeling guidelines

- There is a need for a better understanding of groundwater resources in mining activities; Operation, Closure, and Post Closure
- Groundwater modeling plays a big role in all stages
- Standard groundwater modeling practices do not exist

Key Legislation and Policy for Managing Groundwater in Alberta

Governance Jurisdiction (Provincial Acts, Regulations and Authorizations):

- Alberta Land Stewardship Act (ALSA)
- Environmental Protection and Enhancement Act (EPEA)
- Water Act
- Approvals, monitoring and reporting requirements
- Compliance and enforcement
- Licences, approvals, monitoring and reporting requirements

Guidelines and Policies

- Alberta Tier 1 and Alberta Tier 2 Soil and Groundwater Remediation Guidelines (AE 2009a & 2009b)
- Alberta Environment Guide to Groundwater Authorization (2011)
- Water Conservation and Allocation Policy for Oilfield Injection (2006)
- Guidelines for Canadian Drinking Water Quality

Strategies

- Land-use Framework (LUF)
- Regional Sustainable Development Strategy for the Athabasca Oil Sands Area
- Responsible Actions: A Plan for Alberta's Oil Sands
- Water for Life

Federal Acts

- Canadian Environmental Assessment Act Canada
- Canadian Environmental Protection Act Canada

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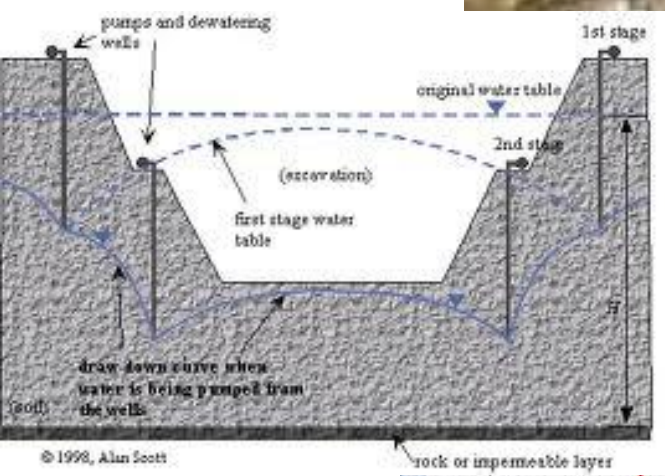
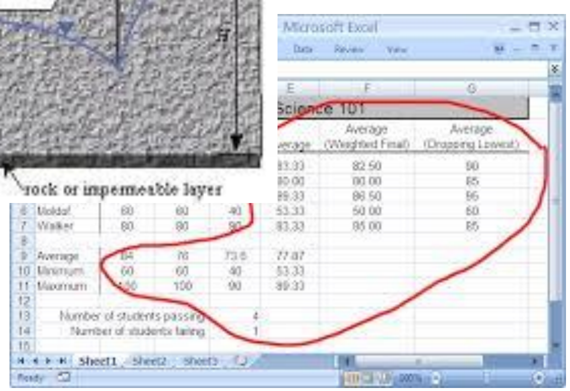
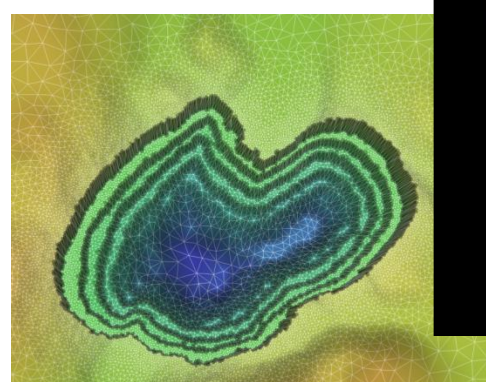
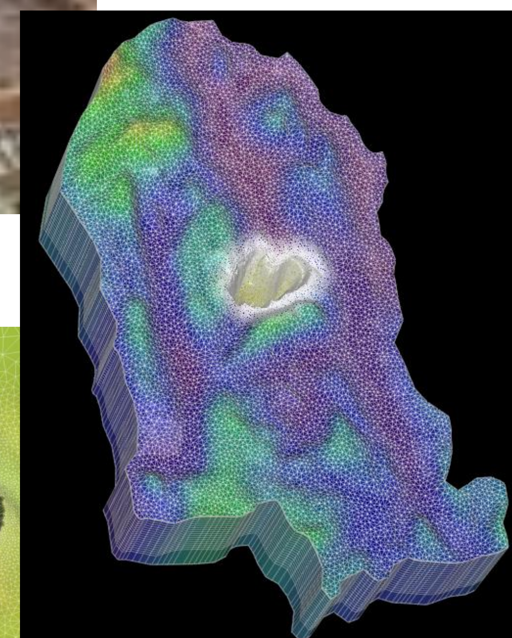
Approaches in Absence of Guidelines









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OBJECTIVES

Objectives of *groundwater modelling guidelines* are:

1. to promote a consistent and sound approach to development of groundwater flow and solute transport models.

2. to include all types of groundwater models and modelling approaches

3. to address a range of groundwater problems; and

4. to support decision-making processes in management of groundwater resource

5. Towards best practice model practices

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IMPLEMENTATION

British Columbia Ministry of Environment

Groundwater Modeling Guidelines

in addition to

Key Legislations and Policies

STUDY CASE

Assessment of long-term brine migration impact in the environment using a saturated-unsaturated, density-dependent groundwater flow and contaminant transport FEFLOW model

- To develop an understanding of regional groundwater flow patterns and major groundwater pathways within Project area.
- To investigate the changes to on-site groundwater regime due to Project, and to quantify groundwater contaminant mass loadings.
- To identify potential for vertical and lateral brine transport from brine ponds through thick till units to deeper confined aquifers under several migration scenarios.
- To evaluate several mitigation options that could, alone or in combination, limit salt pile and brine contaminants from leaving tailings management area (TMA) during operation phase and subsequently during closure and post closure phases.

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Regional Geologic Setting

Surficial stratified deposits consisting of a range of clay, silt, sand and gravel deposits

A series of overburden formations occur in a series of layered aquifers and aquitards

21 hydrostratigraphic units : Bfd Tills and Stratified Surficial Sediments; Bfd Aquifer; Upper Fl Till; Upper Fl Aquifer; Middle Fl Till; Lower Fl Aquifer; Lower Fl Till; Wm Till; Wm Aquifer; Upper Dn Till; Upper Dn Aquifer; Middle Dn Till; Lower Dn Aquifer; Lower Dn Till; Upper Mn Till; Upper Mn Aquifer; Lower Mn Till; Emp Group Aquifer; and Pie Formation.

Model Construction

- Conceptual geological model is developed using **Leapfrog Hydro**
- Numerical groundwater flow and contaminant transport model is developed using **FEFLOW**
  - 3D groundwater flow
  - 2D variably saturated density dependent flow and contaminant transport
- Potential numerical issues:
  - Deep groundwater table ➔ unsaturated
  - Thick tills ➔ dispersivity, Peclec Number
  - Brine concentration 345,000 mg/L ➔ density dependent transport
  - Operation, closure and post-closure phases ➔ long-term transient

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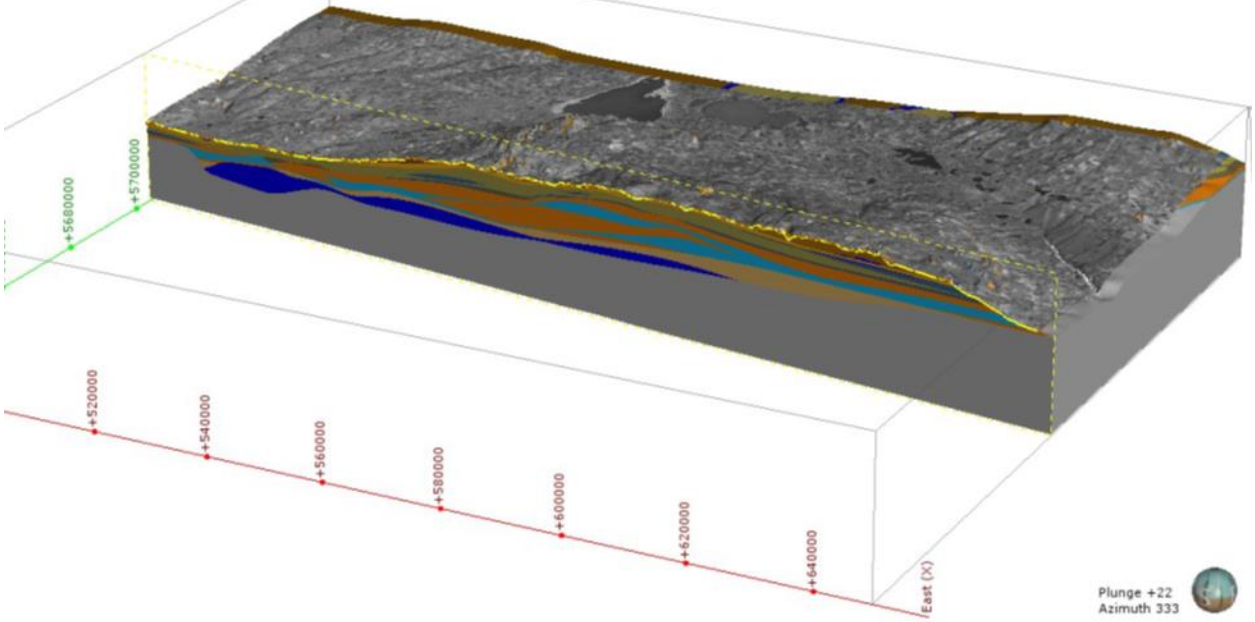
Geological Model

- Oblique view of 3D model sliced through assessment area from northeast to southwest
- Till units within each Formation are represented with various shades of brown
- Aquifer units are represented in shades of blue, and
- Base geological unit is represented in grey



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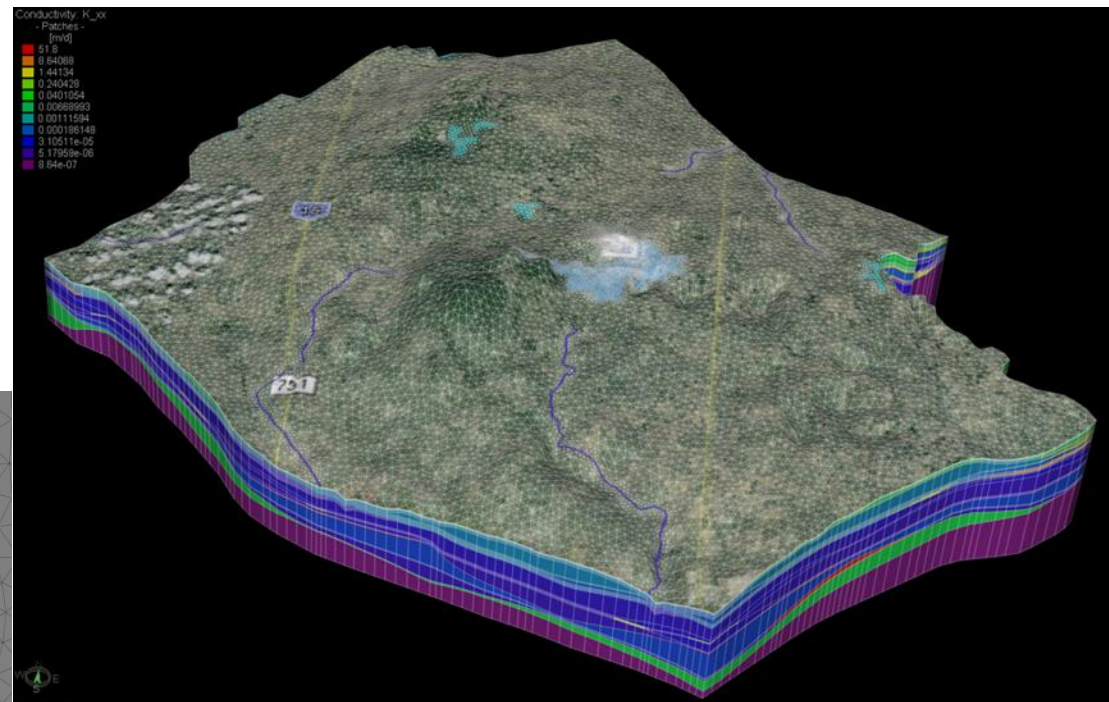
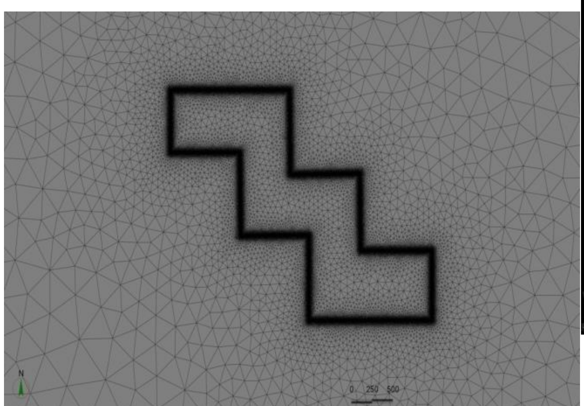
Numerical Model

- Model boundaries were selected to coincide with the regional aquifer boundaries where possible
- Previous groundwater flow model prepared for neighboring project
- TMA are represented in light blue

- Model has 89,442 nodes and 178,571 triangular elements
- Mesh in perimeter of TMA is refined





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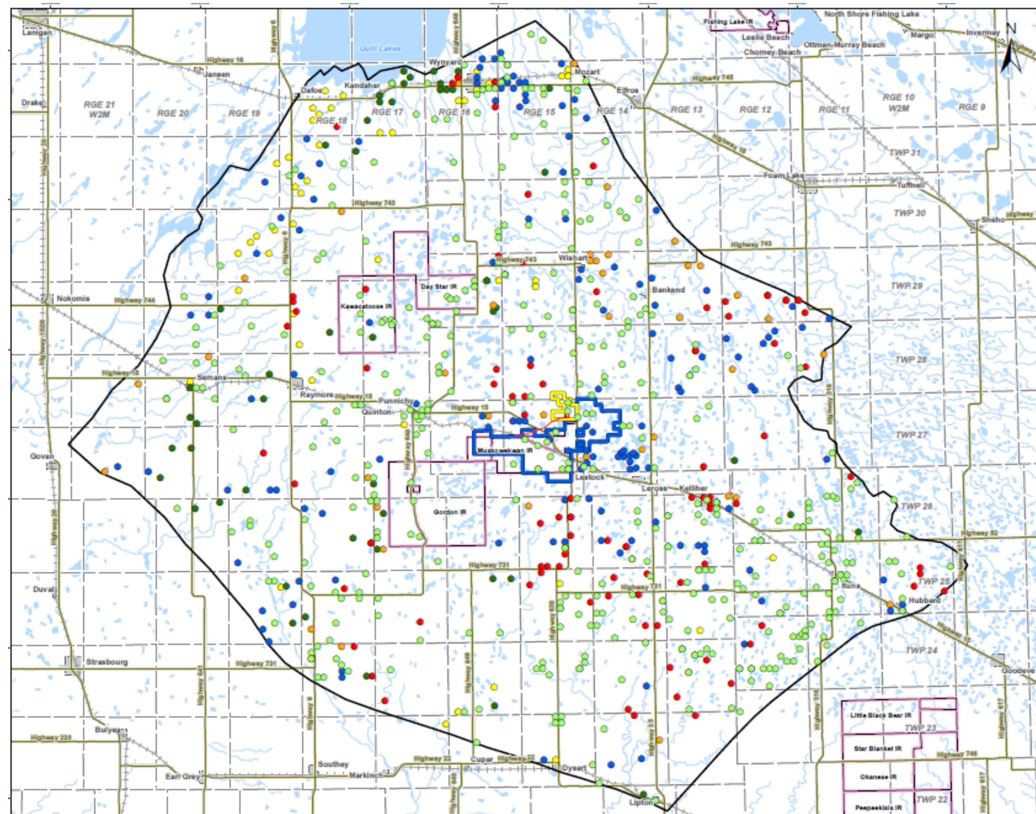
Model Calibration

- FEPEST was used to calibrate regional gw flow model
- Groundwater levels were collected over a wide range of dates (between 1958 and 2012)



- Different colors represent different layers
- Top three major aquifers were selected for calibration

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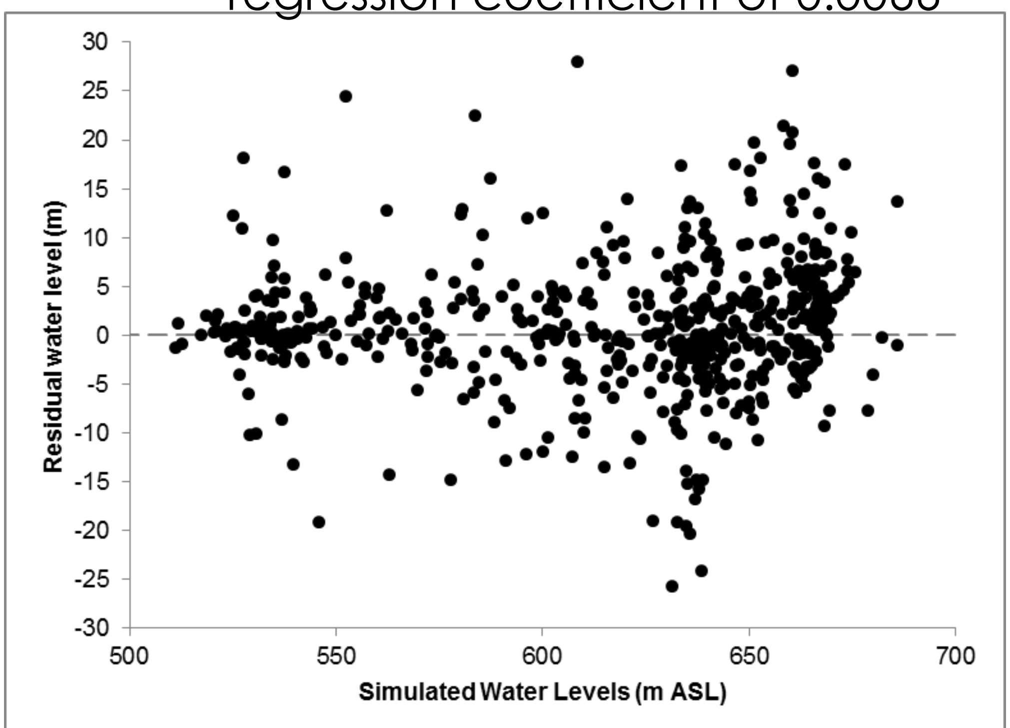
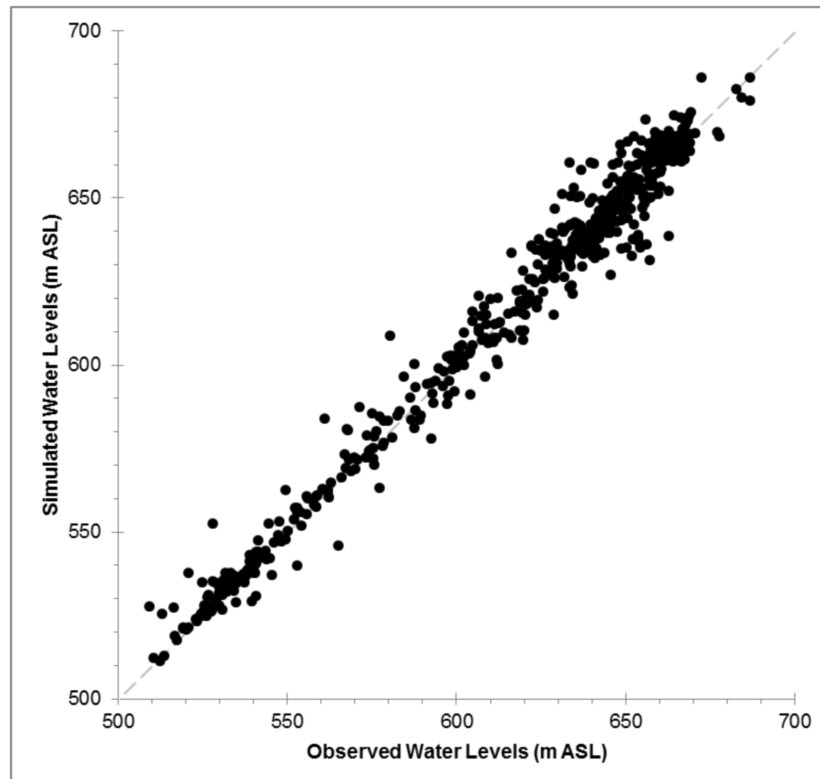
Calibration Results

- Comparison of Observed and Simulated Water Levels
- Mean error is -0.96 m, absolute mean error is 4.84 m, NRMS residual is 3.9%, and correlation coefficient is 0.989
- Comparison of Residual Water Level to Simulated Water Level
- slope of 0.0119
- regression coefficient of 0.0066





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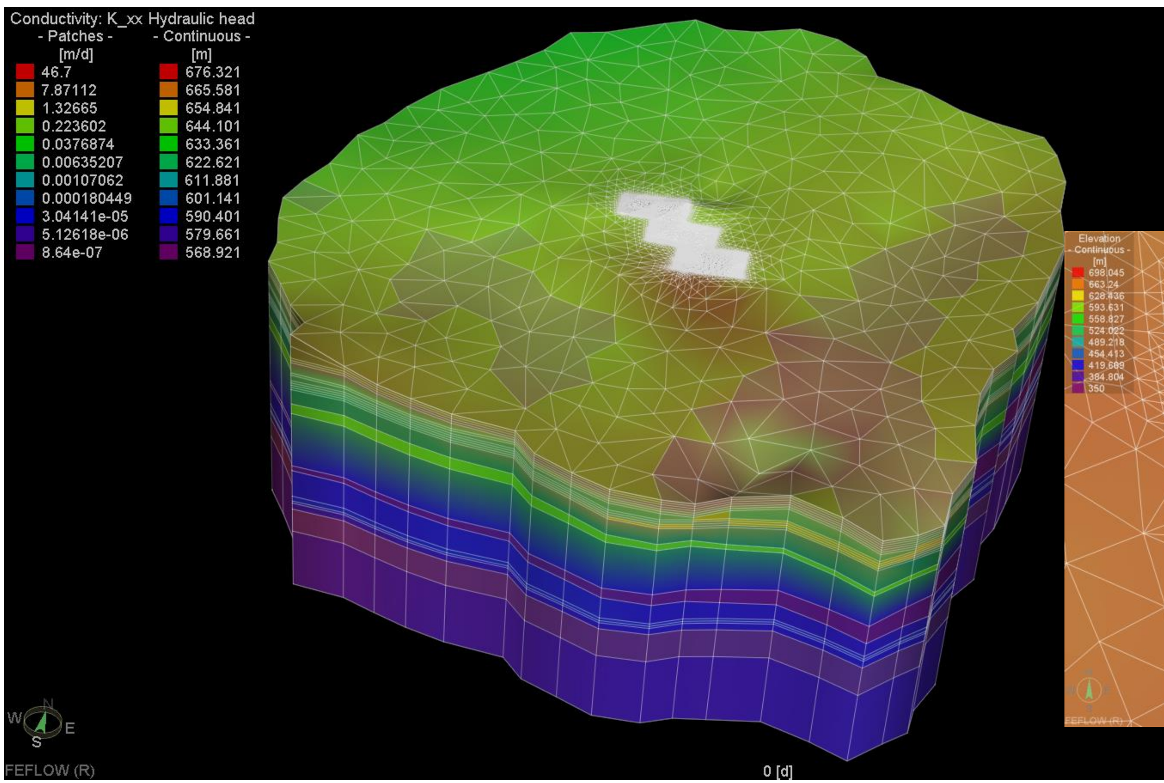
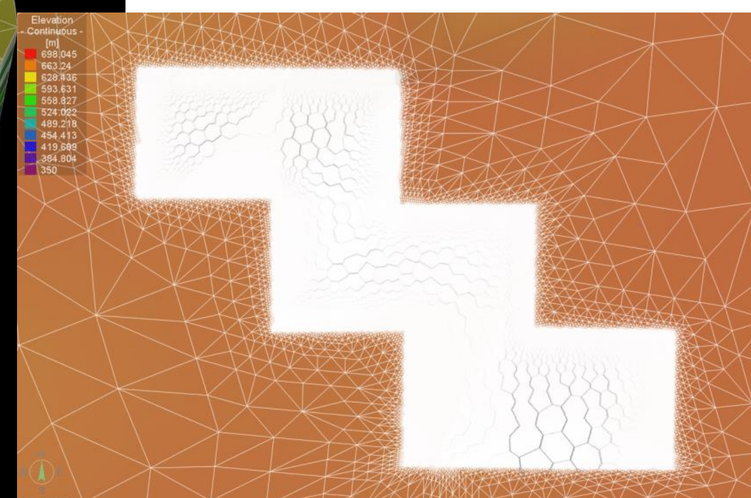
Simulated Effects

Test 1: Reduced Model Domain, mesh within TMA remains

Test 2: Reduced Model Domain, refined mesh within TMA





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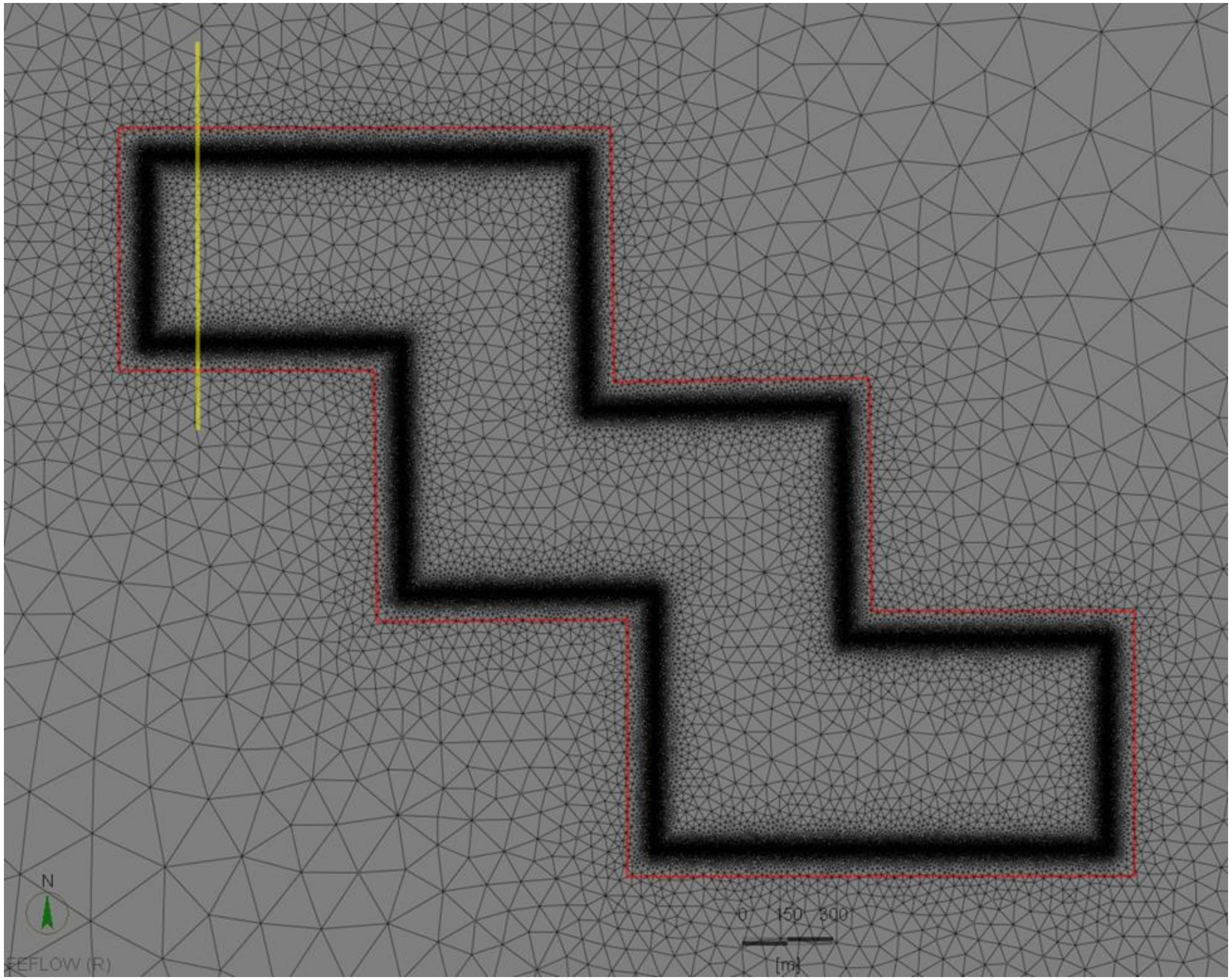
Simulated Effects

Location of 2D Slice Extracted from 3D Groundwater Flow Model



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Simulated Effects

Scenario 1: Base Case Simulation of Effects without Mitigation

- Scenario 1a: Brine Source and Brine Pond Remain
- Scenario 1b: Brine migration from TMA with no mitigation, brine source is depleted and a freshwater pond remains within TMA footprint
- Scenario 1c: Brine migration from TMA with no mitigation, brine source is depleted and TMA area is capped

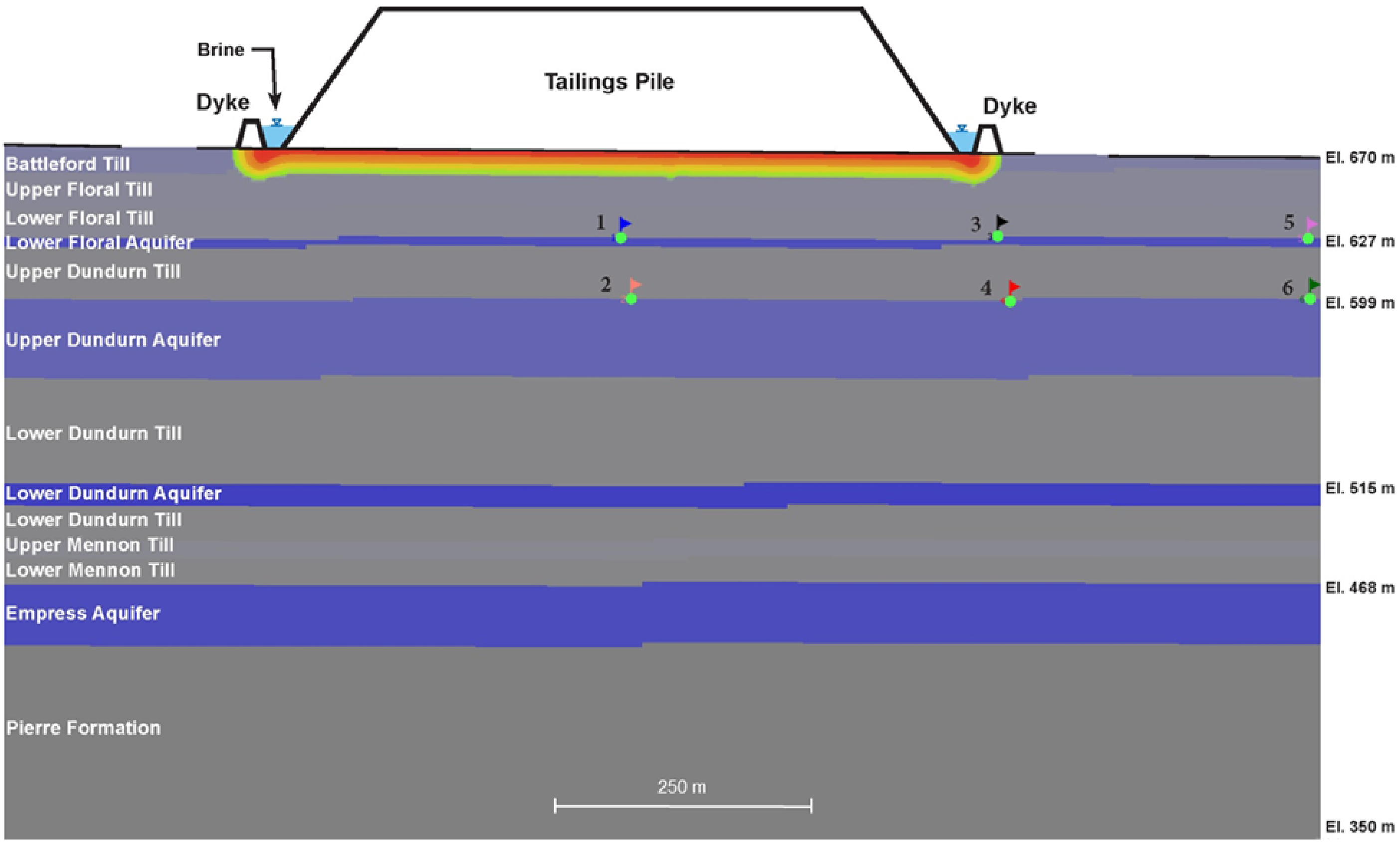
Scenario 2: Mitigation Case Simulation of Effects with Mitigation

- Scenario 2a: Brine migration from TMA with mitigation, driving head remains after brine source is depleted
- Scenario 2b: Brine migration from TMA with mitigation, brine source is depleted and a freshwater pond remains within footprint of TMA
- Scenario 2c: Brine migration from TMA with mitigation, brine source is depleted and TMA area is capped

Base Case Simulations

Scenario 1: Base Case Simulation of Effects without Mitigation

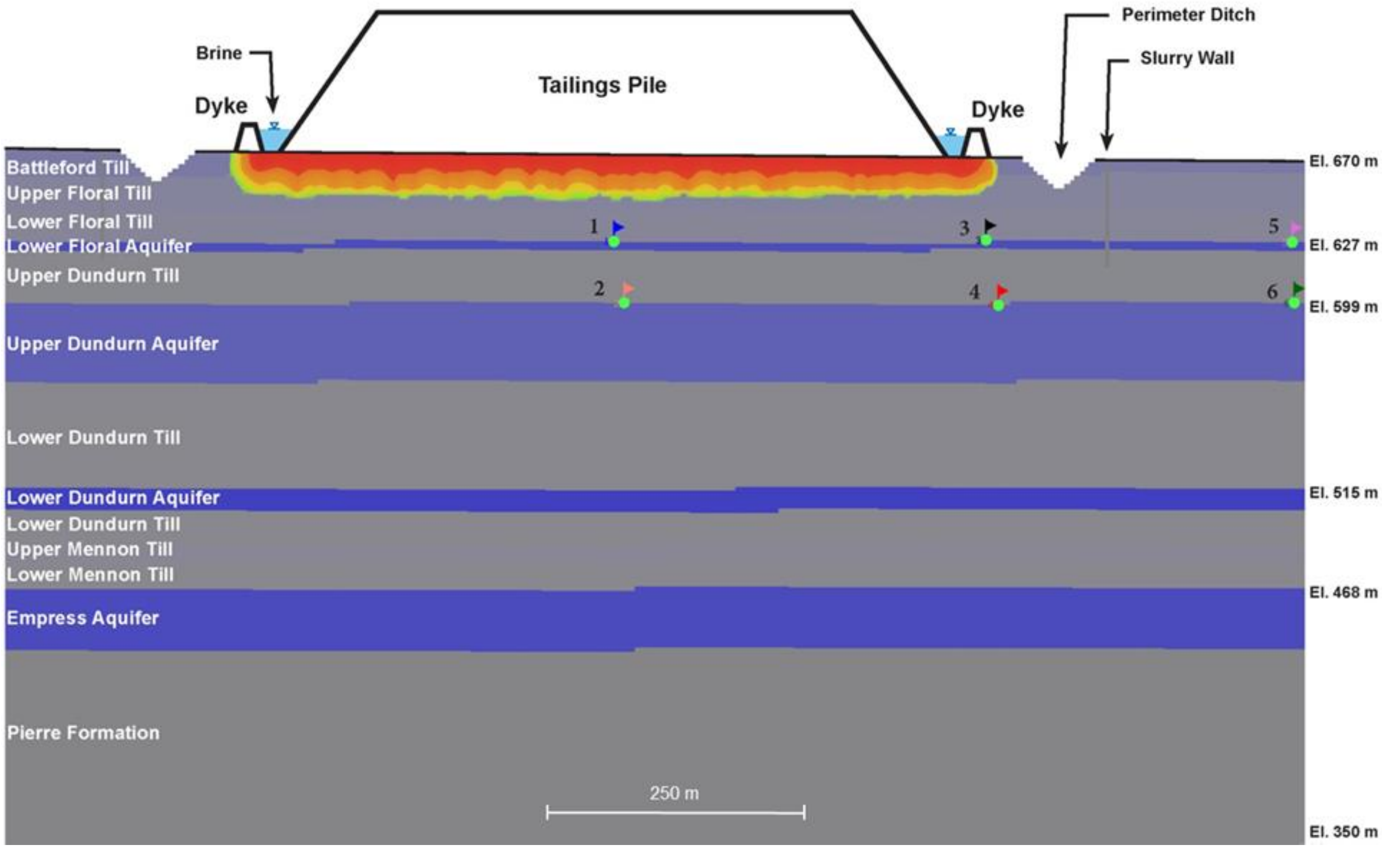
- No perimeter drainage ditch
- No slurry wall



Mitigation Case Simulations

Scenario 2: Mitigation Case Simulation of Effects

- Perimeter drainage ditch
- Slurry wall



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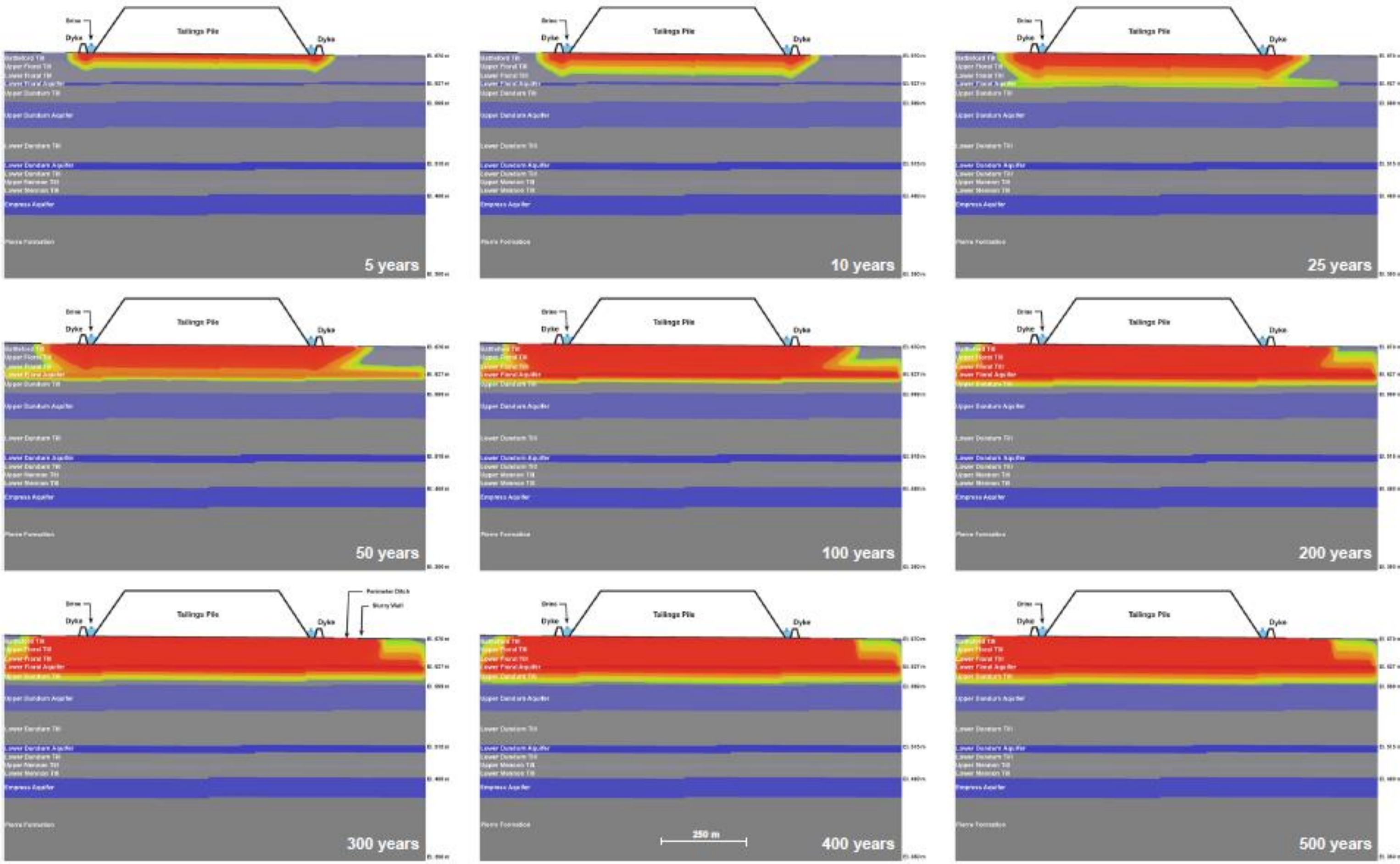
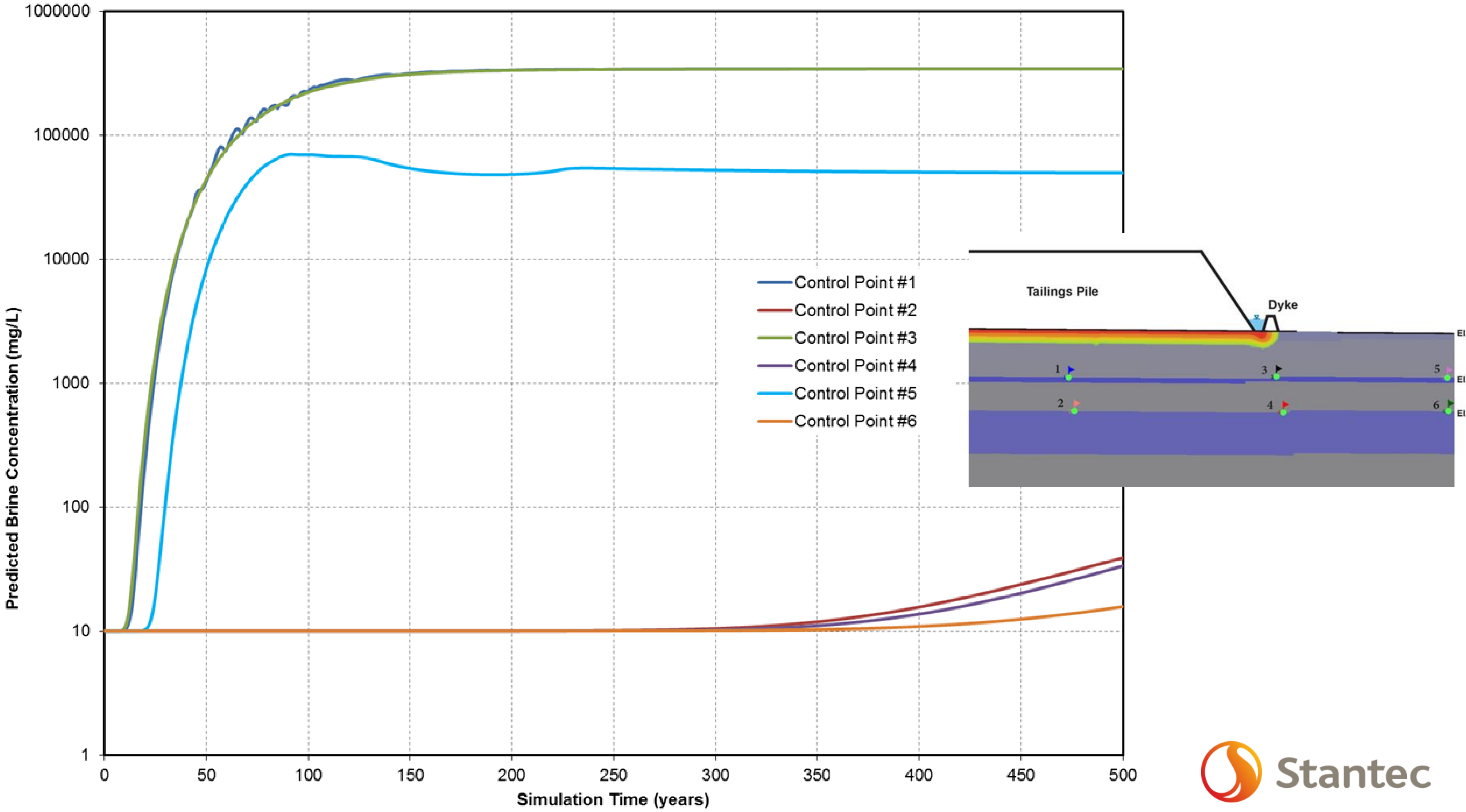
Base Case Results

Scenario 1a: Brine Source and Brine Pond Remain



Base Case Results

Scenario 1a: Brine Source and Brine Pond Remain
Concentration Breakthrough Curves at Selected Control Points



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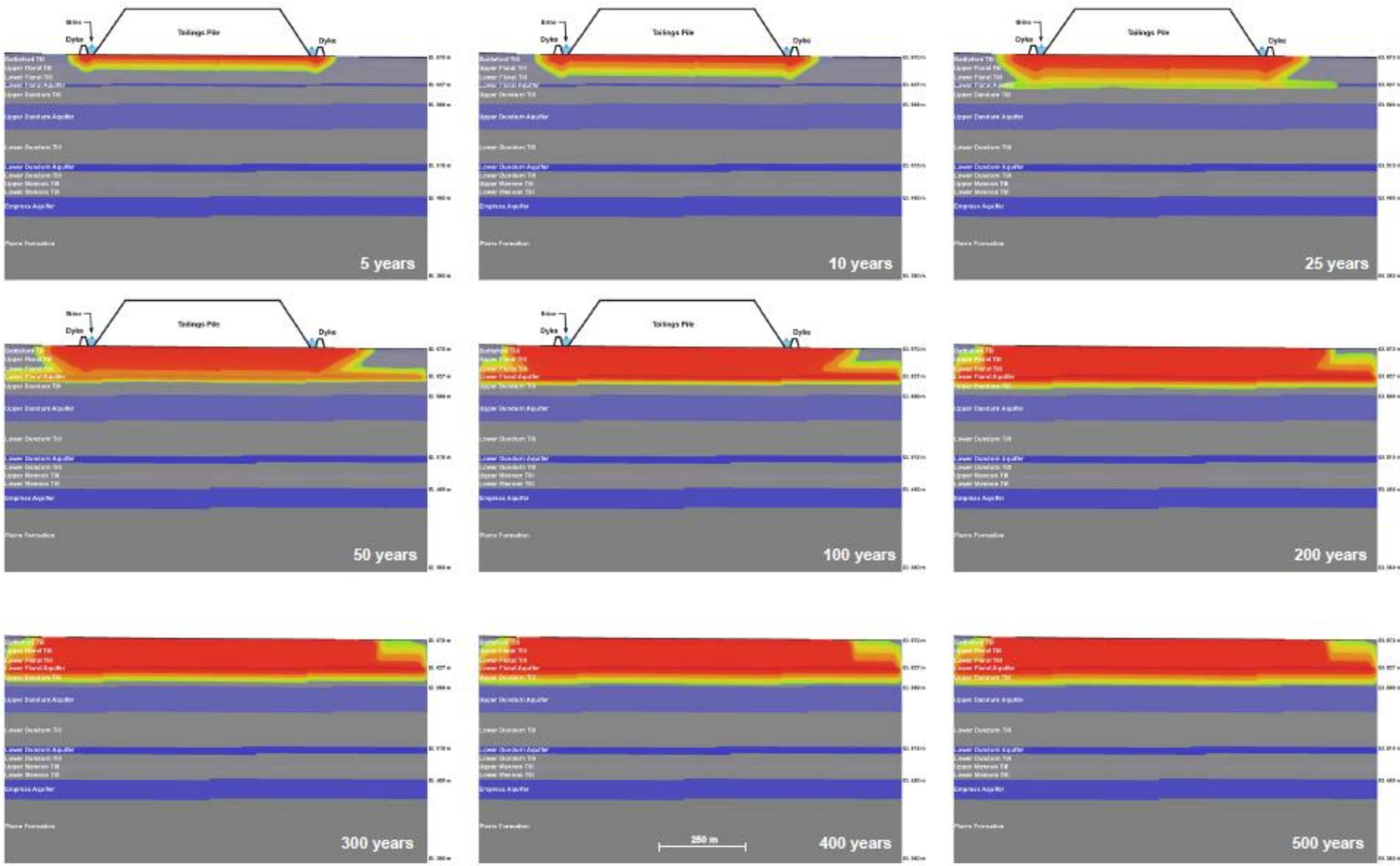
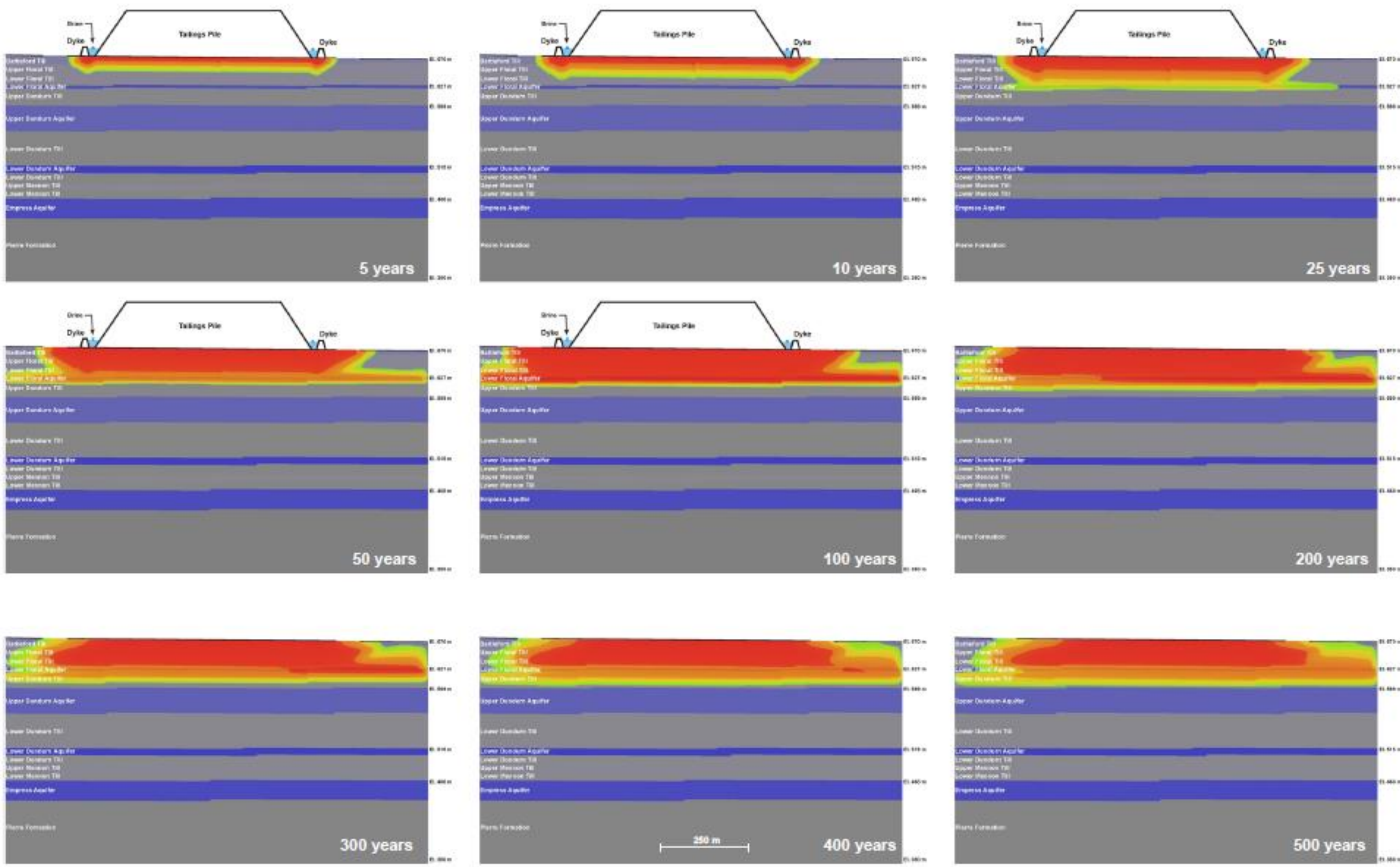
Base Case Results

Scenario 1b: Brine migration from TMA with no mitigation, brine source is depleted and a freshwater pond remains within TMA footprint



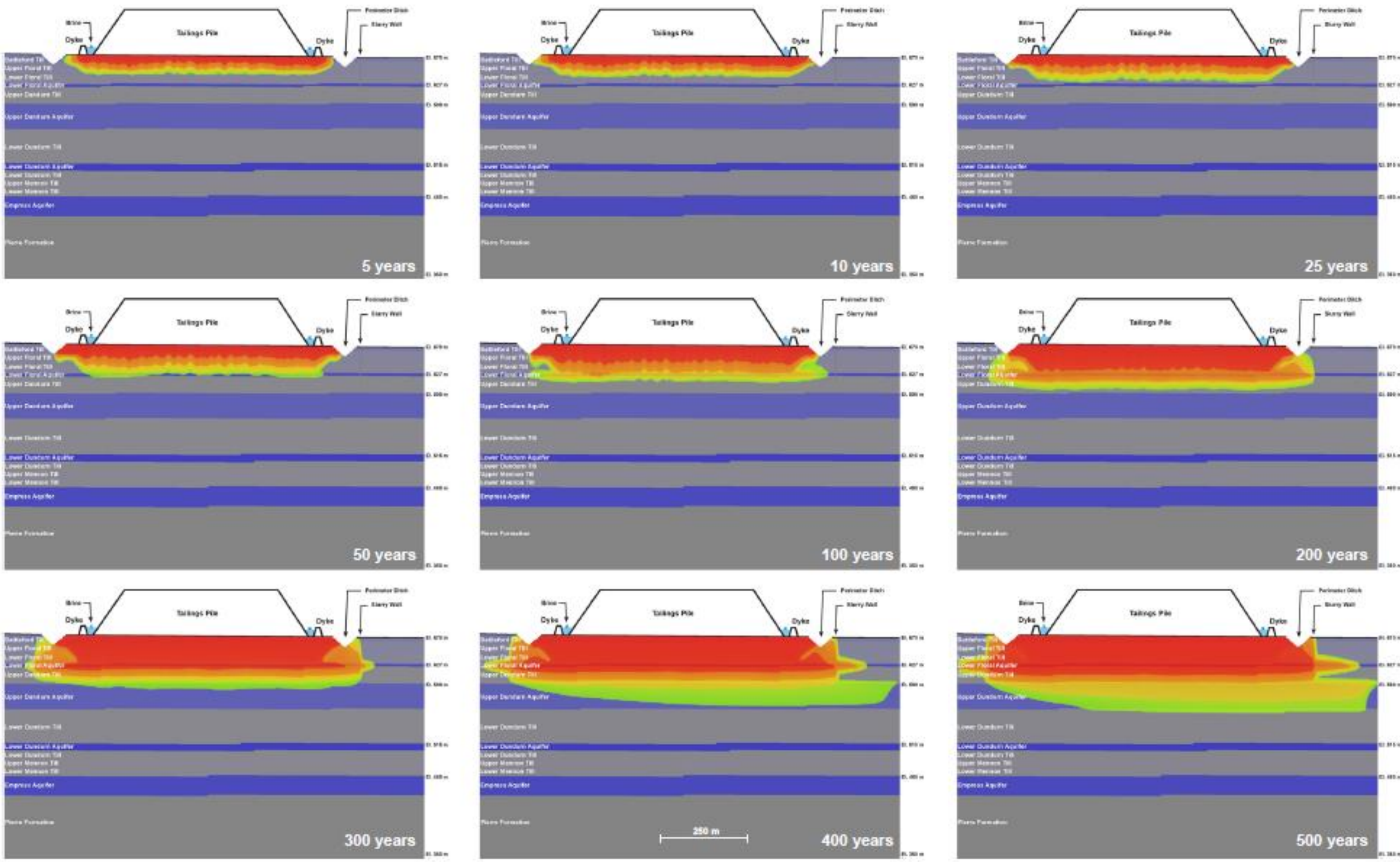
Base Case Results

Scenario 1c: Brine migration from TMA with no mitigation, brine source is depleted and TMA area is capped



Mitigation Case Results

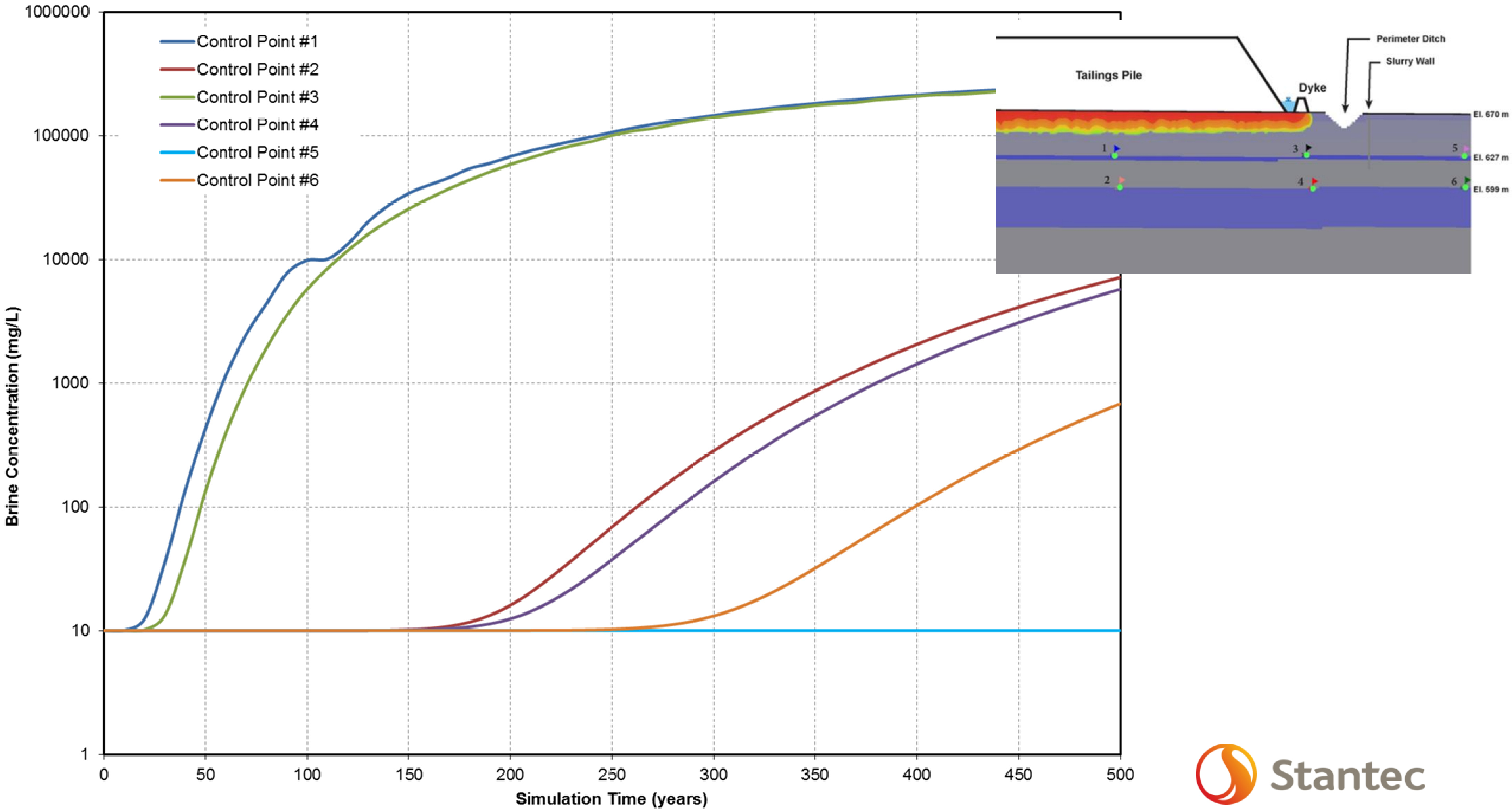
Scenario 2a: Brine migration from TMA with mitigation, driving head remains after brine source is depleted



Mitigation Case Results

Scenario 2a: Brine migration from TMA with mitigation, driving head remains after brine source is depleted

Concentration Breakthrough Curves at Selected Control Points



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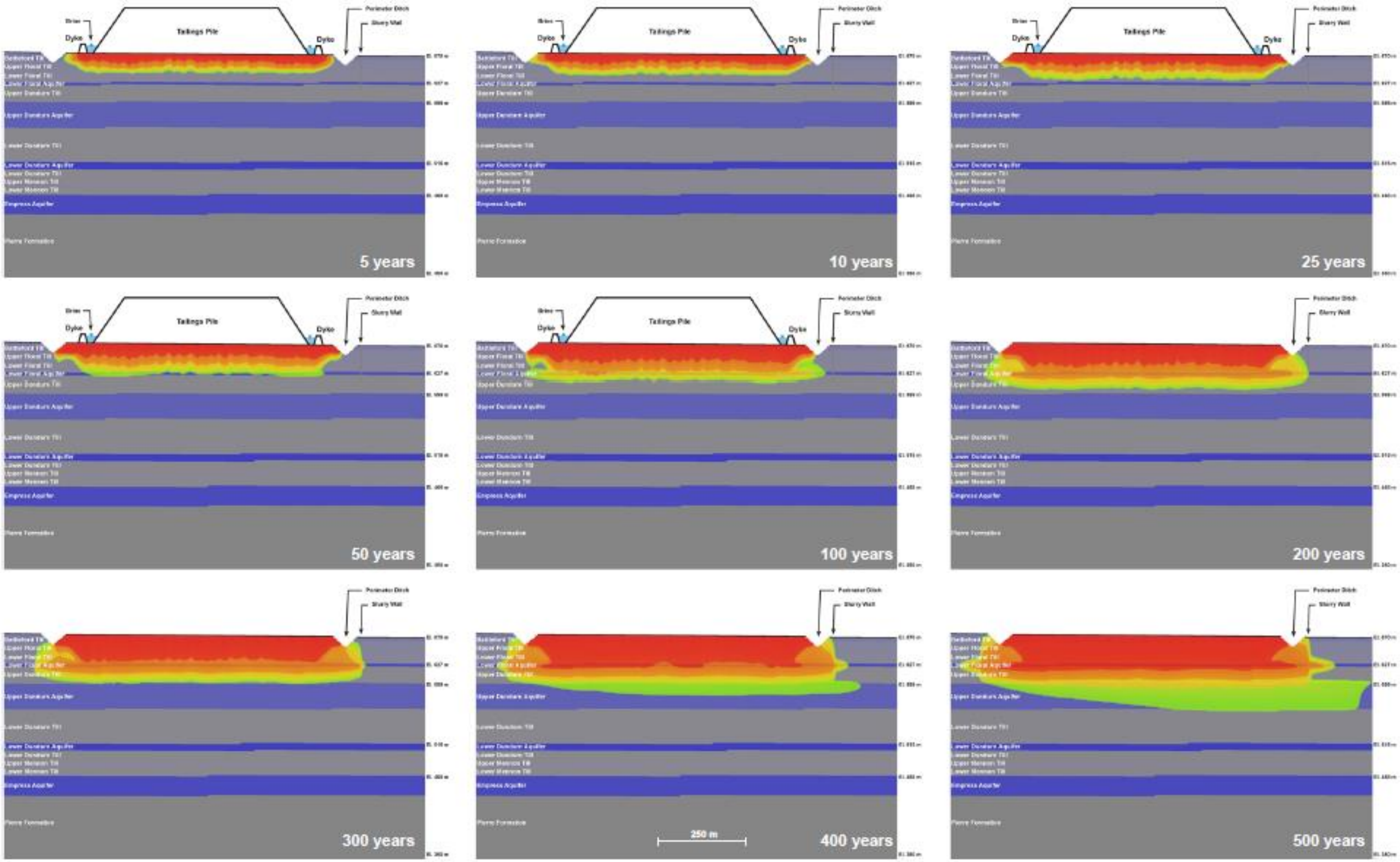
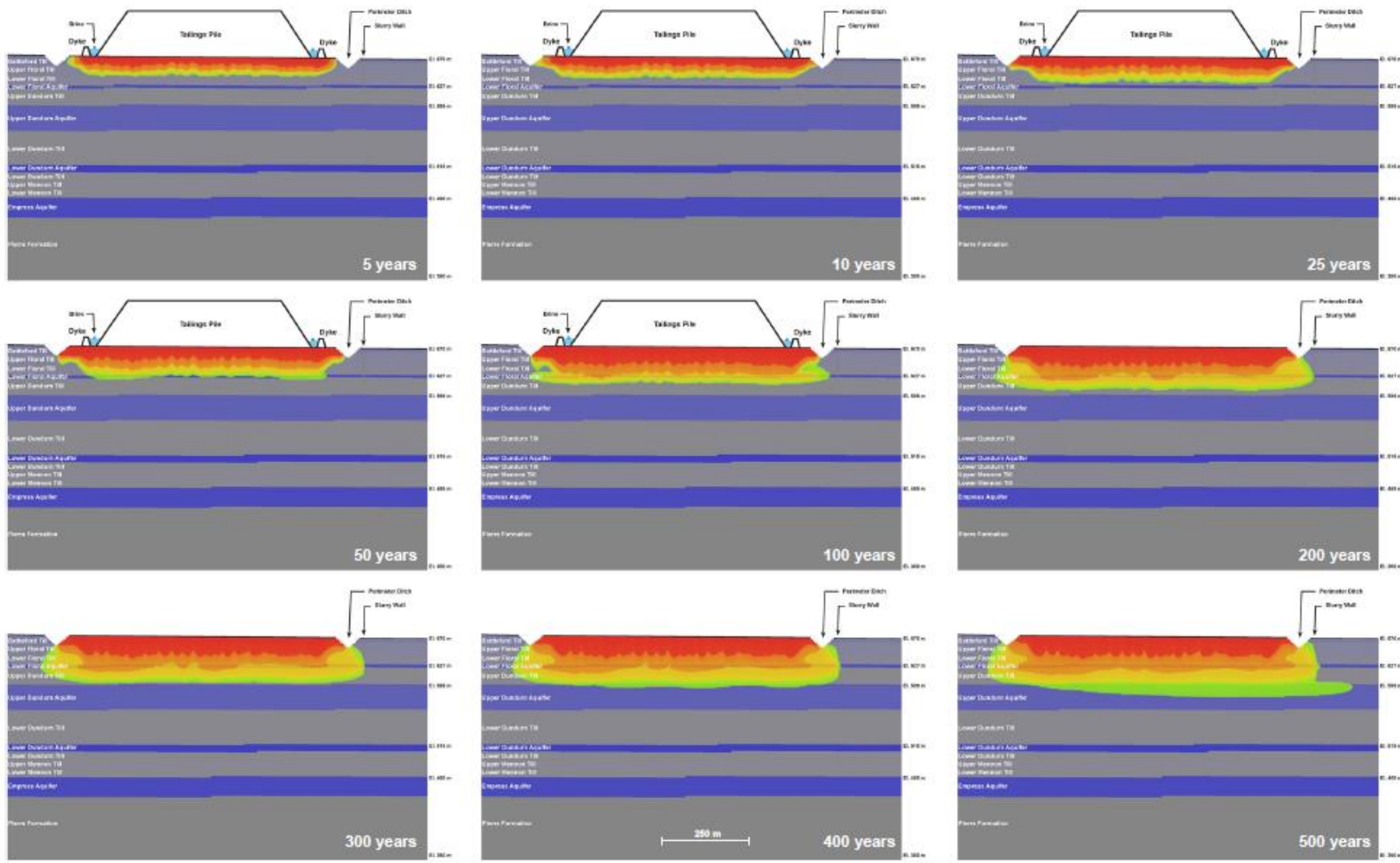
Mitigation Case Results

Scenario 2b: Brine migration from TMA with mitigation, brine source is depleted and a freshwater pond remains within footprint of TMA



Mitigation Case Results

Scenario 2c: Brine migration from TMA with mitigation, brine source is depleted and TMA area is capped



Summary

A three-dimensional groundwater flow model was constructed using FEFLOW to evaluate the groundwater flow patterns in the region surrounding the proposed potash development

A two-dimensional cross-sectional models was extracted from 3D regional model to simulate transport of brine from TMA into the underlying aquifers.

Without mitigation, lateral movement of very high concentrations of brine will reach limits of Lower Fl Aquifer within 50 years of operating TMA.

With mitigation, lateral spread of brine plume in Lower Fl Aquifer, but at expense of shorter transit times toward Upper Dn Aquifer

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Questions?

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