INFRASTRUCTURE

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Variable-Density Groundwater Flow Modelling of the Injection of Cooling Tower Blowdown Into a Deep Saline Aquifer

9-12 September 2019
Liège, Belgium

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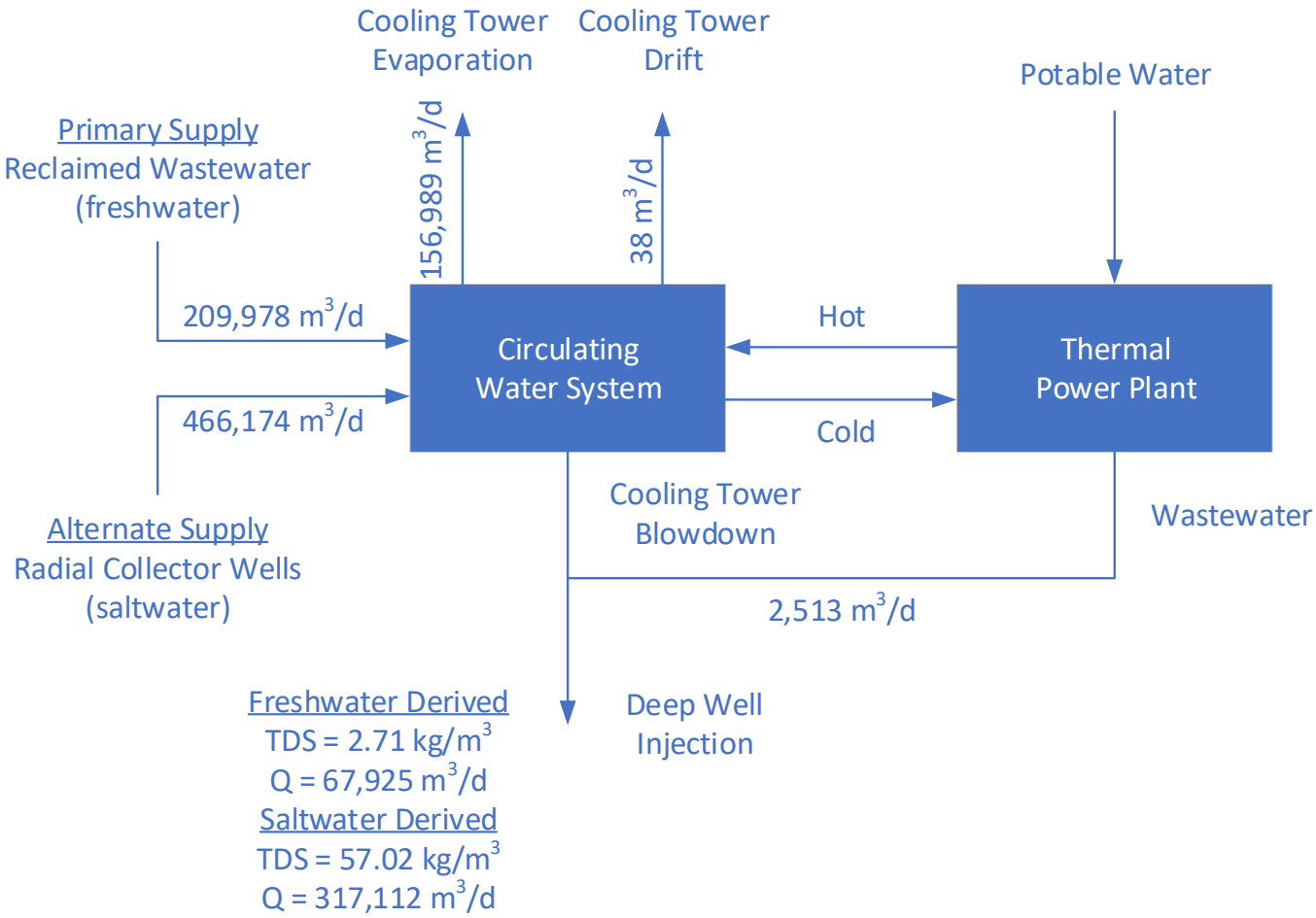
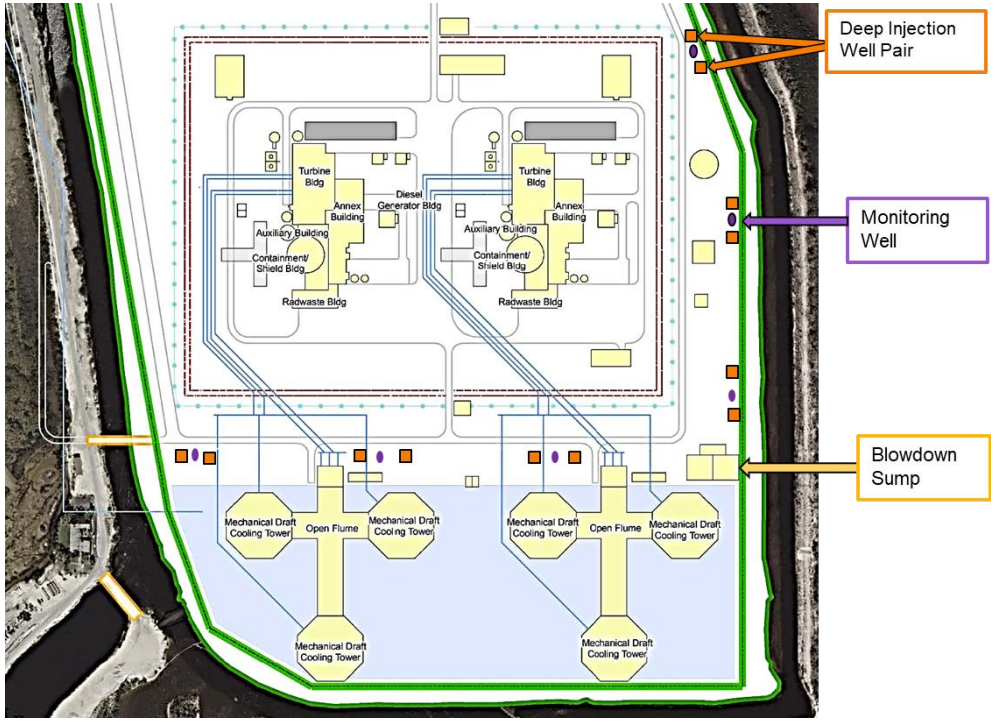
Presentation Outline

1. Power Plant Water Balance
2. Deep Well Injection of Cooling Tower Blowdown
3. Hydrogeological Characteristics of Injection Zone
4. Modelling Objectives and Challenges
5. Variable-Density Groundwater Flow Model
   a. Conceptual model
   b. Numerical model
6. Modelling Results for TDS and Trace Constituents
   a. Steady injection
   b. Transient injection
7. Summary and Conclusions

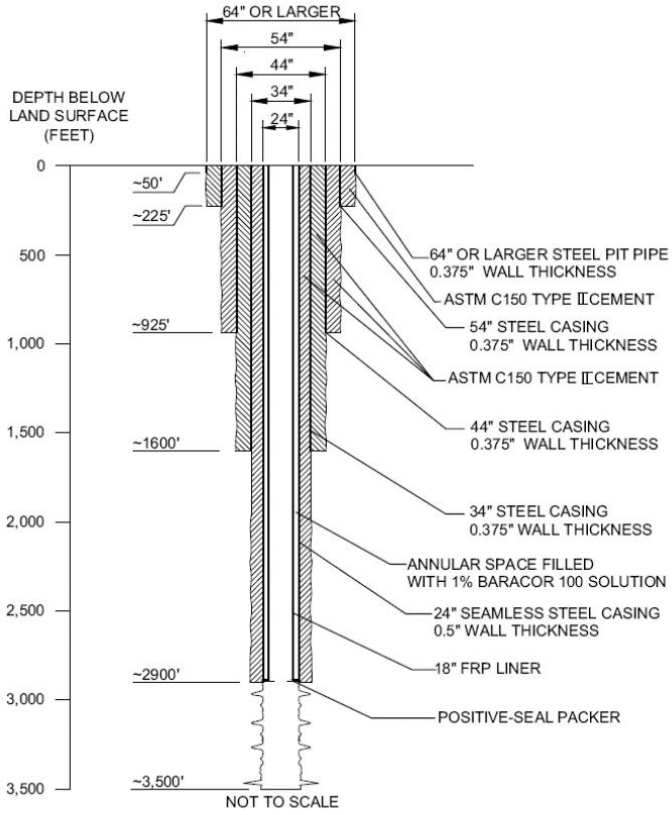
Power Plant Water Balance (Simplified)



Deep Well Injection of Cooling Tower Blowdown



Injection Well Field Plan View

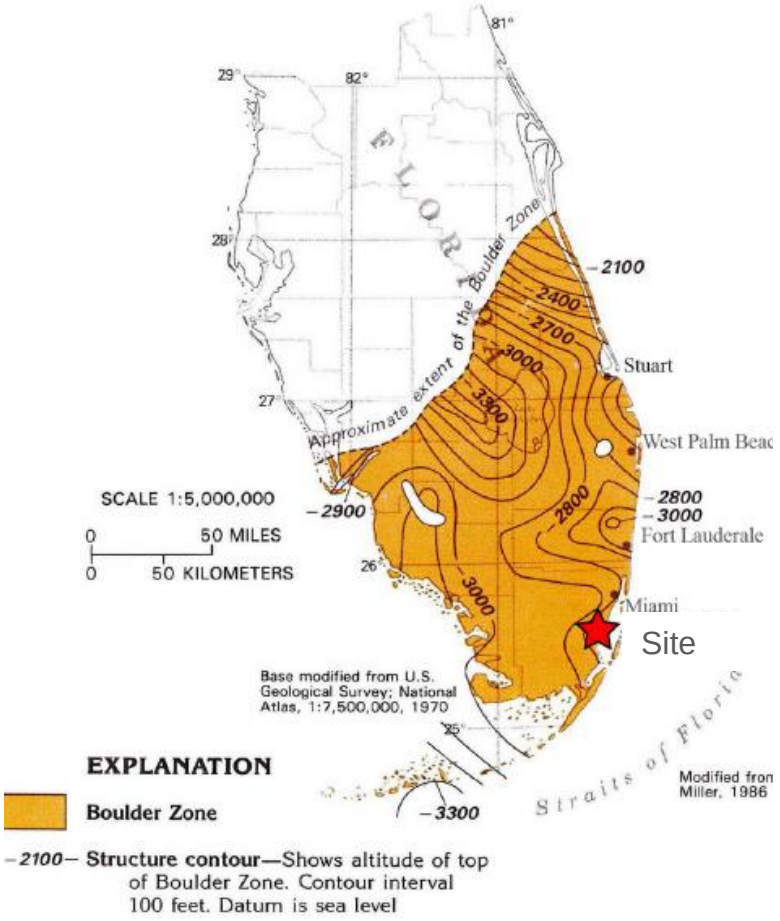


Typical Injection Well Construction

Hydrogeological Characteristics of Injection Zone

Boulder Zone

- Fractured dolomite formation in Lower Floridan aquifer
- 900 m below ground surface
- 150 m thick
- 23,000 m^2/d transmissivity
- Small regional hydraulic gradient
- TDS ~ seawater
- Municipal and industrial wastewater disposal
  - Below underground sources of drinking water (USDW)
  - 180+ Class I injection wells



The Boulder Zone in South Florida

Groundwater Modelling Objectives and Challenges

Modelling Objectives:

- Assess impacts of deep well injection on groundwater quality
  - Total dissolved solids (TDS)
  - Trace constituents

Modelling Challenges:

- Relative density differences
  - Receiving formation, TDS = 36.20 kg/m^3
  - Freshwater-derived injectate, TDS = 2.71 kg/m^3
  - Saltwater-derived injectate, TDS = 57.02 kg/m^3
- Injection rates source-water and time dependent
  - Freshwater-derived, Q = 68,000 m^3/d (up to 365 days/year)
  - Saltwater-derived, Q = 317,000 m^3/d (up to 60 days/year)

Groundwater Flow Model

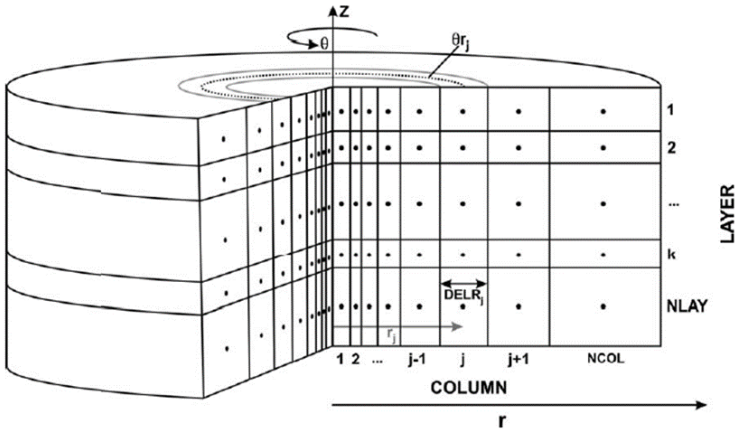
Conceptual Model of Boulder Zone:

- Density-dependent groundwater flow and transport
- Uniform, horizontal, confined aquifer of nearly infinite areal extent
- No vertical leakage through overlying confining unit
- Two-dimensional, axisymmetric flow

Numerical Model:

- SEAWAT Version 4: A Computer Program for Simulation of Multi-Species Solute and Heat Transport (Langevin et al. 2009)
- Coupled version of MODFLOW and MT3DMS designed to simulate three-dimensional, variable-density, saturated groundwater flow

Finite-Difference Model



Parameter Transformation

$$K^*_{h,j} = r_j \theta K_h$$

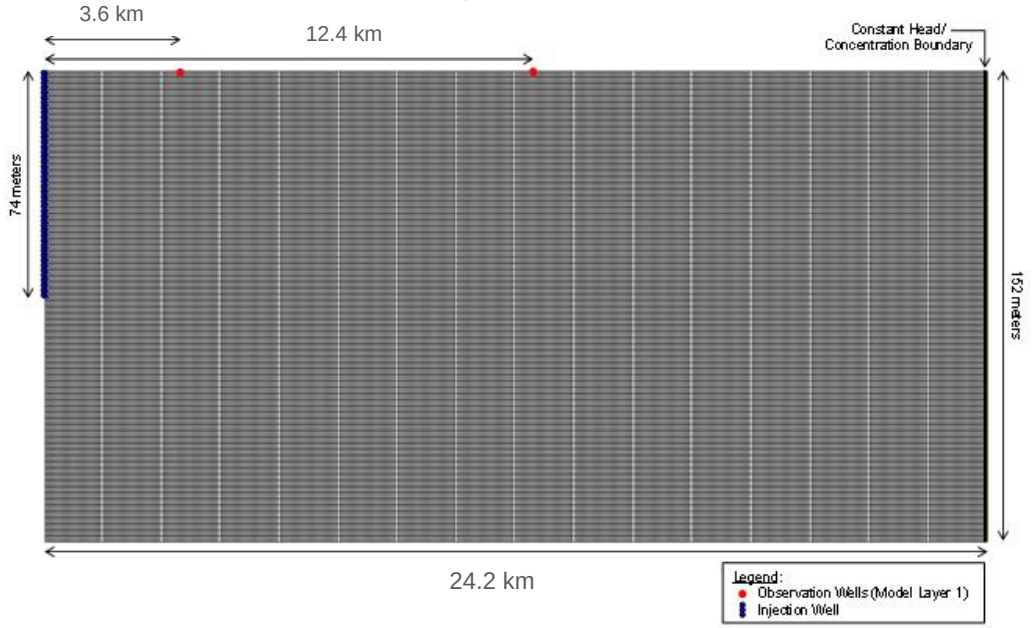
K_h = horizontal hydraulic conductivity

r_j = radial distance from injection well to center of cell in column j

θ = angle open to flow (radians, equal 2π)

$K^*_{h,j}$ = transformed hydraulic conductivity assigned to equivalent finite-difference grid cell

3D Grid → 2D Grid



Predictive Scenarios

Case 1: Steady Injection

Steady injection of freshwater-derived blowdown for 60 years

- Q = 68,000 m^3/d
- TDS = 2.71 kg/m^3

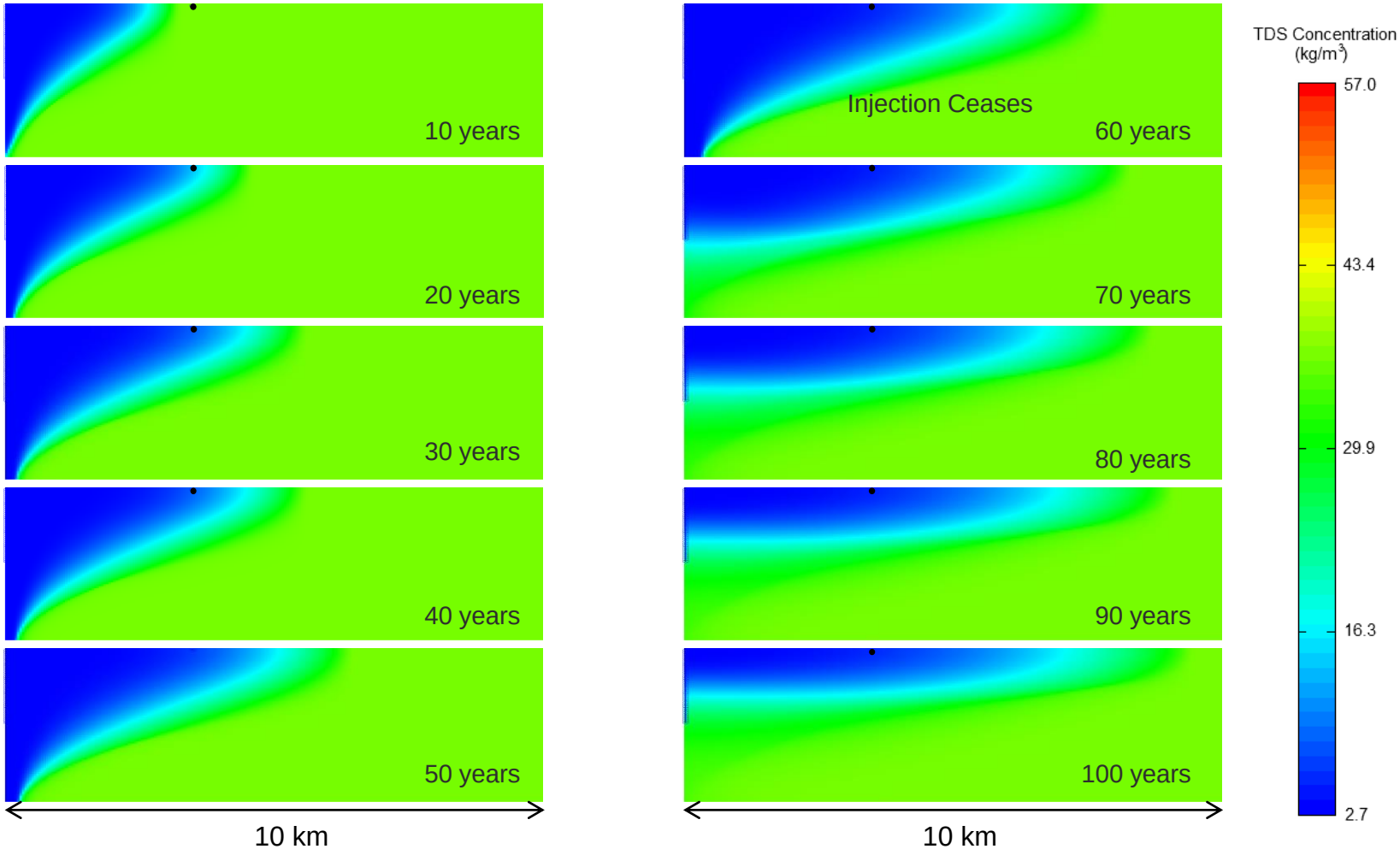
Case 2: Transient Injection

Transient injection alternating between freshwater- and saltwater-derived blowdown for 60 years

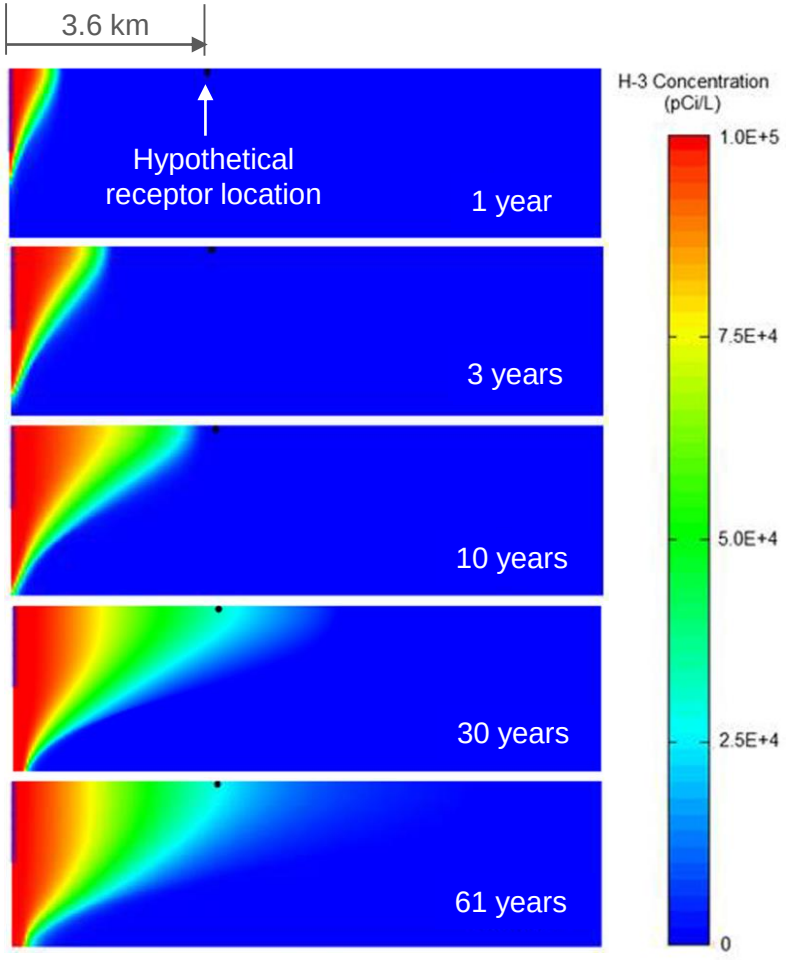
- Q = 68,000 m^3/d for 305 days
- TDS = 2.71 kg/m^3

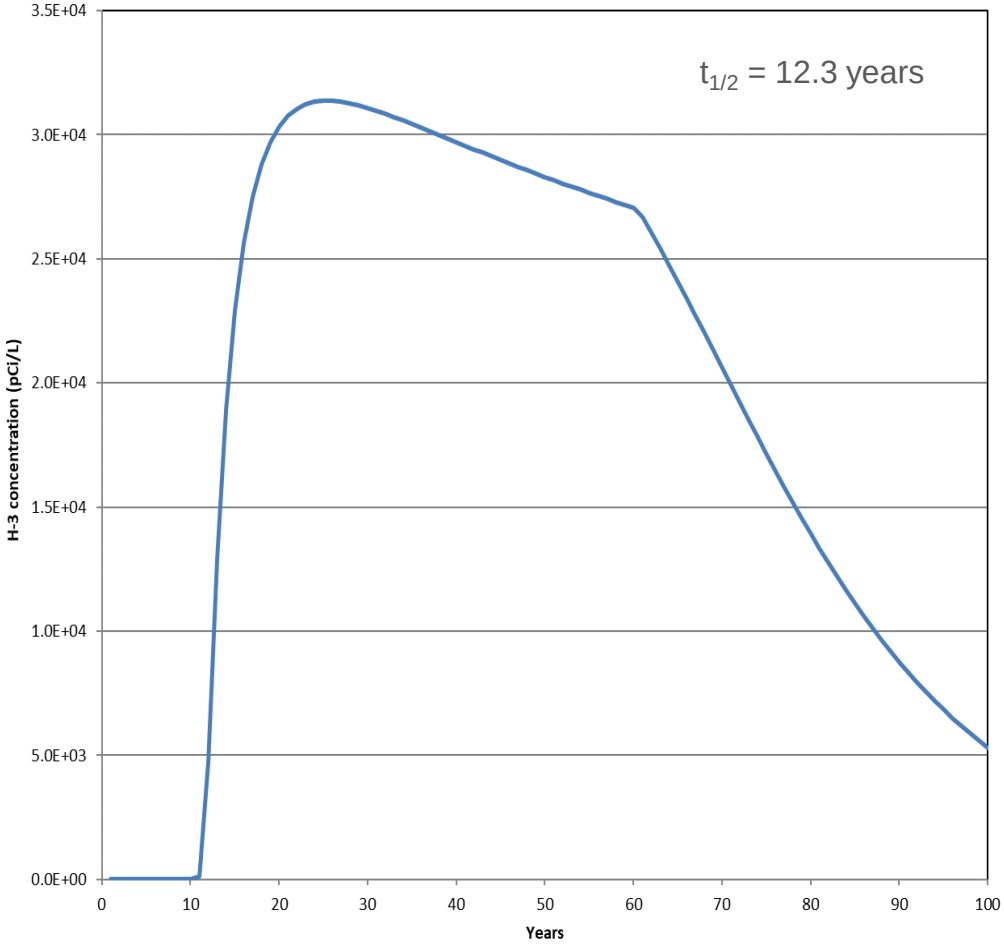
- Q = 317,000 m^3/d for 60 days
- TDS = 57.02 kg/m^3

Case 1: Steady Injection
TDS Concentrations

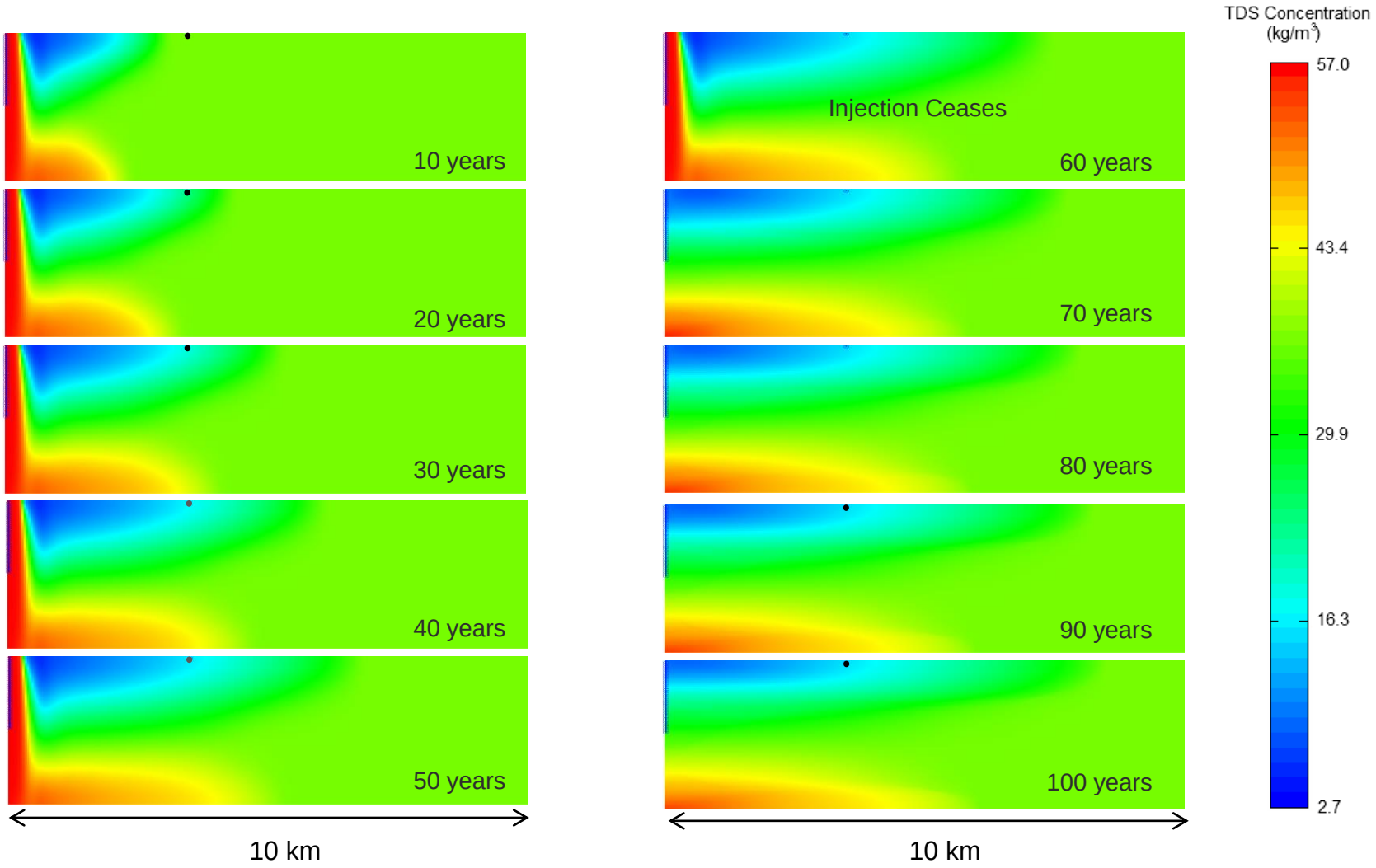


Case 1: Steady Injection
Trace Constituent Concentrations

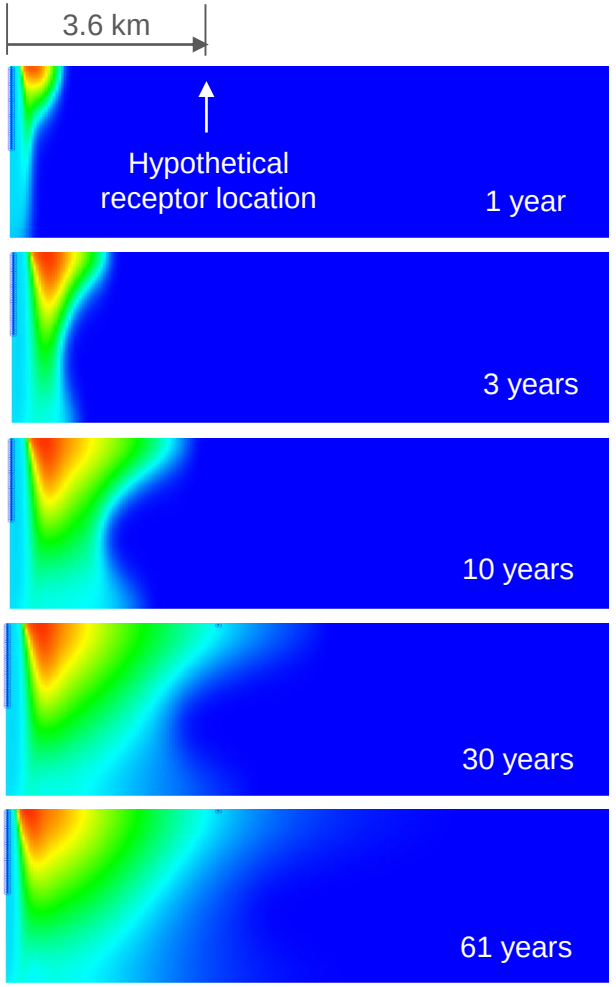




Case 2: Transient Injection TDS Concentrations



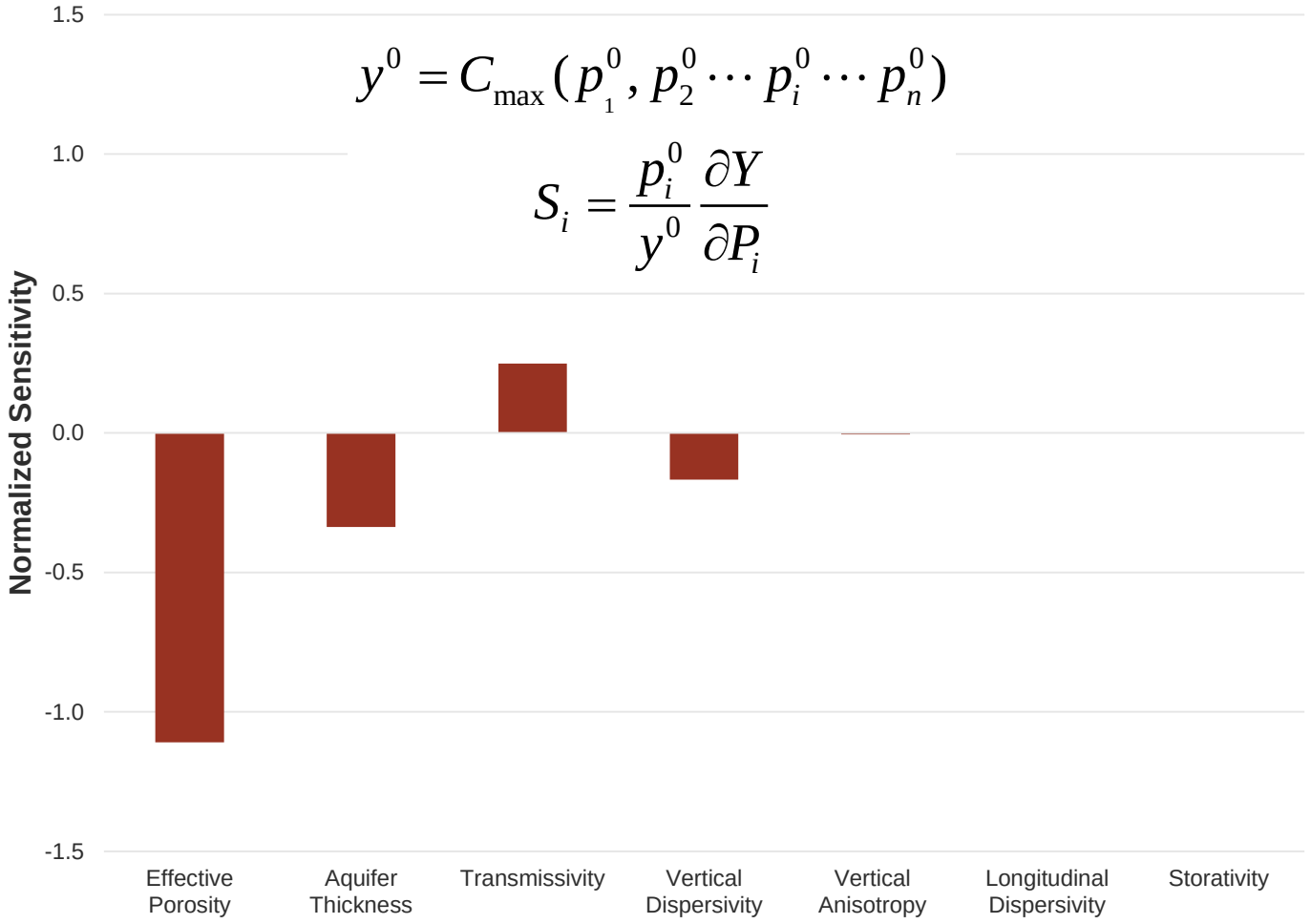
Case 2: Transient Injection
Trace Constituent Concentrations



Sensitivity Analysis

$$y^0 = C_{\max}(p_1^0, p_2^0 \cdots p_i^0 \cdots p_n^0)$$

$$S_i = \frac{p_i^0}{y^0}\frac{\partial Y}{\partial P_i}$$



Summary and Conclusions

- Variable-density groundwater flow modelling key to understanding complex behavior of injectate
- Steady injection produced higher TDS and trace constituent concentrations at receptor
- Transient injection yielded lower concentrations at receptor
  - Greater dilution due to higher injection rate
  - Chemicals more broadly distributed over vertical extent of aquifer
- Parameters determining advective velocity and vertical mixing exhibited greatest sensitivity
  - Effective porosity
  - Aquifer thickness
  - Transmissivity
  - Vertical dispersivity
- Regulatory compliance demonstrated for hypothetical receptor

Questions?