Identification of Groundwater Basin Shape and Boundary using Hydraulic Tomography

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Outline

• Introduction
• Materials and Methods
• Results and Discussions
• Conclusion
Groundwater basin and boundary

Desert Research Institute - https://www.dri.edu/theoretical-analysis-of-optimal-groundwater-basin-development

Constant head boundary

Flux boundary

Lake, River

Infiltration, impermeable material

(Ferris et al. 1962)
Groundwater basin and boundary

• The importance of identification of basin boundary and heterogeneity
Hydraulic Tomography

• More details of aquifer with limited number of wells
• Contain more information from different views of aquifer
Hydraulic Tomography

1 Pumping test

2 Pumping tests

3 Pumping tests

4 Pumping tests

5 Pumping tests

True material

Material Field

iteration 13

iteration 12

iteration 11

iteration 10

iteration 12

iteration 13

iteration 12

iteration 13

iteration 12

iteration 13

iteration 12

iteration 13

iteration 12

iteration 13

iteration 12

iteration 13

iteration 12

iteration 13

iteration 12
Questions

1. Identification of the true geometry and boundary with incorrect geometry and boundary model.
2. The effect of unknown geometry on the estimates inside the domain.
3. Role of the prior information to the improvement of parameter estimation.
Scenario

- 5 pumping tests, 8 observation wells
  - **Grid spacing:** 4 m
  - **Mean lnT:** -1.498 m²/d  \( \text{var lnT: } 1.61 \)
  - **Mean lnS:** -7.457  \( \text{var lnS: } 1.10 \)
  - **Correlation scale:** 50 in x and y
Q1: Identification of basin geometry using HT
Q1: Identification of basin geometry

True Geometry

Drawdown Data

Forward Model

Steady State

Transient State

Heterogeneous Material
Q1: Identification of basin geometry

Incorrect Geometry Model

Constant Head

Steady State Estimation

Inverse Model

+ Drawdown Data

+ Uniform Initial Guess

Transient State Estimation
Q1: Identification of basin geometry

Estimated transmissivity (T): Steady State
Q1: Identification of basin geometry

Estimated transmissivity (T): Transient State

True Material

Incorrect Geometry and Boundary Model
Q1: Identification of basin geometry

Histogram of estimated T outside the true domain
Q1: Identification of basin geometry

Average estimated T outside the true domain of 10 realizations

Comparison of average T outside the domain of each realization
Q1: Identification of basin geometry

Q1 Conclusion

• Both steady and transient state estimation can delineate the impermeable material zones by representing them as low T values.
• The estimation using transient state results in the better approximation of the low permeable medium outside the domain; mean value is much closer to the true mean than using steady state.
Q2: Effects of unknown basin geometry on the estimates inside the domain
Q2: Effects of unknown basin geometry

True Geometry

Drawdown Data

Transient State

Forward Model

+ Heterogeneous Material
Q2: Effects of unknown basin geometry

True Geometry VS Incorrect Geometry

+ Drawdown Data
+ Uniform Initial Guess

Inverse Model → Transient State Estimation
Q2: Effects of unknown basin geometry

Estimated T

True Material

True Geometry

Incorrect Geometry
Q2: Effects of unknown basin geometry
Q2: Effects of unknown basin geometry

Q2 Conclusion

• T estimation using correct geometry and type of the boundary yields better result of the estimation inside the domain.

• Estimation with the incorrect geometry model results in lower average T due to low permeable region along the no flow boundaries.

• Knowing true geometry and boundary type can improve the estimation.
Q3: Role of prior information
Q3: Role of prior information

True Geometry

Prior information of mean $T$

Case A

Prior information of geology

Case B

Prior information of estimated $T$

Case C
Q3: Role of prior information

True Material

Material Field

Case A

Case B

Case C
Q3: Role of prior information

![Graph showing the role of prior information](image-url)
Q3: Role of prior information

Q3 Conclusion

• Using geology information (Case B), the mean value of estimated $T$ inside the basin is closer the true mean than the other cases.

• The performance metrics of ten realizations indicates that the prior information of geology (Case B) and distribution of $T$ (Case C) can improve the estimation in the basin area.
Conclusion

Based on ten realizations...

• With the incorrect assigned boundary, HT can delineate the no-flow boundary and geometry and also can estimate the heterogeneity inside the domain.

• More prior information about the basin, e.g., geology, hydraulic conductivity, can improve the estimation of the heterogeneity.

• More realizations have to be taken into account in order to create more robust conclusion.
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Performance metrics

- **R-squared**: \( R^2 = 1 - \frac{\sum_{i=1}^{N}(x_i - \hat{x}_i)^2}{\sum_{i=1}^{N}(x_i - \bar{x})^2} \)

- **L1 (MAE)**: \( L_1 = \frac{1}{N} \sum_{i=1}^{N} |x_i - \hat{x}_i| \)

- **L2 (MSE)**: \( L_2 = \frac{1}{N} \sum_{i=1}^{N} (x_i - \hat{x}_i)^2 \)

- Simple Linear Regression Equation: \( Y = mX + b \)
  - **Slope**: \( m \)
  - **Intercept**: \( b \)

*where*

- \( i \) = Element number
- \( x_i \) = True T value at the element \( i \)th
- \( \hat{x}_i \) = Estimated T value at the element \( i \)th
- \( N \) = Total number of elements