Effects of Grid Discretization on Coastal Aquifer Models

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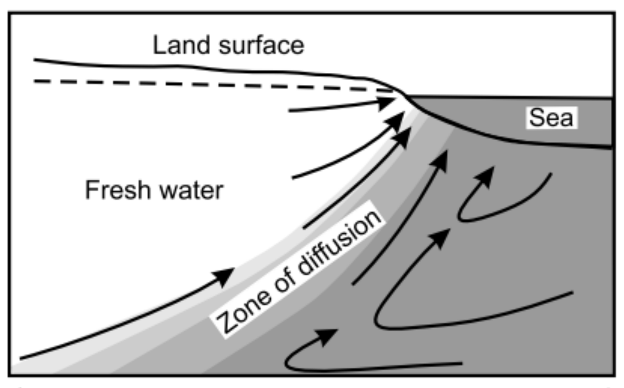
Introduction

Understanding coastal aquifer processes is imperative for management of freshwater resources, as <1% of seawater makes freshwater undrinkable. Seawater intrusion (SI), the landward movement of seawater, occurs globally, and is exacerbated by increased freshwater withdrawal and sea level rise.[3] Submarine groundwater discharge (SGD), solute flux from the seafloor, is significant to both ocean chemistry and nutrients budgets.



Coastal aquifer flow model representation by Smith, 2004. The freshwater-saltwater interface is not a separation of distinct layers, but has a zone of diffusion.

Coastal aquifers are often represented with a layer of less dense freshwater overlying saltwater. In reality, the interface between the freshwater and saltwater is a mixing zone, which also gains complexity in heterogeneous systems.

Due to the large spatial and time scales of groundwater processes, numerical models are used to study these aquifers. However, they require significant computational time, especially in highly discretized grids with many cells. Thus, this study aims to use efficient computational methods to find the optimum grid discretization for a modeled aquifer.

Research Question

What are the effects of grid discretization on coastal aquifer simulations?

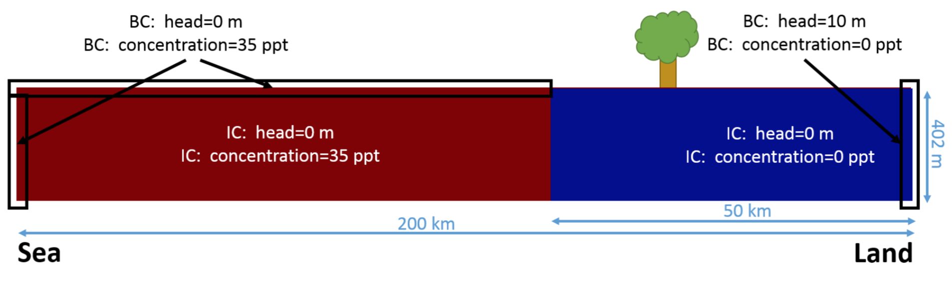
Background

The goal of any modeling exercise is to produce results where:

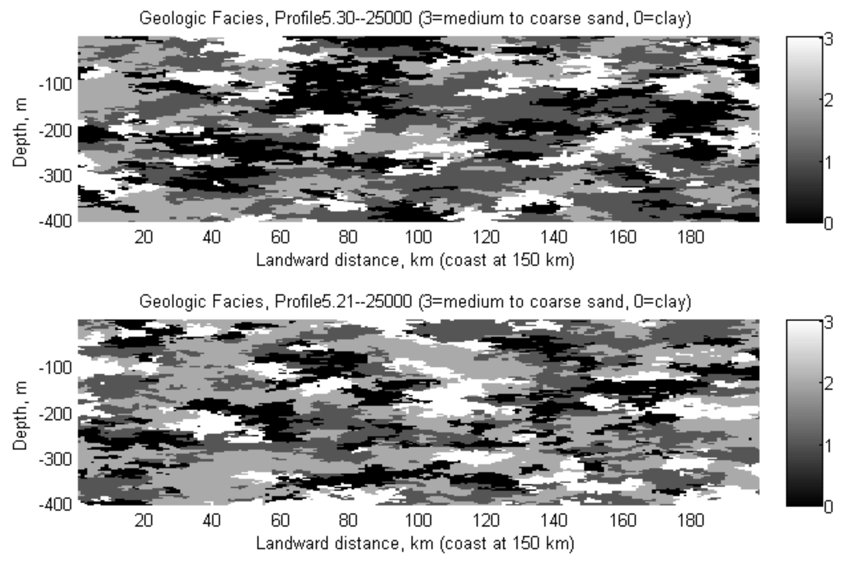
- models converge independent of grid size
- further grid discretization will not significantly change the results

Finer grids can produce more accurate results, but also require greater computational time.

Numerical Aquifer Model



Using SEAWAT, a numerical groundwater simulation program developed by the U.S. Geological Survey, coastal aquifer simulations were run to steady-state conditions in a previous study. They analyzed the effects of geologic heterogeneity, as represented by geostatistical hydraulic conductivity fields with different connectivities. The current study compares those results to output from more discretized grids.

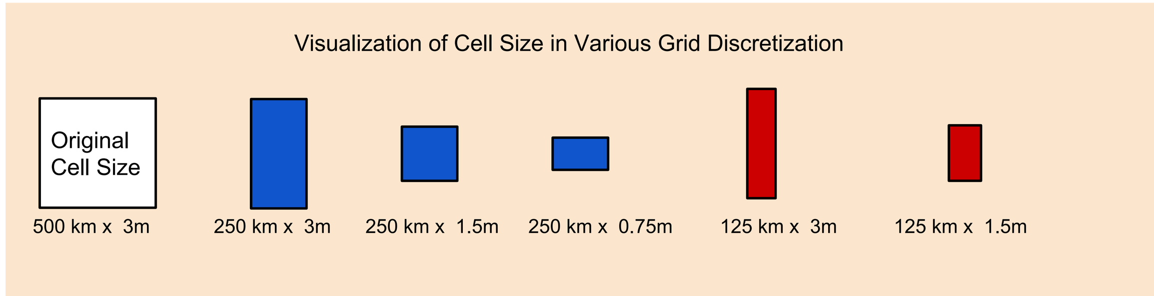


Lithographical profiles of medium connectivity, modeled off of borehole logs in Bangladesh, created through geostatistical simulations.

Methods

Step 1: Create more discretized grids

- Cells sizes were decreased in the z direction (depth) and x direction (width) of the model
- Larger number of cells per grid → increase computation time; potentially reduce numerical errors



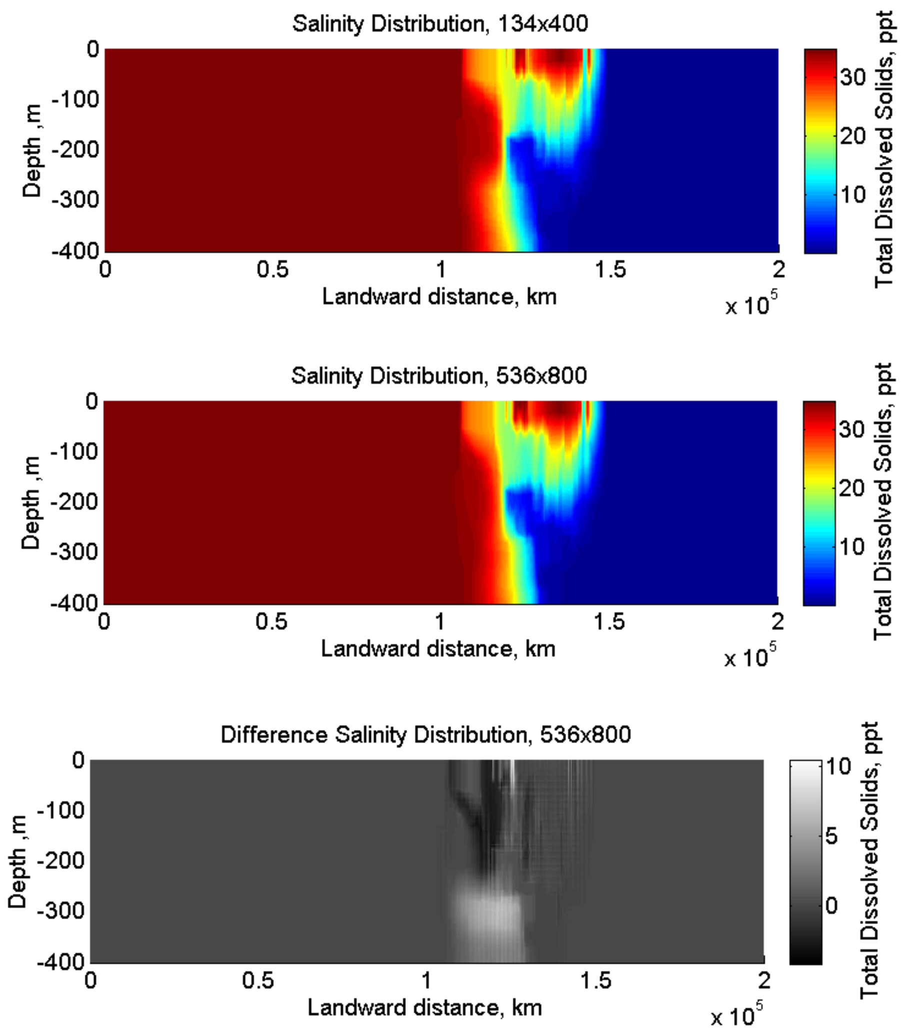
Step 2: Map steady-state values to discretized grid

- Steady state head and concentration values for each cell were written as input data for larger grids in each model.
- models simulated for 100k years to near steady-state conditions

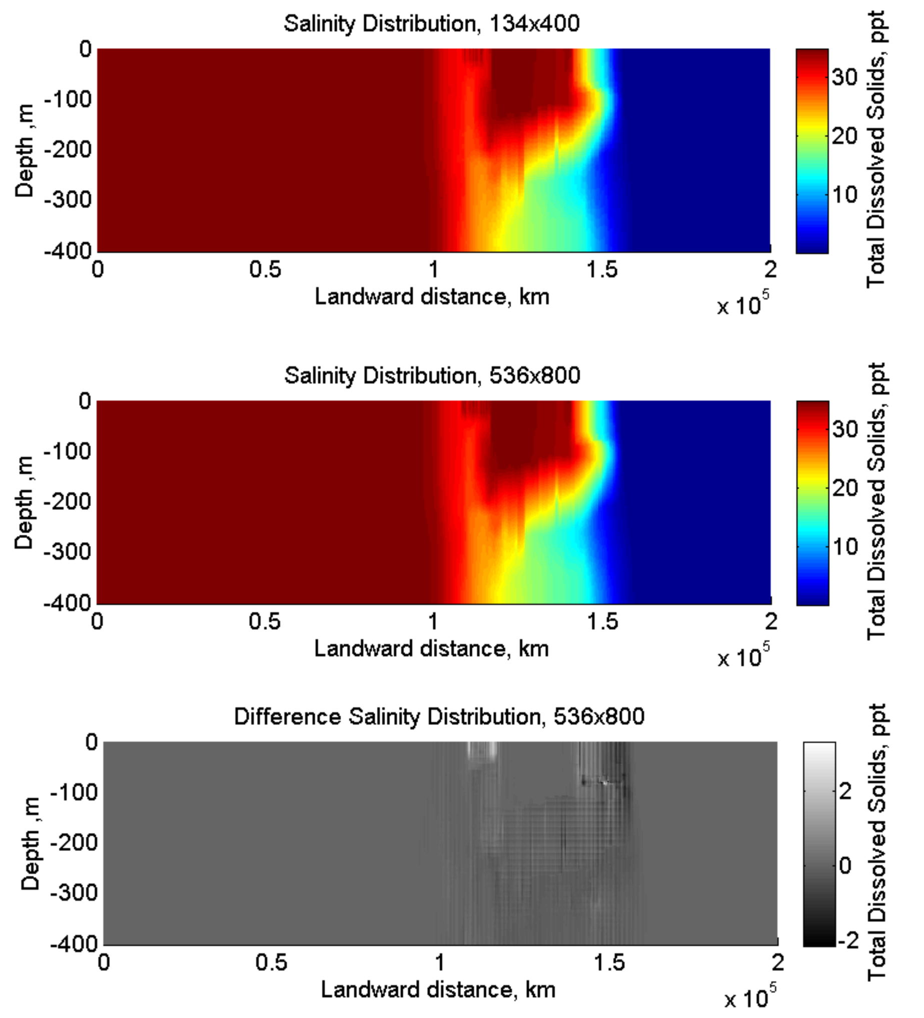
Step 3: Quantify impact of discretization on simulation results

- salinity distribution patterns: subtract prior salinity distribution from final salinity distribution on more discretized grid
- determine percent change in aquifer processes at different grid discretizations

Results 1: Patterns of Salinity

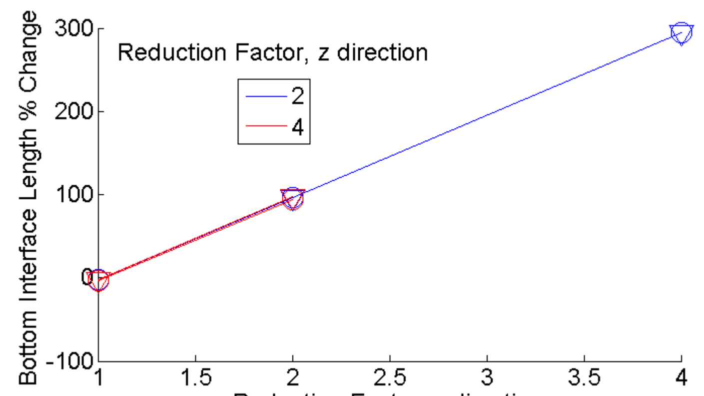


Steady-state salinity distribution pattern with hydraulic conductivity profile 5.30. From top, results with original grid, discretized grid 536 x 800, and changes in salinity distribution.



Steady-state salinity distribution pattern with hydraulic conductivity profile 5.21. From top, results with original grid, discretized grid 536 x 800, and changes in salinity distribution.

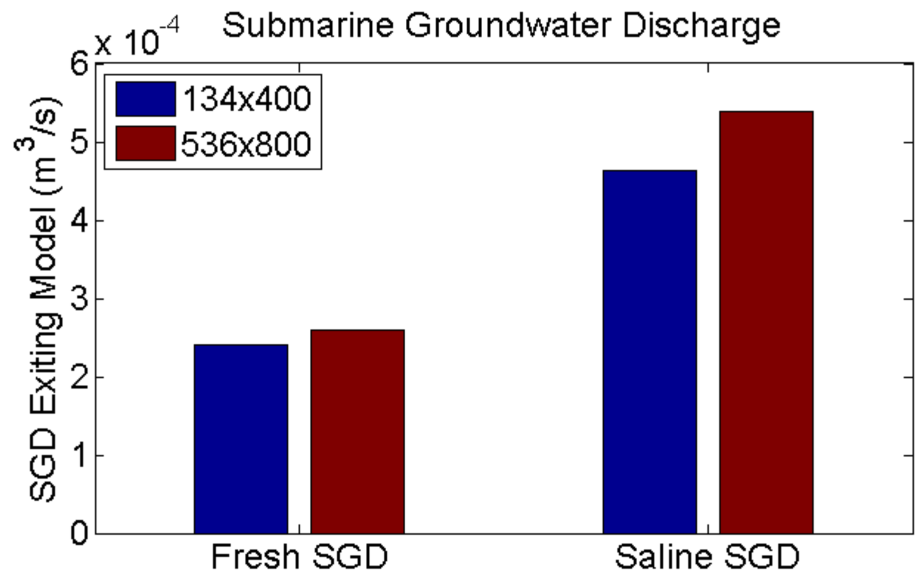
- Changes in salinity patterns were primarily near the mixing zone
- Mixing zone location was constant through all simulations with center movement < 1% in both X and Z directions



- Size of the bottom of the freshwater-seawater interface increased with further vertical discretization, independent of horizontal discretization and hydraulic conductivity fields

Percentage change in the mixing zone length at the bottom of the aquifer for all simulated grids. Profile 5.30 has circles while and triangles indicate profile 5.21.

Results 2: Submarine Groundwater Discharge

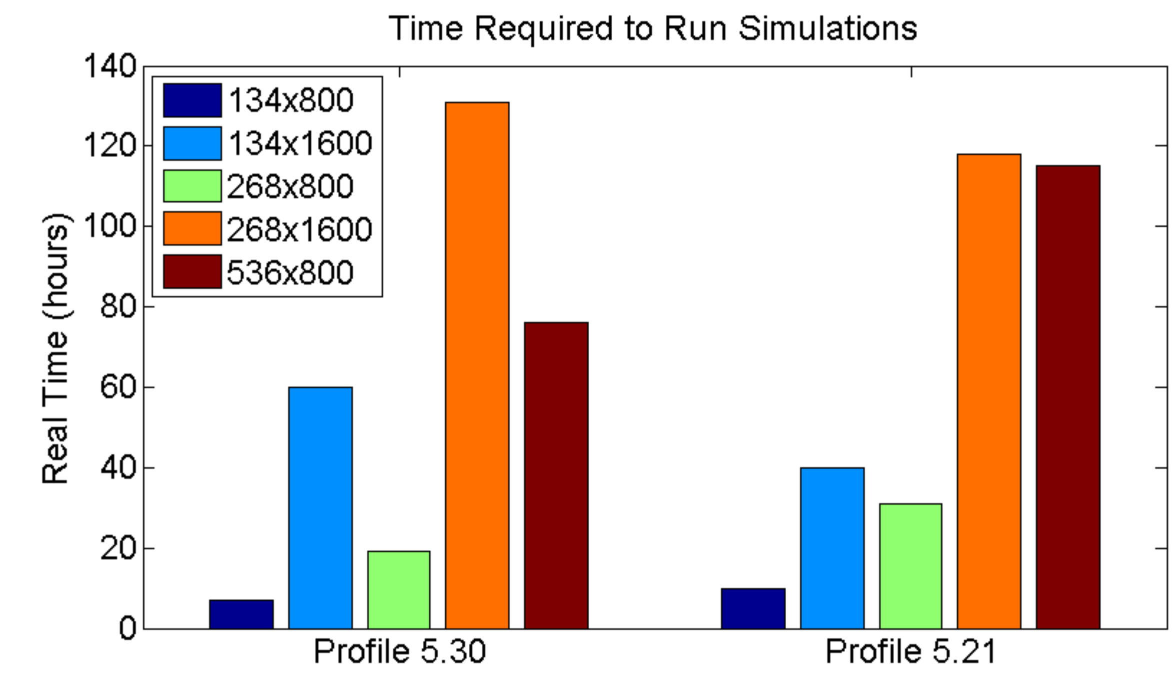


Comparison of results from grid 536 x 800 for SGD. The more discretized grid 536 x 800 resulted increased fresh and saline SGD.

Running the model on a grid of 536 x 800 impacted flow parameters

- Smaller cell size leads to an increase in fresh and saline SGD, saline circulation, greater total storage, freshwater recharge
- Greater circulation: total percent saltwater circulation increased by 8.3%, freshwater recharge increased by 7.7%

Discussion



Time required to run models for each grid discretization; an estimated **400% improvement in model runtime** with regular methods. Runtime is sensitive to lithological profiles and generally increases with higher grid discretization.

- Assumed steady state conditions after 100k years
- All simulations with discretized grids had less than a 1% change in total mass from initial conditions, but contained a consistent upward or downward trend
- Higher grid discretization generally requires additional computational time

Conclusion

Grid Discretization Produces Different Steady State Conditions

- Patterns and length of the bottom of the interface were dependent on grid size, but overall location of the mixing zone was not
- Saline circulation and freshwater recharge increased with grid discretization
- A grid-independent set of results will require running more highly discretized simulations

Future Work

- multiple, higher grid discretizations for further sensitivity tests
- run models for longer simulated time to ensure stable conditions

Acknowledgements

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