Upscaling hydraulic conductivity using CNN

CEE 696
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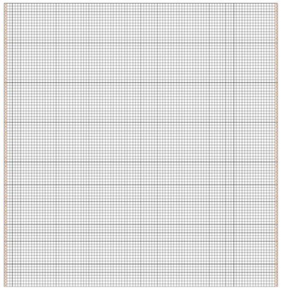
1. Hydraulic Conductivity Upscaling

1.1 Background

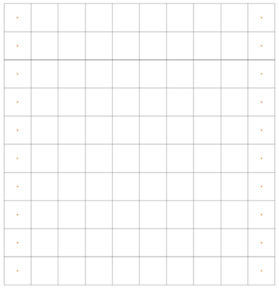
- Natural porous media exhibit significant spatial variability
- Spatial heterogeneity makes modeling groundwater and solute transport challenging

(from Lock, B. E. 2011)

How many grids do we need?



vs



- Time consuming
- Accurate

- Fast
- May not be accurate

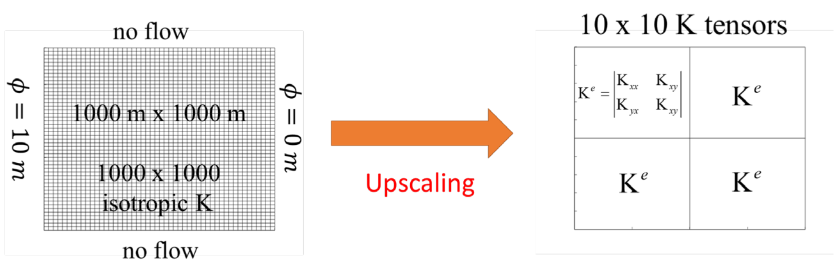
1. Hydraulic Conductivity Upscaling (contd.)

1.2 Motivation

- Large variation in conductivity can cause ill-conditioned matrix in numerical scheme
- Computational resources to account for all the variabilities
- Impossible to know the function K(x) precisely

$$\nabla \cdot [K(\mathbf{x})\nabla\phi] = S\frac{\partial\phi(\mathbf{x},t)}{\partial t} \quad \longrightarrow \quad \nabla \cdot [K^e\nabla\phi^e] = S\frac{\partial\phi^e(\mathbf{x},t)}{\partial t}$$

$$K^e = \begin{vmatrix} K_{xx} & K_{xy} \\ K_{yx} & K_{yy} \end{vmatrix}$$

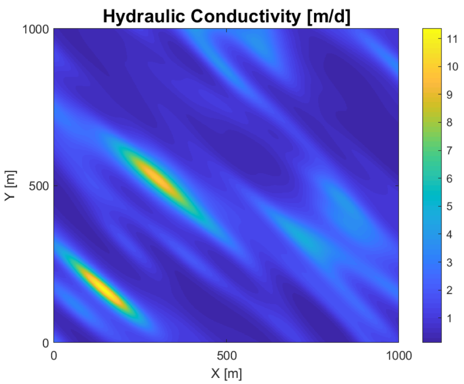


What is the optimal assignment of the "effective" hydraulic conductivity at arbitrary larger scale for efficient coarse-scale model simulations?

2. Upscaling with Two Approaches

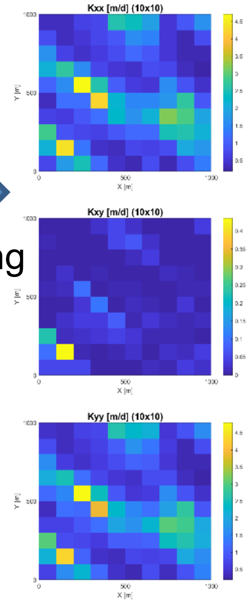
- Model-based approach [Kitanidis, 1990]

Original (1000 x 1000 grid)



Upscaled (10 x 10 grid)

Upscaling



Converting it to USGS model format
e.g., K in principal Axis with angle

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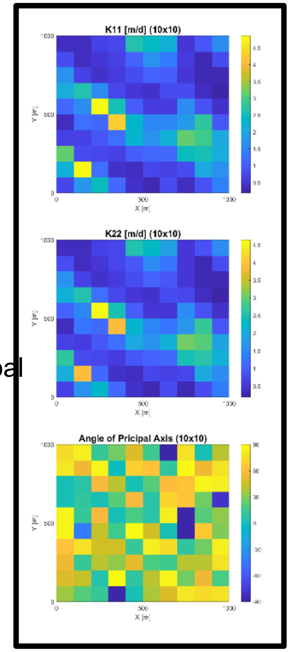
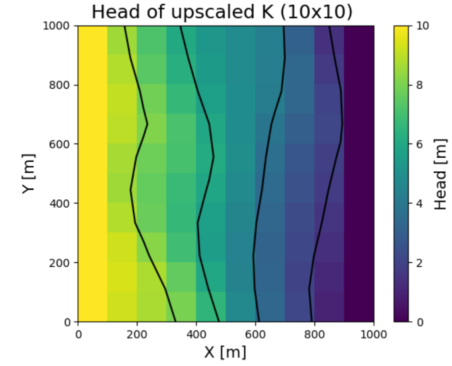
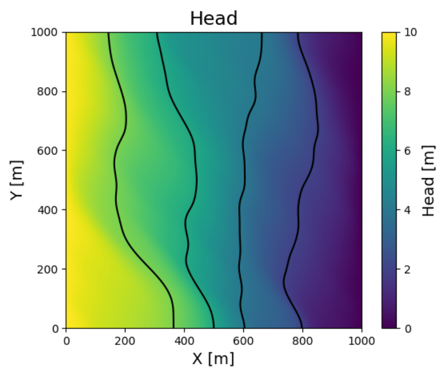


Head result from the upscaled grid



Head result from the original grid

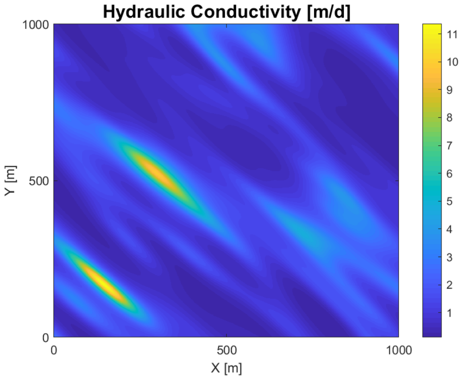


Took 3 mins to compute 10x10 K tensor from 1000x1000 K grid
Would take more for 3D domain with fine-scale discretization

2. Upscaling with Two Approaches

- ML-based approach

Original (1000 x 1000 grid)



Trained model

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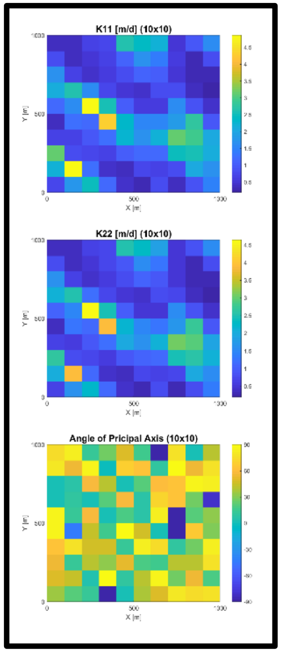
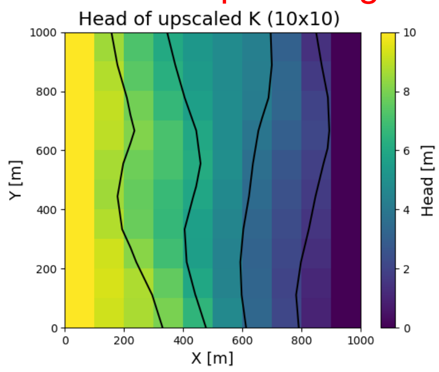
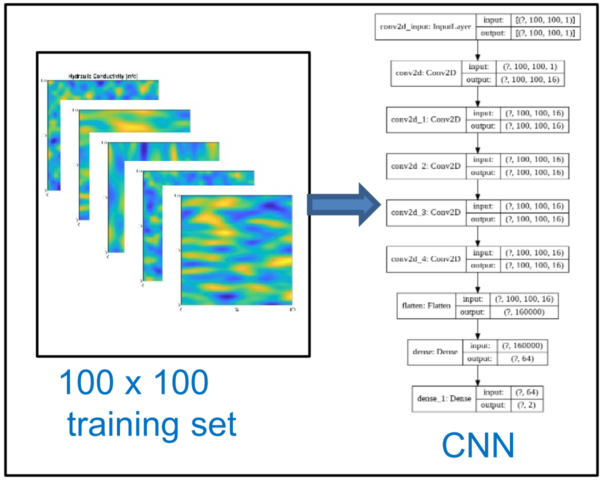


Head result
from the upscaled grid



Trained model



100 x 100
training set

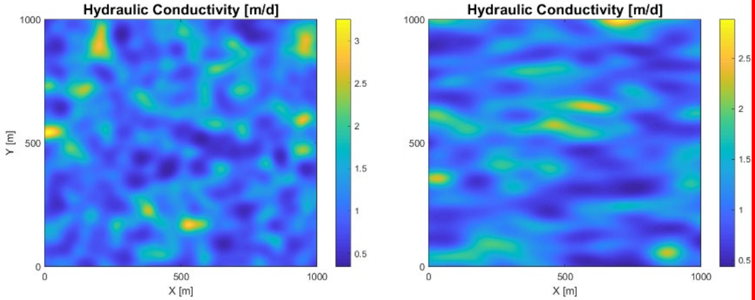
CNN

Took 1 sec to compute 10x10 K tensor from 1000x1000 K grid after training
Will be similar for any arbitrary large domain applications!

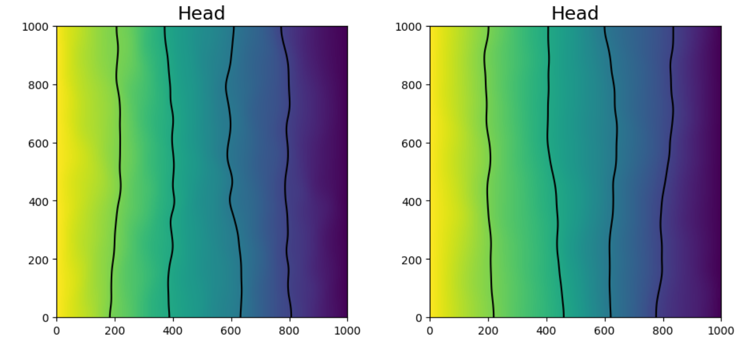
3. Test Results

Training set

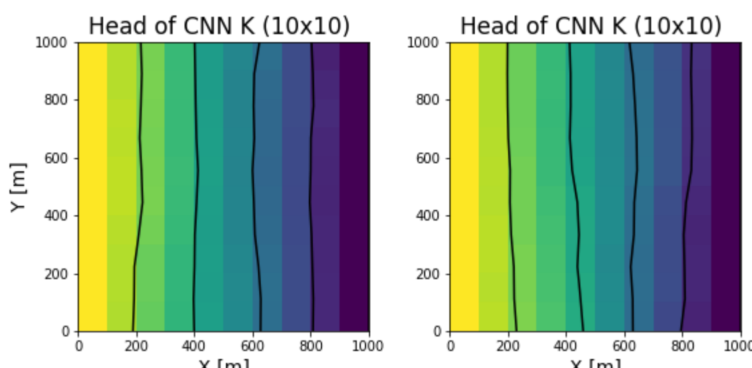
Original K



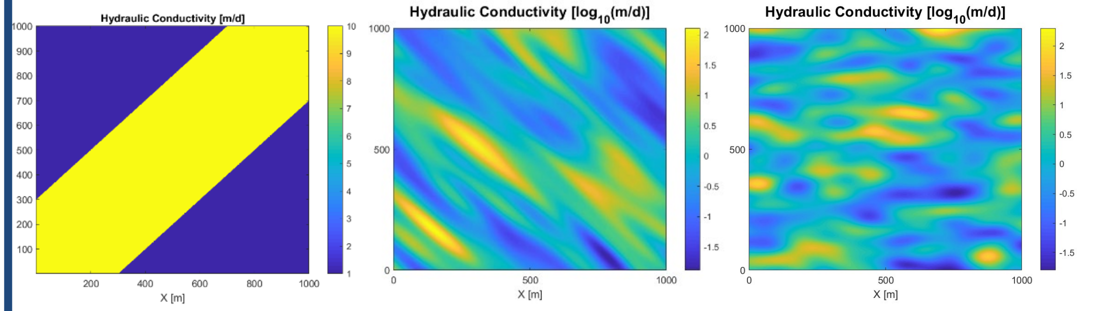
Head from original grid

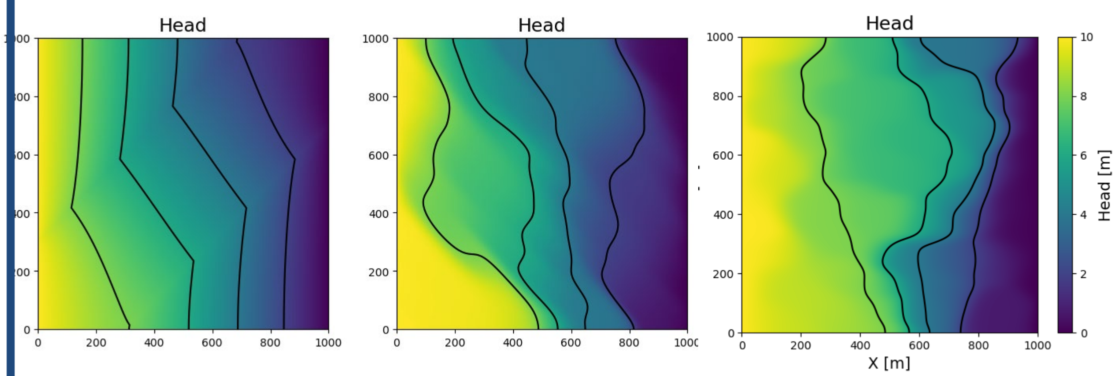


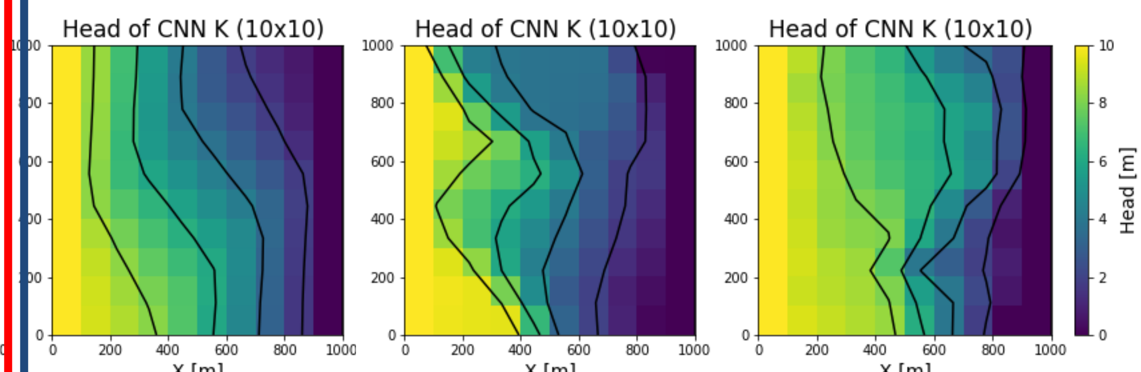
Head from CNN upscaled grid



Testing (unseen) set

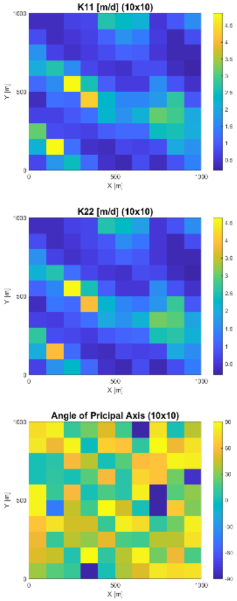






4. Remarks and Future Works

- CNN model trained with locally isotropic samples worked reasonably for high variance and anisotropic media upscaling.
- ML-based upscaling would take (much) less time than physics model-based approaches



5. References

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Thank you!