Upscaling Regional, 3D, Non-Fickian Solute Transport with 2D Equivalent Models

H43I-2582

AGU Fall Meeting 2018
Washington, DC

Rich Pauloo[1]* | Graham Fogg[1] | Zhilin Guo[1] | Christopher Henri[1]
[1] Univeristy of California, Davis | * corresponding author

Background & Motivation

The past half century has witnessed the emergence of non-point source pollutants [1, 2] that challenge conventional models of contaminant transport in porous media, and demand regional groundwater quality management models [3].

For example, decreasing water quality associated with increases in Total Dissolved Solids (TDS) has been documented at regional scales in aquifers across the United States in the past half century [4], yet to our knowledge, no models of regional groundwater quality management have been developed to appropriately describe the transport dynamics and the groundwater quality and quantity management options needed to protect against loss of fresh groundwater resources.

Previous work emphasizes the importance of geologic heterogeneity, and in particular the presence of connected pathways, in accurately modeling non-Fickian solute transport phenomena (early arrival and tails) [5, 6, 7, 8], but at the basin scale, this problem becomes computationally intractable. Therefore, this research proposes developing upscaled 2D equivalent models that reproduce non-Fickian transport.

Upscaled non-Fickian solute transport models are urgently needed to ascertain regional scale groundwater quality and the management strategies that will avert or remediate the degradation fresh groundwater resources.

CORE QUESTION:

> ***Can non-Fickian contaminant transport effects produced by 3D heterogeneity be represented in 2D, and at what information loss?***

Approach

1. Wessmann (1999) developed a 3D hydraulic conductivity domain from thousands of well logs and a transition probability geostatistical approach (T-PROGS) in the King's River Fan in California, USA [9]. Derive 63 2D realizations from this domain by taking "slices" along the zy plane. Let the set of all slices be called S, and individual slices, s_i. Then,

$$S = \{s_1, s_2, s_3, \dots, s_{63}\}$$

2. Solve the regional-scale, steady state groundwater flow problem with finite difference groundwater modeling in MODFLOW for the 3D domain and all 2D realizations.

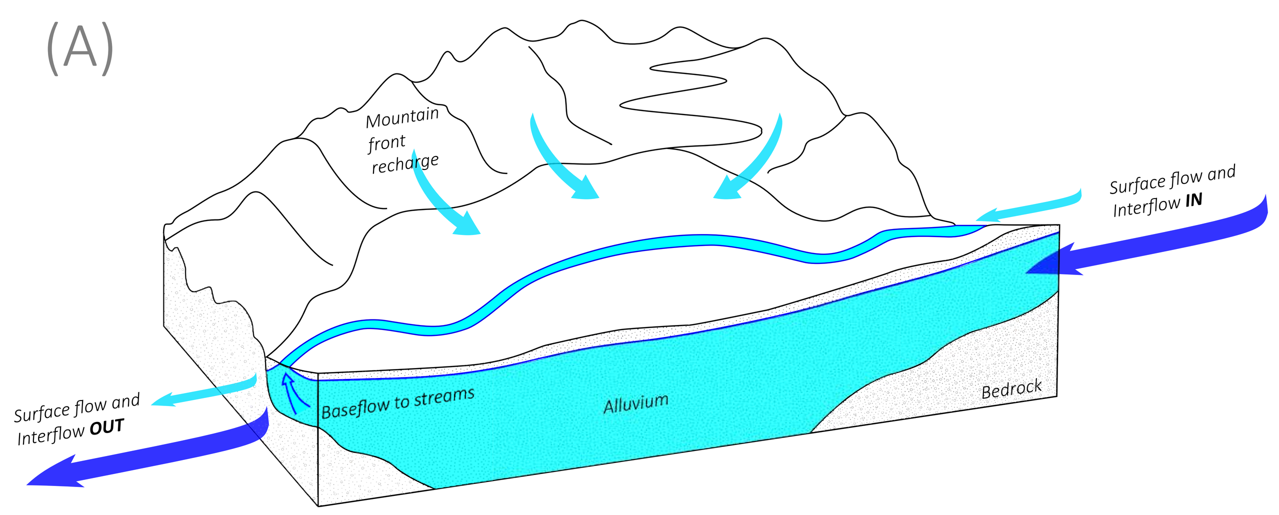
3. Using the flow from **2.**, solve the advection-dispersion equation in the 3D domain and all 2D realizations with RW3D [10]. For 3D domain and all 2D realizations, compare breakthrough curves, and Bianci and Pedretti's (2006) transport connectivity indicator [11].

4. If 2D transport can approximate 3D transport, use the developed T-PROGS model to simulate multiple 2D basin-scale realizations.

5. Using MODFLOW and RW3D, simulate:
(a) business as usual groundwater quality evolution
(b) climate change impacts to groundwater quality
(c) effects of mitigative practices (clean recharge via MAR)
(d) water budget required to reverse closed basin salinization

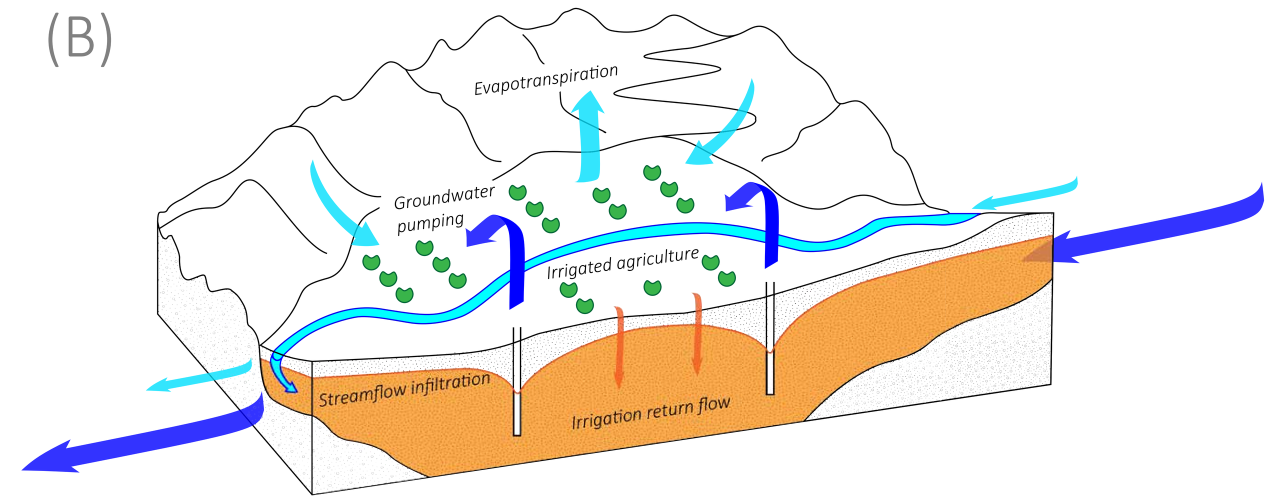
Closed Basin Groundwater Salinization

(A)



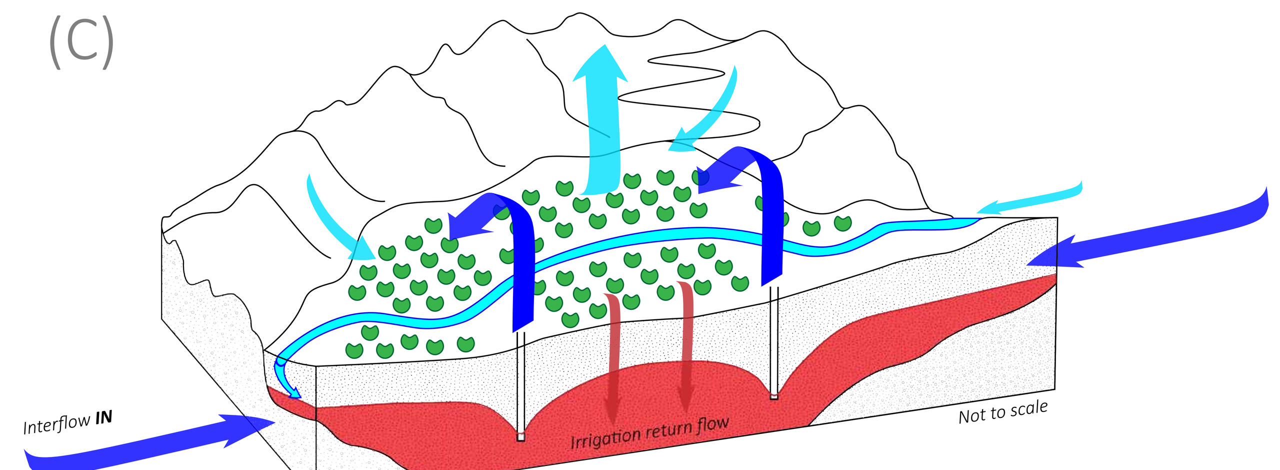
Open basin, pre-groundwater development: surface and groundwater systems connect. Groundwater discharges dissolved solids into surface water which exit the basin. Groundwater at this stage is predominantly fresh (e.g., < 1,000 mg/L).

(B)



Partial closure of basin: groundwater pumping causes reduction or elimination of baseflow to streams. Pumped groundwater returns to the basin via irrigation return flow. Dissolved solids begin to accumulate in groundwater.

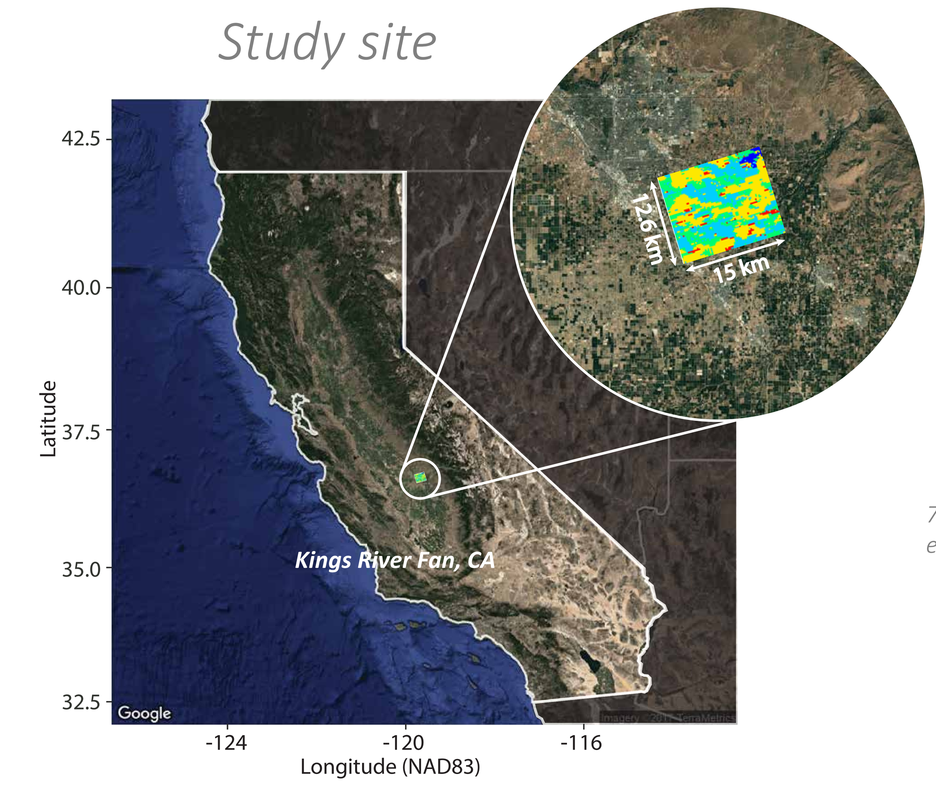
(C)



Closed basin: falling groundwater levels cause subsurface interflow to drain adjacent basins. Streams lose to groundwater. Water primarily exits via evapotranspiration, which further concentrates dissolved solids in groundwater.

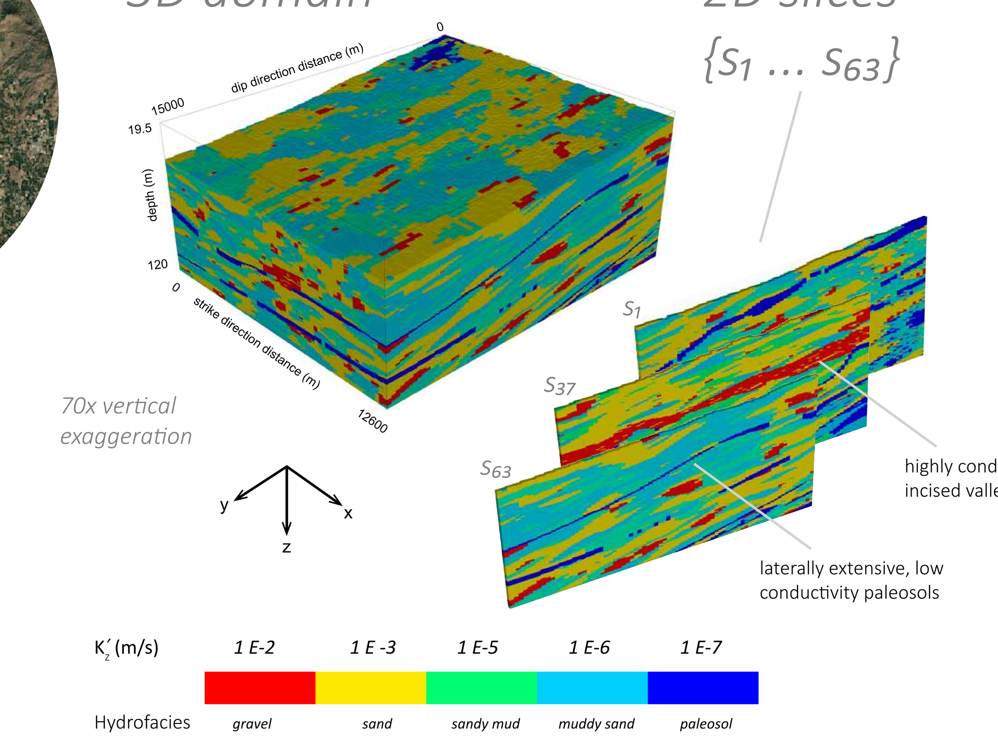
Geostatistical Transition Probability Model

Study site

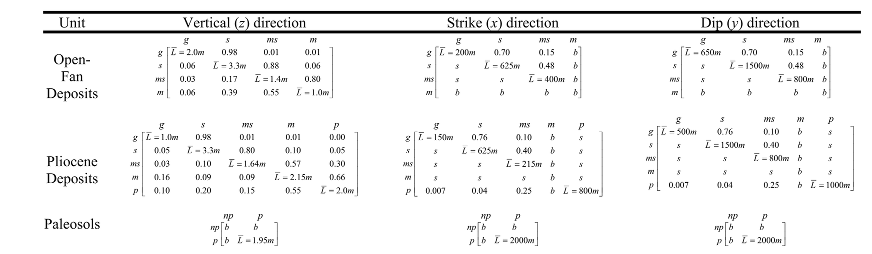


3D domain

2D slices $\{S_1 \dots S_{63}\}$



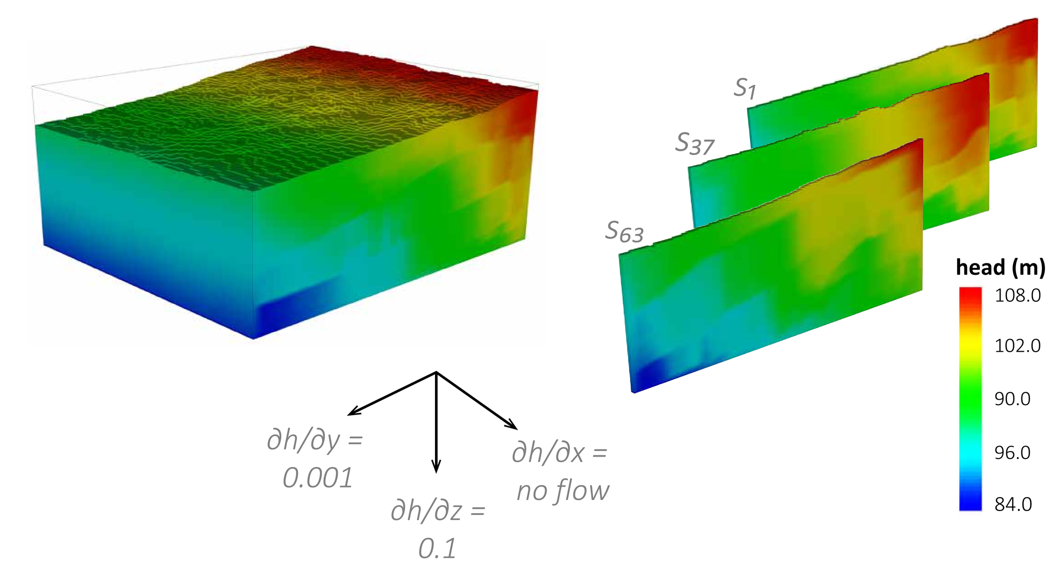
Transition probability matrices



Embedded transition probability matrices for the Markov chain models of the open fan, Pliocene, and paleosol (from Weissmann and Fogg, 1999) [9].

Entries in the matrix diagonals indicate mean lengths (L) for that hydrofacies. Entries in the off-diagonal are the embedded probability values used to represent facies juxtaposition relationships. Facies abbreviations are g – gravel; s – sand; ms – muddy sand; m – mud; p – paleosol; np – no paleosol. b indicates the background category, and s indicates an assumption that the embedded transition probabilities are statistically symmetrical.

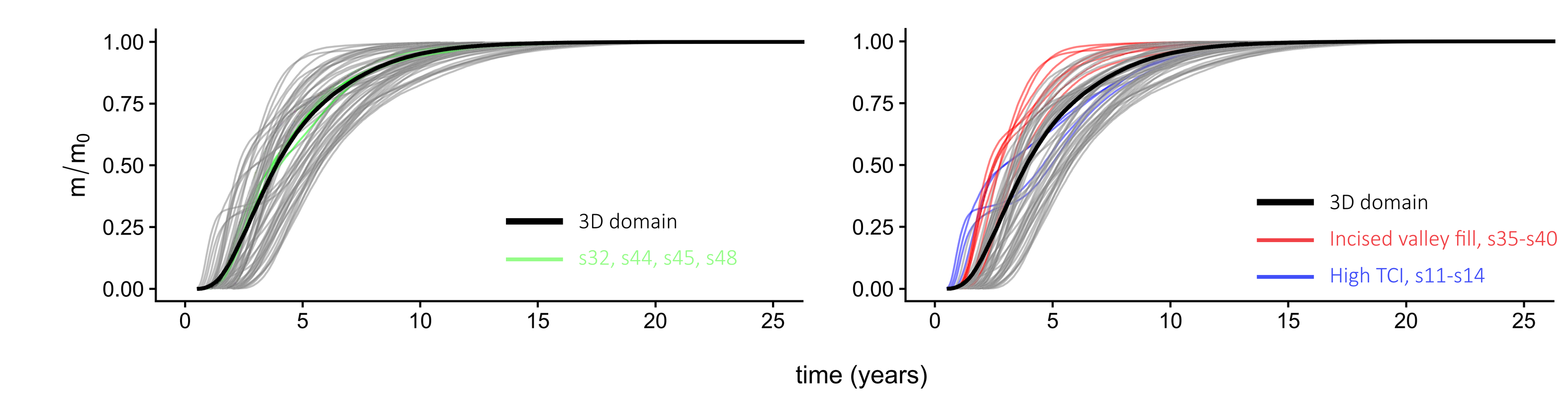
Steady State Flow Model



Non-Point Source, Random Walk Particle Transport

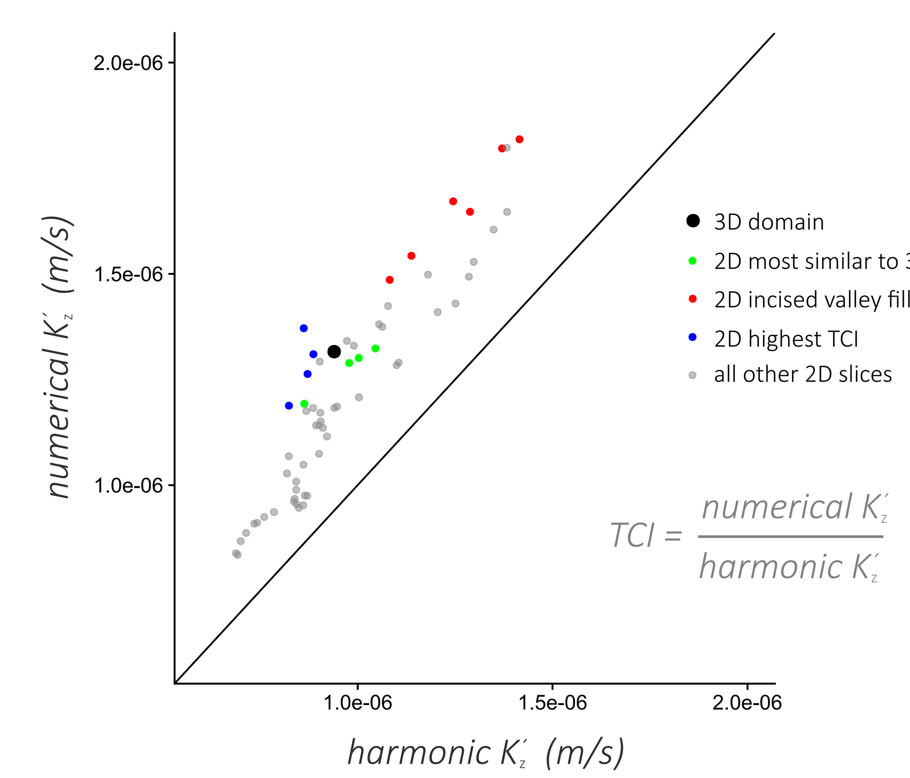
2D slices most similar to 3D domain

Early arriving particles



Non-point source pulse injection of 100,000 particles at 10m below land surface. Simulation time = 10,000 days (27.4 years). Standard Random Walk with Eulerian integration of velocity. Dispersivity in (x,y,z) = (2m, 2m, 0.05m). No diffusion. No mass transfer.

Transport Indicators



Discussion & Future Research

Regional non-point source groundwater salinization threatens fresh aquifers worldwide. Solute transport models capable of simulating regional-scale, non-Fickian effects are needed to model this phenomenon.

These experiments suggest that 3D non-Fickian transport may be upscaled in 2D, and this upscaling hinges on characterization of the geologic heterogeneity, and the flow and transport boundary conditions.

Early arriving particles are explained by the presence of high-K facies, and high TCI, but the characteristics of 2D domains that mimic 3D transport behavior are not yet explained.

Graph based approaches are a promising avenue forward. It is hypothesized that 2D domains with similar graph efficiency to the 3D domain will exhibit similar contaminant breakthrough curves.

Acknowledgements

This work was supported by NSF DGE # 1069333, the Climate Change, Water, and Society IGERT, to UC Davis, and by the U.S./China Clean Energy Research Center for Water-Energy Technologies (CERC-WET). Special thanks is given to Dr. Henri for the development of RW3D, the ADE solver used in this research.

UCDAVIS
UNIVERSITY OF CALIFORNIA

Open your phone's camera and scan to view this poster online, or visit: **bit.ly/2zArXqQ**

rpauloo@ucdavis.edu
richpauloo.github.io
@RichPauloo

References

[1] Buresh, J. C. (1986). Source Pollution Control Notes State and Federal Land Use Regulation : An Application to Groundwater and Nonpoint Source Pollution Control. The Yale Law Journal, 95(7), 1433–1458.
[2] Nativ, R. (2004). Can the desert bloom? Lessons learned from the Israeli case. Ground Water, 42(5), 651–657. https://doi.org/10.1111/j.1745-6584.2004.tb02719.x
[3] Fogg, G. E., & LaBolle, E. M. (2006). Motivation of synthesis, with an example on groundwater quality sustainability. Water Resources Research, 42(3), 1–5. https://doi.org/10.1029/2005WR004372
[4] USGS, N. W. A. (2010). Water Quality in Principal Aquifers of the United States , 1991 – 2010 Circular 1360.
[5] Fogg, G. E. (1986). Groundwater Flow and Sand Body Interconnectedness in a Thick, Multiple-Aquifer System. Water Resources Research, 22(5), 679–694. https://doi.org/10.1029/WR022i005p00679[
6] Webb, E. K., & Andersen, M. P. (1996). Simulation of preferential flow in three-dimensional, heterogeneous conductivity fields with realistic internal architecture. Water Resources Research, 32(3), 533–545. https://-doi.org/10.1029/95WR03399
[7] Fogg, G., Carle, S., & Green, C. (2000). Connected Network Paradigm for the Alluvial Aquifer System.
[8] Fogg, G. E., & LaBolle, E. M. (2006). Motivation of synthesis, with an example on groundwater quality sustainability. Water Resources Research, 42(3), 1–5. https://doi.org/10.1029/2005WR004372
[9] Weissmann, G.S., S.A. Carle, and G.E. Fogg. 1999. "Three-dimensional hydrofacies modeling based on soil survey analysis and transition probability geostatistics." Water Resources Research 35 (6): 1761–70.
[10] Fernàndez-Garcia, D., Illangasekare, T. H., and Rajaram, H. (2005), Differences in the scale-dependence of dispersivity estimated from temporal and spatial moments in physically and chemically heterogeneous porous media, Advances inWater Resources (ISSN 0309-1708), 28, 745-759.
[11] Bianci, M., & Pedretti, D. (2017). "Geological entropy and solute transport in heterogeneous porous media." Water Resources Research, 4691–4708. https://doi.org/10.1002/2016WR020195.