CORRELATING ELECTRICAL CONDUCTIVITY TO UNCONSOLIDATED SEDIMENT PARAMETERS USING NUMERICAL MODELING

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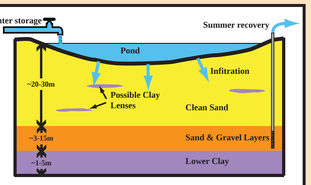
1) Motivation & Introduction

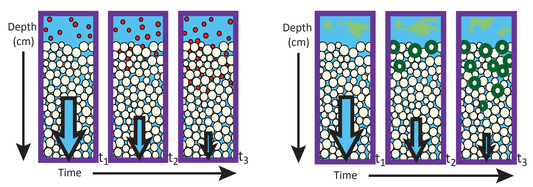
Decreasing Infiltration

An artificial recharge pond has been created in Watsonville, California to augment groundwater resources. Infiltration rate in the pond decreases over time due to clogging (Pidlisecky & Knight, 2010).



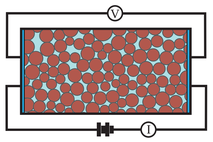
Why??

Sediment Clogging? *or* Biological Clogging?



Using Electrical Conductivity (EC)

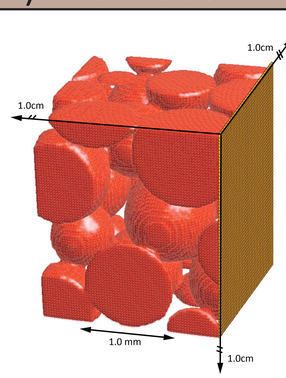
Treat the earth as a simple circuit and use the conductance ($C = I/V$) to calculate the EC. The model used in this study simulates lab EC measurements completed on core sample.



Rock Physics

Electrical conductivity (EC) is not a hydrogeologic parameter of interest, however, it can be related to soil properties, such as porosity, through rock physics transforms (e.g. Archies law (Archie, 1942)). When modeling these systems the goal is to create a database of values and relationships that link EC to parameters of interest.

2) The Model



The Grain Packs

Three distributions from a uniform random grain pack (Jodrey&Tory, 1979).

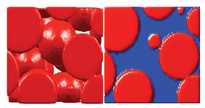
Packs were discretized on a three dimensional grid. Bulk EC was numerically calculated using a finite volume approximation (Pidlisecky et al. 2007).

Grain Distributions	Discretization
0.80-1.20 mm * 2	Model size: ~1.00cm³
1.00-1.00 mm * 2	Voxel side: 64μm
1.00-1.50 mm * 2	Voxels: 16.5 million
Porosity, ϕ	**Computer**
0.39 < ϕ < 0.43	8core, 3Ghz Xeon
	64GB ram
	Run Time: 36 hrs/model

3) Parameters of Interest

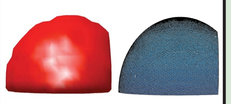
Porosity, ϕ
Volume ratio of the void space (V_V) to the total volume of the sample (V_T); measured in voxels.

$$\phi = \frac{V_V}{V_T}$$



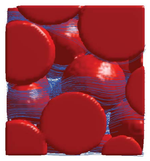
Specific Surface Area, S_S
A Delauny mesh approximation was applied in the case of three or more overlapping spheres. Otherwise, an analytical solution was used.

$$S_S = \frac{S_T}{V_T}$$



Electrical Tortuosity, τ
Found by particle tracking using the gradient of the electrical potential field. The geometric mean of the logged tortuosity distribution is used for comparisons.

$$\tau = \frac{L_P}{L_S}$$

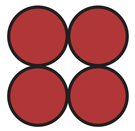


4) Clogging Experiments

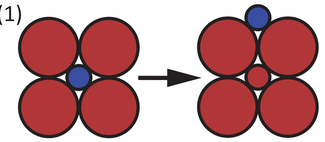
Pack Perturbations

The sphere packing program generated random grain packs that had a porosity of 0.40±0.03. Thus, to explore the effects of time-varying grain packs on electrical conductivity two simple algorithms were employed: a grain-addition algorithm and a grain-growing algorithm. The grain-growing algorithm has the option to turn added material to grain or biofilm conductivity. These algorithms represent *changes* to a sediment pack over **time** through changes in porosity.

Initial Grain Pack

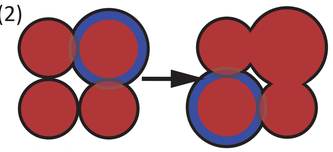


(1)



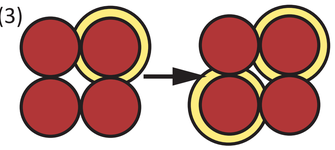
ADD
Represents addition of fines to the soil matrix through the random addition of non-overlapping, voxel centered spheres.

(2)



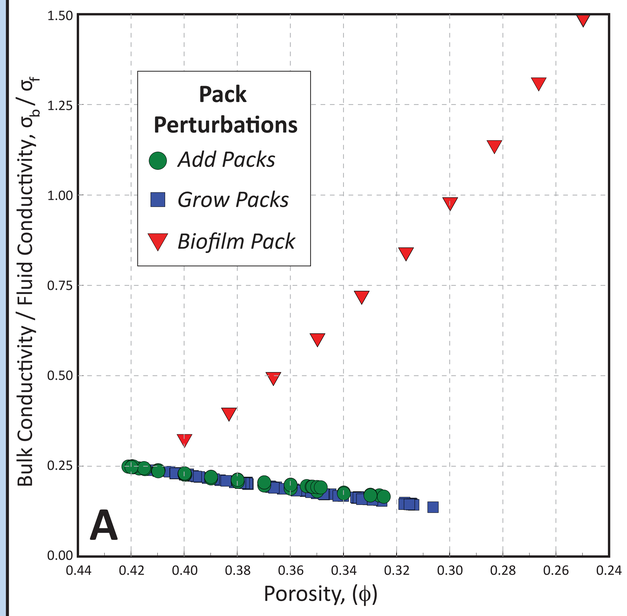
GROW
Represents pore throat clogging. This model has been used to represent grain cementation (Roberts and Schwartz 1985).

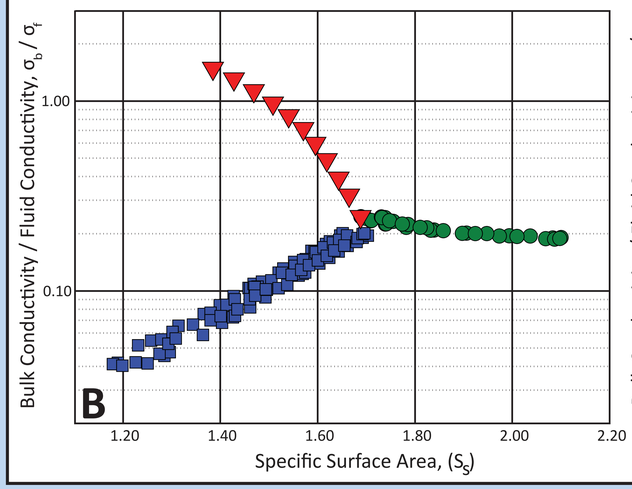
(3)

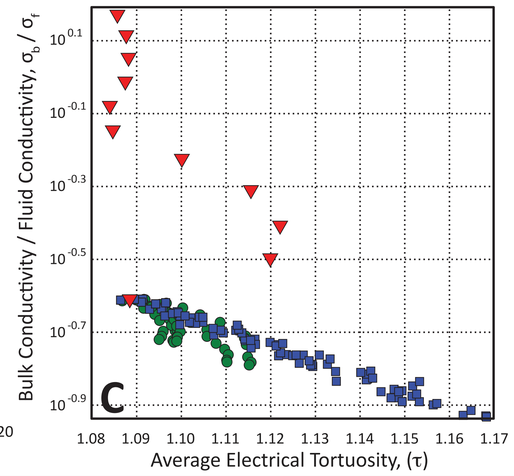


Conductive Film
Represents pore throat clogging caused by a conductive biofilm. The conductivities used for the biofilm and pore fluid are based on lab results (Regberg et al., 2010).

5) Results







(A) Pack Perturbations

- Biofilm creates packs that are more conductive than the Add & Grow algorithm.
- Add & Grow algorithms have similar EC response
  - Based primarily on porosity.

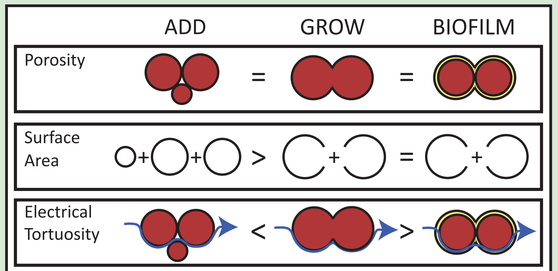
(B) Specific Surface Area

- **Add algorithm:**
  - Increasing as porosity decreases.
- **Grow algorithm**:
  - Decreasing as porosity decreases
- **Biofilm algorithm**:
  - Decreasing as porosity decreases
  - Same relationship to porosity as Grow

(C) Electrical Tortuosity

- **Add algorithm**:
  - Negative non-linear relationship to EC
- **Grow algorithm**:
  - Negative linear relationship to EC
- **Biofilm algorithm**:
  - Multiple local minima with no obvious functional form

6) Conclusions



Take home messages:

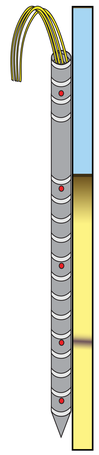
1) Differences in surface area and electrical tortuosity between the three algorithms.
2) EC can be diagnostic of biofilm growth, but cannot (easily) distinguish ADD & GROW.
3) Electrical tortuosity is not equivalent to hydraulic tortuosity.

7) Future Work

Applying the Model

Probe Data

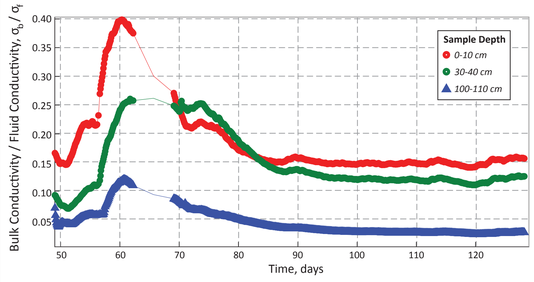
Time-lapse EC data have been collected from multiple 2m long probes in an artificial recharge pond in California. EC measurements are taken every 18 minutes for four months. The numerical modeling results presented here are being applied to this high-quality timelapse probe data.



Moving Forward

To apply what has been learned through numerical modeling, multiple signals and processes of different scales captured by the EC measurments must be filtered or seperated. These include changes in:

- Saturation;
- Water chemistry (e.g. residual salts);
- Sediment chemistry (e.g. adding clays);
- Temperature.



8) References & Acknowledgments

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References

Archie, G.E. 1942, "The electrical resistivity log as an aid in determining some reservoir characteristics", Transactions of the American Institute of Mechanical Engineers, vol. 146, pp. 54-61.

Jodrey, W.S. & Tory, E.M. 1979, "Simulation of random packing of spheres", Simulation, vol. 32, no. 1, pp. 1-12.

Pidlisecky, A., Haber, E. & Knight, R. 2007, "RESINVM3D: A 3D resistivity inversion package", Society of Exploration Geophysicists, vol. 72, no. 2, pp. H1-H10.

Pidlisecky, A., & Knight, R. 2010, "The use of wavelet analysis to derive infiltration rates from time-lapse 1D resistivity records", Vadose Zone, In Press

Regberg, A., Singha, K., Tien M., Picardal F., Zheng Q., Roden E., & Brantley S.L. 2010, "Electrical conductivity as a measure of iron reduction rates in abiotic and biological systems", Water Resources Research, In Press

Roberts, J.N. & Schwartz, L.M. 1985, "Grain consolidation and electrical conductivity in porous media", Phys.Rev.B, vol. 31, no. 9, pp. 5990-5997.