SAND2016-2177PE

Exceptional service in the national interest

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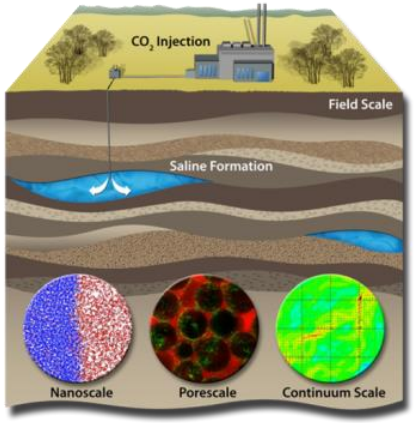

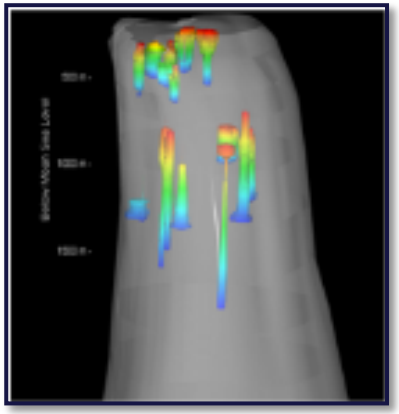


Coupling Observational Geology and Applied Mathematics for Predictive Tools, Uncertainty, and Social Decisions

U.S. DEPARTMENT OF ENERGY | NNSA

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Mastuo Basho (松尾 芭蕉) 1644 - 1694

Z71-451941 [RM] (c) www.visualphotos.com

Oku no Hosomichi

Concept

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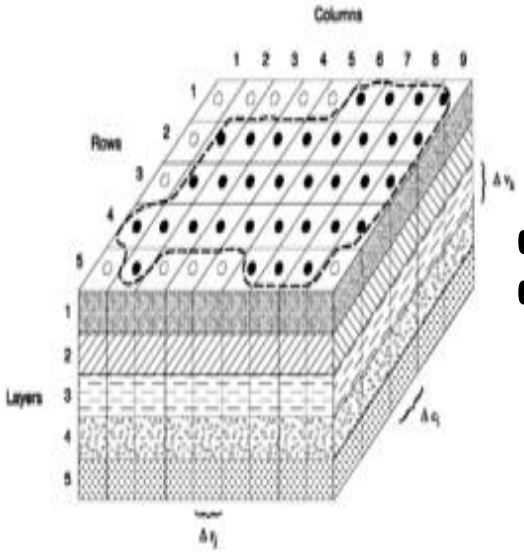

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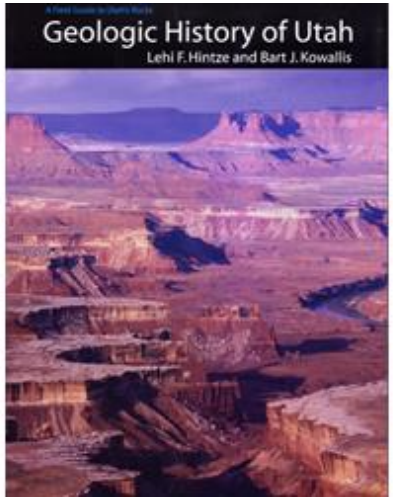
Interpretive Geology

Applied Math

Prediction Uncertainty & Decisions

Knowledge Base Examples



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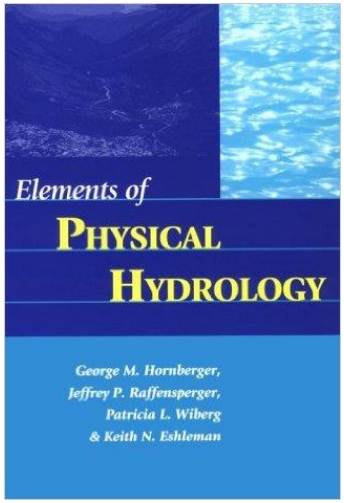

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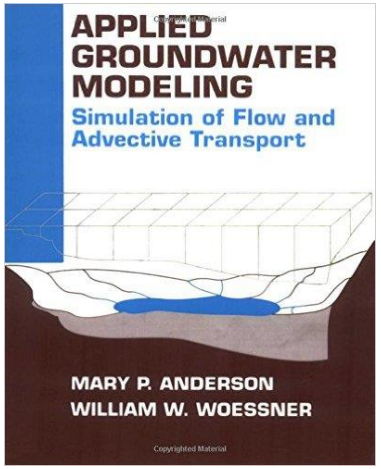
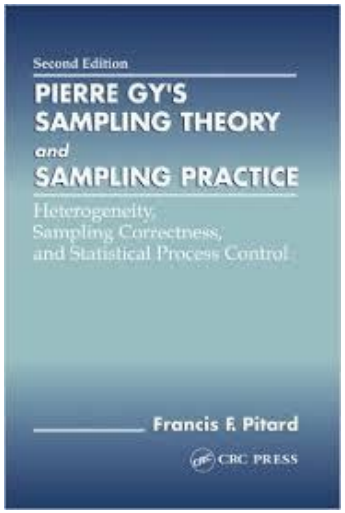


Foundation Design
Surface Hydrology
Water Supplies
Environ. Restoration
Geothermal Energy



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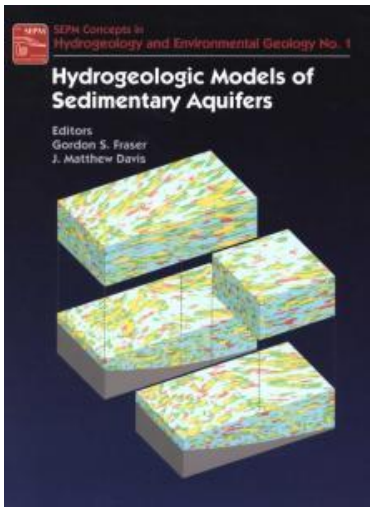
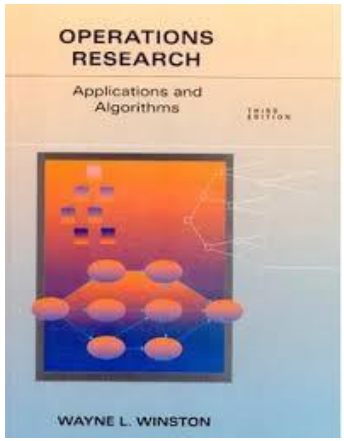


Petroleum Extraction & Exploration
Mining
Nuclear Waste Disp.



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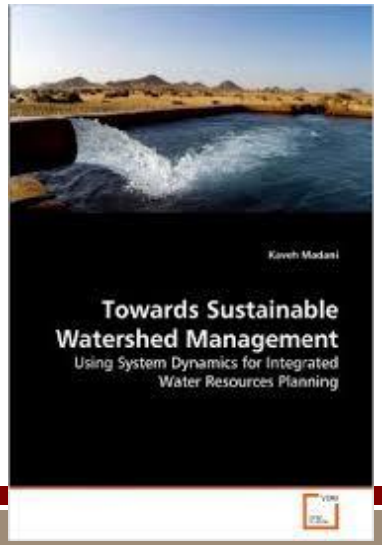

Risk Analysis
Hazard Analysis & Prediction
Environmental Impact Assess.
Governmental Decisions

Civil Engineering Type Examples

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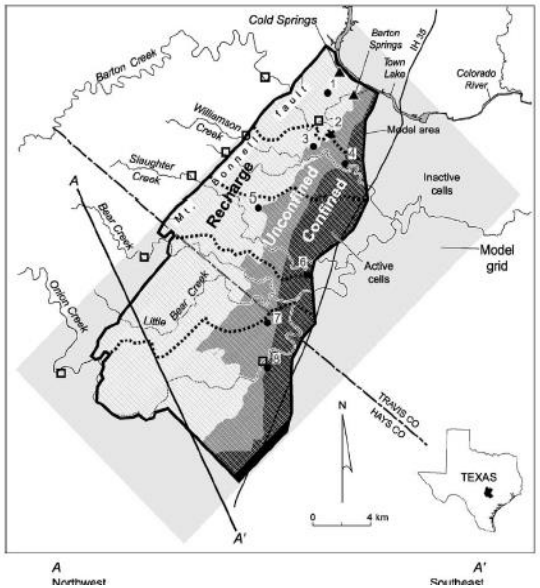
Stream Discharge Prediction

Demonstrate real-time field measurement calibration to reduce prediction error

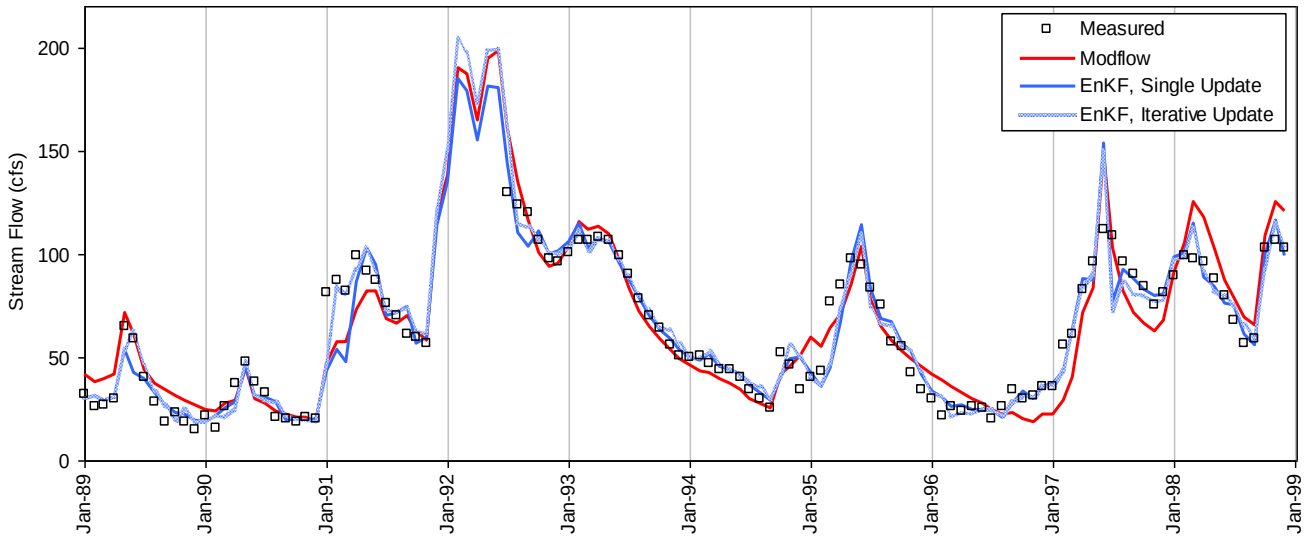
- MODFLOW model combined with real-time calibration methods improves prediction
- Ensemble Kalman Filter predicts a future state using data as it comes available
- Model parameters are updated based on error statistics to improve the fit over time
- Case study at Barton Springs prediction of stream discharge

$$State_u = State_p + KG * (Control - Observation) \qquad KG = \frac{COVA(State, Control)}{VAR(Control)}$$

Barton Springs map, including stream gauging stations, monitoring wells, and creeks



Comparison of measured stream discharge with predicted values from the MODFLOW model and integrated Ensemble Kalman Filter methods



Klise and McKenna (2007), On the use of ensemble Kalman filters to predict stream discharge at Barton Springs, Edwards Aquifer, Texas. Proceedings of the 2007 World Environmental and Water Resources Congress

Classical and Spatial Statistics Examples

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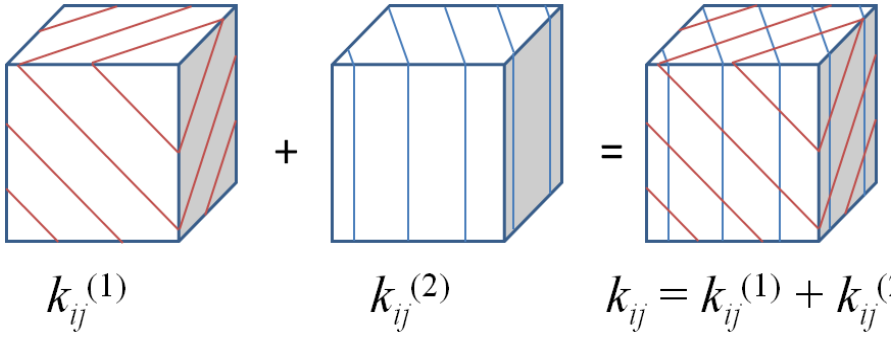
Fracture Continuum Models

Model enhanced geothermal reservoir conditions and analyze heat extraction based on different well orientations

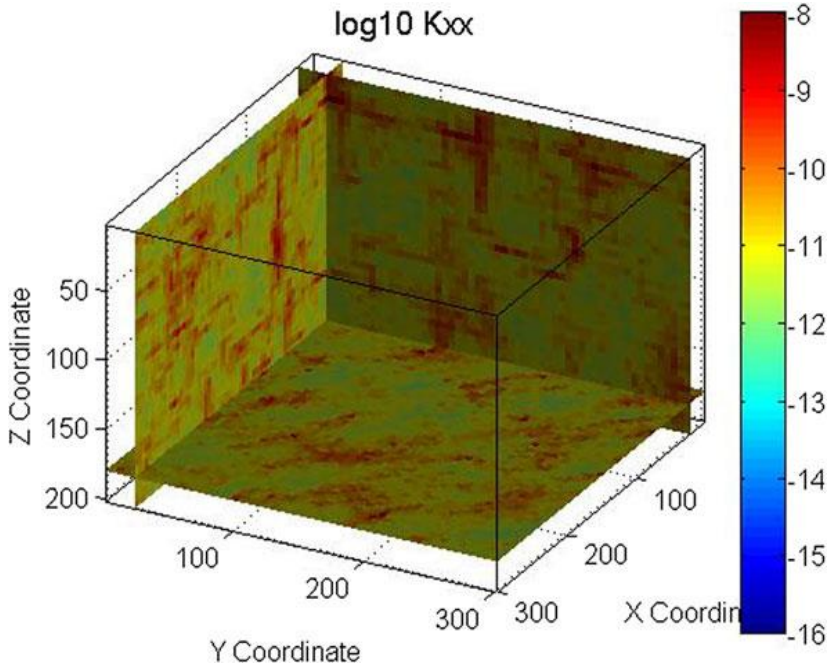
- Fracture network models are computationally expensive, continuum approaches help simplify the model
- Fracture properties measured in the field are converted to permeability tensors
- Geostatistical methods ensure continuity in fracture properties across multiple grid cells
- Approach used to

Permeability tensor computed from fracture strike, dip, aperture and spacing

$$k_{ij} = \frac{b^3}{12d}\begin{bmatrix} (n_2)^2 + (n_3)^2 & -n_1 n_2 & -n_3 n_1 \\ -n_1 n_2 & (n_3)^2 + (n_1)^2 & -n_2 n_3 \\ -n_3 n_1 & -n_2 n_3 & (n_1)^2 + (n_2)^2 \end{bmatrix}$$



$k_{ij}^{(1)}$ $k_{ij}^{(2)}$ $k_{ij} = k_{ij}^{(1)} + k_{ij}^{(2)}$



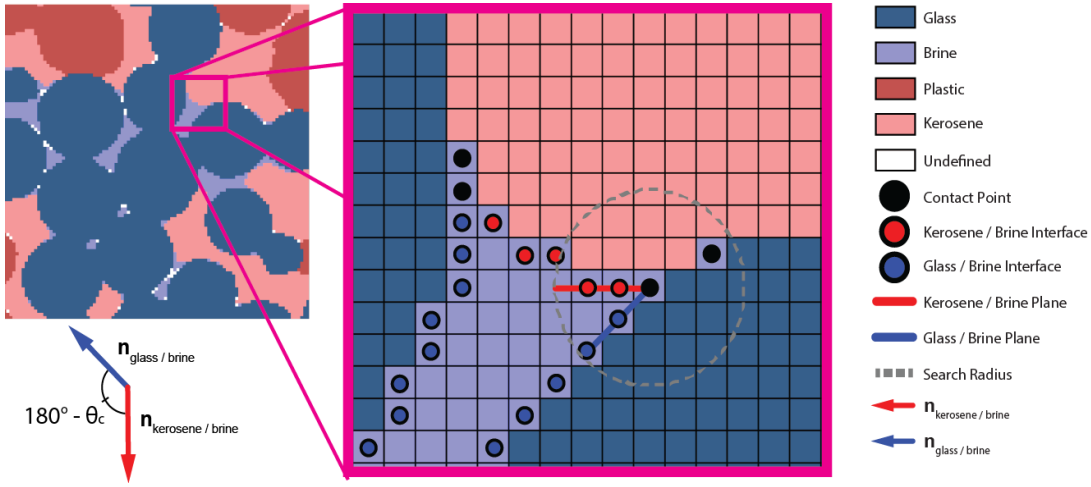
Kalinina, E.A., K.A. Klise, S.A. McKenna, T. Hadgu, T.S. Lowry (2014), Applications of fractured continuum model to enhanced geothermal system heat extraction problems, SpringerPlus, 3(1), doi:10.1186/2193-1801-3-110.

Automated Contact Angle Algorithm

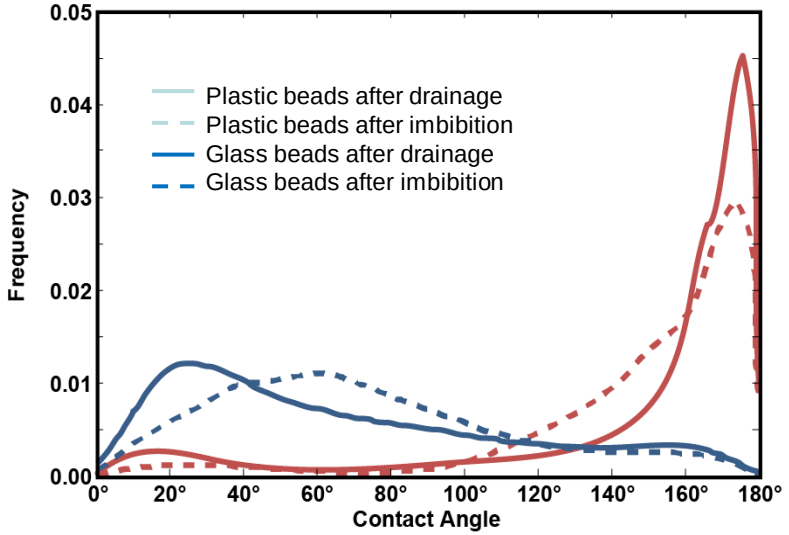
Map realistic oil, water, solid contact angle distributions – w/ natural variability and uncertainty, for reservoir characterization

- Automated algorithm computes 3D in-situ contact angles
- Developed to analyze micro-CT data of multiphase flow experiments under different wettability conditions
- Segmentation methods differentiate solid and liquid phases

Two-dimensional schematic of the interfaces and contact points used in the 3D algorithm



Distribution of contact angles in glass and plastic bead packs after imbibition and drainage



Klise, K.A., D. Moriarty, H. Yoon, Z. Karpyn (2015), Automated contact angle estimation for three-dimensional X-ray microtomography data, *Advances in Water Resources*, doi: 10.1016/j.adwatres.2015.11.006

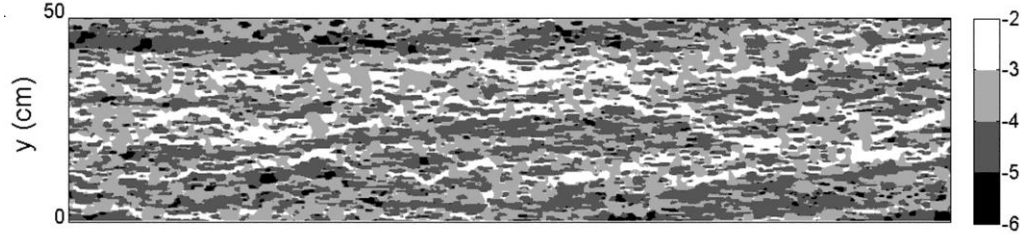
Aquifer Analogs using Lidar

Explain non-Fickian behavior (early and late time arrival) in solute transport.

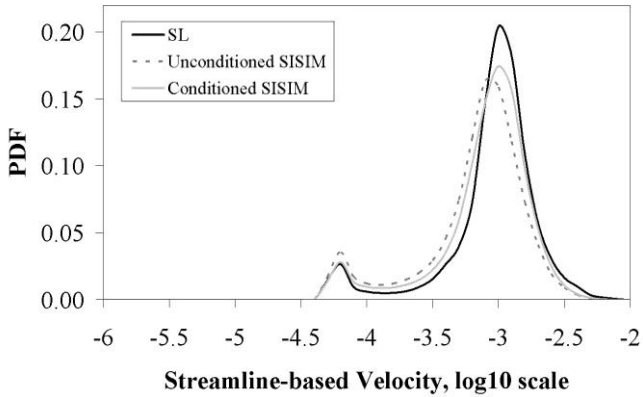
- High-resolution lidar scans produce realistic analogs to study aquifer heterogeneity
- Geostatistical and pattern recognition methods characterize the outcrop
- Analysis methods extract streamline-based connectivity and solute transport characteristics

Braided stream deposit

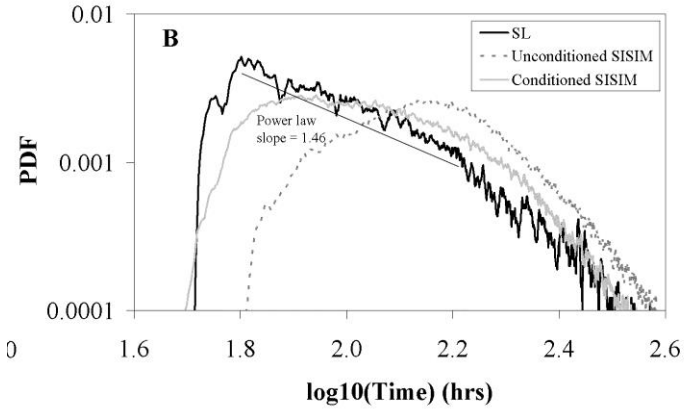
Simulated Velocity field



Velocity distribution



Travel time distribution



Klise, K. A., G. S. Weissmann, S. A. McKenna, E. M. Nichols, J. D. Frechette, T. F. Wawrzyniec, and V. C. Tidwell (2009), Exploring solute transport and streamline connectivity using lidar-based outcrop images and geostatistical representations of heterogeneity, Water Resources Research, 45, W05413, doi:10.1029/2008WR007500.

Enhanced Oil Recovery and CO2 Sequestration

Mapping spatial persistence of macropores and authigenic Clays in a reservoir sandstone

- Optical and electron petrography
- Mercury intrusion capillary pressure on clean/uncleaned samples
- Laser scanning confocal microscopy
- Robotic serial sectioning and reflected light imaging
- Relative permeability and capillary pressure testing

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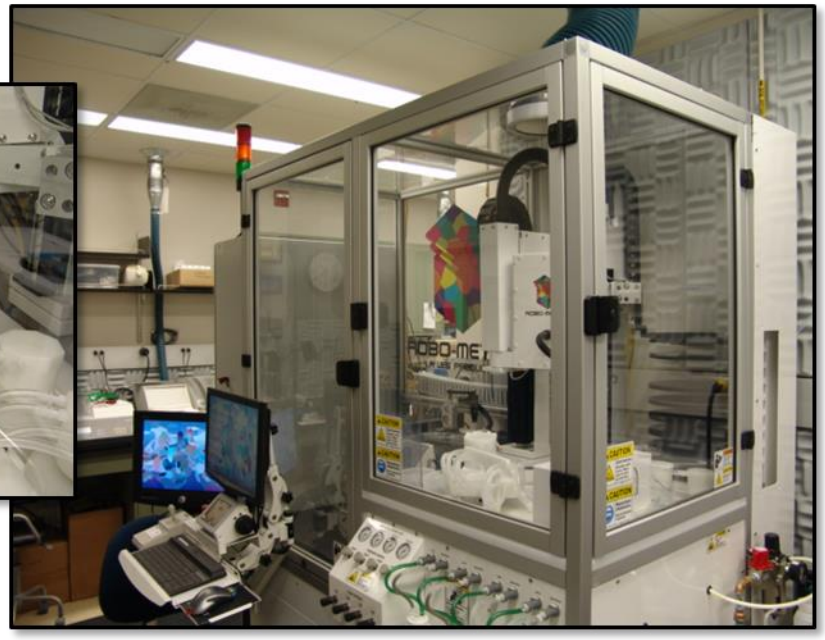
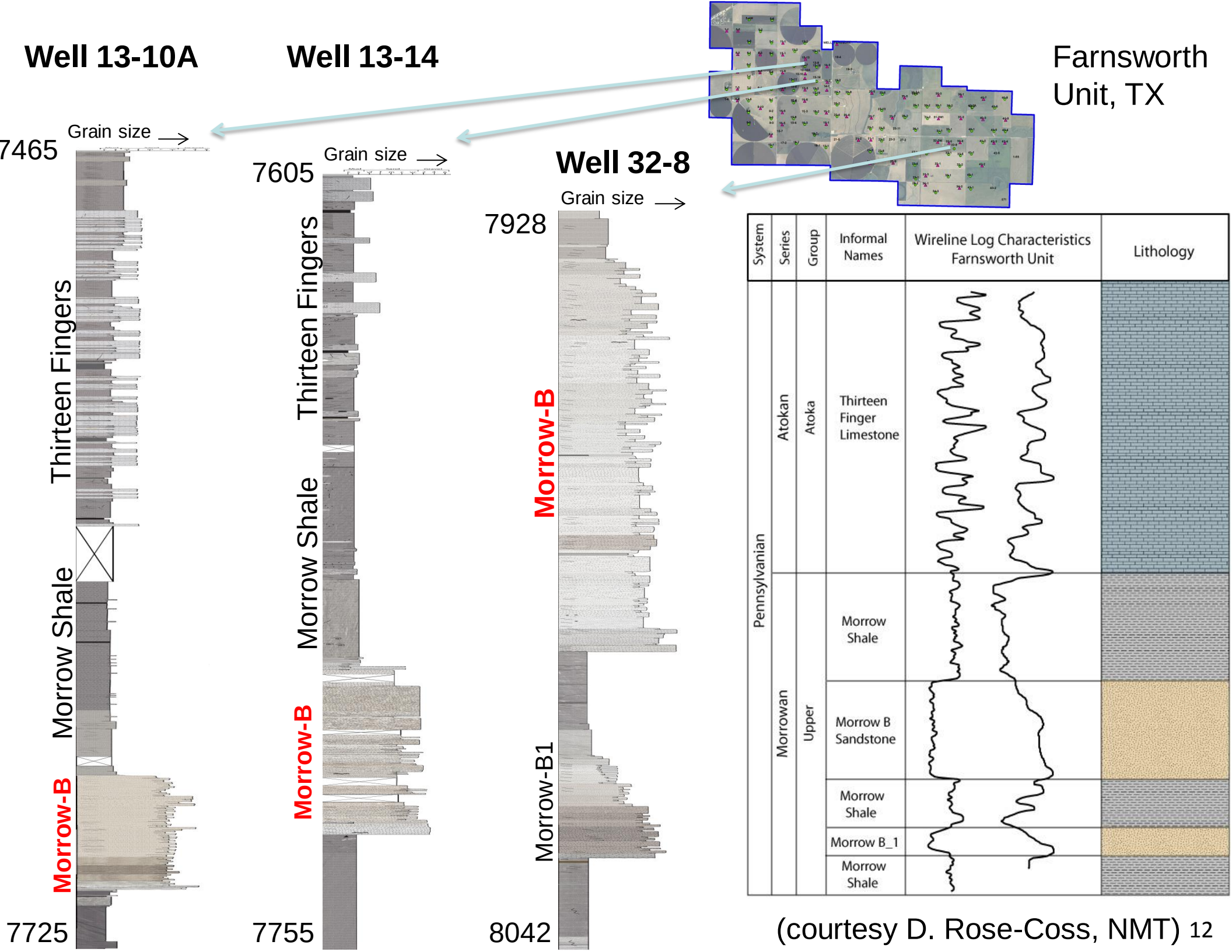
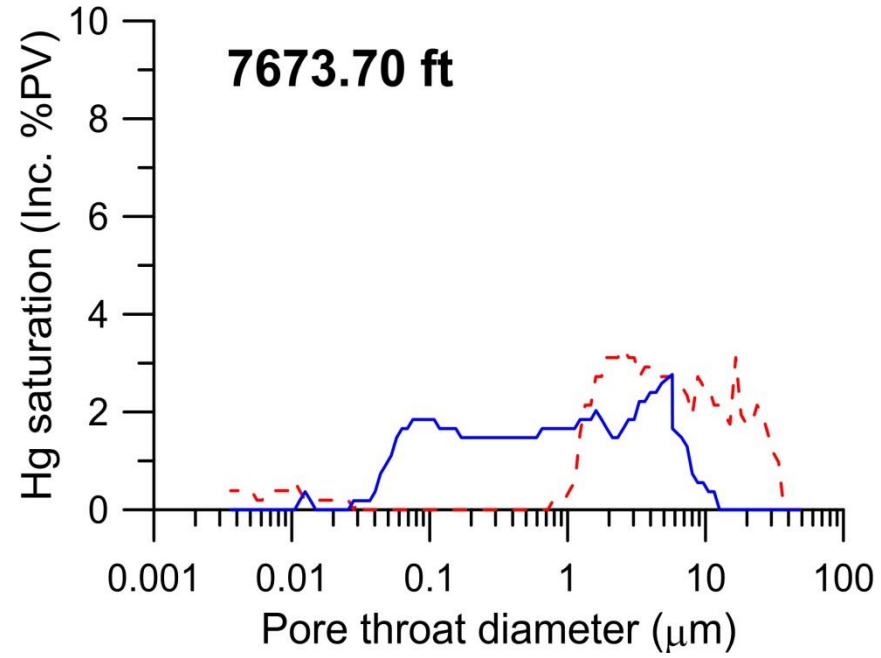


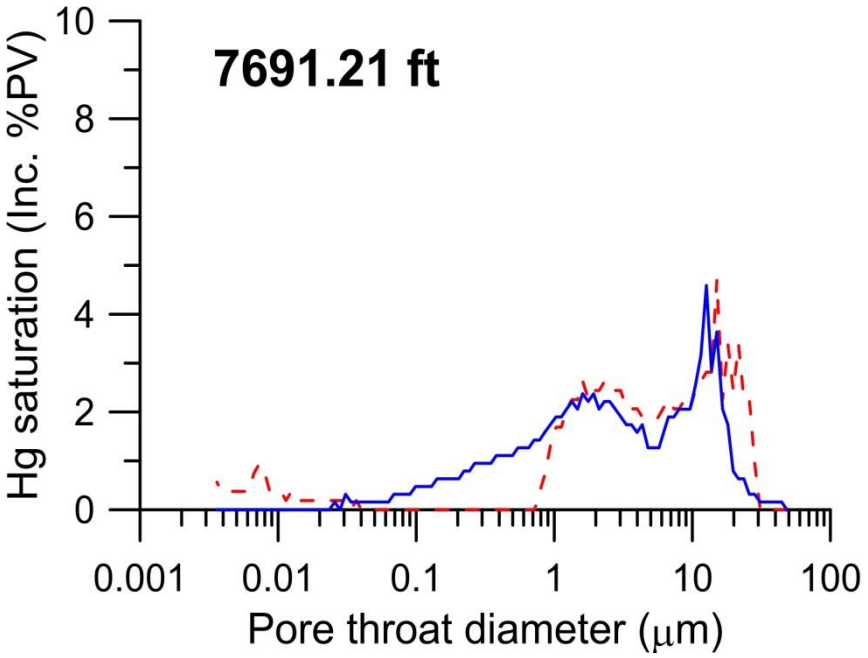
Thomas Dewers, Jason Heath, Jonathan Madison, Sandia National Laboratories , Peter S. Mozley, New Mexico Tech, Spatial Persistence of Macropores and Authigenic Clays in a Reservoir Sandstone: Implications for Enhanced Oil Recovery and CO2 Storage, AGU Presentation 2015, SAND2015-10961C

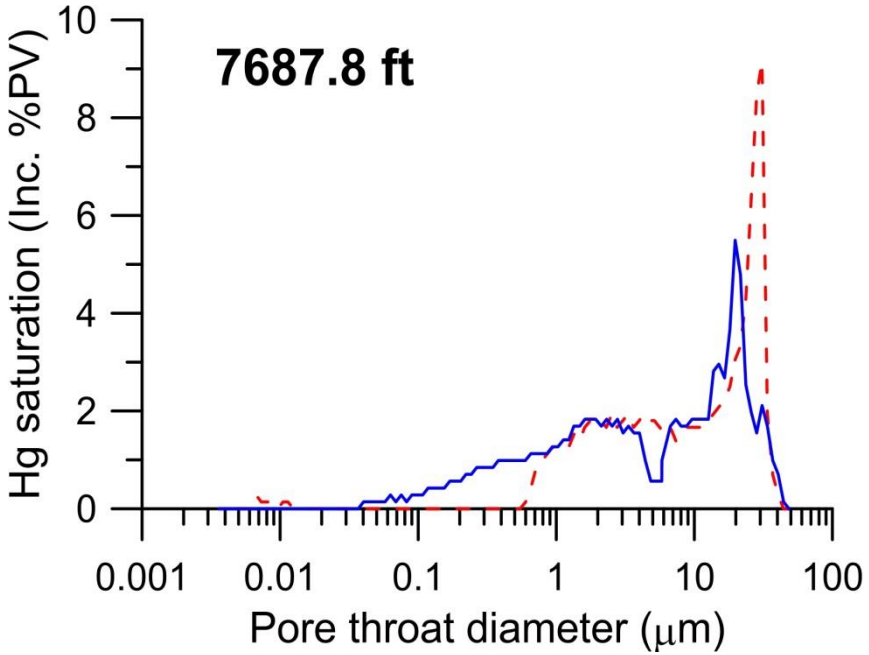


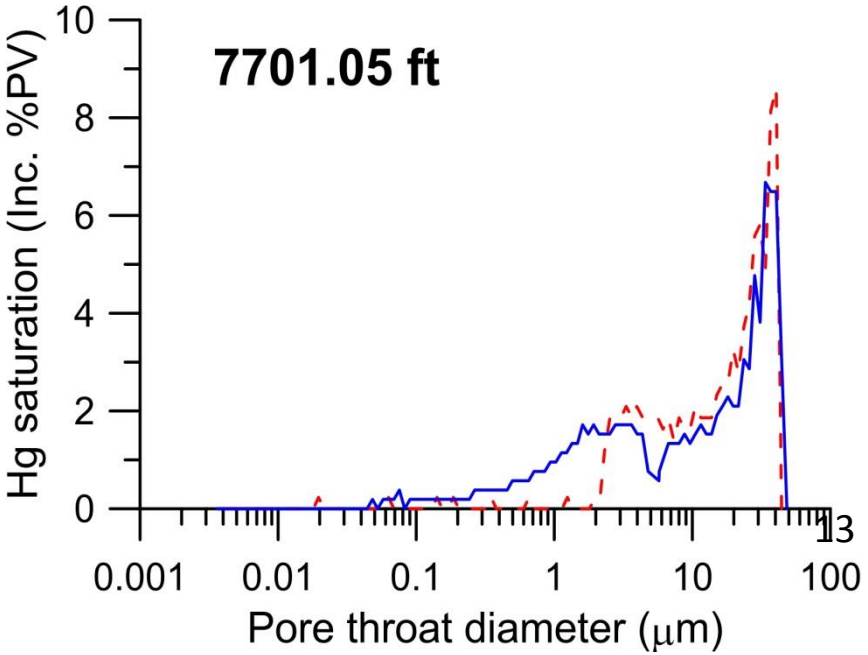
(courtesy D. Rose-Coss, NMT)

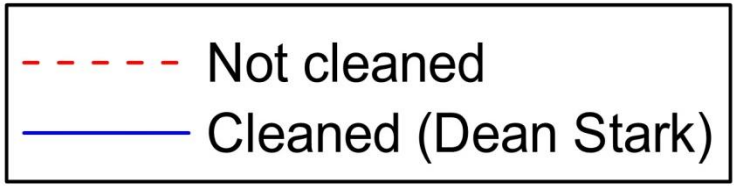
Results: Hg Cap. Press. / Pore Structure









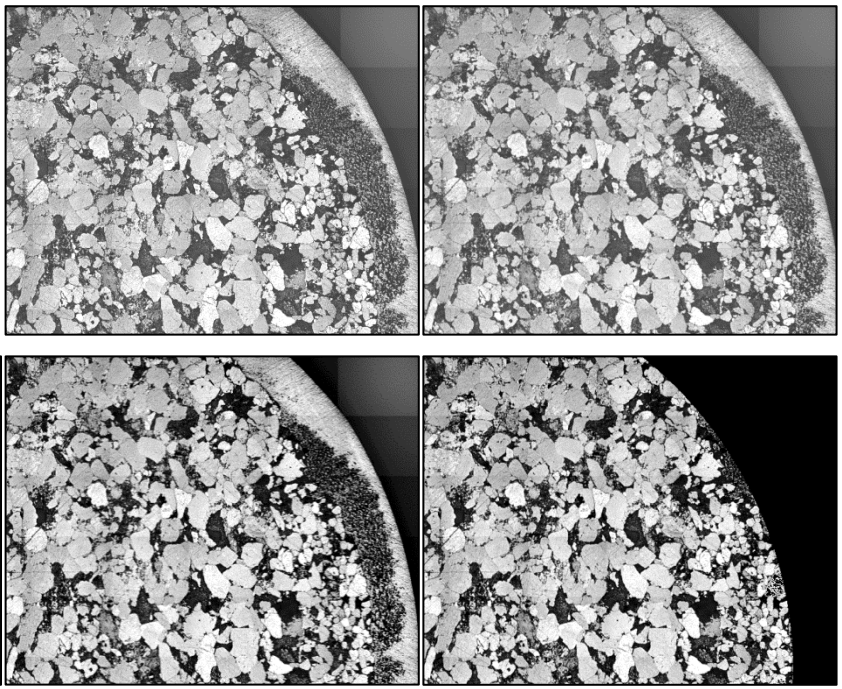


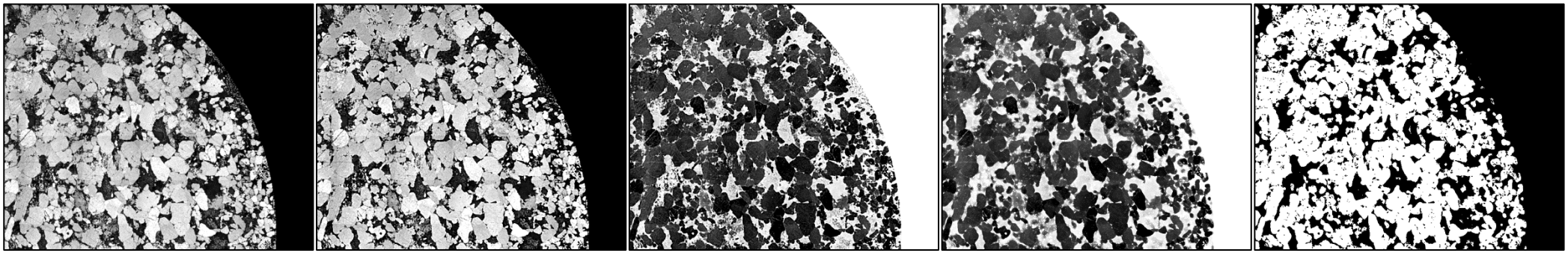
Segmentation:

montage: 10 x 10
magnification : 5X

Segmentation approach, 10 steps:

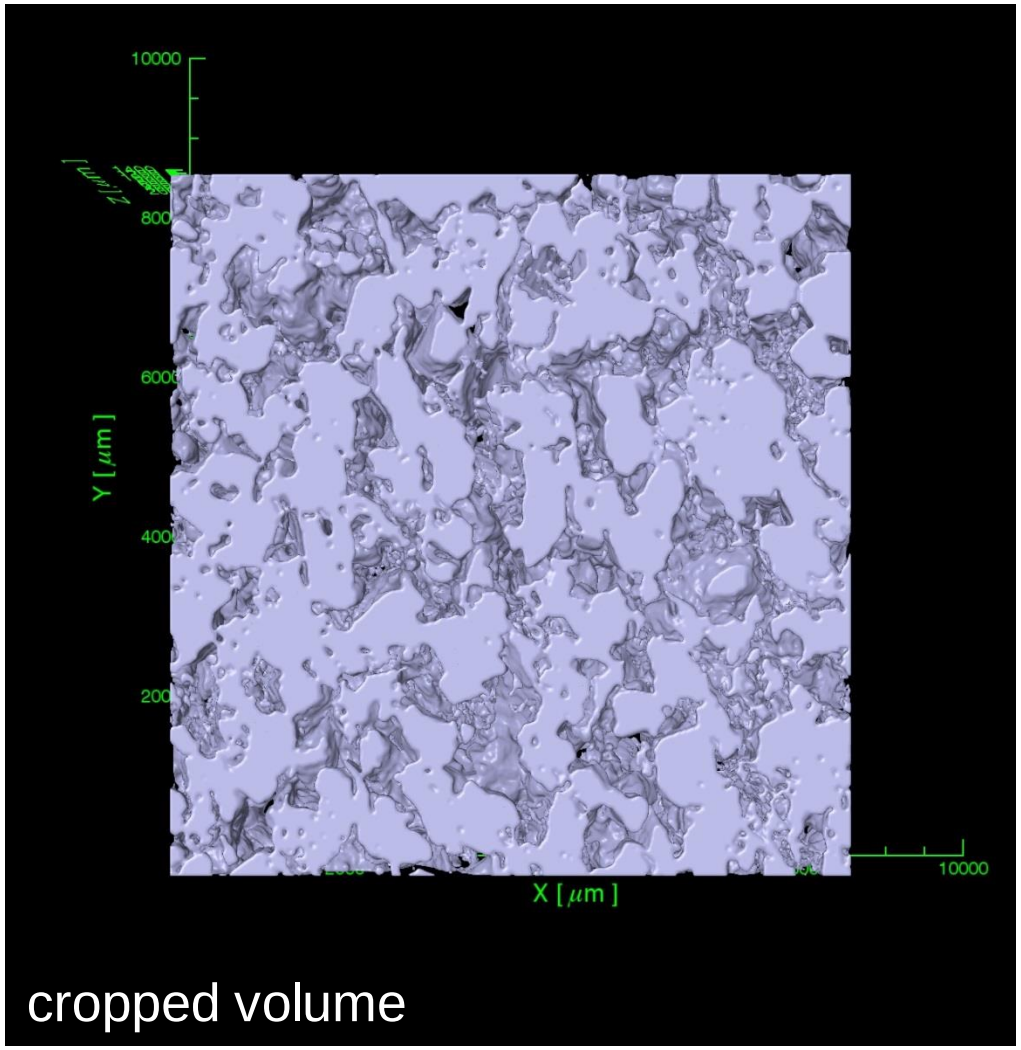
1. Make grayscale
2. Sift align (rigid)
3. Bleach correction (histogram matching)
4. Autolevel stack
5. Remove mount from image
6. Upper right crop
7. Despeckle
8. Invert grayscale
9. Remove outliers & levels adjust
10. Stack local Bernsen threshold



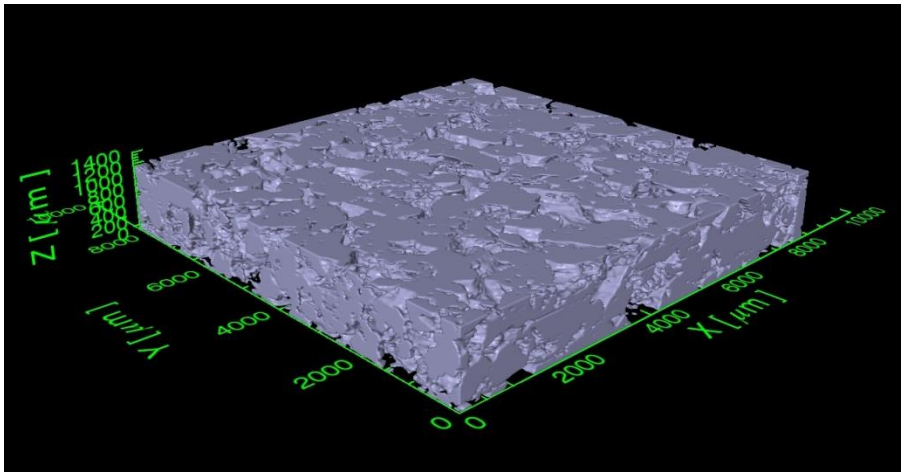


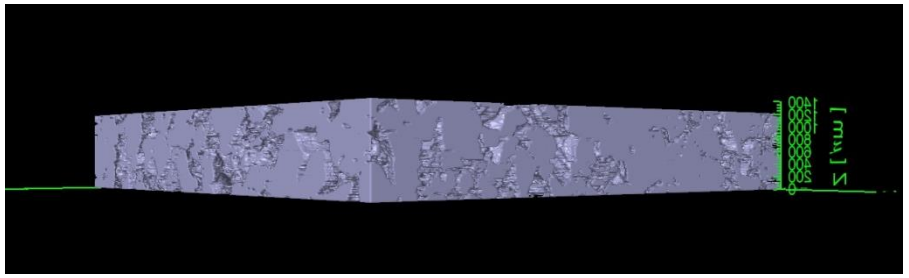
Segmentation: Macro- and Micro-Porosity

montage: 10 x 10
magnification : 5X



cropped volume

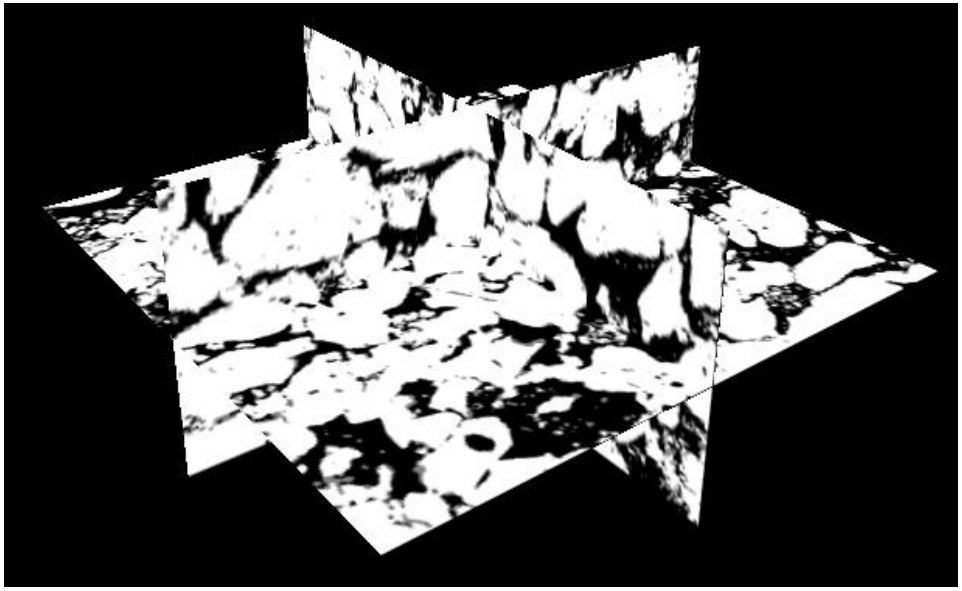




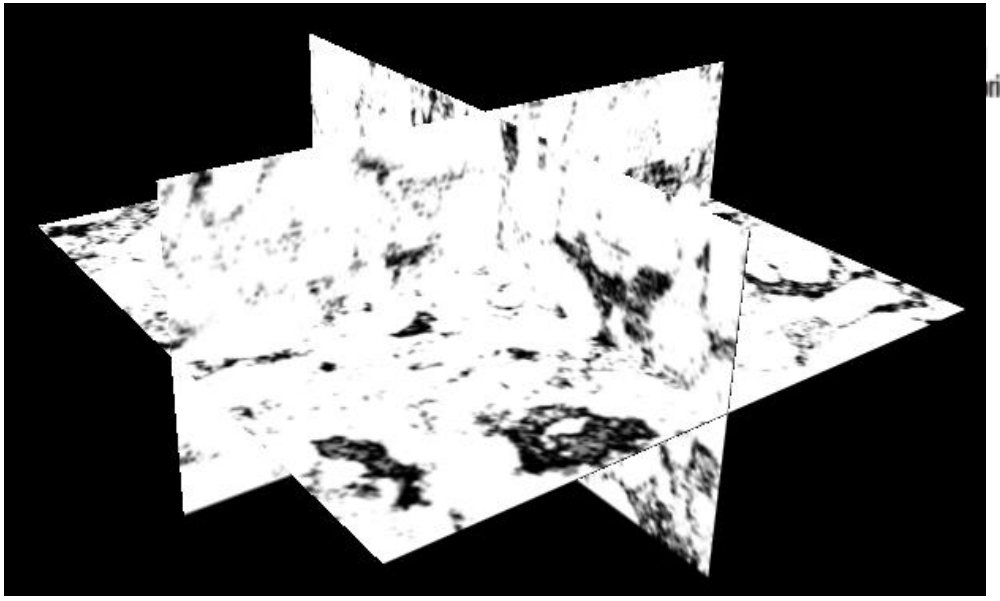
Quartz – FY 2015

- Cropped Volume
- Sectioned through about 1-1.5 quartz grains

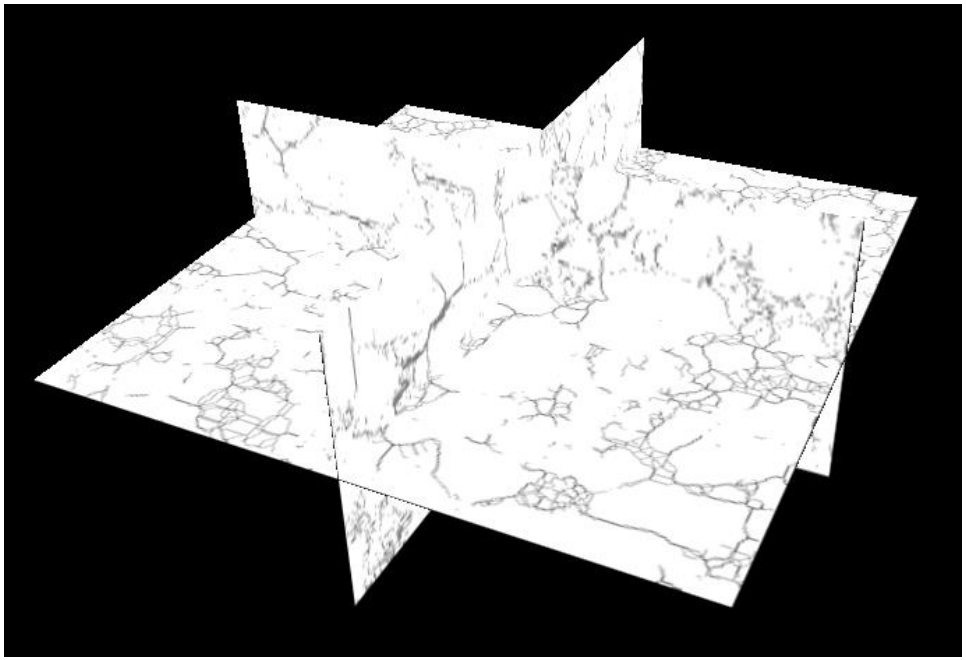
J. Madison[1814], L. Huffman[1819]



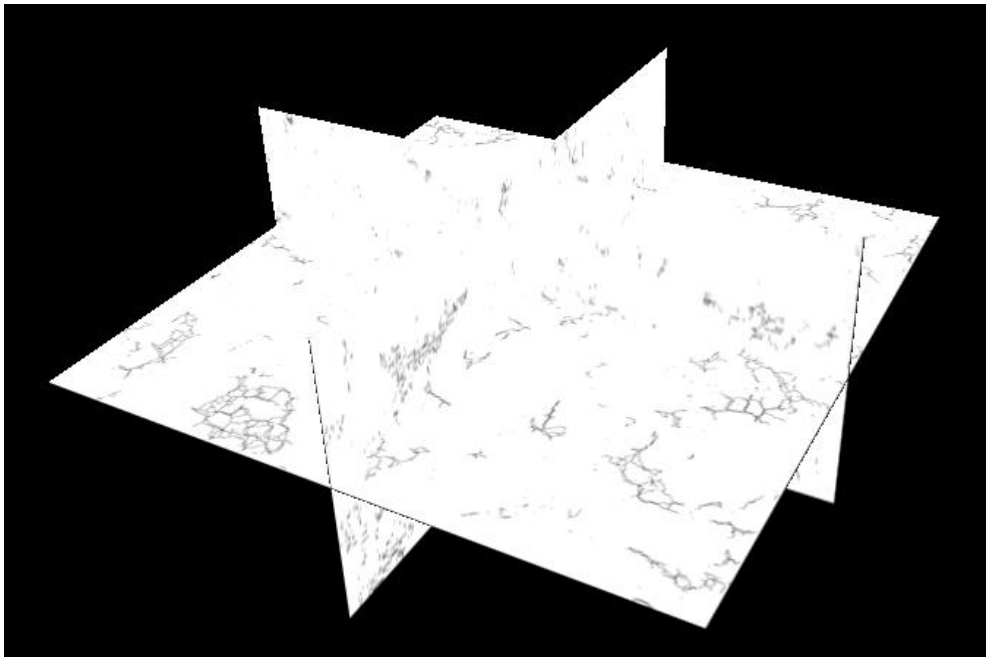
3D Ortho-slice of Total Pore Recon.



3D Ortho-slice of Macro Pore Recon.



Medial Axis of Total Pore Space



Medial Axis of Macro Pores

Operations Research Based Example

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System Dynamics Analysis of Water Resources

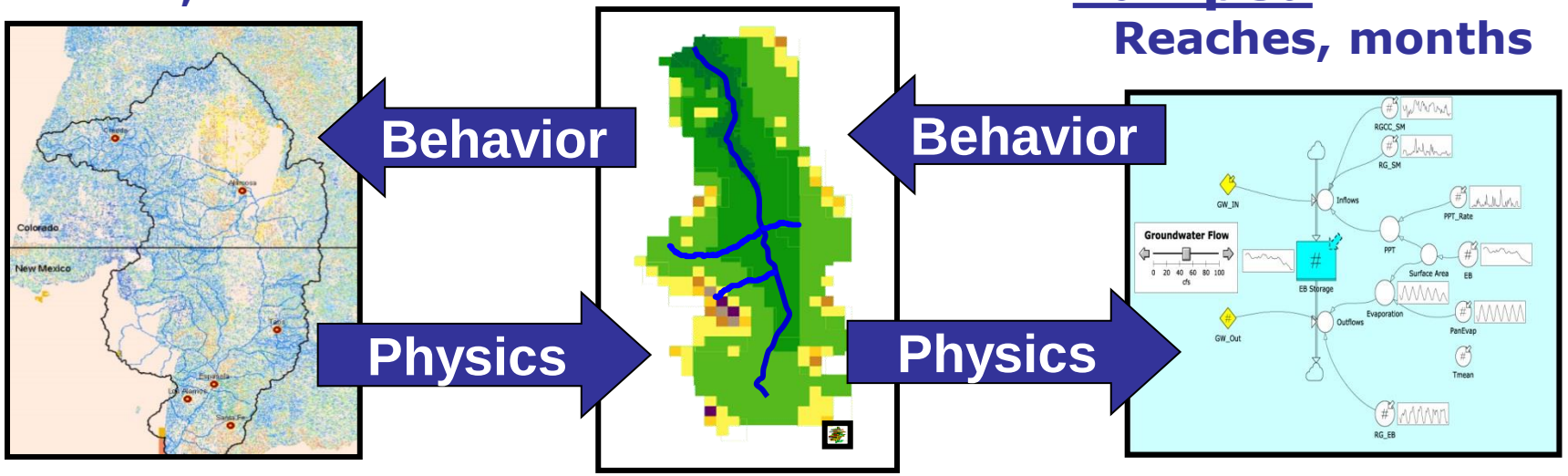
Integrate geohydrology, surface hydrology, legal and social constraints to find community based water management solutions.

- Classic observational geohydrology of water quality and quantity at the basin scale
- Numerical simulation of each component
- Integration using System Dynamics
- Community based collaborative development

Fine Resolution — **100m, minutes**

Medium Resolution — **1 to 10km, hours**

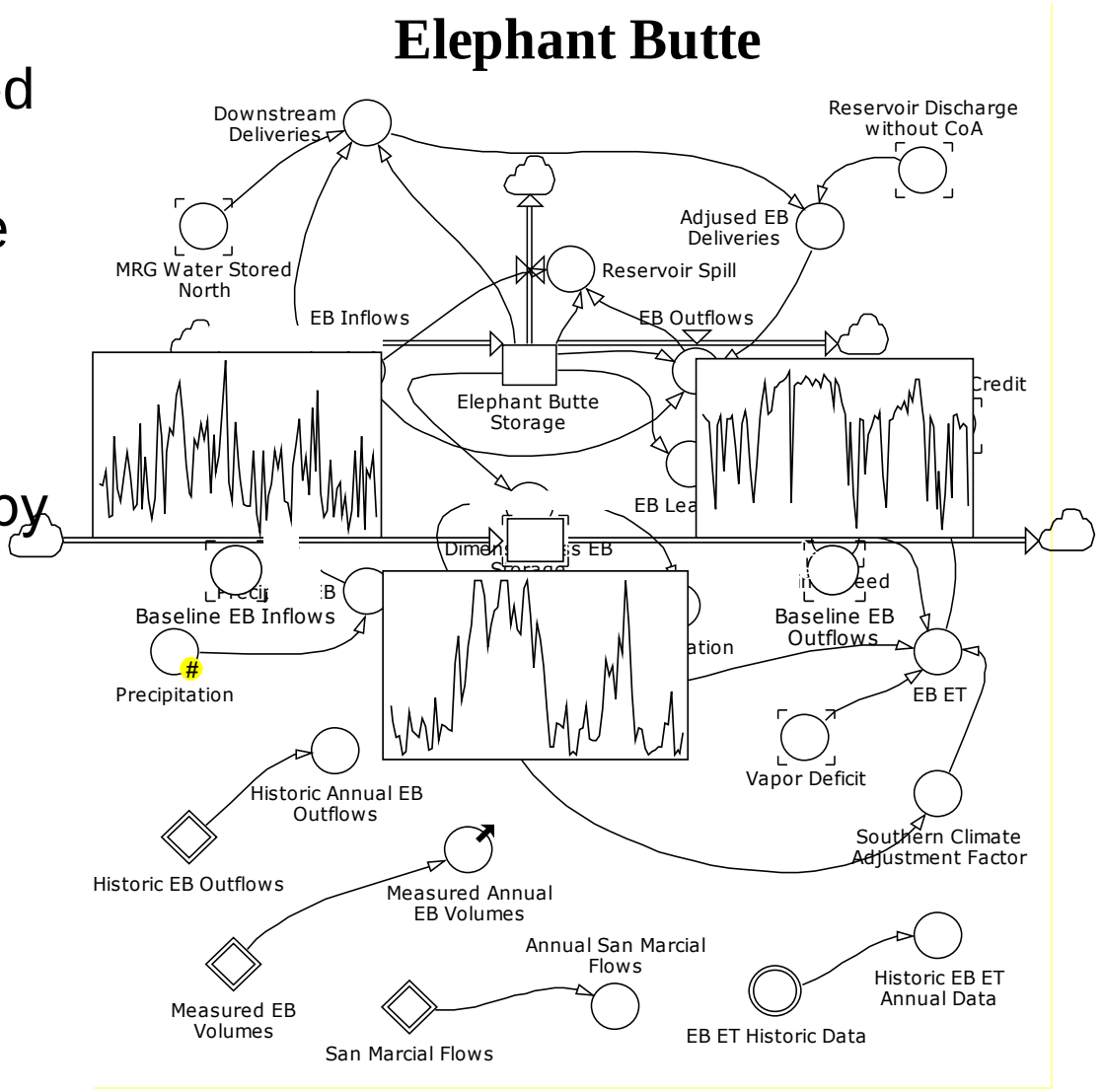
Coarse / Lumped — **Reaches, months**



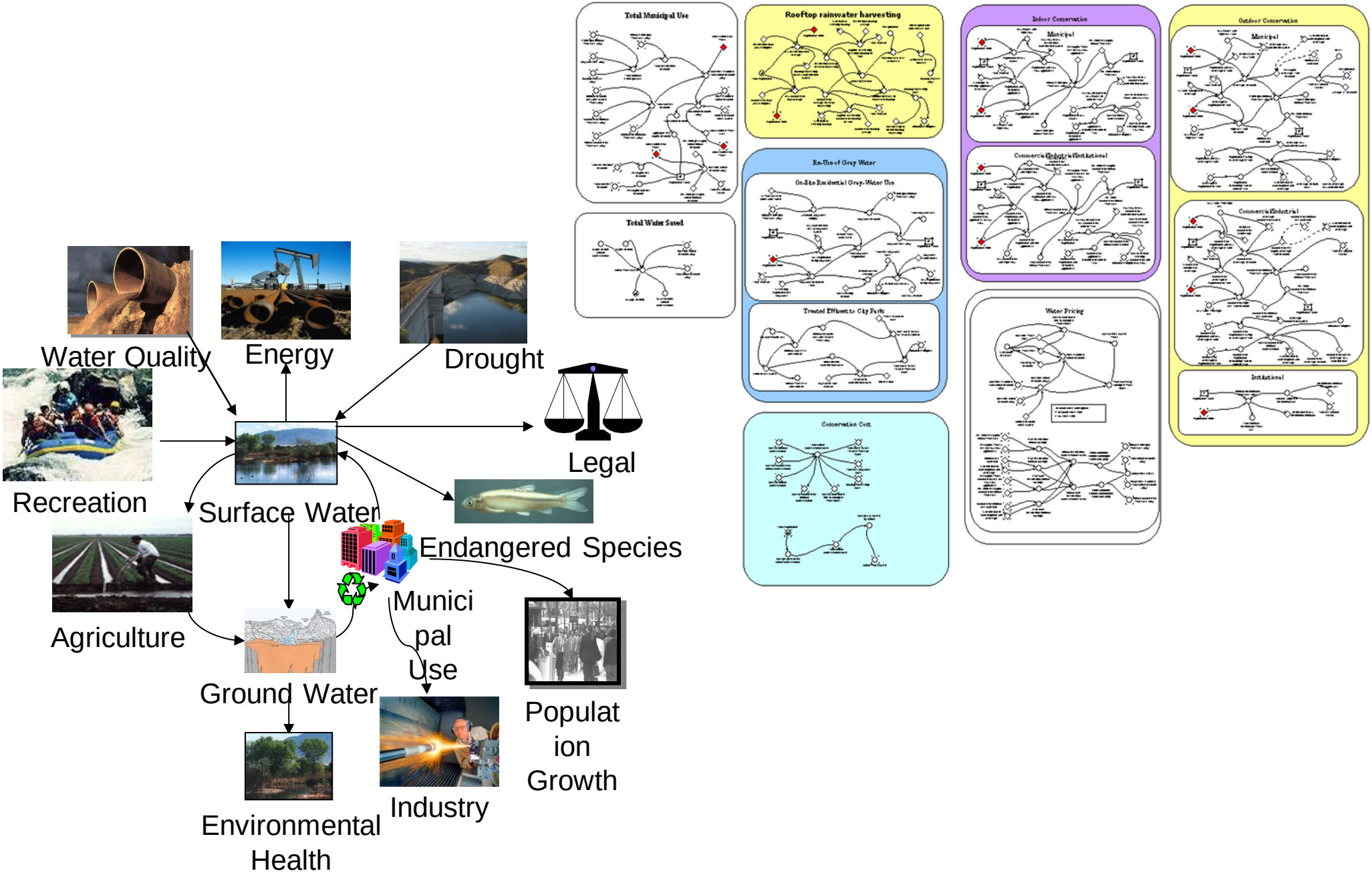
Vince Tidwell and Howard Passell, 2006, System Dynamics Modeling to Support Community Based Water Planning,

System Dynamics: How It Works

- Formulated as a temporally dynamic spatially aggregated commodity balance
- Stocks fluctuate in response to:
  - Commodity inflows, and
  - Commodity outflows
- These “flows” are modeled by way of:
  - Historic data,
  - Empirical relations,
  - Analytical models, or
  - Other models.
- Stocks and flows rarely operate independently but rather in a system of feedback and time delays

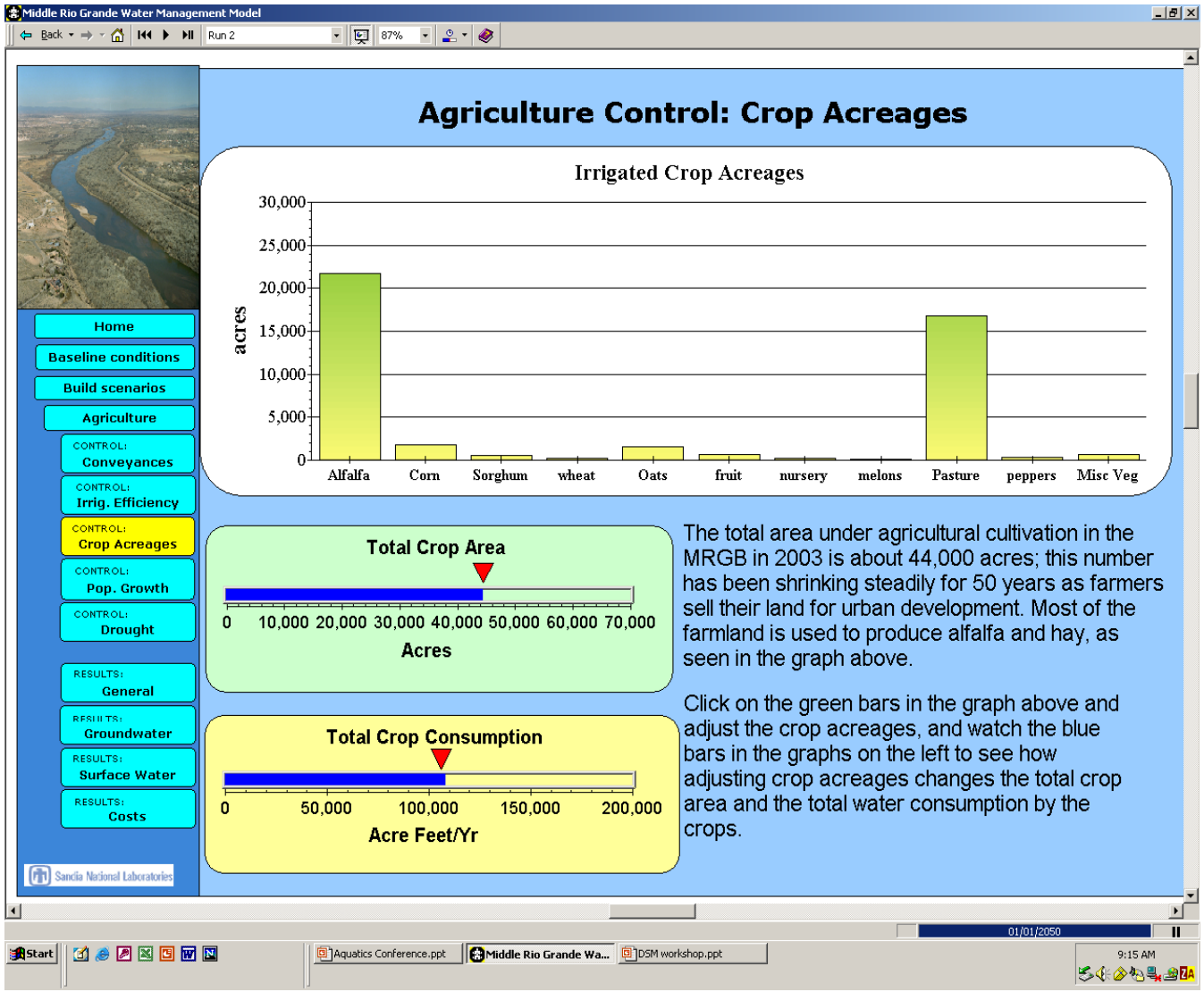


System Dynamics: Integrative Modeling



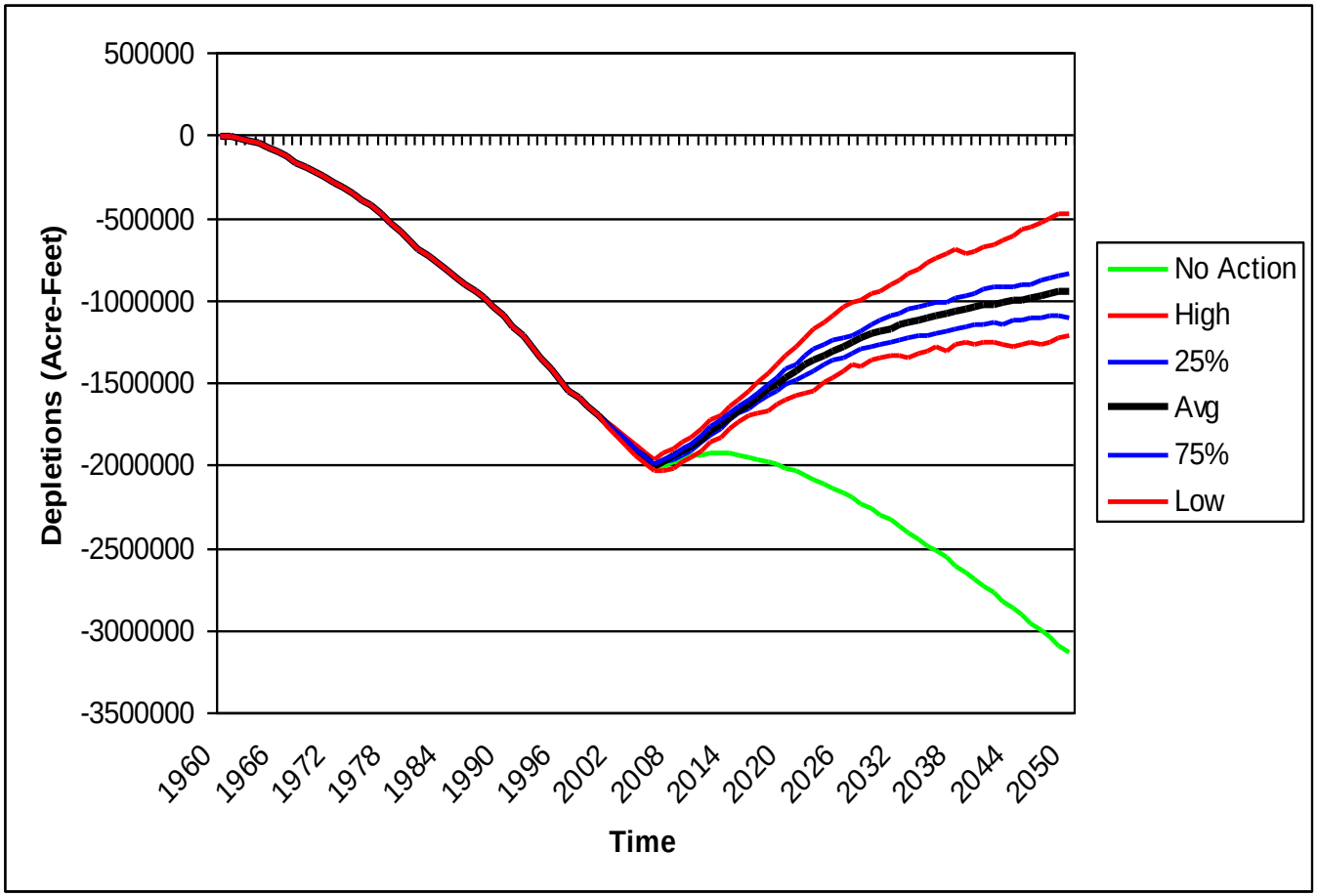
Alternative Conservation Measures

- Bosque restoration
- Irrigated agriculture
  - Irrigation efficiency,
  - Conveyance system losses, and
  - Alternative crops
- Municipal Conservation
  - Water pricing,
  - Water re-use, and
  - Household conservation
- Desalination
- Reservoir storage
  - Up-stream storage,
  - Artificial recharge, and
  - New reservoir



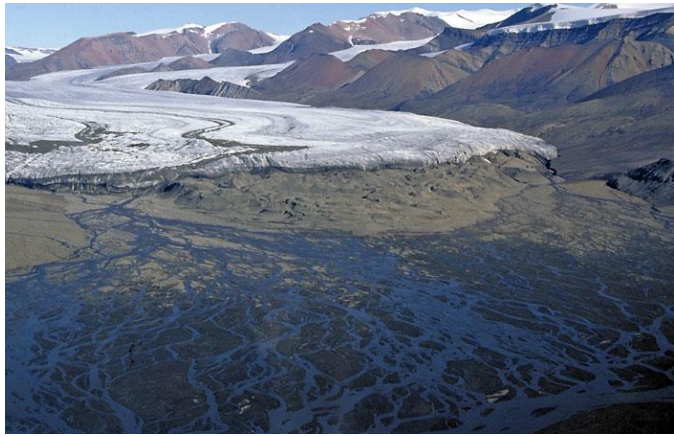
Results

- Actions taken in the Preferred Scenario significantly improve water supply metrics
- Projected uncertainty is in terms of climate variability



Personal Example

“Ergodicity”



Backup Slides

Sandia National Laboratories

Webb “hosonomichi”

Arid Region Hydrology

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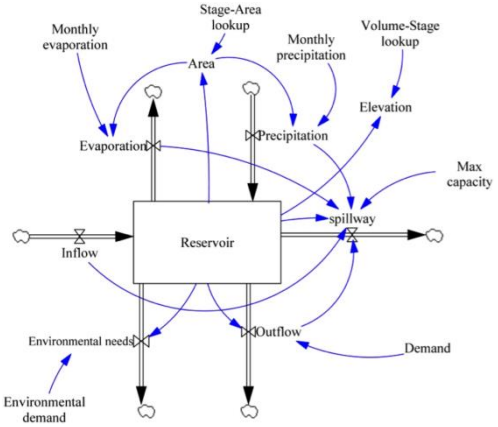

System Dynamics

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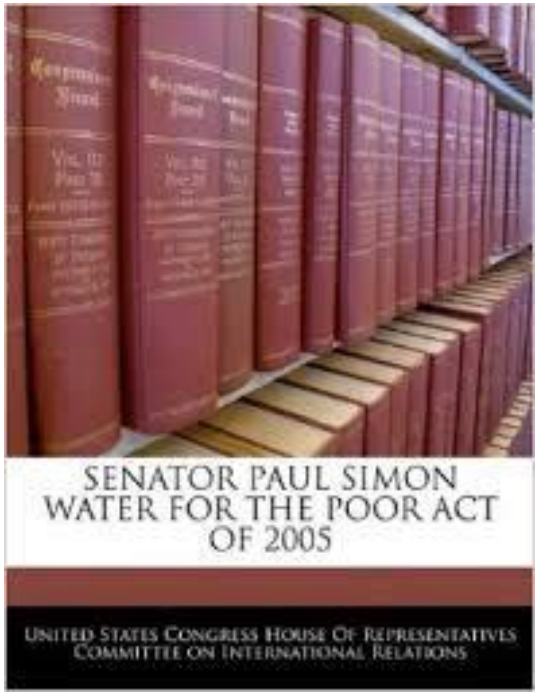

Dept of State Policy

A few heros