

DANIEL T BIRDSSELL

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EDUCATION AND LICENSURE

University of Colorado, Boulder

December, 2018

Ph.D., Civil Engineering

Dissertation Title: *An Investigation of Subsurface Fluid Injections Related to Oil and Gas Operations: Modeling Induced Seismicity and Hydraulic Fracturing Fluid Migration.*

Advisor: Harihar Rajaram

GPA: 3.8

The University of New Mexico

May, 2013

B.S., Chemical Engineering with Environmental Concentration, *summa cum laude*

GPA: 3.9

Engineer Intern, Colorado

April, 2015

PROFESSIONAL EXPERIENCE

Postdoctoral Research Assistant

Nov 2018 -

ETH Zürich, Geothermal Energy and Geofluids

Zürich, Switzerland

My research seeks to understand how hot water can safely and economically be stored in shallow aquifers near Geneva and Bern during the summer and be retrieved for district heating needs in the winter. To capture the physics correctly, numerical models must include site-specific geology, account for coupled thermo-poro-elasticity, and take advantage of high-performance computing (HPC). I work closely with researchers and industry partners through the European Geothermica HEATSTORE project.

Graduate Research Assistant (Ph.D.)

May 2013 - Oct 2018

University of Colorado, Boulder

Boulder, CO

My dissertation research focused on two themes: (a) induced seismicity caused by injection of fluids and (b) hydraulic fracturing fluid migration. Induced seismicity typically migrates away from an injection well according to a nonlinear diffusion process, occurs in fractured and faulted basement rock with uncertain hydrologic and mechanical properties, and is a function of pore pressure and stress. I added the capability to calculate Mohr-Coulomb shear failure (i.e. seismicity) and evolving hydraulic diffusivity on discrete fracture networks (DFNs). I used PFLOTRAN, a coupled subsurface flow and geomechanics simulator that uses PETSc and object-oriented FORTRAN 2003 for massive parallelization, which allows for large domains and robust sensitivity analysis. This work explains why earthquakes are not *more* common, shows that previous work used unrealistic hydrogeologic parameters, and offers suggestions to reduce future induced seismicity. I also published a paper about the porosity-pressure relationship within subsurface flow codes.

Due to public and E.P.A. concern, my earlier research focused on understanding whether hydraulic fracturing fluids could migrate towards and contaminate shallow drinking water aquifers. I constructed a FEHM model that accounts for the important aspects of hydraulic fracturing fluid migration identified in a literature review. Results of the model and sensitivity analysis showed that the presence of a permeable pathway, the pressure transients due to injection and production of fluids, and capillary imbibition all play a significant role while other effects like buoyancy are less important. I also published work about a semi-analytical solution for capillary imbibition.

Graduate Research Assistant

July 2017 - July 2018

Los Alamos National Laboratory T-5

Los Alamos, NM

I contributed to and verified national lab computer codes such as PFLOTRAN and PyFLOTRAN, which are used to calculate coupled subsurface flow, transport, and geomechanics. My major project was to develop fracture flow and mechanics capabilities that are important in understanding induced seismicity. These capabilities allow us to calculate normal deformation and Mohr-Coulomb shear failure on fractures and update hydraulic diffusivity as a function of pressure, stress, and fracture orientation for thousands of fractures in a simulation domain. Some of this work was published in the 52nd US Rock Mechanics/Geomechanics Symposium. I also added a new porosity-pressure constitutive relationship to PFLOTRAN and published a *WRR* paper discussing its importance.

Environmental Engineering Research Experience for Undergraduates (REU) Summer 2012
University of Colorado Boulder, CO

I estimated riparian evapotranspiration using the water balance method and a plant root uptake model. This involved numerical modeling, laboratory work with soil samples, and field work.

Editing Consultant 2011
Kerry Howe Consulting, LLC Albuquerque, NM

Edited equations, sample problems, and references for textbooks including *Principles of Water Treatment* and *MWH's Water Treatment: Principles and Design, 3rd Ed.*

Technical Student Intern Summers 2008 - 2011
Los Alamos National Laboratory, Computational Earth Sciences (EES-16) Los Alamos, NM

Verified and presented a system level model of risk assessment for geologic carbon sequestration using the GoldSim model CO₂-PENS, determined the sorption processes of radionuclides via inverse modeling, and built a nodal analysis model for multiphase fluid flow.

PEER-REVIEWED PUBLICATIONS

Journal Publications

- [1] **Birdsell, D.T.**, Karra, S., & Rajaram, H. (2018). On the representation of the porosity-pressure relationship in general subsurface flow codes. *Water Resources Research*, 54, <https://doi.org/10.1002/2017WR022001>; Cited by: 4
- [2] **Birdsell, D.T.**, H. Rajaram, D. Dempsey, and H.S. Viswanathan. (2015), Hydraulic fracturing fluid migration in the subsurface: A review and expanded modeling results. *Water Resources Research*, 51, 7159-7188, <http://dx.doi.org/10.1002/2015WR017810>; Cited by: 84
- [3] **Birdsell, D.T.**, H. Rajaram and G. Lackey. (2015), Imbibition of hydraulic fracturing fluids into partially saturated shale. *Water Resources Research*, 51, 6787-6796, <http://dx.doi.org/10.1002/2015WR017621>; Cited by: 41

Under Review

- [1] **Birdsell, D.T.**, B.M. Adams and M.O. Saar. (submitted 2020), "Minimum Transmissivity and Optimal Well Spacing and Flow Rate for High-Temperature Aquifer Thermal Energy Storage from Economic and Reservoir-Engineering Constraints." *Applied Energy*.
- [2] Mindel, J.E.,..., **D.T. Birdsell**, et al. (submitted 2020), "Thermo-hydrologic modelling benchmark of simulators for application in high-temperature aquifer thermal energy storage." *Geothermics*.

In Revision

- [1] **Birdsell, D.T.**, H. Rajaram, and S. Karra. (2020) "Understanding Induced Seismicity with a Discrete Fracture Network and Matrix Model with Mohr-Coulomb Failure and Nonlinear Hydraulic Diffusivity." *JGR: Solid Earth*. doi.10.1002/essoar.10502135.1

Conference Proceedings

- [1] **Birdsell, D.T.**, M.O. Saar. "Modeling Ground Surface Deformation at the Swiss HEATSTORE Underground Thermal Energy Storage Sites." World Geothermal Congress, Reykjavik, Iceland (2020). Paper accepted, but conference was delayed until 2021 due to Coronavirus. [doi.10.3929/ethz-b-000421353](https://doi.org/10.3929/ethz-b-000421353).
- [2] Guglielmetti, L., Alt-Epping P., **Birdsell D.**, De Oliveira Filho F., Diamond L., Driesner T., Eruteya O., Hollmuller P., Jutzeler M., Makhloufi Y., Martin F., Meier P., Meyer M., Mindel J., Moscariello A., Nawratil De Bono C., Quiquerez L., Sohrabi R., Saar M., Valley B., Van den Heuvel D., and Wanner C. "HEATSTORE SWITZERLAND: New Opportunities of Geothermal District Heating Network Sustainable Growth by High Temperature Aquifer Thermal Energy Storage Development." World Geothermal Congress, Reykjavik, Iceland (2020). Paper accepted, but conference was delayed until 2021 due to Coronavirus.
- [3] **Birdsell, D.T.**, S. Karra, and H. Rajaram. "Code development for modeling induced seismicity with flow and mechanics using a discrete fracture network and matrix formulation with evolving hydraulic diffusivity." American Rock Mechanics Association, 52nd US Rock Mechanics / Geomechanics Symposium and 2nd Discrete Fracture Network Engineering Conference, number ARMA 18-565. Seattle, WA, June 2018.
- [4] **Birdsell, D.T.**, H. Rajaram, D. Dempsey and H.S. Viswanathan. "Numerical Model of Hydraulic Fracturing Fluid Transport in the Subsurface with Pressure Transient and Density Effects." American Rock Mechanics Association, 49th US Rock Mechanics / Geomechanics Symposium. San Francisco, CA, July 2015.

TEACHING, MENTORING & OUTREACH EXPERIENCE

Student Mentoring

- **Richard Fisher, M.S. student.** *Co-advised 2017- 2018* Mr. Fisher is using the multiphase flow and transport code PFLOTTRAN to simulate the transport of methane and benzene away from a faulty well in western Colorado. I am helping Mr. Fisher learn to use PFLOTTRAN and PyFLOTTRAN and offering expert insight about his conceptual and numerical model setup.

NSF AirWaterGas Outreach Team Member

- Developed curriculum based on the science of unconventional oil and gas development for an online summer course for Colorado middle and high school teachers.
- Collaborated with visiting middle and high school teachers to develop age appropriate classroom activities and lessons for their students focused on unconventional oil and gas development.
- Presented the classroom activities and lessons developed by local middle and high school teachers to other teachers at the 2015 Colorado Science Teacher's Conference and the 2015 AGU Geophysical Information for Teacher's Workshop.
- Taught classroom activities that explain the science of hydraulic fracturing to K-12 students at University of Colorado and at the Trinidad Water Festival.

Teaching and Grading

- I have acted as grader and substitute lecturer for the graduate courses CVEN 5537: Numerical Methods in Civil Engineering and CVEN 6383: Flow and Transport through Porous Media.

SERVICE

Peer Reviewer

Listed in order of frequency

Jan 2015 - Present

Water Resources Research (*WRR*)
Geophysical Research Letters (*GRL*)
Journal of Natural Gas Science and Engineering (*JNGSE*)
American Rock Mechanics Association (*ARMA*)

InterPore Minisymposium

May 2018

Assisted my advisors in organizing and inviting scientists to our session “Advances in Observation and Modeling of Coupled Flow and Deformation in Fractured Rock”.

NSF AirWaterGas Student Seminar

Jun 2014 - Aug 2015

Seminar Organizer, Presenter

I recruited speakers from academia, industry, and government agencies to speak about impacts of oil and gas development on air quality, water quality, public policy, and best practices for communication with the public. I also organized the schedule and lunch delivery for this weekly to monthly seminar.

Univ. of Colorado Water Resources Seminar

2015

Seminar Organizer

I assisted with seminar organization, introduced speakers, and organized food delivery.

Water Resources Graduate Student Group

Fall 2016 - Present

Shared research methods and techniques with other environmental and water resources graduate students during weekly meetings. My introductory presentation about parallel computing with example codes and homework exercises are available at https://gitlab.com/daniel.birdsell/danny_understanding_PETSc.

Tau Beta Pi Engineering Honors Society

2011 - 2013

UNM Treasurer, Member

I acted as treasurer for a year and a half, organizing finances, helping with the Engineering Futures professional development course, and representing UNM at the national conference.

HONORS & AWARDS

Outstanding Dissertation Award, <i>University of Colorado, Civil Engineering</i>	2018
Best Oral Presentation, <i>University of Colorado Hydrologic Sciences Symposium</i>	April 2018
Doctoral Assistantship of Excellence, <i>University of Colorado</i>	2013 - 2018
Dean’s Outstanding Merit Fellowship, <i>University of Colorado School of Engineering</i>	2013
Honors Thesis on Thin Film Metal Oxide Synthesis <i>UNM Chemical Engineering Dept.</i>	May 2013
Outstanding Senior Award, <i>UNM Chemical Engineering Dept.</i>	May 2013
University of New Mexico Dean’s List	2011 - 2013
University of New Mexico Presidential Scholarship	2008
Los Alamos National Laboratory Foundation Scholarship, <i>Bronze Scholar</i>	2008

TECHNICAL STRENGTHS

Reservoir Simulators	PFLOTRAN, MOOSE, MODFLOW-2000 (with MT3D), FEHM
Computer Languages & Skills	Fortran, Python, PETSc, MPI, Bash, MATLAB, Mathematica
Debugging & Version Control	Gnu Project Debugger (GDB), Python Debugger (pdb), Git, Hg
Operating Systems	Linux (Ubuntu, RedHat), OS X, Windows
Visualization	VisIt, Paraview, Matplotlib, L ^A T _E X, Microsoft Office

TECHNICAL REPORTS

- [1] L. Guglielmetti, M. Meyer, P. Meier, T. Driesner, J. Mindel, **D. Birdsell**, L. Diamond, and B. Valley, "Rapport intermédiaire du 22.05.2019 HEATSTORE Swiss Consortium Annual Meeting," Switzerland, SI/501725-01, May 22, 2019.
- [2] F. Lander, M. Saaltink, S. Olivella, P. Alt-Epping, and **D. Birdsell**, "WP2: Subsurface Modelling - UTES Bern-Forsthaus," Switzerland, Jan, 2019.
- [3] Driesner, T. (ed.) et al. and **D. Birdsell** 2019: Initial report on tools and workflows for simulating subsurface dynamics of different types of High Temperature Underground Thermal Energy Storage. GEOTHERMICA – ERA NET Cofund Geothermal, unpublished report, 143 pp.
- [4] Tómasdóttir, S. & Gunnarsson, G. (ed) et al. and **D. Birdsell** 2019: HEATSTORE –Interim report on UTES-type/site-specific simulators based on academic/research codes. GEOTHERMICA –ERA NET Cofund Geothermal. 55pp.

PRESENTATIONS

Oral Presentations

- [1] **D.T. Birdsell**, B.M. Adams, and M.O. Saar. "Determination of minimum transmissivity for high-temperature aquifer thermal energy storage from reservoir-engineering and economic constraints." 18th Swiss Geoscience Meeting, Online, Hosted by ETH Zurich, 6-7 November 2020.
- [2] **D.T. Birdsell** and M.O. Saar. "Predicting Surface Deformation for Geothermal Energy with a Thermo-Poro-Elastic Model." InSAR - Radar satellite interferometry and ground deformation workshop, Geneva, Switzerland. April 2019.
- [3] **D.T. Birdsell**, H. Rajaram, and S. Karra. "Modeling Induced Seismicity with Fracture and Matrix Flow, Geomechanics, and Evolving Hydraulic Diffusivity." InterPore 10th Annual Meeting, New Orleans, LA. May 2018.
- [4] **D.T. Birdsell**, S. Karra, and H. Rajaram. "Modeling Induced Seismicity at Greeley, CO with Fracture and Matrix Flow, Geomechanics, and Evolving Hydraulic Diffusivity." University of Colorado Hydrologic Sciences Symposium, April 2018. (Best Oral Presentation).
- [5] **D.T. Birdsell**, S. Karra, and H. Rajaram. "On the Representation of Aquifer Compressibility in General Subsurface Flow Codes: How an Alternate Definition of Aquifer Compressibility Matches Results from the Groundwater Flow Equation." American Geophysical Union, Fall Meeting, December 2017.
- [6] Lackey, G., L.S. Gardiner and **D.T. Birdsell**. "The Science of Fracking." AGU-NESTA GIFT Workshop, American Geophysical Union, Fall Meeting, December 2015.
- [7] Rajaram, H., **D.T. Birdsell**, G. Lackey, S. Karra, H.S. Viswanathan and D. Dempsey. "Modeling Studies to Constrain Fluid and Gas Migration Associated with Hydraulic Fracturing Operations." American Geophysical Union, Fall Meeting, December 2015.
- [8] Hafich, K.A., L.S. Gardiner, G. Lackey and **D.T. Birdsell**. "The Science of Fracking: Activities Developed by Colorado Teachers and Scientists." Colorado Science Conference, November 2015.

- [9] **Birdsell, D.T.**, H. Rajaram, D. Dempsey, and H.S. Viswanathan. "Numerical Model of Hydraulic Fracturing Fluid Transport in the Subsurface with Pressure Transient, Density Effects, and Imbibition." Center for Nonlinear Studies Grand Challenges in Geological Fluid Mechanics Workshop, Santa Fe, NM, August 2015.
- [10] **Birdsell, D.T.**, H. Rajaram, D. Dempsey, and H.S. Viswanathan. "Numerical Model of Hydraulic Fracturing Fluid Transport in the Subsurface with Pressure Transient, Density Effects, and Imbibition." 49th Annual American Rock Mechanics/Geomechanics Symposium, San Francisco, CA, June 2015.

Poster Presentations

- [1] **Birdsell, D.T.** and M.O. Saar "Coupled Thermo-Hydro-Mechanical Model of Ground Surface Deformation at Swiss Heat Storage Sites." Poster Presentation, DECOVALEX 2019 Symposium, Brugg, Switzerland, 4-5, Nov 2019
- [2] **Birdsell, D.T.** and M.O. Saar. "Modeling Ground Surface Deformation at the Swiss HEATSTORE Underground Thermal Energy Storage Sites." SCCER-SoE Annual Conference, Lausanne, Switzerland. 3-4 Sep 2019.
- [3] **Birdsell, D.T.** and M.O. Saar. "Use of a coupled thermo-hydro-mechanical model to constrain the risk of ground surface deformation due to subsurface energy storage and production." AAPG 3rd Hydrocarbon Geothermal Cross Over Workshop, Geneva, Switzerland, April 2019.
- [4] **Birdsell, D.T.**, H. Rajaram and G. Lackey. "Capillary Imbibition of Hydraulic Fracturing Fluids into Partially Saturated Shale (MR41A-2627)." American Geophysical Union, Fall Meeting, December 2015.
- [5] **Birdsell, D.T.**, H. Rajaram, H.S. Viswanathan, and D. Dempsey. "Numerical Model of Hydraulic Fracturing Fluid Transport in the Subsurface with Pressure Transient, Density Effects, and Imbibition." American Geophysical Union, Fall Meeting, December 2014.

Other Presentations

- [1] **Birdsell, D.T.**, H. Rajaram, and S. Karra. "Numerical Modeling of Induced Seismicity: Background, Code Development, and New Results for the Porosity-Pressure Constitutive Relationship." Water Resources Seminar, University of Colorado, Oct. 18, 2017.
- [2] **Birdsell, D.T.**, H. Rajaram, and S. Karra. "Numerical Modeling of Induced Seismicity: Challenges in Code Development and New Results for Soil Matrix Compressibility." Los Alamos National Laboratory Center for Space and Earth Science Seminar, Los Alamos, NM, Aug. 8, 2017.
- [3] H.S. Viswanathan, H. Rajaram, **D.T. Birdsell**, G. Lackey, and S. Pandey. "Coupled Thermo-Hydrologic-Mechanical-Chemical (T-H-M-C) Processes in Subsurface Systems (special emphasis on fractures)." Los Alamos National Laboratory Institute of Geophysics, Planetary Physics, and Signatures Workshop, Los Alamos, NM, April 2015.