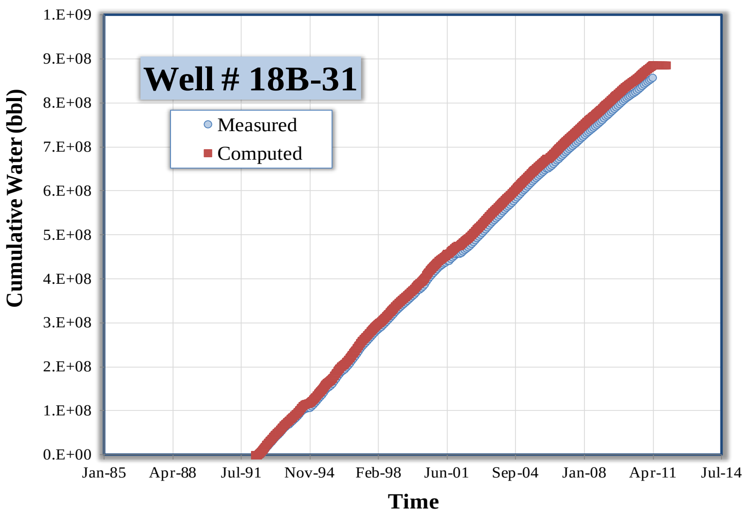
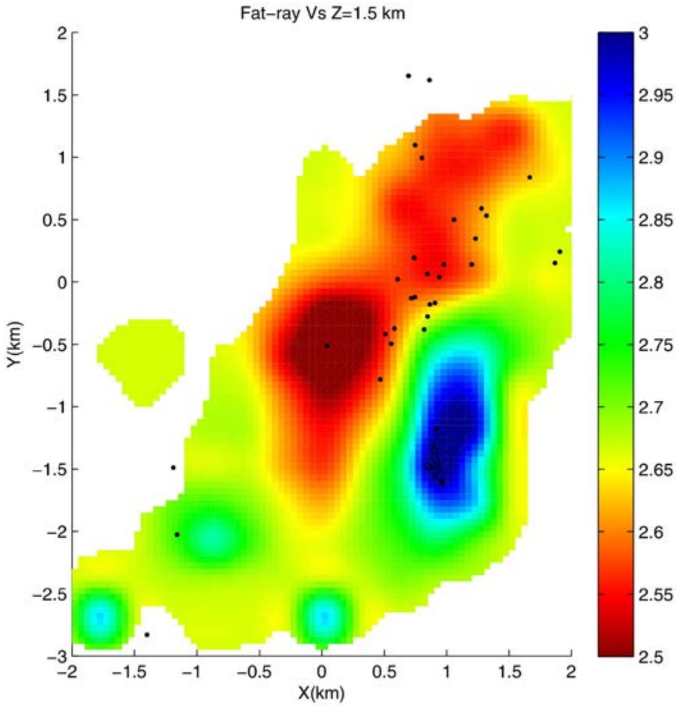




I: Imaging, Characterizing, and Modeling of Fracture Networks and Fluid Flow in EGS Reservoirs; II: Full-Waveform Inversion of 3D-9C VSP data from Brady's EGS Site and Update of the Brady Reservoir Scale Model

Project Officer: Lauren Boyd

Total Project Funding: Part I: $855,430 (LANL), $1M (NETL); Part II: $250,000 (LANL)

April 22-25, 2013

Lianjie Huang

Los Alamos National Laboratory

Fluid Imaging

Project Objectives (Project Part I):

- Develop novel imaging methods for monitoring EGS reservoirs.
  - Innovation: Use time-lapse seismic data and elastic-waveform inversion for high-resolution reservoir imaging; Improve microseismic event locations
- Develop discrete fracture network models based on known geologic features at Brady's EGS site.
  - Innovation: Use fracture network from core studies to develop permeability tensor of an EGS site for improving flow prediction.
- Enhance the prediction of fluid flow, temperature distributions and stress changes in EGS reservoirs.
  - Innovation: Use LANL's unique reservoir modeling code FEHM that fully couples heat transfer, fluid flow, and rock to improve prediction of EGS performance.

Project Objective (Project Part II):

- Obtain a quantitative, high-resolution VSP image of Brady's EGS reservoir
  - Innovation: Apply full-waveform inversion to three-dimensional (3D), nine-component (9C) vertical seismic profiling (VSP) data

Impact of Research:

- This work will help optimize the operation of injection and production wells and the placement of new wells so that the operator can make informed decisions regarding optimal EGS reservoir development to maximize return on investment and minimize levelized cost of electricity.
- The success of this project will impact the following DOE-GTO's goal: "**Enhanced Geothermal Systems (EGS)-Secure the Future with Enhanced Geothermal Systems:** Demonstrate 5 MW reservoir creation by 2020; Lower LCOE to 6 cents/kWh by 2030."

Elastic-Wave Reservoir Imaging

- Develop several new elastic-waveform inversion methods for improving quantification of changes in EGS reservoirs caused by fluid injection.
- Validate all new imaging methods using an EGS model for the Brady's EGS field, and demonstrate that our new imaging methods can accurately quantify fluid-injection-induced reservoir changes.

Microseismic Imaging

- Develop a fat-ray double-difference tomography method to simultaneously improve the accuracy of tomographic inversion of seismic-wave velocities and the precision of microseismic event locations.
- Validate the method using microseismic data from Brady's EGS field provided by LBNL (Ernest Majer, Steve Jarpe, and Katie Boyle).

Discrete Fracture Network

- Conduct experimental analysis of core sample from Brady's EGS field.
  - 13 core samples collected from Brady's field December 2010
  - Imaging of core at multiple scales performed and ultrasonic rock velocities measured on core samples under various confining pressures
- Construct a discrete fracture network model for Brady's EGS field.
- Perform thermo-hydro-geomechanical modeling of Brady's geothermal field site
- Compare computed values with available measured values of pressure and temperature, and production and injection water in each well.

FEHM Reservoir Modeling

- Develop models with faults and layers as simplified conceptualizations of the Brady's and Desert Peak EGS reservoirs to study the effects of cold fluid injection into a hotter formation
- Match FEHM modeling results with pumping data obtained during shear-stimulation treatment of the DP 27-15 well.
- Develop enabling technological tools for reservoir management
  - Coupled Thermal-Hydrologic-Mechanical (THM) models
  - Conceptual models for permeability-stress dependence

Project Part I

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Reservoir imaging: estimating geophysical property changes in EGS reservoirs	Reservoir imaging: Developed a suite of novel elastic-waveform inversion methods for joint inversion of time-lapse seismic data to quantitative estimate reservoir changes.	09/30/2011
Microseismic imaging: improving event locations	Microseismic imaging: Developed a novel fat-ray double-difference tomography method	09/30/2012
Reservoir modeling: matching modeling results with field measurements	Reservoir modeling: Constructed a discrete fracture network model for Brady's EGS field, modeled coupled heat transfer and stress changes in the reservoir, and matched the modeling results with measurements from wells	09/30/2012

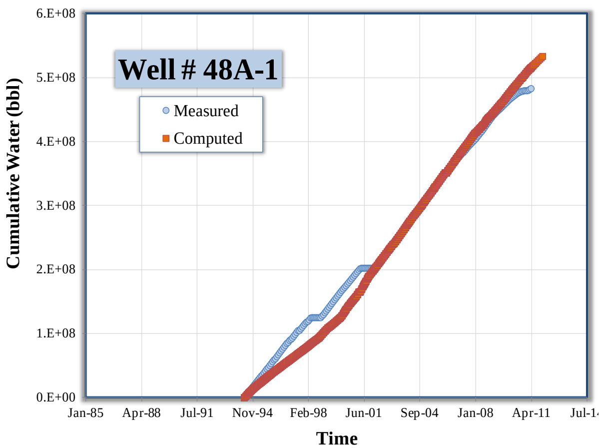
Project Part II

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Provide a quantitative, high-resolution image of Brady's EGS reservoir	Originally plan to start the work in January, 2013, but VSP data acquisition has been postponed till May, 2013 (LBNL and Hi-Q Geophysical Inc). Will start the work when the VSP data are available.	To be completed one year after data are available for analysis.

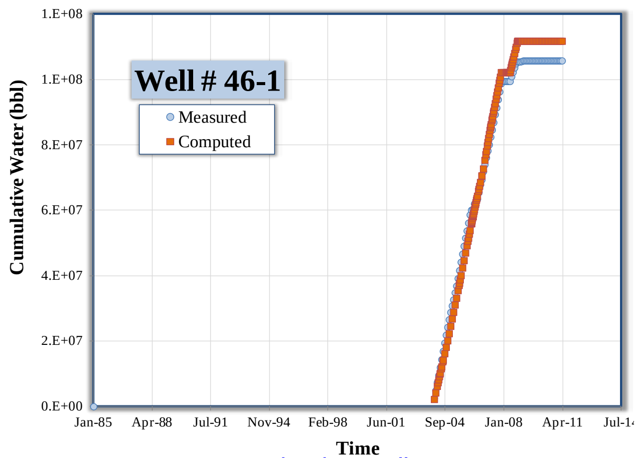
Accomplishments, Results and Progress

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

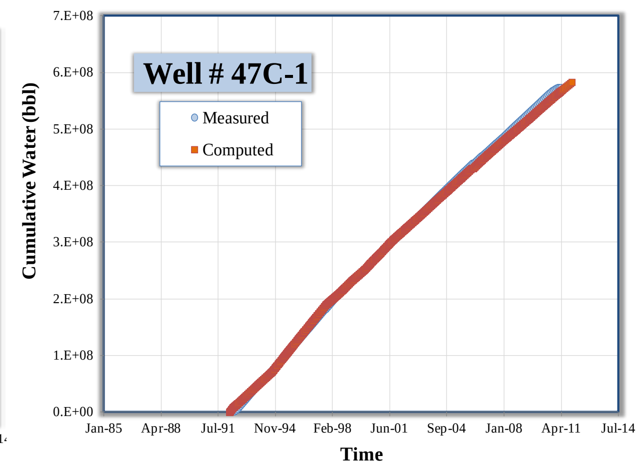
- Performed thermo-hydro-geomechanical modeling of Brady's geothermal field site
- History matching results show a good comparison of computed values with available measurements for production and injection



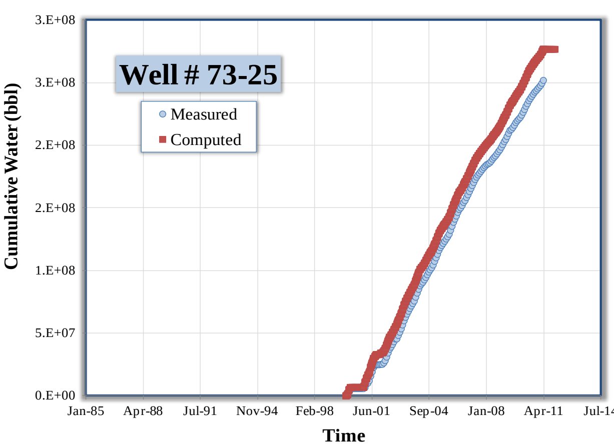
Production well # 48A-1



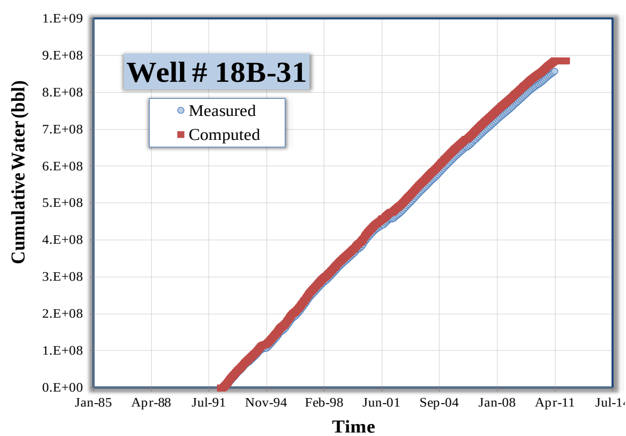
Production well # 46-1



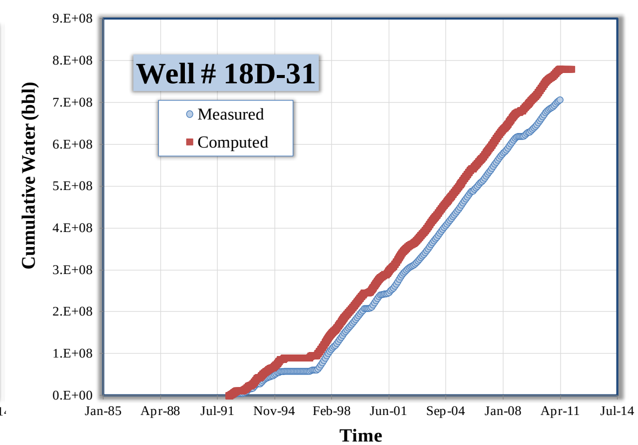
Production well # 47C-1



Injection well # 73-25



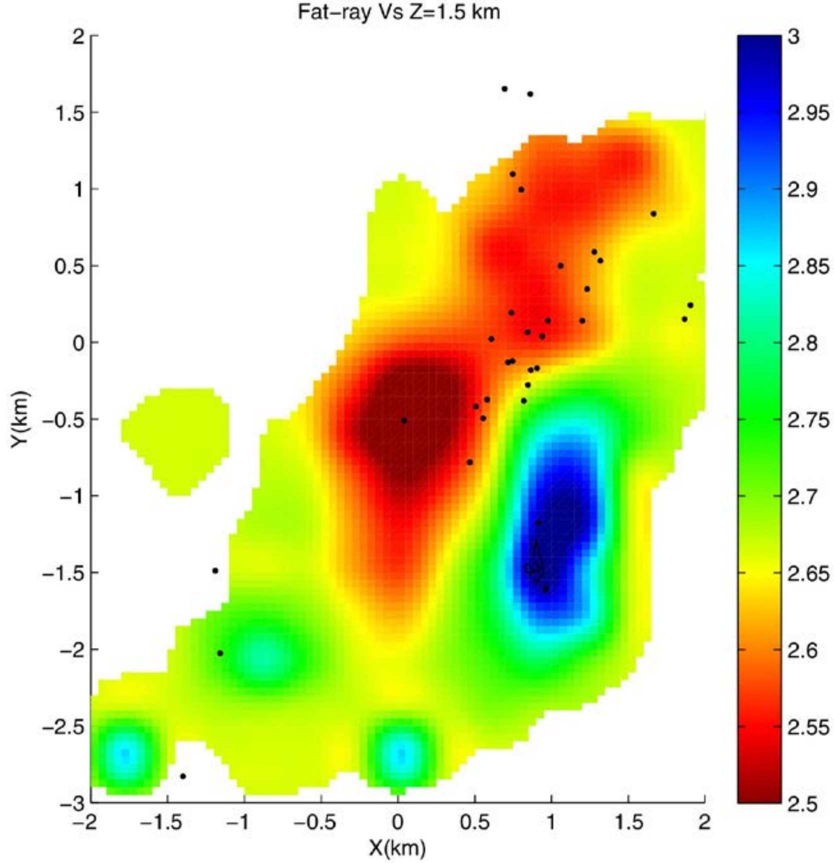
Injection well # 18B-31



Injection well # 18D-31

Accomplishments, Results and Progress

- Developed a fat-ray double-difference tomography method for improving the accuracy of microseismic imaging
- Applied the method to microseismic data from Brady's EGS field (before stimulation), reveal the shear-wave velocities along both sides of a fault are different, and microseismic events are mostly along the fault.



Future Directions

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- During the course of this project, several novel reservoir imaging and modeling methods have been developed.
- We will seek opportunities to apply these imaging and modeling for EGS reservoirs in collaboration with industrial partners. These imaging and modeling methods will provide useful information for optimal development and management of EGS reservoirs.
- Planned milestone for FY13 and beyond (For Project Part II):

Milestone	Status & Expected Completion Date
Obtain a quantitative, high-resolution image of Brady's EGS reservoir using full-waveform inversion	LBNL and Hi-Q Geophysical Inc. plan to acquire 3D-9C VSP data at Brady's EGS field in May, 2013. We will start analyze the data when they are ready, and expect to complete the work within one year.

Summary

- Our thermo-hydro-geomechanical modeling of Brady's EGS field shows a good history match of computed values with available measurements for production and injection water and for pressure drop and temperature changes along each well.
- Our novel elastic-waveform inversion methods jointly invert time-lapse seismic data to obtain accurate estimates of EGS reservoir changes.
- Our novel fat-ray double-difference tomography imaging method reveals different shear-wave velocities along different sides of a fault at Brady's EGS field, and shows microseismic events along the fault.

Project Management

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Timeline:
(Project Part I)

Planned Start Date	Planned End Date	Actual Start Date	Current End Date
10/01/2009	09/30/2012	10/01/2009	09/30/2012

Budget:
(Project Part I)

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
$1.86M	$0	$1.86M	$1.86M	$1.86M	$0

- Held teleconferences among LANL and NETL researchers to update project progress and coordinate collaborative efforts.
- Attended meetings with Ormat and other collaborators.
- Coordinated with project partners to obtain core samples and other geologic information for Brady's EGS field.
- Worked closely with geologists at Ormat and University of Nevada in Reno to build a discrete fracture network model for Brady's EGS site.
- The work for Project Part II is waiting for VSP data from Brady's EGS site to be provided by LBNL and Hi-Q Geophysical Inc. who plan to acquire the VSP data in May, 2013.