Hydrothermal Reservoir Productivity

Project Officer: Timothy Reinhardt
Total Project Funding: $100K
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Systems Analysis: Resource Assessment

Relevance/Impact of Research

Objective:

- Examine how hydrothermal reservoir productivity (in particular production temperature) evolves with time
  - Quantify changes in productivity for both binary and flash plants
  - Determine variability in the change between facilities
  - Identify remedial actions taken by operators to offset impact of any decline in productivity

Impact:

- Many geothermal resources experience some level of decline in resource productivity over the life of a power plant. Using the GTO's GETEM, the impact of temperature decline over 30 yr for a 30 MW (sales) plant can be quantified for a 175ºC resource (assuming no makeup wells drilled):

Annual Temperature Decline	Power (EoP)	Total Power	LCOE impact
No Decline (0%/yr)	30 MW	7,490 GW-hrs	reference
0.5% decline per yr	17 MW	5,848 GW-hrs	19% increase
1% decline per year	4.0 MW	4,135 GW-hrs	69% increase

Relevance/Impact of Research

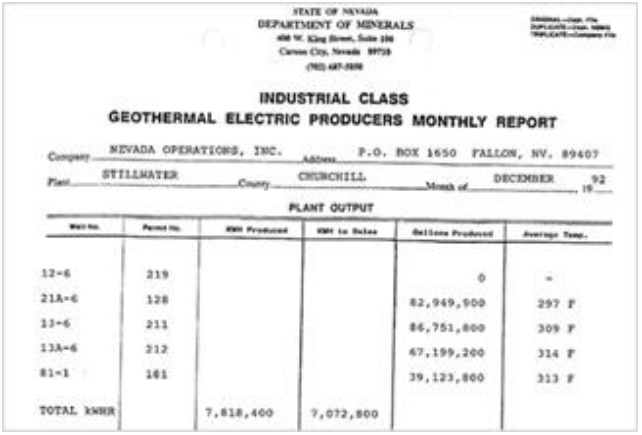
Benefit:

- Provide data to validate that the GTO is properly accounting the impact of changes in reservoir productivity when estimating generation costs from geothermal
- Identify other well field parameters - typical well flow rates, the number of production and injection wells used, …
- Establish distances between wells, project areas, etc., when coupled with maps, GIS or well data bases
- Provide insight to the steps taken by operators to mitigate any adverse impact of decreases in reservoir productivity.

Scientific/Technical Approach

Approach:

- Monthly production and injection reports submitted by NV geothermal operators were available on Nevada Bureau of Mines & Geology web site. Reports typically include flow and temperature for each well; in some instances, pressures and power produced during month were also reported.



STATE OF NEVADA
DEPARTMENT OF MINERALS

INDUSTRIAL CLASS
GEOTHERMAL ELECTRIC PRODUCERS MONTHLY REPORT

Company NEVADA OPERATIONS, INC. Address P.O. BOX 1650 FALLON, NV. 89407
Plant STILLWATER County CHURCHILL Month of DECEMBER 19 92

PLANT OUTPUT

Well No.	Permit No.	KWH Produced	KWH to Sales	Gallons Produced	Average Temp.
12-6	219			0	-
21A-6	128			82,949,900	297 F
13-6	211			86,751,800	309 F
13A-6	212			47,199,200	314 F
81-1	181			39,123,800	313 F
TOTAL kWHR		7,818,400	7,072,800		

- Information downloaded and inputted into Excel spreadsheets for each facility
- Binary temperature decline
  - Assumed single phase (liquid) flow produced
  - Calculated fluid enthalpy at plant

$$enthalpy = \frac{\sum(mass\ flow * enthalpy)_{well}}{\sum mass\ flow_{well}}$$

  - Enthalpy used to determine flow weighted temperature of produced flow
  - Calculation made for each month of reported data

Approach (continued):

- Flash-steam facility temperature decline
  - Estimates are based on total production in a given month
    - Data suggests two-phase flow produced; a steam fraction at well head (not reported) is required to perform individual well calculations (approach used with binary facilities)
  - Initially assumed steam fraction could be approximated as difference between produced and injected flow
  - Modeled plant to determine resource temperature that matched reported flow and power production
  - Modeled steam flow using turbine (choked flow) and assuming lowest reported well head temperature corresponded to 1st flash temperature to determine total flow steam fraction
- Data and calculations used to identify trends in temperature, flow and power with time

Scientific/Technical Approach

Issues:

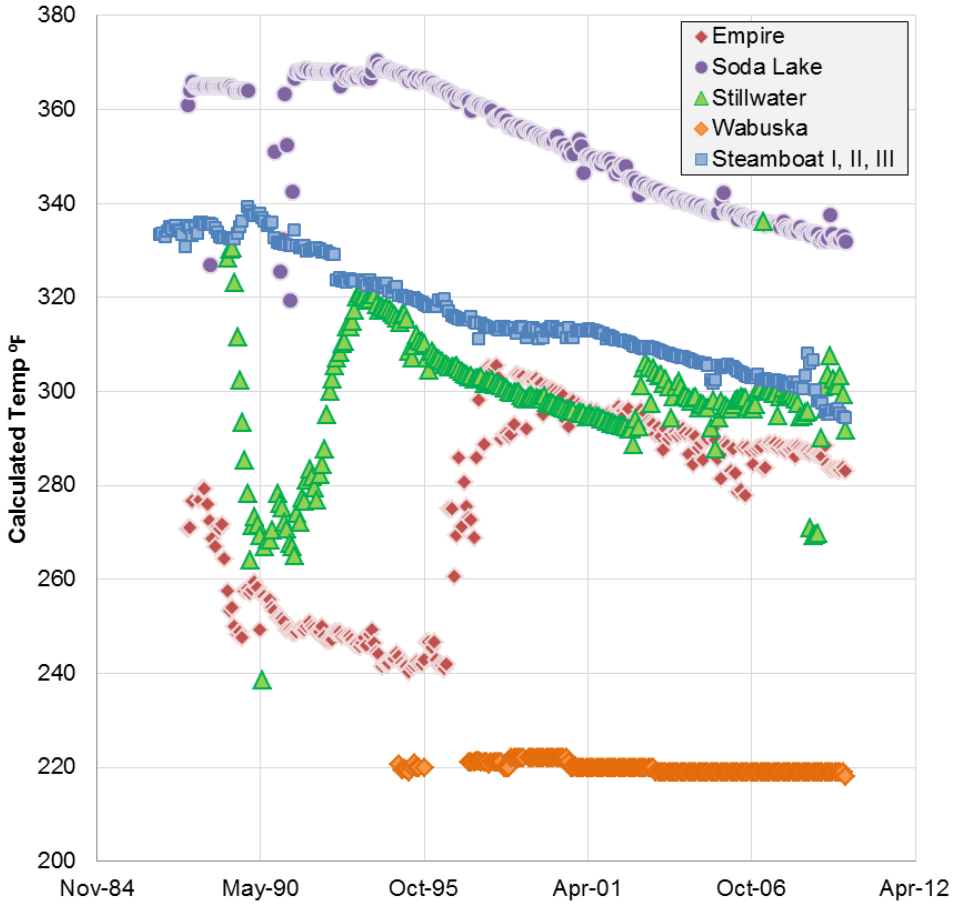
- Operator reports
  - Unable to scan reports to get in digital format – manually inputted
  - Format for report changed
  - Quality and consistency of reported data
  - Uncertainty as to how reported production flow for flash plants determined
- Flash-steam facility assessment
  - Unable to determine change in resource temperature directly from data
  - Approach required did not allow for each month of operation, nor for all facilities
  - Temperatures dependent upon calculation method – more uncertainty in trends
- Resources having multiple operating plants (i.e., Steamboat) complicate looking at individual plants
- Operator reports on Nevada Bureau of Mines and Geology (NBMG) web site were thru 2009 – more recent reports are not available to public

Accomplishments, Results and Progress

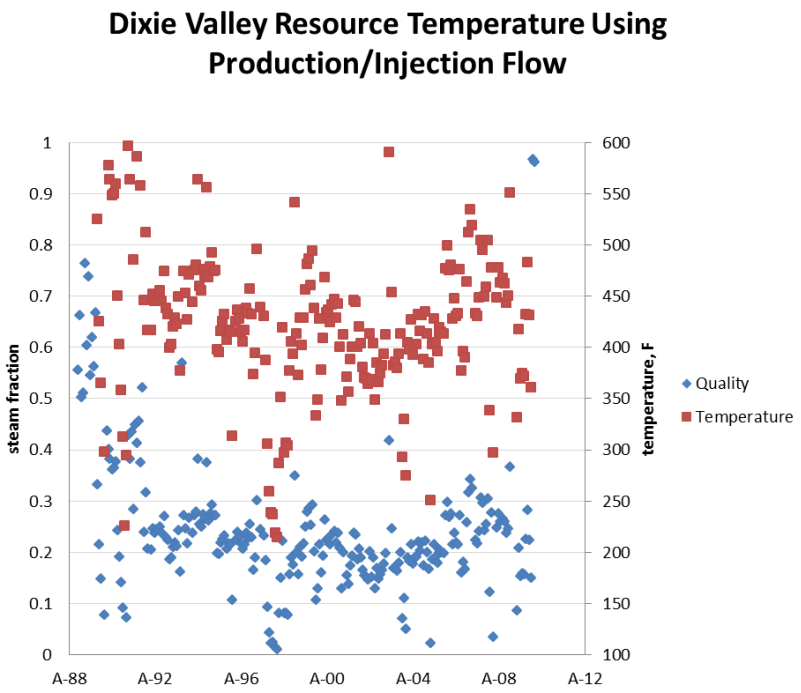
- Inputted monthly report data into Excel files (uploaded to GDR)
- Identified temperature decline rates for NV binary facilities
- Identified temperature decline rates for two NV flash plants
- Assessed the utility of Carslaw-Jaeger solution for heat conduction in understanding thermal decline at Stillwater
- Provided support to NREL's development of well data base
- Provided support to GTO in understanding why the EIA was calculating a decreasing geothermal capacity factor using recent information reported by operators

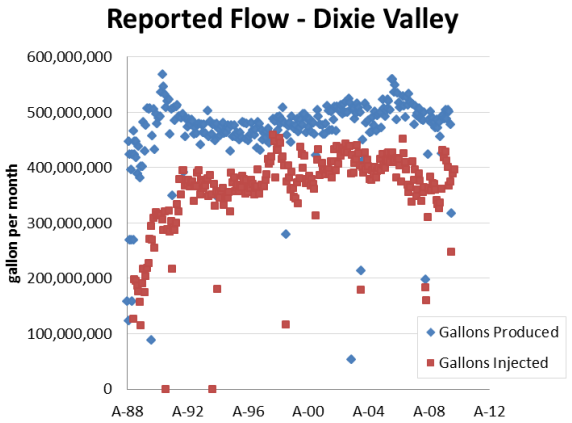
NV Binary Facility Production Temperature

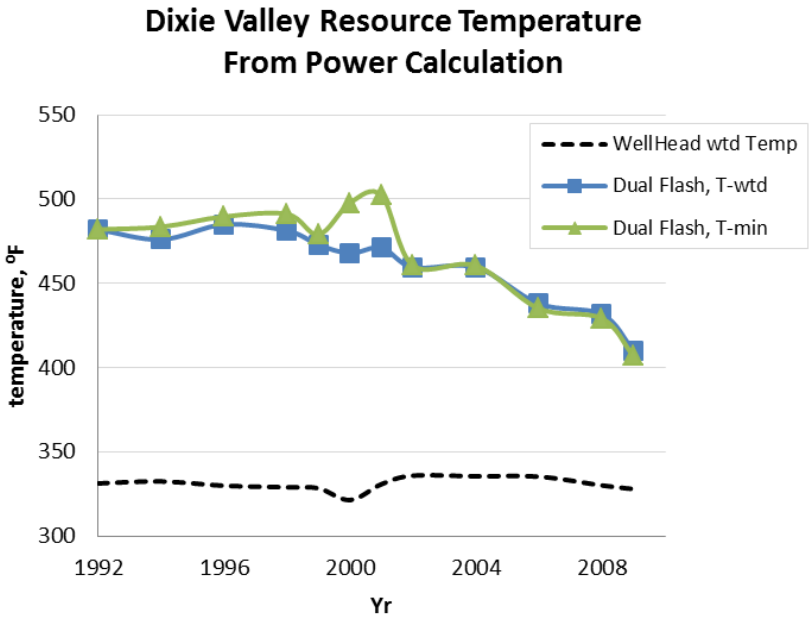
Facility	Annual Decline
Empire (12/87 – 8/96)	-3.3ºF
Empire (9/97 – 12/09)	-1.5ºF
Soda Lake	-1.7ºF
Steamboat I, II, III	-1.7ºF
Stillwater (1/94-12/09)	-1.0ºF
Wabuska	-0.2ºF



Dixie Valley Production Temperature







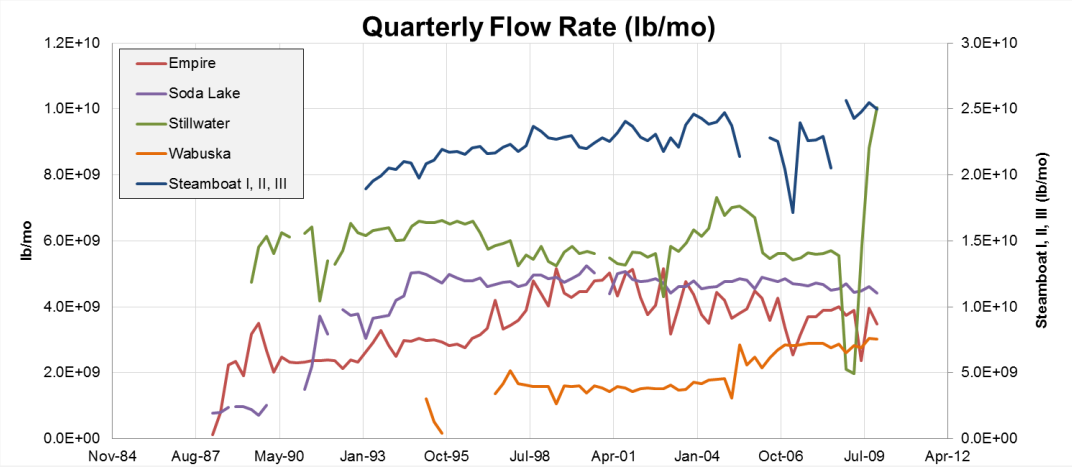
Approach Used	Annual Decline
Production/Injection Flow (all data)	+1.4°F
Production/Injection Flow (thru 2003)	-5.6°F
Plant model	-3.9°F

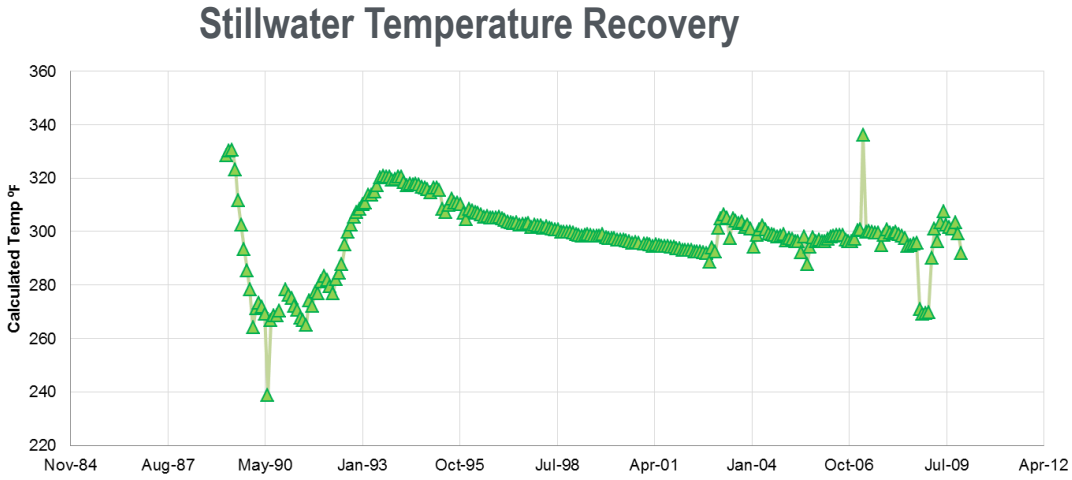
Response to Changing Resource Productivity

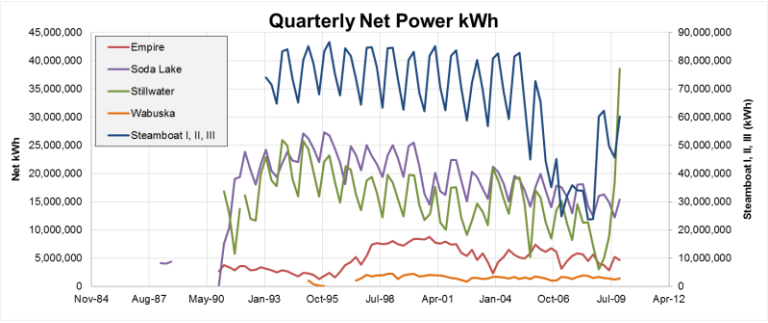
Operator's response

- Increase flow
- Change injection strategy (Stillwater)

Power eventually declines







Accomplishments, Results and Progress

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Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Upload NV binary facility data to GDR	Data uploaded in Excel format	12/2013
Upload NV flash-steam facility data to GDR	Data uploaded in Excel format	3/2014
Evaluate resource decline for binary facilities	Completed evaluation of NV binary plants	7/2014
Establish which INL reservoir model best suited to characterize reservoir decline	Evaluated Carslaw-Jaeger model with Stillwater data & found it inappropriate for that site	9/2014

Other:

- Both interns presented papers and posters at 2014 GRC
- Both interns received Special Recognition awards from GEA in 2014 for their support in improving the GTO's understanding of evolving performance and operation of geothermal plants

Future Directions

This project did not receive FY15 funding. Uncosted funds from FY14 will be used to sponsor another undergraduate student intern in FY15.

- Student will continue work with data files for NV facilities and help to validate other GETEM inputs
- Determine whether similar data is reported in other states by geothermal operators, and whether that data is available

Mandatory Summary Slide

This project has two primary goals

- Provide the GTO with information to help it better characterize how reservoir productivity changes and how those changes impact power production
- Introduce student interns to geothermal energy

This project has met those goals.

Additional Information

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- This slide is provided in order to allow space for any additional information/images that you would like to share with the Peer Review Panel. Insert this slide wherever you deem it most appropriate.

Optional slide- keep to one slide