Co-Produced Geothermal Power*

William D. Gosnold[1] and Anna M. Crowell[1]

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[1]Harold Hamm School of Geology and Geological Engineering, University of North Dakota, Grand Forks, ND (will.gosnold@engr.und.edu)

Abstract

Advances in binary energy conversion technology, i.e. small organic Rankine cycle engines, have generated interest in the potential for electric power generation from low-to-intermediate temperature fluids in deep sedimentary basins. Estimates of the power that could be produced have been based on calculations of the energy stored in permeable formations, formation properties relevant to reservoir productivity and on total fluid production data from oil and gas databases. These general estimates indicate that large quantities of power could be extracted from many intracratonic basins using co-produced fluids and fluids pumped from hot permeable formations.

Estimates of the resource potential for the Williston Basin are on the order of 1020 Joules which implies a resource potential of several GW of electrical power. However, the water-to-oil production ratio (WOR) for the Williston Basin is low, 1.22:1 based on 8,013 working wells in 2013. Other than the Bakken, the Madison (Mississippian) and the Red River (Ordovician) formations produce the greatest fluid volumes from the basin. Power production for the top ten producing wells in the Madison and Red River formations based on an exit temperature of 160 °F (71.1 °C) and an ambient air temperature of 60 °F (15.6 °C) for an ORC with 6 percent efficiency are approximately 671 kW and 814 kW respectively. Repeating the calculations for the unitized Madison and Red River fields yields co-production potentials of 3 MW for the Madison and 4 MW for the Red River. Thus, actual power production from co-produced fluids in the Williston Basin may be several orders of magnitude less than was predicted in earlier estimates.

Selected Reference

MIT Report, 2007, The Future of Geothermal Energy: Web accessed October 11, 2013.
http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf

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AAPG Rocky Mountain Section

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Will Gosnold and Anna Crowell

Geothermal Laboratory

Harold Hamm School of Geology and Geological Engineering

University of North Dakota

Take Home Message

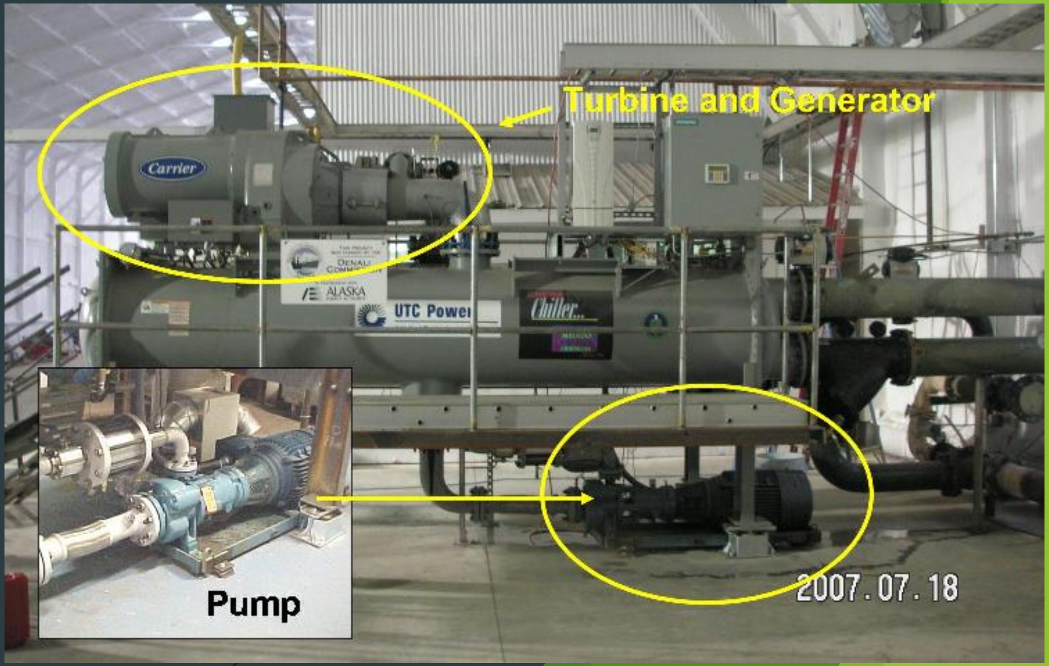
- Advances in ORC and other energy conversion technologies make low temperature (90 °C-150 °C) geothermal waters a promising electric power resource
- Initial assessments over-estimated the resource by using total water production for states or regions
- Co-produced resource assessment must include oil and water production data by well, unit, field and formation
- Water production in the Williston Basin is too low for most conventional production settings
- Distributed binary systems in unitized or watered-out fields could provide a significant power resource although energy extraction technology could be improved
- Increasing development of multi-well pads will make co-produced water from the Bakken – Three Forks boom a power resource

Optimism for ORC power

- The potential power production using oil field waste waters with ORC technology is estimated to be at least 5.9 GW and could be as high as 21.9 GW

- Co-produced power would be economically competitive with 1,000 gpm and temperatures of at least 90 ºC (192 ºF)

(McKenna et al., 2005; MIT – 2007)



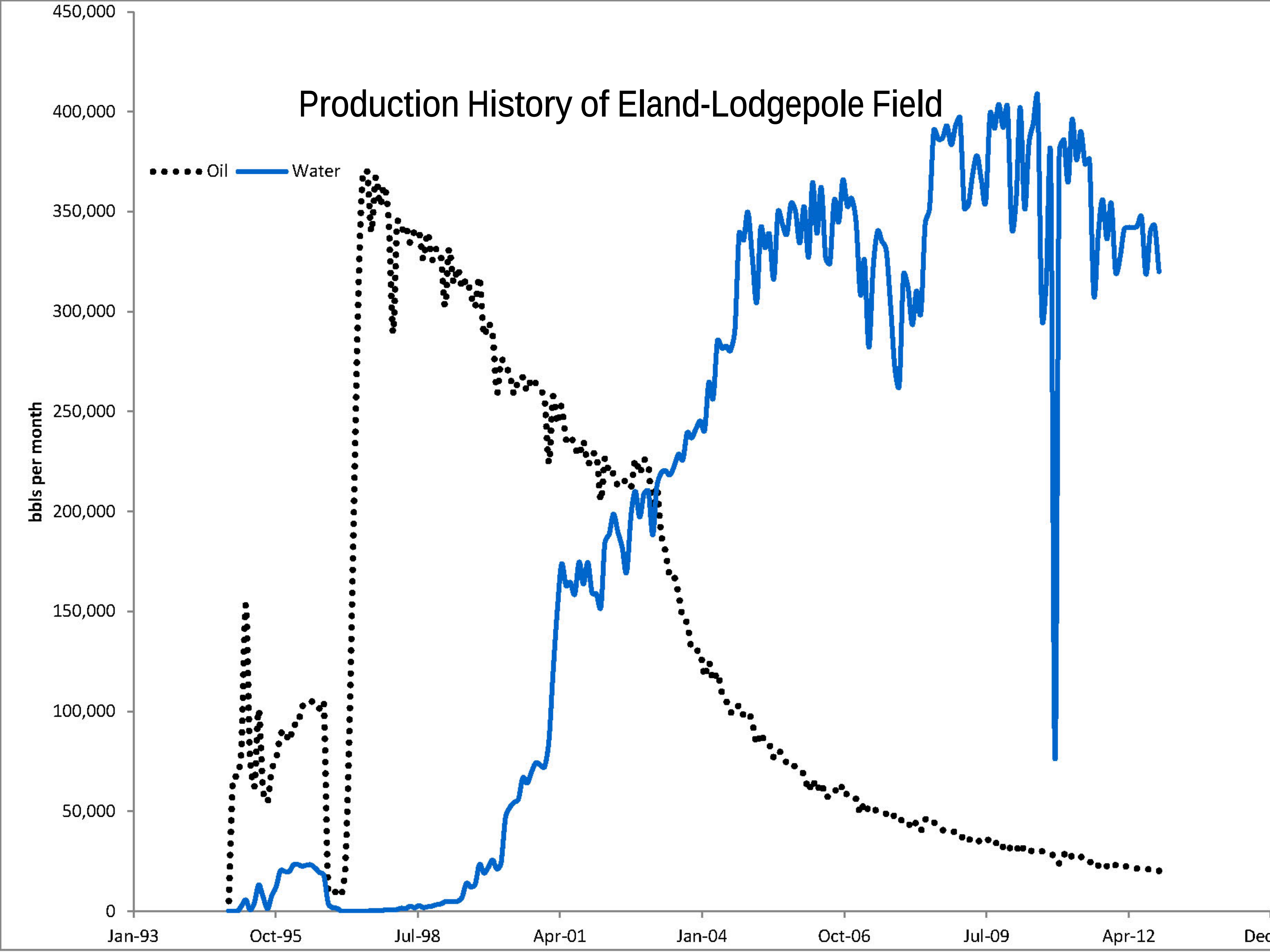
Optimism for co-produced waters

- “Collecting and passing the fluid through a binary system electrical power plant is a relatively straightforward process.”
- “Piggy-backing on existing infrastructure should eliminate most of the need for expensive drilling and hydrofracturing operations, thereby reducing the risk and the majority of the upfront cost of geothermal electrical power production.”

Source: "The Future of Geothermal Energy," MIT Report, January 22, 2007.

Co-Produced Project Dickinson, ND

- Water Flood EOR
- Eland-Lodgepole Field
- 210 °F, 400 gpm, high TDS water from Lodgepole Fm.
- Twelve wells collecting fluids at a central location
- Ormat & Pratt & Whitney estimated 350 kWe
- Local electric utility highly interested


Production History of Eland-Lodgepole Field
Oil
Water
bbls per month
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Jan-93
Oct-95
Jul-98
Apr-01
Jan-04
Oct-06
Jul-09
Apr-12
Dec

Estimated U.S. geothermal resource base to 10 km depth by category

Category of Resource	Thermal Energy, in Exajoules (1EJ = 10^{18} J)	Reference
Conduction-dominated EGS		* Excludes Yellowstone National Park and Hawaii ** Includes methane content
Sedimentary rock formations	100,000	MIT - 2007
Crystalline basement rock formations	13,300,000	MIT - 2007
Supercritical Volcanic EGS*	74,100	USGS Circular 790
Hydrothermal	2,400 – 9,600	USGS Circulars 726 and 790
Coproduced fluids	0.0944 – 0.4510	McKenna, et al. (2005)
Geopressured systems	71,000 – 170,000**	USGS Circulars 726 and 790

Source: "The Future of Geothermal Energy," MIT Report, January 22, 2007.

Resource Assessment

$$Q = \rho C_p V \Delta T$$

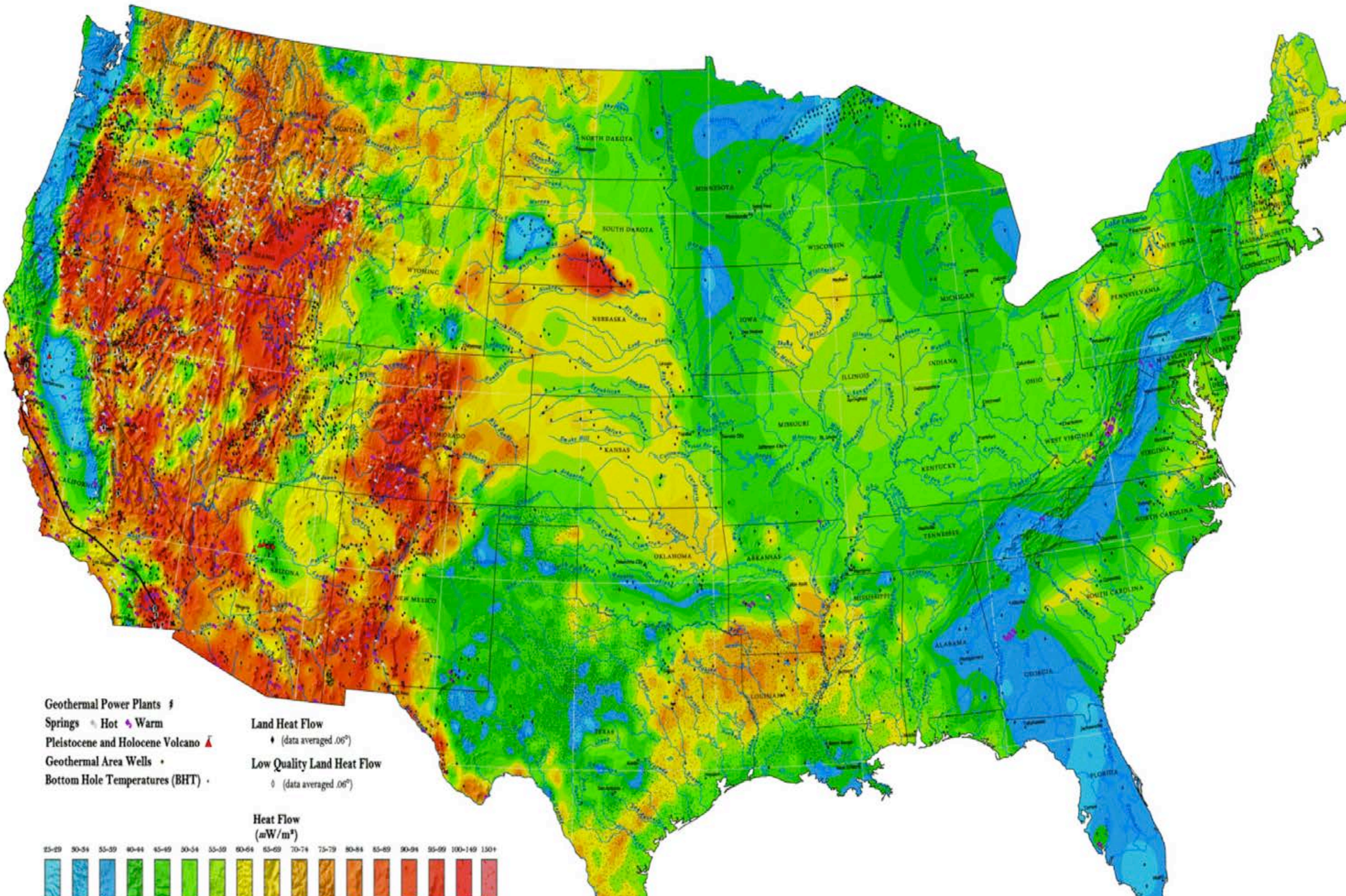
ρ is rock density
C_p is volumetric heat capacity
V is volume of rock
ΔT is the temperature difference between the geothermal fluid and temperature exiting the heat exchanger

Resource Assessment

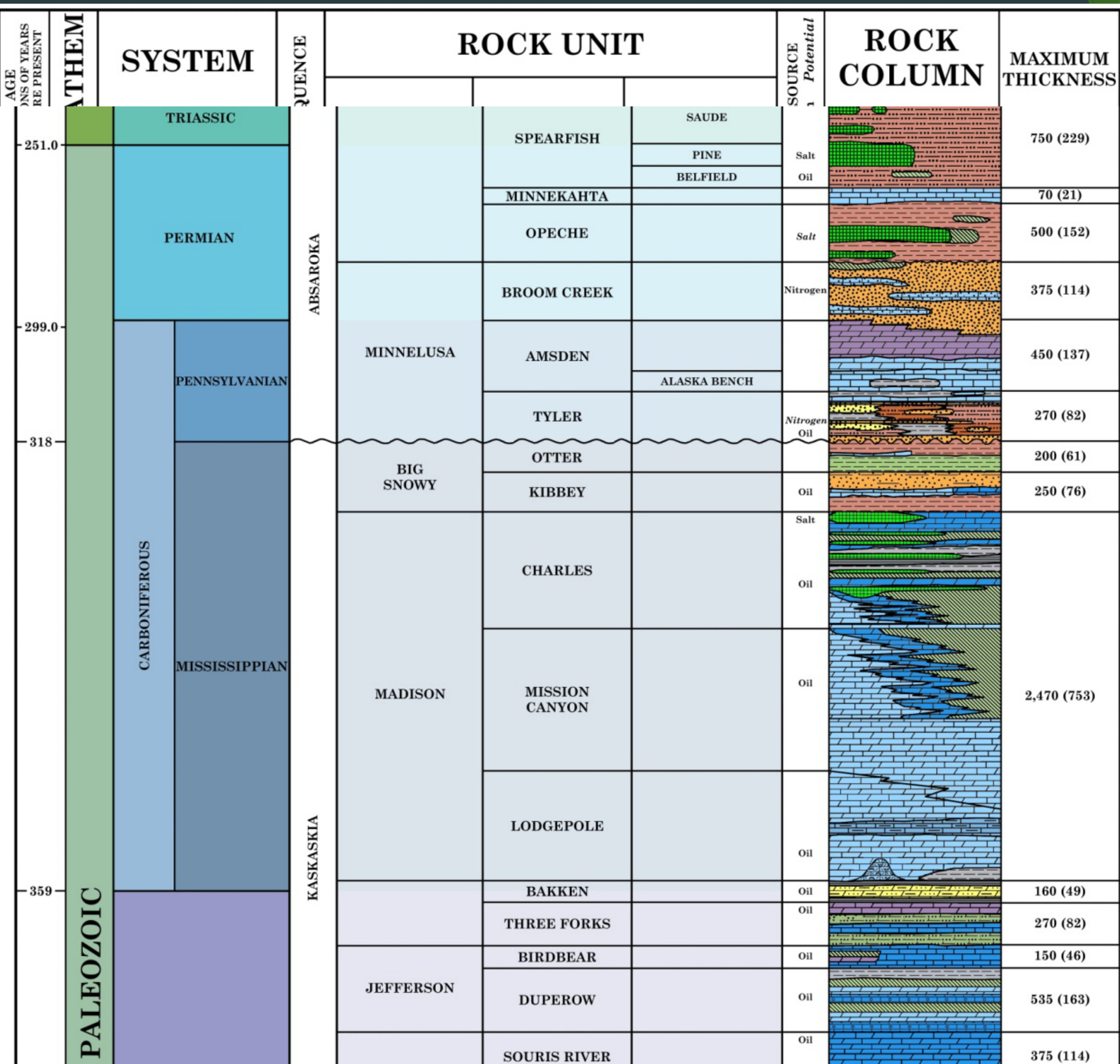
- Heat Flow
  - Temperature and temperature gradient
    - Measured or derived from BHT data
  - Thermal conductivity
    - Measured or from literature
- Rock Formation Properties
  - Porosity
  - Permeability
  - Thickness
  - Depth
  - Composition – mineralogy – fabric
  - Fluid composition
  - Fluid production

Determine subsurface temperature at any depth where heat flow, q, and thermal conductivity, λ, are known

$$T(z) = T_0 + \sum_{i=1}^{n} \frac{qz_i}{\lambda_i}$$



SMU Geothermal Lab, Geothermal Map of United States, 2004



$W m^{-1} k^{-1}$

2.5

2.2

4.0

2.2

2.2

2.7

2.49 ±. 048

1.10 ± 0.20

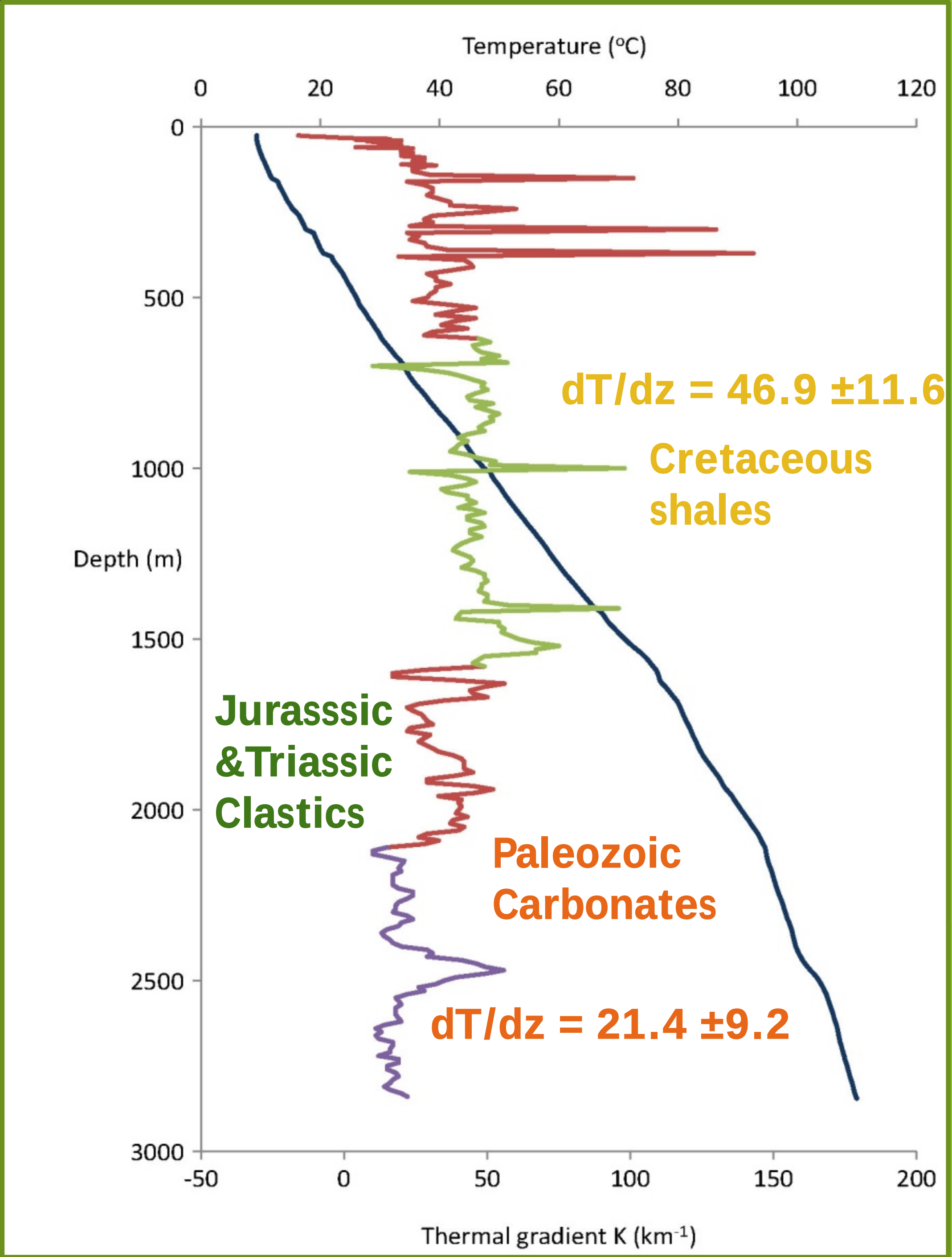
3.13 ± 0.73

3.19 ± 0.51

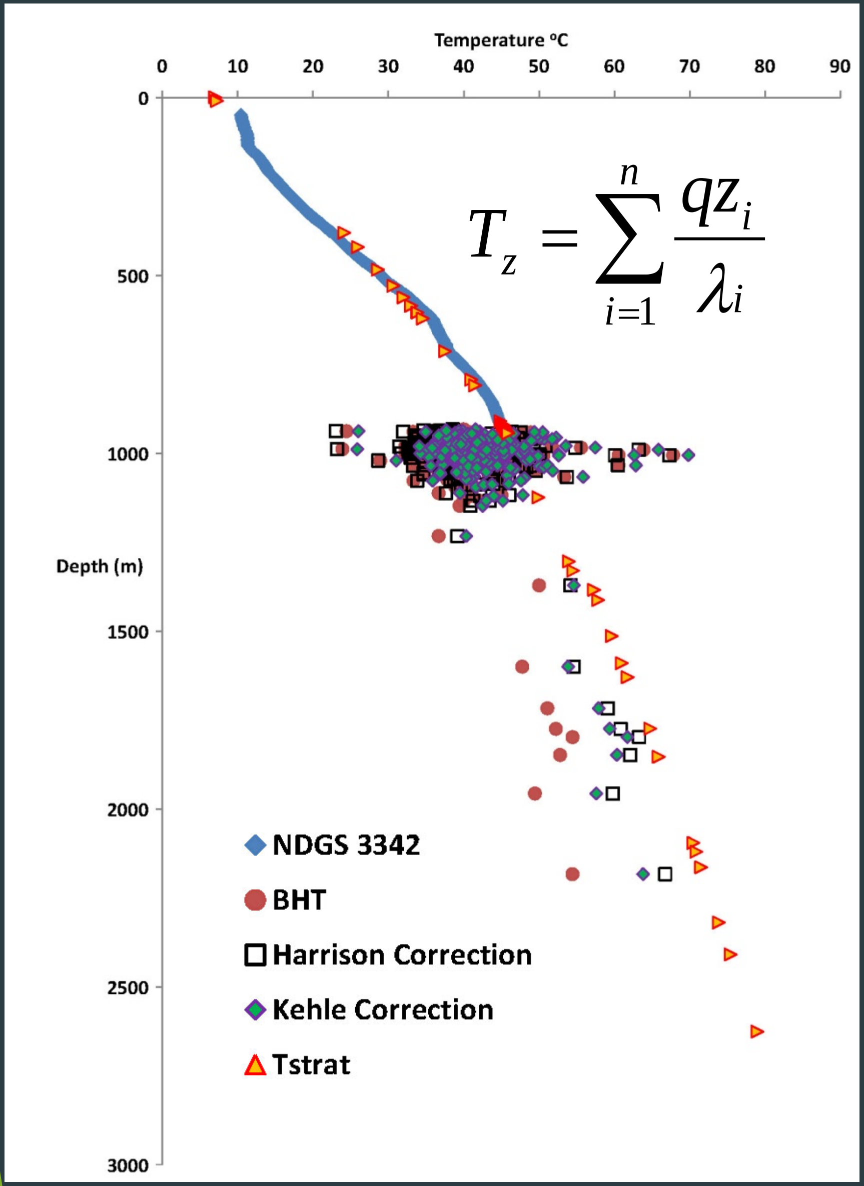
2.92 ± 0.48

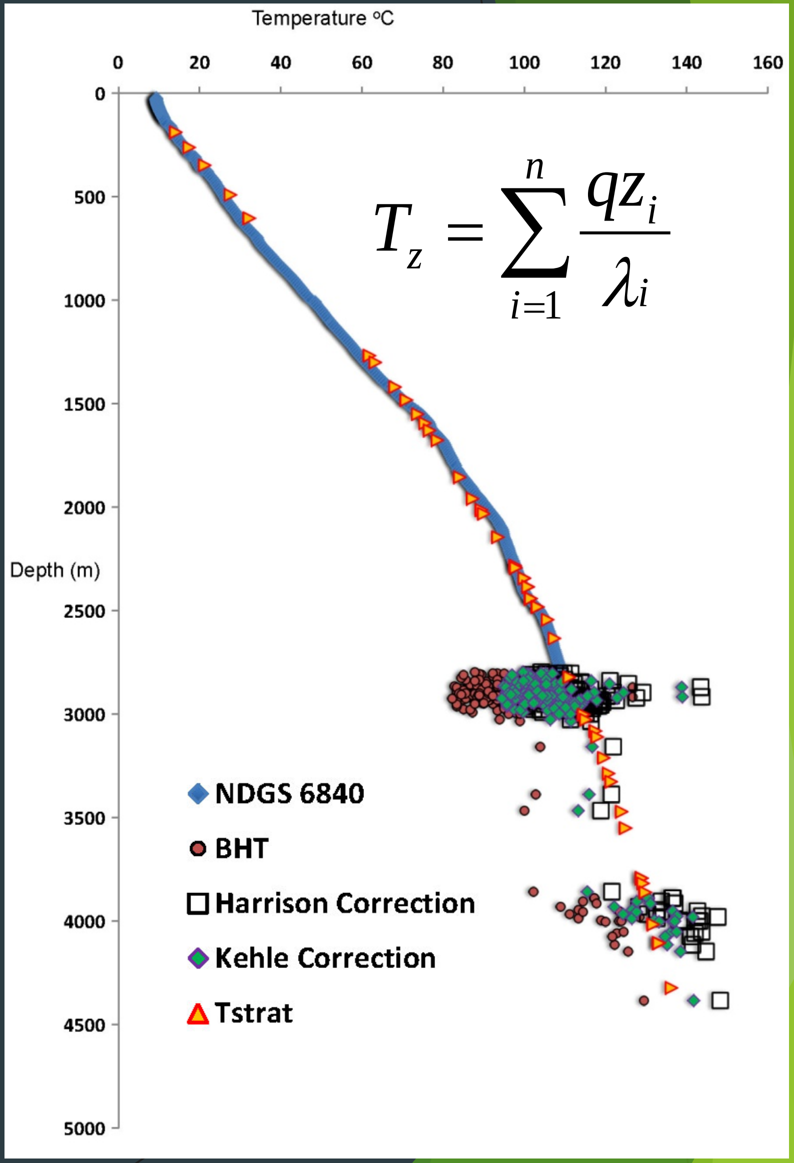
The geothermal gradient varies inversely with thermal conductivity

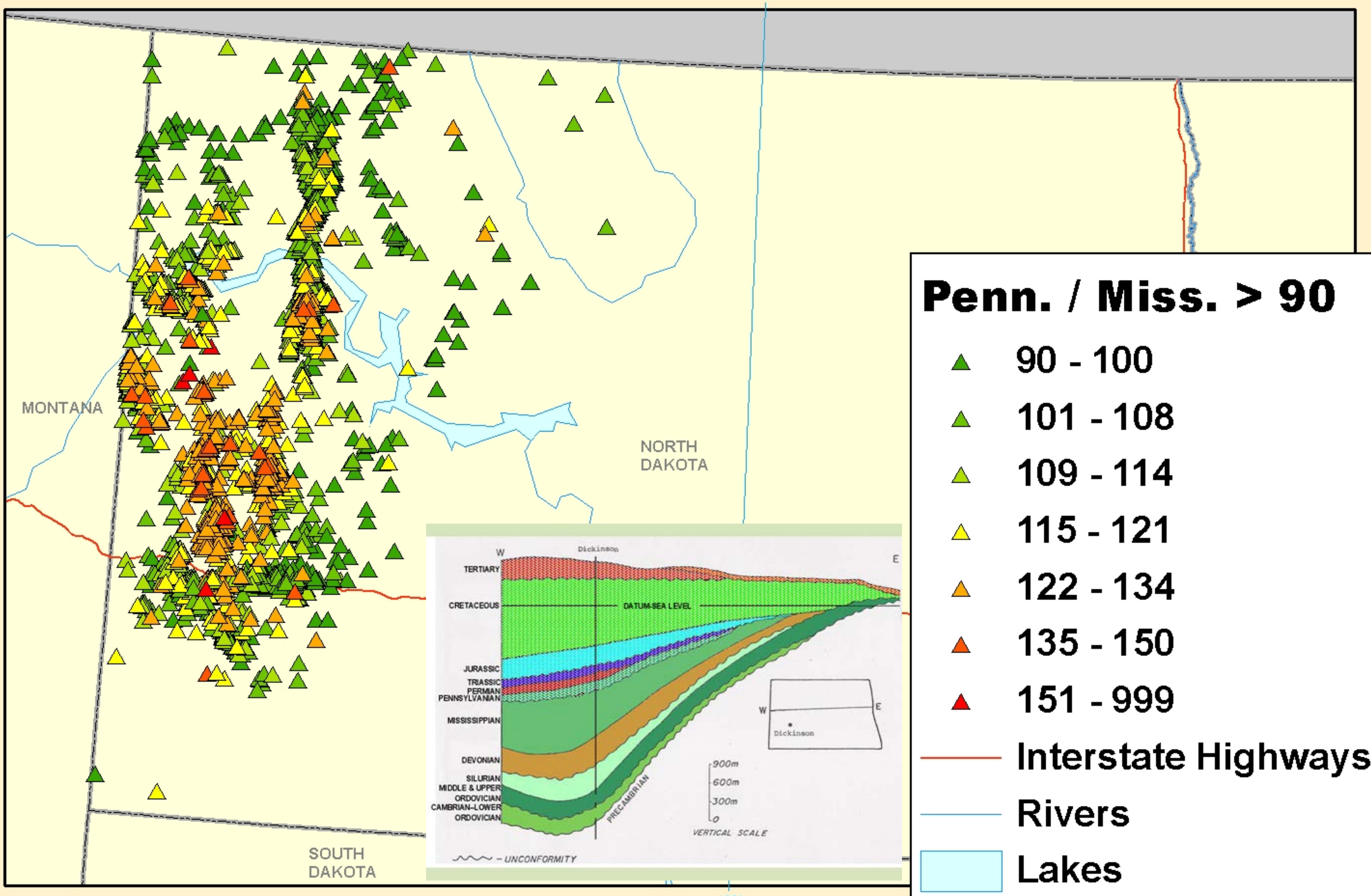
Temperature and gradient vs. depth in NDGS 6840 near the ND-MT border



Thermal Stratigraphy and BHTs







Geothermal Laboratory
The University of North Dakota

North Dakota

Pennsylvanian/Mississippian Wells

N

Anna M. Crowell
University of North Dakota
Department of Geology and Geological Engineering

0 10 20 40 60 80 Km

Albers Projection
Central Meridian: -96
1st Std Parallel: 20
2nd Std Parallel: 60
Latitude of Origin: 40

Resource estimate for Williston Basin

$$Q = \rho C_p V \Delta T$$

GIS mapped formation volumes at 10 °C intervals with water volumes determined from published data on formation porosity

Table 2. Volume and Energy Totals for the Williston Basin.

Anna Crowell, 2011, M.S. thesis

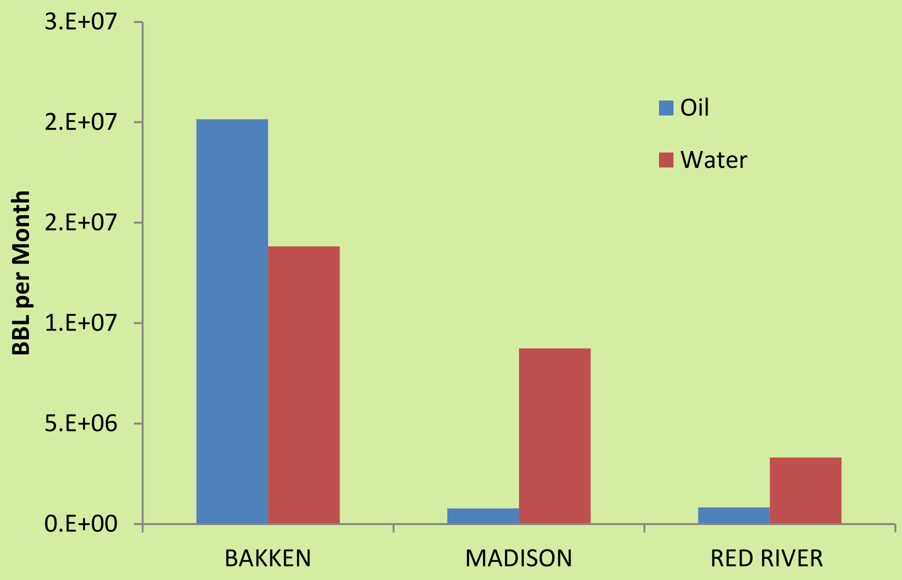
Temp Range	90°-100°C	100°-110°C	110°-120°C	120°-130°C	130°-140°C	140°-150°C	150°C +
Rock Volume	65,167.9 km^3	51,673.1 km^3	48,174.2 km^3	44,626.1 km^3	26,213.4 km^3	11,696.9 km^3	8,825.8 km^3
Water Volume	4,037.2 km^3	3,091.9 km^3	2,891.5 km^3	2,723.3 km^3	1,594.7 km^3	726.3 km^3	530.2 km^3
Thermal Energy	6.88×10^{18} J	6.81×10^{18} J	7.57×10^{18} J	8.17×10^{18} J	5.49×10^{18} J	2.80×10^{18} J	2.36×10^{18} J
Power Availability	2.15×10^9 MW	1.89×10^9 MW	2.10×10^9 MW	2.27×10^9 MW	1.52×10^9 MW	7.78×10^8 MW	6.56×10^8 MW

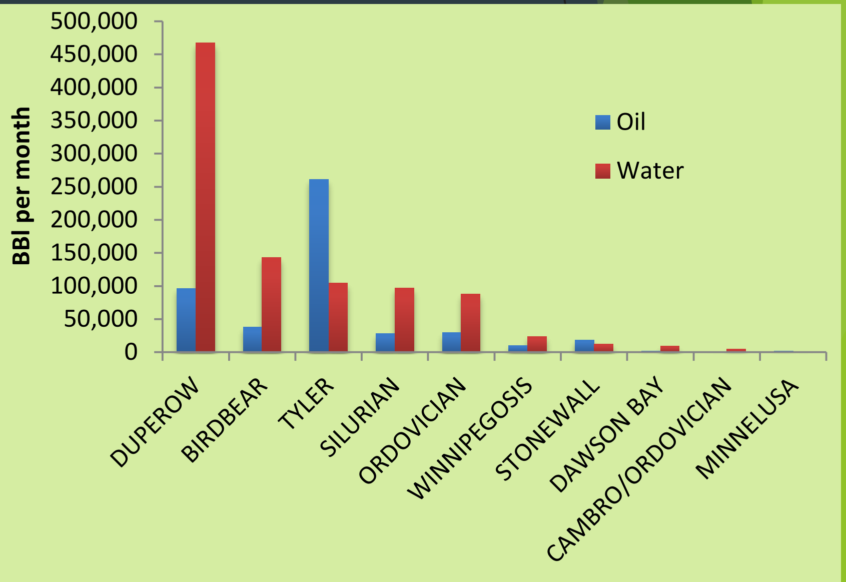
Can co-production yield significant power ?

- The main oil and water producing formations in the Williston Basin

Pool	BBLS Oil	BBLS Water	WOR Ratio	BBl oil/well	BBl water/well
BAKKEN	20,046,962	13,818,929	0.7	4,163	2,869
RED RIVER	829,559	3,305,592	4.0	1,659	6,611
MADISON	699,470	8,119,405	11.6	366	4,253

Numbers are BBLS per month for Oct. 2012





- The average temperatures of the main producing formations were determined from corrected BHTs

Pool	BBLS Oil	BBLS Water	Max T °C at 1 Σ	Min T °C at 1 Σ	Avg T °C
BAKKEN	20,046,962	13,818,929	128	116	122
RED RIVER	829,559	3,305,592	147	113	130
MADISON	768,496	8,691,561	118	92	105

- The energy that can be extracted from produced waters was calculated assuming a temperature drop to 70°C and efficiencies varying by formation temperature for the Access Energy XLT

Pool	T °C	kWe
BAKKEN	122	10,946
RED RIVER	140	2,021
MADISON	105	4,011
Cedar Hills	105	348

The total from the GIS analysis is 656 MWe

Power Production from top Madison and Red River Units in Co-Production Scenario

Unit	Oil bbl	Water bbl	No. Wells	Water gpm	kWe
Cedar Hills S. Red RR B	292,351	2,282,671	117	2,045	1,170
Cedar Hills N. Red RR B	385,634	605,212	115	542	426
Medicine Pole Hills RR	27,908	127,200	22	114	62

Unit	Oil bbl	Water bbl	No. Wells	Water gpm	kWe
Renville Madison	10,009	786,028	18	704	384
T.R. Madison	24,564	416,072	23	373	235
Eland Lodgepole	21,388	318,719	12	286	146

Co-produced vs. Water Only

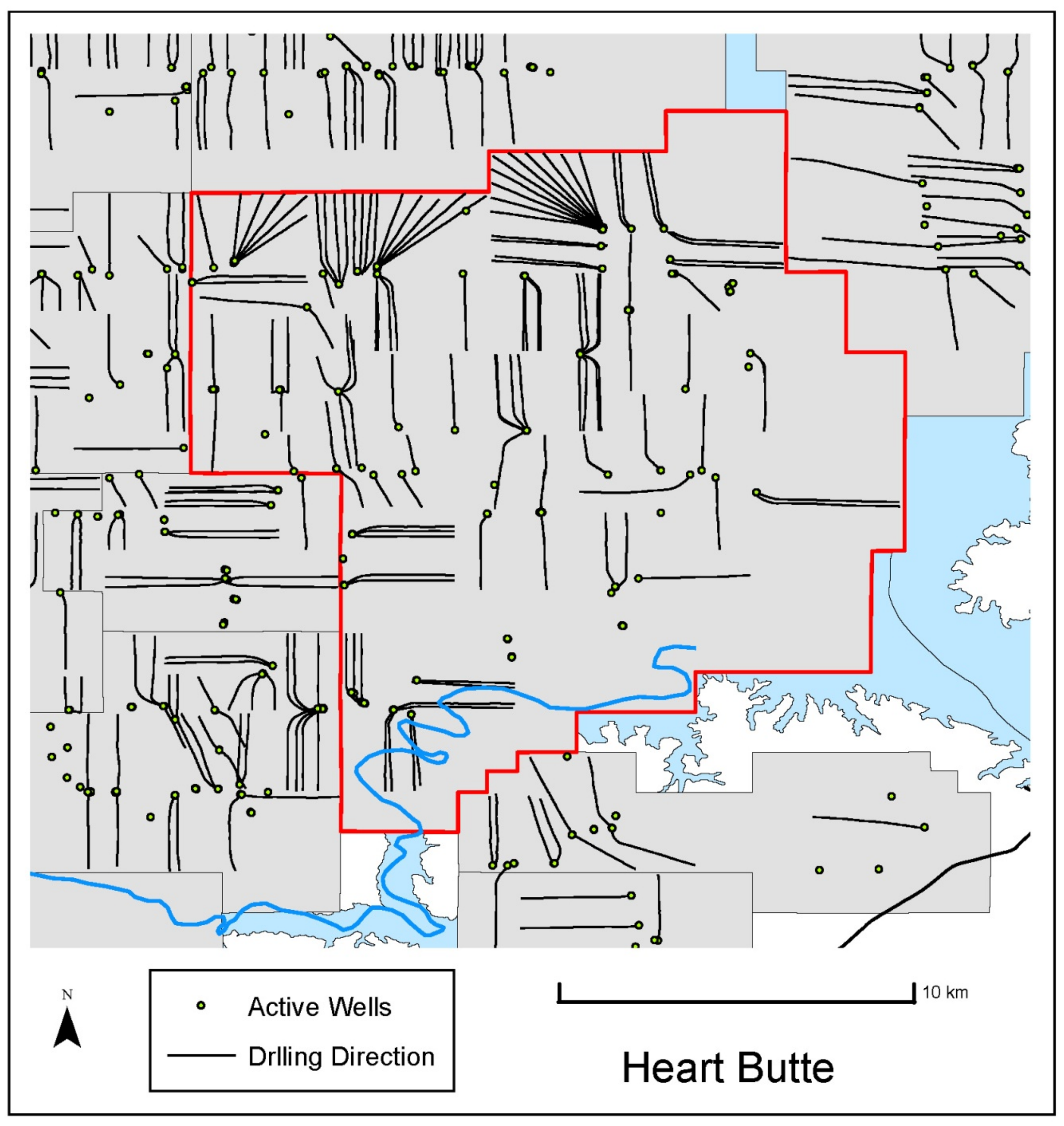
The top producing individual oil wells in the Madison, Red River and Bakken formations do not yield sufficient water to be economic as a co-production electrical power system.

If the wells were produced solely for water, the power production would be significant.

Madison Oil bbl/day	100 °C H_2O bbl/day	Fluid bbl/day	H_2O gpm	lb/hr	Co-produced power (kW)	Moderate Rate (kW)	High Rate (kW)
28	3511	3539	98	46809	**110**	**2,200**	**22,000**
92	3006	3099	84	40084	**80**	**1,600**	**16,000**
36	2722	2758	76	36287	**73**	**1,460**	**14,600**

New Developments

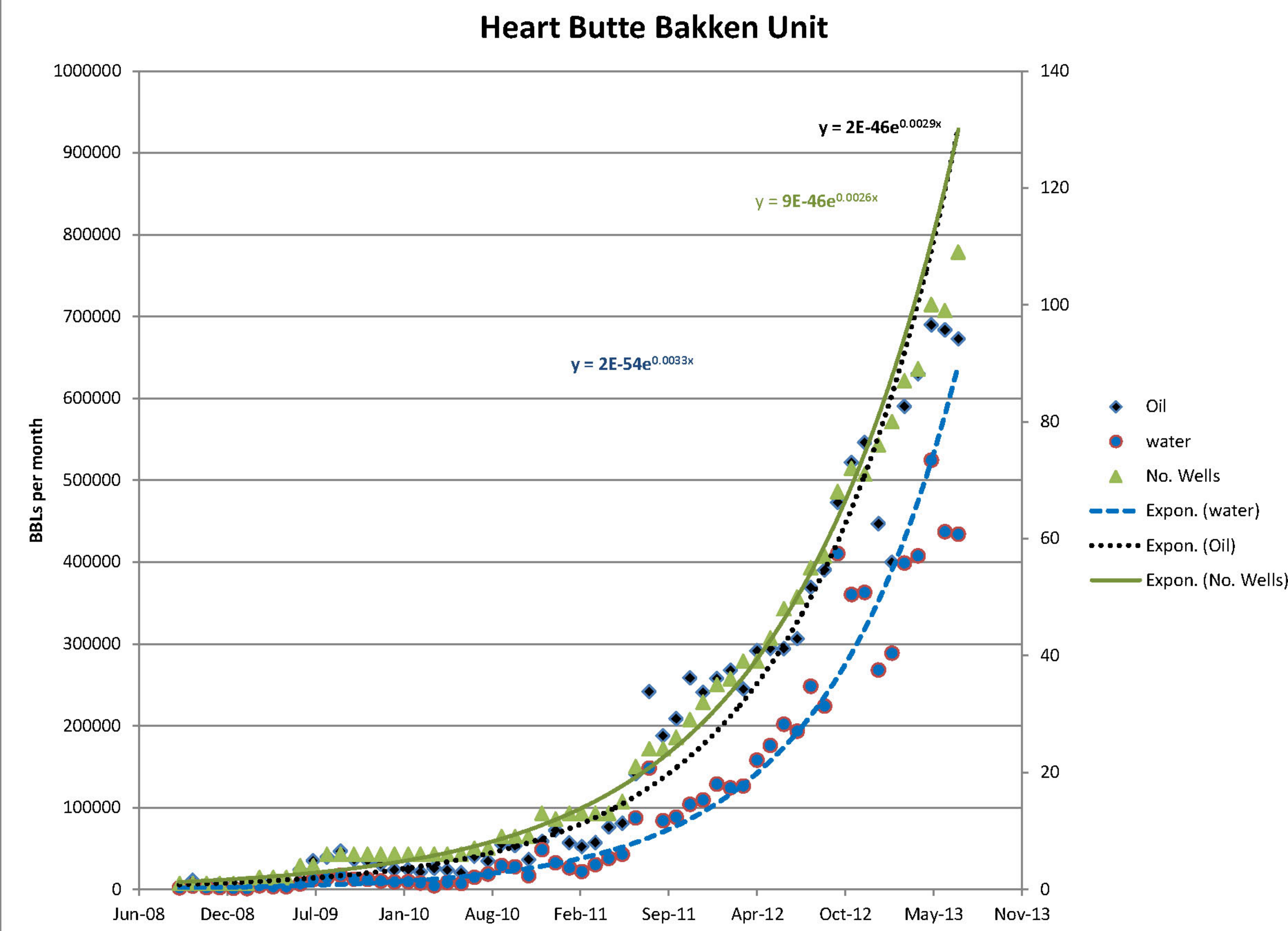
multi-well pads and high density infill drilling



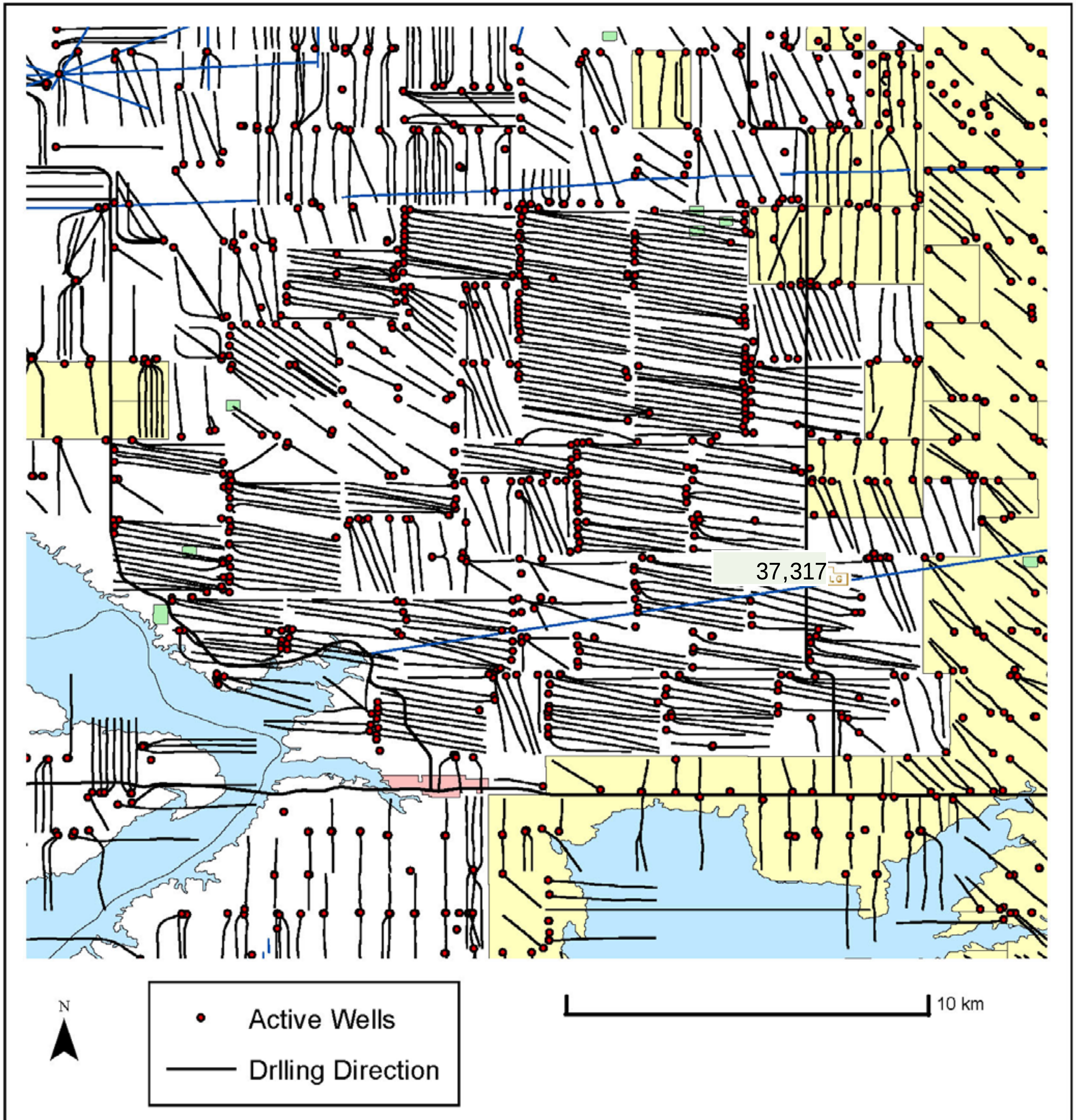
Horizontal drilling and fluid production in the Heart Butte Bakken field have increased exponentially since February 2011.

Fluid production has averaged 37,317 bbl per day since April, 2013.

Estimate of power using oil water mix before separation: > 2 MWe

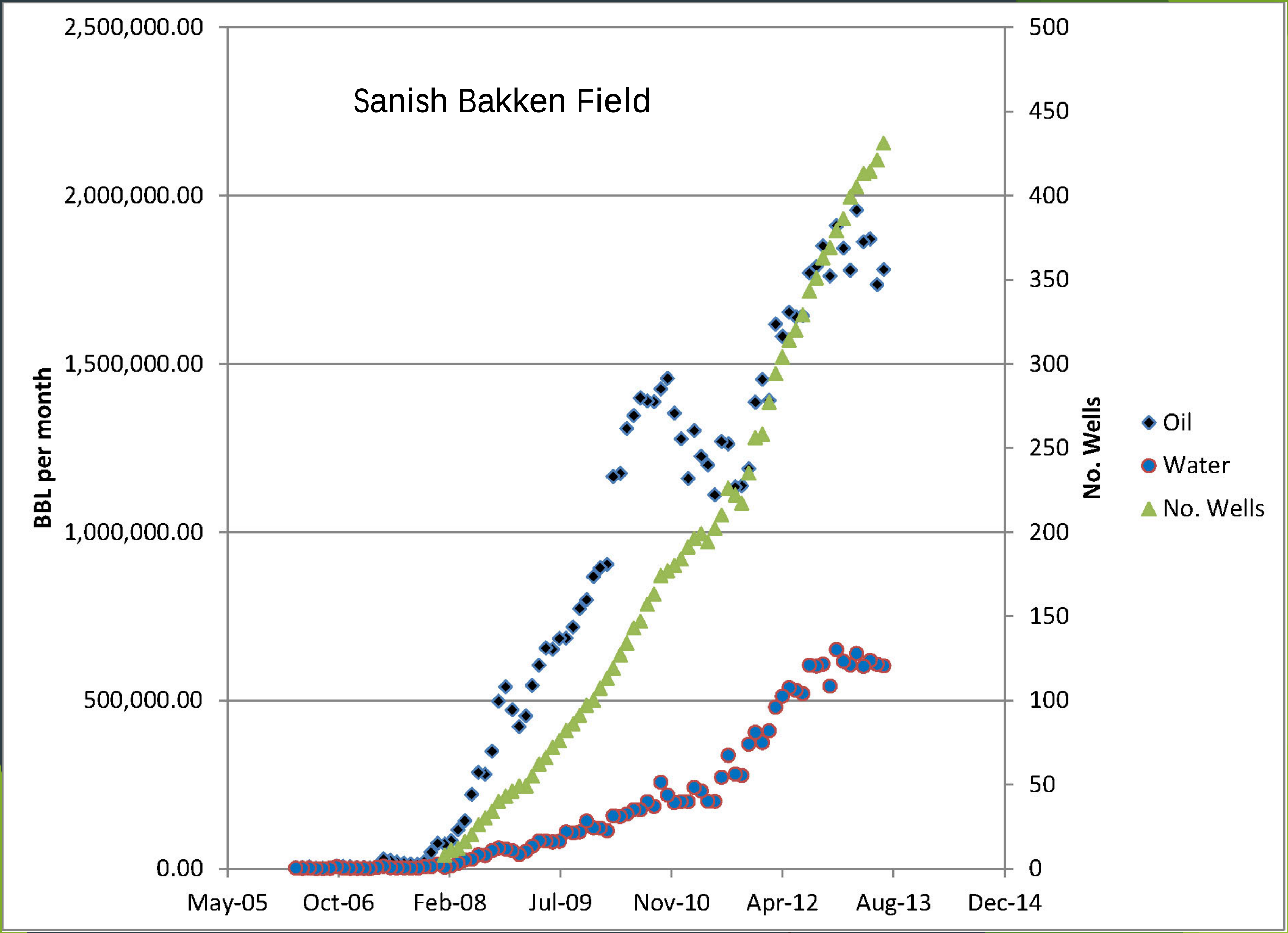


Heart Butte Bakken Unit
BBLs per month
1000000
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
140
120
100
80
60
40
20
0
Jun-08
Dec-08
Jul-09
Jan-10
Aug-10
Feb-11
Sep-11
Apr-12
Oct-12
May-13
Nov-13
y = 2E-46e0.0029x
y = 9E-46e0.0026x
y = 2E-54e0.0033x
Oil
water
No. Wells
Expon. (water)
Expon. (Oil)
Expon. (No. Wells)



Horizontal drilling and fluid production in the Sanish Bakken field have increased linearly at a rate of 1,235 bbl/month since February 2008.

Fluid production has averaged 80,264 bbl per day since April, 2013. Estimate of power using oil water mix before separation: >4 MWe



Sanish Bakken Field
BBL per month
No. Wells
2,500,000.00
2,000,000.00
1,500,000.00
1,000,000.00
500,000.00
0.00
500
450
400
350
300
250
200
150
100
50
0
May-05
Oct-06
Feb-08
Jul-09
Nov-10
Apr-12
Aug-13
Dec-14
Oil
Water
No. Wells

Current data (August 2013) show that the unitized Madison, Red River and Bakken formations do yield sufficient water to be economic for co-produced electrical power.

The table shows power that could be produced by using the water-oil mix prior to separation.

Pool	Oil bbl/day	H_2O bbl/day	gpm	Total MW	MWe
Red River 130^o	1,534,083	12,016,573	350,483	1,569	210
Madison 100^o	710,216	8,212,515	239,532	1,052	114
Bakken 122^o	23,028,598	15,240,015	444,500	3,222	380
Total	25,272,897	35,469,103	1,034,516	**5,843**	**704**

The total from the GIS analysis is 656 MWe

Impact on oil industry

- Installing binary power systems for power generation using co-produced oil field fluids has potential to make a positive impact on oil field economics
- An economic model based on oil and water production rates, water temperature, O & M, oil futures, and electrical cost, shows that power generation using co-produced fluids could generate millions of dollars in additional revenue by saving on electrical costs, extending the Estimated Ultimate Recovery (EUR), and facilitating early development of the field.

Summary

- We have compiled data and developed methods that have enabled us to reach a clear understanding of the geothermal potential of the Williston Basin.
- Water production in the basin is too low for most conventional production settings.
- Distributed binary systems in unitized or watered-out fields could provide a significant power resource although energy extraction technology could be improved.
- Increasing development of multi-well pads and infill drilling will make co-produced water from the Bakken – Three Forks boom a power resource.

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