# GIS-Based Geothermal Resource Assessment of the Denver Basin: Colorado and Nebraska

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***Keywords***

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## ABSTRACT

We have completed a volumetric analysis of the geothermal resource potential of the Denver basin using bottom-hole temperatures (BHTs) from approximately 53,000 wells in Colorado and Nebraska. Re-evaluation of our correction scheme shows that a Harrison-type correction yields the best results for a mid-continental United States sedimentary basin. Formation names are not always constant across state boundaries, so we grouped the wells according to seven geochronological units; Lower Cretaceous, Upper Cretaceous, Jurassic, Permian, Pennsylvanian, Mississippian, and Ordovician. We utilized the recovery factor from Sorey et al., which is 0.001 for a structure the size of the Denver Basin. Our estimate of the thermal energy in place, after the recovery factor, is listed by temperature range as follows: 1.49 x $10^{19}$ Joules (J) at 90° Celsius (C) and up, 8.15 x $10^{18}$ J at 100° C and up, 3.44 x $10^{18}$ J at 110° C and up, 1.08 x $10^{18}$ J at 120° C and up, 2.35 x $10^{17}$ J at 130° C and up, and 2.09 x $10^{15}$ J at 140° C and up.

## Introduction

The Denver basin is an asymmetric foreland basin with an area of approximately 156,000 square kilometers (km), underlying portions of Colorado, Nebraska, Wyoming, and Kansas. The basin is about four kilometers deep near the Denver area, and contains sedimentary rocks ranging in age from the Cambrian to the Miocene (Martin, 1965). The structure produces both oil and gas; and, with population centers near the region of hottest temperatures, this basin is of interest for geothermal power production.

**Table 1.** Heat capacity and density of dominant rock types (Touloukian et al., 1981).

| Rock Type | Density (kg/km$^3$) | Heat Capacity (J/kg°C) |
|---|---|---|
| Shale | 2.35E+12 | 1046.03 |
| Sandstone | 2.30E+12 | 920.48 |
| Limestone | 2.60E+12 | 830 |
| Dolomite | 2.90E+12 | 920 |

## Methods

We calculate the available thermal energy in place (Q) from:

$$Q=\rho CpV\Delta T,$$

where ($\rho$) is the density of the major rock type in the unit, and (Cp) is the heat capacity of the rock type. The values we used for each geochronological unit were the density and heat capacity of the rock found in the oil producing formations. Shale is the predominant rock type of the Upper Cretaceous unit, and Sandstone,

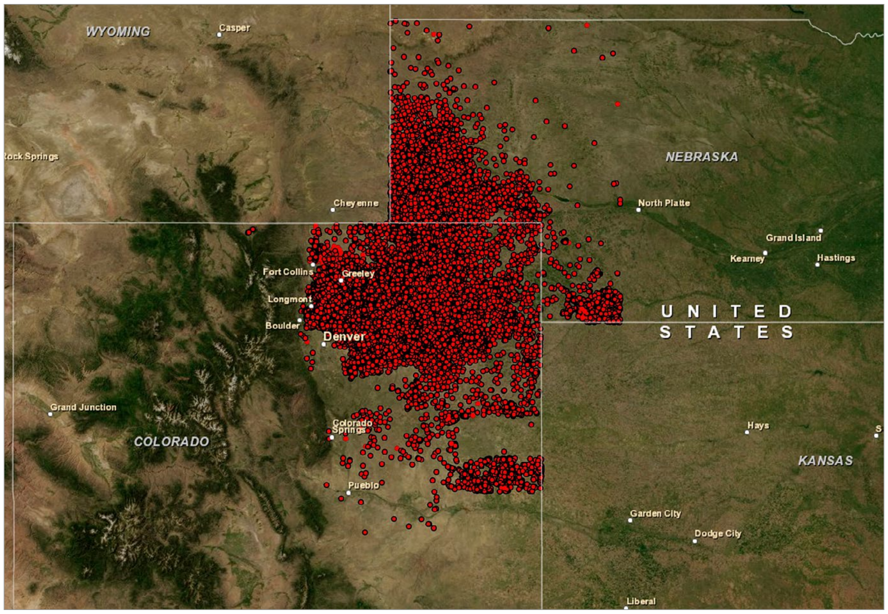

**Figure 1.** Location of Denver Basin wells with BHT data.

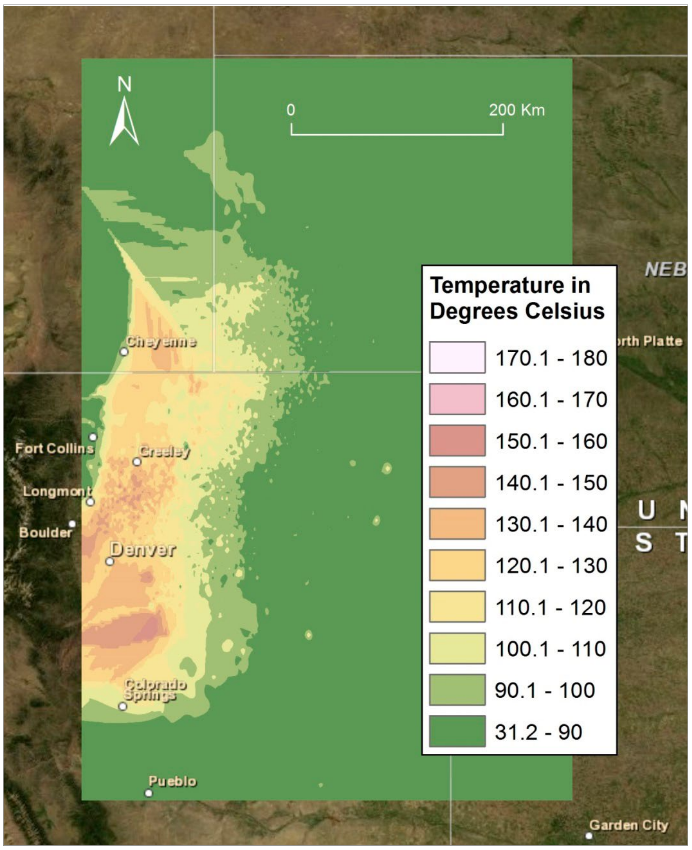

**Figure 2.** Interpolation (kriging method) of the Lower Cretaceous wells, manually classified according to temperature range.

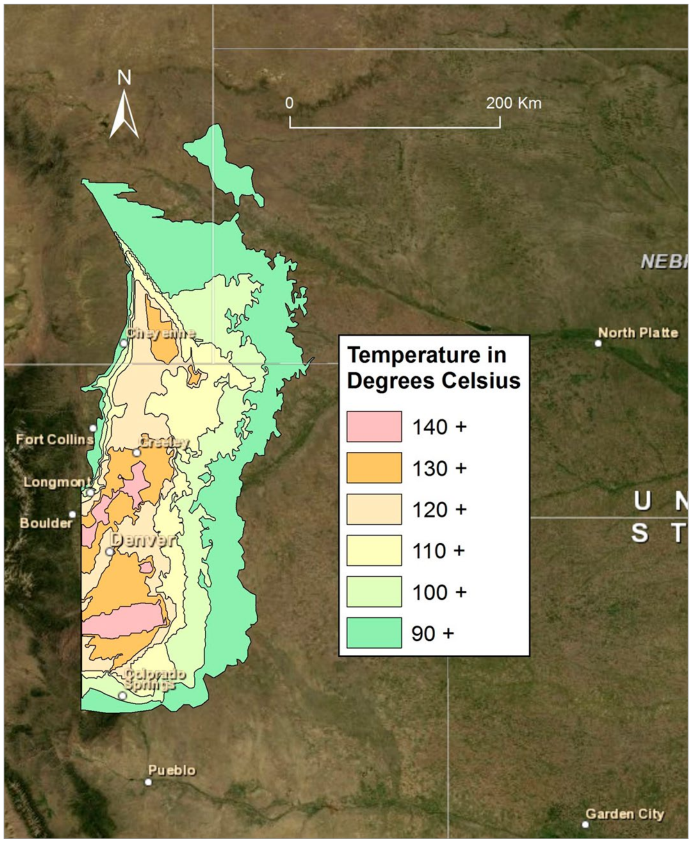

**Figure 3.** Area polygons created from the reclassified temperature raster.

Limestone, and Dolomite were the major rock types for the other six units (Table 1) (Touloukian et al., 1981). The density and heat capacity values for sandstone were the lowest value of the three dominating rock types; therefore, the values for sandstone were used in units that had an even mix of all three rock types.

We determined rock volume from oil and gas well data. About 53,000 wells (Figure 1) were compiled from the Nebraska Oil and Gas Conservation Commission and Dr. Paul Morgan of the Colorado Geological Survey. Prior work regarding a correction scheme based on equilibrium data was re-evaluated with the availability of new data (Crowell and Gosnold, 2012). A new correction scheme based on the new, deeper data that were more representative of the entire basin was found to be similar to the Harrison correction, indicating that the Harrison is the appropriate correction to use for this basin.

Formation names vary across state lines; therefore, formations were correlated and grouped by geochronological unit. The standard deviation was computed and values outside of two sigma were eliminated, which resulted in the deletion of approximately 2,000 wells of the 53,000 well dataset. The prepared spreadsheets were imported into a file geodatabase within ArcGIS, each geochronological data set was interpolated with the kriging method, and the resulting raster was classified manually into ten classes representing temperature ranges of 90+, 100+, 110+, 120+, 130+, 140+, etc. up to 180 (Figure 2). The temperature rasters were reclassified into integer units and converted into polygon form to obtain surface areas of the appropriate temperatures (Figure 3). The lower limit of 90° C was determined from the MIT report, “The Future of Geothermal Energy,” by Tester et al., (2006), where it is stated that with current technology, using temperatures below 90° C is infeasible for economic power production.

Statistical sampling of well depth determined average geochronological unit thickness. Five percent of the wells from each unit, both top to bottom and with an even surface distribution, were analyzed point to point. The thickness at each point was weighted and averaged. The result was multiplied by area, and volumes were calculated for each unit.

We determined the change in temperature by sorting the wells within each geochronological unit by temperature range and calculating average temperature. The mean annual temperature of Colorado is approximately 9.8° C; therefore, our ΔT was determined by subtracting 40 from each average temperature to obtain the difference. “Methods for Assessing Low-Temperature Geothermal Resources,” (Sorey, 1982) analyzes appropriate well spacing, drawdown, temperature, structure, size, time, and transmissivity variables. A structure the size and type of the Denver Basin has a recovery factor of 0.001 per year.

## Results

Tables 2-8 show the area, volume, average depth, average temperature, assumed ΔT, the thermal energy in place after the recovery rate is taken into consideration in Joules, and the amount that translates to in Megawatts Thermal (MWt). Values for density and heat capacity used can be found in Table 1.

**Table 2.** Upper Cretaceous, average unit thickness 0.278 km.

| Temp (°C) | Area (km$^2$) | Volume (km$^3$) | Average Depth (km) | Average Temperature ( °C) | ΔT (°C) | Recoverable (J) | in MWt |
|---|---|---|---|---|---|---|---|
| 90+ | 15,773.36 | 4,384.99 | 2.12 | 107.71 | 67.71 | 7.30x10$^{17}$ | 2.03x10$^{8}$ |
| 100+ | 8,190.99 | 2,277.10 | 2.13 | 109.39 | 69.39 | 3.88x10$^{17}$ | 1.08x10$^{8}$ |
| 110+ | 2,312.52 | 642.88 | 2.18 | 115.2 | 75.2 | 1.19x10$^{17}$ | 3.30x10$^{7}$ |
| 120+ | 273.28 | 75.97 | 2.2 | 126.97 | 86.97 | 1.62x10$^{16}$ | 4.52x10$^{6}$ |
| 130+ | 3.92 | 1.09 | 2.21 | 137.78 | 97.78 | 2.62x10$^{14}$ | 7.28x10$^{4}$ |

**Table 3.** Lower Cretaceous, average unit thickness 0.485 km.

| Temp (°C) | Area (km$^2$) | Volume (km$^3$) | Average Depth (km) | Average Temperature ( °C) | ΔT (°C) | Recoverable (J) | in MWt |
|---|---|---|---|---|---|---|---|
| 90+ | 31,660.00 | 15,355.10 | 2.09 | 107.45 | 67.45 | 2.19x10$^{18}$ | 6.10x10$^{8}$ |
| 100+ | 18,113.88 | 8,785.23 | 2.27 | 114.43 | 74.43 | 1.38x10$^{18}$ | 3.85x10$^{8}$ |
| 110+ | 4,716.80 | 2,287.65 | 2.39 | 118.95 | 78.95 | 3.82x10$^{17}$ | 1.06x10$^{8}$ |
| 120+ | 1,182.80 | 573.66 | 2.43 | 125.85 | 85.85 | 1.04x10$^{17}$ | 2.90x10$^{7}$ |
| 130+ | 70.71 | 34.29 | 2.44 | 138.88 | 98.88 | 7.18x10$^{15}$ | 2.00x10$^{6}$ |

**Table 4.** Jurassic, average unit thickness 0.107 km.

| Temp (°C) | Area (km$^2$) | Volume (km$^3$) | Average Depth (km) | Average Temperature ( °C) | ΔT (°C) | Recoverable (J) | in MWt |
|---|---|---|---|---|---|---|---|
| 90+ | 29,413.99 | 3,147.30 | 2.27 | 109.65 | 69.65 | 4.64x10$^{17}$ | 1.29x10$^{8}$ |
| 100+ | 13,898.03 | 1,487.09 | 2.35 | 113.88 | 73.88 | 2.33x10$^{17}$ | 6.47x10$^{7}$ |
| 110+ | 7,373.59 | 788.97 | 2.41 | 117.9 | 77.9 | 1.30x10$^{17}$ | 3.62x10$^{7}$ |
| 120+ | 490.45 | 52.48 | 2.49 | 125.65 | 85.65 | 9.52x10$^{15}$ | 2.65x10$^{6}$ |

**Table 5.** Permian, average unit thickness 0.346 km.

| Temp (°C) | Area (km$^2$) | Volume (km$^3$) | Average Depth (km) | Average Temperature ( °C) | ΔT (°C) | Recoverable (J) | in MWt |
|---|---|---|---|---|---|---|---|
| 90+ | 47,539.43 | 16,448.64 | 2.53 | 109.28 | 69.28 | 2.41x10$^{18}$ | 6.71x10$^{8}$ |
| 100+ | 24,871.64 | 8,605.59 | 2.62 | 112.06 | 72.06 | 1.31x10$^{18}$ | 3.65x10$^{8}$ |
| 110+ | 8,311.67 | 2,875.84 | 2.67 | 117.81 | 77.81 | 4.74x10$^{17}$ | 1.32x10$^{8}$ |
| 120+ | 731.21 | 253 | 2.74 | 126.4 | 86.4 | 4.63x10$^{16}$ | 1.29x10$^{7}$ |

**Table 6.** Pennsylvanian, average unit thickness 0.560 km.

| Temp (°C) | Area (km$^2$) | Volume (km$^3$) | Average Depth (km) | Average Temperature ( °C) | ΔT (°C) | Recoverable (J) | in MWt |
|---|---|---|---|---|---|---|---|
| 90+ | 90,230.49 | 50,529.07 | 2.26 | 102.93 | 62.93 | 6.73x10$^{18}$ | 1.87x10$^{9}$ |
| 100+ | 44,560.55 | 24,953.91 | 2.42 | 109.41 | 69.41 | 3.67x10$^{18}$ | 1.02x10$^{9}$ |
| 110+ | 23,912.79 | 13,391.16 | 2.53 | 122.28 | 82.28 | 2.33x10$^{18}$ | 6.48x10$^{8}$ |
| 120+ | 8,229.94 | 4,608.77 | 2.65 | 132.65 | 92.65 | 9.04x10$^{17}$ | 2.51x10$^{8}$ |
| 130+ | 2,004.70 | 1,122.63 | 2.78 | 135.98 | 95.98 | 2.28x10$^{17}$ | 6.34x10$^{7}$ |
| 140+ | 17 | 9.52 | 3.09 | 143.49 | 103.5 | 2.09x10$^{15}$ | 5.80x10$^{5}$ |

**Table 7.** Mississippian, average unit thickness 0.129 km.

| Temp (°C) | Area (km$^2$) | Volume (km$^3$) | Average Depth (km) | Average Temperature ( °C) | ΔT (°C) | Recoverable (J) | in MWt |
|---|---|---|---|---|---|---|---|
| 90+ | 73,509.15 | 9,482.68 | 2.15 | 95.91 | 55.9 | 1.12x10$^{18}$ | 3.12x10$^{8}$ |
| 100+ | 44,656.60 | 5,760.70 | 2.23 | 104.58 | 64.6 | 7.88x10$^{17}$ | 2.19x10$^{8}$ |
| 110+ | 76 | 9.8 | 2.42 | 110.41 | 70.4 | 1.46x10$^{15}$ | 4.06x10$^{5}$ |

**Table 8.** Ordovician, average unit thickness 0.013 km.

| Temp (°C) | Area (km$^2$) | Volume (km$^3$) | Average Depth (km) | Average Temperature ( °C) | ΔT ( °C) | Recoverable (J) | in MWt |
|---|---|---|---|---|---|---|---|
| 90+ | 54,476.96 | 9,907.82 | 2.09 | 98.96 | 58.96 | 1.24x10$^{18}$ | 3.44x10$^{8}$ |
| 100+ | 31,953.68 | 2,901.75 | 2.39 | 102.14 | 62.14 | 3.82x10$^{17}$ | 1.06x10$^{8}$ |

# Conclusion

The area from Denver to Greeley appears to have the best geothermal potential in the Denver Basin, as indicated by the interpolated temperature rasters. This is also the location of the primary population centers in the state of Colorado, and as such has access to necessary infrastructure. The thermal energy in place for the Denver basin is listed in Table 9, below.

**Table 9.** Total thermal energy in place by temperature range, and translated to Megawatts Thermal and number of homes that amount of energy can theoretically power.

| Temp. Range (°C) | Recoverable (J) | In MWt | After Efficiency (12%) (MWe) | # Homes Powered |
|---|---|---|---|---|
| **90 +** | 1.49x10$^{19}$ | 4.14x10$^{9}$ | 4.97x10$^{8}$ | 2.49x10$^{11}$ |
| **100 +** | 8.15x10$^{18}$ | 2.27x10$^{9}$ | 2.72x10$^{8}$ | 1.36x10$^{11}$ |
| **110 +** | 3.44x10$^{18}$ | 9.56x10$^{8}$ | 1.15x10$^{8}$ | 5.74x10$^{10}$ |
| **120 +** | 1.08x10$^{18}$ | 3.00x10$^{8}$ | 3.60x10$^{7}$ | 1.80x10$^{10}$ |
| **130 +** | 2.35x10$^{17}$ | 6.53x10$^{7}$ | 7.84x10$^{6}$ | 3.92x10$^{9}$ |
| **140 +** | 2.09x10$^{15}$ | 5.81x10$^{5}$ | 6.97x10$^{4}$ | 3.49x10$^{7}$ |

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