Using Hydrogeologic Data to Evaluate Geothermal Potential in the Eastern Great Basin

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ABSTRACT

In support of a larger study to evaluate geothermal resource development of high-permeability stratigraphic units in sedimentary basins, this paper integrates groundwater and thermal data to evaluate heat and fluid flow within the eastern Great Basin. Previously published information from a hydrogeologic framework, a potentiometric-surface map, and groundwater budgets was compared to a surficial heat-flow map. Comparisons between regional groundwater flow patterns and surficial heat flow indicate a strong spatial relation between regional groundwater movement and surficial heat distribution. Combining aquifer geometry and heat-flow maps, a selected group of subareas within the eastern Great Basin are identified that have high surficial heat flow and are underlain by a sequence of thick basin-fill deposits and permeable carbonate aquifers. These regions may have potential for future geothermal resources development.

Introduction

Located within the Basin and Range Physiographic Province, the Great Basin carbonate and alluvial aquifer system (GBCAAS) covers an area of approximately 284,900 km2 (110,000 mi2) and lies predominantly within eastern Nevada and western Utah (Heilweil et al., 2011). Altitudes range from below sea level to above 4,500 m (14,000 ft). Most of the study area is categorized as having a semi-arid or steppe climate, except for the extreme southwestern basins which have an arid desert climate, and the extreme northeastern mountains which have an alpine/tundra climate (Heilweil et al., 2011). Annual precipitation ranges between 3.8 cm (1.5 inches) in southern Nevada to 178 cm (70 inches) in northern Utah (Heilweil et al., 2011). The physical geography of the study area is characterized by north or northeast trending mountain ranges approximately 8-24 km (5-15 mi) wide separated by broad basins approximately 8-16 km (5-10 mi) wide (Heilweil et al., 2011). Mountain ranges can be longer than more than 80 km (50 mi); basins are typically 56-112 km (35-70 mi) long, although some are as long as 241 km (150 mi). These longer basins are bordered by multiple mountain ranges. Topographic relief between the mountain crests and basin floors generally ranges from 305 to 1,830 m (1,000 to 6,000 ft).

Interest in the development of geothermal energy includes a national effort to evaluate potential resources. Current installed and utilized power production capacity in the U.S. is more than 2,500 Megawatts-electric (MWe) and the potential for additional conventional geothermal resource development is estimated to be about 9,000 MWe (Williams et al., 2008). Historical geothermal power development has largely focused on hydrothermal system fault-controlled reservoirs. Estimated potential for Enhanced Geothermal System (EGS) development from low-permeability reservoirs adds more than 500,000 MWe to this estimate. In addition, there is significant potential for unconventional geothermal resources associated with deep sedimentary basins in the U.S. Following on this, Allis et al. (2011) noted that there are large areas in the western U.S., especially in the Basin and Range high heat-flow province, where high near-surface temperature gradients indicate the potential for elevated temperatures at relatively shallow depths. There is a particular focus on areas of the Great Basin where significant permeability in consolidated rock exists at depths of 2,000 to 5,000 m and the consolidated rock is blanketed by basin-fill sediments with low thermal conductivity (Allis et al., 2012, in prep.). Such areas may have significant potential for geothermal production where this bedrock permeability is laterally extensive.

This study examines carbonate aquifer thickness, extent, depth beneath sediments and groundwater flow in the context of geothermal resource potential by using recently published data. A hydrogeologic study of the eastern Great Basin (Heilweil and Brooks, 2011) included a three-dimensional hydrogeologic framework (Sweetkind et al., 2011a), evaluation of groundwater flow directions (Sweetkind et al., 2011b), and groundwater budget estimates (Masbruch et al., 2011). The eastern Great Basin study follows upon several previous regional groundwater studies (Welch et al., 2007; Harrill and Prudic, 1998; Prudic et al., 1995).

In addition, a recently published surficial heat-flow map of the conterminous U.S. (Blackwell et al., 2011) improves upon the spatial resolution of previously reported surficial heat flow in the eastern Great Basin (Blackwell, 1983).

Purpose and Scope

The objectives of this study are to (1) evaluate potential effects of groundwater flow on subsurface thermal conditions, and (2) identify areas where carbonate rocks are covered by at least 2 km of basin-fill sediments and are located in high heat-flow areas. These areas may have potential for geothermal resources development in the eastern Great Basin. To meet these objectives, hydrogeologic and thermal data were combined using geographic information system (GIS) techniques to generate maps and cross sections highlighting these areas.

Groundwater Flow

The GBCAAS comprises Cenozoic unconsolidated basin-fill sediments and volcanics, Paleozoic carbonates, and Late Proterozoic and Early Cambrian bedrock. Permeable Cenozoic rocks, which exceed thicknesses of 5,000 m in places, have been divided into three hydrogeologic units: an upper basin-fill aquifer unit (UBFAU), a lower basin-fill aquifer unit (LBFAU) and a volcanic unit (VU) (Sweetkind et al., 2011b). In many areas, these Cenozoic aquifers are underlain by permeable carbonate rocks which form regionally extensive aquifers that are hydraulically connected between basins. These carbonate aquifers have been divided into a lower carbonate aquifer unit (LCAU) and an upper carbonate aquifer unit (UCAU).

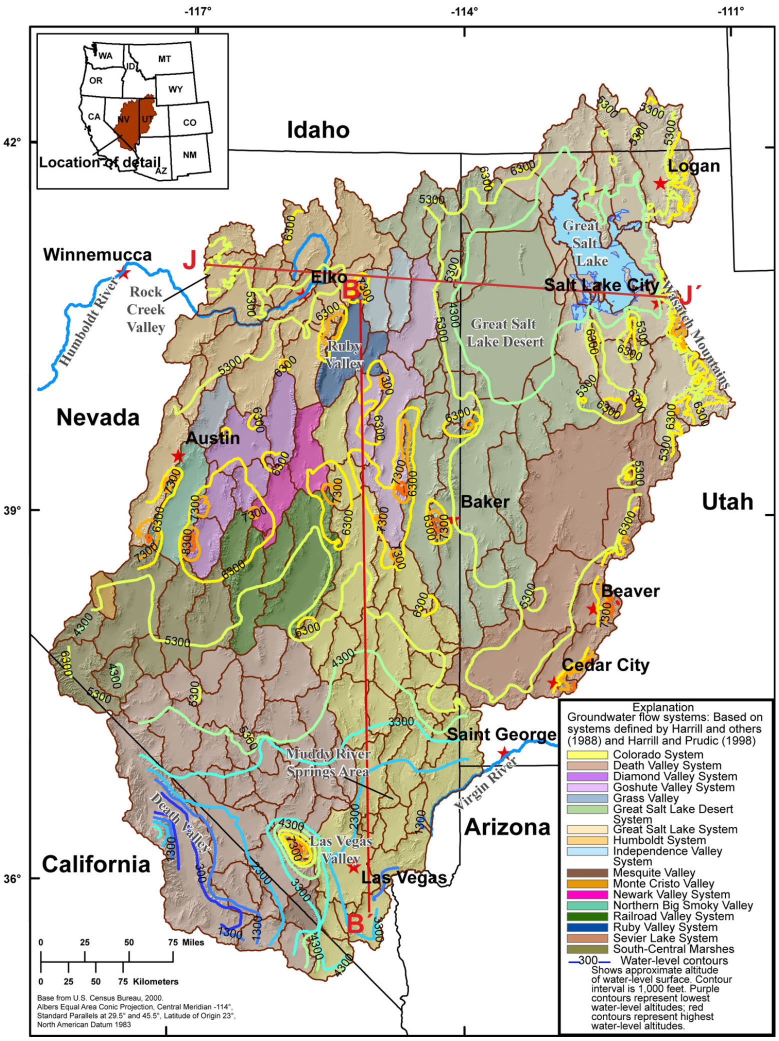


Figure 2. Potentiometric-surface map of the Great Basin carbonate and alluvial aquifer system study area (modified from Heilweil and Brooks, 2011).

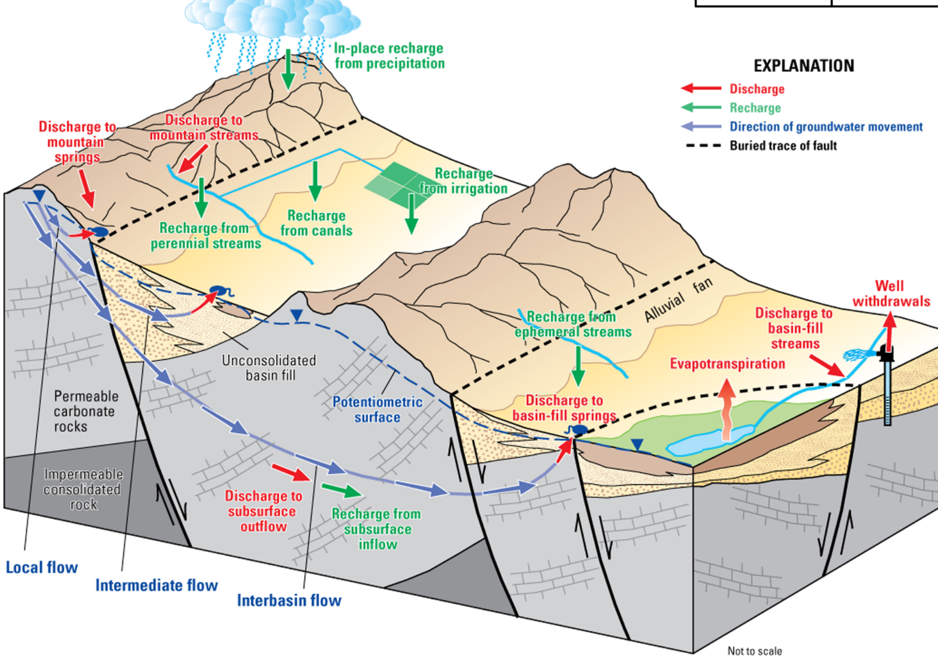


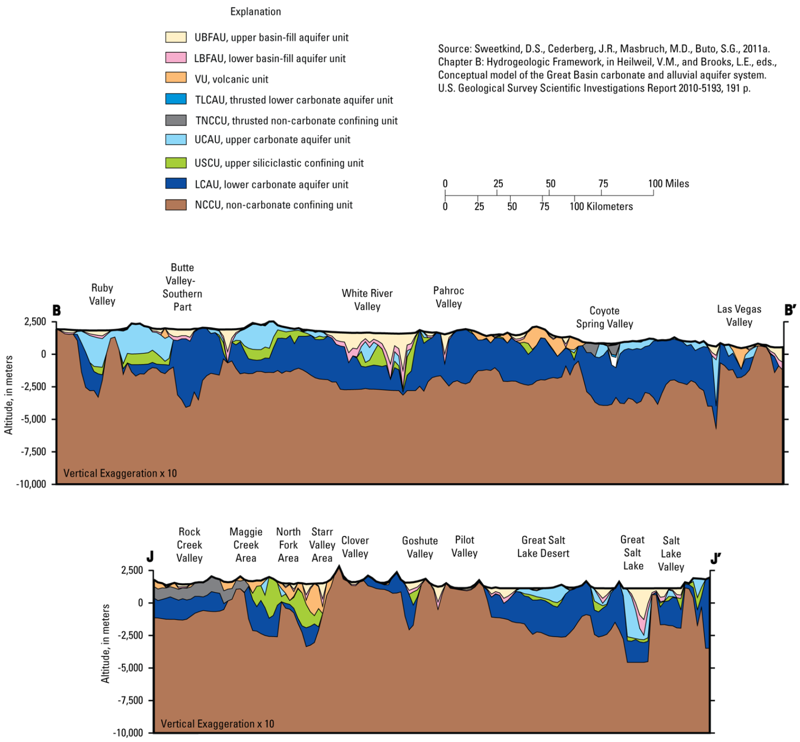
Figure 1. Schematic diagram showing conceptualized groundwater flow in the Great Basin carbonate and alluvial aquifer system study area (from Sweetkind et al., 2011b).

Groundwater movement within the GBCAAS typically is from recharge areas in higher- altitude mountains towards lower-altitude discharge areas (figure 1), consistent with previous conceptual models of groundwater flow in areas of high topographic relief (Toth, 1963). Within the study area, most groundwater flow occurs in the UBFAU, the UCAU, and the LCAU.

Figure 2 is a simplified version of a recently published (Heilweil and Brooks, 2011, plate 1) potentiometric-surface map showing contours of equal groundwater-level altitude, indicating generalized hydraulic gradients throughout the GBCAAS. Groundwater generally flows perpendicular to these contours, moving from higher to lower groundwater-level altitudes. Because of the large contour interval (1,000 ft), this potentiometric-surface map indicates only regional-scale movement of groundwater. Groundwater flow is indicated from the higher-altitude areas in the center of the area towards the Great Salt Lake Desert, the Muddy River Springs Area, the Virgin River, Death Valley, and the Humboldt River.

It has been previously recognized that regional-scale groundwater flow likely influences the thermal regime of the eastern Great Basin, sweeping heat away from several areas (Lachenbruch and Sass, 1977; 1978). The presence of regionally extensive aquifer units and groundwater flow at depth, such as within the LCAU, likely results in heat transport through advective flow. Heat transport by groundwater flow, therefore, needs to be considered when evaluating the geothermal resource potential.

Carbonate rocks within the GBCAAS study area have relatively high bedrock permeability (geometric mean of 4 ft/d) and underlie 2,000 m of basin-fill sediments in several areas (Sweetkind et al., 2011a). In general, the carbonate units are more continuous in the north-south direction than in the west-east direction, mainly because of structural extension and the existence of intervening mountain ranges and normal faults in the west-east direction (Dettinger and Schaefer, 1996). Figure 3 shows both north-south and west-east cross sections through the study area. Cross-section B-B’ extends from Ruby Valley in the north to Las Vegas Valley in the south and shows continuity of LCAU along this north-south profile. Cross-section J-J’, extending east from Rock Creek Valley in north-central Nevada to the Wasatch Mountains of Utah, illustrates the disconnected nature of LCAU along this west-east profile.



Source: Sweetkind, D.S., Cederberg, J.R., Masbruch, M.D., Buto, S.G., 2011a. Chapter B: Hydrogeologic Framework, in Heilweil, V.M., and Brooks, L.E., eds., Conceptual model of the Great Basin carbonate and alluvial aquifer system. U.S. Geological Survey Scientific Investigations Report 2010-5193, 191 p.

Figure 3. Cross sections B-B′ (north-south) and J-J′ (west-east) representing the three-dimensional hydrogeologic framework developed for the Great Basin carbonate and alluvial aquifer system study area (from Sweetkind et al., 2011a). See figure 2 for cross-section locations.

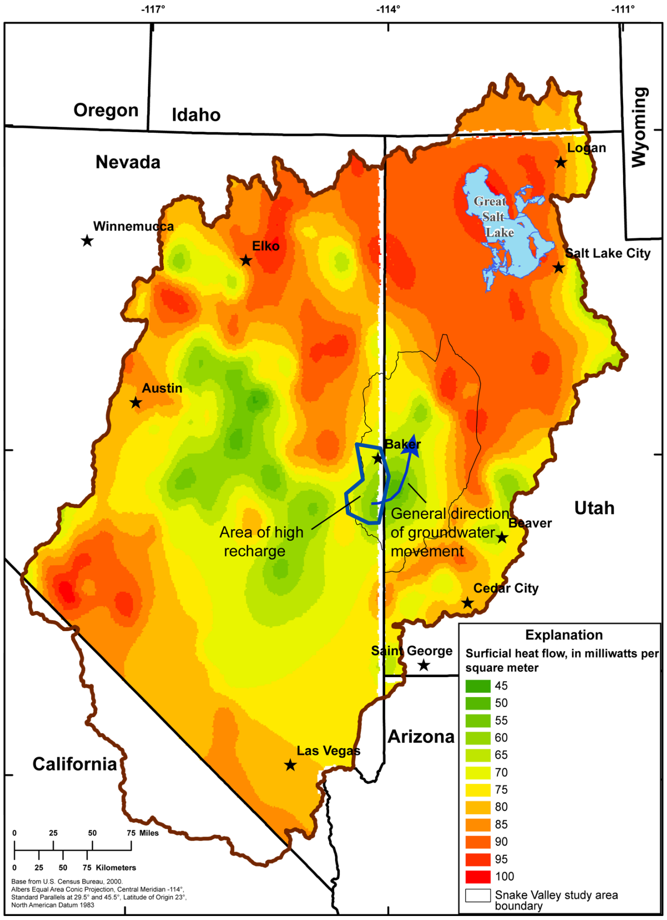


Figure 4. Surficial heat flow in the Great Basin carbonate and alluvial aquifer system study area and an area of high recharge in the Snake Valley study area (modified from Blackwell et al., 2011).

Heat Flow

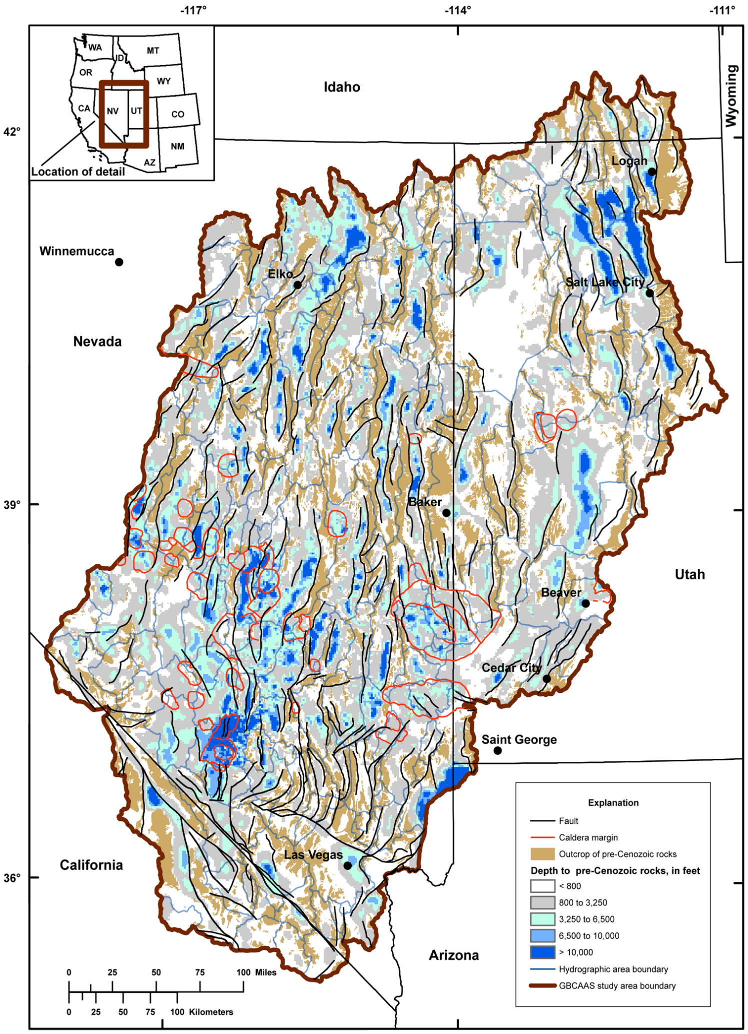
The Great Basin portion of a surficial heat-flow map recently updated by Blackwell et al. (2011) is reproduced in figure 4. Heat flow within the Basin and Range province is complicated by a combination of extension (including volcanism and intrusion), effects of thermal refraction, variations in radioactive heat production, erosion and sedimentation, and advective effects of groundwater flow (Blackwell, 1983). Surficial heat-flow values in the study area range from 45 to 100 milliwatts per square meter (mW/m^2) (Blackwell et al., 2011); values of less than 70 mW/m^2 might be the result of groundwater movement flushing heat from the subsurface, as proposed by Lachenbruch and Sass (1977; 1978). One area of low surficial heat flow that has undergone detailed hydrological study in recent years is the Snake Valley area along the Utah-Nevada border. It is likely that groundwater is significantly affecting surficial heat flow in this area. Results of a groundwater flow and heat transport numerical model (Melissa Masbruch, U.S. Geological Survey, written commun., May 2012), recent temperature measurements (Blackett, 2011), and analysis of groundwater geochemical data (Phil Gardner, U.S. Geological Survey, written commun., May 2012) indicate that low surficial heat flow south of Baker, Nevada, corresponds to an area with high groundwater recharge rates and active groundwater flow from southwest to northeast.

On the basis of these Snake Valley area findings, it is possible that similar areas of low surficial heat flow in a large portion of east-central Nevada are also caused by the flushing of heat by groundwater flow. Figure 5 shows groundwater-budget imbalances and possible subsurface flow between groundwater flow systems and subareas within the GBCAAS study area (Masbruch et al., 2011), and areas of low surficial heat flow (less than 70 mW/m2) (Blackwell et al., 2011). This suggests that heat is being swept by regional groundwater flow, particularly by subsurface outflow from the Diamond Valley, Newark Valley, and the northern part of the Colorado groundwater flow systems. Additionally, these areas of low surficial heat flow contain thick, continuous deposits of permeable carbonates (Cederberg et al., 2011) which are likely conduits for groundwater flow.

Use of Hydrogeologic and Surficial Heat-Flow Data to Highlight Areas of Potential Geothermal Development

A study by Allis et al. (2012, in prep.) indicates that at least 2,000 m of sediments and high surficial heat flow (greater than 80 mW/m^2) are needed to produce temperatures of more than 150 °C at about 3,000 m depth; this combination of high temperature at relatively shallow depths is preferred for geothermal development. Figure 6 shows locations within the GBCAAS where pre-Cenozoic rocks underlie sequences of Cenozoic units (UBFAU, LBFAU, VU) that have thickness greater than 2,000 m. Where thick sequences of Cenozoic units overlie permeable bedrock, a geothermal resource may occur at depths of 2,000 to 3,000 m.

GIS techniques were used to combine areas of high surficial heat flow (greater than 80 mW/m^2) and areas of thick (greater than 2,000 m) Cenozoic units (figure 7) in the GBCAAS study area. Areas with high potential for geothermal development include



Base from U.S. Census Bureau, 2000.
Albers Equal Area Conic Projection, Central Meridian -114°,
Standard Parallels at 29.5° and 45.5°, Latitude of Origin 23°,
North American Datum 1983

Figure 6. Surface exposure and depth to pre-Cenozoic rocks in the Great Basin carbonate and alluvial aquifer system study area (from Sweetkind et al., 2011a).

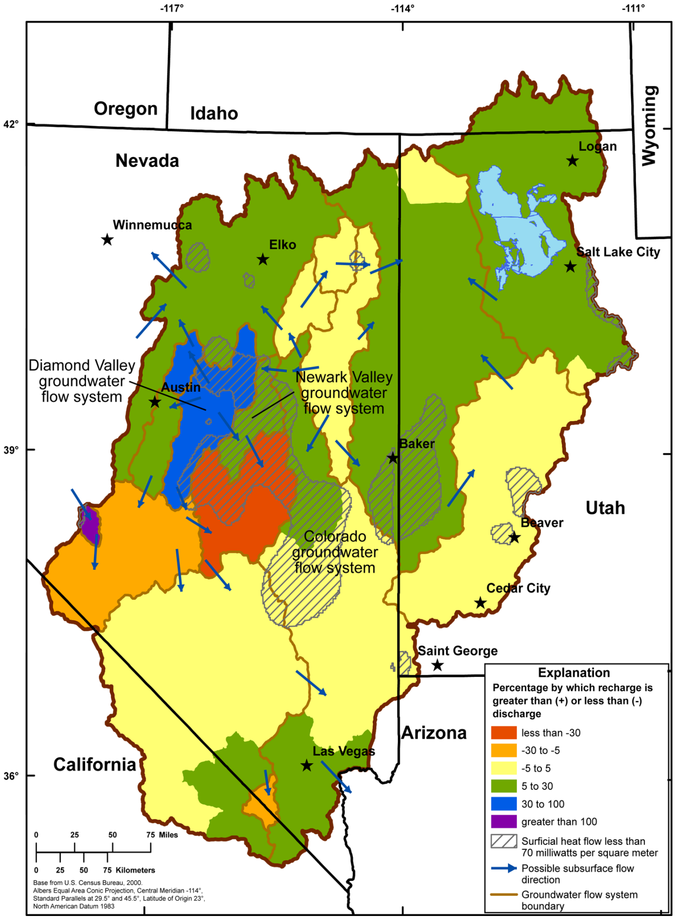


Figure 5. Possible subsurface flow between groundwater flow systems and groundwater budget imbalances in groundwater flow systems and subareas in the Great Basin carbonate and alluvial aquifer system study area and areas of low surficial heat flow (modified from Masbruch et al., 2011).

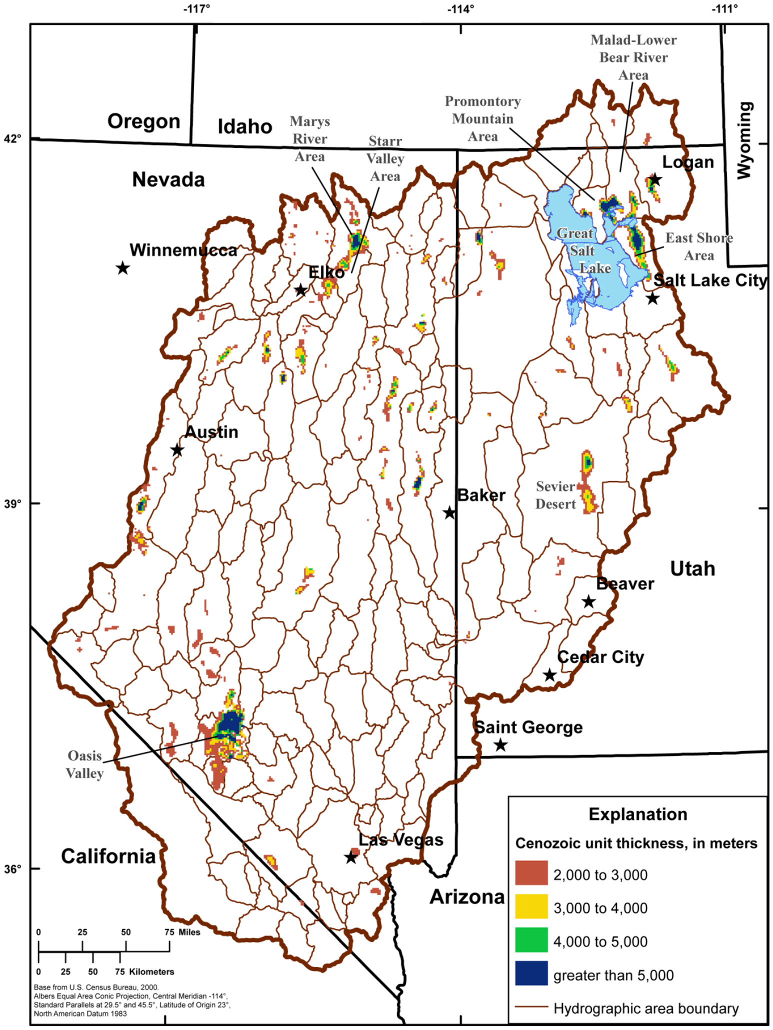


Figure 7. Areas of Cenozoic units greater than 2,000 meters thick and surficial heat flow greater than 80 mW/m2 within the Great Basin carbonate and alluvial aquifer system study area.

(1) Oasis Valley, Nevada, in the Death Valley groundwater flow system; (2) Sevier Desert, Utah, in the Sevier Lake groundwater flow system; (3) East Shore, Promontory Mountain, and Malad-Lower Bear River areas, Utah, in the Great Salt Lake groundwater flow system; and (4) Marys River and Starr Valley areas, Nevada, in the Humboldt groundwater flow system.

Conclusions

The following conclusions can be drawn from recently published hydrogeologic concepts of the Great Basin carbonate and alluvial aquifer system and surficial heat flow, as presented in this paper:

The continuity of thick, permeable carbonates at depth allow for regional-scale groundwater flow within the study area.

The existence of areas of low surficial heat flow (less than 70 mW/m^2) within the study area may indicate flushing of heat by groundwater flow. Such areas may not be ideal targets for geothermal resources development because of the likelihood of cooler groundwater temperatures and lower geothermal gradients.

The existence of thick sequences of low thermal conductivity Cenozoic units in areas of high surficial heat flow such as Marys River and Starr Valley areas, and Oasis Valley, Nevada, and East Shore, Promontory Mountain, and Malad-Lower Bear River areas, and Sevier Desert, Utah, indicate potential areas that may warrant further investigation of geothermal resources development within the study area.

Future Work

We recommend a more detailed study than has been possible for this paper on groundwater flow and surficial heat-flow relations. This is likely to provide more insight regarding effects of groundwater movement on lateral heat-flow variations.

Acknowledgements

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