UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

WYOMING STATE OFFICE
RESERVOIR MANAGEMENT GROUP

FINAL DRAFT
Reasonable Foreseeable Development Scenario for Geothermal
Bighorn Basin Planning Area, Wyoming
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Introduction

The Bighorn Basin Planning Area represents the combined lands managed by the Cody, and Worland, Wyoming Bureau of Land Management (Bureau) Field offices. A Resource Management Plan is currently being prepared for the Planning Area for the Planning Period 2008-2027. In support of the Resource Management Plan, this geothermal energy Reasonable Foreseeable Development scenario has been prepared.

Geothermal leases have not been issued for the state of Wyoming, and only limited development activity has occurred within the Planning Area. This document is presented as a technical analysis of the geothermal resource occurrence within the Planning Area, and of the development that may reasonably be expected to occur during the Planning Period. This analysis represents a base line projection and assumes that future activity levels will not be constrained by management-imposed conditions (Rocky Mountain Federal Leadership Forum, 2002). Where legislatively imposed restrictions are applied to lands within the Planning Area, such restrictions were considered when determining future activity levels.

The Reasonable Foreseeable Development scenario for geothermal resource development presented herein briefly summarizes the types of geothermal systems and their potential uses, the various geothermal environments known or expected to be located within the Planning Area, and the nature of the resource's occurrence and distribution. Recent geothermal resource assessments which include the Planning Area lands are also discussed. This information was used to develop a geothermal resource development potential map (Figure 5) and a projection of the types of geothermal development which may occur during the Planning Period. Other information relevant to geothermal resource development in the Planning Area such as current and past development activity and infrastructure needs were also considered in developing the development potential projection.

It must be emphasized that the Reasonable Foreseeable Development scenario presented herein is a scientific-based projection of anticipated geothermal development activity and is based on a limited amount of available information relative to the Planning Area lands. The Reasonable Foreseeable Development scenario includes all lands regardless of surface or mineral ownership, with the exception of those areas currently under legislative restrictions for development.

Geothermal Energy

While Wyoming has one of the largest concentrations of geothermal energy in the United States, very little geothermal development has occurred in the Planning Area. However, various hot springs and thermal anomalies occur across the state, including in the Bighorn Basin and the Planning Area.

Types of Geothermal Systems

There are two main categories of geothermal energy environments. These are hydrothermal environments, where water or steam are the primary carriers of the associated energy, and "dry"

environments where hot, water-free rocks and magma are the energy sources. While dry environments are also the primary mechanism from which the hydrothermal environments derive their heat, current technology used to exploit these dry environments for energy use is in the experimental phase and such extraction is usually not economically viable.

Hydrothermal Systems

The U.S. Geological Survey recognizes 4 distinct hydrothermal systems. These are electrical-grade, warm-water, geopressured, and normal-temperature systems (Duffield and Sass, 2003).

Electrical-Grade Systems

Electrical-grade systems are hydrothermal systems which can generate electricity via geothermal fluids used to drive turbines. Such systems must have relatively high temperature fluids (liquid and/or vapor water) to efficiently drive the turbines. As technology evolves, the temperatures required have become lower, but generally must still be greater than 150 degrees Celsius (~300 degrees Fahrenheit) (Duffield and Sass, 2003).

There are three types of electrical-grade systems. These are hot-water, vapor-dominated, and moderate temperature (also known as binary) systems. Hot-water systems require water temperatures of at least 200 degrees Celsius (~390 degrees Fahrenheit) in order to produce steam at pressures high enough to drive the turbines. Water from these systems rise through wells drilled into the reservoir, and convert partially to steam as the overlying pressures decline, and the surrounding temperatures decrease. Once utilized, the water is reinjected into the formation to recharge. Vapor-dominated systems behave essentially the same way except that the fluid is already steam at depth in the reservoir and is condensed at the surface prior to being reinjected. Moderate-temperature systems are not hot enough to produce steam from liquid water, but do have sufficiently high temperatures to cause other liquids with lower boiling points, such as isobutane, to convert to steam in heat-exchangers. These are then used to run turbines for electrical generation in the same way steam would be in a vapor-dominated system.

All electrical-grade systems must be sited as near the wells as possible to avoid heat loss as the water or steam is transported to the facility. Additionally, they benefit also from being near existing infrastructure and customer bases. The thermal springs near Thermopolis would be the most likely location in the Planning Area to site such a facility, but the groundwater temperatures [100 to 150 degrees Celsius (~210 to 300 degrees Fahrenheit)] are near the lower limit of what may be used for such projects (see Figures 1 and 2). Therefore, the potential for development of electrical-grade hydrothermal systems in the Planning Area during the Planning Period is to be considered low and will be restricted to thermal springs where the geothermal fluids are hot enough to efficiently power such operations.

Warm-Water Systems

Warm-water systems use waters too cool for electrical generation, but still warmer than surface temperatures, for direct use in heat exchangers (e.g., heating homes, swimming pools, etc.). As

these uses are generally restricted to municipal areas already developed, new housing developments, etc., the disturbance from these types of systems is directly tied to the developments they service. As such, any reasonable foreseeable development will not generally be associated with the energy sector, will likely be restricted to municipalities, and will create little to no impact to lands beyond those associated with the structures they are designed to heat. The most likely areas for development outside of existing municipalities are in lands heated by thermal springs around the communities of Thermopolis, Cody, and Greybull (Figure 1).

Normal-Temperature Systems

Normal-temperature systems use heat-exchange similar to warm-water systems except that the fluid (generally water) is pumped into the ground in a closed system of pipes allowing the fluid to warm to the temperature of the soil and is then brought back to the surface for direct use. Such systems are generally small in scale, and, if developed in the Planning Area, would be almost exclusively associated with new or existing municipal or residential developments. Like warm-water systems, any reasonable foreseeable development will not generally be associated with the energy sector and will create little to no impact to lands beyond those associated with the structures they are designed to heat.

Geopressured Systems

Geopressured systems are deep water reservoirs where the water is completely or nearly completely sealed off from the surrounding formations. Their depth and seal allows the waters to become heated and pressurized and are often also rich with dissolved methane gas. The heat, pressures, and associated methane all have the potential for use in energy production. However, such systems were in the early experimental stages in the 1980's, and only in off-shore environments (see U.S. Department of Energy, 1985). Industry has not expanded on the U.S. Department of Energy's work, nor have they shown any interest in doing so, primarily due to the unfavorable economics of such projects. Furthermore, no geopressured systems have yet be identified in the Planning Area. Geopressured systems are not expected to be developed in the Planning Area during the Planning Period.

Dry Geothermal Systems

Also known as "Enhanced Geothermal Systems" (Duffield and Sass, 2003), dry geothermal systems are generally deep rock and magma with little to no permeability and no free water, but contain vast amounts of heat compared to hydrothermal systems. Dry systems are "mined" for their energy; that is, deep wells are drilled to the high-temperature rocks and water is pumped down injection wells to be heated or converted to steam and brought back to the surface via production wells for use in electrical power generation plants (Massachusetts Institute of Technology, 2006). As with hydrothermal electrical-grade systems mentioned above, temperatures of the target rock formations generally need to be greater than 150 degrees Celsius (~300 degrees Fahrenheit) (assuming the injected water is allowed enough time to equilibrate to the formation temperature) to efficiently operate the power plants, though the U.S. Geological Survey requires temperatures in excess of 200 degrees Celsius (~390 degrees Fahrenheit) at

depths of 6 kilometers (~20,000 feet) or less (Williams and Pierce, 2008). Only the area associated with the thermal springs near Thermopolis have rocks in excess of 150 degrees Celsius (~300 degrees Fahrenheit) as shallow as 4.5 kilometers (approximately 15,000 feet) in depth; however, all lands within the Planning Area have temperatures in excess of 150 degrees Celsius (~300 degrees Fahrenheit) at 6.5 kilometers (approximately 21,000 feet). (Massachusetts Institute of Technology, 2006). Drilling wells of this type and depth require large drilling rigs used for oil and gas well drilling. Oil and gas wells 15,000 feet and deeper are classified as "deep" wells (U.S. Geological Survey, 1997), and drilling to such depths greatly increases cost and risk. Drilling wells for geothermal energy production to depths greater than 15,000 feet is currently cost prohibitive. Resultantly, the potential for development of such projects in the Planning Area during the Planning Period is negligible. Any such projects, if developed, would likely be located on lands associated with the thermal springs near Thermopolis.

Geothermal Resource Assessments

Several recent assessments of geothermal resources covering lands which include Wyoming and the Bighorn Basin have been performed and their results help provide an understanding of the potential for occurrence of geothermal resources within the Planning Area.

Electrical-Grade Hydrothermal and Dry Geothermal Environments

In 2008, the U.S. Geological Survey published an update to their geothermal resource assessment of 1978 (U.S. Geological Survey, 2008, and Williams and Pierce, 2008). This assessment studied the electrical power generation potential of geothermal resources concentrated in the western United States (Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming). These 13 states contain all of the identified moderate temperature [90 to 150 degrees Celsius (~195 to 300 degrees Fahrenheit)] and high temperature [greater than 150 degrees Celsius (300 degrees Fahrenheit)] geothermal systems located on private or accessible public lands within the U.S. Geothermal systems located on closed public lands (e.g., National Parks such as Yellowstone) were not included in the assessment. The assessment also included an estimate of the power generation potential of dry geothermal systems in several of these states, including Wyoming.

Within the Planning Area, the U.S. Geological Survey identified no conventional (hydrothermal) geothermal resources capable of electricity generation. Additionally, the study reported geothermal resource occurrence as low for the entire Planning Area with the exception of the thermal springs near Thermopolis which are ranked as moderately low. It should be noted, however, that at an average depth of 6.5 kilometers (~21,000 feet), all of the lands within the Planning Area have temperatures in excess of 150 degrees Celsius (~300 degrees Fahrenheit), sufficiently hot enough for hot- and moderate-temperature hydrothermal systems, but at depths currently uneconomic for development.

Dry/enhanced geothermal systems are characterized in the assessment as those areas where temperatures exceed 200 degrees Celsius at depths less than 6 kilometers (approximately 20,000 feet). They identified no such systems within the Planning Area.

The state of Wyoming was estimated to contain approximately 31 Megawatts-electric of identified electrical power generating capacity. However, only one geothermal system was identified in Wyoming which is located outside of the Planning Area.

The 2008 study did not characterize direct use (warm- and normal-temperature) hydrothermal, nor geopressured geothermal resource potentials. Similar studies by the U.S. department of Energy's National Renewable Energy Laboratory (Petty and Porro, 2007) and the Massachusetts Institute of Technology (2007) also recognize the lack of suitable electrical-grade hydrothermal and dry geothermal environments in the Planning Area.

Geopressured Systems

As mentioned above, the only testing of geopressured systems in the U.S. were conducted off-shore in the 1980's (U.S. Department of Energy, 1985). No lands onshore have been studied for either the potential for occurrence nor development of such systems.

Direct Use (warm-water and normal temperature) Systems

Several past studies have characterized the direct use geothermal resource in the U.S. and Wyoming, though most recent characterizations have focused on electrical-grade and enhanced geothermal resources. The following is a discussion of those studies which analyzed lands for the various direct-use systems.

In their 1971 assessment, the U.S. Geological Survey characterized several areas within the Planning Area has prospectively valuable for geothermal resources. Lands classified as such contain thermal springs of at least 40 degrees Fahrenheit higher than the average ambient temperature. The lands classified as such are the various thermal springs of Thermopolis and Cody, as well as those north of Greybull (Kane, Sheep Mountain, and Little Sheep Mountain springs) (Figure 1).

Anderson and others (1990) ranked known geothermal resource lands within the Planning Area for their geothermal resource potential (Figure 3). Those areas outside of known geothermal mineral deposits were all ranked as low potential; however, the thermal springs of Thermopolis, Cody, and north of Greybull, as well as several smaller known geothermal mineral deposit areas were ranked as moderate potential for geothermal favorability, with a concentrated area within the Thermopolis thermal springs ranked as high. One assumption in the study was that development of these geothermal resources would principally be for recreational use.

Several studies by Hinckley, Heasler, and others (Hinckley, et al., 1982; Heasler and Hinckley, 1985; Heasler, 1985) have specifically studied the geothermal resource within the Bighorn Basin. In Heasler and Hinckley's 1985 study, they note that the geothermal resources in the Bighorn

Basin "are suited to relatively small-scale, direct-use projects located close by" (Heasler and Hinckley, 1985). The study shows that the majority of the basin is underlain by water at temperatures greater than 120 degrees Fahrenheit, though most is too deep for economic use. The isolated areas with high temperature gradients which they concluded might be suitable for economic development are generally those areas associated with the thermal springs mentioned above, as well as several other anomalous gradients around the margins of the basin (Figure 2). Only those areas found at depths less than 4,500 feet (~1.4 kilometers) would likely be considered for direct use geothermal systems.

Duffield and Sass (2003) have estimated Wyoming's direct-use geothermal energy capacity to be 10 megawatts of energy. This energy would be derived almost exclusively from low-temperature thermal aquifers such as those associated with the thermal springs found within the Planning Area.

The Bureau of Land Management and the Department of Energy (U.S. DOI and U.S. DOE, 2003) joint report on the potential for renewable energy on public lands assessed in a broad sense those areas in the United States that may prove suitable for future geothermal energy development. Their report includes a map produced by the Southern Methodist University outlining areas of geothermal potential based on heat flow, thermal gradient, sediment thickness and hot springs data. The study outlines the whole of the Planning Area as falling within "medium" development potential for the geothermal resource.

Geothermal Development Potential and Projections of Future Activity

Several maps have been compiled showing various features discussed in the above referenced documents which may suggest areas of future interest in geothermal development. Figure 1 shows the thermal springs and aquifers with water temperatures exceeding 50 degrees Celsius (~120 degrees Fahrenheit) as identified by Anderson and others, 1990. Figure 2 shows the areas of anomalous temperature gradients in the subsurface as identified by Heasler and Hinckley (1985). Figure 3 and 4 show the favorability for geothermal resource occurrence as ranked by Anderson and others, 1990 and Williams and Pierce, 2008, respectively. These maps and the above discussion were used to create a development potential map for geothermal energy within the Planning Area during the Planning Period (Figure 5).

As can be seen by reviewing each of the above maps, geothermal resources and the favorability for the occurrence of those resources are generally shown around areas of known thermal springs and anomalies in the subsurface temperature gradient. These areas are considered to have some potential for future exploration, but due to the expected nature of such projects (small, direct-use, systems) it is unlikely that development will occur outside of established municipalities or other isolated lands developed for other commercial or residential use. Areas in this category are marked as "low" development potential on Figure 5.

Areas marked "very low" on Figure 5 are those which are underlain by aquifer waters with temperatures in excess of 50 degrees Celsius (~120 degrees Fahrenheit) as identified by Anderson and others, 1990. These waters, while too cool for electrical generation may still be utilized in direct-use systems, though less effectively than those waters found associated with thermal springs.

Areas marked "negligible" represent the remainder of the lands within the Planning Area. As the entire area is underlain by rocks in excess of 150 degrees Celsius (~300 degrees Fahrenheit) at an average depth of 6.5 kilometers (~21,000 feet), the whole of the Planning Area may be suitable for future deep enhanced geothermal development as the technology for such systems is improved upon. However, as such projects are currently not economically feasible, such development is the least likely type of geothermal development to occur in the Planning Area during the Planning Period.

Quantifying the potential surface disturbance for the above scale ("low," very low," and " negligible") is not at this time possible as there is not a way to determine (based on historical development, or development in similar areas) what form such development would take. As any such development in the above categories is unlikely, and the development would be concentrated on lands with disturbance associated with other activities (e.g., municipal, residential, industrial, etc), future surface impacts directly related to geothermal energy development are projected to be minimal on Bureau managed lands.

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Figure 1.
Thermal springs and aquifers with water temperatures exceeding 150 degrees Celsius (~300 degrees Fahrenheit) within the Bighorn Basin Planning Area (after Anderson, et al., 1990.

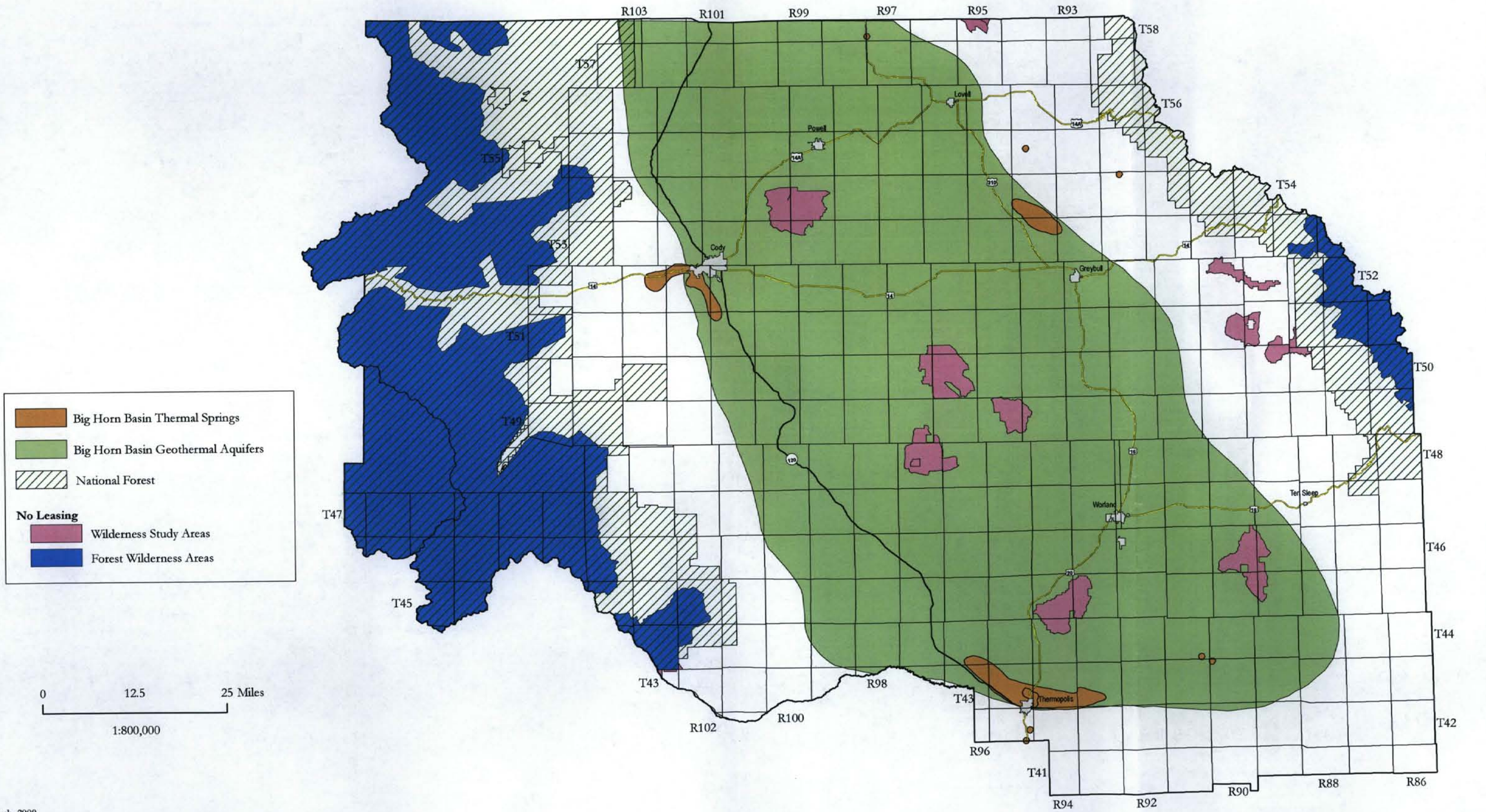

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Figure 2.

Anomalous temperature gradients within the Bighorn Basin Planning Area (after Heasler and Hinckley, 1985).

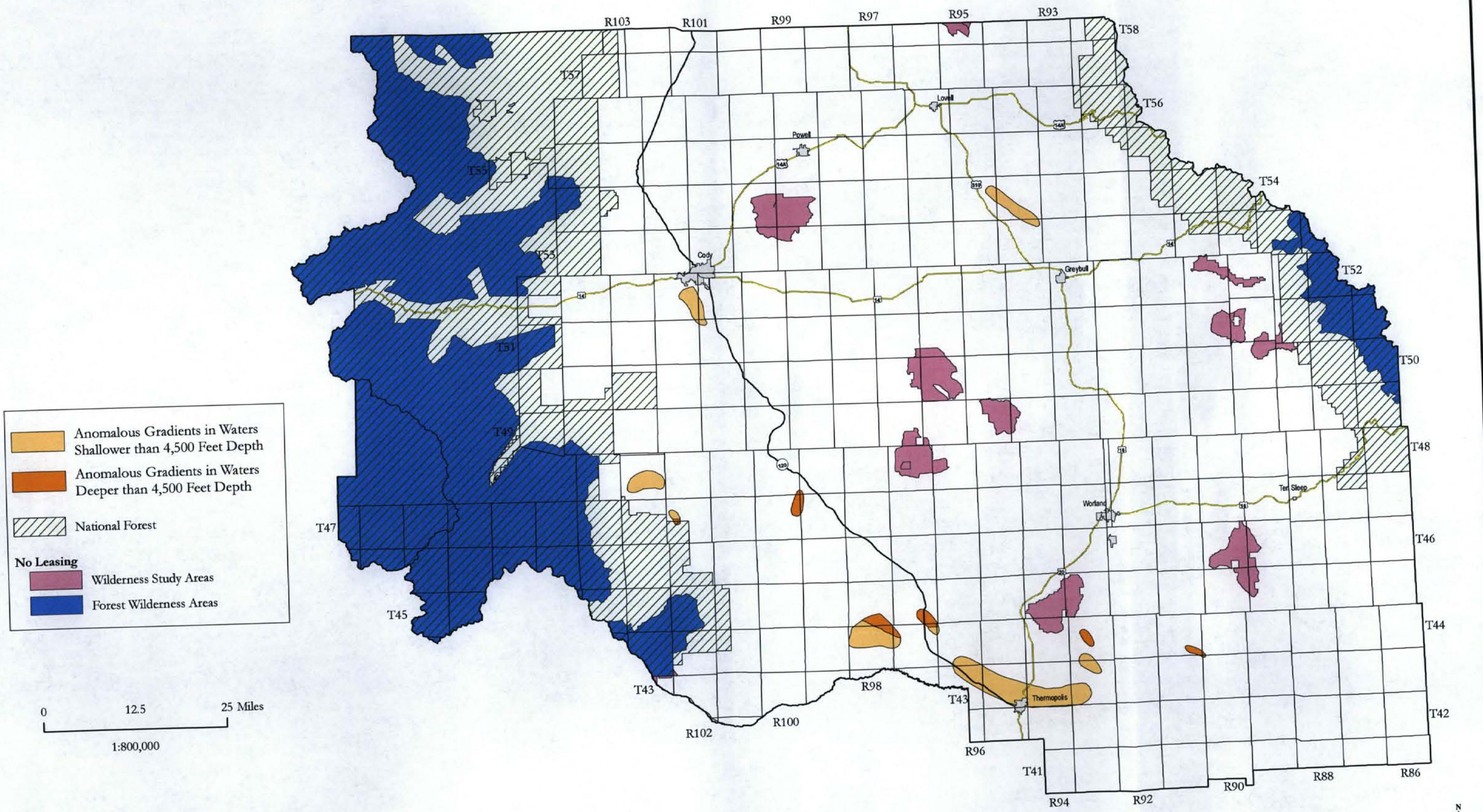

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Figure 3.

Geothermal resources favorability within the Bighorn Basin Planning Area (after Anderson, et al., 1990.

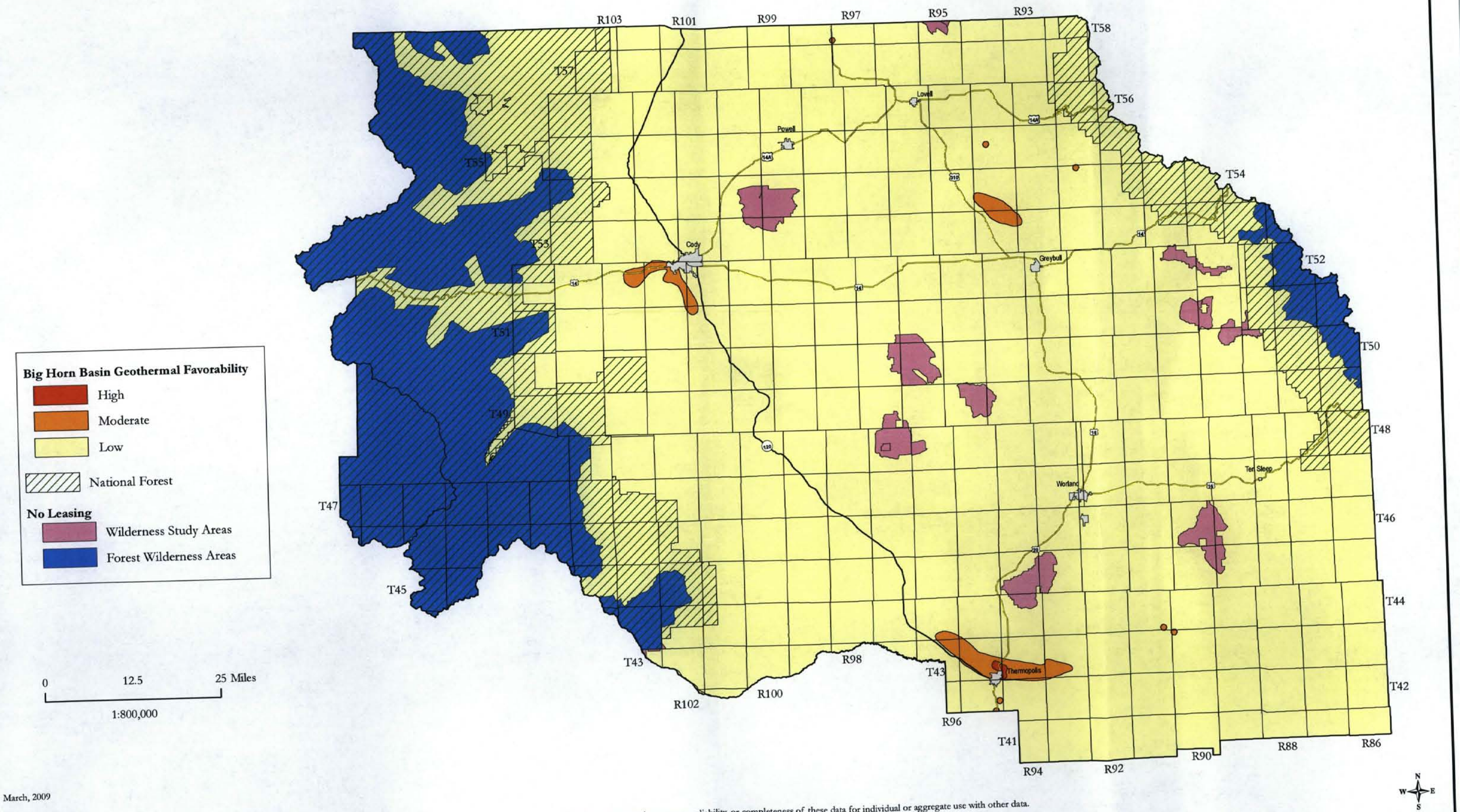

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Figure 4.
Geothermal resources favorability within the Bighorn Basin Planning Area (after Williams and Pierce, 2008).

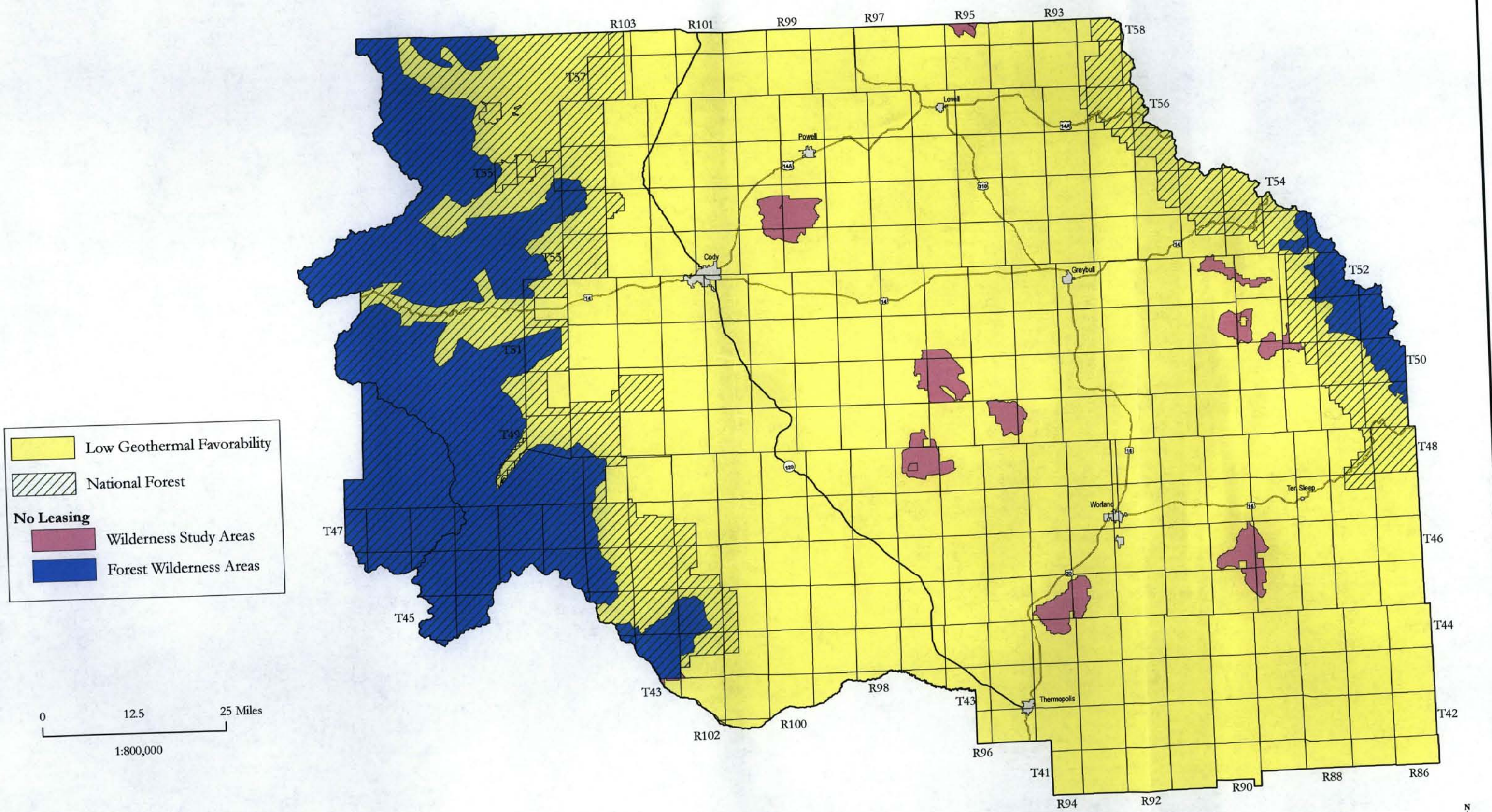

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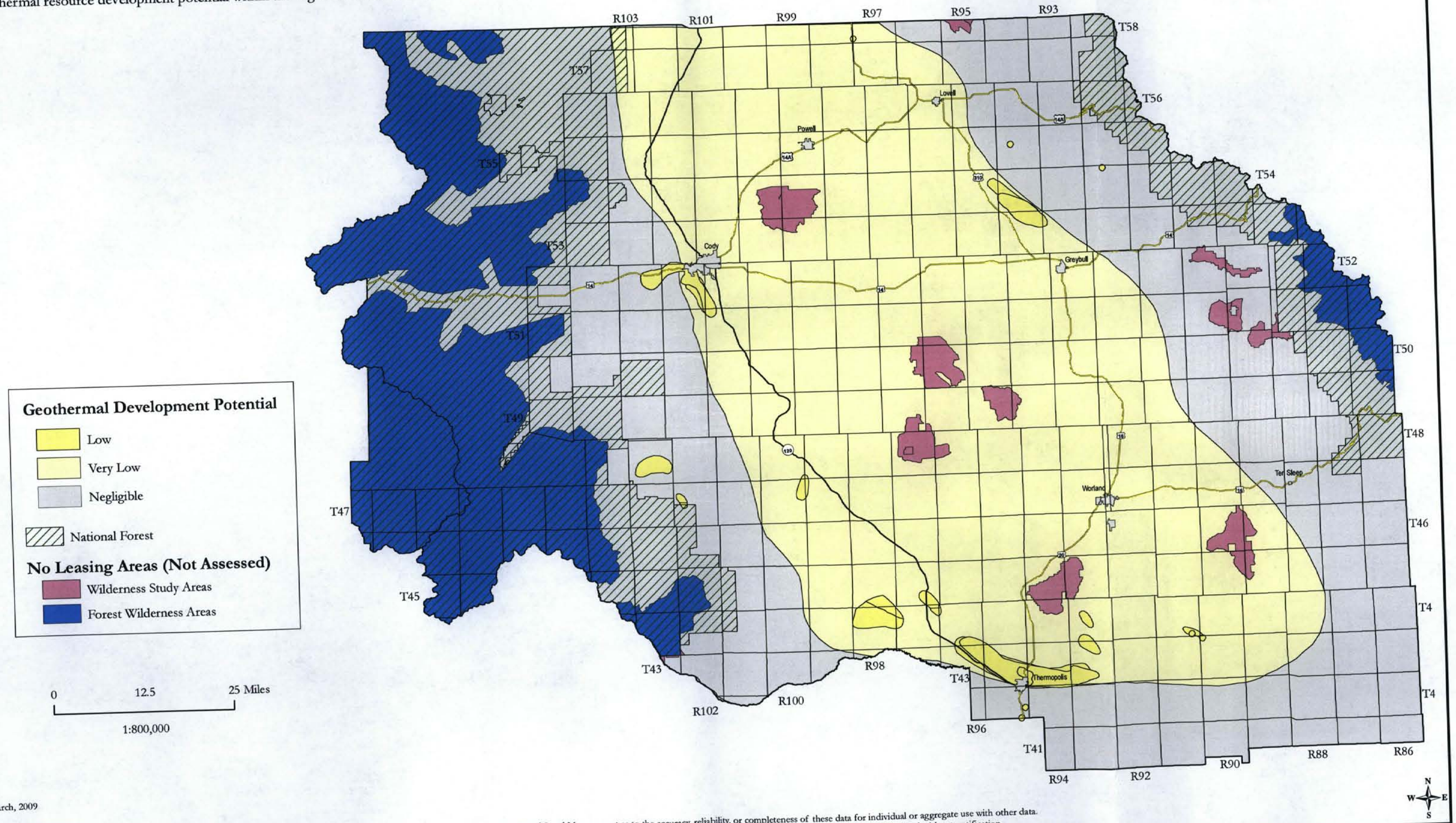
Figure 5.

Geothermal resource development potential within the Bighorn Basin Planning Area for the period 2008 to 2027.



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