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Resource Characterization and Conceptual Modeling of the Rico Geothermal System to Support TEN Development: A Community-Scale Development Case Study

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ABSTRACT

The Rico geothermal system in southwestern Colorado represents a promising low- to medium-temperature resource with potential to support a community-scale Thermal Energy Network (TEN). Surface manifestations include three thermal springs from historical artesian mining wells with discharge temperatures ranging from 38–46 °C and flow rates up to 0.95 l/s. However, geothermometry and historical data suggest subsurface temperatures up to 120–140 °C.

To evaluate the feasibility of utilizing this resource for direct-use heating, Teverra, with support from Seequent Ltd., developed a preliminary 3D geological model in Leapfrog Energy. This model integrates geological information, mapped fault structures, geophysical datasets, and known hydrothermal features to characterize the subsurface geometry and identify key controls on permeability and fluid flow. Early modeling results indicate a structurally complex but favorable setting for geothermal circulation, with fault networks that may enhance reservoir connectivity and recharge. The ongoing conceptual modeling effort incorporates additional datasets, including spring temperature and geochemistry, historic mining data, resistivity and magnetotelluric surveys, and thermal gradient anomalies, to refine the resource characterization and develop a conceptual model for the geothermal system.

In parallel with the technical work, stakeholder engagement, regulatory evaluation, and phased development planning have been undertaken to support the implementation of a community-scale geothermal project. These efforts include coordination with local government, public outreach and education initiatives, assessment of Colorado's evolving geothermal regulatory framework, and planning for a monitoring well to reduce key subsurface uncertainties.

This integrated technical, regulatory, and socio-economic approach will guide future exploration and infrastructure planning, laying the foundation for a resilient, locally sourced geothermal energy solution tailored to Rico's heating needs. By systematically compiling legacy and newly acquired data into a coherent conceptual framework and 3D resource model, while simultaneously advancing community engagement and development planning, this work establishes a technically and commercially defensible pathway toward confirmation drilling, reducing subsurface uncertainty and increasing confidence for subsequent investment and development decisions. The workflow presented in this study demonstrates how geothermal resources in small communities can be advanced from early-stage characterization to development planning, and may serve as a model for similar community-scale geothermal projects.

1 INTRODUCTION

Direct-use geothermal systems and thermal energy networks (TEN) are gaining increasing attention as practical decarbonization solutions for small and mid-sized communities, particularly in cold regions where space heating represents a major portion of total energy demand (Herreras Martínez et al., 2025). Unlike geothermal power generation, which requires high-temperature resources and significant infrastructure investment, direct-use systems can operate effectively at moderate temperatures when integrated with district heating systems and modern heat pump technology. This creates an opportunity for many communities located in regions with elevated geothermal gradients to utilize local geothermal resources even when surface manifestations are limited or subtle.

Despite this potential, geothermal development in small communities is often constrained not only by subsurface uncertainty, but also by regulatory complexity, funding limitations, and the need for strong community engagement and stakeholder alignment. As a result, early-stage geothermal projects must balance

technical resource assessment with development planning, risk reduction, and public communication. This paper presents a case study from the Town of Rico, Colorado, where geological characterization, conceptual modeling, and community-scale development planning are being carried out in parallel to evaluate the feasibility of a geothermal-based TEN.

Thermal water discharge from historic mining-era wells, elevated temperature gradients observed in legacy boreholes, and travertine deposits located south of town all indicate ongoing hydrothermal activity in the Rico area (Medlin, 1983; Oerter, 2011). Surface discharge temperatures are relatively modest, generally between 38 and 46 °C, but subsurface temperature estimates derived from geothermometry and historical records suggest reservoir temperatures in the range of approximately 120–140 °C (Oerter and Sares, 2010). Temperature gradients measured in historic wells are significantly higher than regional background values, indicating an anomalous heat source or enhanced heat transport through structurally controlled fluid circulation (Medlin, 1983). Importantly, the limited number of surface manifestations likely represents only localized discharge points rather than the full extent of the geothermal system.

Previous work in the Rico area has documented thermal springs, mining-era temperature data, and geophysical anomalies, but these datasets had not previously been combined into a unified geological and conceptual framework suitable for evaluating geothermal development (Oerter, 2011; Dunnington, 2018). In addition, most prior investigations focused primarily on describing geothermal occurrences rather than assessing how the resource could be developed to support community-scale energy use. The work presented here addresses this gap by integrating geological mapping, structural interpretation, thermal data, geochemistry, and geophysical surveys into a three-dimensional geological framework and conceptual model of the Rico geothermal system. This technical work is being conducted alongside regulatory evaluation, stakeholder engagement, and planning for a monitoring well to reduce key subsurface uncertainties. The objective is not to produce a definitive resource estimate at this stage, but rather to develop a defensible conceptual understanding of the system that can guide exploration drilling, reduce development risk, and support long-term planning for a TEN.

By combining technical characterization with early-stage development planning, the Rico project provides an example of how geothermal resources can be evaluated and advanced in small communities with limited existing subsurface data. The approach described here may serve as a framework for similar communities seeking to develop local geothermal resources for direct-use heating and district-scale energy systems.

2 GEOLOGICAL AND STRUCTURAL FRAMEWORK

2.1 Regional Geological Setting

The Rico geothermal system is located in the western San Juan Mountains of southwestern Colorado, a region shaped by a complex tectonic and magmatic history involving Laramide deformation, Cenozoic intrusive activity, and widespread volcanism (Figure 1) (Pratt et al., 1969). This geologic evolution produced a structurally complex crust characterized by doming, faulting, intrusive bodies, and significant lithologic variability, all of which influence subsurface fluid circulation and heat transport.

Elevated regional heat flow in the San Juan Mountains has been attributed to a combination of magmatic heat input, crustal thinning, and deep circulation of fluids along regional fault systems, creating favorable conditions for hydrothermal systems even in areas with limited surface geothermal expression (Geldon, 1989).

Within this regional context, the Rico area occupies a structurally elevated position associated with the Rico Dome, a prominent structural feature that has long been recognized for its relationship to mineralization and hydrothermal alteration (Pratt et al., 1969). The same structural complexity that controlled mineral deposition is interpreted to also influence modern geothermal fluid circulation, making the area a natural target for geothermal exploration.

2.2 The Rico Dome: Structure and Formation

The Rico Dome is a structural uplift defined by outward-dipping stratigraphy surrounding the town of Rico and is interpreted to have formed through a combination of intrusive emplacement, doming, and subsequent faulting (Pratt et al., 1969). Deformation associated with dome formation resulted in extensive fracturing and fault development, which likely enhanced permeability throughout the subsurface. The dome is intersected by multiple fault systems trending predominantly north–south and northwest–southeast, with several major structures intersecting near the center of the uplift (Pratt et al., 1969). These structures were historically important in localizing ore deposits and are inferred to play a similar role in controlling hydrothermal fluid movement. The spatial association between mapped faults, mineralized zones, and present-day thermal

manifestations suggests that the Rico Dome continues to act as a structural focus for fluid circulation, providing pathways for both deep recharge and upward migration of heated fluids (Medlin, 1983; Oerter and Sares, 2010).

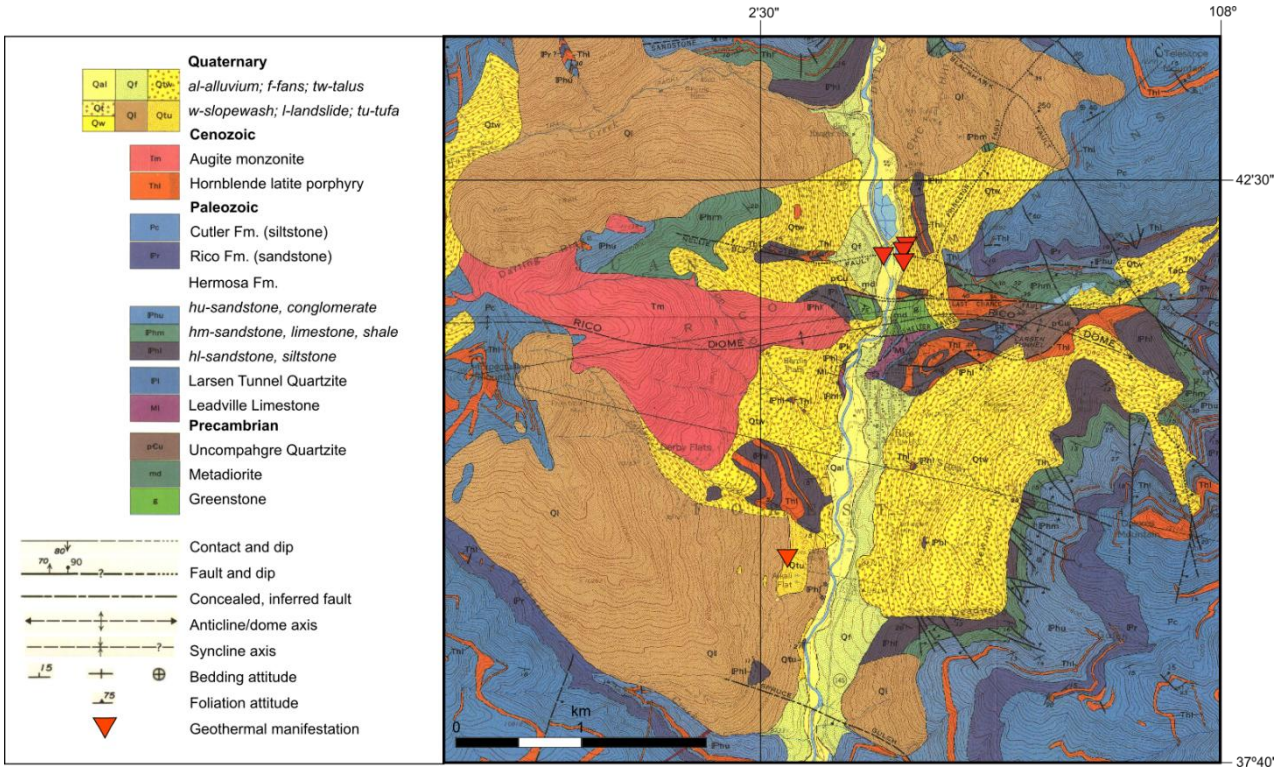


Figure 1. Geological map of the Rico area showing the Rico Dome, major mapped structures, and known geothermal manifestations. Red triangles indicate the artesian thermal boreholes used as key thermal control points for the project. Modified from Pratt et al. (1969).

From a geothermal perspective, the importance of the Rico Dome lies not in a single heat source, but in the structural architecture created by doming and faulting. Increased fracture density, permeability anisotropy, and vertical structural connectivity create conditions that promote hydrothermal circulation and heat redistribution, a configuration commonly observed in carbonate-hosted hydrothermal geothermal systems (Geldon, 1989).

2.3 Stratigraphic Framework

The stratigraphy beneath Rico consists of Paleozoic carbonate and clastic units overlain by Mesozoic sedimentary formations and locally intruded or covered by Cenozoic igneous and volcanic rocks (Pratt et al., 1969). Of particular importance for geothermal development are the Mississippian Leadville Limestone and the Pennsylvanian Hermosa Formation, both of which contain carbonate intervals that may develop significant secondary porosity through fracturing, dissolution, and karst processes.

The Leadville Limestone is a regionally extensive carbonate unit that serves as an important aquifer and hydrothermal reservoir elsewhere in Colorado (Geldon, 1989). In the Rico area, the depth of the Leadville Limestone varies due to doming and faulting, with the unit exposed along the flanks of the dome but interpreted to be present at depth beneath the town based on integration of surface mapping, cross-sections, and geophysical data (Pratt et al., 1969; Dunnington, 2018). The overlying Hermosa Formation consists of interbedded carbonates and clastic units and may act either as a secondary reservoir or as a transmissive interval connecting deeper and shallower circulation zones (Oerter and Sares, 2010).

Overlying volcanic and intrusive rocks associated with Cenozoic magmatism may locally act as low-permeability barriers that restrict vertical flow. These units may contribute to the confinement of geothermal fluids within carbonate reservoirs and promote lateral heat retention, potentially supporting the development of laterally extensive conductive thermal anomalies (Pratt et al., 1969).

2.4 Structural Controls on Fluid Flow

Structural deformation associated with the Rico Dome exerts a primary control on geothermal fluid circulation. Major mapped faults, including the Last Chance, Nellie Bly, Smelter, and Blackhawk faults, form the main

structural framework controlling permeability distribution (Pratt et al., 1969). These structures vary in orientation, displacement, and hydraulic behavior, with some faults likely acting as fluid conduits and others acting as partial flow barriers (Dunnington, 2018).

Fault intersections are particularly important for geothermal circulation because they often correspond to zones of increased fracture permeability and focused fluid upflow. The alignment of thermal springs and artesian boreholes with mapped fault intersections supports the interpretation that fluid discharge is structurally controlled (Medlin, 1983; Oerter, 2011). At depth, these same structures are interpreted to provide vertical connectivity between deeper heat sources and carbonate reservoir units such as the Leadville Limestone and Hermosa Formation. Fault zones do not behave uniformly across the system. Some faults may be mineralized or sealed, reducing transmissivity, while others remain permeable. This variability suggests that the geothermal system is likely compartmentalized, with hydraulic boundaries that influence reservoir extent, flow direction, and long-term sustainability (Dunnington, 2018).

Geophysical data, particularly resistivity and magnetotelluric (MT) surveys, show conductivity anomalies aligned with mapped fault trends, indicating zones of enhanced fluid saturation or hydrothermal alteration (Dunnington, 2018). These conductive zones are interpreted as permeable fault zones that facilitate fluid movement, while more resistive areas may represent sealed faults or intrusive bodies that limit flow. This combination of conductive and resistive structures suggests a hydraulically segmented system rather than a uniformly connected reservoir.

3 ANALYSIS OF THERMAL MANIFESTATIONS AND DATA

3.1 Surface Thermal Manifestations

The most visible evidence of geothermal activity in Rico consists of three historic mining-era boreholes located north of the town center that discharge warm water under artesian conditions. Measured discharge temperatures range from approximately 40 to 46 °C, with reported flow rates up to approximately 0.95 L/s (Oerter, 2011). Seasonal temperature variation is minimal, generally within 1–2 °C, indicating a relatively stable thermal source with limited influence from shallow meteoric groundwater dilution.

Although the discharge temperatures and flow rates are modest, these features provide clear evidence of upward fluid migration from depth. Their spatial relationship to mapped fault intersections suggests that discharge is structurally controlled rather than the result of diffuse conductive heat loss. Importantly, the small number of surface manifestations should not be interpreted as evidence of a small geothermal system, as surface discharge points typically represent localized hydraulic connections rather than the full extent of subsurface thermal circulation.

Additional evidence of geothermal activity is present south of town in the form of travertine deposits, reported snow-free ground, and sulphurous, mildly thermal springs. These features are interpreted as fossil or recently inactive discharge locations, suggesting that the location of thermal upflow has shifted over time in response to changing structural or hydraulic conditions (Pratt et al., 1969; Medlin, 1983). The distribution of these features indicates that geothermal activity may be more laterally extensive than suggested by the currently flowing artesian wells alone.

3.2 Subsurface Temperature Data from Historic Boreholes

Historic mining operations within the Rico Dome produced numerous boreholes that provide valuable subsurface temperature information. Several mining-era wells encountered artesian flows at depths of a few hundred meters, and reported geothermal gradients in some wells reached values as high as approximately 140 °C/km (Medlin, 1983). In addition to thermal fluids, some boreholes reported gas emissions including CO_2 and H_2S, which are consistent with deep hydrothermal fluid circulation.

Available temperature–depth data from historic boreholes indicate geothermal gradients ranging from approximately 90 to 140 °C/km, significantly higher than typical continental background gradients of approximately 25–30 °C/km. Although these wells do not extend to depths typically associated with geothermal production wells, the consistently elevated gradients observed across multiple boreholes strongly indicate the presence of an anomalous heat source or enhanced heat transport mechanism beneath the Rico area.

For this study, temperature and gradient information from thirteen historic boreholes were compiled and evaluated, building on a broader regional heat-flow and geothermal gradient assessment completed for the Rico area (Teverra, 2024). In cases where only gradient data were available, bottom-hole temperatures were estimated based on reported depth and gradient values. Uncertainty in these data arises from incomplete well

records, unknown well completion conditions, and possible thermal disturbance during drilling. However, the consistency of elevated gradients across multiple wells supports the interpretation that the thermal anomaly is real and regionally significant rather than an artifact of individual wells.

3.3 Geochemistry and Reservoir Temperature Estimates

Geochemical analyses of thermal spring waters provide additional constraints on subsurface temperature and fluid–rock interaction. Previous studies indicate water chemistries consistent with interaction between geothermal fluids and carbonate formations, particularly the Leadville Limestone and Hermosa Formation (Oerter and Sares, 2010). These geochemical signatures support the interpretation that carbonate units serve as the primary reservoir or storage interval for geothermal fluids.

Reservoir temperature estimates derived from silica geothermometers suggest subsurface equilibration temperatures on the order of approximately 120–140 °C. These estimates are subject to uncertainty due to potential mixing with shallow groundwater, re-equilibration during fluid ascent, and the limited number of available geochemical samples. Consequently, geothermometry results should be interpreted as approximate indicators of reservoir temperature rather than precise measurements. Nevertheless, the geothermometry results are consistent with temperature gradients observed in historic boreholes and support the interpretation of a moderate-temperature geothermal system at depth.

4 GEOPHYSICAL INTERPRETATION OF RESERVOIR GEOMETRY

4.1 Resistivity and Magnetotelluric Results

Electrical resistivity surveys conducted across the Rico Dome identified zones of relatively low resistivity at shallow depths beneath the artesian thermal boreholes. These conductive zones are interpreted to represent areas of increased fluid saturation, hydrothermal alteration, or a combination of both (Dunnington, 2018). While ERT surveys provide relatively high-resolution imaging at shallow depths, their depth of investigation is limited, and therefore magnetotelluric surveys were conducted to investigate deeper portions of the system.

Magnetotelluric inversion results indicate the presence of a laterally extensive conductive zone at depths of approximately 500 to 1,000 m. This conductive body appears to have a limited upward extension toward the surface in the vicinity of the known thermal manifestations. The spatial relationship between this deeper conductive zone, the shallow conductive anomalies identified in ERT data, and the mapped fault systems suggests that the anomaly may represent the main geothermal upflow zone or a region of hydrothermal alteration and fluid circulation associated with it.

4.2 Interpretation of Conductive Zones

Low-resistivity anomalies in geothermal environments can result from several factors, including elevated temperatures, saline formation fluids, clay alteration, mineralization, or inherently conductive lithologies. In the Rico area, interpretation of the geophysical data must therefore be carried out in conjunction with geological and structural information to reduce ambiguity.

Integration of the geophysical data with geological mapping and the three-dimensional geological model suggests that the conductive anomaly is unlikely to be explained solely by lithologic variations. Instead, its geometry, depth range, and alignment with major fault structures indicate a strong hydrothermal influence, likely related to fluid circulation along structurally controlled pathways.

Earlier interpretations had suggested that more resistive zones might correspond to geothermal reservoir units. However, when stratigraphic information and the three-dimensional geological framework are considered, some of these resistive zones are more likely associated with intrusive rocks or altered volcanic units rather than permeable carbonate reservoir units. This demonstrates the non-uniqueness of geophysical interpretations when considered in isolation and highlights the importance of integrating geophysical data with geological and structural models.

4.3 Implications for Reservoir Geometry

When integrated with geological and thermal data, the geophysical results suggest that the Rico geothermal system is characterized by a structurally controlled conductive zone at moderate depth that may represent the primary zone of hydrothermal circulation. The lateral extent of the conductive anomaly indicates that the geothermal system may be more extensive than suggested by surface thermal manifestations alone.

The conductive zone appears to be structurally controlled and spatially associated with major fault systems, supporting the interpretation that faults play a central role in controlling fluid flow and heat transport. The depth range of the anomaly, approximately 500–1,000 m, is particularly significant because it falls within a depth range that is potentially accessible for community-scale geothermal development.

From a development perspective, these geophysical results help constrain the likely depth and lateral extent of the geothermal reservoir and provide important guidance for future exploration drilling and monitoring well placement. Rather than targeting surface thermal manifestations directly, the geophysical data suggest that drilling should focus on structurally controlled conductive zones at depth where fluid circulation is likely to be concentrated.

5 INTEGRATED 3D GEOLOGICAL AND CONCEPTUAL MODELING

5.1 Model Inputs and Data Integration

The 3D geological model incorporates multiple data sources, including regional geological mapping, stratigraphic contacts, mapped fault traces, historical mining records, borehole data, thermal spring locations, and geophysical survey interpretations (Figure 2). Stratigraphic units represented in the model include the Hermosa Formation, Leadville Limestone, Molas Formation, and overlying sedimentary units, as well as intrusive bodies associated with the Rico Dome uplift. Due to the limited availability of subsurface well control, the model relies heavily on the geological mapping and cross-sections presented by Pratt et al. (1969), as well as later structural and hydrothermal interpretations developed from geophysical cross-sections and circulation models (Nakagawa, 2022).

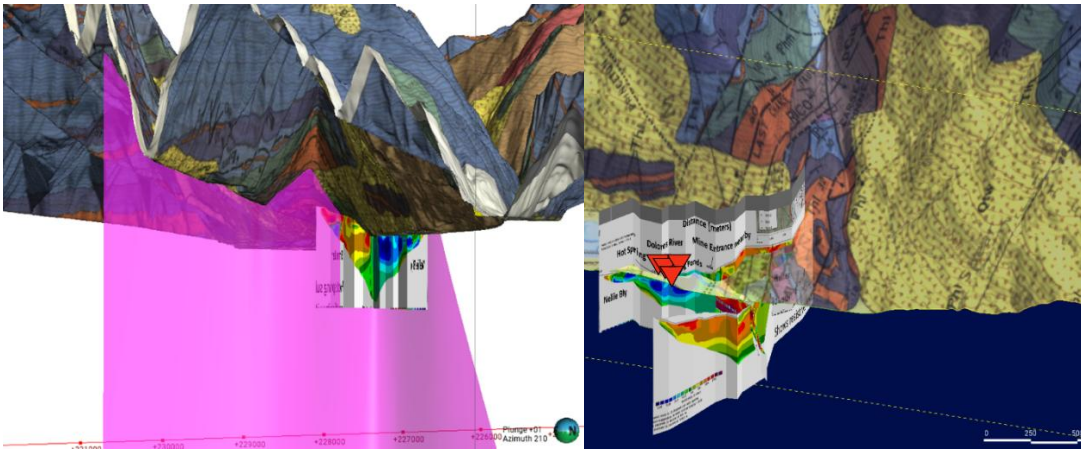


Figure 2. Cross-sectional (left) and oblique (right) views used in construction of the Rico 3D geological model. The figure illustrates how historical geologic cross-sections, mapped stratigraphy, structural interpretation, geophysical information, and geothermal manifestations were integrated into a common three-dimensional framework for resource characterization and exploration planning. Taken from Baird et al., 2025.

Major fault systems, including the Last Chance, Nellie Bly, and Blackhawk faults, were modeled as discrete structural surfaces where sufficient data were available. In areas where fault geometry is poorly constrained at depth, fault surfaces were extrapolated using surface traces, interpreted dip directions, topographic lineaments, and geophysical anomalies. Uncertainty in fault geometry and stratigraphic depth is preserved within the model rather than artificially reduced, allowing the model to represent a range of plausible subsurface configurations.

Thermal and geochemical datasets were not interpolated directly into continuous temperature fields due to the limited number of data points. Instead, these datasets were used qualitatively to inform interpretation of likely fluid circulation pathways, reservoir intervals, and potential upflow zones. This approach reduces the risk of over-interpreting sparse data while still allowing thermal information to inform the overall conceptual model.

5.2 Model Extent and Resolution

The model domain extends laterally beyond the immediate town area to capture the broader structural setting of the Rico Dome and the surrounding thermal anomaly (Figure 3). Vertically, the model extends from the ground surface to depths exceeding approximately 2 km to encompass the range of observed geothermal gradients and the stratigraphic units most likely to host geothermal fluids.

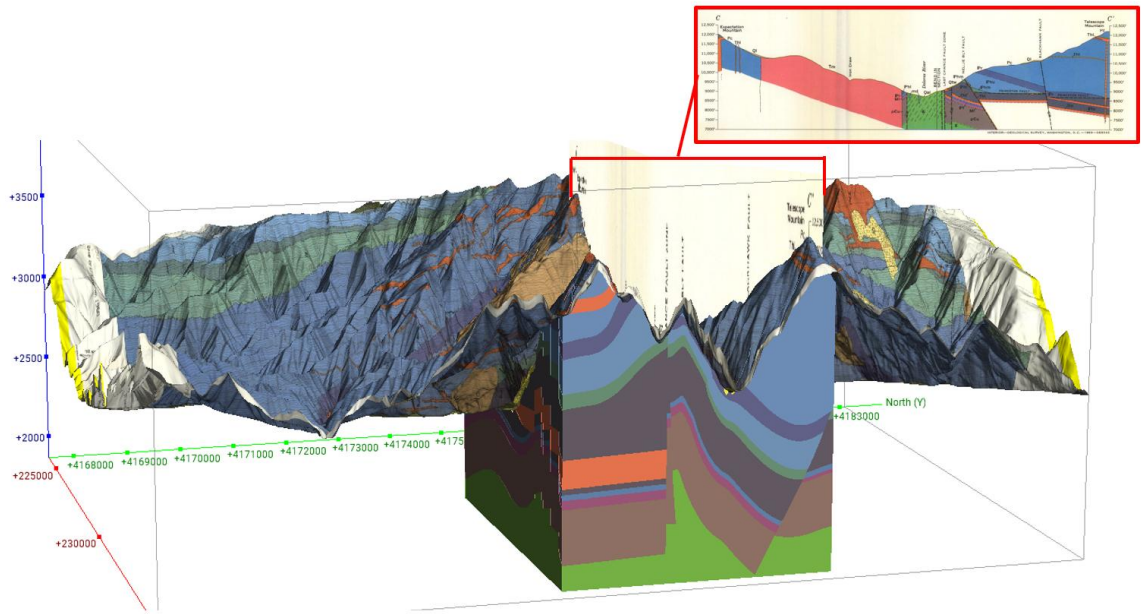


Figure 3. Preliminary three-dimensional geological model of the Rico area showing the interpreted stratigraphic architecture and structural framework of the geothermal system. The model integrates mapped geology, cross-sectional interpretations, fault surfaces, and subsurface control to provide a spatial framework for conceptual modeling and future drilling target evaluation. Taken from Baird et al., 2025.

5.3 Conceptual Model of the Rico Geothermal System

Integration of geological, structural, thermal, and geophysical data supports a conceptual model in which geothermal circulation is structurally controlled and occurs primarily within permeable carbonate units, consistent with earlier hydrothermal circulation models developed for the Rico Dome (Nakagawa, 2022). Several observational constraints are well supported by the available data, including: (1) elevated geothermal gradients relative to regional background values, (2) thermal discharge localized along mapped fault structures, (3) geochemical evidence for fluid interaction with carbonate formations, and (4) geophysical evidence for laterally extensive conductive zones at depth that appear to be structurally controlled.

Despite these constraints, uncertainties remain regarding the primary heat source, the degree of permeability continuity within reservoir units, and the lateral extent of economically useful temperatures. The conceptual model must therefore remain flexible and capable of incorporating new data as they become available.

5.4 Fault-Controlled Circulation and Conductive Heat Transfer

The most likely conceptual model involves fault-controlled convective circulation within carbonate reservoir units, particularly the Leadville Limestone and possibly portions of the Hermosa Formation. In this model, meteoric fluids circulate to depth along permeable fault zones, are heated at depth, and then rise along structurally controlled pathways to shallower depths, where discharge occurs at artesian wells and thermal springs.

In addition to localized convective upflow, the data also support the presence of a broader conductive thermal anomaly beneath the Rico Dome. Elevated geothermal gradients observed in historic boreholes and the laterally extensive conductive zone identified in MT surveys suggest that heat is distributed over a larger volume than indicated by surface manifestations alone. In this framework, faults act as conduits that focus fluid circulation and localize upflow within a broader region of elevated heat flow.

6 COMMUNITY ENGAGEMENT, REGULATORY FRAMEWORK, AND DEVELOPMENT STRATEGY

6.1 Community Engagement and stakeholder Coordination

Community engagement has been a central component of the Rico geothermal project from the early stages of resource evaluation. Because the project is intended to support a community-scale TEN, long-term success depends not only on technical viability but also on community support, stakeholder alignment, and public understanding of geothermal development.

A coordinated stakeholder group was established to bring together local government, technical consultants, engineers, geoscientists, outreach coordinators, funding organizations, and community members. This structure enables technical work, regulatory planning, funding efforts, and community engagement to proceed in parallel, ensuring alignment with community priorities while reducing project risk and supporting informed decision-making.

Outreach efforts have focused on transparency, education, and consistent communication. Public meetings, workshops, and recurring stakeholder sessions have been used to present technical findings, discuss project goals, and communicate uncertainties related to geothermal exploration and development. A dedicated communications and outreach role has supported these efforts by maintaining consistent messaging, organizing engagement activities, and ensuring that technical information is accessible to non-technical audiences.

Public education has been a key component of this process, particularly given the initially limited familiarity with geothermal systems within the community. Educational initiatives, including presentations from external experts, have addressed geothermal technologies, drilling processes, district heating systems, regulatory frameworks, and project financing. These efforts have helped contextualize the Rico project within broader geothermal development practices and have demonstrated the feasibility of similar systems in other communities.

6.2 Regulatory Considerations for Geothermal Development

Regulatory considerations represent a significant component of geothermal project planning and must be addressed early in the development process. In Colorado, geothermal development may involve multiple permitting pathways depending on whether the project is classified as geothermal production, groundwater production, or injection (Figure 4). Permitting requirements may include drilling permits, water rights considerations, injection permits, environmental review, and land access agreements.

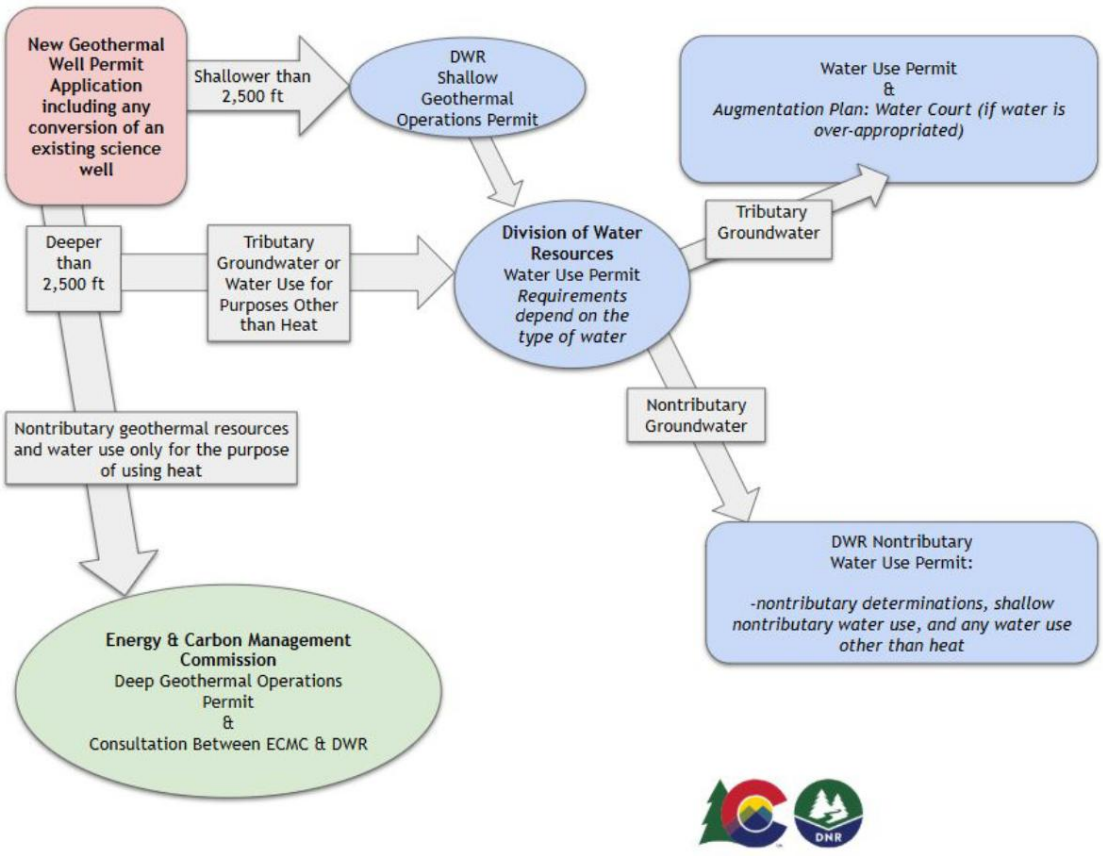


Figure 4. Simplified overview of geothermal permitting pathways in Colorado, illustrating how permitting requirements vary depending on drilling depth, groundwater classification, and intended resource use. For the Rico project, this evolving regulatory framework is an important component of early-stage development planning (Rigby, 2026).

For community-scale geothermal projects, regulatory classification can influence both project cost and development timeline. As a result, regulatory review has been conducted in parallel with technical work to ensure that exploration and development plans align with state and local requirements. Understanding regulatory pathways early in the project helps avoid delays and allows permitting timelines to be incorporated into the overall development schedule.

6.3 Monitoring Well as a Risk Reduction Strategy

The proposed monitoring well represents a critical step in reducing subsurface uncertainty prior to full-scale development. The monitoring well is intended to confirm geothermal gradients, measure temperature at depth, collect fluid samples, and evaluate permeability and flow characteristics. Data collected from the monitoring well will be used to refine the geological model, improve conceptual understanding of the system, and support the design of future production wells. In addition to reducing technical uncertainty, the monitoring well plays an important role in reducing financial and community risk. Confirmed subsurface temperature data improves confidence for investors and funding agencies, while successful drilling demonstrates tangible progress to the community. For small geothermal projects, a monitoring well often represents the transition point between conceptual evaluation and project development.

6.4 Economic and Community Benefits

Development of a geothermal-based TEN has the potential to provide several long-term benefits to the Rico community. These include more stable heating costs, reduced dependence on imported fuels, improved energy security, and reduced greenhouse gas emissions. For small and remote communities, energy costs can be volatile, and locally sourced geothermal energy can provide long-term price stability. In addition to energy cost savings, geothermal development can contribute to local economic development through job creation during drilling, construction, and system operation. The project also represents an opportunity for economic diversification in a community historically dependent on mining and tourism, providing a pathway toward renewable energy development while maintaining the town's historic identity.

7 IMPLICATIONS FOR THERMAL ENERGY NETWORK DEVELOPMENT

Available thermal, geological, and geophysical data suggest that the Rico geothermal system may be characterized by moderate subsurface temperatures (estimated ~120–140 °C), elevated geothermal gradients, and structurally controlled fluid circulation, although these interpretations, based on geothermometry and historical data, remain unconfirmed. Current evidence indicates that economically useful temperatures could potentially be encountered at moderate depths (~1–2 km), supporting consideration of the resource for direct-use applications and Thermal Energy Networks (TENs), particularly when coupled with heat pump technology. The system is interpreted to be heterogeneous, with permeability likely concentrated along intersecting fault zones within carbonate formations such as the Leadville Limestone and Hermosa Formation. A laterally extensive conductive anomaly identified in geophysical data (~500–1,000 m depth) is interpreted as a potential hydrothermal circulation zone and represents a key exploration target, suggesting that successful wells may be more likely where fault intersections coincide with permeable reservoir units rather than at surface manifestations alone. A proposed monitoring well is intended to test these interpretations by constraining temperature, permeability, and fluid characteristics, thereby reducing subsurface and financial uncertainty; while key parameters remain unverified, the combination of inferred resource characteristics and the compact layout of the Rico community indicates that a community-scale TEN may be feasible pending confirmation through drilling and testing.

7.1 Key Challenges, Uncertainty, and Project Risks

Despite favorable geological and thermal indicators, several uncertainties and risks remain. The primary technical risk is drilling uncertainty, particularly with respect to permeability and sustainable flow rates. While temperature gradients and geophysical data suggest favorable conditions, permeability at depth cannot be confirmed without drilling. Additional risks include the cost of drilling and district heating infrastructure, regulatory timelines, and the economic challenges associated with developing energy infrastructure for a small population. Seasonal heating demand and load variability also introduce design and economic considerations that must be addressed during system planning. For these reasons, the Rico project emphasizes a phased development strategy in which uncertainty is reduced incrementally through monitoring wells, temperature measurements, and flow testing before large capital investments are made. This approach allows technical, financial, and community risks to be managed in parallel as the project advances from conceptual evaluation toward implementation.

8 CONCLUSIONS

Available data indicate that the Rico system is characterized by elevated geothermal gradients, structurally controlled fluid circulation, and permeable carbonate reservoir units, particularly the Leadville Limestone and Hermosa Formation. Geophysical surveys identify a laterally extensive conductive zone at depths of approximately 500–1,000 m, interpreted as a zone of hydrothermal circulation and potential geothermal reservoir development. Geothermometry and thermal gradient data suggest subsurface temperatures in the range of approximately 120–140 °C, which are suitable for direct-use geothermal applications and TEN development when combined with heat pump technology.

The integrated geological model and conceptual framework indicate that successful geothermal development in Rico will depend on targeting structurally controlled permeability zones, particularly where major fault systems intersect carbonate reservoir units. As a result, a monitoring well is proposed as the next step in development to confirm temperature, evaluate permeability, and reduce subsurface uncertainty prior to full-scale system development.

Beyond the technical evaluation, this study highlights the importance of community engagement, regulatory planning, and phased development strategies in the successful implementation of community-scale geothermal projects. In small communities, geothermal development must be approached as both an energy project and a community infrastructure project, requiring coordination between technical teams, local government, funding organizations, and community stakeholders.

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