Resource Series 14

An Appraisal for the Use of Geothermal Energy

in State-Owned Buildings in Colorado

by Richard T. Meyer,
Barbara A. Coe,
Jay D. Dick

Colorado Geological Survey
Department of Natural Resources

Denver, Colorado / 1981

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NP--3901255

DE83 901255

AN APPRAISAL OF THE USE OF GEOTHERMAL
ENERGY IN STATE-OWNED BUILDINGS IN COLORADO

Performed By

Western Energy Planners, Ltd.
2180 So. Ivanhoe, Suite 4
Denver, Colorado 80222

Principal Authors

Richard T. Meyer, Ph. D.
Barbara A. Coe, M.P.A.
Jay D. Dick, Consultant

for

Colorado Geological Survey
Department of Natural Resources
1313 Sherman Street
Denver, Colorado 80203
Contract No. 34-11-00

January 30, 1981

\$5.00

PURCHASE ORDER NO. 03K-48252

RECEIVED 2-15-83

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

THE UNIVERSITY OF CHICAGO

THE UNIVERSITY OF CHICAGO

THE UNIVERSITY OF CHICAGO

THE UNIVERSITY OF CHICAGO

TABLE OF CONTENTS

Disclaimer.....	Page vi
Acknowledgement.....	vii
Abstract.....	i
I. OVERVIEW OF GEOTHERMAL APPRAISAL.....	1
Introduction.....	1
Geothermal Technologies.....	2
The Resources and Its Production.....	2
Heat Distribution Systems.....	4
Space and Hot Water Heating.....	5
Disposal of the Geothermal Water.....	5
Resource Assessment of Colorado Sites.....	6
Production Well System and Costs.....	9
Building Retrofit Engineering Design.....	17
Economic Evaluation.....	24
Definitions of Economic Measures.....	24
Economic and Financial Assumptions.....	26
Geothermal Capital Improvement Costs.....	26
Annual Operating and Maintenance Costs.....	26
Summary of Economic Evaluations.....	31
Conclusions.....	42
Institutional Requirements.....	43
Surface Control of Drill Site.....	43
Geothermal Resource Control.....	43
Well Permits.....	44
Water Rights.....	45
Right-of-Way.....	45
Construction Permit.....	45
Other.....	45
Fluid Disposal Permits.....	46
Summary.....	46
Environmental Considerations.....	49
Water.....	51
Air.....	51
Land.....	52
Noise.....	52
Ecological Interrelationships.....	52
Water Availability.....	52
Socio-Economic Impacts.....	53
Summary.....	53
Financing Options.....	54
Budget Appropriations.....	54
General Obligations Bonds.....	54
Revenue Bonds.....	55
Assistance from Another Level of Government.....	55
Summary.....	56
Summary and Conclusions.....	57
Site Specific Analysis.....	62
References.....	63

LIST OF TABLES

		<u>Page</u>
Table 1	Geothermal Resource Characteristics for Six Colorado Sites.....	8
Table 2	Estimated Well Drilling Costs at Glenwood Springs..	13
Table 3	Estimated Total Well Drilling Costs for Colorado Sites.....	14
Table 4	Estimated Pumping Depths and Pump Costs.....	15
Table 5	Production Well Placements and Disposal Methods Selected for Colorado Facilities.....	16
Table 6	Summary of Existing Conventional Heating Systems and Heating Requirement for State-Owned Buildings.....	18
Table 7	Summary of Design Parameters for Geothermal Options for State-Owned Buildings.....	21
Table 8	Baseline Set for Assumed Economic and Financial Factors (Applicable for 20-Year Period of 1981 to 2000).....	27
Table 9	Summary of Geothermal Capital Improvement Costs for the State-Owned Buildings.....	28
Table 10	Summary of First Year Operating and Maintenance Expenses for Geothermal and Conventional Heating Systems.....	32
Table 11	Summary of Economic Evaluations for Geothermal Options Compared to Conventional Fuel Systems for State-Owned Buildings.....	35
Table 12	Summary of Economic Evaluations for Geothermal Options Compared to Conventional Fuel Systems for State-Owned Buildings.....	39
Table 13	Legal and Regulatory Requirements for Geothermal Development (1980).....	47
Table 14	Preliminary Appraisal of Environmental Impacts of Selected Geothermal Projects.....	50
Table 15	Estimated Overall Feasibility Ranking of Geothermal Options for State-Owned Buildings.....	58

LIST OF FIGURES

	<u>Page</u>
Figure 1 Geothermal System with Magma Heat Source.....	3
Figure 2 Proposed Plan-View of the Geothermal Drilling Site at Glenwood Springs, Colorado.....	10
Figure 3 Well Profile for Glenwood Springs.....	11
Figure 4 Well Head Completion Assembly.....	12

Disclaimer

Every effort was made by Western Energy Planners, Ltd., to obtain and to use the most recent and most accurate information on the state-owned buildings and on the geothermal resource area addressed in this geothermal appraisal. Complete information was not always available, so certain assumptions had to be made in order to proceed with the appraisal. It must be observed, in particular, that the geothermal resource characteristics are not really known until well drilling and testing are accomplished. The engineering designs are based upon standard HVAC design principles, but must be recognized as only conceptual designs not as final designs for construction purposes; indeed, the actual design of a geothermal hot water heating system for any building is likely to be a significantly different design. Similarly, the equipment cost estimates are merely estimates, generated for the economic evaluations of this study but not to be construed as actual market prices. The economic evaluations are based on a number of assumed values for economic and financial factors; the assumed values appear reasonable in today's energy and economic environment, but in no way can they be regarded as accurate projections of the future. Therefore, the conclusions on economic feasibility must be regarded as indications of opportunity but not as fact.

This report has been prepared in fulfillment of Contract No. 34-11-00 between the Colorado Geological Survey and Western Energy Planners, Ltd. of Denver, Colorado. There are no other intents or purposes, expressed or implied, to be derived from this report.

All information and data contained herein has been subject to the professional interpretation of Western Energy Planners, Ltd. and is accurate and valid in all good faith to the best of the corporation's knowledge. However, Western Energy Planners, Ltd. and its employees, consultants and subcontractors do not make any warranty, expressed or implied, nor assume any legal liability for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed "herein," or represents that its use would not infringe upon privately owned rights.

The view, opinions and conclusions contained in this report are solely of Western Energy Planners, Ltd. and do not necessarily represent those of any other person, corporation or entity discussed herein.

Acknowledgement

Western Energy Planners, Ltd. and the principal authors of this report wish to express appreciation to several persons who contributed significantly to the information gathering, the engineering designs, and the economic evaluations.

The following individuals associated with the state-owned facilities provided necessary and valuable data and specifications on the existing heating systems: Adams State College - Leonard McLean and A.J. Hall; Colorado State Reformatory - Ed Kochman; Fort Lewis College - Dan Black and Gene Fisher; National Guard Buildings - Capt. John S. Materi, Sgt. Fritz Reinwald and Bob Milleson; State Fish Hatchery - Mike Zgainer and Bob Little; and State Highway Department Buildings - John Springer, Larry Logan, John A. Kier, Robert D. Sherman, and Lester Vickers. For the State Buildings Department, Ralph Alexander and George Collins provided coordination and advice.

The engineering evaluations and design specifications were performed by several consulting engineers that are used regularly by Western Energy Planners, Ltd. (WEPL). In addition, Dr. W. Darrell Gertsch of WEPL and Loyd Donovan of Appropriate Technologies Inc. provided assistance and technical review of the engineering tasks.

Rob Raskin and Kim A. Meyer, both WEPL personnel, participated significantly in the calculations of the economic measures for all of the geothermal heating options applied to the state-owned facilities.

Secretarial support for typing and manuscript preparation was coordinated by Aldona R. Rayton and performed by Jeanne L. Barber, Cindy Johnson and Patsy Collier.

The Colorado Geological Survey and Richard Pearl, Project Monitor, provided invaluable guidance and assistance throughout the geothermal appraisal project.

AN APPRAISAL OF THE USE OF GEOTHERMAL
ENERGY IN STATE-OWNED BUILDINGS IN COLORADO

Richard T. Meyer, Ph.D.
Barbara A. Coe, M.P.A.
Jay D. Dick, Consultant

ABSTRACT

An appraisal of the use of geothermal energy for space heating requirements for selected state-owned buildings in six communities in Colorado is presented in this report for the Colorado Geological Survey. The appraisal addresses several components of a feasibility study for geothermal applications, including resource assessment, pipeline rights-of-way, well design and drilling program, conceptual engineering designs for retrofits of building heating systems, evaluations of economic feasibility, institutional requirements, and environmental considerations. Economic feasibility is determined from evaluation of four economic measures: simple payback period in years; twenty-year annualized system costs (geothermal system versus conventional system); total twenty-year undiscounted "energy" savings; and total twenty-year present value "energy" savings. The results of the analyses of each feasibility component are finally ranked, using a weighting system, to arrive at an order ranking of the eleven state-owned buildings for overall feasibility.

The relative total feasibility rankings and the absolute evaluations of economic competitiveness with the existing conventional-fuel heating systems show that several of the state facilities are likely candidates for conversion to geothermal hot water heating systems. The best candidate by far is the Colorado State Reformatory at Buena Vista. The geothermal resource at Buena Vista (Cottonwood Canyon and Chalk Creek) is a high quality resource with high water temperatures and a water quality adequate for direct flow through the building heating units. The retrofit engineering requirements are minimal because of the direct availability of geothermal water at 250°F or higher. The economics are favorable on all measures because of shallow well depths, gravity flow through the pipeline, low-cost retrofit of buildings and surface disposal of the discharge water. The fact that the existing steam boiler system is nearing its life expectancy and that major repair or replacement costs may be encountered in the near future adds credibility to a favorable decision to make a geothermal capital improvement of approximately \$4.5 million. For this investment, the State could realize a simple payback in twelve years and total "energy" savings over the next twenty years of about \$30 million.

Three facilities with essentially equal scores follow the Colorado State Reformatory in order of overall feasibility: Adams State College (with a central heat pump), the Buena Vista Highway Department Building, and the Glenwood Highway Department Buildings. The real distinguishing feature among these facilities is the absolute values of the capital improvement costs, being \$2,111,387, \$34,253, and \$114,356, respectively. In addition, each facility is based upon a different type of geothermal option: a central heat pump with a deep well, distributed water-to-air heat pumps coupled to a shallow aquifer, and a central heat exchanger with the geothermal water apportioned from a deep well.

Next in order of overall ranking are the Highway Department Buildings at Steamboat Springs, the National Guard Building at Durango, Adams State College with a central heat exchanger, and the Highway Department Buildings at Alamosa. Of these, the Highway Department Building at Steamboat Springs is considered to be the best candidate for a geothermal system. It has characteristics very similar to the Glenwood Springs facility and is lower ranked only because of the prospect of a deeper geothermal resource and more costly well drilling. The ranking of the National Guard Building at Durango is based largely on the speculation that a warm shallow aquifer can be tapped for a heat pump application. A central exchanger system for Adams State College is lower ranked than the central heat pump system because of the requirement for two deep wells on campus and the costs of adding terminal heating units to all of the buildings. The Alamosa Highway Department Buildings would fare better in the rankings if the geothermal water could be obtained from an existing nearby pipeline (possibly the prospective Alamosa Industrial Park) rather than from deep wells drilled on-site.

None of the other Durango facilities really appear feasible because of the high costs associated with the 15-mile geothermal trunk line required from the resource area north of Durango. A heat pump application at the Burlington Highway Department Building is feasible because of the existence of the Ogallala Aquifer at a shallow depth.

In conclusion, this appraisal of the prospective use of geothermal energy for the heating of eleven state-owned buildings at six locations in Colorado has shown that at least six of the facilities have a high to moderate feasibility for successful development and economic benefit. The next steps that might be taken by the State are (1) to select one or more facilities for more sophisticated and detailed engineering and economic feasibility studies and (2) to provide funds for final engineering design of the facilities which prove out to be acceptable to the State for capital improvements.

OVERVIEW OF GEOTHERMAL APPRAISAL

Introduction

The Colorado Geological Survey has been conducting assessments of the geothermal resources of the State for several years. In addition, a major geothermal commercialization planning program has been underway since 1977. Results of these projects are documented in numerous publications by the Survey (see list of references). In 1980, the State Legislature appropriated funds for an appraisal of the use of geothermal energy in state-owned buildings. This report represents the product of that appraisal, which was conducted during the fall and winter of 1980.

Originally, thirteen state-owned buildings in seven Colorado communities were selected by the Colorado Geological Survey for the appraisal. The selection of locations and facilities was based upon proximity to documented geothermal resource areas within the state. The locations are:

- Alamosa
 - Adams State College
 - State Highway Department Buildings
- Buena Vista
 - Colorado State Reformatory
 - State Highway Department Building
- Burlington
 - National Guard Building
 - State Highway Department Building
- Durango
 - Fish Hatchery
 - Ft. Lewis College
 - National Guard Building
 - State Highway Department Building
- Glenwood Springs
 - State Highway Department Buildings
- Idaho Springs
 - State Highway Department Buildings
- Steamboat Springs
 - State Highway Department Building

Very early in the project, state agency personnel pointed out that the State no longer had an ownership interest in the Burlington National Guard Building and that the State would be vacating the Highway Department Buildings in Idaho Springs. Therefore, these two facilities were deleted from the study reducing the number of sites to six. Further, it was learned that the Highway Department planned to construct a new facility near the Bodo Industrial Park in Durango; hence the new building was chosen for analysis rather than the existing buildings in Durango.

In this overview chapter, several topics are summarized to provide the reader with a synopsis of the prospective uses of geothermal energy in state-owned buildings. The first section below describes in a general way the key elements of the geothermal energy technologies. The following sections summarize the results of this appraisal, including the topics of resource assessment, well engineering, building retrofit engineering, economic evaluations, institutional requirements and environmental considerations for the six locations and eleven facilities. Finally, an overall appraisal for the set of state-owned buildings is presented. Subsequent chapters of this report document in detail the findings for the individual locations and facilities included in the appraisal.

Geothermal Technologies

The Resource and Its Production

The geothermal resource in Colorado is a hydrothermal type resource, as distinguished from dry steam, hot dry rock and geopressured resources. Hydrothermal resources are of two types: water-dominated and steam dominated; the Colorado resource is primarily a water-dominated resource.

In the Colorado area, hydrothermal resources may originate either with the circulation of rain water through permeable rock that is heated by heat conduction from the magma core of the earth or with the flow of deep hot waters, also heated conductively, upward through geologic faults. A cartoon of the first case is presented in Figure 1 as a simple illustration of the mechanics of a geothermal resource.

Hot surface springs and thermal wells are principal indicators of geothermal occurrences. The Colorado Geological Survey has identified and documented 56 separate areas of hot springs and wells in various parts of Colorado (Barrett and Pearl, 1978). Surface manifestations of geological structure are another major clue to the possible locations of geothermal resources. These manifestations often occur as faults, uplifts, and altered rock formations. Subsurface manifestations are analyzed by geochemical and geophysical measurements. Actual determinations of the location, size and quality of geothermal reservoirs requires the drilling and testing of wells.

GEOHERMAL SYSTEM WITH MAGMA HEAT SOURCE

Figure 1

SOURCE: UNIVERSITY OF UTAH RESEARCH INSTITUTE, 1980.

Production of energy from a geothermal resource, except in the cases of surface springs of adequate water flow, does require the drilling of wells into a permeable rock formation or into a fault zone. Well depths can vary substantially from a few hundred feet to several thousand feet in order to intercept a zone of permeability or a fault zone of sufficient water flow rate and temperature to satisfy the energy requirements of the specific application. Several production wells may be required to satisfy the total required flow rate.

The maximum temperature of the reservoir is highly unpredictable prior to the drilling, although some indication may be available from geothermal analyses of spring and well waters and from thermal gradient measurements. Once a maximum water temperature for flowing or pumped well water is achieved, that temperature is likely to apply to the body of the geothermal reservoir. It is, therefore, the temperature to be used for the engineering design of the specific energy application.

Heat Distribution Systems

Once a geothermal reservoir has been tapped by production wells, the hot water must be pumped and piped to its points of use. An energy efficient distribution system requires that heat loss be minimized during the piping of the geothermal water from the wells to the point of use. Current designs of piping systems use insulated pipes, generally buried in trenches to reduce heat losses further. Several types of piping are available today for effective use with low to moderate temperature geothermal waters. A rule of thumb for heat losses from a well-designed, well-insulated piping system is a water temperature reduction of 1°F per mile of piping.

Depending on the chemical content (water purity) and the temperature of the geothermal water, the engineering design for the heat distribution system may use heat exchangers, heat pumps or direct flow. Central heat exchangers and central heat pumps (water-to-water type) are often used to provide protection of the end-use facilities from chemical corrosion or scaling caused by high concentrations of various kinds of salts in the geothermal water; instead, the heat exchangers and heat pumps are subjected to those chemical degradations and may be cleaned or replaced as part of the maintenance schedule. In other applications, chemical treatment and prevention of oxidation are used to prevent these problems. Direct flow of the geothermal water to the end-use facilities is feasible when the chemical impurities are low enough.

In addition, central water-to-water heat pumps are used to boost the temperature of the heating water when the geothermal water temperature is not high enough to provide effective heat transfer to the building air for space heating. A heat pump boosts the temperature by using an electrically-driven compressor with a vaporizing refrigerant to extract energy from the geothermal water and transfer it to the circulating heating water.

Space and Hot Water Heating

In this appraisal for the Colorado Geological Survey, both space heating and heating of domestic hot water for the several state-owned buildings are treated. The actual space heating of buildings from a geothermally-derived hot water source is essentially identical to hot water heating designs for any source of heated water, whether it be a gas-fired boiler, a solar collector system, coal or wood. Hot water is hot water for purposes of designing the heat transfer system for space heating. Typical heat transfer units include fancoils, radiators, fin tubes, exposed coils, etc. The actual design, however, does depend upon the temperature and flowrate of the hot water, the same as in any heating, ventilation and air conditioning (HVAC) design process.

One variation in space heating technology that has been applied to several of the smaller buildings included in this appraisal is the use of water-to-air heat pumps as unit heaters. These heat pumps are applied in cases where warm shallow water aquifers are available as a source of thermal energy. The warm water is pumped directly to the heating locations of the heat pumps in the buildings. The heat pump extracts energy from the warm water and transfers it directly to the space air that is circulating in the heated area.

Disposal of the Geothermal Water

Basically two methods exist for the disposal of the geothermal water once its use as a source of thermal energy has been completed. The two methods are reinjection into the earth, generally into the same aquifer from which it originated, and dumping the water into some surface medium, such as a pond, stream, lake, open field, drainage/seepage ditch and sewer system. The environmental considerations for these two operations are discussed later in this chapter.

The advantages of reinjection of the discharged geothermal water are that non-consumptive use is made of the water - that is, only energy is extracted - and that several environmental consequences are eliminated or minimized. The disadvantage of reinjection is the cost of drilling and operating another geothermal well.

Surface disposal of the geothermal water can achieve beneficial purposes, but environmental protection should be preserved. Secondary use of the water in cascaded lower temperature applications is one option. Another application is irrigation water for crops if the water purity is adequate. Evaporation ponds which provide for a confined collection of the dissolved solids is another practical option for smaller applications. Finally, discharge of low flowrates of the geothermal water into sewer systems or rivers may also be acceptable.

Resource Assessment for Colorado Sites

The quality of the geothermal resource at each of the locations of the state-owned buildings is a critical factor in the adaptability of the buildings to geothermal space heating. The geothermal resource must, as a minimum, provide water at a high enough temperature and flowrate to deliver the required amount of energy for heating to the buildings. Generally speaking, the water temperature must equal or exceed 140°F, although higher temperatures are more favorable; conventional hot-water heating systems are designed for 180°F to 200°F water. If water-to-air heat pumps are used, aquifer temperatures as low as 50°F may be feasible. Heating with less than 140°F is also possible.

The flowrate required is directly proportional to the total space heating load. For smaller buildings, rates of 50 or 100 gpm of 150°F water are adequate. For large complexes of buildings, e.g., a college, flowrates of the order of 5000 gpm at 150°F are required.

Individual geothermal wells will have a limiting flowrate which is dependent upon the geological structure of the reservoir formation, being dependent upon porosity, permeability, fracturing, faulting, etc. The maximum flow achievable from a geothermal reservoir will depend upon the number of wells, reservoir volume, water recharge rates, geological factors, and other parameters.

In order to obtain the necessary resource information for the building retrofit engineering design, a compilation and assessment of existing data on the geothermal reservoirs at the seven Colorado locations was performed. Most of the information upon which the assessment is based is available in public records; however, in a few cases knowledge of private or unpublished data is drawn upon to adjust the final conclusions.

For each geothermal resource area, existing information on hot springs and wells, geologic structures, geochemical and geophysical measurements, and geologic models and interpretations are examined. From these examinations, projections of the individual resource characteristics are made. Each resource is characterized in terms of the following parameters:

- Reservoir temperature
- Depth
- Production/rate per well
- Areal extent
- Formation
- Total dissolved solids
- Useable heat content

In addition, validity ratings are assigned to certain of the resource parameters in order to lend credibility to the projections. The rating system is as follows:

- (3) - Very confident of the accuracy of the projected data, greater than 50% validity.
- (2) - Sufficient data to indicate the possibility of these characteristics, approximately 50% validity.
- (1) - Some data to indicate these characteristics, a "best guess" at the accuracy of the projection.

Table 1 presents a summary of the geothermal resource characteristics for all of the sites, except for Burlington. Burlington does not have a known geothermal resource, but does overlie a shallow aquifer - the Ogallala Aquifer. Its characteristics for heat pump applications will be discussed in Chapter IV. Detailed discussions of the characteristics for each of the six sites listed in Table 1 are presented in subsequent chapters of this report.

Based upon the resource characteristics projected herein, the best areas for further geothermal energy activity are at Glenwood Springs, Alamosa and Buena Vista. The geothermal resources at Glenwood Springs are apparently only 500 feet deep immediately beneath the state-owned highway department facilities. Geothermal temperatures of 150°F should be encountered at relatively shallow depths, with sufficient geothermal resources to supply energy to expanded state-owned facilities plus additional users.

At Alamosa and Buena Vista, geothermal development has great potential but varying risk factors. The resources at Alamosa appear to be deep (4000+ feet) and the resource may be risky to encounter. However, once successful drilling has been accomplished, pipeline distances should be minimal and end users abundant. Buena Vista has just the reverse situation. Geothermal resources definitely exist at very shallow depths (as proven by existing wells) with excessively high subsurface temperatures (greater than 250°F at less than 200 feet). However, the geothermal fluids must be piped greater than six miles in order to get to the energy intensive Colorado State Reformatory.

TABLE 1

Geothermal Resource Characteristics for Six Colorado Sites.

Location	Reservoir Temperature (°F)	Depth (feet)	Production per Well (gpm)	Areal Extent (square miles)	Formation	TDS (mg/l)	Useable Heat 10 ¹¹ Btu
<u>Alamosa</u>	150 (2)	4000+ (2)	500-1000 (2)	>10-15 (3)	Poorly consolidated sediments interlayered with volcanics	300	200 (2)
<u>Buena Vista</u>							
Chalk Creek	250-350 (2)	<500-2000* (2)	200-250 (1)	3.0+ (2)	Fractured and altered Mt. Princeton Quartz Monzonite	250-300	640 (2)
Cottonwood Canyon	250-300 (2)	<300(3)	150 (2)	1.35 (3)	Fractured and altered Mt. Princeton Quartz Monzonite	<350	230 (2)
<u>Durango</u>	<150 (2)	200-300 (1)	100 (2)	1.18 (2)	Leadville Limestone	3000-4000	15 (1)
<u>Glenwood Springs</u>	150 (2)	500-800 (2)	1000 (1)	0.5-2.0 (3)	Leadville Limestone	17,000-20,000	23 (1)
<u>Idaho Springs</u>	175 (2)	2000(1)	100 (2)	0.13 (2)	Fractured Precambrian basement	1000-2000	103 (1)
<u>Steamboat Springs</u>							
Routt Hot Springs	200-250 (2)	2900 (3)	100 (2)	0.75 (3)	Fractured Precambrian basement	550	90 (2)
Steamboat Springs	150 (2)	800-6000** (1)	500 (1)	0.52-1.0 (2)	Dakota Sandstone	1000-6000	30 (1)

* Dependent on drill site

** Geology indicates approximately 800 feet and geophysics indicates approximately 6000 feet.

Production Well System and Costs

A major cost item for any geothermal energy application is the cost of production well drilling. The total costs for a complete production well system include exploration, reservoir engineering, well drilling, well pumps, valves and controls, among other items. The well drilling costs, in particular, are strongly dependent upon the geological structures encountered and the final depth of the well. Therefore, the drilling costs must be separately estimated for each resource site included in this appraisal. Only estimated costs are possible because of the uncertainties and risks involved in geothermal well drilling.

For purposes of this appraisal report, a detailed description of a production well design and drilling program is presented in Chapter VI for Glenwood Springs. The detailed description was obtained from Chaffee Geothermal Ltd. and was produced as a component of the Denver Research Institute feasibility study "Municipal Geothermal Heat Utilization Plan for Glenwood Springs, Colorado" (Denver Research Institute, 1980).

A few excerpts from the Glenwood Springs well design and drilling program are presented here to indicate the general nature of this component of a total geothermal project. Figure 2 shows a drilling site-plan, including relative locations and sizes of drilling rig, mud pit, flow line and settling pond. The total area to be impacted is less than one-half acre. Figure 3 shows a well and casing profile for a 800-foot deep well into the Leadville Limestone Formation. The sizes indicated have been adjusted to those required for a well to supply the State Highway Department Building. Figure 4 shows a typical wellhead completion assembly.

Approximate well costs to drill a six inch geothermal exploration well to a depth of 800 to 1000 feet at Glenwood Springs are estimated in Table 2. A major portion of drilling costs are dependent on drilling rates and these projections are merely estimates. The total well costs include a 25% contingency to cover unanticipated drilling conditions. Total drilling costs are estimated at approximately \$118,000.

Figure 2- Proposed Plan-View of the Geothermal Drilling Site at Glenwood Springs, Colorado

SOURCE: Chaffee Geothermal, Ltd., 1980

FIGURE 3
WELL PROFILE FOR GLENWOOD SPRINGS

SOURCE: Chaffee Geothermal, Ltd., 1980

SOURCE: Chaffee Geothermal, Ltd., 1980

Figure 4: Well Head Completion Assembly

Table 2

Estimated Well Drilling Costs at Glenwood Springs

Activity	Cost
1) Site preparation	\$2,000
2) Mobilization	5,000
3) Drilling time	
Cable-tool, \$80/hr., 3 days (12 hrs. each)	2,880
Rotary, \$175/hr., 6 days (24 hrs. each)	25,200
Stand-by, \$110/hr., 36 hrs.	3,960
	<u>32,040</u>
4. Drilling supervision	
Drilling supervisor, \$300/day, 9 days + expenses	3,500
Drilling engineers, \$450/day, 6 days + expenses	3,500
	<u>7,000</u>
5) Casing	
13-3/8" conductor, 40', \$20/ft.	800
9-5/8" surface, 150', \$13/ft.	1,950
6" production, 505', \$9/ft.	4,545
Bottom 300' is open-hole	
	<u>7,295</u>
6) Cement	
400 sx. Class G + 2% CaCl	3,000
Trip charges (2 trips)	600
Pump charges	1,400
Valves, plugs, centralizers, grout baskets	2,000
	<u>7,000</u>
7) Mud	
300 sx. gel	2,000
500 sx. barite	4,000
200 sx. LCM and mica	2,000
	<u>8,000</u>
8) Bits and equipment rental	
Bits (possibly figured in hourly rate)	5,000
Drilling stack	3,000
Pumps, compressors, shale shaker (optional)	3,000
	<u>11,000</u>
9) Wellhead	
Master valve - 6"	5,000
Safety valve	1,200
Wellhead "T"	1,500
Casinghead flange	800
Misc. fittings, gaskets, bolts, flanges	1,500
	<u>10,000</u>
10) Well logging	5,000
11) Contingencies	
25% of well costs	<u>23,584</u>
Total Well Drilling Costs:	\$117,919

Estimated total well drilling costs for geothermal production wells at six Colorado sites (excluding Burlington and the shallow aquifers at other sites) are summarized in Table 3. Variations in cost are largely due to both depth and geologic structure.

Table 3
Estimated Total Well Drilling Costs for Colorado Sites

Site	Depth	Cost	Remarks
Alamosa	4000'	\$120,000	Similar to Glenwood Springs
Buena Vista			
Cottonwood	300'	\$ 60,000	High temperature; highly altered rocks.
Chalk Creek No. 1	500'	\$100,000	High temperature; highly altered rocks.
Chalk Creek No. 2	2000'	\$135,000	High temperature; highly altered rocks.
Durango	300'	\$ 50,000	
Glenwood Springs	800'	\$120,000	See Chapter VI
Idaho Springs	2000'	\$200,000	Extremely hard rock drilling conditions.
Steamboat Springs	1000'	\$120,000	Similar to Glenwood Springs

Another geothermal well variable which must be specified in well engineering and provided for in the cost estimates is the pumping depth. The depth at which a geothermal well pump is placed and the pumping rate govern the size (horsepower), the initial cost, and the operating cost (electricity) of the pump. The existence of Artesian flow or pressure at any location will reduce the pumping depth and the costs. Table 4 lists the estimated pump depths, flow rates per well, and pump costs per well for the Colorado locations, including options in a few cases for drawing warm water from shallow aquifer for use with water-to-air heat pumps.

Table 5 summarizes the assumed locational placements of the production wells and the reinjection wells or disposal method for the Colorado facilities. These choices are discussed in more detail in the subsequent chapters on each Colorado location.

TABLE 4
Estimated Pumping Depths and Pump Costs

Site	Pump Depth	Flowrate Well (gpm)	Pump Cost/Well
Alamosa	300'	500-1000	\$30,000-67,400
Buena Vista			
Cottonwood	100'	150	\$ 2,480
Chalk Creek No. 1	100'	200-250	\$ 4,533
Chalk Creek No. 2	300'	200-250	\$16,533
Shallow Aquifer	100'	70	\$ 1,075
Burlington			
Shallow Aquifer	200'	30	\$ 1,000
Durango			
Tripp/Trimble	100'	100	\$ 1,109
Shallow Aquifer	100'	80	\$ 1,250
Glenwood Springs	100'	1000	\$25,714
Steamboat Springs			
Steamboat	200'	500	\$ 3,000
Shallow Aquifer	100'	50	\$ 775

TABLE 5

Production Well Placements and Disposal Methods Selected for Colorado Facilities

LOCATION/FACILITY	PRODUCTION WELL PLACEMENT	DISPOSAL METHOD
<u>ALAMOSA</u>		
Adams State College	On-site	Reinjection on-site
Highway Department Building	On-site	Reinjection on-site
<u>BUENA VISTA</u>		
Colorado State Reformatory	One of three well sites	Surface
Highway Department Building	On-site	Surface
<u>BURLINGTON</u>		
Highway Department Building	On-site or purchased water	Surface
<u>DURANGO</u>		
Fish Hatchery	Trunk line from Tripp/Trimble & Pinkerton	Mixing with fish ponds
Ft. Lewis College	Trunk line from Tripp/Trimble & Pinkerton	Reinjection on-site
Highway Department Building (new)	Trunk line from Tripp/Trimble & Pinkerton	Reinjection on-site
National Guard Building	On-site	Surface
<u>GLENNWOOD SPRINGS</u>		
Highway Department Building	On-site	Reinjection on-site
<u>STEAMBOAT SPRINGS</u>		
Highway Department Building	On-site	Surface

Building Retrofit Engineering Design

As indicated in the section above on resource assessment, the building retrofit engineering design is based upon the projected quality of the geothermal resource at each location. Table 1 documents the resource parameters used in the engineering designs which are summarized here. Detailed descriptions of the designs are provided in the subsequent chapters on each location and facility.

The design approach for each building retrofit is first to determine the design peak heat load, second to calculate the total annual energy consumption, third to compare the calculated value with the actual annual energy consumptions over the past one to three years, fourth to select a final design peak heat load, fifth to evaluate alternative geothermal heating designs to determine which one, if any, can match the peak heat load requirement, sixth to select the optimum engineering design that matches the geothermal resource with the heating load, seventh to define the replacement or supplemental building space heating equipment, and finally to design the complete retrofit system, including the geothermal heat distribution system and the building space heating equipment.

Table 6 summarizes the existing conventional heating systems for each of the state-owned buildings, including the total annual energy consumption and the peak heat load. Most of the buildings are fueled by natural gas, some have propane heating units and one has a small component of electric heating. Ft. Lewis College, Adams State College and the Colorado State Reformatory use fuel oil as a back-up fuel to the natural gas.

The two National Guard Buildings and most of the State Highway Department Buildings use natural gas or propane fired unit heaters. New space heating equipment would have to be installed to use geothermally derived hot water heating. The main office building and the garage of the Highway Department Buildings at Alamosa are heated with hot water; a portion of that plumbing system can be reused for the geothermal system. The proposed new Highway Department Building at Durango can be readily redesigned to provide for geothermal hot water heating. All of these buildings are compact in size and layout and can be retrofitted easily and at only moderate cost.

The Fish Hatchery at Durango has a dispersed set of buildings with a relatively small total heat load. Extensive retrofit of the separate heating systems is required and a distribution piping system is needed to place all

TABLE 6

Summary of Existing Conventional Heating Systems and Heating Requirement for State-Owned Buildings

LOCATION/FACILITY	SQUARE FOOTAGE	CONVENTIONAL HEATING SYSTEM	FUEL	ANNUAL ENERGY CONSUMPTION (10 ⁶ Btu)	PEAK HEAT LOAD (Btu/hr)	REMARKS
<u>ALAMOSA</u>						
Adams State College	955,000	Steam boilers	Natural gas and fuel oil	46,234	20,000,000	Repair costs increasing, leaking condensate lines
State Highway Department Buildings	27,112	Water boiler Unit Heaters	Natural gas Propane	5,097	2,650,000	Dispersed set of buildings.
<u>BUENA VISTA</u>						
Colorado State Reformatory	400,016	Steam boilers	Natural gas	85,000	24,405,200	System is 20-25 years old. Year round demand for hot water.
State Highway Department Building	6,380	Unit heaters	Natural gas	694	480,000	
<u>BURLINGTON</u>						
State Highway Department Building	4,080	Unit heaters	Natural gas	220	205,000	
<u>DURANGO</u>						
Fish Hatchery		Forced air Unit heaters	Natural gas	2,632	1,038,000	Dispersed set of buildings.

TABLE 6 (cont'd)

LOCATION/FACILITY	SQUARE FOOTAGE	CONVENTIONAL HEATING SYSTEM	FUEL	ANNUAL ENERGY CONSUMPTION (10 ⁶ Btu)	PEAK HEAT LOAD (Btu/hr)	REMARKS
<u>DURANGO-cont'd</u>						
Ft. Lewis College	546,218	Water boilers, Steam	Natural gas	70,000	25,000,000	Each building is individually heated.
Highway Department Building (new)	34,920	Forced air	Natural gas	6,288	2,484,000	Still to be con- structed.
National Guard	7,522	Unit heaters, Forced air	Natural gas	912	565,000	
<u>GLENWOOD SPRINGS</u>						
Highway Department Building	13,510	Forced air, Unit heaters, Electric heaters	Natural gas Electricity	2,160	698,000	
<u>STEAMBOAT SPRINGS</u>						
Highway Department Building	4,000	Unit heaters	Natural gas	535	300,000	

of the buildings on a central hot water supply. However, the discharge water could possibly be mixed with the spring water in the fish ponds and runs to warm that water to a more favorable temperature for fish production and yield.

The campus buildings at Ft. Lewis College are all individually heated by natural gas fired water boilers, with supplemental steam heat in a couple of buildings. Retrofit consists largely of installing a central hot water distribution piping system and additional terminal space heating equipment in the buildings.

The central heating system at Adams State College consists of three steam boilers, a high pressure steam piping network, and steam-to-water converters in the individual buildings. A portion of the piping network and the terminal space heating equipment are useable for a geothermal system. For purposes of this project, only six buildings constituting about 50 percent of the heat load are included in the retrofit design. The reasons for the partial systems are to test a geothermal system at a demonstration scale prior to converting the entire campus and to allow for the prospect of drilling the production and reinjection wells on-campus.

Some portions of the condensate return lines of the existing steam piping system at Adams State College have aged and begun to leak; immediate replacement is needed. Other portions are going to need replacement within a few years. As a consequence, maintenance expenses for the current system are increasing. A cost incentive, therefore, exists that starts to favor consideration of a new geothermal heating system as a replacement option.

The Colorado State Reformatory has a steam boiler and distribution system that is fully functional now but may be reaching a point soon where major repairs may become necessary. The system is 20 to 25 years old. Originally a coal-fired steam boiler, it was converted to natural gas, with fuel oil backup, a number of years ago. The existing system is ideally suited to a retrofit to a direct flow geothermal hot water system because of the projected high temperature water (250-350°F) available from the Cottonwood or Chalk Creek resource sites. New hot water distribution piping to the individual buildings is required, but the existing space heating equipment is reusable. In addition, a central heat exchanger is not required because of the expected quality of the geothermal water. Furthermore, surface disposal of the discharge water appears feasible for agricultural irrigation on the state property.

Table 7 presents a summary of the basic design parameters for the geothermal heating systems for the several state-owned buildings. In addition to the design maximum heat load, specifications are presented for the entering water temperature ($T^{\circ}\text{F}$), water temperature drop ($\Delta T^{\circ}\text{F}$), and the flow rate (GPM) on the geothermal side of the water distribution system and for the leaving water temperature ($T^{\circ}\text{F}$), temperature drop ($\Delta T^{\circ}\text{F}$), and flow rate (GPM) on the building side. An identification of the retrofit space heating equipment is also provided. A complete set of design specifications, including engineering schematics, for each state-owned facility is presented in the following chapters.

TABLE 7

Summary of Design Parameters for Geothermal Options for State-Owned Buildings

LOCATION/FACILITY	GEOTHERMAL OPTION	MAXIMUM DESIGN HEATING LOAD (Btu/hr)	GEOTHERMAL SIDE			BUILDING SIDE			BUILDING SPACE HEATING EQUIPMENT
			T(°F)	ΔT(°F)	GPM	T(°F)	ΔT(°F)	GPM	
<u>ALAMOSA</u>									
Adams State College	Heat exchanger, Artesian flow with pumping, on-site	20,000,000	150	20	2,000	140	20	2,000	Additional terminal units.
	Heat pump, Artesian flow with pumping, on-site	20,000,000	150	50	800	200	20	2,000	Existing Units.
Highway Dept. Building	Heat exchanger Artesian flow with pumping, on-site	2,650,000	150	10	500	140	20	250	Fan coils, Unit Heaters.
<u>BUENA VISTA</u>									
Colorado State Reformatory	Direct heating, pumped flow from Chalk Creek No. 1	24,405,200	250	N/A	700	250	70	700	Existing units.
	Direct heating, pump flow from Chalk Creek No. 2	24,405,200	250	N/A	700	250	70	700	Existing units.
	Direct heating, gravity flow from Cottonwood	24,405,200	250	N/A	700	250	70	700	Existing units.

TABLE 7 (cont'd)

LOCATION/FACILITY	GEOTHERMAL OPTION	MAXIMUM DESIGN HEATING LOAD (Btu/hr)	GEOTHERMAL SIDE			BUILDING SIDE			BUILDING SPACE HEATING EQUIPMENT
			T(°F)	ΔT(°F)	GPM	T(°F)	ΔT(°F)	GPM	
<u>BUENA VISTA-cont'd</u>									
Highway Dept. Building	Heat pump, (COP=4), Shallow well on-site	\$480,000	100	15	70				Heat pump (water-to-air)
<u>BURLINGTON</u>									
Highway Dept. Building	Heat pump, (COP=4), Shallow well on-site	205,000	80	15	30				Heat pump (water-to-air)
	Heat pump, (COP=4), Purchased Water	205,000	80	15	30				Heat pump (water-to-air)
<u>DURANGO</u>									
Fish Hatchery	Heat exchanger coupled to trunk line	1,038,000	150	20	104	145	40	52	Fan coils, Coil ducts, Unit heaters
Ft. Lewis College	Heat pump (COP=6) coupled to trunk line	25,000,000	150	50	1,000	200	20	2,500	Existing units.
	Heat exchanger coupled to trunk line	25,000,000	150	25	2,000	140	20	2,500	Additional ter- minal units.

TABLE 7 (cont'd)

LOCATION/FACILITY	GEOTHERMAL OPTION	MAXIMUM DESIGN HEATING LOAD (Btu/hr)	GEOTHERMAL SIDE			BUILDING SIDE			BUILDING SPACE HEATING EQUIPMENT
			T(°F)	ΔT(°F)	GPM	T(°F)	ΔT(°F)	GPM	
<u>DURANGO-cont'd</u>									
Highway Dept. Building (new)	Heat exchanger coupled to trunk line	2,484,000	150	10	200	140	20	250	Fan coils, Coil ducts
National Guard	Heat pump, (COP=4), Shallow well on-site	565,000	100	15	80				Heat pump (water-to-air)
<u>GLENWOOD SPRINGS</u>									
Highway Dept. Building	Heat exchanger, Deep well on- site	698,000	150	10	140	140	20	70	Fan coils, Unit heaters
<u>STEAMBOAT SPRINGS</u>									
Highway Dept. Building	Heat exchanger, Deep well on- site	300,000	150	20	50	140	20	30	Fan coils,
	Heat pump, (COP=4), Shallow well on-site	300,000	100	15	50				Heat pump (water-to-air)
	Heat pump, (COP=4), Shallow well on-site, Artesian flow	300,000	100	15	50				Heat pump (water-to-air)

Economic Evaluations

The purpose of the economic evaluations of the prospective geothermal space heating systems for the state-owned buildings is to determine which geothermal systems are economically competitive with the existing conventional fuel systems according to specified decision criteria. Generally speaking, new heating systems can only be competitive with existing systems when the sum of initial capital costs and the associated annual energy, operating and maintenance expenses, aggregated over a period of years, are less than the aggregated fuel, operating and maintenance costs for the existing system over the same period of years. Existing systems have the outright advantages that the initial capital costs for those systems have already been expended in the earlier construction of the facility and/or are being amortized in the price of fuel delivered to the facility by the fuel supplier. Therefore, from a purely economic point of view, new systems must achieve savings in actual energy costs over some future period of time in order to be competitive.

Factors other than just economic competition can exist for some facilities or circumstances, however, which can influence a decision to install a new heating system. One example occurs if the existing system is old, wearing out, and in need of substantial repair. A second example occurs if the availability of the conventional fuel becomes limited or highly interruptible. Another example occurs when a governmental entity declares that a given type of fuel can no longer be used as a heating fuel by certain classes of facilities. In these situations and others, economics may no longer be important.

For the purposes of this appraisal of geothermal systems for state-owned buildings, four different economic measures have been calculated. The four measures are (1) simple payback period in years, (2) twenty-year annualized costs, (3) total 20-year "energy" savings without discounting the future value of money, and (4) the present value of the 20-year "energy" savings with a 10 percent per annum discount factor applied. The definitions of these economic measures are given in the next paragraph. The reason for generating four measures rather than just one is to satisfy the interests, perspectives and criteria of several groups of readers and decision makers, including the state-owned building engineers and superintendents, state agency personnel and administrators, legislative staff, state legislators, and the general public.

Definitions of Economic Measures

Simple payback period is the number of years in which a new energy system will pay for itself relative to the total annual costs of the existing conventional system. Current year dollars are used for the calculation, which assumes a zero inflation rate and no increases in real costs. Within the context of energy conservation investments, the Colorado State Buildings Department is applying a five to ten year criterion for simple payback. The simple payback guideline for replacement of worn-out major equipment is fifteen to twenty years.

Annualized cost is the cost per year in equal numbers of dollars that is paid to amortize the initial capital cost and the successive annual operating and maintenance costs over a specified number of years. Twenty years is a frequently used period of time for amortizing the costs of geothermal energy systems

and other new alternative energy facilities. It represents approximately the minimum expected lifetime of the geothermal wells and equipment with proper maintenance. The annualized cost figure is basically similar to a home mortgage payment, except for the fact that escalation/inflation rates and the future value of money are accounted for in the calculation of annualized cost. For comparison purposes, two annualized cost figures are calculated - one for the new geothermal system and one for the existing conventional system. The lower of the two numbers indicates the lower cost and the better investment, if annualized cost is the decision criterion.

Total 20-year "energy" savings (undiscounted) is the total of the dollar savings between the operating and maintenance costs of the geothermal system and the conventional system over the assumed 20-year period of operation. It accounts for the escalation of costs but does not discount the future value of money; rather it assumes that an investment by the state in a capital improvement now does not have to provide the state with an "interest-type" return on that investment. If the total 20-year "energy" savings exceeds the original capital improvement cost, then the capital investment has paid for itself in less than 20 years; in fact, the investment has paid for itself in the year in which the accumulated annual savings equal the original capital investment. The earlier the year the better the investment. Once again, though, the criterion of payback period in this context is set by the investing body. Major capital improvements are most often designed, constructed and operated in the context of providing a 15 to 30 year life.

Present value "energy" savings are the same as the total annual "energy" savings except that the future values of those annual savings are discounted back to the present time, the time at which the capital improvement investment is made. It assumes that the investing body, the State in this case, either wants to obtain an "interest-type" return on its investment or wants to compare the capital improvement investment with other prospective investments. The period of time over which the investments are compared is optional, but 20 years is assumed again for the present case. If the sum of the present values of the 20-year "energy" savings is greater than the original capital investment, then the investment is favorable to the investing body. In this context, actual payback occurs in the future year in which the accumulated sum of the present value "energy" savings equals the capital investment.

Of the four economic measures evaluated in the appraisal, probably simple payback and total undiscounted annual savings are most widely understood and used. Simple payback provides the number of years in which the investment pays for itself if escalation and inflation do not occur. Total undiscounted annual savings accounts for escalation and inflation rates and provides the number of years for the improvement to pay for itself in the context of no competitive investments. Annualized cost and present value savings both include discount factors to provide for the future value of money against competitive investments. It must be observed and remembered that each different economic measure has a different "payback period" associated with it; there is not just one definition of payback period, just as there is not just one definition of interest rate.

Economic and Financial Assumptions

Certain economic and financial assumptions are made in the calculations of the four economic measures. Assumptions have to be made because the future cannot be projected with absolute accuracy. Specific values have to be assumed for the escalation rates of fuel and electricity prices, escalation rates of labor and maintenance expenses, costs of capital for construction and investment, and interest and bond rates. For the purpose of this appraisal, the assumed baseline set of economic and financial factors is listed in Table 8. The values are based upon information and data from the Wharton Econometric Model and the Department of Energy (DOE) Energy Information Administration.

Values other than those assumed for the baseline set of economic and financial factors are also equally valid, since it is difficult to project the future in today's energy and economic environment. Sensitivity studies can be performed by varying the assumed value of each parameter. This has been done in this geothermal appraisal only for the escalation price of the conventional fuels - natural gas, propane and fuel oil. Two cases are assumed: first, a 15 percent per annum escalation and, second, a 12 percent per annum escalation through year 1984 followed by a 9 percent per annum escalation thereafter. The break at 1985 in the latter case is tied to the natural gas deregulation feature of the National Energy Act of 1978, but the numerical values are probably highly conservative estimates. It appears that most observers of fuel prices believe that fuel price increases will continue to equal or exceed 15 percent per annum for years to come.

Geothermal Capital Improvement Costs

The geothermal capital improvement costs for each state-owned building are compiled from the resource assessment data, the production well engineering program, the building retrofit engineering designs, and the fluid disposal procedures. The capital cost data are provided in considerable detail in the subsequent chapters. Table 9 presents a summary of the costs of the major components of the geothermal system for each location and facility. The total capital costs span a large range, from \$23,597 for the Highway Department Building in Burlington to \$16,721,437 for Ft. Lewis College in Durango. Most of the water-to-air heat pump systems for the smaller Highway Department Buildings fall in the cost range of \$23,000 to \$40,000. Next in capital cost is the heat exchanger/deep well system for the Highway Department Buildings at Glenwood Springs at \$114,356. Then follow the Fish Hatchery at Durango at \$721,138 and the Highway Department Buildings at Alamosa at \$722,880. The larger facilities, the two colleges and the reformatory with their several geothermal options, all run several million dollars each. The geothermal system costs for the Fish Hatchery, Highway Department Building, and Ft. Lewis College in Durango are exceptionally high because of the prorated costs from the 15-mile geothermal trunk line from the Tripp/Trimble and Pinkerton resource areas.

Annual Operating and Maintenance Costs

Annual operating and maintenance costs are estimated for both the new geothermal systems and the existing conventional fuel systems. Only fuel, electricity and maintenance costs are accounted for in the cost estimates; it is assumed that administrative, management, insurance and similar expenses are approximately

TABLE 8

Baseline Set of Assumed Economic and Financial Factors
(Applicable for the 20-Year Period of 1981 to 2000)

Economic/Financial Factor	Annual Escalation Rate
Cost of capital construction	8%
Labor and maintenance	10%
Natural gas, propane and fuel oil	15%
Electricity	9%
Long term commercial interest rates	12%
State investment and municipal bond rates	10%
General inflation rate	8%

Sources: Wharton Econometric Model and DOE Energy Information Administration, 1980.

TABLE 9

Summary of Geothermal Capital Improvement Costs for the State-Owned Buildings

LOCATION/FACILITY	GEOHERMAL OPTION	PRODUCTION WELL SYSTEM	TRANSMISSION LINE SYSTEM	CENTRAL DISTRIBUTION SYSTEM	BUILDING RETROFIT	REINJECTION OR DISPOSAL	TOTAL CAPITAL COSTS
<u>ALAMOSA</u>							
Adams State College	Heat exchanger, Artesian Flow with pumping on-site	\$828,800	\$45,738	\$281,325	\$1,962,325	\$556,490	\$3,674,678
	Heat pump, Artesian flow with pumping, on-site	\$391,900	\$15,246	\$1,017,445	\$387,926	\$298,870	\$2,111,387
Highway Dept. Building	Heat exchanger, Artesian flow with pumping, on-site	\$379,500	\$4,235	\$44,813	\$22,687	\$271,645	\$722,880
<u>BUENA VISTA</u>							
Colorado State Reformatory	Direct heating, pumped flow from Chalk Creek No. 1	\$408,600	\$3,201,759	\$423,016	\$350,910	\$36,300	\$4,420,585
	Direct heating, gravity flow from Chalk Creek No. 2	\$581,100	\$3,251,095	\$423,016	\$350,910	\$36,300	\$4,642,421
	Direct heating, gravity flow from Cottonwood	\$402,900	\$2,904,319	\$423,016	\$350,910	\$36,300	\$4,117,445

TABLE 9- (cont'd)

LOCATION/FACILITY	GEOHERMAL OPTION	PRODUCTION WELL SYSTEM	TRANSMISSION LINE SYSTEM	CENTRAL DISTRIBUTION SYSTEM	BUILDING RETROFIT	REINJECTION OR DISPOSAL	TOTAL CAPITAL COSTS
<u>BUENA VISTA-cont'd</u>							
Highway Dept. Building	Heat pump, Shallow Well on-site	\$11,475	\$1,331	-	\$20,963	\$484	\$34,253
<u>BURLINGTON</u>							
Highway Dept. Building	Heat pump, Shallow well on-site	\$6,500	\$1,331	-	\$14,798	\$968	\$23,597
<u>DURANGO</u>							
Fish Hatchery	Heat exchanger coupled to trunk line	\$70,298	\$592,191*	\$38,018	\$19,663	\$968	\$721,138
Fort Lewis College	Heat pump coupled to trunk line	\$666,000	\$5,639,912*	\$1,597,890	-	\$461,615	\$8,365,417
	Heat exchanger coupled to trunk line	\$1,329,957	\$11,235,200*	\$597,220	\$2,643,695	\$915,365	\$16,721,437
Highway Dept. Building (new)	Heat exchanger coupled to trunk line	\$132,996	\$1,127,634*	\$17,951	\$243,210	\$21,296	\$1,543,087

*Includes prorated portion of trunk line

TABLE 9 - (cont'd)

LOCATION/FACILITY	GEOHERMAL OPTION	PRODUCTION WELL SYSTEM	TRANSMISSION LINE SYSTEM	CENTRAL DISTRIBUTION SYSTEM	BUILDING RETROFIT	REINJECTION OR DISPOSAL	TOTAL CAPITAL COSTS
<u>DURANGO-cont'd</u>							
National Guard	Heat pump, Shallow well on-site	\$12,150	\$1,331	-	\$26,116	\$968	\$40,565
<u>GLENWOOD</u>							
Highway Dept. Building	Heat exchanger, deep well on- Site	\$26,440	0	\$38,306	\$23,474	\$26,136	\$114,356
<u>STEAMBOAT SPRINGS</u>							
Highway Dept. Building	Heat exchanger, Deep well on- site	\$10,700	\$1,331	\$5,082	\$21,151	\$968	\$39,232
	Heat pump, Shallow well on-site Artesian flow	\$10,775	\$1,331	0	\$17,600	\$968	\$30,674

the same for both systems and, therefore, are tradeoffs for purposes of the comparative economic evaluations.

The conventional fuel prices used in calculating the annual fuel costs are approximately the local prevailing prices for each state-owned building. The 1980 fuel prices were actually escalated by 15 percent to provide an estimated 1981 fuel price. Therefore, the fuel prices vary from location to location because of the variation in prices actually paid in 1980. For electricity prices, however, a standard price of \$0.045 per kilowatt-hour for 1981 is used in the calculations for all of the facilities. The only electrical usage considered in the economic evaluations is the electricity to run motors, pumps, and fans for the heating systems.

The annual maintenance expenses for the complete geothermal systems are based upon the initial capital costs of the components, ranging from 0.5 percent per year for certain pipelines to 4 percent per year for the production well systems. The annual maintenance expenses for the conventional systems are taken at 2 percent of the estimated value of the current capital equipment, except for additional major repair costs assumed for Adams State College and the Colorado State Reformatory.

Table 10 presents a summary of the estimated annual operating and maintenance costs for both the conventional and geothermal systems at the state-owned buildings.

Summary of Economic Evaluations

Table 11 summarizes the results of the economic evaluations for the geothermal options considered for each state-owned building, listed alphabetically by location. The results in Table 11 are for an assumed 15 percent per year conventional fuel price escalation, a 20-year life cycle, and a 10 percent discount rate. In all cases except the Colorado State Reformatory, an average accumulated use duration of 4320 hours (approximately 6 months) per year is assumed; domestic hot water requirements during the warm months are assumed to be provided by existing or replacement conventional fuel hot water heaters. The Colorado State Reformatory uses a considerable amount of hot water all year round for laundry, cooking, cleaning, and bathing purposes, so the geothermal system is prescribed to operate continuously.

In examining the contents of Table 11 to ascertain economic feasibility, one should pick the economic measure which fits the decision maker's criteria. Generally speaking, simple payback should be less than 20 years, the annualized cost for the geothermal system should be less than the annualized cost for the conventional system, total 20-year undiscounted savings should significantly exceed the initial capital improvement cost, and the total 20-year present value savings should equal or exceed the initial capital costs.

On the simple payback period measure of 20 years, the geothermal options at the following facilities appear to be economically feasible:

TABLE 10

Summary of First Year Operating and Maintenance Expenses for Geothermal and Conventional Heating Systems

LOCATION/FACILITY	GEOTHERMAL OPTION	GEOTHERMAL		FUEL	CONVENTIONAL	
		OPERATING	MAINTENANCE		OPERATING*	MAINTENANCE
<u>ALAMOSA</u>						
Adams State College	Heat exchanger, Artesian flow with pumping on-site	\$65,538	\$67,169	\$192,238	\$ 1,825	\$ 48,000
	Heat pump, Artesian flow with pumping on-site	\$82,148	\$46,482	\$192,238	\$ 1,825	\$ 48,000
Highway Dept. Building	Heat exchanger, Artesian flow, pumping on-site	\$11,290	\$21,646	\$ 14,488	0	\$ 1,500
<u>BUENA VISTA</u>						
Colorado State Reformatory	Direct heating, pumped flow from Chalk Creek No. 1	\$119,931	\$43,783	\$323,000	\$ 3,500	\$ 45,000
	Direct heating, gravity flow from Chalk Creek No. 2	\$36,452	\$50,929	\$323,000	\$ 3,500	\$ 45,000
	Direct heating, gravity flow from Cottonwood	\$9,113	\$42,068	\$323,000	\$45,000	\$ 3,500

TABLE 10 (cont'd)

LOCATION/FACILITY	GEOTHERMAL	GEOTHERMAL		CONVENTIONAL		
		OPERATING	MAINTENANCE	FUEL	OPERATING *	MAINTENANCE
<u>BUENA VISTA-cont'd</u>						
Highway Dept. Building	Heat pump, Shallow well on-site	\$803	\$42,068	\$323,000	\$45,000	\$500
<u>BURLINGTON</u>						
Highway Dept. Building	Heat pump, Shallow well on-site	\$1,188	\$449	\$1,290	0	\$300
<u>DURANGO</u>						
Fish Hatchery	Heat exchanger coupled to trunk line	\$841	\$6,749	\$11,633	0	\$700
Fort Lewis College	Heat pump coupled to trunk line	\$147,331	\$80,051	\$238,680	0	\$70,000
	Heat exchanger coupled to trunk line	\$101,121	\$166,062	\$238,680	0	\$70,000
Highway Dept. Building (new)	Heat exchanger coupled to trunk line	\$8,005	\$12,677	\$27,793	0	\$3,580

TABLE 10 (cont'd)

LOCATION/FACILITY	GEOTHERMAL	GEOTHERMAL		FUEL	CONVENTIONAL	
		OPERATING	MAINTENANCE		OPERATING *	MAINTENANCE
<u>DURANGO-cont'd</u>						
National Guard	Heat pump, Shallow well on-site	\$3,731	\$1,040	\$4,031	0	\$522
<u>GLENWOOD</u>						
Highway Dept. Building	Heat exchanger, Deep well on- site	\$1,665	\$2,320	\$8,974	0	\$1,240
<u>STEAMBOAT SPRINGS</u>						
Highway Dept. Building	Heat exchanger, Deep well on- site	\$464	\$935	\$3,289	0	\$400
	Heat pump, Shallow well on-site, Artesian flow	\$2,211	\$1,324	\$3,289	0	\$400

* Zero entry for conventional operating expenses assumes that electrical costs are minimal and a trade-off with unaccounted-for similar costs in the geothermal system.

TABLE 11

Summary of Economic Evaluations for Geothermal Options Compared to Conventional Fuel Systems for State-Owned Buildings (Assumptions: 15% Fuel Price Escalation, 10% Discount Factor, 20-Year Life)

LOCATION/FACILITY	GEOTHERMAL OPTION	CAPITAL COSTS	SIMPLE PAYBACK (years)	ANNUALIZED COSTS		TOTAL 20-YEAR SAVINGS AND PAYBACK PERIOD (years)	
				CONVENTIONAL	GEOTHERMAL	Undiscounted	Present Value
<u>ALAMOSA</u>							
Adams State College	Heat exchanger, Artesian flow with pumping, on-site	\$3,674,678	16	\$720,535	\$658,049	\$15,336,331 (11-12)	\$4,096,455 (18-19)
	Heat pump, Artesian flow with pumping, on-site	\$2,111,387	9	\$720,535	\$476,912	\$15,670,359 (9-10)	\$4,194,979 (13)
Highway Dept. Building	Heat exchanger, Artesian flow with pumping, on-site	\$722,800	47	\$50,946	\$138,145	(\$245,141)	Negative
<u>BUENA VISTA</u>							
Colorado State Reformatory	Direct heating, pumped flow from Chalk Creek No. 1	\$4,420,585	12	\$1,159,497	\$819,544	\$27,202,360 (10)	\$7,333,888 (15)
	Direct heating, gravity flow from Chalk Creek No. 2	\$4,642,421	13	\$1,159,497	\$691,077	\$31,063,857 (8-9)	\$8,597,520 (13)

TABLE 11 (cont'd)

LOCATION/FACILITY	GEOTHERMAL OPTION	CAPITAL COSTS	SIMPLE PAYBACK (years)	ANNUALIZED COSTS		TOTAL 20-YEAR SAVINGS AND PAYBACK PERIOD (years)	
				CONVENTIONAL	GEOTHERMAL	Undiscounted	Present Value
<u>BUENA VISTA - cont'd</u>							
Colorado State Reformatory	Direct heating, gravity flow from Cottonwood	\$4,117,445	11	\$1,159,497	\$562,871	\$32,970,061 (7-8)	\$9,215,012 (11-12)
Highway Dept. Building	Heat pump, Shallow well on-site	\$34,253	12	\$9,021	\$6,600	\$200,629 (11)	\$53,800 (17)
<u>BURLINGTON</u>							
Highway Dept. Building	Heat pump, Shallow well on-site	\$23,597	16	\$4,779	\$5,757	\$62,852 (16-17)	\$14,425 (>20)
<u>DURANGO</u>							
Fish Hatchery	Heat exchanger coupled to trunk line	\$721,138	59	\$40,170	\$97,090	\$798,258 (20)	\$209,530 (>20)
Fort Lewis College	Heat pump coupled to trunk line	\$8,365,417	28	\$905,338	\$1,388,312	\$16,338,129 (16)	\$4,220,014 (>20)
	Heat exchanger coupled to trunk line	\$16,721,437	55	\$905,338	\$2,404,646	\$13,784,921 (21)	\$3,410,250 (>20)
Highway Dept. Building	Heat exchanger coupled to trunk line	\$1,543,087	44	\$119,737	\$215,442	\$1,917,916 (19)	\$497,658 (>20)

TABLE 11 (cont'd)

LOCATION/FACILITY	GEOTHERMAL OPTION	CAPITAL COSTS	SIMPLE PAYBACK (years)	ANNUALIZED COSTS		TOTAL 20-YEAR SAVINGS AND PAYBACK PERIOD (years)	
				CONVENTIONAL	GEOTHERMAL	Undiscounted	Present Value
<u>DURANGO-cont'd</u>							
National Guard	Heat pump, Shallow well on-site	\$40,565	10	\$14,327	\$13,599	\$192,606 (13)	\$43,955 (19-20)
<u>GLENWOOD</u>							
Highway Dept. Building	Heat exchanger, Deep well on- site	\$114,356	12	\$29,974	\$20,081	\$697,883 (9-10)	\$192,360 (14)
<u>STEAMBOAT SPRINGS</u>							
Highway Dept. Building	Heat exchanger, Deep well on- site	\$39,232	11	\$11,651	\$6,882	\$282,555 (10)	\$76,773 (14)
	Heat pump, Shallow well on-site, Artesian flow	\$30,674	9	\$11,651	\$9,870	\$170,900 (12)	\$40,537 (17-18)

- Adams State College (central heat exchanger or heat pump)
- Colorado State Reformatory (all three resource sites)
- Buena Vista Highway Department Building (heat pump)
- Burlington Highway Department Building (heat pump)
- Durango National Guard Building (heat pump)
- Glenwood Highway Department Building (heat exchanger)
- Steamboat Springs Highway Department Building (heat exchanger and heat pump).

Of these seven facilities, only Adams State College (central heat pump), the Durango National Guard Building, and the Steamboat Springs Highway Department Building (heat pump) satisfy the state energy conservation criterion of payback within 10 years.

On the 20-year annualized cost measure, six facilities (and ten geothermal options) appear economically feasible, as follows:

- Adams State College (central heat exchanger or heat pump)
- Colorado State Reformatory (all three resource sites)
- Buena Vista Highway Department Building (heat pump)
- Durango National Guard Building (heat pump)
- Glenwood Highway Department Building (heat exchanger)
- Steamboat Springs Highway Department Building (heat exchanger or heat pump).

On the total 20-year present value savings measure, the same facilities and geothermal options as identified above for the 20-year annualized cost measure are economically feasible. The total 20-year undiscounted savings measure, however, finds all of the facilities and geothermal options to be feasible except for the Alamosa Highway Department Buildings and the heat exchanger option for Ft. Lewis College.

Table 12 summarizes the results for a similar set of economic calculations in which the 12 percent (through 1984)/9 percent (thereafter through 2000) schedule for the escalation of conventional fuel prices is used; in addition, a few other variations in the geothermal operational parameters are involved. The more important findings are discussed here.

Operation of the geothermal well pumps and the central heat pump on an all-year schedule at Adams State College, with their associated high electrical bills, makes the geothermal options unattractive from three of the four economic measures. For the Colorado State Reformatory, only the case of gravity flow from the Cottonwood resource site appears economically feasible; equal percentage (9%) increases

TABLE 12

Summary of Economic Evaluations for Geothermal Options Compared Conventional Fuel Systems for State-Owned Buildings (Assumptions: 12% Fuel Price Escalation, 10% Discount Factor, 20-Year Life)

LOCATION/FACILITY	GEOTHERMAL OPTION	CAPITAL COSTS	SIMPLE PAYBACK (years)	ANNUALIZED COSTS		TOTAL 20-YEAR SAVINGS AND PAYBACK PERIOD (years)	
				CONVENTIONAL	GEOTHERMAL	Undiscounted	Present Value
<u>ALAMOSA</u>							
Adams State College	Heat pump, Artesian flow with pumping, on-site	\$2,093,987	10	\$444,617	\$607,156	\$1,823,300 (>20)	\$587,455 (>20)
	Heat exchanger, Artesian flow with pumping, on-site	\$3,619,218	17	\$444,617	\$678,464	\$4,266,640 (18-19)	\$1,394,265 (>20)
Highway Dept. Building	Heat exchanger, Artesian flow with pumping, on-site	\$709,818	50	\$30,775	\$123,779	(\$649,527)	Negative
<u>BUENA VISTA</u>							
Colorado State Reformatory	Direct heating with gravity flow from Cottonwood	\$3,886,745	11	\$746,432	\$558,054	\$17,058,831 (8-9)	\$5,561,116 (14-15)
	Direct heating with gravity flow from Chalk Creek No. 2	\$4,692,821	13	\$746,432	\$772,577	\$13,848,408 (11)	\$4,197,121 (>20)

TABLE 12-(cont'd)

LOCATION/FACILITY	GEOTHERMAL OPTION	CAPITAL COSTS	SIMPLE PAYBACK (years)	ANNUALIZED COSTS		TOTAL 20-YEAR SAVINGS AND PAYBACK PERIOD (years)	
				CONVENTIONAL	GEOTHERMAL	Undiscounted	Present Value
<u>BURLINGTON</u>							
Highway Dept. Building	Heat pump with shallow well on-site	\$23,597	16	\$3,158	\$5,757	\$2,061 (>20)	626 (>20)
	Heat pump with purchased water	\$32,948	24	\$3,158	\$15,223	(\$216,783)	Negative
<u>DURANGO</u>							
Highway Dept. Building (new)	Heat exchanger coupled to trunk line from Tripp/Trimble	\$1,318,389	43	\$60,838	\$187,338	\$723,824 (>20)	\$236,237 (>20)
National Guard Building	Heat pump with shallow well on-site	\$42,165	10	\$9,262	\$12,556	(\$17,120)	Negative
<u>GLENWOOD SPRINGS</u>							
Highway Dept. Building	Heat exchanger with deep well on-site	\$147,837	15	\$20,735	\$32,350	\$119,523 (>20)	\$39,022 (>20)

TABLE 12- (cont'd)

LOCATION/FACILITY	GEOTHERMAL OPTION	CAPITAL COSTS	SIMPLE PAYBACK (years)	ANNUALIZED COSTS		TOTAL 20-YEAR SAVINGS AND PAYBACK PERIOD (years)	
				CONVENTIONAL	GEOTHERMAL	Undiscounted	Present Value
<u>STEAMBOAT SPRINGS</u>							
Highway Dept. Building	Heat exchanger with deep well on-site	\$40,952	12	\$7,520	\$9,686	\$58,341 (16-17)	\$19,030 (>20)
	Heat pump with shallow well on-site and Artesian flow	\$30,674	9	\$7,520	\$9,870	\$15,917 (>20)	\$5,110 (>20)
	Heat pump with shallow well on-site	\$45,502	12	\$7,520	\$14,246	(\$50,290)	Negative

-41-

in natural gas and electricity after 1984 diminish the feasibility of the other two geothermal options.

All of the heat pump installations in the several highway department buildings are economically unattractive because of the initially high electrical prices and the equal increases in price assumed after 1984. Finally, the heat exchanger systems for the Glenwood and Steamboat Springs buildings are also not economically practical.

Conclusions

Several of the state-owned buildings appear to be economically feasible for retrofit to geothermal heating systems, particularly if conventional fuel prices escalate faster than electricity prices in future years. The Colorado State Reformatory at Buena Vista is by far the most economically attractive facility for a geothermal capital improvement because of the year-round consumption of large quantities of hot water, the high price of natural gas, the match between the resource temperature and the required hot water temperature, and the ease of disposal of the discharge water; all of these factors contribute to favorable economics. Adams State College also appears to be economically suited to a geothermal demonstration project, at least for a central heat pumps system and if domestic hot water requirements during the warm months can be provided by auxillary heaters. The Highway Department Buildings at Glenwood Springs and Steamboat Springs are economically practical applications of geothermal heat exchanger systems under either the simple payback or the total 20-year undiscounted savings measures, if the geothermal well costs are prorated to other users of the excess flow of hot water. The use of heat pumps for the Highway Department Building at Buena Vista and for the National Guard Building at Durango is economically feasible if fuel prices escalate faster than electricity prices. Finally, geothermal systems for the Fish Hatchery, Ft. Lewis College and the new State Highway Department Building in Durango are not economically practical because of the high capital cost for the 15-mile trunk line from the Tripp/Trimble and Pinkerton resource areas.

Institutional Requirements

In order to develop a geothermal heating system at any site in the State of Colorado, some institutional requirements must be met. For the state-owned buildings covered in this report, the requirements are similar and will, therefore, be described here for all the sites. Then site specific requirements will be described for each site. For a more detailed description of each of the requirements, the reader is referred to Regulation of Geothermal Energy in Colorado, published by the Colorado Geological Survey (Coe and Forman, 1980). In some cases, more detailed investigations of the institutional requirements will be required prior to geothermal activity.

The legal requirements for geothermal development can be classified by the following six categories:

- Surface control of drill site (need leases or title)
- Geothermal resource control (need leases or title)
- Well permits
- Right-of-way for pipelines
- Construction permits (for construction or retrofit of heating system and pipeline)
- Fluid disposal permits

Surface Control of Drill Site

The State of Colorado owns the surface at the sites where the state buildings are located. Therefore, where the well is to be drilled on-site, no action is required regarding use of the surface. At some of the sites, however, including Durango, Buena Vista, and Idaho Springs, land not owned by the State would be required for a drill site. In Idaho Springs, the proposed drill site is privately-owned. An agreement to use the surface would need to be negotiated with the land owner. In the case of Buena Vista, one potential drilling site is on federal land that would require federal leases. Since the federal leases are currently held by Petro-Lewis Corporation, the most efficient way to obtain surface and geothermal rights would probably be to negotiate an agreement with Petro-Lewis for an assignment of those federal leases.

Geothermal Resource Control

In order to assure control of the geothermal energy, the surface and mineral rights must be owned outright or must be leased. Colorado law is not entirely clear concerning such rights. There are several possible cases, including:

- One owner of both surface and mineral rights
- Severed minerals and surface -- state mineral rights
- Severed minerals and surface -- federal mineral rights

All combinations of mineral and surface ownership are also possible. The requirements for controlling the geothermal energy in the three above cases are addressed individually below.

One Owner, Surface and Minerals

Where both the mineral and the surface are under one owner, that owner should control the geothermal without question. Where the State owns one or both, use of the geothermal rights is subject to approval of the State Board of Land Commissioners (Coe and Forman, 1980).

Severed Minerals, State Ownership

Where surface and minerals are severed, with the State owning one and a private entity owning the other, the ownership of the geothermal rights is very unclear. Although, by Statute, the geothermal rights are not part of the mineral estate unless so stated (C.R.S. 1973, 38-35-121), ownership cannot legally be legislated (T.E. Brétz, pers. comm., 1980). To learn whether or not the State owns the mineral rights under any specified site would require a title search. That information is not readily available because sites are generally comprised of a number of parcels obtained at various times from various owners. The State retained the mineral rights for any lands that it was originally deeded and subsequently sold. However, the State does not generally develop any mineral resources. When it purchased land, therefore, obtaining the mineral rights was not of particular concern. Once sites are selected for further, more detailed investigations, a title search should be included in those investigations (Michael Ghourdjian, pers. comm., 1980).

Severed Minerals, Federal Ownership

Where the minerals are federal (part of the public domain), the geothermal rights are part of the federal mineral estate (ruling of Ninth District Court and U.S. Supreme Court). Therefore, if the mineral estate is federal, federal geothermal leases would be required. Arrangements must be made with the surface owner, or, in the cases of federally-controlled surface, with the Surface Management Agency (SMA) (e.g. U.S. Forest Service, Bureau of Land Management or Bureau of Indian Affairs) to use the surface for a drilling site and for access (Coe and Forman 1980).

Well Permits

A well permit must be obtained from the Colorado Oil and Gas Conservation Commission prior to drilling any geothermal well, including an observation well, in the state. A fee of \$75.00 is required and a \$10,000 bond per well must be posted in order to assure proper completion or abandonment. The Commission will refer the application to the State Division of Water Resources for evaluation of the impact on water rights (Coe and Forman, 1980). No particular difficulty in obtaining a well permit for any state-building geothermal project is expected.

Permission of the lessor, if there is one, must also be obtained. Some local governments also require their approval prior to drilling a well within their jurisdictions. In some cases, well drilling is prohibited. The local requirements are described by site.

Water Rights

Any geothermal well permit application must be evaluated by the State Division of Water Resources to see whether a well would have an adverse effect upon prior water rights. If water will be put to beneficial use (e.g. consumed) in the process of using the geothermal energy, water rights must be obtained - either adjudicated or purchased from another owner. If water will be diverted but not consumed, a plan of augmentation must be filed and approved by the State Division of Water Resources (Coe and Forman 1980). In those state-building geothermal systems that would not consume water but would remove the heat and then reinject the water into the same aquifer, no water rights are likely to be required. Where waste water would be surface-disposed, water rights would more likely be required. (Coe and Forman, 1980).

Right-Of-Way

Where a state building is located some distance from a recommended drilling site, right-of-way will generally be required for pipeline construction. Sites where this is true are Durango, Buena Vista and Idaho Springs. Such right-of-way may be on federal, state, city, county or private land, or any combination of these. If it is federally-owned, application for right-of-way must be made to the Surface Management Agency. If it is state-owned, application must be made to the State Board of Land Commissioners. If it is local government owned, the City and County Administration must approve a request for right-of-way use. If it is privately-owned, an agreement must be negotiated with the owner. The ownership will be noted in each site description where it is applicable.

Construction Permit

The installation of a geothermal heating system in a building, either new or retrofit, will require a building and/or plumbing permit to assure that construction standards are met. The process is generally similar among the building locations; however, some slight differences were noted and they will be described individually for each site. In every case, the engineering design will be considered by the regulatory agency based on its merit and appropriateness to the situation. Existing design standards for water systems, therefore, should not create an institutional barrier for a geothermal system. In some cases, permits or approvals will be required for pipeline construction. Road cut permission, construction permits or special-use land-use permits are among them. These, too, are quite variable, so will be described for each individual site.

Other

Some additional institutional requirements are expected to be imposed by the private sector. Where existing road or utility R.O.W. is to be followed or crossed, other utility lines or equipment are likely to be impediments. Approval and assistance of the telephone company, the electric utility company and the gas utility company may be required to preclude interference with these systems.

Fluid Disposal Permits

Once the heat is removed from the geothermal fluid, the cooled water must be disposed. It may be consumed by using it for water supply either by the user or by another party; it may be disposed into a river or stream; or it may be reinjected into an underground aquifer, usually the same one from which it is withdrawn. Disposal requires a permit from the Colorado Department of Health, Water Quality Control Division. The disposal method will depend on several considerations: (1) whether water rights are owned by the geothermal user, (2) the quality of the fluid, and 3) the analysis and decision by the Control Division. An application for disposal is required to be submitted at least 180 days in advance of that disposal (Coe and Forman 1980).

At some of the sites being appraised in this study, surface disposal seems most appropriate. At others, particularly where the fluid is highly saline, reinjection is advised. At one site (Burlington), the possibility of using the cooled water for domestic use is worth consideration.

Summary

The legal and regulatory requirements for geothermal development at these state buildings have been generally outlined above. The legal and regulatory requirements that are specific to each site are summarized in Table 13.

The analysis of legal and regulatory requirements has revealed no such requirements that definitely preclude geothermal exploration and/or development. Some sites, namely Buena Vista and Durango, could require federal leases and permits. Because of the time and effort required for obtaining such approvals, these are not generally warranted by very limited development for direct heat use of geothermal energy. Only large, profit-making enterprises would generally be considered to justify such expense. However, where sites requiring federal leases and permits appear to be very promising economically, the possibility of obtaining necessary federal leases and permits should not be precluded. In any event, at both these sites, some alternatives to federal leases were observed.

At two sites, namely Glenwood Springs and Buena Vista, local government approval in addition to State approval would be required for well drilling. There is no indication, however, that this would be particularly difficult to obtain.

The primary legal and regulatory difficulties of developing geothermal energy at these sites stem from requirements and uncertainties in the State system. In Colorado, geothermal well permits are issued by the Oil and Gas Conservation Commission. Because the energy is usually associated with water, however, the approval of the State Engineer is also required. Further-

TABLE 13
LEGAL AND REGULATORY REQUIREMENTS
FOR GEOTHERMAL DEVELOPMENT (1980)

Site	Drill Surface Control	Geothermal Resource Control	Water Rights	Well Permits	Pipeline Right of Way	Construction Permit	Disposal Permit
Alamosa Adams State College State Highway Department Buildings	State or private	Unknown	Probably not needed, will reinject.	State	State, private and city, if any. ROW re- quired. 30-60 days to obtain.	City	State
Buena Vista Colorado State Reformatory	Private if drilled at Cottonwood. Could be federal or private if drilled at Chalk Creek.	Need lease: private owner if Cottonwood drill site, possibly federal if Chalk Creek. Leases from BLM if federal or obtain assignment from current federal lessee (Petro- Lewis).	Probably need water rights or plan of augmentation for surface disposal.	State, county Special Use Permit.	Private, state county and road cutting permit; fee contingent upon distance.	County	State. Potable water, no dis- posal permit problems anticipated. County coordi- nation with state.
State Highway Department Building	State	Unknown	Same as above.	State, city.	Not applicable	City	City
Burlington State Highway Department Building	State	Unknown	Probably not need water rights if drill well and augment city water. Do not need water rights if city water is purchased.	State wells in city prohibited. Could try for waiver of prohibition for non-consumptive well and provide water to city after removing heat.	None required	None required	Good quality water; no disposal needed if add to city water supply or dispose in sewer.

TABLE 13 - (cont'd)
LEGAL AND REGULATORY REQUIREMENTS
FOR GEOTHERMAL DEVELOPMENT (1980)

Site	Drill Surface Control	Geothermal Resource Control	Water Rights	Well Permits	Pipeline Right of Way	Construction Permit	Disposal Permit
Durango							
Armory	State	Unknown	Probably need water rights or plan of augmentation.	State; notify city	City permit for pipeline requires Public Works Department review. County requires Planning Commission and Board of Commissioners approval.	City Plumbing Permit	State
Fish Hatchery Ft. Lewis College State Highway Department Building (New)	Private	Private, would need lease; or current owner could develop geothermal and sell heat.	Probably not needed, will reinject.	State	County, state, possibly city ROW.	City Plumbing Permit	State
Glenwood Springs							
State Highway Department Building	State, if drill on- site.	Private owner of spa.	Probably not needed, if reinject.	State, probably city.	None required if drill on-site.	City	State
Steamboat Springs							
State Highway Department Building	State	Unknown	Probably need water rights or plan of augmen- tation for sur- face disposal.	State	None required	City mechanical permit	State

more, since the geothermal energy definition is inclusive of "natural heat,..... in whatever form," with no minimum temperature cut off indicated, presumably drilling even a shallow ground water well to be used to supply a water to water or air heat pump could require, the following actions, as do all geothermal wells:

1. Geothermal leases;
2. Drilling permits from the Oil and Gas Conservation Commission;
3. State Engineer's approval; and
4. A filing fee of \$75.00 plus a plugging bond of \$10,000 per well (Coe and Forman, 1980).

Some states, such as Utah, in their proposed legislation, have included a minimum temperature in the definition of geothermal energy. Any hydrothermal resources of a lower temperature are treated as water.

Still another potential difficulty has to do with ownership uncertainties. According to Colorado law, mineral rights are not assumed to include geothermal energy unless specifically stated. Since it is not clearly part of the surface ownership, the ownership of geothermal energy is undefined. Further, federal law has been interpreted by the Courts to mean that geothermal energy is part of the Federal Mineral Ownership. The prospective developer must, therefore, obtain federal geothermal leases if the minerals are federal. If the minerals are not federally-owned, the developer is advised to obtain geothermal leases from the mineral owner for security. Compounding the problem at these State sites, the ownership of the mineral rights at these sites is unknown pending a title search. As previously stated, none of these problems seem insurmountable or inordinately troublesome but does add to the activities required for and uncertainties surrounding geothermal development.

Environmental Considerations

Although geothermal energy is a relatively environmentally benign source of energy, there are some possible negative environmental impacts, most of which are controllable. The major possible impacts are described in this section along with some of the measures used for their control. Since the possible environmental problems are generally associated with the minerals in the geothermal fluid, the water chemistry for each site has been reviewed. A summary of the preliminary appraisal of environmental impact of selected geothermal projects is presented in Table 14. In the chapters describing each site, the findings from this review are presented in more detail.

TABLE 14

Preliminary Appraisal of Environmental Impacts of Selected Geothermal Projects *

LOCATION	AREAS OF IMPACT				
	Air Quality	Water Quality	Land Stability	Noise**	Socioeconomic
Alamosa	0	0	1	1	0
Buena Vista	0	0	1	1	0
Burlington	0	0	0	1	0
Durango					
Tripp/Trimble	0	1	1	1	0
Pinkerton	0	2	1	1	0
Glenwood Springs	0	2	1	1	0
Steamboat Springs	0	0	1	1	0

* All these conclusions are tentative and are based only on existing available information

** Probably a problem only during well drilling, if at all

Key: 3 Is likely to be a severe problem, not mitigable
 2 May be a significant problem that will require special measures
 1 May be a slight problem, but mitigable
 0 Not considered to be a significant potential problem

Water

Water quality is the primary environmental consideration of hydrothermal energy development. When the fluid is hot, the mineral content tends to be higher than that of water or ordinary ground water temperatures. (This is not, however, always true.) In using or in disposing of geothermal fluid, without proper attention, ground water, surface water, or domestic water supplies could be harmed by certain minerals.

Plants and wildlife can be harmed from improperly handled geothermal fluids. Certain chemicals can kill or retard the growth of plants. They may also be poisonous to or retard the growth of wildlife, including fish.

To avoid degradation of water quality, the fluids must be disposed of in an appropriate manner, depending upon the fluid characteristics. Furthermore, the disposal method must be satisfactory to the State Water Quality Control Division, the agency responsible for preventing water quality degradation.

Disposal can be simply disposal into a surface drainage system with treatment to desalinize it before disposal. Or, it may require reinjection into another well, probably into the same formation from which it was withdrawn. In some situations, the fluid is pure enough for domestic consumption (e.g. Buena Vista). A rough gauge of the treatment required is the total minerals content in the fluid. At the Colorado sites, the mineral content ranges from a low of 229 milligrams per liter (mg/l) of total dissolved solids (TDS) at Mt. Princeton Hot Springs to a high of over 20,000 mg/l TDS at Glenwood Springs (Barrett and Pearl, 1976).

Air

Air pollution is another possible adverse effect of geothermal development. Although air pollution will not generally be as severe with water-dominated hydrothermal resources as it can be with steam-dominated resources, toxic gases could be emitted. Hydrogen sulfide, for example, is often associated with geothermal energy. Other gases or vapors not uncommon to geothermal resources are carbon dioxide, methane, ammonia, arsenic, mercury, radon and boron. Prior to development, a specific site should be evaluated for this potential in order to plan for measures to preclude air pollution when necessary.

Dust from vehicular movement and construction activity could also pollute the air. Preventing this generally requires little more than sprinkling with water during such activity. The State Air Quality Control Division is charged with assuring that air quality standards are met and with issuing permits for discharging pollutants into the air (Coe, in prep.).

Land

Another possibility for environmental damage is damage to the land. For instance, some subsidence (sinking) could result from the extraction of geothermal fluid. If subsidence should occur, however, it may or may not be detrimental, depending upon the location of such subsidence. Although a usual preventive measure is to reinject fluid, the proper procedure cannot be definitely known until after exploratory drilling and testing.

Soil erosion (primarily from vehicle movement and construction) is also a potential negative environmental impact of geothermal development. Although generally considered to be negligible, site-specific analysis is required to determine the severity of any problem.

It is also possible that reinjection of geothermal fluids could stimulate seismic (earthquake) activity. Reinjection of the small amounts of fluid involved at these sites does not seem likely to be cause for alarm, however.

Noise

Although noise has been a severe problem at a major geothermal power generation site, the Geysers area in California, because of the pressure of the steam being emitted, noise should not be a problem at hot water sites. The most significant noise problem would probably be that of the well drilling rig engine, a short-term event.

Ecological Interrelationships

If drilling were to cause natural hot springs to decline or cease discharging, several results could be anticipated, according to a U.S. Bureau of Land Management report. As the report indicates, "Growing seasons would be shorter, aquatic plants and animals currently dependent upon the hot water would have smaller populations or die out, perishable archaeologic remains possibly located in the presently boggy drainage below the springs would lose their protective stable temperatures and wet conditions, and the effect of a winter oasis on the wildlife and nearby terrestrial plants would be greatly reduced or lost" (McElderly, 1975). Conversely, new environments could be created, if desirable.

Water Availability

The availability of water is a key concern surrounding geothermal energy throughout the arid West. In Colorado, removal of geothermal water will not be allowed if it will constitute a threat to prior water appropriations. Where consumptive wells are not allowed, because of such limitations, non-consumptive use with reinjection of the fluid is a solution (Coe and Forman, 1980).

Socio-economic Impacts

Sometimes geothermal development can have severe socio-economic impacts. There might be competition for water or competition for land for development. Large population influxes for large facility construction or operation can strain the housing, roads and other goods and services of the community. Development can alter the economic structure and/or the social relationship. Generally speaking, only large electric power plants or other major industrial agricultural facilities would stimulate such extreme impacts. Competition for water where water is scarce, could, however, be problematic even for a small system. As previously mentioned, if water is not available for consumption, the heat can usually be removed and the geothermal fluid then reinjected. No significant socio-economic impacts are expected, therefore, as a result of any of these prospective geothermal developments.

Summary

As indicated above a variety of environmental considerations of geothermal development were appraised, based on existing information. They include possible impacts on water, air and land; also considered were noise, ecological interrelationships, water availability and socio-economic impacts.

For the most part, environmental impacts of geothermal developments discussed in this report are expected to be minimal. One reason is that geothermal development is relatively environmentally benign. Another is that these geothermal projects are all limited to one or a few buildings and are all relatively small energy users. A massive project would have a more significant impact.

The primary environmental concern is water, both quality and quantity. Disposal of the fluid must be in a manner that will preclude negative impacts on other water sources and must be approved by the State Division of Water Quality. Furthermore, existing water rights must be protected not jeopardized by well drilling and fluid removal for geothermal systems.

Based on the available data, only three of the geothermal sites investigated seem to have the potential for water quality problems. Glenwood Springs, with its high minerals content and Pinkerton Hot Springs with its observed, apparent impact on pine trees in the area may need particular care. The Tripp and Trimble Hot Springs area has a fairly high mineral content and has been known to result in scale build-up.

At all the sites, noise from the engine of a drilling rig could create a disturbance of very limited duration. Most of the sites should be analyzed further to predict whether subsidence will occur and if so, whether it will be of importance.

Financing Options

For many prospective geothermal developments, the need for substantial front-end capital has been a deterrent to development. Even where a very advantageous and clear-cut saving over other fuels can be incurred over the life of an energy system, a new system may not be possible because the funds for initial construction are simply unavailable; or they may be available at too high a penalty in the form of interest payments or in other priority opportunities that would be lost.

The types of financing options appropriate for geothermal development depend largely upon the total dollar amount of the project. If a geothermal well is already available and the heating system is one that is easily retrofitted at low cost (e.g. a forced air system), then the cost would not be high. If, at the other end of the spectrum, geothermal development requires an extensive exploration program, a test well, several production wells and reinjection wells, and buildings are expensive to retrofit (e.g. radiant electric systems), then the front-end costs will be much more. The appropriate financing form must, therefore, be gauged based upon the total capital required for development. The primary financing options available for geothermal development are described in this section.

For public agencies, the financing options for geothermal development generally take four forms. These include:

- Budget appropriation
- General obligation bonds
- Revenue bonds
- Assistance programs from another level of government

Budget Appropriations

If a public agency has sufficient financial means relative to the cost of a geothermal development, a budget appropriation is the easiest and most expeditious means of providing the necessary funds. If a project cost is low or the budget surplus large, this funding form could fit the situation.

General Obligation Bonds

To fund a project that must be paid for over a period of time, general obligation bonds are often used by local governments. They are not an option for converting these state buildings because of the prohibition on State indebtedness (Constitution of Colorado, Art. II, Sec. 3). This prohibition, in fact, limits the state's use of any program that provides loan funds. Legislative authorization for a special authority may be one way, however, that the State could finance geothermal development for state buildings.

Revenue Bonds

By issuing revenue bonds, front-end capital can be obtained. The bonds are then repaid from revenues received from the specific activity, without any encumbrance on the government's general revenues. In cases where geothermal development is relatively expensive in terms of front-end capital expenditures for the reasons mentioned previously, a special legislatively-created authority and the issuance of revenue bonds might be the most desirable financing approach. If desired, the project cost could be amortized over a long enough period of time such that annual costs for the geothermal system would approximate or even be lower than the current operating costs for heat.

Assistance from Another Level of Government

Several federal programs provide financial assistance for alternative energy development. Some of these might be appropriate for financing activities required for converting state-owned buildings to geothermal energy. Those that are most applicable are listed below:

DOE User-Coupled Reservoir Confirmation Drilling Program

This DOE program provides sharing the cost of geothermal drilling for direct heat applications. The program absorbs most of the risk of an unsuccessful well by paying from 20 percent of a completely successful project to 90 percent of the cost of a completely unsuccessful project. The contact for this program is the DOE Idaho Operations Office.

Program Research and Development Announcement (PRDA)

This cost-sharing program is also made available by DOE from time to time to conduct economic and engineering feasibility studies. These awards are based on competitive proposals but generally are directed toward geothermal uses that have not previously been studied. Cost sharing by the proposer is required. Interested parties should contact the Department of Energy, Division of Geothermal Energy, for information about upcoming announcements.

DOE Geothermal Loan Guaranty Program

Still another DOE program is the Geothermal Loan Guaranty Program. The program will guaranty 100 percent of a loan for up to 75 percent of the project cost for a period of time up to 30 years. The borrower must contribute at least 25 percent of the project cost. A loan guaranty application is submitted to the DOE San Francisco Operations Office.

DOE Appropriate Technology Small Grants Program

Another DOE funding program is the Appropriate Technology Small Grants Program. This program provides grants of up to \$50,000 for studies, models, testing and hardware development. The DOE Regional Offices are in charge of this program.

Schools and Hospitals Grant Program

Finally, the Schools and Hospitals Grant Program administered by the State is a DOE program that might be a source of funds for conversion of state buildings to geothermal energy. This is administered by the Colorado Energy Conservation Office.

Joint State and Municipal Participation

In some cases, the State can participate in community projects. For example, the City of Alamosa was awarded a DOE Cost-Shared Drilling Contract. They could include Adams State College and the Highway Department in the group of prospective geothermal users.

Other Federal Agency Programs

Additionally, other federal agencies sometimes have programs available. There may be conservation-oriented assistance programs available to state agencies now or in the future from their primary federal grant or from agencies such as the Federal Highway Administration, the Department of Defense or the Department of Education.

Summary

One or more of these financing options should be appropriate for those geothermal conversions of Colorado state buildings that are economically justified. Revenue bonds, a legislative appropriation or federal assistance are all possibilities. A decision about a specific approach to be used would require further study of the available options relative to a specific site.

Summary and Conclusions

In order to provide guidance to building superintendents, state agency administrators, and legislators on the order ranking of the state-owned buildings for retrofit to geothermal heating systems, this study concludes with an estimate of overall feasibility. The actual feasibility for retrofit of the buildings depends on all the topics addressed above. The principal elements of total feasibility include the geothermal resource quality and its match to the building heat loads, the extent of engineering retrofit required to accommodate the geothermal option, the economic feasibility considering all measures, and the ease with which institutional and environmental requirements can be satisfied.

These four elements of feasibility have different degrees of importance and, therefore, are weighted accordingly. The relative weights that are assigned, on a scale of one (least important) to three (most important), are three (3) for resource quality and match, two (2) for retrofit engineering requirements, three (3) for economic feasibility, and one (1) for institutional and environmental ease.

Each of the geothermal options for the several state-owned buildings is individually ranked on a scale of one to three, with three (3) indicating the best case. Table 15 tabulates the relative rankings within each principal feasibility element (columns) for each geothermal option (rows); the scores indicated are the product of the weighting for the feasibility element times the relative ranking of each geothermal option. Finally, the scores are summed across the rows to generate an overall order ranking.

The highest overall score for feasibility goes to the Colorado State Reformatory at Buena Vista. The geothermal resource at Buena Vista is a high quality resource with high water temperatures and a water quality adequate for direct flow through the building heating units. The retrofit engineering requirements are minimal because of the direct availability of geothermal water at 250°F or higher. The economics are favorable on all measures because of shallow well depths, gravity flow through the pipeline, low-cost retrofit of buildings and surface disposal of the discharge water. The facts that the existing steam boiler system is nearing its life expectancy and that major repair or replacement costs may be encountered in the near future adds credibility to a favorable decision to make a geothermal capital improvement of approximately \$4.5 million.

Three facilities with essentially equal scores follow the Colorado State Reformatory in order of overall feasibility: Adams State College (with a central heat pump), the Buena Vista Highway Department Building, and the Glenwood Highway Department Buildings. The real distinguishing feature among these facilities is the absolute values of the capital improvement costs, being \$2,111,387, \$34,253, and \$114,356, respectively. In addition, each facility is based upon a different type of geothermal option: a central heat pump with a deep well, distributed water-to-air heat pumps coupled to a shallow aquifer, and a central heat exchanger with the geothermal water apportioned from a deep well.

Next in order of overall ranking are the Highway Department Building at Steamboat Springs, the National Guard Building at Durango, Adams State College with a central heat exchanger, and the Highway Department Buildings at Alamosa. Of these, the Highway Department Building at Steamboat Springs is considered to be

TABLE 15

Estimated Overall Feasibility Ranking of Geothermal Options for State-Owned Buildings

LOCATION/FACILITY	GEOHERMAL OPTION	RESOURCE QUALITY MATCH (3)	RETROFIT ENGINEERING REQUIREMENTS (2)	ECONOMIC FEASIBILITY (3)	INSTITUTIONAL & ENVIRONMENTAL EASE (1)	OVERALL FEASIBILITY SCORE
<u>ALAMOSA</u>						
Adams State College	Heat exchanger, Artesian flow with pumping, on-site	6	2	6	3	17
	Heat pump, Artesian flow with pumping, on-site	6	4	9	3	22
Highway Dept. Building	Heat exchanger, Artesian flow with pumping, on-site	6	4	3	3	16
<u>BUENA VISTA</u>						
Colorado State Reformatory	Direct heating, pumped flow from Chalk Creek No. 1	9	6	9	3	27
	Direct heating, gravity flow from Chalk Creek No. 2	9	6	9	2	26
	Direct heating, gravity flow from Cottonwood	9	6	9	3	27

TABLE 15- (cont'd)

LOCATION/FACILITY	GEOTHERMAL OPTION	RESOURCE QUALITY MATCH (3)	RETROFIT ENGINEERING REQUIREMENTS(2)	ECONOMIC FEASIBILITY (3)	INSTITUTIONAL & ENVIRONMENTAL EASE (1)	OVERALL FEASIBILITY SCORE
<u>BUENA VISTA-cont'd</u>						
Highway Dept. Building	Heat pump, Shallow well on-site	6	6	6	3	21
<u>BURLINGTON</u>						
Highway Dept. Building	Heat pump, Shallow well on-site	3	6	3	2	14
<u>DURANGO</u>						
Fish Hatchery	Heat exchanger coupled to trunk line	3	2	3	2	10
Fort Lewis College	Heat pump coupled to trunk line	3	4	3	2	12
	Heat exchanger coupled to trunk line	3	2	3	2	10
Highway Dept. Bldg. (new)	Heat exchanger coupled to trunk line	3	6	3	2	14

TABLE 15- (cont'd)

LOCATION/FACILITY	GEOHERMAL OPTION	RESOURCE QUALITY MATCH (3)	RETROFIT ENGINEERING REQUIREMENTS (2)	ECONOMIC FEASIBILITY (3)	INSTITUTIONAL & ENVIRONMENTAL EASE (1)	OVERALL FEASIBILITY SCORE
<u>DURANGO-cont'd</u>						
National Guard	Heat pump, Shallow well on-site	3	6	6	3	18
<u>GLENWOOD</u>						
Highway Dept. Building	Heat exchanger, Deep well on- site	9	4	6	2	21
<u>STEAMBOAT SPRINGS</u>						
Highway Dept. Building	Heat exchanger, Deep well on- site	6	4	6	3	19
	Heat pump, Shallow well on-site Artesian flow	6	4	6	3	19

the best candidate for a geothermal system. It has characteristics very similar to the Glenwood Springs facility and is lower ranked only because of the prospect of a deeper geothermal resource and more costly well drilling. The ranking of the National Guard Building at Durango is based largely on the speculation that a warm shallow aquifer can be tapped for a heat pump application. A central exchanger system for Adams State College is lower ranked than the central heat pump system because of the requirement for two deep wells on campus and the costs of adding terminal heating units to all of the buildings. The Alamosa Highway Department Buildings would fare better in the rankings if the geothermal water could be obtained from an existing nearby pipeline (possibly the prospective Alamosa Industrial Park) rather than from deep wells drilled on-site.

None of the other Durango facilities really appear feasible because of the high costs associated with the 15-mile geothermal trunk line required from Tripp/Trimble and Pinkerton. A heat pump application at the Burlington Highway Department Building may be feasible because of the existence of the Ogallala Aquifer at a shallow depth.

The analysis of legal and regulatory requirements has revealed no such requirements that definitely preclude geothermal exploration and/or development. Some sites, namely Buena Vista and Durango, could require federal leases and permits. At two sites, namely Glenwood Springs and Buena Vista, local government approval in addition to State approval would be required for well drilling. The primary legal and regulatory difficulties of developing geothermal energy at the Colorado sites stem from requirements and uncertainties in the State system. In Colorado, geothermal well permits are issued by the Oil and Gas Conservation Commission. Because the energy is usually associated with water, however, the approval of the State Engineer is also required. Another potential difficulty has to do with ownership uncertainties. According to Colorado law, mineral rights are not assumed to include geothermal energy unless specifically stated. Since it is not clearly part of the surface ownership, the ownership of geothermal energy is undefined.

For the most part, environmental impacts of geothermal developments discussed in this report are expected to be minimal. The primary environmental concern is water, both quality and quantity. Disposal of the fluid must be in a manner that will preclude negative impacts on other water sources and must be approved by the State Division of Water Quality. Furthermore, existing water rights must be protected not jeopardized by well drilling and fluid removal for geothermal systems. Based on the available data, only three of the geothermal sites investigated seem to have the potential for water quality problems. Glenwood Springs, with its high minerals content and Pinkerton Hot Springs with its observed, apparent impact on pine trees in the area may need particular care. The Tripp and Trimble Hot Springs area has a fairly high mineral content and has been known to result in scale build-up.

In conclusion, this appraisal of the prospective use of geothermal energy for the heating of eleven state-owned buildings at six locations in Colorado has shown that at least six of the facilities have a high to moderate feasibility for successful development and economic benefit.

SITE SPECIFIC ANALYSIS

For the complete engineering, economic, institutional and resources evaluation relative to the individual state owned buildings considered, the reader is referred to Colorado Geological Survey Open-File Report 81-3. The buildings evaluated are discussed in the following sections:

Section 81-3a Alamosa, Colorado:	Adams State College State Highway Dept.
Section 81-3b Buena Vista, Colorado:	State Reformatory State Highway Dept.
Section 81-3c Burlington, Colorado:	State Highway Dept.
Section 81-3d Durango, Colorado:	Ft. Lewis College State Fish Hatchery State Highway Dept. National Guard Building
Section 81-3e Glenwood Springs, Colorado:	State Highway Dept.
Section 81-3f Steamboat Springs, Colorado:	State Highway Dept.

REFERENCES

- American Association of Petroleum Geologists, 1974, Geothermal gradient map of North America: Amer. Assoc. Petroleum Geol. Geothermal Gradient Portfolio Maps 14 and 15, Tulsa, Oklahoma.
- Barrett, J.K. and Pearl, R.H., 1976, Hydrogeological data of thermal springs and wells in Colorado: Colorado Geol. Survey Info. Series 6, 124 p.
- Barrett, J.K. and Pearl, R.H., 1978, An appraisal of Colorado's geothermal resources: Colorado Geol. Survey Bull. 39, 224 p.
- Bretz, T.D., Minerals Director, Colorado Board of Land Commissioners, Denver, Colorado, pers. comm., 1980.
- Bureau of Reclamation, 1976, Colorado River water quality improvement program Glenwood/Dotsero springs unit - Appraisal report: U.S. Bur. Reclamation, Upper Colorado Region, Denver, Colorado.
- Chaffee Geothermal, Ltd., 1980, Appraisal of geothermal resources near state-owned buildings throughout Colorado: Contract report CGS-80-008.
- Christopherson, K.R., 1979, A geophysical study of the Steamboat Springs, Colorado geothermal systems: Univ. Colorado, M.S. Thesis, 107p.
- Coe, B.A., 1980, Geothermal energy potential in the San Luis Valley, Colorado: Colorado Geol. Survey Open-File Report 80-13, 43p.
- Coe, B.A. and Forman, N.A., 1980, Regulation of geothermal energy development in Colorado: Colorado Geological Survey Info. Series 15, 27 p.
- Coe, B.A. and Zimmerman, Judith, in prep., Geothermal energy opportunities at four Colorado towns: Colorado Geological Survey Open-File Report.
- Collins, Phyllis, City Clerk, Burlington, Colorado & McClain, Les, City Administrator, Burlington, Colorado, pers., comm., 1980.
- Denver Research Institute, 1980, Municipal geothermal heat utilization plan for Glenwood Springs, Colorado: U.S. Dept. of Energy, Idaho Operations Office, 266 p.
- Denver Research Institute, Draft, Environmental report for Glenwood Springs: Colorado Geological Survey, Denver, Colorado.
- Department of Energy, Energy Information Administration, 1980, communicated by Leonard Bronder, DOE Office of Resource Applications, January 1981.

- Energy Management Consultants, Inc., 1978, Report on energy conservation study for selected buildings located at Fort Lewis College: Colorado Energy Research Institute, 80 p.
- Fritzpatrick, Joan, Denver Research Institute, pers. comm., 1980.
- Gaca, J.R., and Karig, D.E., 1965, Gravity survey in the San Luis Valley area, Colorado: U.S. Geol. Survey open-file rpt., 16 p.
- Ghourdjian, Michael, Real Estate Office, State of Colorado, pers. comm., 1980.
- Glenwood Springs Geothermal Advisory Group, pers. comm., 1977.
- Green, Harvey, Public Works Dept., City of Durango, Colorado, pers. comm., 1980.
- Hansen, R.L., 1975, Analysis of thermal infrared remote sensing data - Colorado River, Glenwood Springs to Dotsero: Bur. Reclamation Memorandum, Engineering Physics Section, Denver, Colorado, 23 p.
- Hartley, Robert, P., 1978, Pollution control guidance for geothermal energy development: Industrial Environmental Research Laboratory, Cincinnati, Ohio.
- Hupper, Julie, City Clerk, Buena Vista, Colorado, pers., comm., 1981.
- McEldery, R.M., 1975, Umbrella conventional assessment for geothermal leasing in San Luis and upper Arkansas Valleys: U.S. Dept. of the Interior, Bureau of Land Management, Denver, Colorado.
- Park, Don, Public Works Dept., Alamosa, Colorado, pers. comm., 1981.
- Pearl, R.H., 1972, Geothermal resources of Colorado: Colo. Geol. Survey Spec. Pub. 2, 54 p.
- _____, 1979, Colorado's hydrothermal resource base - an assessment: Colo. Geol. Survey Res. Series 6, 144 p.
- Pierce, Tom, County Building Dept., Routt County, Colorado, pers. comm., 1981.
- Proprietary industrial data, 1980.
- Reynolds, Dallas, Phillips, Brandt, Reddick & Assoc., Inc., pers. comm., 1980.
- Ringrose, C.D., 1980, Temperature-depth profiles in the San Luis Valley and Canon City areas, Colorado: Colo. Geol. Survey Open-File Rpt. No. 80-12, 17 p.

- Rupp, Craig, W., 1980, Environmental assessment, Forest Service response to geothermal applications within the upper Arkansas River: U.S. Forest Services, Lakewood, Colorado.
- Snyder, G., 1977, Geologic map of the northern most Gore Range and southernmost Northern Park Range, Grand, Jackson, and Routt counties, Colorado: U.S. Geol. Survey Open-File Rpt. 77-189.
- Stotler, Robert, County Administrator, Chaffee County, Colorado, pers. comm., 1981.
- University of Utah Research Institute (Debra W. Struhsacker, Earth Science Laboratory Division), 1980, A review of geothermal geology and exploration.
- Water Quality Control Division, Colorado Department of Health, 1977, Primary drinking water regulations for the State of Colorado, Denver, CO.
- Wharton Econometric Model, Memorandum from Bob Edelstein, University of Southern California, to Tom Cassel, Technecon Analytic Research, Inc., April 21, 1980.