REPORT CDOH-DTP-R-80-6

EVALUATION OF GEOTHERMAL ENERGY FOR HEATING HIGHWAY STRUCTURES

Herbert N. Swanson
Colorado Department of Highways
4201 E. Arkansas Avenue
Denver, Colorado 80222

Interim Report
May 1980

Prepared in Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Colorado Department of Highways or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Technical Report Documentation Page

1. Report No. FHWA-CO-80-6	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Evaluation of Geothermal Energy For Heating Highway Structures		5. Report Date May, 1980
		6. Performing Organization Code
7. Author(s) Herbert N. Swanson		8. Performing Organization Report No. CDOH-DTP-R-80-6
9. Performing Organization Name and Address Colorado Department of Highways, Division of Transportation Planning, 4201 E. Arkansas Avenue, Denver, Colorado 80222		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. 1474
12. Sponsoring Agency Name and Address Colorado Department of Highways, 4201 E. Arkansas Avenue, Denver, Colorado 80222		13. Type of Report and Period Covered Interim
		14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U. S. Department of Transportation, Federal Highway Administration

16. Abstract This study was undertaken to determine the feasibility of using geothermal energy to prevent preferential icing of bridge decks. A preliminary reconnaissance of known geothermal springs was made for the Glenwood Canyon corridor through which Interstate 70 will be constructed. A prototype bridge structure was built to test the feasibility of using geothermal water and heat pipes to prevent preferential icing. This is the first known application of geothermal energy combined with heat-pipe technology. The hot water from springs in the Glenwood area cannot be piped directly into a concrete structure because of a possibility of a breakdown and freeze. Heat pipes which have been evacuated and backfilled with ammonia serve as an excellent heat exchanger and transfer device. By combining the geothermal water and heat pipes at a header the concrete deck is kept warm and snow and ice are melted. The results of this pilot project could lead to similar design and construction of heated sections of structures which are susceptible to preferential icing in the Glenwood Springs area or other applicable areas in Colorado and possibly other states.

17. Key Words GEOTHERMAL, ENERGY, HEATPIPE, BRIDGE, STRUCTURE	18. Distribution Statement No Restrictions. This Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	62	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

CONVERSION FACTORS
English to Metric System (SI) of Measurement

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40	millimetres (MM)
		.02540	metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (Km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2)	.09290	square metres (m^2)
	acres	.4047	hectares (ha)
Volume	gallons (gal)	3.785	litres (1)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (1/s)
	gallons per minute (gal/min)	.06309	litres per second (1/s)
Mass	pounds (1b)	.4536	kilograms (kg)
Velocity	miles per hour (mph)	.4470	metres per second (m/s)
	feet per second (fps)	.3048	metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic ($1b/ft^3$)	16.02	kilograms per cubic metre (kg/m^2)
Force	pounds (1bs)	4.448	newtons (N)
	kips (1000 1bs)	4.448	newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-1b)	1.356	joules (J)
	foot-kips (ft-k)	1.356	joules (J)
Bending Moment or Torque	inch-pounds (ft-1bs)	.1130	newton-metres (Nm)
	foot-pounds (ft-1bs)	1.356	newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch (ksi $\sqrt{in}$)	1.0988	mega pascals $\sqrt{metre}$ (MPa $\sqrt{m}$)
	pounds per square inch square root inch (psi $\sqrt{in}$)	1.0988	kilo pascals $\sqrt{metre}$ (KPa $\sqrt{m}$)
Plane Angle	degrees (^{o})	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{tF - 32}{1.3} = {}_{t}C$	degrees celsius (^{o}C)

TABLE OF CONTENTS

INTRODUCTION

The removal of ice and snow is a hazardous and costly maintenance operation in Colorado as well as in most of the northern states. Although the problem exists in the entire state of Colorado, a section of Interstate 70 through Glenwood Canyon was selected as the focus of this project for a variety of reasons. The selected corridor contains a large number of bridge structures which pose considerable ice and snow hazard to the public as well as costly maintenance requirements for the facility. The severity of the problem is magnified by the shadows cast on many of the structures and much of the roadway by the high, narrow canyon walls. This condition is intensified in the Cinnamon Creek area. At this site, the roadway comes out of a tunnel onto a bridge structure over the creek and back into another tunnel. Drivers in this area are required to make adjustments for illumination changes as well as possible icing conditions during the winter months.

Maintenance management records show that snow and ice removal in the canyon in fiscal year 1979 was $1419 per lane mile. Accident records in the canyon show a total accident rate of 3.26 per million VMT as compared to 2.96 for other two lane rural highways statewide. There has been an average of 5.84 accidents per mile per year over the last four years.

Since the area is endowed with considerable geothermal activity, a study to determine the feasibility of using this geothermal energy in the design and operation of the highway was undertaken.

The first phase of study included a preliminary reconnaissance to determine the locations, magnitude, and availability of all known sources of geothermal waters which could be used for deicing highway or bridge structures in Glenwood Canyon.

A literature search on the subject of geothermal energy as used in highways and bridges produced information on heating of roadways by closed system plumbing in earth installations and by other types of heating systems. Geothermal energy has been used for many other heating applications but only one small section of roadway has been heated in the United States. This section was built in 1948 in Klamath Falls, Oregon and is still operating effectively; however, heat energy design data for this project was not available. Data gathered on the geothermal springs in the vicinity of Glenwood Canyon by other agencies has been very valuable in our preliminary investigations.

The Project Panel for this study recommended that a feasibility and cost study be conducted before proceeding with additional work on this study. The second phase, (Phase B) includes exploration drilling in the canyon to determine the geothermal gradient and possibly discover new sources near the proposed structures to be heated. The third phase, (Phase C) consists of the design and installation of a prototype bridge structure in the canyon to provide positive evidence of the workability of the concept and to provide heat energy requirements for a given area. The energy required for a unit of area will provide design parameters for future projects.

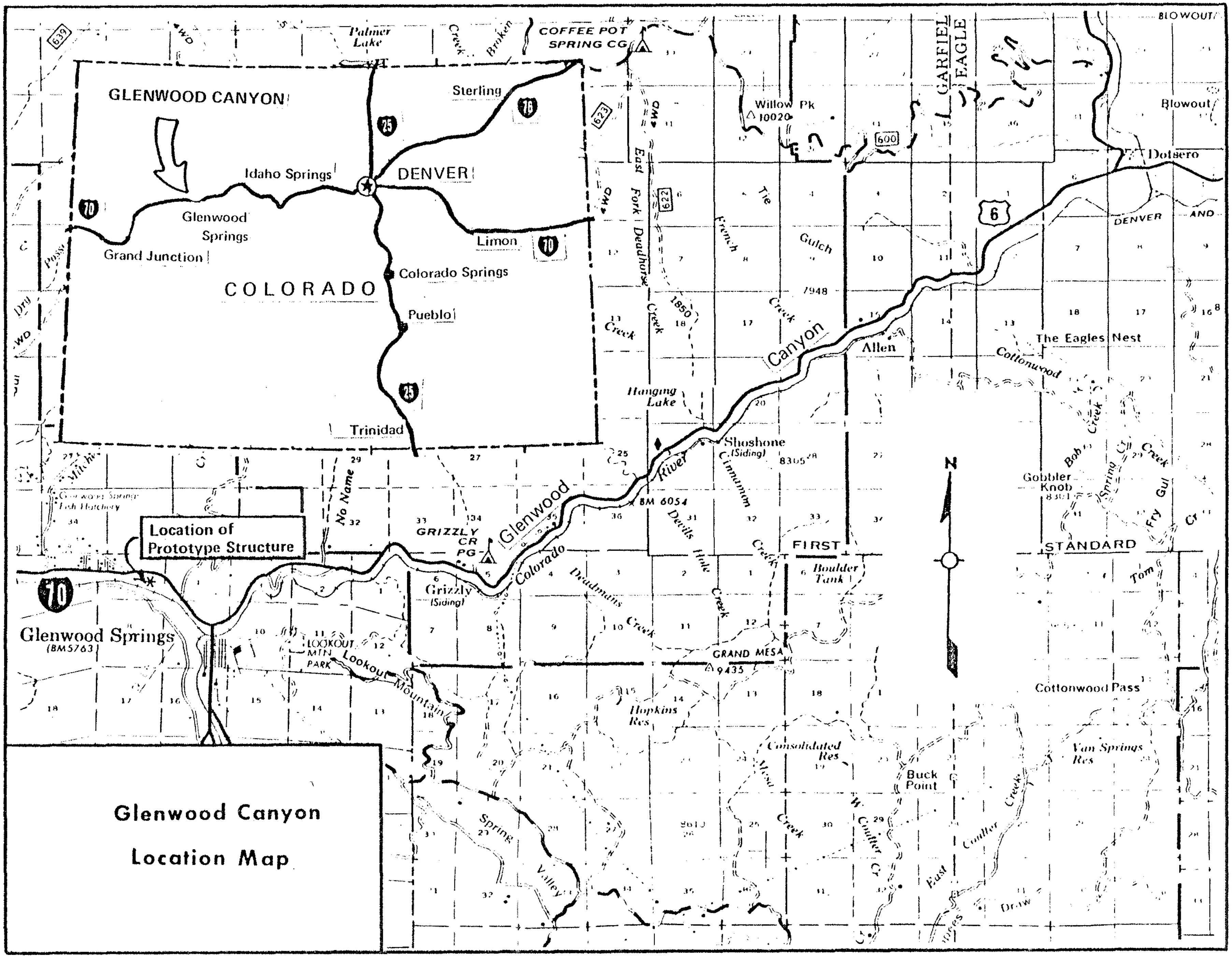
A geothermal engineering consultant for the Department of Energy completed the feasibility and cost study after which the advisory committee approved the work on Phases B and C.

This report includes the initiation of the study in early 1979, economical and feasibility studies and the construction of a prototype structure in Glenwood Springs (Phases A and C).

LOCATION AND GEOLOGY

Glenwood Springs and Glenwood Canyon are located in West central Colorado along the Colorado River (See Figure 1). Current plans to construct I-70 through the canyon include several miles of bridge structure near Hanging Lake. Roadway heating to prevent preferential icing would be an asset for both highway maintenance and safety of the traveling public since most of this alignment is shaded.

The Hanging Lake area is near the center of the canyon where most of the structures are to be built and where geothermal energy will be most needed.



Glenwood Canyon

Location Map

Figure 1

This point is at an elevation of 6140 feet and is ten miles from the center of the known springs in Glenwood Springs at an elevation of 5750 feet. The Hanging Lake area is 5.7 miles from the known geothermal springs at the East end of the canyon which are at an elevation of 6180 feet above sea level.

In the Glenwood Canyon corridor the Colorado River has cut through the South flank of the White River uplift. This wide, flat-topped arch is the last of the major Laramide uplifts dating from perhaps 50 to 60 million years ago. Several thousand feed of sedimentary and a few hundred feed of Precambrian rocks have been cut by the river. There has been considerable techtonic activity in the area in the comparatively recent geologic past. Numerous basalt flows from the flat tops of surrounding mountains, cinder cones, and volcanic ash are common in the entire White River uplift. A cinder cone and basalt flow of particular interest is only a few miles from the East end of the canyon near Dotsero and has been dated at 4000 years. The true source of the geothermal activity in the area in unknown. Possibilities include the residual heat from the volcanic activity and slightly higher than normal geothermal gradient generally present in the area.

There has been considerable faulting and folding of the South flank of this uplift. The faults coupled with the numerous permeable sandstone and limestone formations provide ample opportunity for water to migrate throughout the subsurface rock structure.

The known geothermal springs are mostly concentrated in the alluvial deposits near the river at either end of the canyon. The major source aquifier is generally believed to be the Leadville limestone, however, this presents somewhat of a mystery since all of these waters contain high concentrations of sodium chloride and sulfate irons. The Leadville limestone and underlying formations consist of limestones, dolomites, and sandstones which contain no sulfate minerals and very little sodium. The most likely explanation is that somehow in the faulting and folding, the geothermal water comes into contact with the formations comprising the Eagle Valley evaporites (stratigraphically above the Leadville limestone) which do contain these minerals.

Other warm water springs have been reported on both the North and the South canyon rims and several miles Southwest and Northwest of Glenwood Springs. Travertine deposits (the mineral precipitates around the perimiter of geothermal springs) have been found several feet thick in the Hanging Lake Canyon. Other travertine deposits have been measured to 40 feet thick indicating that the area has been geothermally active in the recent past. It appears to be well worth the investment to sink exploration wells near the center of the canyon to determine the geothermal gradient and possibly discover geothermal sources near the structures to be heated.

LITERATURE SEARCH AND ACQUISITION OF DATA FROM OTHERS

Reports published by the Colorado Geological Survey include data on known geothermal areas and much of the legal responsibilities which are necessary to obtain and use geothermal energy. The data include temperatures, flow rates, and a chemical analyis of each known spring or well. The Water and Power Resources Service (formerly the U. S. Bureau of Reclamation) used infrared imagery and color resolution photography which showed many more geothermal sources.

Copies of their report and color photos were obtained and used. The Water and Power Resources Service (WPRS) has been investigating the geothermal springs in the reach of the Colorado River between the Eagle River and the Roaring Fork River.

The WPRS is also involved in a desalinizing study to improve the water quality of the river. Part of this program has been a measurement of temperatures, flow rates, and chemical composition of geothermal springs. This data and other reports available on the area were used as a data base for field verification of site locations. Many of the assumptions for this study are based on this information.

FIELD RECONNAISSANCE

Early in 1979 researchers set out to make a field verification of the sources reported by the Colorado Geological Survey and the Water and Power

Resources Service. In addition to ground observations, an aerial reconnaissance indicated that there may be more warm water sources on the rims of the canyon and on the higher land of the White River uplift. At least two open pools of water were observed above the canyon rims in early March when all other creeks, lakes, and beaver dams were frozen. The area surrounding these pools was covered by at least five feet of snow.

Overland attempts were made using a snow cat and showshoes to reach these open pools to measure temperatures, flow rates and to take samples for chemical analysis. These attempts were unsuccessful due to the extremely rough topography and thick timber. However, several other areas of open water were encountered on this reconnaissance. Open water temperatures averaged 50°F while the ambient temperature was 30°F and a 30 mph wind was drifting snow. One of these open ponds was an especially striking contrast to the snow and wind. This half-acre pond was ringed first with green grass and then almost-vertical five-foot banks of snow. Fish in the 53° water were feeding on flying mosquitos while only a few feet away the snow was still blowing and drifting.

These open waters in the high country indicate the possibility of higher than normal geothermal gradient in the entire canyon area. However, these waters are not saline and no connection can be made with the known geothermal resource areas in the bottom lands at this time.

Field information collected by the researchers as well as other state and federal agencies is listed in Table A. The information listed gives physical features and descriptions useful for locating known springs.

OWNERSHIP AND LEGAL RESPONSIBILITIES

Researchers reviewed records in the Garfield County Court House and at the Denver Office of the Denver and Rio Grande Western Railroad Company. Personal interviews and consultations were held with various agencies in order to determine land, mineral, and water right ownerships as well as our legal responsibilities in the event that the Department of Highways decides to use geothermal waters. These agencies include the Water Referee, the

TABLE A

CORRELATION AND LOCATION OF KNOWN GEOTHERMAL SPRINGS

Water and Power Resource Service Identification	Colorado Geological Survey Identification	Department of Highways Stations		Prominent Features
Glen 10	Railroad Spring	473 + 20	175' RT	500' W of RR Tunnel
Glen 12		427 + 00	50' RT	From Highway Fill
Glen 15		463 + 50	180' RT	Under RR Fill
Glen 20		461 + 00	200' RT	Near Water Line
Glen 30	B	461 + 50	200' RT	Near Water Line
Glen 40		461 + 50	200' RT	Near Water Line
Glen 50	Vapor Caves	457 + 00	130' RT	Highway ROW
Glen 60	Pool Overflow	449 + 60	55' RT	Highway ROW
Glen 70	Pool Outlet	435 + 80	130' RT	Highway ROW
Glen 76	DOH Yard	413 + 60	300' RT	From Freeway
Glen 78	DOH Yard	412 + 20	450' RT	From Maint. Shop
Glen 80	DOH Yard	408 + 50	290' RT	From Freeway Yard
Glen 90	Graves Hot Spring	403 + 80	525' RT	Redstone Building
Glen100	Graves Gamba	395 + 50	50' RT	Concrete Cistern
DOT W		780 + 00	2000' RT	Dotsero Interchange
DOT V		722 + 00	425' RT	
DOT 5		713 + 56	80' LT	Seeps
DOT 6	Dugout Stockpond	712 + 56	80' LT	Drained to River
	Box	711 + 90	10' LT	
DOT T		691 + 00	475' RT	Island
DOT 9		669 + 80	450' RT	Side Tributary
DOT 10	Dotsero Warm		650' RT	Near Railroad
DOT 11	Springs South		650' RT	Canyon Entrance
DOT 20		670 + 20	80' LT	Highway Embankment
DOT 30	Dotsero Warm	699 + 75	75' LT	Highway Embankment
DOT 40	Springs	699 + 80	75' LT	Highway Embankment
Nedlog Test Hole		667 + 10	44' LT	Open Hole
Nedlog Test Hole		667 + 85	32' LT	Steel Cap

Division Engineer for Division 5 of the Water Resources Section of the Division of Natural Resources of Colorado, officials of the D&RGW railroad, and CDOH Right of Way engineers. A title search is recommended to verify data presented in this report if the Department finds it necessary to acquire water or surface rights.

Table B is a list of known springs and the owners of surface, mineral, and water rights as determined by the researchers. Incidentally, it was found that water discharged by other users may be claimed and used by a second party.

The following is a list of steps required to obtain and use geothermal energy in Colorado:

1. Request a permit to drill, test, or develop a well from the Colorado Oil and Gas Conservation Commission.

2. Request a drilling or well permit from the Ground Water Section of the Division of Water Resources.

3. File for water right in the Division Water Court.

4. Send a copy of plans to the State Engineers Office for approval.

5. Apply for a point discharge permit from the Colorado Department of Health.

The Oil and Gas Conservation Commission is interested in wells drilled for deep geothermal energy. Diversion or development of an existing surface spring would not require a permit. A hole drilled several feet back of and at a higher elevation than the open spring, but which would intercept that spring and develop it before it enters the river is not considered a well. A ruling on each situation by the Oil and Gas Conservation Commission and the Division of Natural Resources should be sought. It will take some time and paper work to obtain all the permits required to develop and use the known geothermal springs. Representatives of the agencies involved have

TABLE B

GEOTHERMAL ENERGY STUDY

OWNERSHIP OF HOT WATER SPRINGS

Water and Power Resource Service Identification	Colorado Geological Survey Identification	Ownership of Hot Water Springs Rights*		
		Surface	Mineral	Water
Glen 10	Railroad Spring	D&RGWRR	D&RGWRR	Open
Glen 12		DOH	DOH	Open
Glen 15		D&RGWRR	D&RGWRR	
Glen 20		D&RGWRR	D&RGWRR	Glenwood Hot Springs and Pool
Glen 30	B	D&RGWRR	D&RGWRR	
Glen 40		D&RGWRR	D&RGWRR	
Glen 50	Vapor Caves	Vapor Caves		Vapor Caves
Glen 60	Pool Overflow	DOH	DOH	Open
Glen 70	Pool Outlet	DOH	DOH	Open
Glen 76	DOH Yard	DOH	DOH	Open
Glen 78	DOH Yard	DOH	DOH	Open
Glen 80	DOH Yard	DOH	DOH	Open
Glen 90	Graves Hot Spring	Redstone Corp.		Redstone Corp.
Glen 100	Hobo Gamba			Gamba
DOT 5	Seeps	DOH	Bair	
DOT 6	Dugout Stockpond	DOH	Bair	
	Box	DOH	Bair	
DOT 9		Bair	Bair	
DOT 10	Dotsero Warm Springs South	Bair	Bair	BLM
DOT 11		Bair	Bair	
DOT 20		DOH	Bair	
DOT 30	Dotsero Warm Springs	DOH	Bair	
DOT 40		DOH	Bair	

* D&RGWRR - Denver and Rio Grande Western Railroad
DOH - Colorado Department of Highways
BLM - Bureau of Land Management

indicated that necessary permits would be granted. It should be noted that in the case of deep wells, special conditions would affect the permits.

The question of the discharge of saline water after use arises. The Health Department has indicated it would be very reluctant to grant a point discharge permit for the addition of mineral water to the environment. The most favorable alternative is reinjection of the used water into the acquifier. Currently, a feasibility study is being proposed by the Water and Power Resources Service to desalinize springs and wells in the Glenwood area.

ENVIRONMENTAL CONSIDERATIONS FOR HIGHWAY USE

The environmental acceptability of the use of geothermal energy to heat bridge structures, roadways, or buildings is addressed here under four headings--water quality, quantity of water, aesthetics, and aquatic life.

Water Quality

The salinity of the Colorado River is becoming more important to users, especially downstream from the state of Colorado. The largest source of dissolved salts in the Colorado River is overland runoff; a smaller contributor is point sources which includes mineral springs. Although mineral springs add only a small percentage of the total salts, the contribution from the Dotsero and the Glenwood Springs area is substantial.

> The largest point source contributors of dissolved solids to the Upper Colorado River are in the reach of the river between the mouth of the Roaring Fork River at Glenwood Springs and the mouth of the Eagle River near Dotsero. These contributions are from thermal springs rising in or near the bed of the river and from ground water entering this reach of the river. Inflow-outflow measurements indicate this reach of the river contributes approximately 25,000 acre-feet of water containing over 500,000 tons of dissolved solids annually.[1]

The Water and Power Resources Service has been engaged in a water quality improvement program in which one of the major targets is this stretch of

[1] Water and Power Resources Service.

the river. It has been investigating and will continue to investigate the feasibility of desalinizing the warm water springs of this area. The completion of the Service's studies and its final decisions on this project are not anticipated for several years. This study and possible implementation decisions must, therefore, precede the desalting efforts.

Water quality law falls under Public Law No. 92-500 and is controlled by the Water Quality Division of the Colorado Department of Health, 4210 East 11th Avenue, Denver, CO 80222. Officials of the Health Department have indicated that the necessary water quality permits would most likely be granted if proper forms and requests are submitted. The discharge request should indicate that the quality of the river will not be degraded and that salinity removal is not feasible in the Department of Highways work plan.

Quantity of Water

The quantity of water in any given drainage is the primary responsibility of the Division of Water Resources, Department of Natural Resources. The Division Engineer in Glenwood Springs has indicated that the main concern is the quantity of water flowing down the river. No problems are anticipated in the diversion of geothermal water, since the use is non-consumptive, similar to piscatorial or recreational use. The quality and quantity of many of the known geothermal springs is given in Appendix B.

Aesthetics

Route selection, shape, size, color, and supports used for pipelines would be major factors to consider. The location and design of heat exchangers are also important aesthetic considerations. These are not considered to be very difficult problems to overcome. Pipelines can be attached to guardrails, handrails, or under structures. Heat transfer units, pumping, and switching stations should be housed in small, inconspicuous shelters. The colors, shapes, and sizes of structures and pipelines should be specified so that they are compatible with the highway or the natural environment as applicable. Shelters for pumps, transfer units, or controls can be made as inconspicuous as possible as a part of a bridge structure or under a structure.

Aquatic Life

Officials at Colorado Division of Wildlife indicate that a temperature reduction of geothermal water entering Colorado River from Dotsero to Glenwood would have no effect on aquatic life. Further confirmation by field wildlife personnel in the area is recommended.

FEASIBILITY AND COST STUDY

The Project Panel met in March of 1979 to review the progress of the initial work. The major recommendation of the Panel was that feasibility and economic studies should be completed and show favorable results before proceeding with Study Phases B and C -- the drilling, exploration, and the construction of a prototype structure. It was learned that several engineering firms in the country are working to assist agencies, industries, and individuals, in the development and use of geothermal energy as an alternative to fossil fuel. These firms are working in this field under an agreement with the U. S. Department of Energy. EG & G, Idaho, Inc. is responsible for assistance and promoting the use of geothermal energy in the Rocky Mountain Region and they agreed to do a feasibility-cost study on this project. EG & G, Idaho, Inc. evaluated the use of a heat exchanger and a grid system in the pavement. Later two heat pipe designs were added for evaluation. Preliminary data was received by September and the complete feasibility study was received by the end of October 1979. During the early part of this work it was assumed that some type of grid system of plumbing would be installed in the roadway or structure deck. E.G & G Idaho, Inc. suggested the possibility of using heat pipes to transfer the energy from geothermal water to the bridge deck. This would eliminate the freezing and corrosion problems. After making some inquiries, it was learned that the University of Wyoming and the University of New Mexico had been experimenting with and using heat pipes for some time. Preliminary design ideas and cost estimates from both universities encouraged CDOH researchers and the consultant in Idaho to combine geothermal and heat pipe technologies. Each heat pipe would serve as a small efficient heat exchanger reducing some of the costs in the original estimate. The use of heat pipes also changed the usable minimum temperature range of the geothermal fluid, from $80^{o}F$ to $50^{o}F$. On the basis of these developments EG & G Idaho, Inc. submitted a revised feasibility-cost analysis. Applicable parts of the recommendations and cost analysis by EG & G, Idaho, Inc. follows:

Geothermal Deicing of Bridge Structures - IAE-143-79 by EG & G, Idaho

"Based on information provided by your office and other available data, a preliminary unit cost estimate for geothermally deicing highway bridge structures has been developed. The estimates are based on systems for maintaining an ice-free roadway surface when air temperature is $25^{o}F$ and snowfall is at a rate of 1/2 inch per hour. A heat rate of 80 BTU/ft^2 is believed to satisfy this heating requirement. Cost estimates are on a per-mile basis for four-lane bridge decks. A supply temperature of $100^{o}F$, an exit temperature of 55^{o} and a flowrate of 860 gpm are used to develop preliminary capital cost estimates for two bridge deck deicing system designs. Systems considered are: 1) a closed circulation grid with an antifreeze solution as the heat transfer medium, 2) heat pipe system as described in information provided by your office. System costs are based on the use of black steel pipe at a spacing of 12 inches for each system. Rationale for costing of the geothermal supply system and the closed circulation pipe system is similar to that for costing of roadway deicing systems previously provided to your office. Major differences are the pipe material selected and the operating temperatures used in developing the estimates. Estimated costs for the heat pipe system include only one supply header, whereas two may be required, depending on the design of the system. Use of a single header will require placement beneath the centerline of the bridge deck.

"Operating and maintenance cost for heat pipe systems can be expected to approach 25% less than comparable circulation systems due to reduced power costs for pumping and reduced maintenance costs for heat pipes as compared to pipe systems for circulation of thermal fluids.

"Table C shows estimated capital costs for the above systems together with estimated costs for an optional heat pipe system based on data received.

"Due to the significant difference between estimated costs for the two heat pipe systems and the significant design differences, it seems advisable to experimentally determine performance of the two systems prior to making a final selection. It should be noted that the optional heat pipe system we discussed will require approximately twice the geothermal flowrate required by the competing heat pipe design, since the exit temperature of the geothermal fluid is assumed to be about $80^{o}F$. This will result in higher power costs for the optional heat pipe system, along with an increase in required pump horsepower. The lower cost heat pipe system does not appear to include adequate costs for installation of the heat pipes; this cost may approach several hundred thousand dollars for each mile of 4-lane bridge deck. An additional cost of about $35/ft should be assessed for transmission-supply pipe in all cases."

TABLE C

PRELIMINARY UNIT COST ESTIMATES FOR

GEOTHERMAL BRIDGE STRUCTURE HEATING

(Thousands $ Per-Mile Basis)
(four lanes)

Item	Heat Exchanger and Black Pipe Grid	Heat Pipe Design "A"	Heat Pipe Design "B"
Well and Pump	50	50	50
550' Supply Line	20	20	20
Circulation Pump	5		
Heat Exchanger	50		
Roadway Grid (12" spacing)	1,000		
Heat Pipes (12" spacing)		500	
Heat Pipes (16" spacing)			1,200
Piping, Headers	240	160	
Control Valves, etc.	40	30	30
Disposal Piping	145	145	145
Subtotal	1,550	905	1,445
Design 10%	155	90.5	144.5
Contingency 10%	155	90.5	144.5
Total	1,860	1,086	1,734
Cost ($) per ft.^{2}	7.60	4.44	7.08
Cost ($) per 100' x 46'	39,960	20,424	32,568

The latest cost estimate (1977) to construct I 70 through the Canyon is $215.7 million or $17.2 million per mile.

% of Cost/Mile	10.8	6.3	10.1

Maintenance and power cost for pumping will be 25 to 30% less using heat pipes - geothermal as compared to geothermal - heat exchanges - grid system.

The heat exchanger and black pipe grid system and the heat pipe design "B" require 100°F geothermal fluid at ΔT of 20°F. The heat pipe design "A" can use 100°F fluid and ΔT of 45°F

Other data developed by the CDOH Research Section includes flow rates and temperatures of known geothermal springs (See Table D). The table was extended to include the BTUs available if the water is discharged at 55°F. Current Glenwood Canyon plans include 35,285 lineal feet of concrete structure, 33.5 feet wide curb to curb. The heat rate required, according to I.A. Engen, is 80 BTU/l hr/ft^2. The 108.3 x 10^6 BTU/hr available by using the known geothermal springs (from Table D) would heat 40,410 lineal feet of structure, or well over the planned quantity. Other sources indicate the 64 BTU/hr/ft^2 is more than sufficient energy to eliminate preferntial icing on a bridge deck in a severe environment. There is then sufficient geothermal energy to heat the planned structures in Glenwood Canyon. This would, however, require that most of the known sources be captured and transported to the required locations. If additional geothermal water is discovered as expected in the exploratory drilling operation, the feasibility and attractiveness of this program will be greatly enhanced. The above calculations will be confirmed or refined after the data is analyzed from the experiments on the prototype bridge.

On November 1, 1979, the Project Panel met and was informed of the progress of the work and of the results of the feasibility-cost study. The committee then suggested that exploration drilling in the center area of the canyon should begin in order to determine the availability of geothermal water in the immediate area where most of the structures are to be built. The Committee directed that a prototype bridge structure was to be constructed in the Glenwood Springs Highway Department Maintenance Yard, making use of the warm water springs in the yard. The deck of this structure was to be heated by heat pipes supplied by both Universities (UNM and UW). The heat exchanger and grid system was not included because of cost and it is more complicated and difficult to install on a small structure.

HEAT PIPES AND DESIGN VARIATIONS FOR USE WITH GEOTHERMAL FLUIDS

"The heat pipe consists of a tube, wick, and fluid that can transfer heat at a phenomenal rate. It has a fraction of the weight and several hundred times the heat transfer capabilities of solid copper, silver, or aluminum.

TABLE D

FLOW RATES AND TEMPERATURES

OF KNOWN GEOTHERMAL SPRINGS

Water and Power Resource Service Identification	Colorado Geological Survey Identification	WPRS Temp °F	CGS Temp °F	WPRS gal/min	CGS gal/min	Lb/hr X 10^4	BTU/hr X 10^6
Glen 10	Railroad Spring	124	124	180	75	9.02	6.2
Glen 12		124		180		9.02	6.2
Glen 15		124	122	270	74	3.71	2.6
Glen 20		123		538			
Glen 30	B	123	124	45	100	5.01	3.5
Glen 40		122		90			
Glen 50	Vapor Caves	119	122	45	5	2.26	1.4
Glen 60	Pool Overflow	117	122	1256	2400	120.31	51.7
Glen 70	Pool Outlet	79		1480			
Glen 76	DOH Yard	87		45		2.26	0.7
Glen 78	DOH Yard	87					
Glen 80	DOH Yard	82		90		4.51	1.2
Glen 90	Graves Hot Spring	106	115	135	5	0.25	0.1
Glen 100	Graves Gamba	102		224		11.23	5.3
DOT W							
DOT V							
DOT 5	Seeps	80		22		11.13	2.8
DOT 6	Dugout Stockpond Box	79		9		0.45	0.1
DOT T							
DOT 9		90		762			
DOT 10	Dotsero Warm Springs South	84	89	494	1000	50.13	15.0
DOT 11		89		628			
DOT 20		89		224			
DOT 30	Dotsero Warm Springs	89	88	180	500-800	38.25	11.5
DOT 40		89		359			
		Total		4,913			108.3

Figures underlined were used to calculations when more than one value is listed.

It can replace many conduction heat transfer systems, thus improving the performance of nearly any energy conversion system from cooling of space vehicles to heating automobiles."[1] Conventional gravity heat pipes have been used to heat roadways and bridges in Alaska, West Virginia, and Wyoming. These heat pipes were generally closed metal tubes which were thoroughly cleaned and evacuated. After evacuation the tubes were filled with a given quantity of working fluid (commonly ammonia) and shipped to the site. Typically, the pipes were buried to sixty feet or more in the ground and bent to be embedded in the roadway (Figure 2). Over the temperature range that the heat pipe was exposed to, part of the ammonia resides as a liquid pool at the bottom while the remaining ammonia is in the vapor phase filling the rest of the tube. When the deck temperature falls below the temperature of the earth, the vapor in the deck condenses and flows toward the bottom of the tube. Energy conducted from the ground to the cooler heat pipe evaporates part of the liquid ammonia completing the cycle".[2]

Three heat pipe design variations were submitted and used in the prototype structure in Glenwood Springs (Figure 3). From the figure it can be seen that the pipes are heated directly by the geothermal fluid, thus eliminating the need of a less efficient heat exchange system.

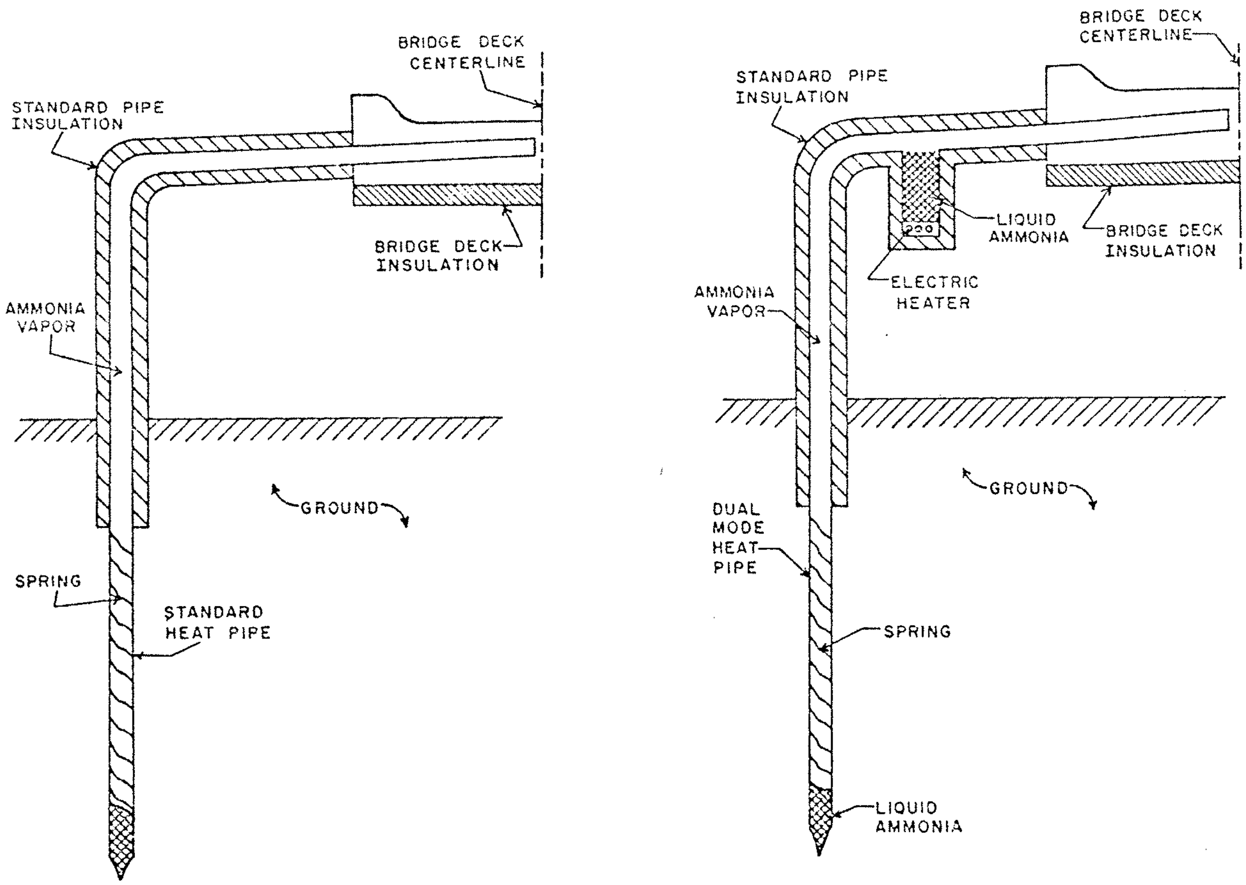
DESIGN AND INSTALLATION OF PILOT PROJECT

DESIGN OF THE STRUCTURE

A Denver firm specializing in prestressed concretes had a surplus of twin tee beams made up which were available at a reduced price. It was decided to purchase two 50-foot by 8-foot twin tee beams for the base of the deck. The CDOH Bridge Design Branch drew plans for the construction of footings, end walls to support the twin tees, and the concrete deck topping. The

[1] T. Feldman, 1968

[2] Transportation Research Record, 664, p. 189

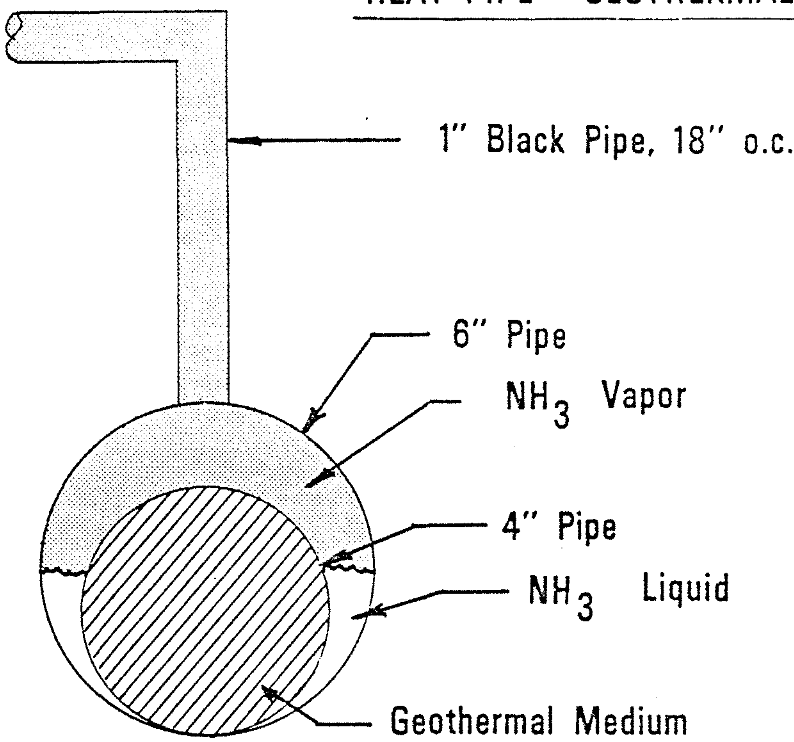


Typical earth heat pipes

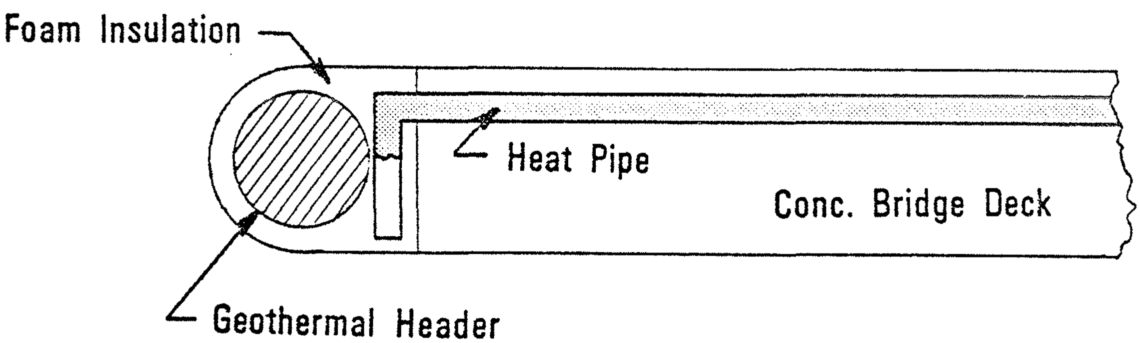
from Transportation Research Record 664

FIGURE 2

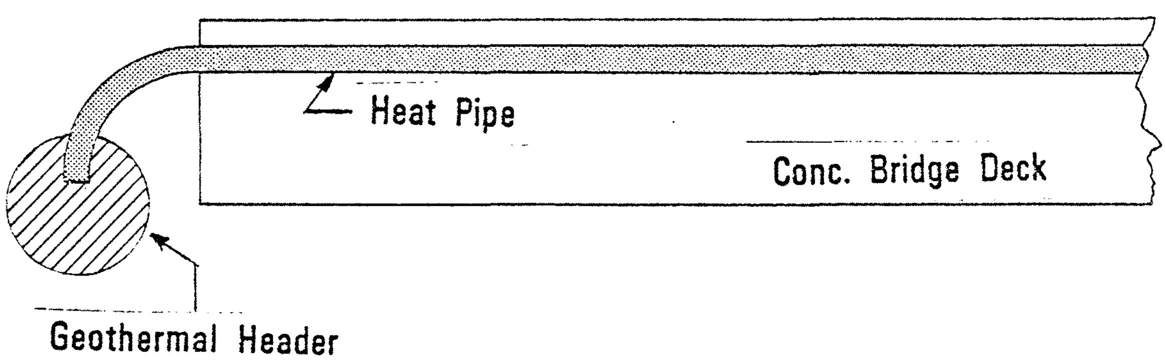
HEAT PIPE - GEOTHERMAL DESIGNS



DESIGN B



DESIGN A



MODIFIED DESIGN A

FIGURE 3

beams were placed side by side to form a 16 x 50 foot structure. This structure was designed to have a minimum of six feet of clearance so that air currents would not be obstructed. The Universities of Wyoming and New Mexico prepared designs and cost estimates for constructing and delivering heat pipe systems to be used on the simulated bridge structure. The proposed 50 x 16 foot structure was divided into six 8 feet long sections to accommodate various spacing of heat pipes. The University of Wyoming designed three heat pipe units of 8 x 16 feet. These three units were designed to provide six, twelve, and eighteen inch spacing to experimentally determine the optimum design.

The University of New Mexico designed two 8 x 16 feet heat pipe systems. The pipe spacing of these were six and eight inches. After sufficient testing of these sections, alternate heat pipes were to be disabled providing twelve and sixteen inch spacings.

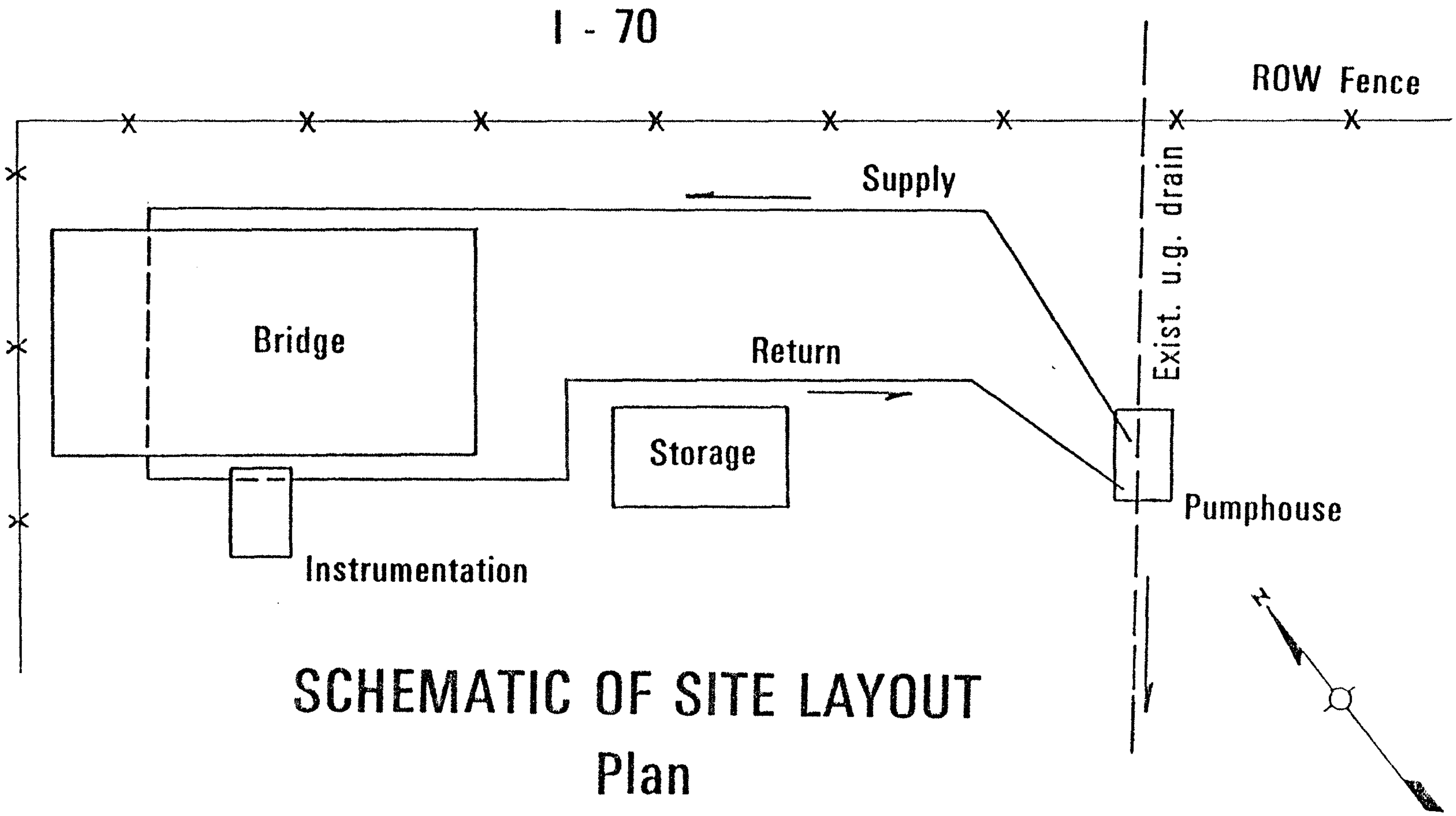
Researchers designed the spring diversion system, and the electrical and plumbing work for the geothermal fluid.

Figures 4, 5, and 6 show the schematic layout of the prototype structure and the plumbing.

CONSTRUCTION OF THE PROTOTYPE BRIDGE

A contract was awarded to begin construction in late January and continue through the first week of March 1980. Footings and end walls were built of reinforced concrete using standard specifications for a comparable structure. The precast twin tee beams were shipped from Denver and set in place with a crane. Reinforcing steel was tied on two-foot centers and spaced one inch above the twin tees. The heat pipe sections which were shipped from Wyoming and New Mexico were placed on top of the deck reinforcing steel. Forms were placed around the perimeter of the deck for later containment of a six-inch concrete deck topping.

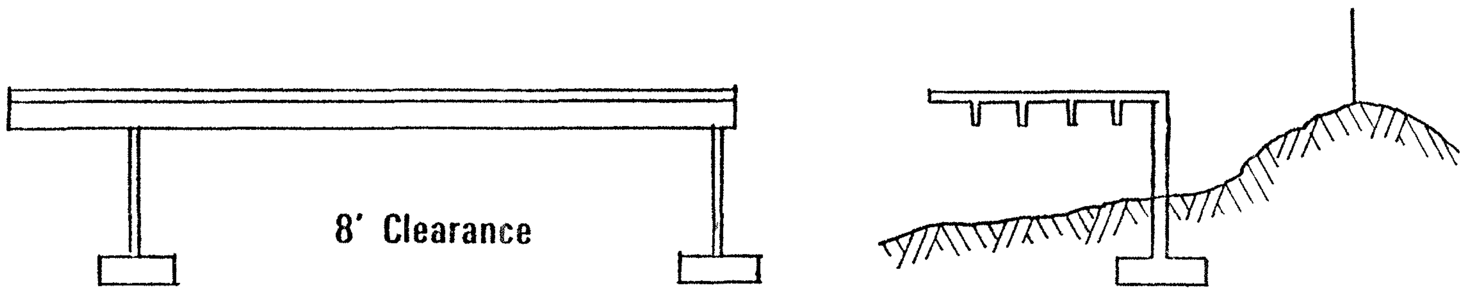
Half-inch wooden dowels for temperature probes were placed through the bottom of the twin tees to heat pipes and between heat pipes in different sections. Dowels were also placed to the surface at various locations.



SCHEMATIC OF SITE LAYOUT
Plan

FIGURE 4

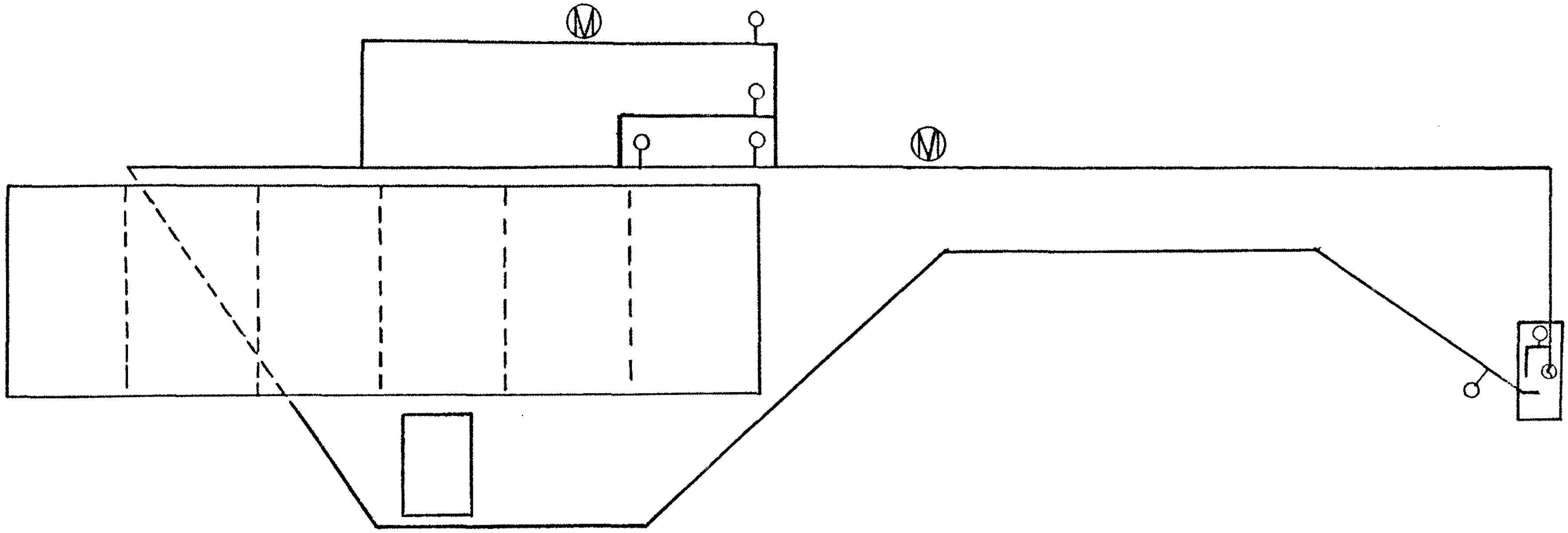
SCHEMATIC OF SITE LAYOUT



Elevation Section

FIGURE 5

FIGURE 6



Schematic Diagram of Plumbing

These dowels were removed after the concrete deck was poured and replaced with thermistors to monitor heat transfer throughout the deck. Small eighth-inch dowels were also placed at similar locations to accommodate a standard stem thermometer. The concrete twin-T deck was then overlayed with six inches of concrete encasing the reinforcing steel/heat pipe system.

During the construction of the bridge the contractor also provided trenching for electrical wiring, a submerged box around the geothermal drain culvert, a pump house, and an instrument shelter. Styrofoam insulation was installed on the underside of the heated sections of the structure and on the metal parts of the plumbing.

All instruments, recording devices, and time-lapse cameras were installed by March 20, 1980. Over fifty sensors are fed into a 100 channel digital data acquisition system which records all data once each minute on magnetic computer tape. The data recorded includes wind speed and direction, barometric pressure, ambient temperature, relative humidity, solar radiation, and fluid and deck temperatures. Data was collected at each of the following locations in or on the deck: in the geothermal fluid within the headers, on heat pipes of each set of pipe spacings, at the deck midplane between heat pipes, at the deck surface in each section, at the bottom of the deck in each section, and in the standard section at equivalent locations to other sections. All of this data will be assembled and analyzed with the aid of computers.

A time-lapse camera (Sankyo EM-60XL) using 8 mm film has been installed on the top of a wooden pole to record the surface condition of the deck during snow and ice storms. A Vivitar flash gun was used so that 24 hour photographic records could be kept. The timer was set for ten minute intervals to provide photos to record changing conditions and yet require changing film only every twenty-five days.

Two flow meters were installed in the geothermal supply line. One of these meters is in the main input line to the headers to measure all of the water flow into the system. The second flow meter was installed in the line which bypasses the Wyoming heat pipes. It may be necessary to divert some of the water past the first sections if the water cools too rapidly through the headers.

Other bypass and restrictive valves in the pump house are used to control the flow rate. A float switch is provided to shut the pumps down if the water level in the tank gets too low. An additional float with a metering device attached indicates the water level in the tank. By adjusting these valves and gauges, the system is automatic and only requires a check every few days.

OPERATION AND RESULTS

The pump was left on providing a continuous flow of 79°F (26°C) geothermal water from March 15 through April 10, 1980. The water temperature in the lines remained constant even though flow rates have fluctuated from 150 gallons per minute (568 l/m) to 35 gpm (132 l/m). As the water temperature is reduced during colder weather and snow storms, temperature between the input and the output of the geothermal header will be monitored. This kind of data will be used to verify quantitive projections of energy required per unit of area under given conditions.

Although the structure wasn't operational until late in the winter season, three storms were recorded. One ice storm on March 31, 1980 proved to be very valuable in evaluating the geothermally heated structure (see attached photos). It is very encouraging that the system works in a storm and at temperatures to a minimum of 20°F. All of the temperatures and weather data has not been analyzed as yet for these storms but the results are expected to give a good idea of the heat required for a given size of structure. These results and more, which are expected to be obtained in the 1980-81 winter, will provide exact design data in the form of quantity and temperatures of water required per unit of area of bridge deck.

During the short Spring operation the temperature of the geothermal fluid has stayed at 79°F even though flow rates have changed and other temperatures have fluctuated. Heat transmitted to the deck by the heat pipes kept the midplane of the deck at temperatures from 58°F to 68°F, and the surface of the deck at temperatures from 40°F to 68°F. These deck temperatures were achieved while the ambient temperatures fluctuated between 20°F and 52°F. The temperature of the standard (non-heated) section of deck generally stayed slightly above ambient but fluctuated with it.

CONCLUSIONS AND RECOMMENDATIONS

It appears that the use of geothermal heat and heat pipes for structures is a very effective method of controlling preferential icing. All heated sections of the prototype structure remained clear of snow and ice during the three storms encountered since the system has been operating. Since weather and temperature data is currently being analyzed, the results are not available for this report. It is anticipated that the energy required to heat a given area can be calculated mathematically and verified using the prototype structure results.

Experimental data gained from testing during the 1980-81 winter will confirm such results. At this time, there appears to be a temperature difference of 30°F between the geothermal fluid and the deck surface for a twelve inch pipe spacing during a storm when the ambient temperature drops to 27°F.

The preliminary cost estimated for heat pipes at a twelve inch spacing for this prototype was \$22.45/ft^2. Estimated cost of \$6.64/ft^2 for larger sections is expected where standardized production would be anticipated.

According to the preliminary feasibility studies, there is sufficient geothermal energy in the known springs to heat the planned structures in Glenwood Canyon however, most of the water would have to be captured and transported to the structure sites. However, drilling of exploratory wells may reveal additional sources closer to the target structures. Thus far, the use of geothermal heat for structures appears feasible in Glenwood Canyon and in Colorado. An additional year of evaluation using the prototype structure will assure the durability of the system in the local environment as well as provide a data base for the design of future facilities. In addition to the Department of Highways work regarding the implementation of geothermal energy use in Glenwood Canyon, it is proposed that an inventory of known geothermal resources in the state be correlated with bridges and sections of highways which are subject to preferential icing and have a higher than normal accident history. In addition, a list of Highway Department buildings within reasonable distances from known geothermal resources should be made. A review of each of the above listed bridges, roadways, and buildings to determine the feasibility and cost of using geothermal energy could then be made. Reviews which yield favorable results on any of the structures or roadway sections should be forwarded to the appropriate District Engineer for implementation as funds become available.

LIST OF REFERENCES

T. Feldman, THE HEAT PIPE, Mechanical Engineering Feb. 1968, Page 30.

Wilson, Pipe, Cundy, Nydahl and Pell, A DEMONSTRATION PROJECT FOR DEICING OF BRIDGE DECKS, Transportation Research Record 664, Page 189.

GEO-HEAT UTILIZATION CENTER Quarterly Bulletins, Jan. 1976 and April 1976 O.I.T.

GEOPHYSICAL STUDIES DOTSERO SALINE WATER PROJECT for U.S. Bureau of Reclamation, May 1973.

COLORADO RIVER WATER QUALITY IMPROVEMENT PROGRAM, DOTSERO-GLENWOOD SPRINGS POINT SOURCE STUDIES, STATUS REPORT, July 1973, Bureau of Reclamation.

1974 GEOPHYSICAL PROGRAM DOTSERO SALINE WATER PROJECT, March 1974 for U.S. Bureau of Reclamation.

GLENWOOD-DOTSERO SPRINGS UNIT, COLORADO, COLORADO RIVER WATER QUALITY IMPROVEMENT PROGRAM APPRAISAL REPORT, June 1976 Bureau of Reclamation.

GEOPHYSICAL SURVEYS AT PAGOSA SPRINGS AND GLENWOOD SPRINGS, COLORADO, 1977, Department of Geophysics, Colorado School of Mines, Golden, CO 80401

N. Wood Bass and Stuart A. Northrop, CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1961, Geological Survey Bulletin 1142.

Barbara Coe, GEOTHERMAL ENERGY DEVELOPMENT IN COLORADO / PROCESSES PROMISES & PROBLEMS, Colorado Geological Survey, 1978.

James K. Barrett and Richard Howard Pearl, AN APPRAISAL OF COLORADO'S GEOTHERMAL RESOURCES, Colorado GEOLOGICAL SURVEY, 1978

James K. Barrett and Richard Howard Pearl, HYDROGEOLOGICAL DATA OF THERMAL SPRINGS AND WELLS IN COLORADO, Colorado Geological Survey, 1976.

APPENDIX A

List of Equipment

LIST OF EQUIPMENT
NOT NORMALLY USED IN A BRIDGE STRUCTURE

Item	Local Source	Cost
Heat Pipes	Energy Engineering Inc.	$7,502.22
Heat Pipes	Seta Corp.	6,870.00
Electrical Supplies	G.E. Supply Co.	750.00
Precast Twin Tees	Stanley Structures	2,000.00
Pump		385.00
Plumbing Supplies	Grimes	2,000.00
Flashgun	Newark	186.00
8 mm Camera	Waxmans	217.00
Interval Timer	Newark	29.00
Flow meters	Sanders Co.	560.00
Instrument Package	University of Wyoming	5,572.00

Note: The instrument package includes the following installed:

1) a 100 channel digital aquisition system
2) wind speed transducer
3) wind direction transducer
4) asperated ambient temperature transducer
5) pyronometer
6) relative humidity transducer
7) time lapse camera
8) fifty-five thermisters

APPENDIX B

Chemical Analysis of the Waters
(from Barrett and Pearl, 1976)

Table 1. Physical Properties and Chemical Analysis of Thermal Waters in Colorado

Dotsero Warm Springs

Location: 39°37'39"N. Latitude: 107°06'22"W. Longitude; T. 5 S., R. 87 W.,

Sec. 12 bd, 6th. P.M., Eagle County

	Date Sampled		
	9/75	1/76	4/76
Arsenic (As), (UG/L):	0	-	-
Boron (B), (UG/L):	210	210	220
Cadium (Cd), (UG/L):	2	-	-
Calcium (Ca), (MG/L):	230	260	240
Chloride (Cl), (MG/L):	5,400	5,800	5,400
Fluoride (F), (MG/L):	-	0.8	0.3
Iron (Fe), (UG/L):	20	0	40
Lithium (Li), (UG/L):	100	-	-
Magnesium (Mg), (MG/L):	62	79	65
Manganese (Mn), (UG/L):	20	0	20
Mercury (Hg), (UG/L):	0.1	-	-
Nitrogen (N), (MG/L):	-	0.06	0.06
Phosphate (PO_4)			
Ortho diss. as P, (MG/L):	-	0.02	0.01
Ortho, (MG/L):	-	0.06	0.03
Potassium (K), (MG/L):	44	95	44
Selenium (Se), (UG/L):	0	-	-
Silica (SiO_2), (MG/L):		13	13
Sodium (Na), (MG/L):	3,500	3,500	3,500
Sulfate (SO_4), (MG/L):	420	430	450
Zinc (Zn), (UG/L):	10	-	-
Alkalinity			
As Calcium Carbonate, (MG/L):	372	370	372
As Bicarbonate, (MG/L):	454	451	454
Hardness			
Noncarbonate, (MG/L):	460	600	490
Total, (MG/L):	830	970	870
Specific conductance (Micromohs):	20,000	17,000	18,500
Total dissolved solids (TDS), (MG/L):		10,400	9,940
pH, Field	-	7.2	7.0
Discharge (gpm):	500E	525E	800E
Temperature (°C):	31	31	32

Remarks: This spring located on north side of Colorado River.

Table 1. Physical Properties and Chemical Analysis of Thermal Waters in Colorado

Dotsero Warm Springs, South

Location: 39°37'37"N. Latitude; 107°06'00"W. Longitude; T. 5 S., R. 87 W.,

Sec. 12 b, 6th. P.M., Eagle County

	Date Sampled
	12/75
Arsenic (As), (UG/L):	1
Boron (B), (UG/L):	190
Cadium (Cd), (UG/L):	0
Calcium (Ca), (MG/L):	250
Chloride (Cl), (MG/L):	4,900
Fluoride (F), (MG/L):	0.3
Iron (Fe), (UG/L):	10
Lithium (Li), (UG/L):	80
Magnesium (Mg), (MG/L):	54
Manganese (Mn), (UG/L):	20
Mercury (Hg), (UG/L):	0
Nitrogen (N), (MG/L):	0.09
Phosphate (PO_4)	
Ortho diss. as P, (MG/L):	0.02
Ortho, (MG/L):	0.06
Potassium (K), (MG/L):	37
Selenium (Se), (UG/L):	0
Silica (SiO_2), (MG/L):	13
Sodium (Na), (MG/L):	3,100
Sulfate (SO_4), (MG/L):	480
Zinc (Zn), (UG/L):	10
Alkalinity	
As Calcium Carbonate, (MG/L):	345
As Bicarbonate, (MG/L):	421
Hardness	
Noncarbonate, (MG/L):	500
Total, (MG/L):	850
Specific conductance (Micromohs):	15,000
Total dissolved solids (TDS), (MG/L):	9,040
pH, Field	7.0
Discharge (gpm):	1,000E
Temperature (°C):	32

Remarks: This spring located on south side of Colorado River.

Table 1. Physical Properties and Chemical Analysis of Thermal Waters in Colorado

Glenwood Springs Area: Big Spring (feeds swimming pool)

Location: 39°32'59"N. Latitude; 107°19'18"W. Longitude; T. 6 S., R. 89 W., Sec. 9 ad, 6th. P.M., Garfield County

	Date Sampled
	7/75
Arsenic (As), (UG/L):	0
Boron (B), (UG/L):	890
Cadium (Cd), (UG/L):	0
Calcium (Ca), (MG/L):	510
Chloride (Cl), (MG/L):	11,000
Fluoride (F), (MG/L):	2.3
Iron (Fe), (UG/L):	60
Lithium (Li), (UG/L):	800
Magnesium (Mg), (MG/L):	91
Manganese (Mn), (UG/L):	80
Mercury (Hg), (UG/L):	0
Nitrogen (N), (MG/L):	0.01
Phosphate (PO_4)	
Ortho diss. as P, (MG/L):	0.04
Ortho, (MG/L):	0.12
Potassium (K), (MG/L):	180
Selenium (Se), (UG/L):	0
Silica (SiO_2), (MG/L):	32
Sodium (Na), (MG/L):	6,900
Sulfate (SO_4), (MG/L):	1,100
Zinc (Zn), (UG/L):	30
Alkalinity	
As Calcium Carbonate, (MG/L):	634
As Bicarbonate, (MG/L):	773
Hardness	
Noncarbonate, (MG/L):	1,000
Total, (MG/L):	1,600
Specific conductance (Micromohs):	36,800
Total dissolved solids (TDS), (MG/L):	20,200
pH, Field	6.3
Discharge (gpm):	2,263
Temperature (°C):	50

Remarks: Located on north side of Colorado River.

Table 1. Physical Properties and Chemical Analysis of Thermal Waters in Colorado.

Glenwood Springs Area: Railroad Spring*

Location: 39°33'16"N. Latitude; 107°18'51"W. Longitude; T. 6 S., R. 89 W.,

Sec. 10 bab, 6th. P.M., Garfield County

	Date Sampled	
	1/76	4/76
Arsenic (As), (UG/L):	-	-
Boron (B), (UG/L):	850	890
Cadium (Cd), (UG/L):	-	-
Calcium (Ca), (MG/L):	460	460
Chloride (Cl), (MG/L):	10,000	10,000
Fluoride (F), (MG/L):	2.4	2.1
Iron (Fe), (UG/L):	20	40
Lithium (Li), (UG/L):	-	-
Magnesium (Mg), (MG/L):	80	86
Manganese (Mn), (UG/L):	70	80
Mercury (Hg), (UG/L):	-	-
Nitrogen (N), (MG/L):	0.01	0.01
Phosphate (PO_4)		
Ortho diss. as P, (MG/L):	0.04	0.04
Ortho, (MG/L):	0.12	0.12
Potassium (K), (MG/L):	200	180
Selenium (Se), (UG/L):	-	-
Silica (SiO_2), (MG/L):	29	29
Sodium (Na), (MG/L):	6,100	6,200
Sulfate (SO_4), (MG/L):	1,100	880
Zinc (Zn), (UG/L):	-	-
Alkalinity		
As Calcium Carbonate, (MG/L):	636	627
As Bicarbonate, (MG/L):	775	764
Hardness		
Noncarbonate, (MG/L):	840	880
Total, (MG/L):	1,500	1,500
Specific conductance (Micromohs):	30,500	29,900
Total dissolved solids (TDS), (MG/L):	18,400	18,200
pH, Field	7.1	6.5
Discharge (gpm):	75	75
Temperature (°C):	51	51

* Remarks: Located on south side of Colorado River west of railroad tunnel.

Table 1. Physical Properties and Chemical Analysis of Thermal Waters in Colorado.

Glenwood Springs Area: Spring B*

Location: 39°33'02"N. Latitude; 107°19'04"W. Longitude; T. 6 S., R. 89 W.,

Sec. 10 cb, 6th. P.M., Garfield County

	Date Sampled			
	7/75	10/75	1/76	4/76
Arsenic (As), (UG/L):	0	1	-	-
Boron (B), (UG/L):	760	830	840	840
Cadium (Cd), (UG/L):	0	0	-	-
Calcium (Ca), (MG/L):	450	490	49	360
Chloride (Cl), (MG/L):	9,900	9,800	9,500	9,500
Fluoride (F), (MG/L):	2.1	2.3	2.1	2.1
Iron (Fe), (UG/L):	30	60	30	40
Lithium (Li), (UG/L):	800	860	-	-
Magnesium (Mg), (MG/L):	86	79	76	86
Manganese (Mn), (UG/L):	70	70	70	60
Mercury (Hg), (UG/L):	0	0	-	-
Nitrogen (N), (MG/L):	0.02	0.18	0.01	0
Phosphate (PO_4)				
Ortho diss. as P, (MG/L):	0.01	0.03	0.04	0.04
Ortho, (MG/L):	0.03	0.09	0.12	0.12
Potassium (K), (MG/L):	170	160	190	170
Selenium (Se), (UG/L):	0	0	-	-
Silica (SiO_2), (MG/L):	30	27	28	28
Sodium (Na), (MG/L):	6,300	6,400	6,500	6,300
Sulfate (SO_4), (MG/L):	1,000	1,100	1,000	990
Zinc (Zn), (UG/L):	20	20	-	-
Alkalinity				
As Calcium Carbonate, (MG/L):	613	617	614	612
As Bicarbonate, (MG/L):	747	752	749	746
Hardness				
Noncarbonate, (MG/L):	870	930	0	640
Total, (MG/L):	1,500	1,600	440	1,300
Specific conductance (Micromohs):	35,000	31,000	29,100	29,700
Total dissolved solids (TDS), (MG/L):	18,300	18,400	17,700	17,800
pH, Field	6.5	7.0	6.7	7.0
Discharge (gpm):	75	75	100	110
Temperature (°C):	51	50	51	51

* Remarks: Located on south side of Colorado River 27 feet west of siphon.

Table 1. Physical Properties and Chemical Analysis of Thermal Waters in Colorado

Glenwood Springs Area: Spring D*

Location: 39°33'05"N. Latitude; 107°19'00"W. Longitude; T. 6 S., R. 89 W.,

Sec. 10 cb, 6th. P.M., Garfield County

	Date Sampled
	7/75
Arsenic (As), (UG/L):	0
Boron (B), (UG/L):	810
Cadium (Cd), (UG/L):	0
Calcium (Ca), (MG/L):	450
Chloride (Cl), (MG/L):	9,800
Fluoride (F), (MG/L):	2.1
Iron (Fe), (UG/L):	30
Lithium (Li), (UG/L):	800
Magnesium (Mg), (MG/L):	82
Manganese (Mn), (UG/L):	70
Mercury (Hg), (UG/L):	0
Nitrogen (N), (MG/L):	0.01
Phosphate (PO_4)	
Ortho diss. as P, (MG/L):	0.03
Ortho, (MG/L):	0.09
Potassium (K), (MG/L):	160
Selenium (Se), (UG/L):	0
Silica (SiO_2), (MG/L):	30
Sodium (Na), (MG/L):	89
Sulfate (SO_4), (MG/L):	1,000
Zinc (Zn), (UG/L):	10
Alkalinity	
As Calcium Carbonate, (MG/L):	611
As Bicarbonate, (MG/L):	745
Hardness	
Noncarbonate, (MG/L):	850
Total, (MG/L):	1,500
Specific conductance (Micromohs):	36,000
Total dissolved solids (TDS), (MG/L):	18,000
pH, Field	6.4
Discharge (gpm):	74
Temperature (°C):	50

* Remarks: Located on south side of Colorado River, 225 feet east of siphon.

Table 1. Physical Properties and Chemical Analysis of Thermal Waters in Colorado.

Glenwood Springs Area: Vapor Caves, Mens Hot Spring

Location: 39°32'59"N. Latitude; 107°19'17"W. Longitude; T. 6 S., R. 89 W., Sec. 9 ad, 6th. P.M., Garfield County

	Date Sampled
	9/75
Arsenic (As), (UG/L):	1
Boron (B), (UG/L):	870
Cadium (Cd), (UG/L):	0
Calcium (Ca), (MG/L):	440
Chloride (Cl), (MG/L):	9,600
Fluoride (F), (MG/L):	1.9
Iron (Fe), (UG/L):	80
Lithium (Li), (UG/L):	670
Magnesium (Mg), (MG/L):	40
Manganese (Mn), (UG/L):	70
Mercury (Hg), (UG/L):	0
Nitrogen (N), (MG/L):	0.01
Phosphate (PO_4)	
Ortho diss. as P, (MG/L):	0.03
Ortho, (MG/L):	0.09
Potassium (K), (MG/L):	150
Selenium (Se), (UG/L):	0
Silica (SiO_2), (MG/L):	28
Sodium (Na), (MG/L):	6,300
Sulfate (SO_4), (MG/L):	1,100
Zinc (Zn), (UG/L):	20
Alkalinity	
As Calcium Carbonate, (MG/L):	610
As Bicarbonate, (MG/L):	744
Hardness	
Noncarbonate, (MG/L):	650
Total, (MG/L):	1,300
Specific conductance (Micromohs):	31,000
Total dissolved solids (TDS), (MG/L):	18,000
pH, Field	6.7
Discharge (gpm):	5E
Temperature (°C):	50

Remarks: Located on north side of Colorado River.

Table 1. Physical Properties and Chemical Analysis of Thermal Waters in Colorado.

Glenwood Springs Area: Graves Spring

Location: 39°33'14"N. Latitude; 107°20'08"W. Longitude; T. 6 S., R. 89 W.,

Sec. 9 bb, 6th. P.M., Garfield County

	Date Sampled
	9/75
Arsenic (As), (UG/L):	0
Boron (B), (UG/L):	1,000
Cadium (Cd), (UG/L):	0
Calcium (Ca), (MG/L):	770
Chloride (Cl), (MG/L):	11,000
Fluoride (F), (MG/L):	2.9
Iron (Fe), (UG/L):	70
Lithium (Li), (UG/L):	690
Magnesium (Mg), (MG/L):	150
Manganese (Mn), (UG/L):	50
Mercury (Hg), (UG/L):	0
Nitrogen (N), (MG/L):	0.04
Phosphate (PO_4)	
Ortho diss. as P, (MG/L):	0.05
Ortho, (MG/L):	0.15
Potassium (K), (MG/L):	180
Selenium (Se), (UG/L):	0
Silica (SiO_2), (MG/L):	32
Sodium (Na), MG/L):	7,000
Sulfate (SO_4), (MG/L):	2,000
Zinc (Zn), (UG/L):	20
Alkalinity	
As Calcium Carbonate, (MG/L):	610
As Bicarbonate, (MG/L):	744
Hardness	
Noncarbonate, (MG/L):	1,900
Total, (MG/L):	2,500
Specific conductance (Micromohs):	33,500
Total dissolved solids (TDS), (MG/L):	21,500
pH, Field	7.0
Discharge (gpm):	5
Temperature (°C):	46

Remarks: Located at 0281 164 Road in Glenwood Springs.

Table 1. Physical Properties and Chemical Analysis of Thermal Waters in Colorado.

Glenwood Springs Area: Spring A*

Location: 39°32'58"N. Latitude; 107°19'10"W. Longitude; T. 6 S., R. 89 W.,

Sec. 9 bb, 6th. P.M., Garfield County

	Date Sampled
	7/75
Arsenic (As), (UG/L):	0
Boron (B), (UG/L):	800
Cadium (Cd), (UG/L):	0
Calcium (Ca), (MG/L):	410
Chloride (Cl), (MG/L):	9,600
Fluoride (F), (MG/L):	2.2
Iron (Fe), (UG/L):	40
Lithium (Li), (UG/L):	730
Magnesium (Mg), (MG/L):	88
Manganese (Mn), (UG/L):	70
Mercury (Hg), (UG/L):	0
Nitrogen (N), (MG/L):	0.01
Phosphate (PO_4)	
Ortho diss. as P, (MG/L):	0.03
Ortho, (MG/L):	0.09
Potassium (K), (MG/L):	160
Selenium (Se), (UG/L):	0
Silica (SiO_2), (MG/L):	30
Sodium (Na), (MG/L):	6,000
Sulfate (SO_4), (MG/L):	980
Zinc (Zn), (UG/L):	20
Alkalinity	
As Calcium Carbonate, (MG/L):	604
As Bicarbonate, (MG/L):	736
Hardness	
Noncarbonate, (MG/L):	780
Total, (MG/L):	1,400
Specific conductance (Micromohs):	31,000
Total dissolved solids (TDS), (MG/L):	17,600
pH, Field	6.3
Discharge (gpm):	2-3E
Temperature (°C):	44

* Remarks: Located on south side of Colorado River, 480 feet west of siphon.

Table 1. Physical Properties and Chemical Analysis of Thermal Waters in Colorado.

Glenwood Springs Area: Spring C

Location: 39°32'02"N. Latitude; 107°19'02"W. Longitude; T. 6 S., R. 89 W.,

Sec. 10 cb, 6th. P.M., Garfield County

Temperature: 46°C

Discharge: 2-3 gpm

Specific conductance:--

Remarks: Located 170 feet east of siphon pipe on south side of Colorado River.

Table 1. Physical Properties and Chemical Analysis of Thermal Waters in Colorado.

Glenwood Springs Area: Drinking Spring

Location: 39°32'59"N. Latitude; 107°19'19"W. Longitude; T. 6 S., R. 89 W.,

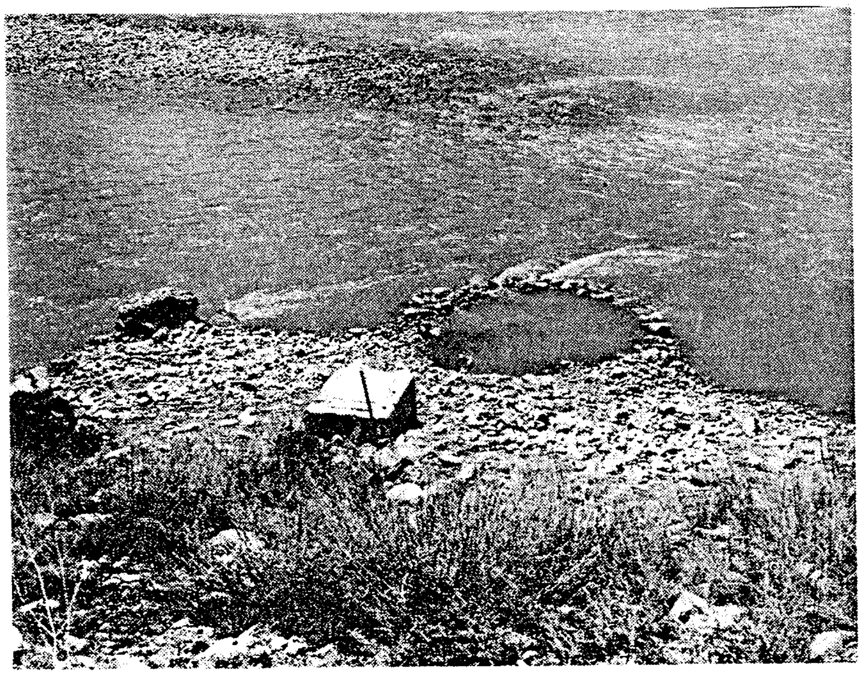
Sec. 9 ad, 6th. P.M., Garfield County

	Date Sampled			
	7/75	10/75	1/76	4/76
Arsenic (As), (UG/L):	1	1	-	-
Boron (B), (UG/L):	910	880	920	870
Cadium (Cd), (UG/L):	0	0	-	-
Calcium (Ca), (MG/L):	510	530	500	480
Chloride (Cl), (MG/L):	11,000	11,000	11,000	10,000
Fluoride (F), (MG/L):	2.3	2.0	2.7	2.2
Iron (Fe), (UG/L):	20	150	20	40
Lithium (Li), (UG/L):	810	900	-	-
Magnesium (Mg), (MG/L):	90	88	82	15
Manganese (Mn), (UG/L):	80	90	70	60
Mercury (Hg), (UG/L):	0	0	-	-
Nitrogen (N), (MG/L):	0.01	0	0.01	0.01
Phosphate (PO_4)				
Ortho diss. as P, (MG/L):	0.03	0.05	0.06	0.05
Ortho, (MG/L):	0.09	0.15	0.18	0.15
Potassium (K), (MG/L):	180	170	380	180
Selenium (Se), (UG/L):	0	0	-	-
Silica (SiO_2), (MG/L):	32	29	30	30
Sodium (Na), (MG/L):	7,000	6,900	7,000	6,600
Sulfate (SO_4), (MG/L):	1,100	1,100	1,100	1,100
Zinc (Zn), (UG/L):	20	10	-	-
Alkalinity				
As Calcium Carbonate, (MG/L):	638	637	634	633
As Bicarbonate, (MG/L):	778	777	773	772
Hardness				
Noncarbonate, (MG/L):	1,000	1,000	950	630
Total, (MG/L):	1,600	1,700	1,600	1,300
Specific conductance (Micromohs):	36,800	30,100	31,100	30,000
Total dissolved solids (TDS), (MG/L):	20,300	20,200	20,500	18,800
pH, Field	6.3	6.5	6.4	6.4
Discharge (gpm):	-	-	161	140
Temperature (°C):	50	50	51	51

Remarks: Located approximately 100 feet east of pool.

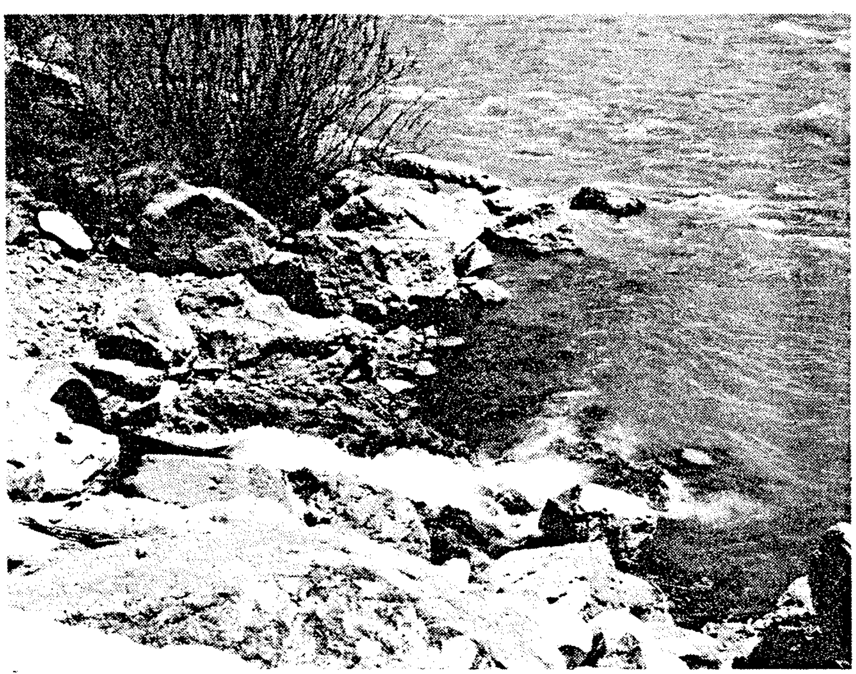
APPENDIX C

A Photographic Record of
the Geothermal Energy Study for
Heating Highway Structures



Glen 100

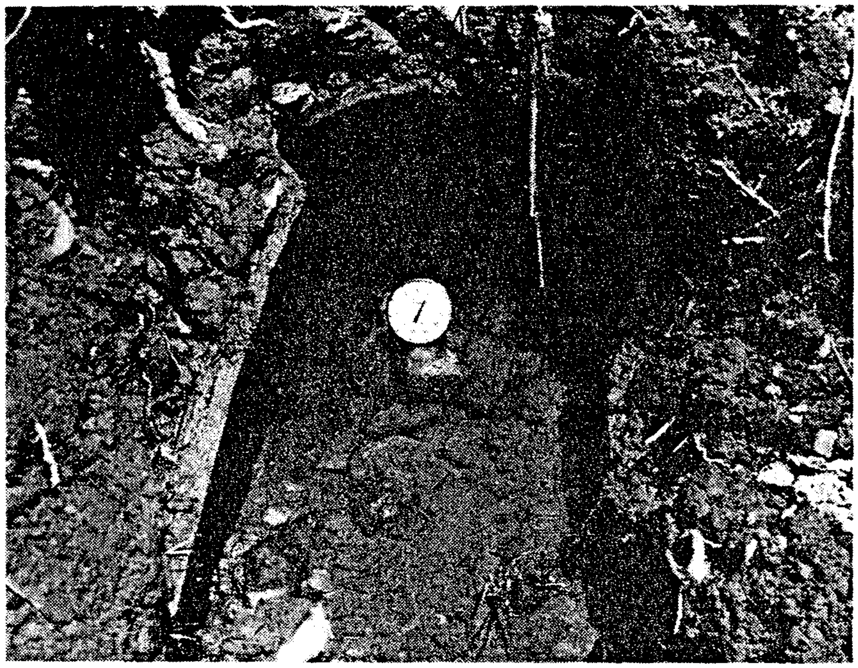
This is the old Gamba Hot Spring which flows 124 gpm at 102°F.



Glen 70

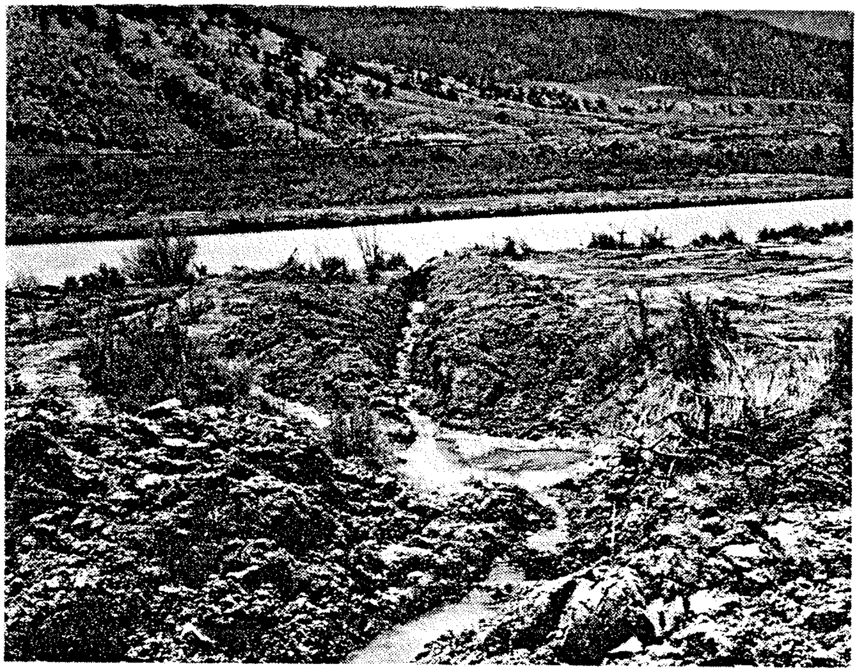
The pool outlet flows 1480 gpm at 80°F.

Roll 340



DOT 6
80°F

DOT 6 and Drainage Ditch



Drainage Ditch from DOT 6

All of the seep waters from the area of DOT 5 and 6 near Dotsero were drained here as part of the construction of I 70.

DOT 20 and 30

These springs emerge from under the highway embankment near Dotsero. They emit 500 to 800 gpm at 88°F.

GEOTHERMAL STUDY

AERIAL SURVEY

March 10, 1979

DOTSERO

DOT 9

DOT 10

These springs are across the river from DOT 20, 30, and 40 and flow 1000 gpm at 89°F.

DOT 9 and 10

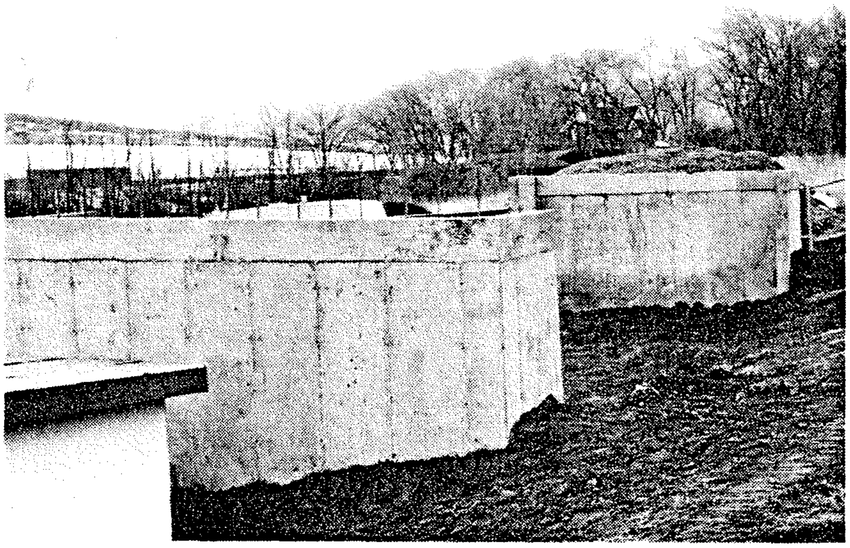
GEOTHERMAL STUDY

SURFACE EXPLORATION

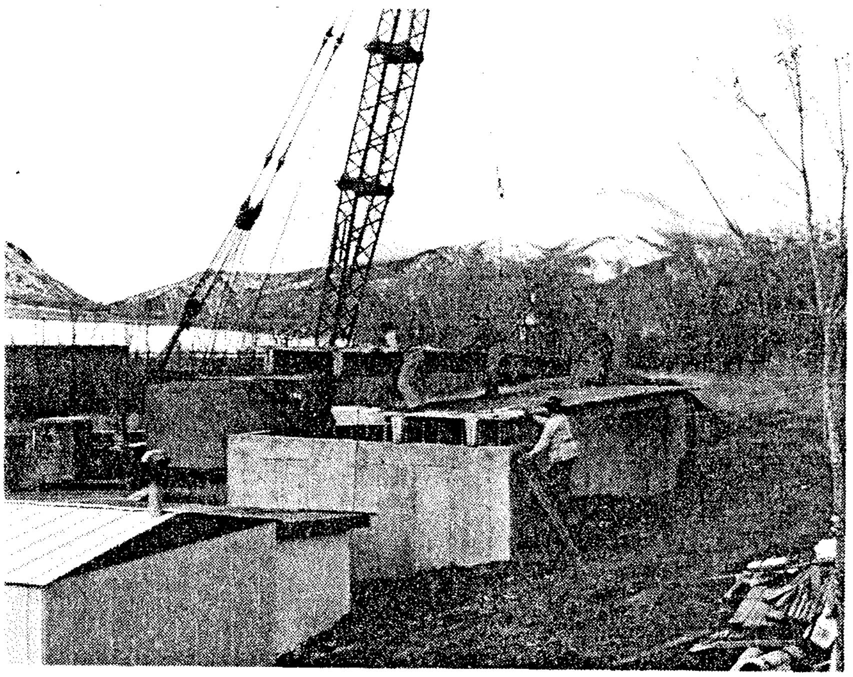
April 5, 1979

WATER ON ROCK OUTCROP 50^{o} AND MELTING DURING STORM AND BLOWING SNOW

A PHOTO RECORD OF THE CONSTRUCTION OF A GEOTHERMALLY HEATED PROTOTYPE BRIDGE IN THE HIGHWAY DEPARTMENT YARD IN GLENWOOD SPRINGS, COLORADO

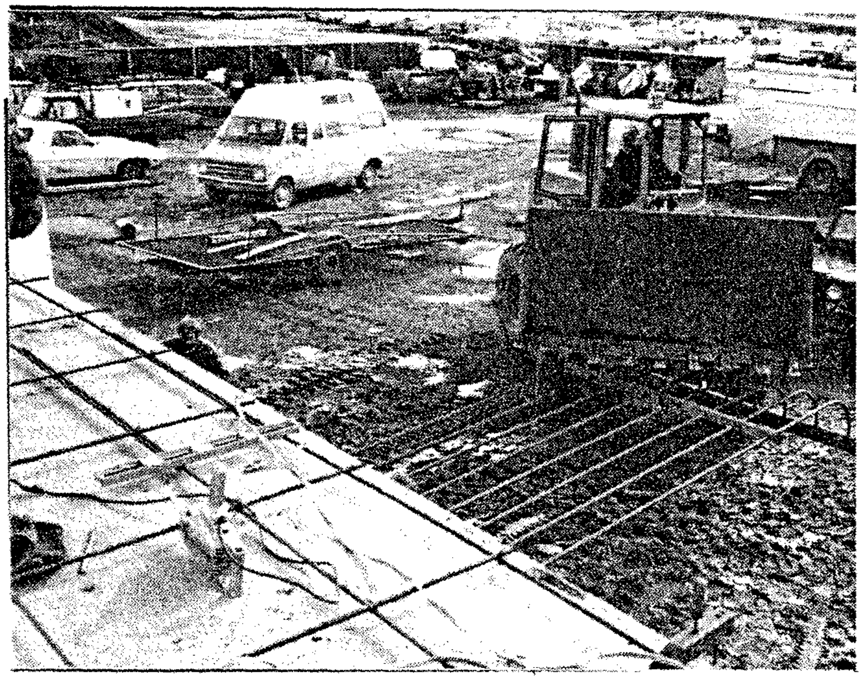


Footings and bearing walls were constructed to hold the structure high enough for air circulation and to simulate a bridge.



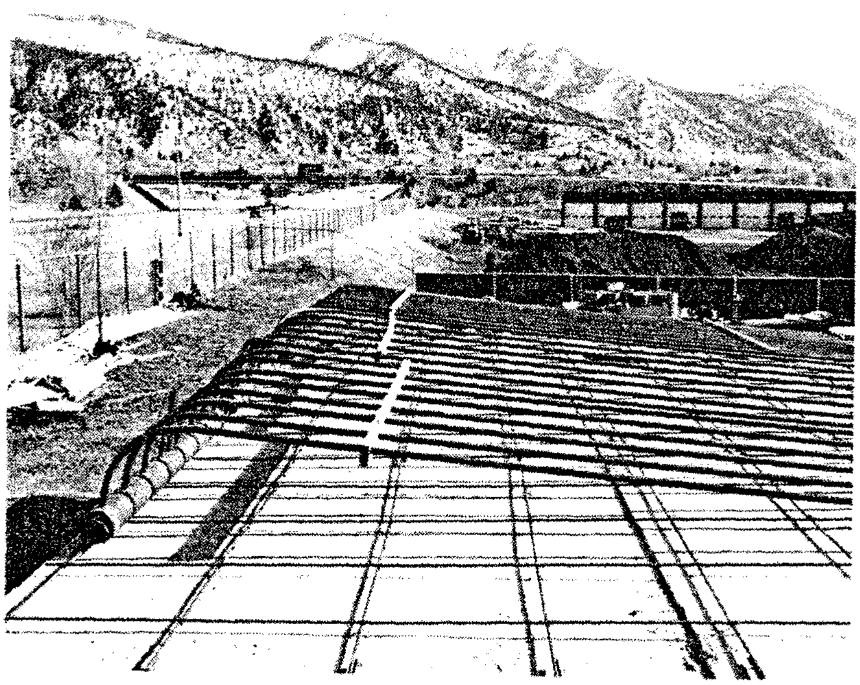
Twin tee beams were set on the walls to form a 50' by 16' deck.

A PHOTO RECORD OF THE CONSTRUCTION OF A GEOTHERMALLY HEATED PROTOTYPE BRIDGE IN THE HIGHWAY DEPARTMENT YARD IN GLENWOOD SPRINGS, COLORADO



Three sets of prefabricated heat pipes were shipped from Laramie, Wyoming.

The 8' x 16' sections weigh about 600 lbs. each. They were lifted up onto the bridge with a front-end loader.

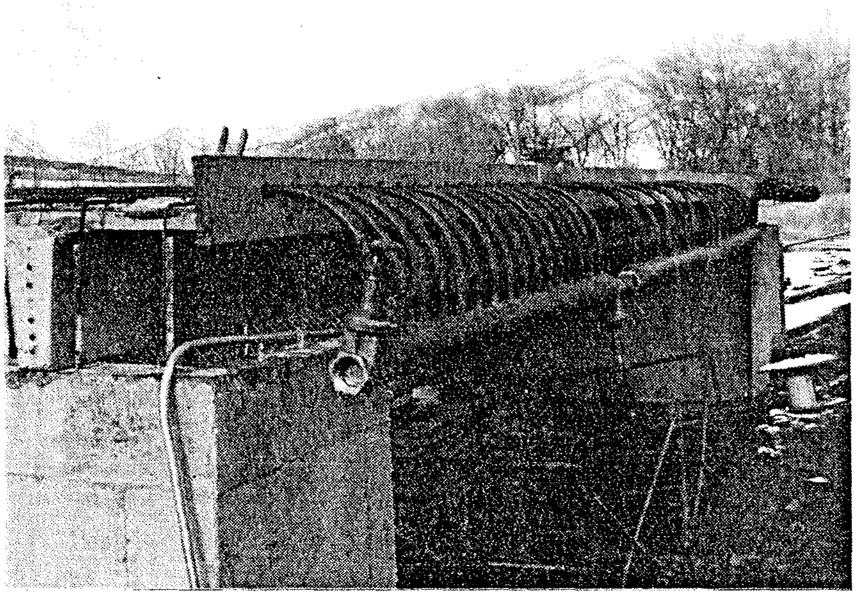


Three eight-foot sections were set up with spacing of 6", 18", and 12" respectively.

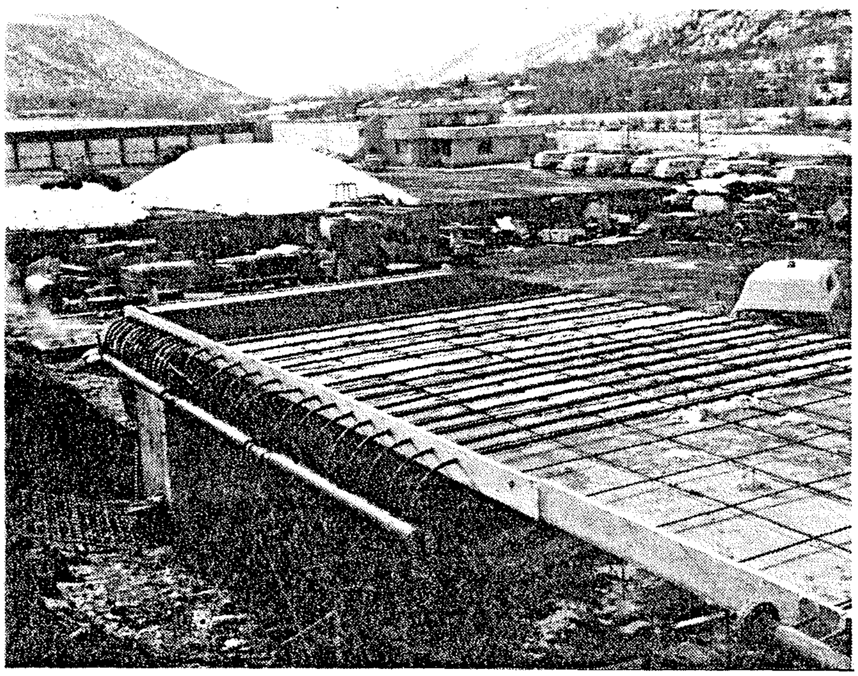
Each section had been evacuated and backfilled with ammonia.

The geothermal water will flow through the inside 3" pipe on the left, which forms the header.

A PHOTO RECORD OF THE CONSTRUCTION OF A GEOTHERMALLY HEATED PROTOTYPE BRIDGE IN THE HIGHWAY DEPARTMENT YARD IN GLENWOOD SPRINGS, COLORADO



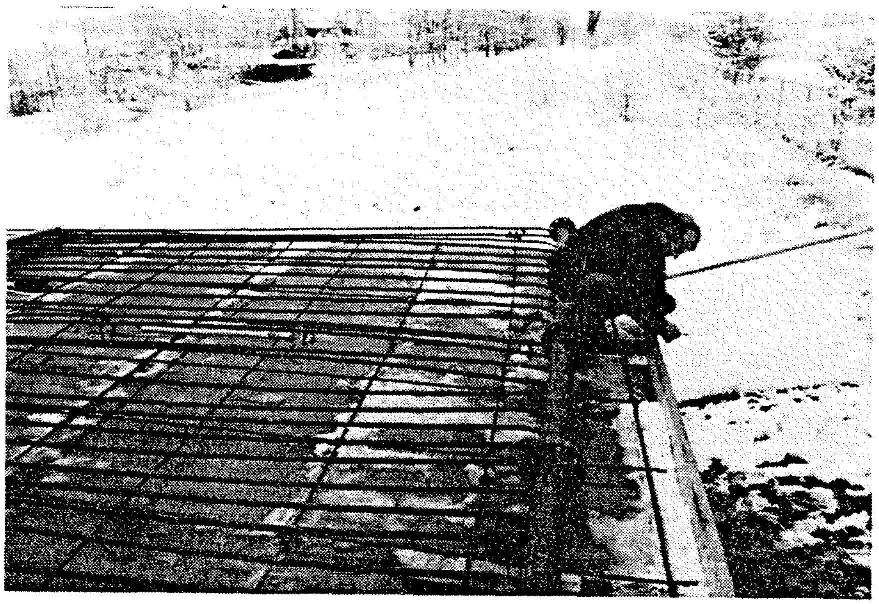
2 x 12s were drilled to fit the pipes and serve as forms for the 6" concrete deck topping which was poured later.



These pipes were tied to the #4 steel.

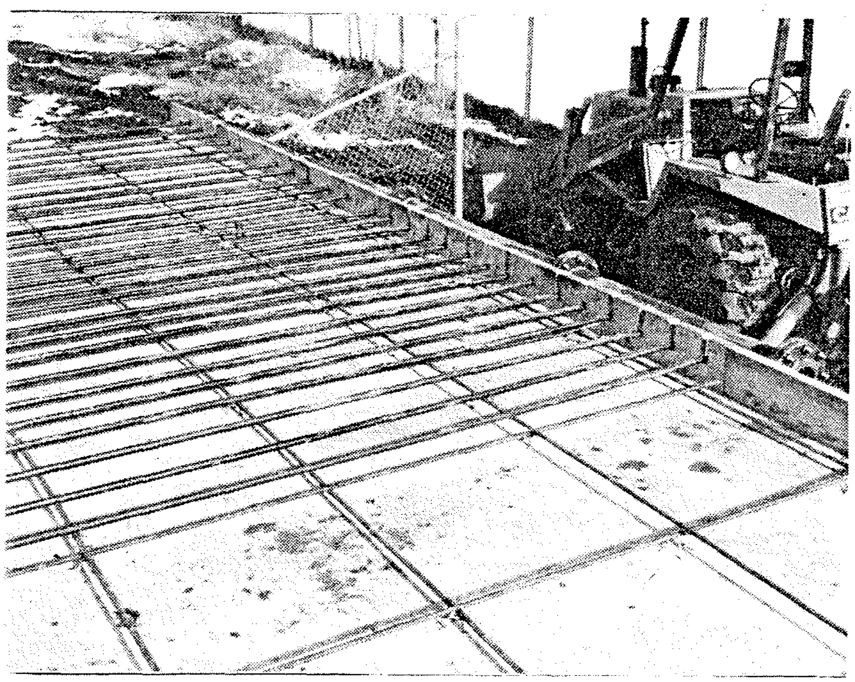
The headers were connected together with pipe unions.

A PHOTO RECORD OF THE CONSTRUCTION OF A GEOTHERMALLY HEATED PROTOTYPE BRIDGE IN THE HIGHWAY DEPARTMENT YARD IN GLENWOOD SPRINGS, COLORADO



Heat pipes from New Mexico were delivered in 4' x 16' sections but had to be assembled in a 16' x 16' unit and then placed on the deck.

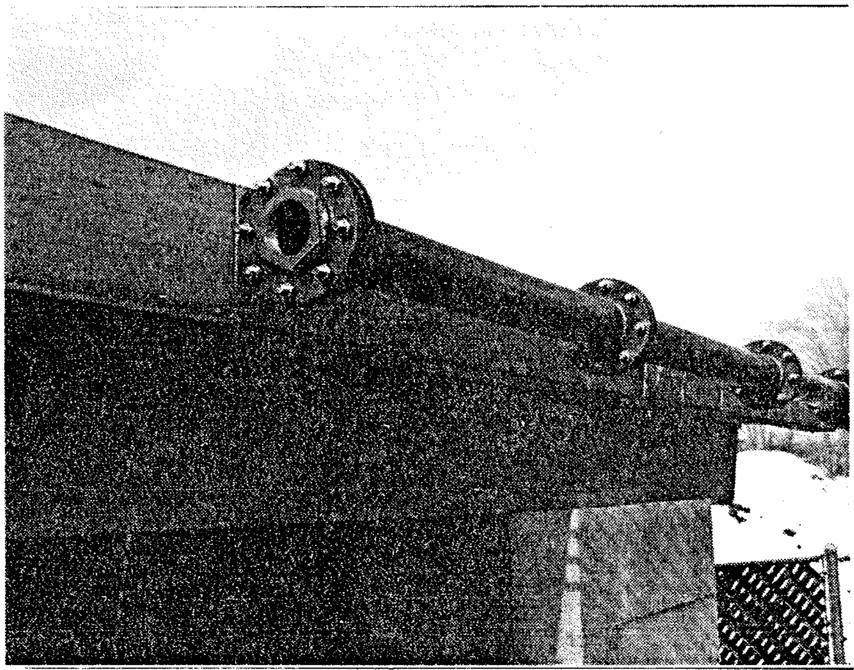
These pipes are spaced 6" and 9" respectively. After some testing at this spacing, every other pipe will be disabled providing a 12" and 18" spacing.



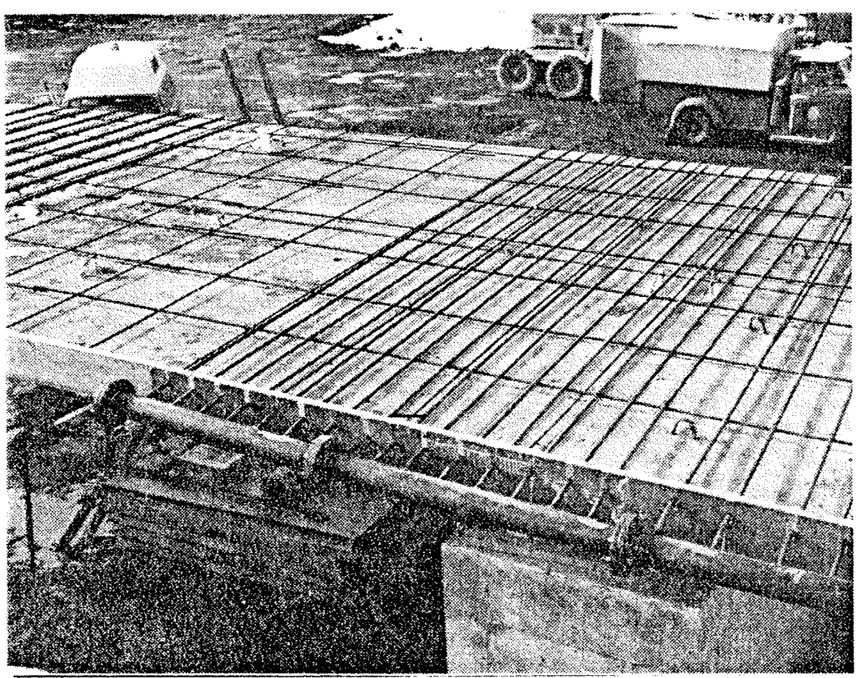
The forms were slotted to drop the pipes in place. These pipes were also tied to the reinforcing steel.

Wooden blocks were replaced to complete the form.

A PHOTO RECORD OF THE CONSTRUCTION OF A GEOTHERMALLY HEATED PROTOTYPE BRIDGE IN THE HIGHWAY DEPARTMENT YARD IN GLENWOOD SPRINGS, COLORADO



These header pipes were connected with flanges and end caps welded on to fit our three-inch plumbing.



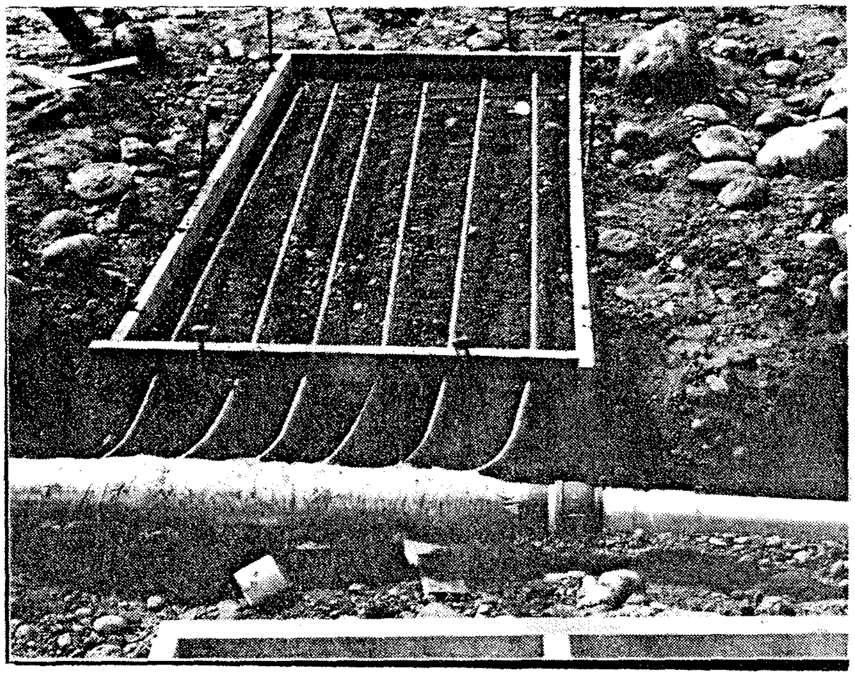
A center section about 9 feet wide was left without heat pipes which provides a standard for comparison.

Wyoming pipes, left.

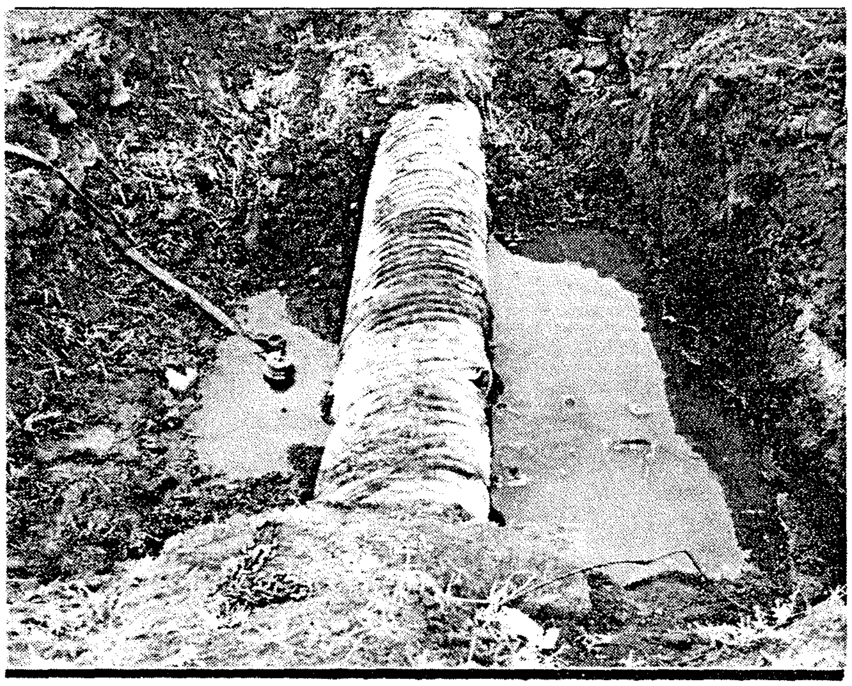
Standard, center.

New Mexico pipes, right.

A PHOTO RECORD OF THE CONSTRUCTION OF A GEOTHERMALLY HEATED PROTOTYPE BRIDGE IN THE HIGHWAY DEPARTMENT YARD IN GLENWOOD SPRINGS, COLORADO



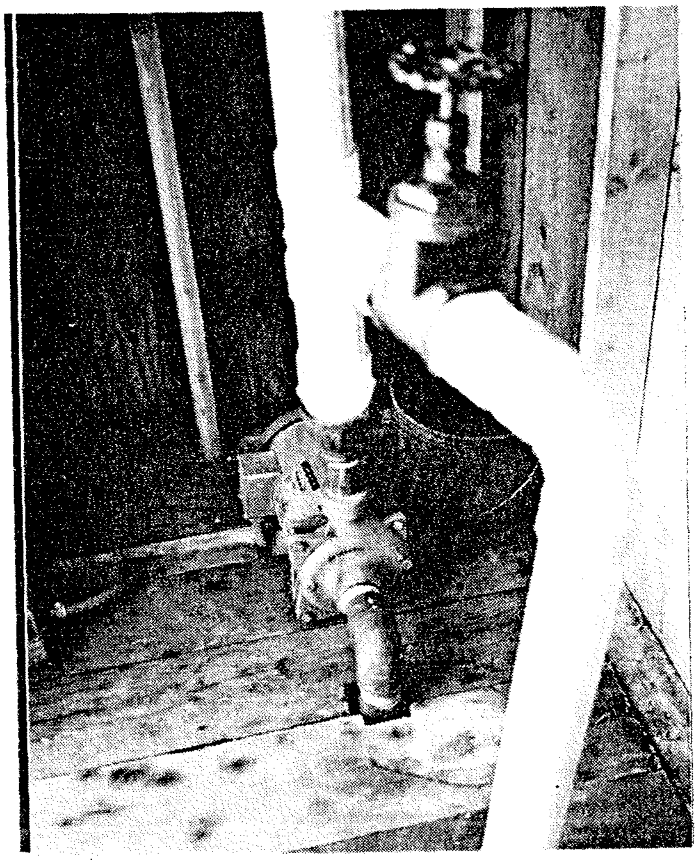
Another small set of heat pipes were made to heat the concrete floor of a 4' x 8' instrument shelter.



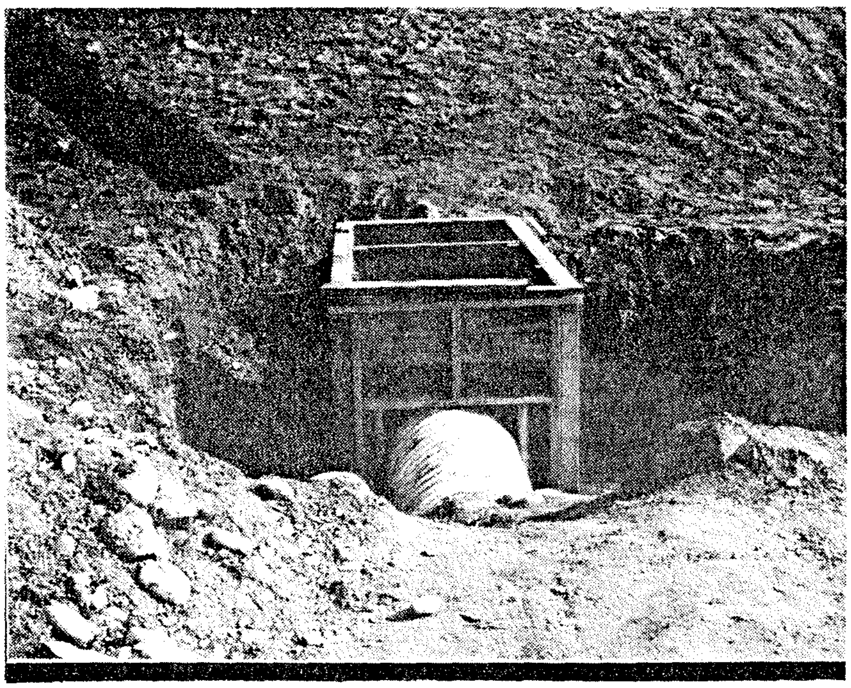
The 24" aluminum culvert which drains geothermal water away from the freeway, through the DOH yard.

This pipe was later cut and a pump house built to provide 150 gallons per minute of 78°F water to heat the bridge.

A PHOTO RECORD OF THE CONSTRUCTION OF A GEOTHERMALLY HEATED PROTOTYPE BRIDGE IN THE HIGHWAY DEPARTMENT YARD IN GLENWOOD SPRINGS, COLORADO

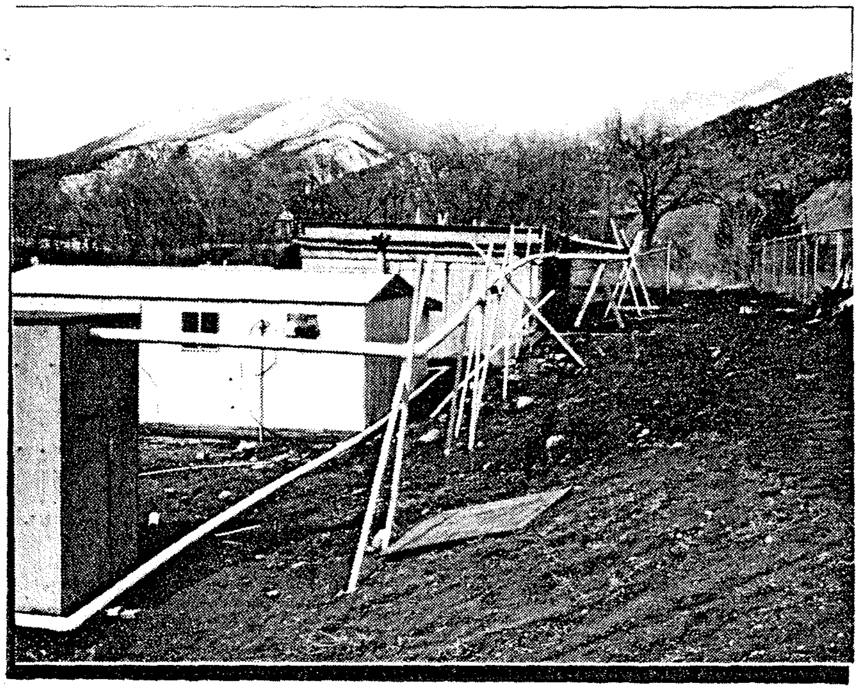


A 2 H.P. Worthington Pump circulates 150 GPM of 79 F geothermal fluid through 3" PVC Pipe.

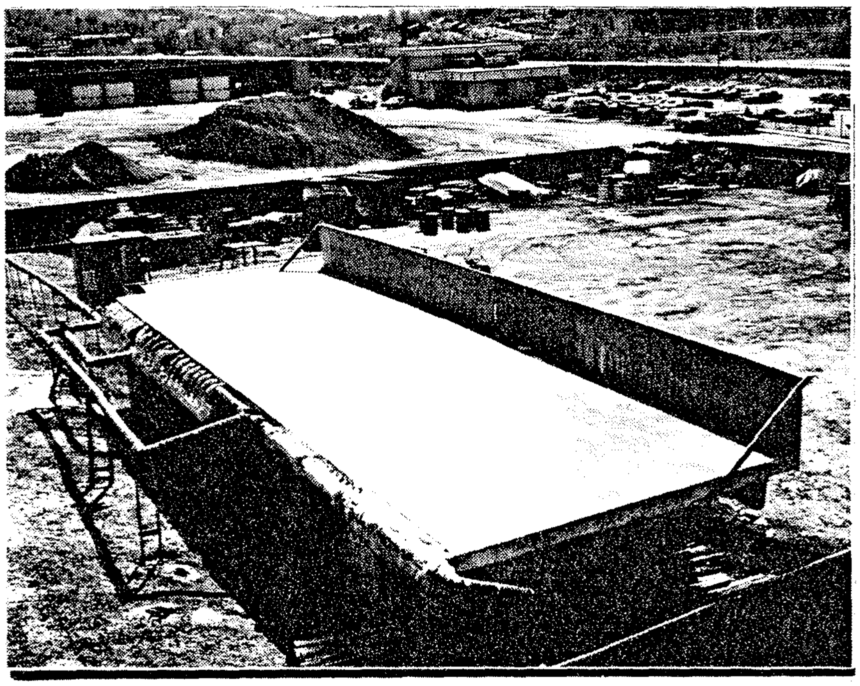


The pipe was cut and a redwood box built to hold water to be pumped.

A PHOTO RECORD OF THE CONSTRUCTION OF A GEOTHERMALLY HEATED PROTOTYPE BRIDGE IN THE HIGHWAY DEPARTMENT YARD IN GLENWOOD SPRINGS, COLORADO

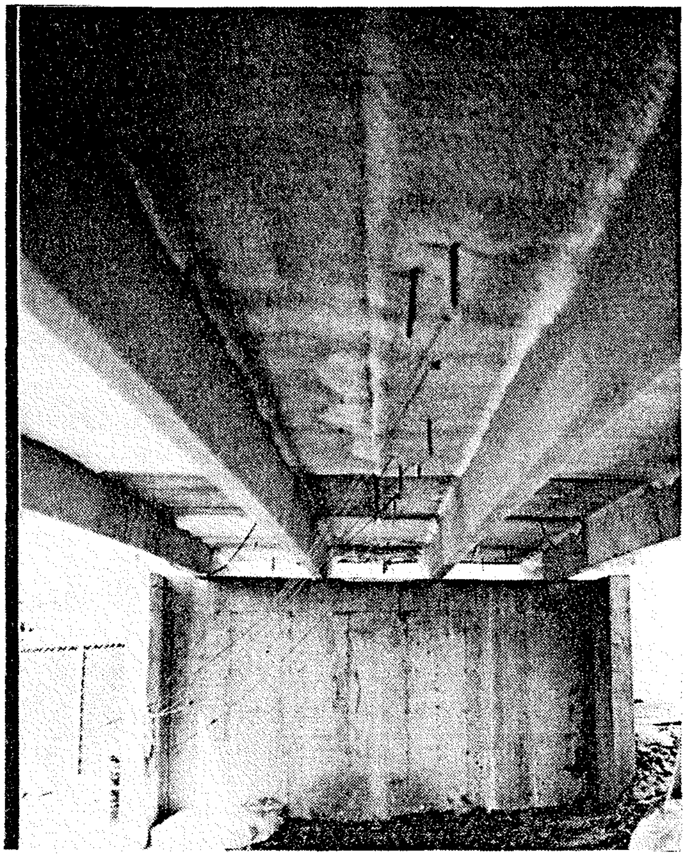


The three inch water line from the pump house to the bridge.

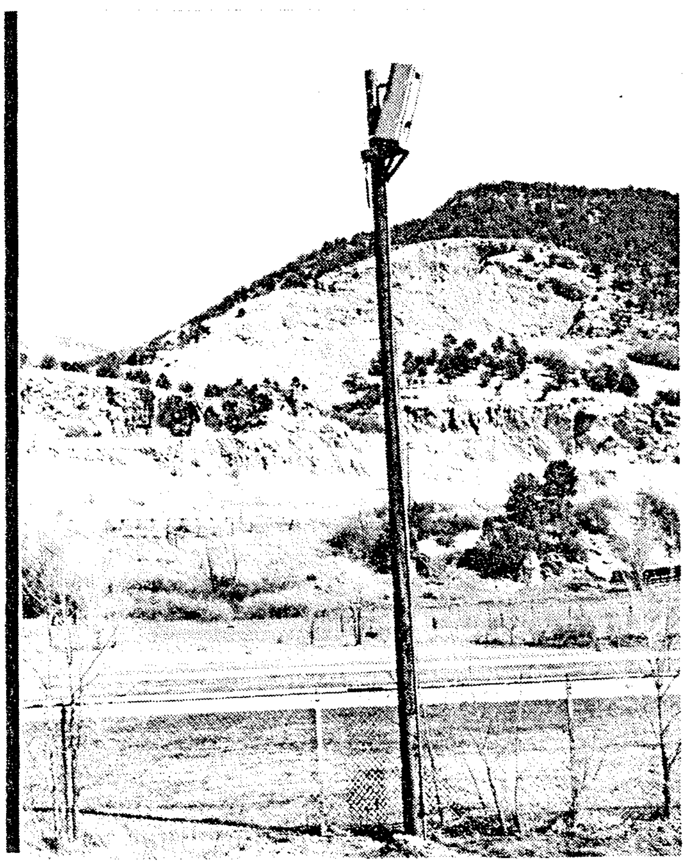


This view, as the structure appears to the time lapse camera mounted atop a utility pole, shows the 6 test sections and the simulated jersey barrier. The entire deck was painted black to resemble an asphalt surface.

A PHOTO RECORD OF THE CONSTRUCTION OF A GEOTHERMALLY HEATED PROTOTYPE BRIDGE IN THE HIGHWAY DEPARTMENT YARD IN GLENWOOD SPRINGS, COLORADO



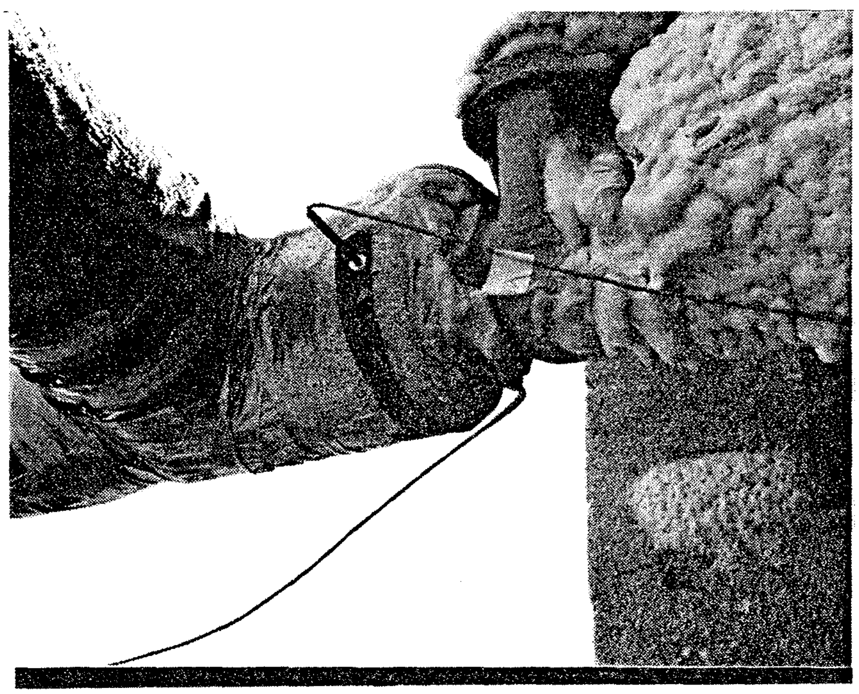
The entire bottom surface except the control section. Received a 2" coating of S7YRO Foam. Note lead wires to temperature probes.



To get a visual record of snow accumulation, a super-8 camera was weather-proofed and mounted atop a 30' pole directly north of the structure. Up to 25 days can be filmed at 10-minute intervals with the aid of an electronic flash and an interval timer on a 50' roll of film.

A PHOTO RECORD OF THE CONSTRUCTION OF A GEOTHERMALLY HEATED PROTOTYPE BRIDGE IN THE HIGHWAY DEPARTMENT YARD IN GLENWOOD SPRINGS, COLORADO

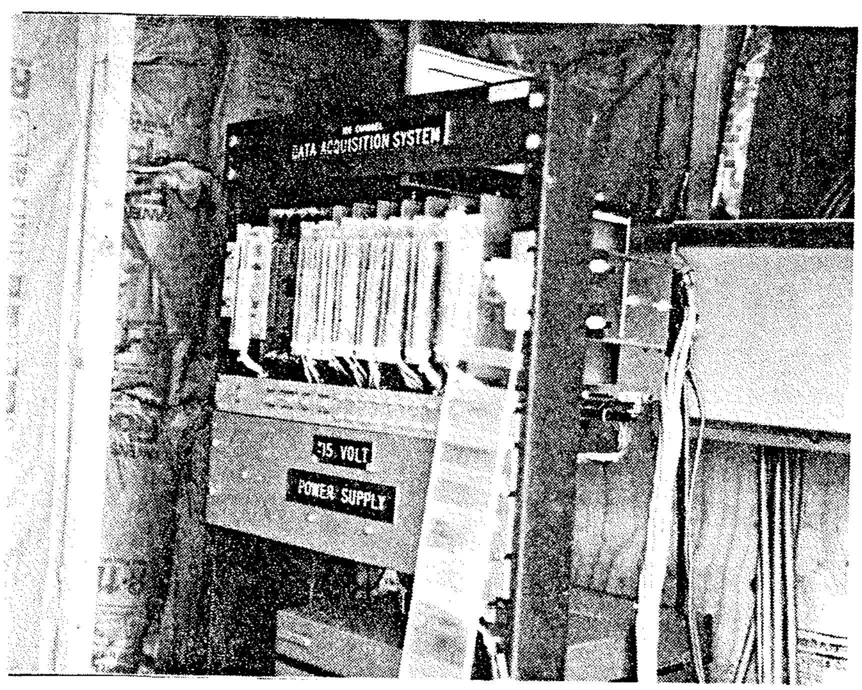
Instrumentation consisted of surface and interior thermistors mounted throughout the deck to monitor the affects of heating the bridge deck.



A series of immersion probes located at various points along the plumbing system monitored changes in temperature of the geothermal medium.

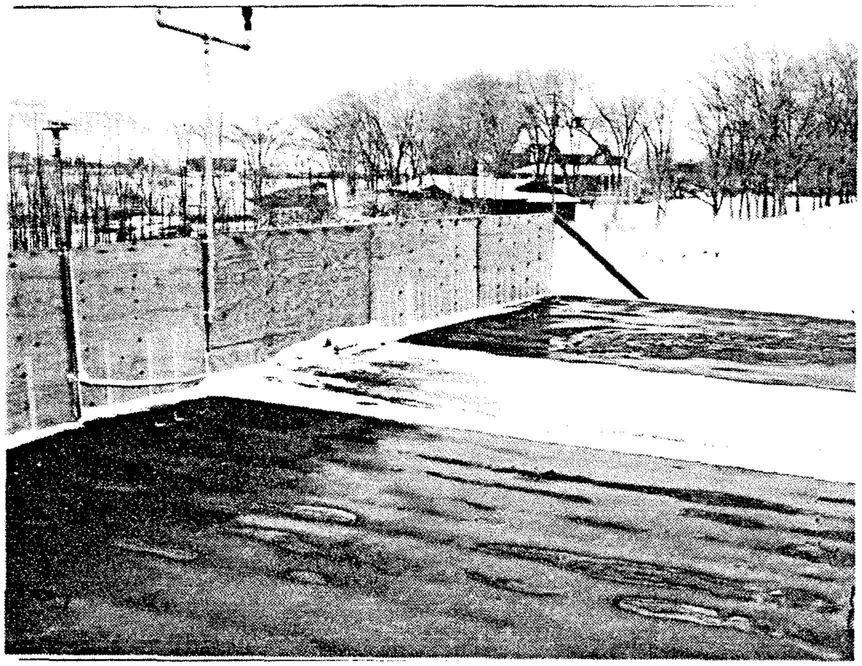
A PHOTO RECORD OF THE CONSTRUCTION OF A GEOTHERMALLY HEATED PROTOTYPE BRIDGE IN THE HIGHWAY DEPARTMENT YARD IN GLENWOOD SPRINGS, COLORADO

Meteorological data consisting of wind speed and direction, solar radiation, relative humidity, ambient temperature, and barometric pressure is also collected.



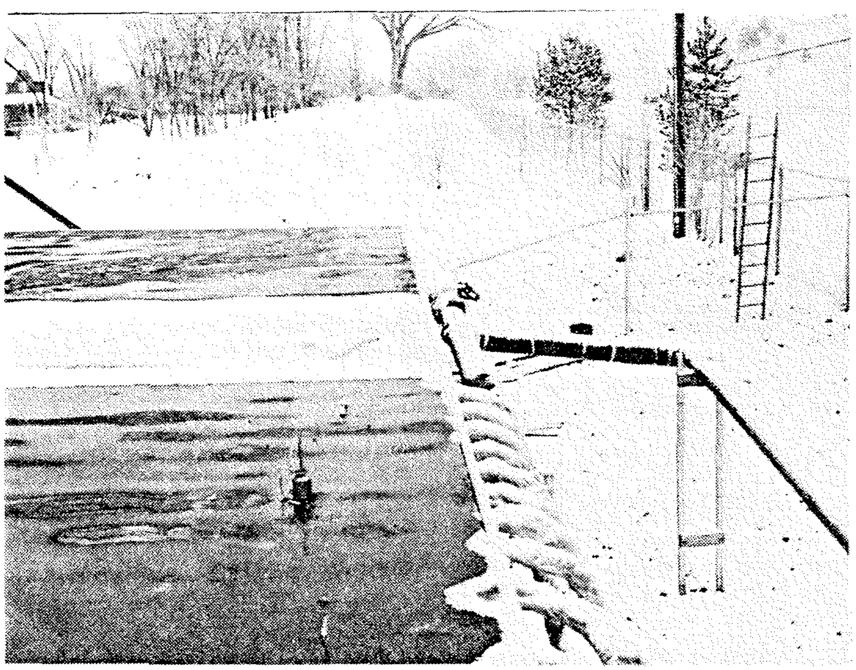
All data is fed into a 100-channel digital recorder and recorded on magnetic tape for later analysis.

A PHOTO RECORD OF THE OPERATION OF A GEOTHERMALLY HEATED PROTOTYPE BRIDGE IN THE HIGHWAY DEPARTMENT YARD IN GLENWOOD SPRINGS, COLORADO



The first ice storm to test the prototype structure occurred on the night of March 30 and the early morning of March 31.

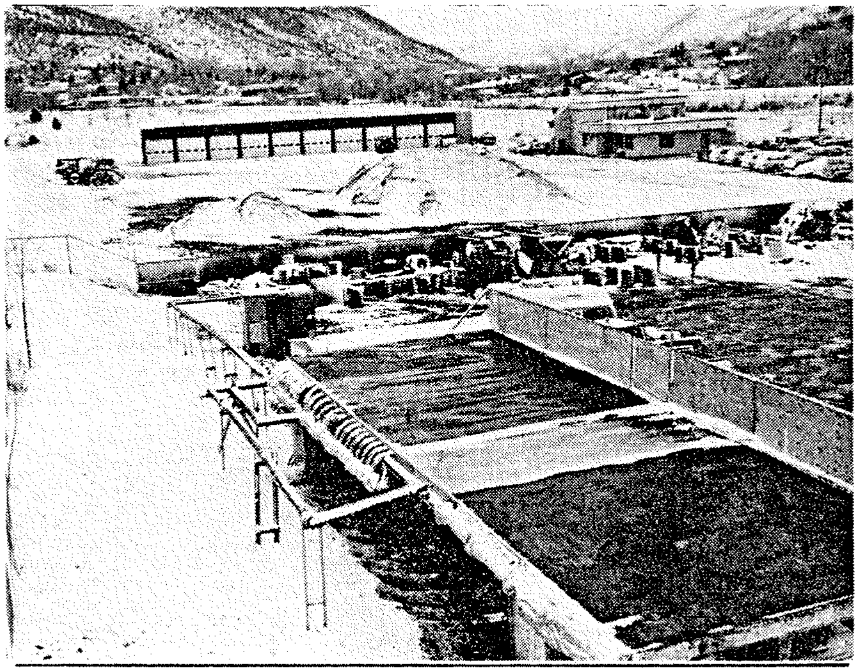
The heated sections of the structure stayed clear throughout the storm.



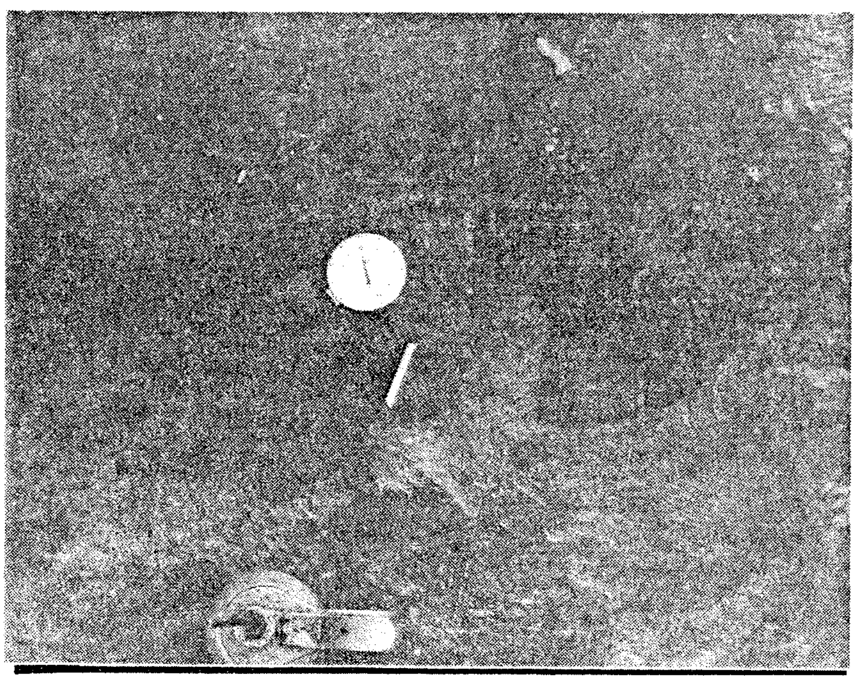
While the standard section and all of the roads and streets were iced over.

There was 3/4" to 1 inch of ice on the untreated section of the structure.

A PHOTO RECORD OF THE OPERATION OF A GEOTHERMALLY HEATED PROTOTYPE BRIDGE IN THE HIGHWAY DEPARTMENT YARD IN GLENWOOD SPRINGS, COLORADO



An overall view of the DOH yard shows ice on the structure and the paved parking lot while the heated sections of the structure were starting to dry off.



This drying occurred by 08:30, by which time the ambient temperature had risen from 20°F to 30°F. The heated deck temperature ranged from 40°F to 60°F.