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ENGINEERING AND ECONOMIC EVALUATION OF
DIRECT HOT-WATER GEOTHERMAL ENERGY
APPLICATIONS ON THE UNIVERSITY
OF NEW MEXICO CAMPUS

Final Technical Report

MASTER

David Kauffman
and
Arthur V. Houghton

December 31, 1980

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The University of New Mexico
Albuquerque, New Mexico

U. S. DEPARTMENT OF ENERGY
Geothermal Energy

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ENGINEERING AND ECONOMIC EVALUATION OF
DIRECT HOT-WATER GEOTHERMAL ENERGY
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FINAL TECHNICAL REPORT

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Arthur V. Houghton

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Albuquerque, New Mexico

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TABLE OF CONTENTS

	<u>Page</u>
Distribution	xiii
Abstract	xiv
Acknowledgements	xv
Project Description and Summary.	1
 I. Data Acquisition and Evaluation	
I.1 Energy and Load Data	9
I.2 Reservoir Data, Known	39
I.3 Reservoir Data, Unknown	47
I.4 Reservoir Model	51
I.5 Scaling and Corrosion	73
I.6 Surface Facilities	96
I.7 Disposal.	104
I.8 Environmental Impact	125
 II. System Synthesis	
II.1 Campus Segment Selection	128
II.2 Air Conditioning Feasibility	137
II.3 Preliminary Designs	148
II.4 Preliminary Costs	162
II.5 Best System Selection	165
 III. System Refinement and Implementation	
III.1 Detailed Design	168
III.2 Final Costs	209
III.3 Overall Economics	212
III.4 Net Energy Ratio	218

TABLE OF CONTENTS
(continued)

	<u>Page</u>
III.5 Institutional Procedures	221
III.6 Overall Environmental and Energy Impacts	226
III.7 Implementation	234
Conclusions	238
Recommendations	240
References.	241
Appendix A: Design Details	A-1
Appendix B: Building Energy Use Model	B-1
Appendix C: Discounted Present Worth Factors	C-1
Appendix D: Reservoir Permeability Estimate	D-1

LIST OF TABLES

<u>Table</u>		<u>Page</u>
I	GEOHERMAL HEATING SYSTEM FEATURES	8
II	TEST BUILDING DATA	10
III	COLLEGE OF EDUCATION HEATING SCHEDULE	15
IV	BUILDING AIR INFILTRATION RATES	21
V	CAMPUS ENERGY USE DISTRIBUTION	22
VI	GENERAL DESCRIPTION OF SUBROUTINES	30
VII	INPUT DATA REQUIREMENTS	32
VIII	TEMPERATURE GRADIENTS FOR WELLS CLOSE TO ALBUQUERQUE . .	45
IX	COEFFICIENT OF PERMEABILITY FOR VARIOUS WELLS IN THE ALBUQUERQUE BASIN	48
X	COEFFICIENTS OF PERMEABILITY FOR CITY WELLS	50
XI	NOMENCLATURE FOR DRAWDOWN EQUATIONS	53
XII	STEADY STATE DRAWDOWN	54
XIII	DRAWDOWN VERSUS TIME, FLOWRATE AND PERMEABILITY AT A RADIUS OF ONE FOOT FROM THE WELL	57
XIV	EXPLOITATION TIME FOR DIFFERENT POROSITIES	67
XV	WATER FLOW COMPARISONS	67
XVI	CHEMICAL QUALITY OF WATER RECOVERED DURING DRILL-STEM AND OTHER TESTS OF THE SHELL OIL CO.	74
XVII	EXPECTED BRINE COMPOSITION	75
XVIII	SYNTHETIC BRINES	80
XIX	MATERIALS OF CONSTRUCTION	82
XX	CORROSION OBSERVATIONS ON SPECIMENS (BRINE I)	83

LIST OF TABLES (continued)

<u>Table</u>		<u>Page</u>
XXI	CORROSION OBSERVATIONS ON SPECIMENS (BRINE II)	84
XXII	SEMIQUANTITATIVE SPECTROGRAPHIC ANALYSIS OF CORROSION PRODUCT SCALE ON CARBON STEEL 1018 TUBULAR SPECIMENS	88
XXIII	CORROSION EXPERIMENT DATA	89
XXIV	CORROSION EXPERIMENT DATA	90
XXV	MAINTENANCE AND LABOR COSTS	105
XXVI	SUMMARY OF THE DISPOSAL POSSIBILITIES	106
XXVII	COST SUMMARY OF PROPOSED FLUID DISPOSAL SYSTEMS	107
XXVIII	AIR POLLUTION REDUCTIONS	125
XXIX	FORD SEGMENT.	130
XXX	NORTH SEGMENT	130
XXXI	COMPUTER SEGMENT	131
XXXII	FIELD SEGMENT	131
XXXIII	REDONDO EAST SEGMENT	133
XXXIV	LITHIUM BROMIDE SYSTEM DATA	141
XXXV	PUMP DATA FOR THE 270 TON SYSTEM	141
XXXVI	PUMP DATA FOR THE 312 TON SYSTEM	141
XXXVII	AIR CONDITIONING COSTS FOR UNM	147
XXXVIII	REVISED SEGMENT TOTALS	149
XXXIX	PRELIMINARY SYSTEM COMPARISONS	161
XL	SEGMENT ECONOMIC COMPARISONS	163
XLI	SEGMENT SELECTION SUMMARY	155
XLII	REDONDO EAST SEGMENT	170

LIST OF TABLES (continued)

<u>Table</u>		<u>Page</u>
XLIII	OUTSIDE AIR TEMPERATURE FREQUENCY	175
XLIV	DESIGN OPERATING CONDITIONS	177
XLV	ESTIMATED ACTUAL OPERATING CONDITIONS	178
XLVI	SECONDARY LOOP DESIGN PROCESS CONDITIONS	190
XLVII	BUILDING HEATING SYSTEMS	194
XLVIII	DOMESTIC HOT WATER SYSTEMS	197
XLIX	EQUIPMENT SUMMARY	205
L	CAPITAL COST ESTIMATE	210
LI	ANNUAL OPERATING COST ESTIMATE	211
LII	ANNUAL UTILITIES USE AND SAVINGS	211
LIII	BASE CASE DISCOUNTED CASH FLOW ANALYSIS	214
LIV	ALTERNATE CASE DISCOUNTED CASE FLOW ANALYSIS	215
LV	NET ENERGY TABULATION	220
LVI	PROGRAM PLAN	222
LVII	IMPLEMENTATION SCHEDULE	235
A-I	BUILDING HEAT LOADS AT 0°F OUTSIDE AIR TEMPERATURE . .	A-3
A-II	BUILDING HEAT LOADS AT 10°F OUTSIDE AIR TEMPERAURE . .	A-4
A-III	BUILDING HEAT LOADS AT 20°F OUTSIDE AIR TEMPERATURE . .	A-5
A-IV	BUILDING HEAT LOADS AT 30°F OUTSIDE AIR TEMPERATURE . .	A-6
A-V	BUILDING HEAT LOADS AT 40°F OUTSIDE AIR TEMPERATURE . .	A-7
A-VI	BUILDING HEAT LOADS AT 50°F OUTSIDE AIR TEMPERATURE . .	A-8
A-VII	BUILDING HEAT LOADS AT 60°F OUTSIDE AIR TEMPERATURE . .	A-9

LIST OF TABLES (continued)

<u>Table</u>		<u>Page</u>
B-I	VALUES OF d, ET, A, B AND C	B-5
B-II	TIME ZONE NUMBERS IN U.S. FOR STANDARD TIME	B-9
B-III	SURFACE ORIENTATIONS AND AZIMUTHS, MEASURED FROM SOUTH	B-12
B-IV	FOURIER COEFFICIENTS	B-14
B-V	POLYNOMIAL COEFFICIENTS FOR USE IN CALCULATION OF TRANSMISSIVITY AND ABSORPTIVITY OF STANDARD 1/8" THICK DOUBLE STRENGTH GLASS	B-15
B-VI	HEAT LOSS BELOW GRADE IN BASEMENT WALLS	B-19
B-VII	HEAT LOSS THROUGH BASEMENT FLOORS	B-20
B-VIII	CLOUD COVER MODIFIER	B-35
B-IX	VALUES FOR CALCULATION OF OUTSIDE HEAT TRANSFER COEFFICIENTS	B-38
D-I	RIO GRANDE BASIN WELL - SONIC LOG DATA	D-3

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Geothermal heating system for UNM.	7
2	Steam load profile for January 22, 1980.	11
3	Daily steam load profile	12
4	Building heating loads, Feb. 12 to April 18, 1980. . . .	13
5	Building heating loads, Apr. 19 to May 23, 1980. . . .	14
6	Heating degree days, 1978-1979 season.	17
7	Energy load distribuion, 1978-1979 season.	18
8	Cumulative energy load distribution, 1978-1979 season. .	19
9	Total load, Feb. 8, 1980 (Friday).	24
10	Total load, Feb. 9, 1980 (Saturday).	25
11	Total load, April 18, 1980 (Friday).	26
12	Total load, April 19, 1980 (Saturday).	27
13	Comparison of weather data	28
14	Interrelationships of computer program subroutines . . .	31
15	Calculated and measured heating loads for Family Practice Center.	34
16a	Wall, ceiling, window, door and basement heat losses . .	35
16b	Infiltration and ventilation heat losses	36
16c	Internal heat sources.	37
17	Heat flow in New Mexico (Reiter, 1974)	42
18	Nearby deep wells (Grant, 1980).	44
19	Water table contours	46
20	A well partially penetrating an unconfined reservoir . .	52
21	A well fully penetrating an unconfined reservoir	52
22	Drawdown versus radial distance from well for $Q_0 =$ 400 gpm and $K = 125 \text{ gpd/ft}^2$	58

LIST OF FIGURES (continued)

<u>Figure</u>		<u>Page</u>
23	Drawdown versus radial distance from well for $Q\tau = 800$ gpm and $K = 125$ gpd/ft ²	59
24	Drawdown versus radial distance from well for $Q\tau = 1200$ gpm and $K = 125$ gpd/ft ²	60
25	Drawdown versus radial distance from well for $Q\tau = 400$ gpm and $K = 23.1$ gpd/ft ²	61
26	Drawdown versus radial distance from well for $Q\tau = 800$ gpm and $K = 23.1$ gpd/ft ²	62
27	Drawdown versus radial distance from well for $Q\tau = 1200$ gpm and $K = 23.1$ gpd/ft ²	63
28	Drawdown versus radial distance from well for $Q\tau = 400$ gpm and $K = 2.31$ gpd/ft ²	64
29	Drawdown versus radial distance from well for $Q\tau = 800$ gpm and $K = 2.31$ gpd/ft ²	65
30	Drawdown versus radial distance from well for $Q\tau = 1200$ gpm and $K = 2.31$ gpd/ft ²	66
31	Hot brine corrosion test loop.	77
32	Corrosion test specimens	85
33	Corrosion test specimens	86
34	Direct heat system surface facilities.	97
35	Indirect heat system surface facilities.	98
36	Average well costs (1980 basis).	99
37	Centrifugal pump costs (1980).	102
38	Perforated height for various pipe diameters with no extra pumping.	118
39	Perforated height for various permeabilities with no extra pumping.	119
40	Typical well with "normal" completion.	121
41	Typical "open hole" completion	122
42	Typical injection well-head.	123

LIST OF FIGURES (continued)

<u>Figure</u>		<u>Page</u>
43	Well-bore and pipeline friction losses	124
44	Utility tunnel system.	129
45	Campus segments selected for study	132
46	Redondo East segment	134
47	Carrier lithium bromide absorption cooler.	136
48	Hourly cooling demand variations for a typical Albuquerque office building (obtained from New Mexico Energy Institute).	139
49	Lithium bromide system	140
50	Average yearly cooling demands for a typical office building (obtained from New Mexico Energy Institute) . .	142
51	Vapor compression cycle.	144
52	Preliminary system schematic	150
53	Typical system for a building with circulating water heating.	151
54	Typical system for a building with circulating air heating.	153
55	Energy cost for various geothermal temperatures.	155
56	Ford segment schematic	156
57	North segment schematic	157
58	Computer segment schematic	158
59	Field segment schematic.	159
60	Redondo East segment schematic	160
61	Approximate equivalent energy costs.	164
62	Redondo East segment	169
63	System block diagram	171
64	Primary loop flow diagram.	172

LIST OF FIGURES (continued)

<u>Figure</u>		<u>Page</u>
65	Secondary loop flow diagram.	173
66	Design process conditions.	179
67	Estimated actual process conditions.	180
68	Process flow temperatures.	181
69	Production well configuration.	182
70	Production pump power requirements	183
71	Primary heat exchangers (limiting case design process conditions).	186
72	Reinjection well configuration	187
73	Secondary loop flow conditions	189
74	Typical circulating water system	195
75	Typical forced-air system.	196
76	Typical domestic hot water system.	199
77	Primary loop controls, supply.	200
78	Primary loop controls, exchangers.	201
79	Secondary loop controls.	202
80	Possible mechanical equipment layout	204
A-1	Schematic for building 58 (Hokona, East and West). . . .	A-11
A-2	Schematic for building 59 (Johnson Gym).	A-14
A-3	Schematic for building 59 (Olympic Pool)	A-15
A-4	Schematic for building 61 (Santa Clara) and 156 (Onate).	A-19
A-5	Schematic for buildings 63, 66, 68, 69 and 70 (Education A, D, F, G and H)	A-21
A-6	Schematic for building 64 (Education B).	A-22
A-7	Schematic for building 65 (Education C).	A-23

LIST OF FIGURES (continued)

<u>Figure</u>		<u>Page</u>
A-8	Schematic for building 67 (Education E).	A-25
A-9	Schematic for buildings 71 and 157 (Santa Ana and Alvarado).	A-28
A-10	Schematic for buildings 74, 75 and 77 (Laguna, DeVargas and La Posada).	A-30
A-11	Schematic for building 155 (Coronado Hall)	A-33
B-1	Solar angles for vertical and horizontal surfaces.	B-4
B-2	Clearness number of non-industrial atmosphere in United States.	B-6
B-3	Ratio of diffuse sky radiation incident upon a vertical surface to that incident upon a horizontal surface during clear days.	B-7
B-4	Time zones in the United States.	B-9
B-5	Latitude, hour angle and sun's declination	B-11
B-6	Heat flow from basement.	B-18
B-7	Lines of constant amplitude.	B-19
B-8	Heat transfer in a typical roof.	B-22
B-9	Unsteady-state conduction in solid slab.	B-22
B-10	Subdivision of a slab.	B-24
B-11	Surface conductance for different 12-inch square surfaces as affected by air movement.	B-37
D-1	Porosity vs Depth for typical basin well	D-4
D-2	Permeability vs porosity (Chilingar, 1963)	D-6

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ABSTRACT

The potential engineering and economic feasibility of low-temperature geothermal energy applications on the campus of the University of New Mexico is studied in detail. This report includes three phases of work: data acquisition and evaluation, system synthesis, and system refinement and implementation.

Detailed process designs are presented for a system using 190°F geothermal water to substitute for the use of 135×10^9 Btu/yr (141 TJ/yr) of fossil fuels to provide space and domestic hot water heating for approximately 23 percent of the campus. Specific areas covered in the report include economic evaluation, environmental impact and program implementation plans.

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PROJECT DESCRIPTION AND SUMMARY OF RESULTS

Rapid and timely development of direct geothermal energy requires not only exploration to identify resources, but also detailed engineering and economic feasibility studies to determine how best to use those resources. This program is evaluating the technical, economic, and institutional feasibility of using direct geothermal energy for space heating, hot water heating, and air conditioning on the campus of The University of New Mexico (UNM) in Albuquerque.

The UNM campus has excellent potential for a demonstration of direct geothermal energy. An extensive, moderate temperature ($\sim 100^{\circ}\text{C}$) reservoir underlies the area. Geological and geophysical studies are now in progress to define the extent and nature of the reservoir. The campus has a central utility system, part of which can be easily adapted to direct geothermal energy.

This project has three major parts. The first part is devoted largely to data gathering: energy loads as functions of temperature, time, location; definition of key reservoir parameters; determination of surface facility requirements and water disposal requirements; and initial estimates of environmental impact. The second part consists of system synthesis and selection. Several alternate system approaches are evaluated technically and economically. The best system is chosen for study in part three, system refinement and implementation. Designs are prepared in more detail. System economics are evaluated, along with overall energy and environmental impacts. Finally, a detailed implementation plan is prepared, taking into account institutional, financial, and technological aspects of direct geothermal use.

The overall objective of this study is to establish the technical and economic viability for the direct application of geothermal energy for space heating and other uses on the Albuquerque campus of The University of New Mexico (UNM). In order to meet this overall objective, it has been necessary to meet a number of specific study

objectives. A brief summary of these twenty objectives is given below in the form of questions and answers. Each one is treated in detail in the body of the report.

I. Data Acquisition and Summary

I.1 What are the thermal energy requirements for various segments of the campus as functions of time and temperature?

Heating requirements vary widely from building to building, with peak loads ranging from 14 to 70 Btu/hr ft² (44 to 220 w/m²). Segment heat loads for various campus segments were estimated using measured data for three buildings and by pro-rating steam use to each building. In addition, we developed and tested a sophisticated building heat load computer model.

I.2 What conclusions regarding the geothermal reservoir can be made from existing geological, geophysical, geochemical, and temperature gradient data?

The reservoir consists of alluvial fill extending to depths of 10,000 to 12,000 feet (3000 to 3600 m) over an area of many square miles. The geothermal gradient varies within the basin, but all data imply a gradient of at least 30°C/km. The water table near the University is at 210 feet (64 m).

I.3 What reservoir parameters cannot be accurately determined from available data? What are likely ranges of values for these parameters?

Since there are no deep wells near the University, it has been necessary to estimate values for permeability and porosity based on extrapolations from shallow wells. We estimate permeability at producing depth (8000 to 9000 feet) to be 80 millidarcies (range 13 to 500 millidarcies). We estimate porosity to be 10% (range 6 to 15%).

I.4 What are the most probable temperatures, flow rates, and fluid compositions available from the geothermal reservoir?

A single production well at 8,000 to 9,000 foot depth should be able to supply up to 1000 gal/min (0.06 m³/s) of water at 195°F

(91°C) with a drawdown of about 12 feet (4 m). Computer modeling of the reservoir shows virtually no effect on the reservoir from a single production well and injection well pair. The water is expected to contain 3,000 to 4,000 ppm dissolved solids.

I.5 What is the nature of any scaling or corrosion problem likely to be encountered?

Corrosion test loop studies with simulated geothermal brine showed that corrosion and scaling are negligible with copper, brass, stainless steel and PVC pipe and fittings. Mild scaling (probably co-precipitated silica and iron hydroxide) occurs on carbon steel.

I.6 What surface treatment and fluid storage facilities will be required for practical direct application of geothermal energy?

The geothermal brine must be kept free of oxygen to avoid corrosion. Surface storage is required only to provide short-term surge capacity for the system.

I.7 What disposal processes and facilities will be required?

A study of all possible disposal schemes showed that only direct release to surface streams and reinjection are economically feasible. If dissolved solids levels are as high as expected, only reinjection is both economically and environmentally acceptable.

I.8 What will be the environmental impact of providing a substantial portion of the campus energy requirement with direct geothermal heat?

During construction there will be local, short-term air, noise and land impacts. In the long-term, there will be net reductions in air pollution. The effect, however, will be very small.

II. System Synthesis

II.1 What segment, or segments, of the UNM campus can most practically be adapted to direct geothermal heat?

Four logically-connected segments of the campus were studied to locate the best area for initial use of geothermal heating.

- II.2 Can the relatively low-temperature geothermal energy be used for air conditioning, through modification of existing lithium bromide absorption chillers, as well as for space and hot water heating?

Studies showed that use of low-to-moderate temperature geothermal energy is not practical for providing air conditioning in Albuquerque.

- II.3 Based on preliminary designs, what system configurations (pure geothermal or hybrid) can be practically applied to various segments of the campus?

The best system is one that provides both space and hot water heating to a group of buildings using a secondary circulating water loop. The existing steam system is maintained for peak loads and back-up duty.

- II.4 Based on preliminary designs, what are the capital and operating costs for the various system configurations?

For the segments considered, initial capital cost estimates (in 1980 dollars) range from \$2.66 million to \$3.04 million. Annual operating costs range from \$164,000 to \$197,000. Energy savings range from 50 to 83 billion Btu/yr (53 to 88 TJ) as delivered heat, equivalent to 69 to 116 billion Btu (73 to 122 TJ) of fossil fuels.

- II.5 From the previous analysis, what is the best system configuration and campus segment for initial application of geothermal energy?

A secondary-loop system with steam back-up was selected for a segment of the campus including several dormitories, The College of Education and the gymnasium.

III. System Refinement and Implementation

- III.1 What detailed design best integrates the selected system configuration and campus segment?

Design details are presented in the body of the report. No insurmountable problems are foreseen. Details are given in Section III.1 and in Appendix A.

III.2 What are the capital and operating costs for the selected system design?

We estimate the total initial cost for the system to be \$3.85 million, with annual operating costs of about \$216,000. Total fossil fuel savings is 135 billion Btu (141 TJ) per year.

III.3 What is the overall economic advantage of using geothermal energy, taking into account the escalating cost and possible decreasing availability of conventional fuels?

Benefit/cost ratios were calculated using discount factors of 6, 8 and 10% and several different projected fuel costs. Using conservatively high costs and low fuel price escalations, we estimate an overall benefit/cost ratio of 1.70 at 6%, 1.40 at 8% and 1.16 at 10% for our base design. The ratio is extremely sensitive to fuel cost projections.

III.4 What is the net energy ratio for implementing the selected system design on the UNM campus?

Net energy ratios were estimated by two methods. Our "engineering method" shows an energy pay-out time of 0.53 years. A matrix-factor method gives a pay-out time of 0.75 years.

III.5 What institutional procedures must be followed to implement the selected system design on the UNM campus?

A suggested procedural plan is outlined in the body of the report. Prime responsibility must shift from the academic to the business operations sector of the University.

III.6 What are the specific environmental and energy impacts on the campus and the surrounding community resulting from implementation of the selected system design?

Use of geothermal energy for campus heating will greatly reduce University dependence on fossil fuels with a small reduction in air pollution and virtually no other long-term environmental impact.

III.7 In order to implement the selected geothermal system design, what specific engineering tasks and institutional approvals

remain, and who should assume responsibility for carrying them out?

An implementation plan is outlined in the body of this report.

Key aspects of the proposed geothermal heating system for a portion of The University of New Mexico campus are shown in Figure 1 and Table I. The system design includes the following features:

1. Minimum interference with existing steam system.
2. Steam system use for back-up and peak loads.
3. Maximum use of existing heating equipment.
4. Geothermal and disposal wells on or adjacent to the campus.
5. Minimum environmental impact.

The design resulting from this study is one which we believe to be technically and economically feasible and one which can be implemented relatively easily. It is, of course, not the only possible design configuration. Later detailed engineering coupled with long-range campus planning could lead to different configurations.

Figure 1. Geothermal heating system for UNM.

TABLE I
GEOHERMAL HEATING SYSTEM FEATURES

BUILDINGS INCLUDED	AREA (square feet)	PEAK HEATING LOAD (million Btu/hr)
Onate	41416	1.12
Alvarado	40896	1.12
Santa Ana	41615	1.13
Coronado	93880	2.91
Santa Clara	39751	1.10
Laguna	43901	0.62
DeVargas	43973	0.67
La Posada	40354	1.13
Hokona	187187	5.80
College of Education	118340	4.94
Johnson Gym	197622	6.38
Total	888935	26.92

GEOHERMAL WELL

Depth	8300 feet
Flow Rate (maximum expected)	829 gpm
Temperature	195°F

INITIAL COST \$3.85 million

YEARLY ENERGY IMPACT

GAS Reduced By 135×10^9 Btu (18.5% of 1979-80 use)
ELECTRICITY Increased By 1037×10^3 kw hr (1.9% of 1979-80 use)

Task I.1 Energy and Load Data

Three approaches were used to estimate heating loads for the various buildings on the campus. First, measurements of steam flow into three typical, but widely different, buildings were made. Second, total campus steam use data were collected. Individual building use rates were estimated by appropriate apportioning of the total load. Third, we developed a comprehensive computer program for calculating heating loads.

A. Experimental Measurements

Heating load profiles were measured for three buildings on the UNM campus: a dormitory, a classroom and office complex, and a medical facility. Table II presents pertinent data on the buildings being studied.

Santa Clara Hall is a women's dormitory having 170 beds for students. Fall and spring semester occupancy is one hundred percent. In the summer session, the occupancy is around fifty percent. During winter break and other vacations, daytime custodians are the only occupants.

In Santa Clara Hall 40 psig steam is used to heat the circulating hot water through a shell-and-tube type heat exchanger. Part of the circulating hot water goes through four forced-air finned-tube heat exchangers located on the three floors and basement. The rest of the circulating hot water is distributed to 102 radiators in the individual rooms. The discharge temperature of the circulating hot water is set at 200°F when the outdoor air temperature is 0°F and 100°F when it is 60°F outside. Steam also supplies heat for domestic hot water, which is used mainly for showers and laundry. The domestic hot water storage tank has 1000 gallons capacity.

An orifice type flow meter was installed on the building steam pipeline. The meter, broken for a long time, was repaired in the middle of January. The recorder ran well for ten days. Later the motor in the recorder stopped occasionally. We installed a new motor in late February. Steam consumption for a typical day (January 22, 1980) is shown in Figure 2. Daily usage for January through May is shown in Figures 3 to 5.

TABLE II
TEST BUILDING DATA

	Santa Clara Dorm	College of Education Complex								Family Practice Center
		Ed. Office	Ind. Arts	Ed. Admin.	Home Ec.	Classroom	Art Ed.	Kiva	Manzanita Center	
Construction Date	1963	1963	1963	1963	1963	1963	1963	1963	1963	1977
Building Orientation	13°E of N	N	N	N	N	N	N	N	N	N
Number of Floors	3	2	1	1	1	2	1	1	1	4
Ceiling Height	11'	12' & 10'4"	24'	20'	10'6"	12'4" & 12'	24'	9' to 24'	10'6"	8' (84%) & 9' to 12'
Floor Area (ft ²)	39751	21782	9234	32255	9854	21606	9900	4299	9350	58230
Masonry Wall Area (ft ²)	16953	5186	6682	--	2577	11241	6682	469	3221	16057
U (Btu/ft ² hr°F)	0.23	0.095	0.19	--	0.23	0.095	0.19	0.23	0.23	0.21
Glass Area (ft ²)	2573	6306	3221	11168	1539	1535	2460	1064	1041	5090
U (Btu/ft ² hr°F)	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Roof Area (ft ²)	14604	14256	7382	19564	9854	11768	7382	4299	9350	12795
U (Btu/ft ² hr°F)	0.15	0.092	0.13	0.14	0.11	0.092	0.13	0.07	0.092	0.07
Below Grade Wall Area (ft ²)	4900	--	--	--	--	--	--	3700	--	3042
U (Btu/ft ² hr°F)	--	--	--	--	--	--	--	--	--	0.24
Door Area (ft ²)	126	483	150	126	105	441	42	147	189	294
U (Btu/ft ² hr°F)	1.12	1.1	0.89	1.11	0.93	0.96	0.89	0.84	0.95	1.1
Skylight Area (ft ²)	--	--	228	--	--	--	232	--	--	--
U (Btu/ft ² hr°F)	--	--	0.70	--	--	--	0.51	--	--	--

Figure 2. Steam load profile for January 22, 1980.

Figure 3. Daily steam load profile.

Figure 4. Building Heating Loads, Feb. 12 to April 18, 1980.

Figure 5. Building heating loads, Apr. 19 to May 23, 1980.

The College of Education complex consists of eight individual buildings: Education Office, Industrial Arts, Education Administration, Home Economics, Education Classroom, Art Education, Kiva, and Manzanita Center. The Education Office Building is used only for faculty and staff offices. Industrial Arts has both classrooms and laboratories. Education Administration is used for offices, library and conference rooms. The remaining buildings are used principally for classrooms, with a few offices and laboratories.

A main steam pipeline supplies 25 psig steam to the building complex. Steam goes through forced-air finned-tube exchangers. The forced air temperature is set at 130°F when outdoor air is 0°F and at 80°F when outdoor air is 70°F. There are nine fan units in the complex. The two-story Education Classroom Building has one unit on each floor. Other buildings each have one. Four units have a midnight shut-down schedule controlled by the computer in the Utility Center. Six Units have weekend-evening shut-down schedules, as shown in Table III.

TABLE III
COLLEGE OF EDUCATION HEATING SCHEDULE

	Hours of Heating	Days
Education Office and Industrial Arts	0600 - 2200	- M T W T F -
	2350 - 0400	S M T W T F S
	0600 - 1700	S - - - - S
Education Administration	0620 - 2200	- M T W T F -
	0620 - 1800	S - - - - S
Classroom Buildings	0630 - 2200	- M T W T F -
	0630 - 1500	S - - - - S
Art Education	0610 - 2200	- M T W T F -
	0610 - 1800	S - - - - S

An orifice type flow meter was installed on the main steam pipeline to the complex. It was repaired in the middle of January. A typical hourly heat load within a day is shown in Figure 2. Figures 3 to 5 show daily average steam usage. Steam use follows outside

weather patterns very closely, primarily because of heat losses through large areas of single-pane glass (see Table II).

The Family Practice Center on the North Campus is used for offices and teaching. 40 psig steam is used to heat hot water which circulates through a shell-and-tube type heat exchanger. The circulating hot water is distributed to 110 fin-tube baseboard units which are the main heat supply for the building. The temperature of the hot water is controlled by the outdoor air temperature. Forty-eight electrically heated ceiling panels in doctors' treatment rooms also heat the building. The temperature setting for electric panels is as high as 80°F. The fan system is scheduled to operate from 6:00 am to 9:00 pm by a local controller. The steam supply is also used to heat domestic hot water.

There is a condensate flow sensor in the condensate return line in this building. A recorder was connected in late January. Hourly steam consumption for January 22, 1980, is shown in Figure 2. Daily average data are shown in Figures 3 to 5. The total steam heating load is relatively low since the building is compact and well insulated.

B. Campus summary model

A second way to estimate building heat loads is to measure the load for the entire campus and apportion it to each building. We have compiled total campus load data and made an initial attempt to apportion it, based on data from July 1978 to June 1979.

Figure 6 shows heating degree days (basis 65°F) for Albuquerque for the 12-month period. Figure 7 shows the total campus steam load, on a unit area basis, less steam used for air conditioning systems. In the summer, the load is for domestic hot water and laboratory steam. In the winter, it is primarily for heating. Figure 8 replots the data of Figure 7 on a cumulative basis.

Data from a variety of sources were used to estimate relative steam loads for the various buildings on the campus.

The approach we used to estimate relative heat loads is based on one in the ASHRAE Handbook (1977):

Figure 6. Heating degree days, 1978-1979 season.

Figure 7. Energy load distribution, 1978-1979 season.

Figure 8. Cumulative energy load distribution, 1978-1979 season.

$$Q = (\sum A_i U_i + 0.0148 V)(T_o - T_i) \quad (1)$$

where

A_i = an external wall or roof surface

U_i = the heat transfer coefficient for a particular wall

0.0148 = volumetric heat capacity of air at 5100 ft altitude
(Btu/ft³°F)

V = air infiltration rate

T_o = outside air temperature

T_i = inside air temperature

Data on A's and estimates of U's are available for most buildings from the on-going campus energy audit program. Infiltration rates are estimated two ways in the ASHRAE Handbook (1977). Table IV summarizes our estimates for campus buildings.

Calculated relative heat loads are presented in Table V for all principal campus buildings.

We examined heating steam use on four specific days to determine the hour-by-hour load pattern. Figures 9 through 12 present these data for February 8 and 9 and April 18 and 19. The February data represent a two-day period of cold weather, including both a weekday and a weekend day. The April data are for a much warmer pair of days.

The overall model has been based on data for the heating seasons of 1978-79 and 1979-80. In order to see whether these years were typical, we compared their weather data with 30-year average data available from the Weather Bureau. Figure 13 plots these data in terms of degree days per month. It is evident that the 1978-79 winter was slightly more severe than average due to colder-than-normal weather in December and January. The 1979-80 winter was less severe, but more prolonged. Despite these variations, we believe that the data we have been using are adequate for preliminary design and analysis.

TABLE IV
BUILDING AIR INFILTRATION RATES

	Air Changes per hour
1. Residences	
Rooms with no windows or exterior doors	0.5
Rooms with windows or exterior doors on one side	1.0
Rooms with windows or exterior doors on two sides	1.5
Rooms with windows or exterior doors on three sides	2.0
Entrance halls	2.0
2. Offices, apartments and multistory buildings	
Rooms with no windows	0.5
Rooms with windows on one side	0.75
Rooms with windows on two sides	1.5
Rooms with windows on three or four sides	2.0
3. Estimates for campus buildings	
New buildings (post-1975)	0.8
Office buildings	0.8
Office and classroom buildings	1.2
Classroom and laboratory buildings	1.5
Dormitories	1.5

TABLE V
CAMPUS ENERGY USE DISTRIBUTION

Bldg. No.	Bldg. Name	GSF Heated by Steam	% GSF	% Steam Used for space heating
	Bern. Cty. Med. Ctr.	374447.	9.645	8.819
59	Johnson Gym & Pool	197622.	5.090	6.426
58	Hokona Dorm.	187187.	4.822	5.901
60	New Mexico Union	149192.	3.843	4.754
53	Zimmerman Library	226112.	5.824	4.670
211	Basic Med. Sciences	175731.	4.527	3.413
62,72	Fine Arts Ctr. & Popejoy Hall	246551.	6.351	3.041
155	Coronado Dorm	93880.	2.418	2.960
218	Bratton Hall	116983.	3.013	2.781
227	Cancer Research Ctr.	96291.	2.480	2.391
56	Mesa Vista Hall	111870.	2.882	2.217
228	Nursing/Pharmacy	93645.	2.412	1.891
84	New Art Bldg.	74708.	1.924	1.874
24	Geology	75745.	1.951	1.872
119	Farris Engr. Ctr.	68339.	1.760	1.818
81	Humanities	70859.	1.825	1.777
11	Anthropology	52557.	1.354	1.754
79	Ortega Hall	53873.	1.388	1.615
10	Scholes Hall	49210.	1.268	1.539
234	Health Sciences Research Ctr.	65804.	1.695	1.510
76	Business School	46405.	1.195	1.462
106/111/				
117	Civil & Chemical Engr.	24750.	0.638	1.336
23	Mitchell Hall	46965.	1.210	1.288
71	Santa Ana Dorm	41615.	1.072	1.171
77	La Posada	40354.	1.039	1.168
156	Onate Hall	41416.	1.067	1.167
157	Alvarado Dorm.	40896.	1.053	1.165
207	Physics & Astronomy	58753.	1.513	1.164
82	Woodward Hall	39622.	1.021	1.151
61	Santa Clara Dorm.	39751.	1.024	1.142
34	Psychology	51898.	1.337	1.133
83	Bookstore	42443.	1.093	1.043
118	Electrical Engineering	21632.	0.557	0.991
248	Family Practice Ctr.	58230.	1.500	0.968
115	Journalism	31542.	0.812	0.967
4	Carlisle Gym	31270	0.805	0.959
73	Student Health Ctr.	42853.	1.104	0.951
35	New Physics	22177.	0.571	0.839
75	DeVargas Dorm.	43973.	1.133	0.782

(continued)

TABLE V (concluded)

Bldg. No.	Bldg. Name	GSF Heated by Steam	% GSF	% Steam Used for Space Heating
74	Laguna Dorm.	43901.	1.131	0.740
51	1915 Roma	21786.	0.561	0.714
8	Bandelier East	9576.	0.247	0.559
107	Mechanical Engr.	17324.	0.446	0.531
153	Computer Ctr.	20330.	0.524	0.475
249	Dental Program	28022.	0.722	0.466
103	Hodgin Hall	15108.	0.389	0.463
16	Bandelier West	15073.	0.388	0.462
230	New Law Ctr.	8398.	0.216	0.223
9	Marron Hall	19982.	0.515	0.613
63	College of Education A	21782.	0.561	0.749
64	College of Education B	9234.	0.238	0.667
65	College of Education C	32255.	0.831	1.387
66	College of Education D	9854.	0.254	0.348
67	College of Education E	21666.	0.558	0.615
68	College of Education F	9900.	0.255	0.629
69	College of Education G	4299.	0.111	0.196
70	College of Education H	9350.	0.241	0.249
21	Biology (old)	67607.	1.741	1.671
21	Biology (new)	46897.	1.208	1.242
22	Chemistry (old)	39127.	1.008	1.238
22	Chemistry (new)	42569.	1.097	1.350
Totals		3,861,190.	99.459	99.459
Others		21010.	0.541	0.541
Campus Totals		3,882,200.	100.000	100.000

Figure 9. Total load, Feb. 8, 1980 (Friday).

Figure 10. Total Load, Feb. 9, 1980 (Saturday).

Figure 11. Total Load, April 18, 1980 (Friday).

Figure 12, Total load, April 19, 1980 (Saturday).

Figure 13. Comparison of Weather Data.

C. Computer Model

A sophisticated computer model was developed to calculate building heating requirements.

Consider a space bounded by walls, floor and ceiling, and having infiltration of air and internal energy sources. The net heat loss from the space can be expressed by the following equation:

$$Q = QT + QI - RS - RL - RE , \quad (2)$$

where QT = transmission heat loss from wall, roof, ceiling, floor or windows

QI = heat loss due to infiltration and ventilation

RS = solar energy absorbed by the surfaces of space

RL = rate of heat radiated from lights and absorbed by the space

RE = rate of heat radiated from equipment and occupants and absorbed by the space

The completed computer model uses five groups of input data, fifteen calculation subroutines and two output subroutines (see Table VI). The interrelationships of the various groups are shown in Figure 14. Details of individual routines and methods are given in Appendix B. Table VII summarizes all the input data requirements for the programs.

The model was used to calculate heat loads for the Family Practice Center, one of the buildings for which we had experimental data. Of the three buildings, it offers perhaps the most severe test of the model since total heat loads are quite small and any discrepancies between model and data will be obvious.

The results of the model calculations are shown in Figures 15 and 16, a to c. Figure 15 compares the calculated and measured heating system loads for a 12-day period in February which included some very cold weather. Data are plotted on a three-hour-average basis, since that is close to the precision limit for our measured heat load data. The comparison between measured and calculated values is quite good. Figure 16-a shows the individual contributions of window, door, wall

TABLE VI

GENERAL DESCRIPTION OF SUBROUTINES

BASFLR:	This routine calculates the heat loss from floor and basement.
CLOUD:	This routine modifies the solar radiation computed for a cloudless sky by instantaneous cloud cover data.
DAYMON:	This routine identifies the day of the month and the month of the year.
DAYSAV:	This routine determines whether given schedule data are in a daylight saving time zone.
EQUIP:	This routine calculates heat gain radiated from equipment.
HIN:	This routine determines the interior surface heat transfer coefficients.
HOUT:	This routine calculates the surface heat transfer coefficients for externally exposed surfaces from weather data.
INFIL:	This routine calculates the heat loss due to infiltration.
LIGHT:	This routine calculates heat gain radiated from lights.
OCCUP:	This routine calculates heat gain radiated from occupants.
SUNLIT:	Basic sun data such as solar angles, direct and diffuse radiation needed for solar heat gain and solar heating of the building exterior surfaces are calculated in this routine.
VENT:	This routine calculates the heat loss due to ventilation.
WALROF:	This routine calculates the outside surface temperature and heat gain into the wall or roof by taking into account solar heating, convective heat loss to the ambient air, and transient heat conduction within the wall or roof.
WINDOW:	This routine calculates solar heat gain through windows and doors, both convective and conductive heat losses.
WKDAY:	This routine determines the day of week when the date and year are given.

Figure 14. Interrelationships of computer program subroutines.

TABLE VII
INPUT DATA REQUIREMENTS

A. Locality Data

These input data describe the character of the area where the building is located.

1. Latitude
2. Longitude
3. Time zone number
4. Sky clearness number
5. Ground reflectivity
6. Mean annual air temperature
7. Ground surface temperature fluctuating amplitude
8. 97.5 percent dry-bulb temperature
9. 5 percent dry-bulb temperature
10. Normal outdoor air pressure
11. Outdoor air density

B. Weather Data (hourly)

Meteorological parameters needed for the hourly load calculations:

1. Outdoor dry-bulb temperature
2. Wind speed
3. Cloud type index
4. Total cloud cover
5. Relative humidity

C. Internal Heat Sources

These data supply total amounts of each internal heat source:

1. Total light wattage
2. Rate of heat gain from occupants
3. Maximum number of persons in building
4. Total equipment wattage

D. Schedule Data

These data provide hour-by-hour descriptions of building usage and internal heat generation:

1. Number of days elapsed from January 1 to reach the starting day.
2. Number of days to be calculated.
3. Hourly ratio of lighting wattage in use on weekdays.
4. Hourly ratio of lighting wattage in use on weekends.
5. Hourly ratio of maximum number of occupants on weekdays.
6. Hourly ratio of maximum number of occupants on weekends.

TABLE VII (continued)

7. Hourly ratio of equipment wattage in use on weekdays.
8. Hourly ratio of equipment wattage in use on weekends.
9. Hourly ratio of building volume for heat loss due to infiltration on weekdays.
10. Hourly ratio of building volume for heat loss due to infiltration on weekends.
11. Hourly ratio of ventilation capacity on weekdays.
12. Hourly ratio of ventilation capacity on weekends.

E. Building Data

1. Wall and roof
 - a. Absorptivity of outside surface of the slabs
 - b. Heat capacity of each slab
 - c. Emittance of inside surface of the slabs
 - d. Wall tilt angle from horizontal plane
 - e. Surface azimuth from south through east
 - f. Directional index of heat flow
 - g. Outside surface index
 - h. Gross area
 - i. Thickness of each slab
 - j. Resistance of the slab when its conductivity, density and heat capacity are unavailable
 - k. Density of each slab
 - l. Heat capacity of each slab
 - m. Conductivity of each slab
 - n. Number of slabs for each wall and roof
2. Glazing and Doors
 - a. Conductivity
 - b. Shading coefficient
 - c. Emittance of inside surface
 - d. Outside surface index
 - e. Gross area
3. Basement and Floor
 - a. Conductivities of slabs
 - b. Perimeter of basement wall and basementless floors
 - c. Gross areas of basement floors
4. Building
 - a. Indoor temperature
 - b. Gross square-foot
 - c. Maximum ventilation capacity
 - d. Building volume
 - e. Indoor humidity

Figure 15. Calculated and measured heating loads for Family Practice Center.

Figure 16a. Wall, ceiling, window, door and basement heat losses.

Figure 16b. Infiltration and ventilation heat losses.

Figure 16c. Internal heat sources.

and basement heat losses. Figure 16-b shows infiltration and ventilation load requirements. A significant portion of these loads, which bring outside air to inside ambient conditions, is due to humidification of the dry, outside air. Figure 16-c shows the heat contributions of building equipment, lights and occupants.

This computer model can be readily adapted to any building on the campus and will be very useful in future load analysis.

Task I.2 Reservoir Data, Known

The extensive investigation of the geothermal reservoir underlying the Albuquerque area by Jiracek and Callendar (1980) is nearing completion. The final report has not been published, but initial findings have been made available to us. The descriptions which follow are, therefore, necessarily subject to later revision.

A. Geology

The Albuquerque Basin is bounded on the west side by the Colorado Plateau and the southern end of the Naciminto uplift and bounded on the east side by the eastward-tilted Sandia, Manzano, and Los Pinos fault blocks. The northern boundary is formed partly by broadening of the Naciminto uplift eastward into the Jemez uplift and partly by convergence with the La Bajada fault scarp. The southern end of the Albuquerque Basin is the Socorro constriction formed by convergence of the east and west borders (Kelley 1977).

The structures on the east side are quite different in exposure, magnitude, and style from those of the west side. This gives a marked asymmetry to the basin. The border on the east side is a line of west-facing fault escarpments that extend about 72 miles. This escarpment is made up of four uplift blocks (Los Pinos, Manzano, Manzanita, and Sandia), each differing to some degree in tilting and internal structure. On the east side of these faults rise the Manzano and Sandia mountains, which are composed of granite, schist, quartz, and greenstone. These mountain areas have very little contribution to the amount of water in the basin (Bjorklund, et al, 1961). The western border is more irregular, quite varied in style of deformation and in places has little or no faulting at the margin. The Sand Hill fault may be chosen to define the west border of the basin. Behind the Sand Hill fault, sedimentary rocks, mostly composed of shale and sandstone, are encountered. Similarly, they yield very little water to the basin.

Although faults with vertical separation of at least several thousand feet bound the Albuquerque Basin in many places, the basin beds themselves are not widely or greatly deformed, but they do result

in large changes in rock composition in horizontal directions at constant depth. In the vicinity of Albuquerque, composition with depth is divided into two distinct layers.

1. 0 to 10,000 feet (0 to 3 km). Santa Fe formation, which is composed of pinkish, light olive and white sandstone; gray and brown mudstone; conglomerate and fanglomerate. There is a narrow strip of alluvium river raft on top of this formation in part of the basin. Although dimensions of this strip vary through the basin, they average 1000 feet in depth and 3000 feet in width.

2. 10,000 feet and deeper (3 km+). Mesaverde and Mancos formations, which are composed of sandstone, shale, and coal. Their contribution to the amount of water in the basin is negligible.

Mesaverde and Mancos formations are considered as the limit of water presence in the vertical direction. Their occurrence with the depth varies from place to place in the river basin. Kelley (1977) discusses the thickness of the saturated layer. It can range from 5,000 to 10,000 feet and is close to 10,000 feet in the vicinity of Albuquerque.

B. Reservoir Dimensions

The Sandia mountains and the Sand Hill faults naturally bound the reservoir on the east and west sides, respectively. The average distance from the I-25 and I-40 highway intersection to the Sandia mountains is 8 miles (13 km), and to Sand Hill fault is 15 miles (24 km). However, there are no distinct natural boundaries for the north and south sides. The Bernalillo county borders are arbitrarily chosen to define the south and north ends of the reservoir. These are 13.8 miles (22 km) south and 14.3 miles (23 km) north of the I-25 and I-40 intersection.

C. Natural Recharge of the Reservoir

In the Albuquerque area, although agricultural exploitation started many years ago, a stable water table is reported throughout the reservoir (Bjorklund 1961). This phenomena may be attributed to the following natural recharge sources.

1. Ground water flow north to south.

Due to differences in permeability and saturated thickness as well as additions and withdrawals of water, the water table in general is not level, but is an irregular sloping surface. The averaged slope is about 20 feet per mile, sloping from north to south.

Bjorklund (1961) estimates the ground water velocity through the basin as less than 100 feet per year based on ideal calculations using Darcy's law.

If the average reservoir thickness is assumed to be 5000 feet at the northern part of the reservoir with a width of 120,000 feet, the annual input from ground water flow from the north will then be about $6 \times 10^{10} \text{ ft}^3$. Similarly, south outflow from the reservoir should be the same as the input.

2. Recharge from the river

The river bed, which is composed of alluvium, has a very high permeability compared to that of the rest of the reservoir. Therefore, this region of the reservoir is constantly saturated. This effect may be assumed as the main cause of the stable water table. This portion of the reservoir acts as a two-way safety valve for the reservoir. In the case of regional water table depression, the river loses water by downward movement. As the water table builds up under the river bed, the water spreads outward. The reverse of this process also takes place, and the river drains out the reservoir to keep the water table at a steady level.

3. Recharge from precipitation.

Most precipitation in Albuquerque occurs during localized thunder-showers which sometimes are torrential and cause floods. About 45 percent of the precipitation occurs during July, August, and September (Bjorklund 1961). The total precipitation within the boundaries defined above averages 8.68 inches per year, for a total of $1.87 \times 10^{10} \text{ ft}^3/\text{yr}$.

D. Geothermal Energy Input

Reiter (1974) reports values of geothermal heat flow in the Albuquerque area of 2 to 2.5 hfu. Over the total area of interest, this amounts to 140 to 175 MW. Figure 17 shows Reiter's mapping of heat

Figure 17. Heat flow in New Mexico.

(Reiter, 1974)

flow throughout New Mexico.

E. Gradients

Jiracek and Callender (1980) have measured gradients in two city wells on the east side of the river close to the UNM campus. At the Lomas field, five miles east of UNM, a gradient of $23.2^{\circ}\text{C}/\text{km}$ was recorded. At the San Jose field, 2.4 miles southwest of UNM, a gradient of $27.6^{\circ}\text{C}/\text{km}$ was found.

In their preliminary data on the west mesa, they have discovered some gradients over $120^{\circ}\text{C}/\text{km}$ in shallow test holes of depths averaging around 25 meters. It is not known what the gradients are at greater depths. For a more complete summary and analysis of the results of their study, their final report will be completed in the late summer, 1980.

A few exploratory oil wells have been drilled at various locations around the Albuquerque Basin. Some of the closer wells are shown in Figure 18. A city well located west of the river is also shown. These wells have gradients from 29.2 to $47.9^{\circ}\text{C}/\text{km}$ with an average value of 34.8 . The gradients are listed in Table VIII.

F. Water table

Data from Bjorklund (1961), Kelley (1977) and topographic maps were used to construct a contour map of the depth of the water table below ground level. (See Figure 19.) The map indicates a depth of 210 feet (± about 10 feet) for the UNM campus.

Figure 18. Nearby deep wells (Grant, 1980).

TABLE VIII
TEMPERATURE GRADIENTS FOR WELLS CLOSE TO ALBUQUERQUE

Well	Depth	Bottom Hole Temp	Gradient (°C/km)	Distance from UNM (km)
Trans Ocean No. 1 Isleta	3.16 km (10,378 ft)	112.8°C (235°F)	30.91	6.5
Shell No. 1 Isleta	4.98 km (16,346 ft)	190.6°C (375°F)	35.24	11.4
Shell No. 1 Laguna	3.39 km (11,115 ft)	119.4°C (247°F)	30.83	12.5
Shell No. 1 Santa Fe	3.37 km (11,045 ft)	113.3°C (236°F)	29.21	11.4
West Mesa No. 1	0.36 km (1,180 ft)	32.2°C (90°F)	47.88	4.0
Shell No. 2 Isleta	6.48 km (21,266 ft)	223.3°C (434°F)	32.14	8.0

Figure 19. Water table contours.

Task I.3 Reservoir Data, Unknown

A. Temperature vs. Depth

The actual temperature gradient on the UNM campus is unknown. Generally on the east mesa of the Albuquerque Basin, gradients of 25 to 35°C have been found with no consistent pattern. Possible fluctuations of the gradient may be due to local streaming or faults which could cause hotter or colder flows. Subsurface water flow off the Sandias can also contribute to lower surface gradients near the mountains. In our studies, a value of 30°C/km was assumed for the gradient with a surface temperature of 15°C. The value of the gradient was assumed constant with depth.

B. Permeability

The permeability of the Albuquerque Basin has been determined at 23 wells by measuring the drawdown and recovery of water levels during and after pumping at measured rates using the Theis recovery formula (Bjorklund, et al. 1961). This value ranges from 12 to 840 gpd/ft² and averages about 340 gpd/ft². There are two probable reasons for the wide range observed.

1. Geologic composition changes with the change of well position in the aquifer (Bjorklund 1961).
2. The existence of faults which create local high permeability in some areas (Garg 1979).

Since the fault density around Albuquerque is not very high and soil composition is continuous compared to the Santa Fe region, we may expect relatively steady and continuous permeability values, probably in the reported range of 130 to 840 gpd/ft² on the east mesa and 54 to 78 in the inner valley for relatively shallow wells.

From these values of permeability, a coefficient of permeability was obtained using

$$K = \frac{kv}{\mu} \tag{3}$$

where K is the permeability, k is the coefficient of permeability, v is the specific gravity, and μ is the viscosity. The units for the coefficient of permeability are darcies (1 darcy $\approx 10^{-8}$ cm²). Table IX lists the results.

The north to south ground water flow through the reservoir was estimated by Bjorklund (1961) to be 100 feet per year for a slope of 20 feet to a mile. Using Darcy's law,

$$v = - K \frac{dz}{dx} \quad (4)$$

where v is the velocity and dz/dx is the slope, a value of permeability was found. The coefficient of permeability was then calculated using Equation 3. The result is eight darcies.

TABLE IX
COEFFICIENT OF PERMEABILITY FOR VARIOUS
WELLS IN THE ALBUQUERQUE BASIN

Permeability gpd/ft ²	Coefficient of Permeability (darcy)
12	0.52
54	2.34
78	3.38
130	5.63
340	14.73
840	36.39

Drawdown data measured at a number of wells near the UNM campus were also used to find values of permeability (Bjorklund, 1961). It was assumed that the drawdown effects would be noticed up to a distance of 1000 feet radially. The equation,

$$\phi = \frac{Q_o}{2 Kh_o} \ln \left(\frac{R}{R_o} \right) \quad (5)$$

is used to find the permeability of each well. ϕ is the drawdown, h_o is the well depth (ft), Q_o is the well yield rate, R is the effective radius (1000 ft), and R_o is the well radius. The coefficient of permeability ranged from 1.4 to 20.0 darcies. The UNM Well No. 7 had the

highest value. The results are listed in Table X.

The range for the coefficient of permeability for all of the above cases is 0.5 to 36.4 darcies. The average is 10.1. These values, however, are based on results from shallow wells. It is commonly found that permeability decreases with depth. Such is the case, for instance, in the Raft River, Idaho, geothermal area (Blake, 1978). Since no deep wells have been drilled and tested near the campus, only an approximate estimate of reservoir permeability can be made. Using the data and approach presented in Appendix D, we estimate a permeability of 0.08 darcies at production depth (8300 ft) and 0.8 darcies at typical re-injection depth (5000 ft). We believe both of these estimates to be conservatively low. The limited data available could be interpreted to be representative of much higher permeabilities at depth. For upper and lower bounds in parametric studies, the permeability limits are assumed to be 0.013 and 0.50 darcies. These correspond to 0.30 and 11.6 gpd/ft². The base case estimate, 0.080 darcies, corresponds to 1.85 gpd/ft².

C. Porosity

Excluding the narrow strip of the river raft, the basin formation of interest is mainly sandstone and mudstone. Their compressibility may be assumed to be reversible; so porosity should show very little change with depth (Mayer-Gurr, 1976). According to Bjorklund (1961), the estimated average porosity value is 0.2 in the Albuquerque area. Again, however, this is a value for conditions near the surface. For values far below the surface, we used the analysis developed in Appendix D, which we believe to be very conservative. The estimated porosity at producing depth (8300 ft) is 0.10. The estimated porosity at reinjection depth (typically 5000 ft) is 0.17.

D. Medium Thermal Conductivity

Thermal conductivity depends on the nature of the soil and its water content. No tests have been performed specifically for the Albuquerque Basin so far. Initial estimates indicate an effective thermal conductivity of about 0.008 cal/cm·sec°C.

TABLE X

COEFFICIENTS OF PERMEABILITY FOR CITY WELLS

Well No.	Location	Well Radius (in)	Drawdown (ft)	Yield Rate (gpm)	Depth (ft)	Water Table (ft)	Distance to UNM (mi)	Permeability (darcy)
10.3.17.412a	Broadway & Granite NE	8	66	1016	442	20	1.13	2.6
10.3.27.243	Burton Park	8	46	2250	1000	368	1.10	5.7
10.3.29.443	Miles Rd & Walter St. SE	8	99	1890	1000	68.67	1.69	1.4
10.3.1.244	Louisiana & Comanche	8	29.5	2200	1020	336.4	3.60	8.0
UNM #7	On Campus	5	33	1750	410	203	0.0	20.0

Task I.4 Reservoir Model

In this section, we estimate reasonable values for drawdown which would be used to calculate the well pumping costs. The values of permeability found in Task I.3 are used here. In addition to the drawdown calculations, a study of different flow magnitudes was made. In part C of this section, the cases run using the computer model are summarized giving the performance of the reservoir under a number of conditions.

A. Drawdown Estimates

Using the information on permeability, a number of estimates were made for the drawdown that would be encountered during the operation of the geothermal well. The steady-state drawdown was calculated two ways. The first equation covered the case of a well partially penetrating an unconfined reservoir (Deju, 1971). (See Figure 20.) This equation has the form

$$h_s - h = \frac{Q_o}{4\pi K} \left(\frac{2}{h_o} \ln \left(\frac{\pi h_o}{2r_w} \right) + \frac{0.20}{h_s} \right) \quad (6)$$

where h is the depth from the new water table to the bottom of the reservoir (feet), h_o is the effective depth of the well (feet), h_s is the reservoir thickness (feet), K is the permeability (gpd/ft²), Q_o is the well flow rate (gpd), and r_w is the well radius (feet). (A list of all the terminology is presented in Table XI.) For all cases, h_o will be 2000 feet, h_s will be 10,000 feet and r_w will be four inches. Q_o will be either 400 gpm, 800 gpm, or 1200 gpm, while permeability will be 11.6 gpd/ft² (0.50 darcies), 1.85 gpd/ft² (0.08 darcy) or 0.30 gpd/ft² (0.013 darcy). The value of 2000 feet for h_o accounts for the expected effects of occasional lenses of clay or other low permeability material. For a completely uniform reservoir, h_o would be the same as the well depth, 8000 feet. The results for the partially penetrating well in an unconfined reservoir are shown in Table XII.

Although the well is a partially penetrating well, Heggen (1980) advised that the well can be assumed to be a fully penetrating well for estimating drawdown. (See Figure 21.) An equation for a fully penetrating well in an unconfined reservoir was also used to calculate a drawdown (Deju, 1971):

$$h_o^2 - h^2 = \frac{Q_o}{\pi K} \ln(r_o/r_w), \quad (7)$$

Figure 20. A well partially penetrating an unconfined reservoir.

Figure 21. A well fully penetrating an unconfined reservoir.

TABLE XI. NOMENCLATURE FOR DRAWDOWN EQUATIONS

- b - saturated thickness of the reservoir (feet)
- d - radial distance from well to the point drawdown is being observed (feet)
- h - depth from new water table to bottom of reservoir (feet)
- h_o - effective depth of well (feet)
- h_s - reservoir thickness (feet)
- K - permeability (gpd/ft²)
- Q_o - well flow rate (gpd)
- r_o - radius of well influence (feet)
- r_w - well radius (feet)
- s - drawdown for unconfined reservoir (feet)
- s' - drawdown for confined reservoir (feet)
- S_c - storage coefficient
- t - time (days)
- T - transmissivity (gpd/ft)

TABLE XII. STEADY STATE DRAWDOWN

From Equation 6.

K (gpd/ft ²)	Q (gpm)	Drawdown (feet)
11.6	400	36
11.6	800	72
11.6	1200	109
1.85	400	227
1.85	800	454
1.85	1200	680
0.30	400	1398
0.30	800	2796
0.30	1200	4195

From Equation 7.

K (gpd/ft ²)	Q (gpm)	Drawdown (feet)
11.6	400	32
11.6	800	64
11.6	1200	96
1.85	400	209
1.85	800	419
1.85	1200	628
0.30	400	1055
0.30	800	2110
0.30	1200	3165

where r_0 is the radius of influence of the well (feet). This equation gave similar results to the partially penetrating well case. (See Table XII.) In using the equation, the radius of influence, which is defined as the radius from the well to the point where drawdown effects are minimal and can be neglected, has to be assumed. However, this value is in a logarithmic term and large changes in the radius produce only small effects in the drawdown.

The drawdown as a function of time may be found using the Theis equation for confined reservoirs and adapting it to unconfined reservoirs (Deju, 1971). The equation for the confined case is

$$s' = \frac{Q_0}{4\pi T} \int_u^{\infty} \frac{e^{-x}}{x} dx = \frac{Q_0}{4\pi T} W(u) \quad (8)$$

where $u = \frac{d^2 S_c}{4Tt}$,

s' is the drawdown (feet), d is the radial distance from the well to the point the drawdown is being observed (feet), S_c is the storage coefficient (non-dimensional), t is time (days), T is the transmissivity (gpd/ft), and $W(u)$ is called the well function. Transmissivity is defined as

$$T = Kh_0.$$

The storage coefficient has been estimated by Bjorklund (1961) to be 0.2 for the Albuquerque Basin. The drawdown for the confined case can be adapted to the unconfined drawdown by the equation:

$$s' = s - \frac{s}{2b}, \quad (9)$$

where s is the drawdown for an unconfined reservoir, and b is the saturated thickness of the reservoir. The value b is assumed to be 8000 feet. Placing b into the equation, it can be seen that $s' \approx s$, therefore, the confined equation may be used directly for the unconfined case. $W(u)$ can be approximated by

$$W(u) = -0.5772 - \ln(u) + u - \frac{u^2}{2!2} + \frac{u^3}{3!3} - \frac{u^4}{4!4} + \dots \quad (10)$$

or if $u < 0.02$, by

$$W(u) = \ln \frac{2.25Tt}{S_c d^2} \quad (11)$$

The drawdown was calculated at a distance of one foot from the well for times of 1 day, 365 days, 10 years, 50 years, and 200 years. The results are presented in Table XIII. The drawdown versus radial distance from each well for each time period is presented in Figures 22 to 30 for flowrates of 400 gpm, 800 gpm, and 1200 gpm. The radial distance from the well runs from 1 foot to 1000 feet.

B. Reservoir Estimates

Table XIV shows the time it takes to exploit 10 to 50 percent of water in a 1 km^3 volume with a porosity of 10, 20, and 30 percent. The water is assumed to have a temperature of 90°C . Even for a porosity of 10 percent, it takes 6.19 years to exploit just 10 percent of its water. The volume of 1 km^3 is only 16 percent of the total volume of water just under the UNM campus.

Table XV compares the flow rates of one well and of five wells to the magnitude of different flows in and out of the reservoir. Each well yields 650 gpm ($0.65 \times 10^6 \text{ m}^3/\text{yr}$). The underground water flow follows the water table which slopes at seven feet per mile in a southwesterly direction. The coefficient of permeability is assumed to be one darcy. The precipitation contribution is one half of the yearly rainfall average of 8.68 inches. The domestic water use is one half of the city's average use per capita per day. The water capacity is found for a 2 km^2 surface area and a depth of 3 km. Values are found for porosities of 12 and 22 percent. The results show comparable values for one well and the water table flow, the gain by precipitation, and the domestic water use, but small values compared to the capacity of the reservoir.

C. Computer Model

To analyze the reservoir performance, a computer model was developed. The math definitions and derivations were presented in detail in the first quarterly report (Kauffman and Houghton, 1979 b).

TABLE XIII. DRAWDOWN VERSUS TIME, FLOWRATE AND PERMEABILITY AT A RADIUS OF ONE FOOT FROM THE WELL

K = 11.6 gpd/ft²

Q_0	1 day	365 days	10 years	50 years	200 years
400	25	36	41	44	47
800	49	73	82	88	94
1200	74	109	123	132	140

K = 1.85 gpd/ft²

Q_0	1 day	365 days	10 years	50 years	200 years
400	132	205	233	253	270
800	264	410	467	507	541
1200	395	615	700	760	811

K = 0.30 gpd/ft²

Q_0	1 day	365 days	10 years	50 years	200 years
400	674	1124	1300	1423	1529
800	1347	2249	2600	2846	3058
1200	2021	3373	3901	4270	4587

Figure 22. Drawdown versus radial distance from well for $Q_0 = 400$ gpm and $K = 11.6$ gpd/ft².

Figure 23. Drawdown versus radial distance from well for $Q_0 = 800$ gpm and $K = 11.6$ gpd/ft².

Figure 24. Drawdown versus radial distance from well for $Q_0 = 1200$ gpm and $K = 11.6$ gpd/ft².

Figure 25. Drawdown versus radial distance from well for $Q_0 = 400$ gpm and $K = 1.85$ gpd/ft².

Figure 26. Drawdown versus radial distance from well for $Q_0 = 800$ gpm and $K = 1.85$ gpd/ft².

Figure 27. Drawdown versus radial distance from well for $Q_0 = 1200$ gpm and $K = 1.85$ gpd/ft².

Figure 28. Drawdown versus radial distance from well for $Q_0 = 400$ gpm and $K = 0.30$ gpd/ft².

Figure 29. Drawdown versus radial distance from well for $Q_0 = 800$ gpm and $K = 0.30$ gpd/ft².

Figure 30. Drawdown versus radial distance from well for $Q_0 = 1200$ gpm and $K = 0.30$ gpd/ft².

TABLE XIV
EXPLOITATION TIME FOR DIFFERENT POROSITIES

Percent Exploitation	Porosity		
	10% (yrs)	20% (yrs)	30% (yrs)
10	6.186	15.47	18.56
20	12.37	30.93	37.12
30	18.56	45.39	55.68
40	24.74	61.86	74.23
50	30.39	77.32	92.79

TABLE XV
WATER FLOW COMPARISONS

		Percent of Flow	
		For One Well	For Five Wells
Water Table Flow (m ³ /yr)	1.913 x 10 ⁶	34.0	170.0
Half of Precipitation (m ³ /yr)	0.9 x 10 ⁶	70.2	361.0
Domestic Use (m ³ /yr)	8.5 x 10 ⁵	76.5	382.0
Capacity (m ³)			
For $\epsilon = 0.12$	1.44 x 10 ⁹	0.05	0.2
$\epsilon = 0.22$	2.64 x 10 ⁹	0.02	0.1

The assumptions used in developing the model are:

1. The reservoir fluid remains a single-phase compressed liquid.
2. The single phase compressed liquid is virtually pure water.
3. The fluid and rock formations are everywhere in local thermal equilibrium.
4. Entering and leaving heat flow to/from the reservoir prior to the exploitation are equal to each other.
5. Capillary pressure is negligible.
6. Compression work is negligible.
7. Chemical reactions in the formation are neglected.

Although the program structure is for confined aquifers for the sake of solution convergence, it is also applicable to unconfined reservoirs if the following assumptions are realistic.

1. Precipitation (and return water from domestic use) may be considered as a source for each top block.
2. Due to high permeability of alluvium, the elements just below a river are kept fully saturated.
3. Steady state subsurface water flow may be neglected.
4. Water flow from the cross-boundaries may be neglected.

The first two assumptions apply for deep well exploitations since their effects on the region of interest are negligible. The third assumption is realistic for small water table slopes and low permeabilities. The fourth assumption is applicable for river bed simulations.

The program was run on an IBM 360 computer at The University of New Mexico Computing Center to predict the behavior of the Albuquerque Basin under geothermal exploitation. Five likely cases were chosen for study:

1. Exploitation from the entire basin without a reinjection well.
2. Exploitation from the entire basin with a reinjection well.
3. Exploitation from a smaller area with increased permeability.
4. Exploitation from a smaller area with increased permeability and flow rate.
5. Exploitation from a reservoir with a $1 \times 1 \text{ km}^2$ surface area and very low permeability.

Cases 1 and 2 were covered in the second quarterly report (Kauffman and Houghton, 1980 a) while cases 3, 4, and 5 were covered in the third quarterly report (Kauffman and Houghton, 1980 b).

Since the withdrawn water will be used primarily for space heating, which applies to only part of the year, the simulation time was chosen as 7 to 9 months for all cases. The basin size is 40.7 km, north to south, 36.2 km, east to west, and 3.05 km in depth. Cases 1 and 2 consider the entire basin as the reservoir. Both cases include the effects of the Rio Grande on the reservoir. In all cases, precipitation and steady state north to south ground water flow are neglected. The withdrawal well is inserted to 2.33 km depth to obtain a water temperature of 90°C.

Case 1

This case investigates reservoir performance for a flow rate of 650 gpm and a permeability of 4 millidarcies. At the end of 9 months, the model predicts the saturation values of all reservoir elements to be very close to one. Investigation reveals that the most change occurs at the well element and the elements next to it. Small saturation decreases in the upper elements may be attributed to the river. The river makes up a total of 5.04×10^6 kg during the nine months. If this amount is compared with the total withdrawn water (9.40×10^8 kg), then we may conclude that about 0.54 percent of the withdrawn water is replaced by the river. If other regions under the river in the vicinity of the well are taken into account, the make-up water amount may be expected to be around 0.7 to 0.75 percent.

The pressure differences created in the reservoir during exploitation may be expected to give an insight to the water movement phenomena. The program predicts no drastic changes in pressure values. The greatest percent pressure change occurs in the top element of the well column (this column includes the element from which the water is being withdrawn and all the elements above and below it). This value was -2.5% after 9 months, indicating downward water movement. The drawdown after nine months was 4.23 meters in the well column.

The horizontal flow at the bottom of the well is higher than at other levels. It is worth noting that the horizontal flow at the depths above the well is smaller than it is in the ones below the well. This result is mainly due to the lack of vertical mass flow to the bottom element.

The model predicts almost no temperature change over the nine months interval. This result may be attributed to the following reasons:

- i. Mass flows through the different temperature boundaries are not high enough to create any temperature change.
- ii. The reservoir recovery is quick enough to compensate for any temperature change.

Case 2 -

The same data for the first case are also used for this application. An injection well with the same flow rate as the withdrawal well is placed in an element in an adjacent column. The return water is at 65°C and is injected to a depth of 1.5 km.

At the end of seven months, the model predicts water saturations of the withdrawal well column elements to be very close to one. All other blocks are at a saturation of one. If the results are compared with the first case, relatively less drop in the saturation values is noticed. This shows that the horizontal mass flow in the regions between the wells is higher than for the first case. At the withdrawal well depth and the injection well depths, the positive and negative pressure variations meet at around 3.5 months. After this time, the horizontal flow gains importance.

Consistent with the above interpretation, at the end of seven months, relatively lower pressure changes than in the first case are expected. The greatest percent pressure change occurs again in the top well column element. Its change after seven months was - 1.48%.

The Rio Grande plays an important part. In this case it removes water from the injection well column elements. In addition to the top element of this column, two other top elements also contribute to the drainage phenomena. The results lead us to conclude that about 12 to 13 percent of the injected water may be expected to leave from the

top elements at a lower temperature. Due to the reinjection, the average drawdown for the withdrawal well column was smaller than the first case. The value was 2.46 meters.

Temperature values over the seven months stayed almost constant. The same interpretation as for the first case is also valid here. By comparing the first and the second cases, it may be concluded that exploitation will not create any drastic changes in the initial properties of the reservoir for the specified well positions, reservoir size, and given data.

Case 3 -

The surface area of the reservoir was reduced to a ten-by-ten kilometer area with the same withdrawal well flow rate and well depth. A value of one darcy was assumed for the permeability of the reservoir. There was no reinjection well.

The results showed a saturation of nearly one in every block, indicating fairly even exploitation throughout the reservoir. The greatest percent pressure change occurred in the top element of the well column. Its value was -2.06%. The temperatures once again showed minimal change in all elements. The average drawdown in the well column after nine months was 3.5 meters.

Case 4 -

A withdrawal well with a flow rate of 2000 gpm was used for this case to show reservoir characteristics if the flow rate was ever increased due to possible expansion of the project. All other values were the same as in Case 3.

The saturation patterns showed a similar reservoir exploitation pattern as had occurred in Case 3, indicating the increased flow rate had little effect on the communication between the elements. The greatest percent pressure change is found in the top well column, as it was also found in all previous cases. This was -6.33%. The pressure and temperature patterns in the reservoir are similar to Case 3, although of different magnitudes. The change in temperatures throughout the reservoir can again be neglected. The drawdown after nine months in the well column was 10.6 meters.

Case 5 -

The surface area was reduced to a two-by-two kilometer area. The permeability was reduced to one millidarcy so the effects of drilling into a reservoir with extremely low permeability could be observed in the vicinity of the well. The flow rate was 2000 gpm. All other values remained the same as the last two cases.

The saturation levels after nine months dropped below one in almost all the elements, as was expected. The greatest percent pressure change was found in the well element. Its pressure dropped 72.3 percent. This shows, unlike the last two cases, more of a local exploitation than a total reservoir exploitation. This would eventually cause problems for such items as pumping cost, and the useful life of the well. The temperatures once again had very small changes throughout the reservoir. The drawdown after nine months had already reached an average value of 25.4 meters in the well column. This drop after only nine months would cause problems concerning the pumping costs as it has not yet reached a steady state value.

D. Results

Based on the calculations of part A, one can assume a good estimate for the drawdown in a reservoir with one darcy as its permeability would be in the range of sixteen to nineteen feet. The value of one darcy is believed to be conservative for the Albuquerque Basin. When one darcy was used in the computer model, the reservoir had small pressure and temperature changes throughout the reservoir, leading one to conclude that the effects of extracting geothermal water from the basin would have minimal effects on the reservoir capabilities for years to come. This fact is also confirmed by the calculations done in part B. They show it would take over fifteen years to exploit ten percent of the water from a volume of one km^3 having twenty percent porosity. Water flow comparisons show similar or much smaller orders of magnitude when the flow rates of one and five 650 gpm wells are compared to other water flow rates. All the calculations of drawdown, and flow and capacity comparisons do not include the effects of fluid reinjection which might be used for the disposal of the geothermal water. If this were taken into account, drawdown and reservoir depletion would be even smaller.

Task I.5 Scaling and Corrosion

A. Expected Brine Composition

Extensive chemical data for water from the upper part of the saturated zone in the northern part of the Albuquerque Basin show that the ground water is of relatively good quality. It commonly contains less than 1,000 mg/l dissolved solids. However, data (Table XVI) obtained from the Shell Oil Company Santa Fe Pacific No. 1 well (Hiss 1975), the Shell Oil Well Isleta Central No. 1 (U.S. Department of the Interior), and from an Office of Saline Water Study (Kelly 1970), suggest deterioration of water quality with increasing depth. Based on extrapolations from these deep well fluid compositions and temperatures, we have made a preliminary "best" estimate of the temperature and brine composition expected at a depth of 8400 ft (see Table XVII). The estimated bottom-hole temperature of 195°F correlates with the calculated local temperature gradient of 30°C/km ascertained from other studies (Jiracek and Callender, 1980).

B. Corrosion

1. Testing Program

a) Purpose and Importance

Corrosion can be one of the primary problems in the use of geothermal energy. The proper application of corrosion engineering fundamentals to potential problems will reduce, to a great extent, the effects of the aggressiveness of the geothermal brine. This corrosion study is intended to be a preliminary guide for design engineers supporting a UNM geothermal project.

b) Test Loop Design

The design of a flow system for corrosion testing with brines involves control of four major environmental conditions:

- 1) Temperature
- 2) Fluid composition
- 3) Fluid velocity
- 4) Dissolved "active" gas content

Therefore any viable test loop design must possess the capability to monitor and control these variables.

	TABLE XVI CHEMICAL QUALITY OF WATER RECOVERED DURING DRILL-STEM AND OTHER TESTS OF THE SHELL OIL CO.			
	Santa Fe Pacific No. 1 NW1/4 SW1/4 Sec. 18 T.13N., R.3E.			Isleta Central 1 07N. 02E. 07. 11414A
Depth of Producing Interval	9392-9510 ft	6720-6753 ft	2935-2945 ft	2578-2628 ft
Bottom-Hole Temp.	100°C	70°C	32.5°C	32°C
pH	8.0	7.5	9.5	9.0
	Dissolved Solids (PPM)			
Ca	49	21	40	4.3
Na	1600	1400	460	150
K	44	62	20	2.4
Mg	9	26	.6	.6
Cl	500	360	86	8
SiO ₂	---	---	24	58
HCO ₃	1140	1350	330	280
CO ₃	220	---	68	17
SO ₄	1700	1580	49	66
Ar	22 ppb	21 ppb	110 ppb	75 ppb
Ba	< 1	< 1	---	--
B	7.1	7.0	2.2	.5
TDS	4700	4730	1330	

TABLE XVII
EXPECTED BRINE COMPOSITION

<u>Component</u>	<u>Concentration (mg/l)</u>
Calcium	30.
Sodium	1200.
Potassium	45.
Magnesium	10.
Chloride	500.
Silica	75.
Bicarbonate	950.
Carbonate	180.
Sulfate	800.
Arsenic	0.02
Barium	1.0
Beryllium	0.01
Boron	2.0
Cadmium	0.01
Total Dissolved Solids	3000.

The test loop employed for this study consists of a centrifugal pump, heater, solution reservoir, orifice meter, control valve, oxygen monitoring system and a series of specimen holders (See Figure 31).

Pump. The pump selected for this application was a Model 6K582 Teel close-coupled centrifugal pump. The pump housing, impeller shaft, and head are all fabricated from bronze, thus minimizing corrosion damage to the pump and resultant contamination of the solution. The pump is driven by a 1 HP, 60 HZ Dayton capacitor motor designed to operate at a maximum of 3450 RPM. The motor is equipped with thermal protection. The inlet and outlet of the pump are 1-1/4 and 1-inch, respectively. A 1-inch CPVC (chlorinated polyvinyl chloride) plastic line and 1-inch CPVC bypass valve were installed to permit the excess output of the pump to be returned to the pump inlet without passing through the hot brine loop. This arrangement is necessary in order to maintain a constant back pressure on the pump independent of flow through the loop.

Orifice Meter. An orifice meter was installed using two 1-inch CPVC flanges and a 1/2-inch aluminum orifice plate. The 1-inch CPVC pipe was tapped on both sides of the flanges using 1/8-inch pipe to 1/4-inch Swagelok taps. From each of these taps, 1/4-inch copper tubing connected Ashcroft Duragauge pressure gauges with a range from 0 to 100 psig. A 1-inch CPVC tee and valve was installed downstream of the orifice meter for calibration purposes.

Oxygen Monitoring. A Weston and Stack Model 3400 Dissolved Oxygen Analyzer (Serial # 0118) with Model 102-5 Flow Cell Assembly (Serial #128) was selected for fast, accurate, and direct measurement of dissolved oxygen in the hot brine stream. The analyzer has three readout scales:

- 1) 0-20 mg/l (ppm)
- 2) 0-200 μ g/l (ppb)
- 3) 0-20 μ g/l (ppb)

After proper temperature and pressure conditioning of the sample to be analyzed, the Model 102-5 Flow Cell Assembly was connected to the hot brine loop. Dissolved oxygen passes through the Teflon Membrane of the immersed Model 60 Sensor Probe. At the platinum cathode, a

Figure 31. Hot Brine Corrosion Test Loop.

reduction reaction is initiated whereby an oxygen molecule gains two electrons to yield two hydroxyl ions. Simultaneously, at the lead anode of the oxygen sensor, two hydroxyl ions release electrons to form an oxide with the anode material. The anode and cathode are connected electrically through an external circuit and the resulting flow of electrons is a current flow directly related to oxygen concentration. This current flow is temperature compensated by a thermistor assembly in contact with the sample stream and the electronic signal fed to the Model 3400 Analyzer where measurement is displayed on the meter.

Heat Supply. The brine will be kept at a constant temperature of 195°F throughout the experiment. A 1-inch, screw-in, Chromalox X791, 120 V, 1500 Watt water heater element supplies the heat to the hot brine loop. The controller is a Honeywell T675A Remote Bulb Temperature Controller, which controls over a temperature range from 160°F to 210°F.

Stand Pipe Reservoir. The stand pipe reservoir consists of a 6-inch CPVC pipe with the associated tee, elbow, and reducing bushings to accommodate the 1-inch CPVC inlet and outlet lines of the loop. On top of the reservoir a 1/2-inch CPVC valve was installed to function as a vapor bleed for oxygen removal. A 1/2-inch copper tube connected to the top of the stand pipe serves as a means to supply a nitrogen cap to keep 50 psig on the system. The heating element is threaded into the 6-inch tee near the top of the reservoir and the thermocouple bulb was inserted 10 inches below the heating element. A 1/4-inch copper tube line inserted 1-foot from the bottom of the stand pipe supplies the nitrogen purge for oxygen removal. A 1/2-inch CPVC valve at the bottom of the stand pipe reservoir serves as a drain for the system.

Materials. Except for the pump, test sections, heat supply and copper tubing, all construction materials are of high-temperature grade CPVC (SCH 80).

Test Sections. The test sections consist of 1 1/4-inch OD metal tube specimens for uniform corrosion studies, 1-inch 90° metal elbow test specimens for erosion corrosion studies, and 3 1/2-inch metal test

strips for stress corrosion studies in continuous contact with the synthetic hot brine. The tube specimens are connected in series with 1 1/4-inch ID Dayco Thoro Flow, Series 7101, reinforced, pressure rated, multipurpose rubber hose to prevent metallic contact between the individual tube specimens. The rubber hoses to metal tube fittings are double clamped to insure a water-tight seal. The 1-inch 90° elbows are connected in series as shown in Figure 31. U-bend specimens will be used for the stress corrosion studies. A Teflon bolt will be placed through the holes in the legs of the U bend and will be loaded by tightening a Teflon nut on the bolt. The stresses applied will range from 50 to 100 percent of the yield strength of the particular metal tested.

c) Brine Composition and Process Conditions

In order to set the four major operating parameters previously mentioned for a corrosion test properly, the actual plant service conditions should be known. Since the UNM geothermal project is now only in the design state, these parameters had to be estimated to simulate the actual service conditions as closely as possible. The greater the deviation from plant conditions the less reliable the test results will be.

Based on extrapolations from deep gas well fluid compositions and temperatures we have made a preliminary "best" estimate of our expected brine (see Table XVII). Two brines were tested, one equivalent to our "best estimate" and one for accelerated testing (Table XVIII). The fluid velocity was set at 5 ft/sec in order to insure highly turbulent flow and proper heat transfer. Geothermal fluids are largely free of dissolved oxygen as a result of the reducing environment caused by chemical reaction of dissolved meteoritic oxygen with underground rocks. Therefore a level of approximately 0.05 ppm dissolved oxygen was maintained throughout the corrosion tests. We do not expect any hydrogen sulfide contamination in the geothermal brine. The test loop was operated at 50 psig to prevent cavitation of the pump and oxygen infiltration.

d) Test Schedule and Techniques:

Proper selection of time and number of periods of exposure is important, and misleading results may be obtained if these factors are not considered. In these tests three exposure periods were used to

TABLE XVIII
SYNTHETIC BRINES

Component (Dissolved)	Brine I (expected composition)	Brine II (for accelerated testing)
	Concentration (mg/l)	Concentration (mg/l)
Ca	30.0	345.0
Na	1,200.0	3,550.0
K	45.0	87.0
Mg	10.0	56.0
Cl	500.0	2,990.0
SiO ₂	75.0	75.0
HCO ₃	950.0	1,450.0
CO ₃	180.0	20.0
SO ₄	800.0	3,260.0
As	0.02	0.6
Ba	1.0	1.0
Be	0.01	0.01
B	2.0	2.0
Cd	0.01	0.01
TDS	3,000.0	11,000.0

provide information on changes in corrosion rate with time and to uncover possible weighing errors. The corrosion test using Brine I was conducted for 45 days total (three 15-day intervals) and the test with Brine II was conducted for 30 days (three 10-day intervals).

All the test specimens were initially prepared by polishing with No. 120 abrasive paper. The 120 finish usually removes sufficient metal to get below any variations (such as decarburization or carburization) in the original metal surface. After surface preparation the specimens were carefully measured to permit calculation of the surface area, degreased and weighed to the nearest 0.1 mg.

e) Materials tested

The resolution of corrosion problems generally involves a combination of materials selection and corrosion inhibitors. Unfortunately, the volumes of water involved in geothermal applications are usually too large to consider chemical means of corrosion control. Further, one must anticipate that any chemical added to the geothermal brine for corrosion inhibition may have to be removed prior to fluid disposal to satisfy environmental quality requirements. Thus, materials selection is the most practical approach to corrosion control.

Materials selections for geothermal service are based on experience in similar applications (Miller 1979), overall history of corrosion resistance for various materials, and their performance in seawater (Orrell 1979, Miller 1976). The types and composition of each construction material tested are presented in Table XIX.

2. Corrosion Test Data

a) Visual Observations

Visual examinations of the corrosion specimens, both before and after cleaning, permitted an evaluation of corrosion product scales as well as the corroded metal surfaces. Visual examination of the carbon steel 1018 samples from both tests showed slight pitting after the corrosion product scale was removed; however, the carbon steel exposed to Brine II showed much more developed pits. The recorded visual observations from tests with Brines I and II are presented in Tables XX and XXI respectively. Figures 32 and 33 show photographs of selected test specimens.

TABLE XIX
MATERIALS OF CONSTRUCTION

MATERIAL	COMPOSITION (%)
Cartridge Brass 260	70 Cu 30 Zn
Copper 122	99.9+ Cu
Aluminum 2024	4.4 Cu 0.6 Si 0.5 Mn 0.4 Mg 0.2 Cr 1.0 Fe 0.2 Ti Al bal
Aluminum 6061	0.25 Cu 0.6 Si 0.15 Mn 1.0 Mg 0.25 Cr 0.25 Zn 0.7 Fe 0.15 Ti Al bal
Stainless Steel Type 304	19 Cr 9 Ni 0.08 C Fe bal
Carbon Steel	0.45 Mn 0.25 Si 0.20 C Fe bal

TABLE XX
CORROSION OBSERVATIONS ON SPECIMENS (BRINE I)

Metal Type	15 Day Interval	30 Day Interval	45 Day Interval
Aluminum 6061 1" O.D. Tube	Encrustation deposits on inside of tube, approximately 16 of them, D = 3.0 mm. Black smut on inside.	Encrustation deposits larger and not as easily removed as before. Inside tube more uniformly black now.	Inside totally black with white-tan encrustation deposits. Severe crevice corrosion on outside of tube.
Aluminum 2024 1" O.D. Tube	Encrustation deposits on inside of tube, 4 deposits, D = 1.0 mm. Gray smut on inside with black color near ends.	Encrustation deposits same. Easily removed, more black color on inside now.	Inside totally black with white-tan encrustation deposits. Slight to moderate crevice corrosion on outside of tube.
Copper 122 1" O.D. Tube	No visible corrosion.	No visible corrosion.	Black smut on inside of tubes, easily removed.
Brass 260 1" O.D. Tube	No visible corrosion.	No visible corrosion.	Black smut on inside of tubes, very loose.
Stainless Steel T 304 1" O.D. Tube	No visible corrosion.	No visible corrosion.	No visible corrosion.
Carbon Steel 1018 1" O.D. Tube	Moderate scaling 20 nodules/cm ² , tightly held, no visible pits.	Heavy scaling. Deposits very tightly held, black spots dispersed in white-tan scaling deposits.	Visually very similar to previous observations.

TABLE XXI
CORROSION OBSERVATIONS ON SPECIMENS (BRINE II)

Metal Type	10 Day Interval	20 Day Interval	30 Day Interval
Aluminum 2024	No crevice corrosion. Pitting on tube edge. Numerous small white tubercles and 6 large ones (~1 mm diameter). Deposits easily removed.	Slight crevice corrosion. Pitting on tube edge more developed. White tubercles larger and more developed. Tubercles not easily removed.	Crevice corrosion developin with severe pitting in this area. Deep pits forming underneath tubercles inside tube. Inside of tube now completely covered with very small tubercles.
S.S. T304	No apparent corrosion. White discoloration inside.	No apparent corrosion. White discoloration inside.	No apparent corrosion. White discoloration inside.
Copper Alloy 122	No apparent corrosion. White discoloration inside.	No apparent corrosion. White discoloration inside.	No apparent corrosion. White discoloration inside.
Brass Alloy 260	No apparent corrosion. White discoloration inside.	No apparent corrosion. White discoloration inside.	No apparent corrosion. White discoloration inside.
Carbon Steel AISI 1018	Formation of rust-red tubercles and broad and shallow pits. Some tubercles rub off black and most of them easily removed. No apparent crevice corrosion.	Increased development of rust-red tubercles now with yellowish scale and white scale. Pitting developing on tube edge.	Inside of tube completely covered with rust-red tubercles. Base metal covered with white and yellow-red scale. Some string-shaped corrosion occurring downstream of pits, approximately 2 mm long and 0.3 mm in height.

1) Carbon
Steel 1018
1" O.D. Tube
Exposed to
Brine I for
1103 hours.

2) Aluminum
6061 1" O.D.
Tube. Exposed
to Brine I for
1103 hours.
Crevice cor-
rosion.

3) Carbon
Steel 1018
1" O.D. Tube
Exposed to
Brine II for
732 hours.

4) Aluminum
6061 1" O.D.
Tube, Exposed
to Brine II
for 732 hours.

Figure 32. Corrosion test specimens.

1) Carbon Steel 1018 U-Bend
Stress-Corrosion Specimen
Exposed to Brine II (732 hr)

2) Carbon Steel Elbow
Erosion-Corrosion Specimen
Exposed to Brine II (732 hr)

3) Carbon Steel 1018 Sheet
Weld-Decay Specimen
Exposed to Brine II (732 hr)

4) Copper Alloy 122
Weld-Decay Specimen
Exposed to Brine II (732 hr)

Figure 33. Corrosion test specimens.

c) Instrumental Analysis

A semiquantitative spectrographic analysis was performed on the corrosion product scales formed on the exposed surfaces of the carbon steel 1018 samples from both tests (Brines I and II). The instrument used was a Wadsworth Mounted, Jarrell-Ash, 1.5 meter, DC Arc Emission Spectrograph. The analytical report from these samples is presented in Table XXII.

Microscopic examination of the corrosion product scales on the carbon steel 1018 specimens was used to measure the average pit depth and diameter as well as to examine the scale morphology. Microscopic examination was also conducted on the stress corrosion and weld decay specimens to ascertain the presence and type of corrosion damage. X-ray diffraction studies were not conducted on the materials reported here.

d) Corrosion Rate Data

Weight loss measurements, complemented by visual and microscopic examinations, were used to evaluate corrosion attack. The corrosion tests operated at 195°F were conducted in the apparatus shown in Figure 31. Uniform corrosion rates were calculated using the formula:

$$\text{Mils per year} = \frac{534 W}{DAT} \quad (12-a)$$

where W = weight loss of specimen, mg
 D = density of specimen, g/cm³
 A = exposed area of specimen, in²
 T = exposure time, hr

Corrosion rate data for the material tested in Brine I and Brine II are presented in Tables XXIII and XXIV respectively. Visual and microscopic examinations were used to evaluate the degree of erosion, crevice, weld decay, stress, and pitting corrosion for the various materials tested.

3. Discussion

One of the purposes of these tests was to predict long-term stability from short-term data. The duration of the test was based on the need for a 30-year life for construction materials. This in turn leads to a maximum allowable corrosion rate of about 2.0 mpy (0.002 in/yr).

	TABLE XXII	
	SEMIQUANTITATIVE SPECTROGRAPHIC ANALYSIS OF CORROSION PRODUCT SCALE ON CARBON STEEL 1018 TUBULAR SPECIMENS	
	Tube scale, exposed to Brine I for 1103 hour	Tube Scale, exposed to Brine II for 732 hours
Metal	Percent by Weight	
Fe	15	20
Mg	0.5	0.2
Ca	1.0	0.1
Si	5.0	1.0
Al	2.0	1.0
K	<0.5	<0.5
Na	0.7	<0.5
P	0.1	<0.1
Cu	0.3	0.2
Pb	0.3	0.3
Zn	0.7	0.3
Sn	>0.1	0.02
Mn	0.07	0.07
Ba	0.02	0.02

TABLE XXIII
CORROSION EXPERIMENT - BRINE I

Metal Tube Tested	15 Day Interval (mpy)	30 Day Interval (mpy)	45 Day Interval (mpy)
Copper Tube I	0.45	0.40	0.49
Copper Tube II			0.42
Brass Tube I	0.44	0.48	0.45
Brass Tube II			0.52
Aluminum 6061 Tube I	7.57	11.01	12.92
Aluminum 6061 Tube II			10.60
Aluminum 2024 Tube I	3.72	4.23	4.88
Aluminum 2024 Tube II			5.77
Stainless T 304 Tube I	0.03	0.03	0.04
Stainless T 304 Tube II			0.03
Carbon Steel 1018 Tube I	593.9*	807.3*	921.9*
Carbon Steel 1018 Tube II			876.4*

* mg weight gain due to scale.

TABLE XXIV
CORROSION EXPERIMENT - BRINE II

Metal Specimen	10-Day Interval (mpy)	20-Day Interval (mpy)	30-Day Interval (mpy)
Copper I	0.35	0.71	0.41
Copper II	----	----	0.65
Brass I	0.25	0.56	0.31
Brass II	----	----	0.19
Al 2024	+44.7 mg	+50.9 mg	+94.2 mg
S.S. T304 I	0.03	0.04	0.01
S.S. T304 II	----	----	+10.4 mg
Steel 1018 I	+98.7 mg	+323.7 mg	+711.1 mg
Steel 1018 II	----	----	+589.3 mg

This criterion was used in the approximation (Fontana & Green 1978):

$$\text{Duration of test (hr)} = 2000/\text{corrosion rate (mpy)} \quad (12b)$$

The test using Brine I ran for the desired 1000+ hours. The Brine II test was somewhat shorter. Since it used more concentrated salts, however, corrosion effects should have been easily observable.

a) Viability of test scheme

The results obtained from the experiments in this corrosion study demonstrate comparable trends found in other corrosion studies in similar environments (Miller 1977, Miller 1979). This would suggest that the test scheme employed in this study is viable.

Tubular samples, rather than the traditional coupons, were used in this study to simulate the actual service conditions present in geothermal systems.

b) Interpretation of test results

Copper and brass show excellent corrosion resistance compared to Aluminum Alloys and low carbon steel for service in low temperature (195°F) geothermal brines. Stainless steel T304 shows about a 10-fold increase in corrosion resistance over the copper and brass. These results are based on using a synthetic geothermal brine to simulate the actual brine we expect to locate under the UNM campus.

Weight loss measurements show that copper 122, brass 260, and stainless steel T304 are acceptable structural materials for geothermal service, carbon steel 1018 can be used but with precautions, and Aluminum Alloys show unacceptable corrosion rates for geothermal service.

All the crevice corrosion specimens showed virtually no attack except for the Aluminum Alloys which exhibited severe crevice corrosion, Aluminum 2024 being attacked more severely than Aluminum 6061 (see Figure 32-2). Results showing that the copper, brass, and steels did not suffer crevice corrosion may be a misleading finding since there is often a long incubation period associated with crevice attack. Six months to a year or more is sometimes required before attack commences. Therefore, these materials could exhibit crevice corrosion in prolonged geothermal service.

None of the materials tested showed any evidence of cracking due to stress. Aluminum 6061 did show some severe pitting near the top of the U-bend (the area where most of the stress is applied). The carbon steel 1018 U-bends showed severe pitting and general corrosion, yet no cracks developed (see Figure 33-1).

The copper, brass, and stainless steel specimens exhibited no joint decay or corrosion in the joined zone. These specimens were lead-tin soldered joints similar to those used frequently in heat exchanger operations. The carbon steel 1018 joint specimen did not exhibit weld decay but did suffer pronounced pitting in the joint zone. The weld-decay zone is usually a band in the parent plate somewhat removed from the weld. The surface of the carbon steel plate was covered with a dark rust-like corrosion scale product (Figure 33-1). The surface corrosion scale can best be described as the formation of rust-red tubercles overlying broad and shallow pits.

Visual examination after cleaning of the carbon steel and aluminum erosion corrosion specimens showed some very shallow identifiable pits. The copper, brass and stainless steel specimens showed no visual sign of erosion corrosion.

c) Recommended further testings

The copper and brass specimens have shown acceptable corrosion resistance, therefore, it would be advisable to conduct additional studies on the various brasses commercially available (naval brass, yellow brass, admiralty brass, etc.) to ascertain the most effective alloy for the UNM project.

As mentioned before, the four major factors controlling corrosion are temperature, fluid composition, fluid velocity, and dissolved "active" gas content. Changing one of these variables while holding the others constant might reveal some corrosion phenomena that would otherwise be overlooked.

C. Scaling

Suspended solids and scale can originate from corrosion, micro-organisms, and dispersed mineral scale deposition. The major suspended solids resulting from corrosion are iron sulfides, carbonates and

various oxidated states of iron:

Suspended solids can also originate from mineral scale deposition. The most potentially damaging species include calcium carbonate, calcium sulfate, barium sulfate, and amorphous silica. Precipitation of calcium carbonate and calcium sulfate is not expected because their solubility increases with decreasing temperature (Helgeson, 1967). Precipitation of barium sulfate will be minimal. At 100°C its solubility is about 4 ppm, and 2.5 ppm at 21°C (Hiss, et al., 1975). Precipitation of amorphous silica should be minimal unless there is a large temperature drop. The species that precipitates from solution at ambient pressure is always amorphous silica (Wahl, 1977), whatever the original source. Equations 12a and b (Wahl, 1977) give the solubility of silica with quartz and amorphous silica, respectively,

$$\text{SiO}_2 = \text{EXP}(11.2 - 2662/\text{T}) \quad (13\text{-a})$$

$$\text{SiO}_2 = \text{EXP}(10.16 - 1573/\text{T}) \quad (13\text{-b})$$

with SiO_2 concentrations in ppm and T in Kelvin. These equations show that silica precipitation is not possible in a system going from 200 to 70°F.

Based on the expected water chemistry for a deep well in the Albuquerque area, we do not expect any precipitation of solids in the geothermal system. Scaling due to fine suspended solid particles from the reservoir or from corrosion, however, cannot be completely ruled out at this time. The commonly occurring problems of CaCO_3 and/or SiO_2 precipitation scale, however, can be ruled out.

The only scale deposition that took place in the corrosion experiments with Brines I and II occurred on the carbon steel 1018 specimens. The texture of this scale is shown in Figures 32 and 33. The deposit formed with Brine I had some uniform areas and some nodular areas. Shallow broad pits underlaid the nodular deposits. Analysis of the metal cation constituents are presented in Table XXI for both brines tested. The deposits from both brines effervesced with dilute HCl, indicating the presence of carbonate ion; however, there was insufficient sample to ascertain the amount quantitatively. A total sulfur, sulfate ion, and pyritic sulfide test was performed on the deposits from both Brines I and II. The results from these analyses were as follows:

	Brine I Deposit	Brine II Deposit
Total sulfur (wt%)	0.05	0.25
Total sulfate (wt%)	<0.05	0.17
Total pyrite (wt%)	<0.05	0.08

The total weight percent of the metal ion constituents for Brines I and II amounts to 25.3 and 24.3 percent, respectively. However, the upper limits of detection for iron (the main constituent in both deposits) in the semi-quantitative emission spectrographic analysis employed was 20 percent by weight, thereby making the weight percent of iron suspect for at least the deposit from Brine II. A much higher weight percent iron than was found for the deposit with Brine II could possibly explain the low sum total of components. Even if all the metal ion constituents found for the deposit with Brine I were present in a carbonate or hydroxide state, this would account for less than half the sum total of sample weight assayed. Entrapped water molecules could account for some of the "missing" weight. With the small amount of deposit sample to work with (less than 1.0 g) it was not possible to measure with accuracy all the components present in the deposits. Therefore, the only conclusion that can be made is that the deposits' main constituents appear to be iron, aluminum, calcium, magnesium, silica, and an unknown yet observable amount of carbonate.

D. Preliminary Recommendations

1. Pipelines and fittings

Results from corrosion studies using Brine I (best estimate of brine located underneath UNM) would suggest the use of low carbon steel 1018 for the well casing and transmission lines and the use of carbon steel for all fittings (i.e. elbows, tees, plugs, couplings, flanges, etc). Results from corrosion testing with Brine II suggest that some corrosion inhibition may be needed for these materials.

2. Heat exchangers

The primary conclusion of these tests is that brass, copper and copper alloys are corrosion-resistant and economical materials for heat exchanger construction. This conclusion holds for both Brine I and II.

3. Pumps and control valves

Results suggest that pump impellers, housings, and casings should be constructed of brasses to insure constant pumping rates. The pump used for those corrosion tests was fabricated from brass and showed negligible corrosion. The pump impeller also constructed of brass developed black surface but showed no cavitation or other damage.

Task I.6 Surface Facilities

Preliminary evaluation of surface facilities upstream of the user were carried out to identify key problem areas and important cost considerations. Figures 34 and 35 show two system designs which could be used. The first uses direct flow of geothermal water to each building. The second system uses a separate clean water circulating loop. It is less efficient thermodynamically, but it may have economic advantages due to more positive control of heat exchanger fouling. Note that these designs include some items which may not be required. Later work defined the system more exactly. Descriptions given below are those used for early working estimates, all subject to later modification.

A. Production Well

The well will produce 500 to 750 gpm of water at about 200°F. The well flow diameter will be 5 to 8 inches. The well will be cased to full depth.

Well costs for a 500 to 700 gpm production well were estimated in several ways. Costs for average onshore oil and gas wells were used to generate cost vs. depth curves (solid lines in Figure 36) (Oil and Gas Journal, 1979). Additional data for geothermal wells were obtained at the project mid-term review with EG&G personnel on April 25, 1980. All data were adjusted to a 1980 basis. The additional data are shown as single points in Figure 36. An adjusted curve was fitted to these data, following the general shape of the earlier correlations. This new curve will be used for current cost estimates:

$$\$/\text{ft} = 18.714 + 9.143 \left(\frac{D}{1000} \right) + 0.4286 \left(\frac{D}{1000} \right)^2 \quad (14)$$

where D is the well depth in feet. The correlation is adequate for wells from 2000 to 12000 feet in depth.

Actual well costs, of course, are usually based on drilling time, not depth. For any given well, the above correlation could be in error by 30 percent or more. Until a deep well is drilled in the area, however, this correlation represents as reasonable an estimate as can be made.

Figure 34. Direct heat system surface facilities.

Figure 35. Indirect heat system surface facilities.

Figure 36. Average well costs (1980 basis).

B. Well Pump

Fluids must be pumped to the surface from a depth corresponding to the local water table plus well drawdown and friction losses. As shown earlier, this depth will be a few hundred feet. It is necessary, therefore, to use a down-hole pump. Since the pump is located in the well, an installed spare cannot be included in the design. No specific type is yet recommended. Selection will be based on reliability and ease of maintenance as well as efficiency. Pump size will be in the range of 50 to 500 HP.

A detailed estimate for a down-hole pump installation was obtained from TP Pump and Pipe Company, Albuquerque (Chavez, 1978). Total equipment cost, adjusted to 1980, for a unit producing 48.7 hydraulic HP (85 HP motor, overall efficiency of 57 percent) is \$32,000. Installation is estimated to be an additional \$20,000. Necessary spare parts and auxiliary equipment add another \$9,000. We estimate a scale factor on pump capacity of 0.4. Thus, we arrive at the following production pump estimated cost:

$$\text{\$} = (61000)(\text{HP}/48.7)^{0.4} \quad (15)$$

where HP is the delivered hydraulic horsepower.

C. Chemical Addition

It may be necessary to add some chemicals to the geothermal water to control corrosion, scaling or environmental problems. Through preliminary design, we included facilities for adding a liquid solution at a rate corresponding to about 0.1 percent of the geothermal water flow rate. This would be sufficient, for example, to add an oxygen scavenger and a corrosion inhibitor.

We estimate installed costs for a 1000 gallon, carbon steel mixing vessel, a 2 HP stirrer, and associated control equipment to be \$21,000.

D. Surge Tank and Inert-Gas Blanketing

A surge tank is needed upstream of users to allow for short-term local variations without disturbing the well pump and to permit minor maintenance on the well or well pump. Capacities corresponding to 1/4 to 2 hours of flow were examined. The tank also serves as a settling

chamber for any suspended solids which may be produced with the water. The tank will be insulated.

E. Inert Gas Blanketing

Many studies have shown that effective corrosion control requires that the geothermal water be oxygen free (for example, Kauffman and Houghton, 1979a). The produced water should be oxygen free. The volume of liquid in the surge tank, however, will fluctuate with time. Normal tank "breathing" would bring the water into contact with air. It will, therefore, be necessary to provide inert gas blanketing of the tank. We also considered other techniques of excluding oxygen, such as sulfite addition or a floating oil cap in the surge tank. We concluded that inert gas blanketing, coupled with sulfite addition, would be most effective.

We estimated installed costs for a surge tank based on data from Guthrie (1969) and Peters and Timmerhaus (1980). The total installed cost for an insulated carbon steel cone-roof tank with an inert-gas blanketing system can be fitted to the following formula:

$$\$ = 6.9 G^{0.83} \quad (16)$$

where G is the capacity in gallons.

F. Distribution Pumps

One or more 25 to 75 HP pumps are required to distribute the geothermal water or secondary loop water from the surge tank to users. They provide sufficient head to move the fluids to, or through, the disposal system. These pumps will have installed spares as a back-up to improve system reliability. Standard centrifugal pumps will be used.

Costs for distribution pumps were compiled using data from Guthrie (1969) and Peters and Timmerhaus (1980). The data are plotted in Figure 37, taking into account typical efficiencies for centrifugal pumps.

G. Distribution Pipelines

Pipelines from the well and to users will be insulated carbon steel. Pipeline configurations and cost estimates were based on data published by Dow Chemical Company (Marshall and Brandt, 1974). For

Figure 37: Centrifugal pump costs (1980).

preliminary comparisons, an average cost of \$40/ft is used for the piping systems (one-way basis).

H. Primary to Secondary Heat Exchanger

Cost data for large heat exchangers are taken from Guthrie (1969) and Peters and Timmerhaus (1980). In the range of interest, the cost of a brass-tube, steel shell exchanger, including installation, is given by

$$\text{\$} = 153000 (A/10000)^{0.6} \quad (17)$$

where A is the heat transfer area in square feet.

Task I.7 Disposal

Preliminary designs and cost estimates were prepared for a variety of geothermal water disposal methods. It soon became clear that only two methods could be at all feasible in terms of economics and environmental effects, release to the storm sewer system and reinjection into the reservoir. Storm sewer release might or might not be permitted due to environmental constraints. ReInjection, therefore, appears to be a very likely requirement.

This portion of the report describes the economic comparisons for the various disposal alternatives. Details of the cost estimation procedures are given in the Second Quarterly Report (Kauffman and Houghton, 1980a). An additional section on disposal well technology is added since this appears to be the most likely alternative.

A. Description of Waste Water Disposal Processes Cost Estimates

All process and cost calculations were based on an effluent with 3000 ppm dissolved solids at 110°F. The operating schedule was based on a flow of 600 gpm for 4000 hours per year. The volume of effluent is 1.44×10^8 gallons/yr.

All capital costs were determined for mid-1980 using a Chemical Engineering cost index of 260. The utility costs were based on power supplied at \$0.06/kW hrs. Criteria for labor and maintenance costs are presented in Table XXV. An estimate of \$10/hr was used as the cost of labor, including supervision and overhead.

A summary of the processes is given in Table XXVI. Total cost estimates are summarized in Table XXVII.

Case I. Direct Release to Surface Water Bodies

Since geothermal effluents can have a wide variety and high concentration of salts dissolved in them, surface disposal can pollute the environment to some extent. By direct release to surface bodies, the natural balance of those bodies will be affected. In some places not only will the bodies be affected, but so will the surrounding groundwater if the surface water flows into the groundwater. If this happens, wells and plants in the vicinity could be adversely affected.

TABLE XXV
Maintenance and Labor Costs

Maintenance Costs

<u>Equipment Item</u>	<u>Annual Charge (% of Capital)</u>
Pumps	10
Mixers	10
Filters	10
Clarifiers	5
Tanks	3
Wells	2
Pipelines and Ponds	0

Operating Labor Requirements

<u>Process</u>	<u>Time, hours/week</u>
I Direct Release	1
II Evaporation	8
III Surface Release	8
IV Sewer	1
V Reinjection Well	6
 <u>Pretreatment</u>	
Mixer	4
Clarifier	2
Filter	20

Table XXVI

Summary of the Disposal Possibilities

I. Direct release to surface bodies

Cost: relatively inexpensive

Technology: existing technology

Legal: must pass strict state and federal regulations

Environmental: unacceptable without pretreatment

II. Evaporation

Cost: major expense is the cost of the land

Technology: existing technology

Legal: not as strict as the previous method, but still has restrictions

Environmental: unacceptable if any leaks in the container are present. Also a problem with the release of dissolved gases and increases in the humidity due to evaporation. Solids must be disposed of.

III. Surface spreading to shallow aquifers

Cost: relatively inexpensive

Technology: existing technology

Legal: must pass strict state and federal regulations

Environmental: unacceptable without pretreatment

IV. Release to a municipal sewer system

Cost: probably an inexpensive method

Technology: existing technology

Legal: not known

Environmental: an acceptable method only if salt levels are very low; probably not acceptable for UNM system.

V. Reinjection

Cost: major cost in the well

Technology: effects of the injected brine on the geology and the brine interaction with the formation are not well understood

Legal: not as strict as the others are, permits required.

Environmental: most acceptable method

TABLE XXVII
Cost Summary of Proposed Fluid Disposal Systems

Case	Pretreatment Used*	Capital Cost \$	Utility Cost \$/yr	Maintenance Cost \$/yr	Labor Cost \$/yr	Total Annual Operating Cost \$/yr
I.A	--	37,000			520	520
B	--	53,000			520	520
II.A	E	7,867,000	20,100	1,300	4,160	25,600
B	E,B	8,009,000	20,100	8,500	5,200	33,800
C	E	26,267,000	20,100	1,300	4,160	25,600
D	E,B	26,409,000	20,100	8,500	5,200	33,800
E	E	8,044,000	29,700	3,200	4,160	37,100
F	E,B	8,186,000	29,800	10,300	5,200	45,300
G	E	8,228,000	29,700	3,200	4,160	37,100
H	E,B	8,370,000	29,800	10,300	5,200	45,300
III.A	E	315,000	12,600	3,200	4,160	20,000
B	E,B	458,000	12,600	10,300	5,200	28,100
IV.A	--		112,000		520	112,500
V.A	D,A,B	487,000	16,200	20,400	6,240	42,800
B	D,A,C	416,000	17,100	20,400	15,600	53,100
C	D,B	451,000	12,600	16,800	4,160	33,600
D	D,C	380,000	13,500	16,800	13,520	43,800
E	D,A,B	661,000	16,200	23,900	6,240	46,300
F	D,A,C	590,000	17,100	23,900	15,600	56,600

(continued)

TABLE XXVII (continued)

Case	Pretreatment Used*	Capital Cost \$	Utility Cost \$/yr	Maintenance Cost \$/yr	Labor Cost \$/yr	Total Annual Operating Cost \$/yr
V.G	D,B	624,000	12,600	20,200	4,160	37,000
H	D,C	553,000	13,500	20,300	13,520	47,300
I	D,A,B	972,000	16,200	30,100	6,240	52,500
J	D,A,C	901,000	17,100	30,100	15,600	62,800
K	D,B	935,000	12,600	26,500	4,160	43,300
L	D,C	863,000	13,500	26,500	13,520	53,500

*A - mixer

B - clarifier

C - Filter

D - Tank (6 hr)

E - Tank (1 hr)

In any type of surface disposal, the effluent must meet state and federal regulations. In New Mexico these requirements are specified by the Water Quality Control Commission (1977). If the effluent does not meet these requirements, three alternatives are possible:

- 1) The Director of the New Mexico Environmental Improvement Agency may grant an exemption.
- 2) If the existing concentration of any water contaminant in the groundwater exceeds the regulations, the effluent may be disposed provided that no degradation of the groundwater beyond the existing concentration will be allowed.
- 3) The effluent may be pretreated to meet disposal criteria.

Environmental concerns include chemical and thermal pollution. Increases in CO_2 and water temperatures can lead to excessive plant growth which has been a problem at the Wairakei plant (Axtmann, 1975). Certain species of fish are temperature sensitive and small changes can have a great effect on them. Certain quantities of dissolved solids can be detrimental to any plants growing in the surrounding area. The amount of dilution will be determined by the quality and quantity of water in the receiving body. The Rio Grande fluctuates greatly in flow rate and total dissolved solids (TDS) over the year (Mercer and Faust, 1977).

The capital and annual costs were calculated for two direct release disposal systems. The cost of piping was the only equipment cost used in calculating the capital costs. System A consisted of 1 mile of 12" concrete piping. System B uses 18" piping. Trench digging costs for both systems were also included in the capital costs. A cost basis of \$6/ft of piping was used for 12-inch pipe and \$9/ft for 18-inch pipe. Trenching costs were estimated at \$5300/mile.

Case II. Evaporation Ponds:

Evaporation of the effluents could be done with evaporation ponds. The pond container could be constructed with existing natural material, man-made materials, or a combination of them. Assuming that the evaporation ponds are constructed on areas where downward leakage is

negligible, brine evaporation should be a feasible method of disposal.

Average annual precipitation and lake-surface evaporation are 10 and 60 inches respectively in the Albuquerque Basin (Kelly, 1970). Rough calculations show a pond area of about 368 acres would be needed. Evaporation leaves the solids behind. Acceptable means of disposing of these salts (on the order of ten tons per day) would have to be provided. Another disadvantage of this method is it may significantly increase the humidity in the vicinity.

Calculations for Cases II A through D are based on the pond being on UNM property or in a residential area within two miles of UNM. Cases II A and B used zero land cost while Cases II C and D were based on \$50,000/acre land cost. Cases E through H provide for piping the effluents a distance of 5 miles before they are released to an evaporation pond. Cases II E and F use zero land cost and Cases II G and H are based on \$500/acre land cost.

Each of the proposed methods for Case II uses different pretreatment systems. These are described below in the section on Pretreatment Equipment.

Land, piping, trenching, site preparation, lining, pumps and various pretreatment equipment costs were included in the capital cost of each of the Case II systems. Site preparation consisted of clearing, grubbing, grading, and leveling. Cost estimates for these were taken from Guthrie (1969).

The utility costs included solids removal and pump utility costs. The solids removal calculations were based on effluents of 0.3 percent solids and a base removal cost of \$20 per cubic yard.

The operating costs for the pumps are based on power supplied at a cost of \$0.06/kW-hr and an operating time of 4000 hrs/yr. The pumps are sized using typical pump efficiencies. Maintenance and labor costs are based on information presented in Table XXV.

Case III. Surface Spreading to Shallow Aquifers:

This method is an environmentally dangerous one because the effluent travels directly into the groundwater. Effluent quality is

controlled by the Water Quality Control Commission and the same regulations pertaining to the disposal to surface bodies apply to surface spreading.

Chemical quality of the shallow groundwater in the Albuquerque Basin has been recorded and is significantly better than the expected effluent quality (Bjorklund, 1961). This groundwater is a very important source of domestic water. In all likelihood, then, the Director would not grant an exemption, nor would the existing shallow groundwater salt concentrations exceed the concentrations of salts in the effluent.

The capital costs for Case III include piping, trenching, pumps and various pretreatment costs. Piping and trenching costs are determined for disposal at a distance of five miles. Labor and maintenance costs are based on information summarized in Table XXV. The utility costs consist of the operating cost of the pumps.

Case IV. Release to Albuquerque Municipal Sewer System

This method could be the most economical method. Whether or not this method is allowable is not known, and restrictions are probably determined by state and local officials. If dilution is of a significant amount, this method should have minimal environmental, scaling, and corrosion effects. Some pretreatment might be necessary.

Since there is direct access on campus to the city's sewer system, no capital costs have been calculated for Case IV. Labor costs were calculated using information in Table XXV. A cost of 37 cents/unit is charged by the city for sewage disposal, where 1 unit = 478 gallons. The estimated volume of waste water to be disposed of is calculated as 1.44×10^8 gallons/year.

Case V. ReInjection:

The Water Quality Control Commission also regulates effluent quality and the same regulations governing surface disposal apply to subsurface disposal. Data on the chemical composition of the deeper groundwater (greater than 1,000 feet) are very limited, but if the TDS increases with depth as expected, the TDS of the effluent will exceed that of all the groundwater except that existing at or below

the depth of the producing well. Therefore, unless an exemption is granted or the effluent is treated, it would have to be reinjected into the producing reservoir.

By reinjecting into the producing reservoir, any type of chemical pollution will be minimized. The reservoir pressure and brine levels will also be reestablished. This is known to be an effective method for controlling subsidence (Viets, et al., 1979).

There are many problems associated with reinjection. Most of them depend on the geology and geochemistry of the receiving formation. Earthquakes have been directly correlated with injection at high pressures near existing faults (Raleigh, 1972). In Rangely, Colorado, when the pore pressure exceeded the original reservoir pressure by about 500 psi, earthquakes resulted. When the pressure in the wells straddling the fault zone was reduced, earthquakes in the area decreased and ultimately ceased. To prevent seismic activity of this sort, injection wells should not be located near existing faults.

Reinjection could possibly induce hydraulic fracturing. This is more likely to occur in an area of existing faults. This could be an advantage or disadvantage. The fracturing could increase reservoir productivity, a method used in the petroleum industry. If this is done in such a way as to create a fracture extending to shallow groundwater, the injected effluent could ultimately travel to this water via the fracture, resulting in shallow groundwater pollution. A minimum injection pressure that can induce vertical fracturing can be estimated (Hubbert and Wills, 1972). Fracturing is not expected in the Albuquerque Basin since it is already highly fractured.

Other possible problems include water pollution by well leakage and the cooling of the reservoir. If there is a leak in the well, the injected water could flow into a potable or domestic water zone. Since the spent geothermal fluid has a lower temperature than the producing reservoir, reinjection of the fluid into the producing reservoir could reduce its temperature.

The most likely problem with reinjection, however, is formation plugging. The rate of injection is governed by the pressure at which

the brine is injected and the permeability of the receiving formation. When the permeability is decreased, the backpressure will increase, resulting in either more pumping work or a reduced rate of effluent injection. There are a number of ways the permeability can be decreased. The most important are effluent-rock interactions, effluent-reservoir interactions, and physical blockage of the pores.

Effluent-rock interactions occur mainly as chemical reactions, but can also occur as adsorption. The latter is more important when organic material is being injected and results in the reduction of pore size. A wide variety of chemical reactions are possible, and the geochemistry of the particular formation must be known before any predictions can be made. The Santa Fe group in the Albuquerque Basin will be the producing reservoir for any geothermal energy utilization near Albuquerque. It consists of mostly unconsolidated to loosely consolidated gravel, sand, silt, and clay (Bjorklund, 1961). Two types of chemical reactions are possible that could reduce the permeability. First, a high pH could dissolve silica, which is a cementing agent for fine sand grains. These fines could then migrate in the formation in such a way as to obstruct flow passage (Hower, et al., 1972). Second, ferrous iron could react with oxygen to produce ferric hydroxide, which would precipitate out and also obstruct pore space. The amount of blockage will depend on existing pore sizes.

Effluent-fluid interactions could occur when there is a change in pH. This could shift equilibrium mixtures in a way to precipitate dissolved species. One possibility is the precipitation of calcium carbonate.

The physical blockage of pores could result when the fines existing in the formation are mobilized and then block the flow passages. If there are particulate solids or colloids in the effluent being injected, they could act in the same way.

Cases V A through D, V E through H, and V I through L are based on 2500 ft, 5000 ft and 8200 ft reinjection wells, respectively. Capital costs consist of well drilling, pumps, well casing, inside PVC pipe and various pretreatment costs. Drilling costs were estimated

using average drilling costs reported for oil and gas wells (Oil and Gas Journal, 1979). The well casing consists of 6" steel pipe estimated at \$8.02/ft. Three inch gray Sch 40 PVC pipe is used as a basis for the inside well pipe. This pipe has an estimated cost of \$2.91/ft.

The utility costs include the pump, filter, and mixer operating costs in cases where the filter and mixer are used for effluent pretreatment. Labor and maintenance costs are calculated using information summarized in Table XXV.

The three well depths were selected on the following basis:

2500 feet: injection temperature matches formation temperature

8200 feet: same depth as production well

5000 feet: an intermediate level

Pretreatment (All Cases):

The degree of pretreatment for any disposal method must be evaluated and established beforehand in order that the proposed disposal operation is assured success. The removal of suspended solids to a minimum particle size in order to prevent permeability reduction is usually required for reinjection processes. The removal of the smaller size particles that will not plug the aquifer is unnecessary and wasteful. Spent geothermal effluents are treated by 1) coagulants or coagulant aids to enhance the sedimentation process, 2) clarifiers to remove most of the suspended solids, and 3) filters to remove remaining solids. This is basically municipal water and sewerage treatment applied to a higher temperature, higher salinity fluid.

The removal of dissolved species that may precipitate in the formation is also important. These species are precipitated by using a coagulant or coagulant aid, usually in the form of metal salts, organic polyelectrolytes, or weighting agents. If particles less than one micron must be removed, precoated diatomaceous earth can be used. The size of the particle that must be removed is determined by core sample laboratory testing for porosity and permeability.

Results of recent tests indicate the following (Quong, et al., 1978):

- Agitation significantly aids in coagulation and flocculation in normal brines (pH = 5.5, T = 85°C)
- Coagulants can be used in the range of 40 to 85°C.
- At a pH of 5.5, coagulants have little effect on precipitation rates of the dissolved solids.
- Silica concentrations decline rapidly to saturated levels by raising the pH to 5.9.
- Of the coagulants, $\text{Fe}_2(\text{SO}_4)_3$ and anionic and cationic polymers were most effective.

Water softening can be used to reduce the calcium and magnesium concentrations by precipitation. This is accomplished by the addition of lime in the form of $\text{Ca}(\text{OH})_2$. This process works best at a high pH and temperature (Ferguson, et al., 1976).

The pretreatment used in each case consists of a combination of five pieces of equipment: (A) 20 HP mixer, (B) clarifier, (C) filter, (D) 6 hour holding tank, and (E) 1 hour holding tank.

The mixer consists of a 20 HP propeller agitator. The capital cost of the mixer is determined using methods presented by Guthrie (1969). The operating cost for the mixer is based on power supplied at \$0.06/kW-hr and an operating time of 4000 hrs/yr.

Two methods were used to calculate the capital cost of the clarifier (Eckenfelder, 1969, and Smith and McMichael, 1969). An average of the two values is used in the capital cost summary. These values are based on 864,000 gallons/day of effluent.

The filter consists of a leaf type, wet filter. Two methods are used to calculate the capital cost of the filter. The estimated cost from the two sources is averaged. The two sources are Guthrie (1969) and Smith and McMichael (1969). Each estimate is based on 864,000 gal/day of effluent.

The operating costs of the filter are based on 2 gpm per square foot of filter. The cost of power is \$0.06/kW-hr for an operating time of 4000 hrs/year.

The capital costs for the tank are calculated using methods presented in Guthrie (1969). Each tank is assumed to be made of carbon steel.

B. Injection Well Technology

The requirements of an injection well are (1) to operate under specified injection pressure limits while maintaining the continuous, designed injection capacity, (2) to comply with any environmental regulations, and (3) to ensure that none of the brine will leak or migrate into any domestic water sources.

Well plugging must be minimized if requirement 1 is to be met. There are various ways to predict the amount of plugging. To do this requires knowledge of the size of the suspended solids in the brine and the formation permeability.

Plugging done by microorganisms can be due to fungi, algae, or bacteria. Fungi should not constitute a problem because they need organic material to subsist on. Very little, if any, organic material is present (Hiss, et al., 1975). Algae require sunlight to survive. Unless the brine is exposed to sunlight in an open pond or tank, they will be absent. Thermophilic (heat loving) bacteria have a temperature range for growth between about 40 to 75°C (Wilson, et al., 1971). Because the brine will originally be at least 90°C, there should be little problem with bacteria growth.

To describe the flow characteristics of a fluid from a reinjection well into a porous medium, Darcy's law (Equation 18) can be used. This equation can be integrated

$$\frac{Q}{A} = - \frac{k}{\mu} \frac{dp}{dr} \quad (18)$$

and is applicable to any fluid flowing through a porous material so long as conditions of flow are viscous (Calhoun, 1953). Equation 19 is the resulting integral assuming radial flow.

$$\frac{Q}{A} = - \frac{\mu \ln(r_e/r_w)}{2\pi k h (P_e - P_w)} \quad (19)$$

where:

- Q = volumetric flow rate
- k = permeability
- h = perforated height of the reinjection pipe
- P_e = pressure at the limit of the well's drainage area
- P_w = pressure in the well
- μ = viscosity
- r_e = radius of the well's drainage area
- r_w = radius of well.

Formation plugging will occur if the reinjected fluid contains particles large enough so the formation actually filters them out. If this occurs, the ability of the formation to accept fluid is greatly decreased. Equation 20 shows the importance of formation plugging (Sandia Laboratories (1978)). The first term on the right

$$\frac{1}{Q} = -\frac{\mu \ln(r_e/r_w)}{2\pi k h (P_e - P_w)} - \frac{\mu \ln(r_c/r_w)}{2\pi K h (P_c - P_w)} \quad (20)$$

describes the resistance to fluid flow due to the formation. The second term describes the resistance due to plugging. In this term K is the permeability of the formation where plugging is taking place (the filter-cake permeability) and r_c is the radius of the extent of plugging.

Figure 38 shows a plot of h versus Q using Equation 18 for different pipe diameters and fixed values of k, $P_e - P_w$, μ , and r_e . The height, h, is the height of perforated pipe needed such that the reinjected fluid will flow into the formation with no external pump work. The temperature was assumed to be 100°C, but the results are only slightly dependent on temperature.

Figure 39 shows the height of perforated pipe needed for a given flow rate for a number of formation permeabilities. The pipe diameter was fixed at 6 inches. Note that the best estimate of the permeability at injection depth is about 0.8 darcy (Section I.3).

Safety and utility are the most important considerations when designing a reinjection well. Care must be taken to ensure the domestic water supply will not be polluted by the injected brine. The well must

Figure 38. Perforated height for various pipe diameters with no extra pumping.

Figure 39. Perforated height for various permeabilities with no extra pumping.

also be designed for maximum utility so that continued disposal of the brine is assured.

The well can be either an "open-hole" or a "normal" completion. The type of completion will depend on the competence of the disposal formation. If the formation stands up to the injected brine, an "open-hole" completion should be used. If it falls apart, a "normal" completion must be used. Figures 40, 41 and 42 show typical "normal" and "open-hole" completions along with a typical well-head unit (Barlow, 1972).

Tubing corrosion is expected to be very low provided free oxygen is not present. Carbon steel casing should be acceptable. The casing should be the correct size to minimize friction losses. Figure 43 shows the pressure drop in the well expected in feet of head per foot of pipe as a function of flow rate. This is done for several tube diameters. It was assumed the tubing was constructed of commercial steel. Equations and constants used for these calculations were taken from Fox and McDonald (1973). The brine temperature was assumed to be 100°C.

As an added safety feature, a removable tubing string may be used inside the casing. We do not now expect this to be necessary. If the tubing is constructed of plastic, the tube is subject to collapse or bursting. To avoid this the annulus must be kept under pressure. The pressure in the annulus is controlled by adding or bleeding some fluid (e.g., diesel oil or kerosene) from the annulus with a low volume pump. This fluid must be non-corrosive to both the tubing and casing. A packer at the bottom of the well separates the fluid from the reinjected brine. The type of packer used will depend on the tubing used. They are used not only to position the tubing, but also to prevent the migration of brine up through the annulus.

The borehole should be wide enough such that when the annular space between the steel casing and the formation is filled with cement, the brine is prevented from migrating upwards from the injection zone. A brine resistant cement should be used in the injection zone.

Figure 40. Typical well with "normal" completion.

Figure 41. Typical "open hole" completion.

Figure 42. Typical Injection Well-Head.

Figure 43. Well-bore and pipeline friction losses.

Task I.8 Environmental Impact

Potential environmental impacts were considered. This section presents some preliminary quantitative and qualitative data on environmental impact. A much more detailed assessment is given in Task III.6, Overall Environmental and Energy Impact.

A. Air

There would be a small short-term increase in particulates, hydrocarbons, CO and NO_x during well drilling operations. In the long run, however, a geothermal system would reduce emissions substantially. A typical system replacing 135×10^9 Btu/yr of fossil fuels would reduce emissions by the amounts shown in Table XXVIII. These data are based on standard EPA emission factors for moderate size industrial boilers without emission controls (Perkins, 1974).

In some geothermal areas, H₂S emissions are a problem. We do not anticipate H₂S since we are dealing with an essentially unconfined reservoir. Only drilling and testing, however, can resolve this question.

TABLE XXVIII
AIR POLLUTION REDUCTIONS
(lb/yr reduction)

Alternate Fuel	Gas	Oil (resid.) 1%S	Coal (0.5%S)
NO _x	29,000	68,000	113,000
SO ₂	54	149,000	107,000
Particulates	2,400	21,000	700,000+

B. Noise

There will be additional noise generated during drilling and construction phases of the project. In the operational phase, however,

we anticipate no problems. Noise levels should be no higher than those associated with the existing heating system. Our system will be entirely liquid-phase, so there will not be any noise problems related to flashing and throttling steam.

C. Land Use

During drilling and construction, we estimate that about one acre will be occupied by heavy equipment and supplies. Permanent equipment (wells, surge tanks, pumps, etc.) should require only about 2000 to 4000 square feet outside of the existing tunnel system and building utility rooms.

D. Flora and Fauna

Since the system would be built on an urban campus, there will be no impact on native flora and fauna. Likely construction areas consist of open grass or dirt fields with no significant environmental value.

E. Water

A City of Albuquerque Ordinance (City of Albuquerque, 1978) states in Sections 4 I (1 - 2) that no ground water can be discharged to any sanitary sewer. It must be discharged to a storm sewer or to a natural outlet approved by the City of Albuquerque and the Water Resources Department. The Water Quality Control Commission Regulations (Water Quality Control Commission, 1977) prohibit disposal of brine with the chemical quality expected from the production well without a special exemption permit.

If a special exemption were granted, the effects on the Rio Grande water quality would be small, but not negligible. The Rio Grande typically has a flow rate past Albuquerque of 100 to 1000 cfs (about 45,000 to 450,000 gpm). Total dissolved solids range from about 300 to 420 ppm. This corresponds to a flow of dissolved solids of 4000 to 44,000 kg/hr.

A hot-water geothermal system is expected to have about 3000 to 4000 ppm of dissolved solids. A 600 gpm system would carry 400 to 550 kg/hr of dissolved solids into the river. By way of comparison, the

City of Albuquerque sewage plant has an average flow of about 35,000 gpm with a dissolved solids level on the order of 200 ppm. This contributes about 1600 kg/hr of dissolved solids to the river.

A single geothermal operation might conceivably be granted a permit for discharge to the storm sewers and river. It is clear, however, that such permission could not be granted for large numbers of systems. The impact on dissolved solids in the river would be too great.

Most other disposal methods can be easily ruled out on economic or environmental grounds. As shown in the previous section, total evaporation is clearly uneconomical, as well as being a potential environmental problem. Surface spreading (irrigation) is unacceptable without treatment to reduce dissolved solids levels. Release to municipal sewers is contrary to city ordinance. ReInjection is therefore left as the only reasonable long-range alternative.

Task II.1 Campus Segment Selection

The results of the load studies and studies of campus geography were used to select four segments of the campus for study. The principal criteria used for selection were:

- A. Access to the existing campus utility tunnel system.
- B. Total peak load of $20 \text{ to } 30 \times 10^6 \text{ Btu/hr}$, based on the overall campus model with no allowance for energy conservation over the 1978-79 season.
- C. Access to at least one plot of open ground large enough for drilling operations.

Figure 44 shows the existing campus utility system. Note, however, that not all tunnels are the same size or carry the same number of utility pipes. Some are very crowded; others have plenty of available space.

The four campus segments selected for initial study are outlined in the map in Figure 45. The buildings contained in each segment are listed in Tables XXIX through XXXII. The peak load given is that estimated for 1978-79 using the overall campus model. The adjusted peak load reduces the peak load value by 5 Btu/hr/sq. ft. We believe this is a reasonable allowance for other campus energy conservation programs now in progress. Clearly, this value will vary from building to building, but our simple approach should be adequate for segment comparisons.

The Ford segment (named for the Ford Utility Center located within it) contains many old campus buildings. The North segment contains new buildings located on the north side of Lomas Blvd. Its largest single user would be the UNM/Bernalillo County Hospital. The Computer segment (named for the Computer Center located within it) contains a mixture of classroom buildings, dormitories, and the main library. The Field segment includes the gym, student center, classroom and office buildings, and dormitories.

After carrying out some preliminary design studies (See Tasks II.3 and II.4), it became evident that a new segment incorporating some

Figure 44. Utility tunnel system.

TABLE XXIX
FORD SEGMENT

Building	Peak Load (10 ⁶ Btu/hr)	Area (ft ²)	Adjusted Peak Load (10 ⁶ Btu/hr)
11 Anthropology	2.01	52,557	1.75
10 Scholes	1.76	49,210	1.52
16 Bandelier West	0.53	15,073	0.45
8 Bandelier East	0.64	9,576	0.59
107 Old Mech. Engr.	0.61	17,324	0.52
117 Chem/Civil Engr.	1.53	24,750	1.41
118 Elect. Engr.	1.13	21,632	1.02
119 Farris	2.08	68,339	1.74
34 Psychology	1.29	51,898	1.03
35 Physics Lect.	0.96	22,177	0.85
21 Old Biology	1.91	67,607	1.57
21 New Biology	1.42	46,897	1.19
24 Geology	2.14	75,745	1.76
22 Old Chemistry	1.41	39,127	1.22
22 New Chemistry	1.54	42,569	1.33
23 Mitchell	1.48	46,965	1.24
79 Ortega	1.85	53,873	1.58
81 Humanities	2.04	70,859	1.68
82 Woodward	1.32	39,622	1.12
83 Bookstore	1.20	42,443	0.98
TOTAL	28.85	858,243	24.55

TABLE XXX
NORTH SEGMENT

Building	Peak Load (10 ⁶ Btu/hr)	Area (ft ²)	Adjusted Peak Load (10 ⁶ Btu/hr)
207 Physics & Astro.	1.33	58,753	1.04
211 Basic Med. Sci.	3.89	175,731	3.02
234 HSLRC	1.73	65,804	1.40
248 Fam. Prac. Ctr.	1.11	58,230	0.82
-- HSSD	1.27	66,800	0.94
228 Nursing/Pharm.	2.16	93,645	1.69
-- BCMC	10.06	374,447	8.19
227 Cancer Research	2.73	96,291	2.25
TOTAL	24.28	989,701	19.35

TABLE XXXI
COMPUTER SEGMENT

Building	Peak Load (10 ⁶ Btu/hr)	Area (ft ²)	Adjusted Peak Load (10 ⁶ Btu/hr)
153 Computer	0.54	20,330	0.44
58 Hokona	6.73	187,187	5.80
61 Santa Clara	1.30	39,751	1.10
74 Laguna	0.84	43,901	0.62
75 De Vargas	0.89	43,973	0.67
77 La Posada	1.33	40,354	1.13
63 Education - A	0.85	21,782	0.75
64 Education - B	0.69	9,234	0.65
65 Education - C	1.73	32,255	1.57
66 Education - D	0.40	9,854	0.35
67 Education - E	0.71	21,666	0.60
68 Education - F	0.63	9,900	0.58
69 Education - G	0.22	4,299	0.20
70 Education - H	0.28	9,350	0.24
76 Management	1.68	46,405	1.44
53 Library	5.35	226,112	4.22
TOTAL	24.17	766,353	20.36

TABLE XXXII
FIELD SEGMENT

Building	Peak Load (10 ⁶ Btu/hr)	Area (ft ²)	Adjusted Peak Load (10 ⁶ Btu/hr)
71 Santa Ana	1.34	41,615	1.13
157 Alvarado	1.33	40,896	1.12
155 Coronado	3.38	93,880	2.91
156 Onate	1.33	41,416	1.12
59 Johnson Gym	7.37	197,622	6.38
56 Mesa Vista	2.54	111,870	1.98
73 Health Center	1.09	42,853	0.87
62/72 Fine Arts	5.95	246,551	4.72
60 Student Union	5.42	149,192	4.68
TOTAL	29.75	965,895	24.91

Figure 45. Campus segments selected for study.

portions of the Computer and Field segments would have distinct advantages. This segment, which we have designated "Redondo East," is outlined in Figure 46. The buildings contained in it are listed in Table XXXIII.

TABLE XXXIII
REDONDO EAST SEGMENT

Building	Peak Load (10^6 Btu/hr)	Area (ft^2)	Adjusted Peak Load (10^6 Btu/hr)
156 Onate	1.33	41,416	1.12
157 Alvarado	1.33	40,896	1.12
71 Santa Ana	1.34	41,615	1.13
155 Coronado	3.38	93,880	2.91
59 Johnson Gym	7.37	197,622	6.38
63 Education - A	0.85	21,782	0.75
64 Education - B	0.69	9,234	0.65
65 Education - C	1.73	32,255	1.57
66 Education - D	0.40	9,854	0.35
67 Education - E	0.71	21,666	0.60
68 Education - F	0.63	9,900	0.58
69 Education - G	0.22	4,299	0.20
70 Education - H	0.28	9,350	0.24
61 Santa Clara	1.30	39,751	1.10
74 Laguna	0.84	43,901	0.62
75 De Vargas	0.89	43,973	0.67
77 La Posada	1.33	40,354	1.13
58 Hokona	6.73	187,187	5.80
TOTAL	31.35	888,935	26.92

Figure 46. Redondo East segment.

Task II.2 Air Conditioning Feasibility

We did a comparative analysis to study the most economical method of providing air conditioning. One method is to use the geothermal energy as a heat source on a refrigeration cycle. The design criteria used for the geothermal air conditioning are as follows:

1. The system will operate 24 hours during the peak cooling days for more efficiency.
2. Any chilled water not needed at the time will be stored for later use.
3. When the maximum mass of water is in storage, there will be a chilled water excess of 30 percent in the storage tank to meet unexpected cooling demands.
4. The chilled water will be moved in existing piping for all cases.
5. No labor costs will be considered. This assumes the existing staff will be able to operate the system.
6. The months of cooling will be from the middle of May to the middle of October.

The geothermal water temperature of 195°F (91°C) is considered low for hot water applications in air conditioning. The only research currently being done using low temperature water is in the solar energy field. There are a number of possibilities under investigation. The three most promising are a Rankine cycle, a lithium bromide absorption chiller, and an ammonia/water absorption chiller (Nash, 1976). The lithium bromide unit operates at better efficiencies than the standard ammonia/water absorption cycle; however, a regenerative ammonia/water cycle can approach the same efficiency as the lithium bromide cycle (Dao, 1978). The Rankine cycle also has comparable efficiency. The final decision of which system to use was based upon availability, initial and operating costs and performance.

On these criteria, the lithium bromide cycle was chosen. In the future, however, the Rankine cycle, if it is mass produced for solar usage, may well be the most economical.

A. The Lithium Bromide Cycle

A lithium bromide cycle operates on the principle that at low solute pressures, water will boil at low temperatures. The system consists of an evaporator-absorber section and a condenser-generator section (see Figure 47). The evaporator contains the refrigerant, which is water. A coil, through which the chilled water passes, is inserted in the evaporator. The refrigerant obtains heat from the chilled water and evaporates because of the low pressure, thereby cooling the chilled water. This vapor is attracted by the lithium bromide solution in the absorber, where it dilutes the strong lithium bromide solution. This diluted solution is pumped to the generator, where heat is added to drive the water vapor out of the solution. The lithium bromide then flows back into the absorber. The separated water vapor flows into the condenser when it is condensed by cooling water. This condensed water then flows back into the evaporator. The geothermal water would provide the heat in the generator.

For this study, a Carrier Hermetic Absorption Liquid Chiller was chosen as the system for analysis. It was selected mainly on the basis that there are currently two 1000-ton units operating on campus, so the units would be familiar to the operators. Also, Carrier manufactures a number of satisfactory units in the range that would be needed for the project.

Two different size units were considered. The first was a 270 nominal ton unit, and the second was a 312 nominal ton unit. They needed geothermal water flow rates of 587 gpm and 674 gpm, respectively. Due to the low hot water temperature of 195°F, the actual tonnage supplied by the 270-ton unit was 121 tons, or a

Figure 47. Carrier lithium bromide absorption cooler.

flow rate of 290 gpm. The 312-ton unit would supply 139.5 tons or 335 gpm. The flow rates are based on a chilled water exit temperature of 44°F with a 10°F temperature rise through the space being cooled. Using Figure 48 and the design criteria, the 270-ton unit was able to supply 196 tons, or 470 gpm of chilled water, for cooling an area of 57,300 ft² at a peak load of 41 Btu/hr/ft², with a backup capacity of 110 gpm for 3.6 hours. This required storage of 100,000 gallons. The 312-ton unit was able to supply 212 tons, or 508 gpm at peak loads, for an area of 62,000 ft². The backup capacity was 125 gpm for 3.6 hours. The 312-ton unit's storage tank had a capacity of 120,000 gallons. The system is shown in Figure 49. A summary of the results can be found in Table XXXIV. The maximum capacity of the pumps used to drive the water through the building was increased above the calculated peak flow rates to be able to supply additional chilled water during unexpected cooling demands. The results of the pump calculations are found in Table XXXV and Table XXXVI. The well pump horsepower requirement is based on a head of 500 feet. The yearly electric costs for pumping were calculated using Figure 50 and a cost of 5¢/kw-hr. The total cooling load for the five months being considered was 73,200 Btu/ft²/yr, or 3,050 hours at 24 Btu/ft²/hr.

The study also investigated how much cheaper the operating cost would be for the lithium bromide unit if the smallest head loss possible for the well was used. This value was estimated to be 242 ft. The electric costs of driving the pumps would be reduced from \$18,000/yr to \$12,200/yr, a drop of about \$6,000/yr.

B. Alternate Air Conditioning Systems

Four alternate air conditioning systems outside the field of low temperature geothermal applications were compared with the results found for the lithium bromide units. They consisted

Average Daily Cooling Demand $\equiv$ 23.9Btu/hr.ft²

Figure 48. Hourly cooling demand variations for a typical Albuquerque office building (obtained from New Mexico Energy Institute).

Figure 49. Lithium bromide system.

TABLE XXXIV
LITHIUM BROMIDE SYSTEM DATA

Nominal Tonnage	270 Tons	312 Tons
Adjusted Tonnage	121 Tons	139.5 Tons
Cooling Tower Flowrate	1053 gpm	1217 gpm
Chilled Water Flowrate	290 gpm	335 gpm
Enter Cooling Water Temperature	85°F	85°F
Exiting Cooling Water Temperature	100°F	100°F
Entering Chilled Water Temperature	54°F	54°F
Exiting Chilled Water Temperature	44°F	44°F
Geothermal Water Flowrate	587 gpm	674 gpm

TABLE XXXV
PUMP DATA FOR THE 270 TON SYSTEM

	Horsepower	Efficiency	Kilowatts	Price
Well Pump	101.8	73 %	75.9	---
Cooling Tower Pump	32.6	66 %	24.3	\$3000
Chilled Water Pump	12.7	52 %	9.4	\$1650
Building Pump	25.2	61 %	17.2	\$2400

TABLE XXXVI
PUMP DATA FOR THE 312 TON SYSTEM

	Horsepower	Efficiency	Kilowatts	Price
Well Pump	115.3	74 %	86.0	---
Cooling Tower Pump	37.0	67 %	27.6	\$3200
Chilled Water Pump	14.3	53 %	10.7	\$1750
Building Pump	26.5	63 %	18.1	\$2500

Total yearly cooling load $\approx 89,300$ Btu/ft²yr

Figure 50. Average yearly cooling demands for a typical office building (obtained from New Mexico Energy Institute).

of an electric vapor compression unit, a number of commercial evaporative coolers, and the existing steam vapor compression unit currently being used on campus.

1. Electric Vapor Compression Unit

The vapor compression refrigeration cycle (Figure 51) uses shaft work provided by electricity. This shaft work is used to drive a compressor. The refrigerant enters the compressor as a vapor after absorbing heat from the chilled water in the evaporator. After the vapor is compressed, it flows through the condenser, where it rejects heat to the cooling water. Once it has been condensed, it then flows through an expansion valve where its pressure and temperature are lowered. The total costs of the system were found by an estimation process presented by Evans (1979).

2. Small Commercial Evaporative Cooler

An evaporative air conditioner evaporates water to cool air which is used to cool some area. The system considered here consisted of a number of units manufactured by McGraw-Edison. (The data were obtained from Sigler & Faiger Distributors.) The idea was to supply the required tons at peak cooling loads. This required 229,000 cfm to supply 196 tons of cooling for a floor area of 57,300 ft² and a ceiling height of 10 feet. A volume flow rate of 248,000 cfm was needed to supply 212 tons of cooling for a floor area of 62,000 ft² and a ceiling height of 10 feet. The major assumption used for the cost analysis was that the units would be tied into existing duct work. Sixteen units were needed to supply 229,000 cfm and seventeen were needed to supply 248,000 cfm.

3. Medium-Sized Commercial Evaporative Coolers

The units chosen for this study were Alton Air Washers coolers (Data obtained from James & Cooke, Inc.). The largest unit supplied a maximum of 40,000 cfm. For supplying 196 tons or 229,000 cfm of air, six units were needed. Seven units were

Figure 51. Vapor compression cycle.

needed to supply 212 tons of 248,000 cfm. As was in the case with the smaller units, the major assumption was the units would be connected into existing duct work.

4. Large Evaporative Coolers

It was decided to use manufactured components for the large evaporative units. The Bahnson Rigidcell evaporative cooler was chosen as a typical unit. It basically includes everything in a package system needed for the air conditioning except the blower used to distribute the cooled air. The blower considered in the evaluation was a Peerless Electric DWDI Airfoil Blower. (All information was obtained from Wm. Carroll and Co., Albuquerque, New Mexico.) The large unit consisted of two Rigidcell coolers and two blowers, each system able to handle half of the cooling requirements.

5. Existing System

The Ford Utility Center, located on campus, currently charges its customers at the University 5.8¢/ton-hr for cooling. Their cooling system consists of a steam-driven vapor compression unit. This charge apparently includes only incremental operating costs.

C. Results

The lithium bromide system has the same order of magnitude as the electric vapor compression in both initial and operating costs. These systems have much higher costs than any of the other cases. All three evaporative air conditioning schemes have the same order of magnitude as the existing system for the operating costs. Since the existing system has been paid off, its initial cost is not reflected in the rate the Ford Utility Center charges. The lithium bromide price was driven up due to poor performance at the low geothermal water temperature.

Only about 44% of the nominal tonnage could be utilized. The yearly operating cost was high due to the large amount of pump work needed to operate the well. Since the system could only cool 10% of the area that can be heated by the geothermal energy, the pump costs were much greater per square foot of building space. At this time, it is concluded that it is not economically feasible to operate an air conditioning system with the geothermal water. System cost comparisons are shown in Table XXXVII.

TABLE XXXVII
AIR CONDITIONING COSTS FOR UNM

	Lithium Bromide Geothermal		Electric Vapor Compression		Small Evaporative		Medium Evaporative		Large Evaporative		Existing System	
System Size Peak Tons	196	212	196	212	196	212	196	212	196	212	196	212
Installed Equipment Costs \$10 ³												
A/C Unit	114	123	318	344	31	33	51	60	157	168	---	---
Pump	21	22	---	---	---	---	---	---	---	---	---	---
Storage	180	200	---	---	---	---	---	---	---	---	---	---
Cooling Tower	9	11	12	14	---	---	---	---	---	---	---	---
Controls	10	10	---	---	5	5	5	5	5	5	---	---
Total	334	366	330	358	36	38	56	65	162	173	---	---
Annual Costs \$10 ³ /yr												
Maintenance	20.0	22.0	26.4	28.6	12.0	12.8	6.0	7.0	3.2	3.5	---	---
Electricity	18.0	20.3	20.1	21.7	9.3	9.8	11.2	11.8	12.8	14.1	---	---
Total	38.0	42.3	46.5	50.3	21.3	22.6	17.2	18.8	16.0	17.6	20.3*	22.0*
\$/Ton-Hr at 15-yr Payout	0.101	0.103	0.115	0.115	0.040	0.039	0.035	0.036	0.045	0.045	.058	.058

*Charge to Users

Task II.3 Preliminary Designs

A. Segment Revision

We examined the heating systems in each building of the five segments listed under Task II.1. We found that a number of buildings, principally older ones, could not be readily adapted to geothermal heating. They presently use steam radiators in each room rather than a circulating water or air system. We, therefore, eliminated the following buildings from the segments:

1. Ford Segment: Scholes, Bandelier West, Bandelier East, Old Mechanical Engineering, Chemical and Civil Engineering, and Electrical Engineering.
2. North Segment: Physics and Astronomy
3. Computer Segment: Computer Center
4. Field Segment: None
5. Redondo East Segment: None

A revised summary of areas and loads for the five segments is given in Table XXXVIII. Note that the number of heating systems is not always the same as the number of buildings. Some large buildings (e.g., Hokona Dormitory) have two or more completed heating systems. In other cases, two or three buildings are served by a single system.

B. Primary Vs. Secondary Systems

We examined both primary and secondary geothermal heating systems. We concluded that a secondary system was preferable, at least for a first system. Thermodynamics favor a primary system, since it has one less point of temperature loss. There is very little economic difference, however, between the two systems. The added cost of a large primary-to-secondary heat exchanger is approximately balanced by reduced costs of individual building heat exchange equipment. This latter effect results from the smaller overall fouling factors used on the secondary loop ($0.001 \text{ ft}^2 \text{ hr}^\circ \text{F/Btu}$), where water quality can be carefully controlled, compared to those used for the geothermal brine ($0.003 \text{ ft}^2 \text{ hr}^\circ \text{F/Btu}$). Examination of the various buildings showed that slightly lower water

TABLE XXXVIII
REVISED SEGMENT TOTALS

	I Ford	II North	Segment III Computer	IV Field	V Redondo East
Original Buildings	20	8	16	9	18
Revised Buildings	14	7	15	9	18
Heating Systems	12	9	14	10	17
Original Area (ft ²)	858,243	989,701	766,353	965,895	888,935
Revised Area (ft ²)	720,678	930,948	746,023	965,895	888,935
Original Adjusted Peak Load (10 ⁶ Btu/hr)	24.55	19.35	20.36	24.91	26.92
Revised Adjusted Peak Load (10 ⁶ Btu/hr)	19.04	18.31	19.92	24.91	26.92

temperatures would not seriously affect system performance. In fact, many buildings have existing hot-water loops that rarely run above 160°F.

The principal reason for selecting a secondary system, however, was the overall risk associated with the system. A secondary system offers much less equipment exposure to potentially corrosive or scaling brine. Until such time as brine composition and long-term fouling propensities are known, we believe that a secondary system should be used. A simple schematic of the system is shown in Figure 52.

C. Typical Building Systems

Virtually all building heating systems remaining on our segment lists fall into one of two categories: circulating water or circulating air. Both of these can be easily adapted to geothermal heating.

A typical circulating water system is shown in Figure 53. The systems are built for essentially constant water flow through the building radiators and exchangers. The temperature of the circulating water is adjusted (sometimes automatically, sometimes manually) up or

Figure 52. Preliminary System Schematic.

Figure 53. Typical system for a building with circulating water heating.

down according to outside air temperature. A typical schedule calls for 170°F water when it is 0°F outside and 100°F water when it is 60°F outside.

Our design keeps the existing water loop. We tap into it with a hot-water supply and a cool water return. The loop water temperature is adjusted by recycling a part of the flow. If the recycle is completely shut off, as for a very cold day, and the temperature of the loop is still too low, then auxiliary heat will be provided by steam.

A typical circulating-air system is shown in Figure 54. Here we keep the basic steam system in place. Additional banks of finned-tube coils are added for geothermal heating. In these buildings, control is now achieved primarily by adjusting steam flow rate to hold building temperatures at proper levels. We would control geothermal heat the same way. The controllers would be modified, however, so that the steam would not come on until after the geothermal system was running full open. A secondary set of controls varies the ratio of fresh outside air to recirculating inside air. These controls would probably not be changed.

D. System Temperature Levels

If the geothermal reservoir temperature continues to increase with depth, an obvious optimization problem arises: what geothermal water temperature (equivalent to well depth) will give the overall optimum design?

As the temperature increases, the depth, and thus the cost, of the production will increase. Offsetting this, however, is the requirement to pump less water for the same geothermal heating requirement and the ability to use smaller heat exchangers. Conversely, shallower wells with lower temperatures lead to lower well costs, higher pumping costs and larger heat exchangers.

An overall economic comparison was made for wells delivering water from 140 to 210°F. Using a simple pay-out criteria, we found that the delivered energy cost is relatively insensitive to geothermal brine temperature over the range of 170 to 210°F. The total variation

Figure 54. Typical system for a building with circulating air heating.

in this range is only about 7 percent, well within the uncertainty in our estimates. The actual optimum shifts from about 190°F with a five-year payout period to about 210°F for a twenty-year payout, assuming all other design parameters are appropriately optimized. Figure 55 illustrates these results for the Redondo East segment. (Note that the actual dollar values are taken from early cost estimates; they may differ slightly from final cost estimates.)

E. Segment Flow Drawings

Simple block flow diagrams for the five segments are given in Figures 56 through 60. Flow paths follow the campus utility tunnel system. The available temperature drops are based on the requirements of existing hot-water loops. The North Segment has several buildings which now circulate 180°F water; thus, the available temperature drop there is much lower.

F. Segment Comparisons

Various design parameters were calculated for each of the five segments so that we could make a rational choice among them. Table XXXIX summarizes the results of these calculations.

In all cases, we assumed an 8700 foot production well (212°F bottom-hole temperature, 200°F delivered temperature, with a 30°C/km gradient) and a 5000 foot disposal well. Well pump head was assumed to be 760 feet, 210 feet to the water table, plus 550 feet of drawdown and friction losses. Distribution piping length includes lengths from the well through the tunnels to each building plus return to the well site. Pressure drop for the distribution piping was estimated to be 0.007 psi/ft. A secondary-loop surge tank with a two hour capacity is included in each system, along with a one hour disposal well surge tank.

The fuel savings estimated in Table XXXIX are based on an overall stream factor (fraction of peak load capacity for the entire year) of 0.30 for office, laboratory, and classroom buildings, and 0.40 for dormitories and the hospital. A fuel-to-heat efficiency of 72 percent is used.

Figure 55. Energy Cost for Various Geothermal Temperatures.

Figure 56. Ford segment schematic.

Figure 57. North Segment schematic.

Figure 58. Computer segment schematic.

Figure 59. Field Segment schematic.

Figure 60. Redondo East Segment schematic.

TABLE XXXIX
PRELIMINARY SYSTEM COMPARISONS

	I Ford	II North	Segment III Computer	IV Field	V Redondo East
Number of Buildings	14	7	15	9	18
Number of Heating Systems	12	9	14	10	17
Total Floor Area (ft ²)	720,678	930,948	746,023	965,895	888,935
Adjusted Peak Load (10 ⁶ Btu/hr)	19.04	18.31	19.92	24.91	26.92
Production Well Depth (ft)	8,700	8,700	8,700	8,700	8,700
Disposal Well Depth (ft)	5,000	5,000	5,000	5,000	5,000
Geothermal ΔT (°F)	60	45	60	70	70
Peak Well Flowrate (gpm)	635	814	664	712	769
Well Pump HP (hydraulic)	122	156	127	137	148
Piping Length (ft) (two way)	9,509	5,189	8,845	10,052	9,408
Distribution ΔP (psi)	67	36	62	70	66
Distribution Pump HP (hydraulic)	25	17	24	29	30
Secondary Surge Tank (10 ³ gal)	76	98	80	85	93
Disposal Surge Tank (10 ³ gal)	36	36	36	36	36
Primary Exchanger Area (ft ²)	10,600	25,400	11,100	9,900	10,700
Estimated Fuel Savings (10 ⁶ Btu/yr)	69,400	76,800	82,600	98,600	115,800

Task II.4 Preliminary Costs

Preliminary capital and operating cost estimates were prepared for each of the five campus segments. Results are summarized in Table XL.

Capital cost estimates are based on correlations presented in Tasks I.6 and I.7 in this and earlier progress reports. These costs are estimated to be accurate to about 25 percent in absolute value, at best. On a relative basis, however, they should order the segments properly. Note that the largest single cost item, the production well, is also the most uncertain in cost.

Operating cost estimates include electric power, labor, maintenance, and water treatment chemicals. Electric power for pumps was estimated to cost \$0.05/kw-hr. (Recent costs in Albuquerque have ranged from \$0.050 to \$0.066/kw-hr). Well pump efficiency was assumed to be 57 percent; distribution pump efficiency, 50 percent. Maintenance costs were estimated at 6 percent of total capital equipment per year, for all equipment except the two wells, plus 1 percent of the total well costs. Chemical treatment for the brine was assumed to be \$0.20/1000 gallons. Labor costs, over and above those required for maintenance or for operation of the present fossil-fueled system, were estimated to be \$25,000/year for all segments.

A comparison of energy costs for the five segments is shown in Figure 61, using a wide range of pay-out periods for capital costs. An overall efficiency of 72 percent was assumed for the existing fossil fuel steam system to estimate fuel savings. This simple economic comparison was used only as an aid in segment selection. A more detailed economic study is included in Task III.3.

TABLE XL
SEGMENT ECONOMIC COMPARISONS

	I Ford	II North	Segment III Computer	IV Field	V Redondo East
Capital Costs, 10³ \$					
Production Well	1,137	1,137	1,137	1,137	1,137
Well Pump	88	97	90	92	95
Chemical Treatment	21	21	21	21	21
Disposal Well	376	376	376	376	376
Disposal Surge Tank	42	42	42	42	42
Primary Exchanger	158	268	163	152	159
Secondary Surge Tank	78	96	81	85	92
Building Systems	480	360	560	400	680
Controls	50	50	50	50	50
Distribution Piping	380	208	354	402	376
Distribution Pumps	8	8	8	8	8
TOTAL	2,818	2,663	2,882	2,765	3,036
Operating Costs, 10³ \$/yr					
Well Pump	21	30	24	26	30
Distribution Pump	5	4	5	6	7
Labor	25	25	25	25	25
Maintenance	93	83	96	89	106
Chemicals	20	28	24	24	29
TOTAL	164	170	174	170	197

Figure 61. Approximate equivalent energy costs.

Task II.5 Best System Selection

A number of different criteria were used to compare and rank the five segments. These criteria are summarized in Table XLI.

The strictly economic criteria are straightforward. Referring back to Figure 61, however, it is clear that the Ford segment is worst and the Field and Redondo East segments are quite close to being tied for best. The North and Computer segments fall in between.

The adjusted peak load is the sum of the peak loads in each individual building for a given segment. This factor is important

TABLE XLI
SEGMENT SELECTION SUMMARY

	I Ford	II North	Segment III Computer	IV Field	V Redondo East
Total Capital Cost, 10^3 \$	2,804	2,648	2,868	2,751	3,021
Annual Operating Cost, 10^3 \$	157	160	166	161	187
Total Fuel Savings, 10^6 Btu/yr	69,400	76,800	82,600	98,600	115,800
Economic Rank	5	4	3	2	1
Adjusted Peak Load, 10^6 Btu/hr	19.04	18.31	19.92	24.91	26.92
Building Systems, 10^6 Btu Peak	0.63	0.38	0.70	0.36	0.67
Tunnels, ft/ 10^6 Btu Peak	499	283	444	404	349
Tunnel Access, Rank	5	1	4	3	2
Load Evenness, Rank	5	2	3	4	1
Well Location, Rank	3	2	1	1	1

when compared to the number of systems and to the feet of tunnel needed for each segment. The number of systems per 10^6 Btu is a measure of the average energy supplied by each system. The smaller this ratio the fewer the systems that must be disrupted in order to retrofit for geothermal heating for a given heat load. Both the Computer and Redondo East segments include the Education Complex, which contains the equivalent of six forced-air systems, which are relatively simple compared to the water systems.

The feet of tunnel per 10^6 Btu is important for several reasons. Both hot water supply and return lines must be installed in the tunnels. Since the initial capital costs along with the maintenance and pumping costs will be approximately the same in all the lines, the lower this ratio, the lower these costs will be. This ratio also dictates how efficient the system will be in terms of heat losses from the transmission lines.

The next area of investigation is tunnel access space and obstacles. The entire tunnel system was visually inspected for both obstruction and space for the two lines that need to be installed. There are several critical points in the Ford, Computer, and Field segments, where extra tunnel space would be required.

Load fluctuation is a very important factor. The further away from design conditions a load is, the more inefficient that system will be. The higher the load is, the faster the flow rate of brine through the heat exchanger. This means a lower temperature drop for the brine and the less energy abstracted from the brine. A lower load will mean a lower flow rate of brine. This means not taking full advantage of system capacity and a slower flow rate of brine through the heat exchanger, causing possible scaling problems.

Well location includes three factors: (1) disruption of existing property, (2) distance to tunnels, and (3) amount of land available for well and accessories such as pumps and heat exchangers.

After examining both quantitative and qualitative factors, we selected the Redondo East segment as the best candidate for detailed design, analysis and ultimate development. We realize, of course, that

future building plans and other factors may require some redefinition of the segment. At this time, however, it is the best candidate.

Task III.1 Detailed Design

A. Overall System

The portion of the UNM campus selected as most suitable for an initial geothermal heating demonstration project is that section lying south of Campus Boulevard on the east side of the campus. It has been designated the Redondo East segment for purposes of this report (though that name has no other particular significance). It consists of a group of eighteen buildings, including dormitories, classrooms, offices, a gymnasium and swimming pool. A map of the segment is shown in Figure 62, which also shows the interconnecting utility tunnel system. The buildings included in this segment are listed in Table XLII.

Well facilities and mechanical equipment could be located anywhere in or adjacent to the triangular area bounded by Redondo Drive, the east-west tunnel linking Buildings 59 and 155, and the north-south tunnel linking Buildings 58 and 59.

The overall geothermal system is illustrated in block form in Figure 63. Process flow systems are shown in Figures 64 and 65. The system involves two loops. Heat is transferred from geothermal brine to a closed circulating hot water loop. These are referred to as the primary and secondary loops, respectively.

The total design is based on several key criteria:

1. Minimum interference with existing buildings and utility systems.
2. Use of the existing steam system for back-up service and peak loads.
3. Maximum use of existing equipment.
4. Minimum environmental impact.
5. Production and disposal wells located on or adjacent to the campus.

We believe that the design outlined in this task meets these criteria quite well. It is not, of course, the only possible design. We believe, however, that it is close to optimum for the UNM campus.

Figure 62. Redondo East segment.

TABLE XLII

REDONDO EAST SEGMENT

Building	Use	Area (ft ²)	Design 30°F Load (10 ⁶ Btu/hr)	Expected 30°F Load (10 ⁶ Btu/hr)
58 Hokona	Dorm	187,187	8.74	4.81
59 Johnson Gym	Gym & Pool	197,622	9.73	5.35
61 Santa Clara	Dorm	39,751	1.15	0.63
63 Education-A	Office	21,782	1.27	0.70
64 Education-B	Classroom & Labs	9,234	0.57	0.31
65 Education-C	Office & Library	32,255	1.28	0.70
66 Education-D	Classroom	9,854	0.42	0.23
67 Education-E	Classroom	21,666	1.01	0.56
68 Education-F	Classroom	9,900	0.44	0.24
69 Education-G	Classroom	4,299	0.44	0.24
70 Education-H	Classroom	9,350	0.44	0.24
71 Santa Ana	Dorm	41,615	1.25	0.69
74 Laguna	Dorm	43,901	1.93	1.06
75 DeVargas	Dorm	43,973	1.93	1.06
77 La Posada	Dining Hall	40,354	1.57	0.86
155 Coronado	Dorm	93,880	2.69	1.48
156 Oñate	Dorm	41,416	2.01	1.11
157 Alvarado	Dorm	40,896	1.25	0.69
Domestic Hot Water		-	1.15	0.79
TOTAL		888,935	37.34	20.69

Figure 63. System block diagram.

Figure 64. Primary loop flow diagram.

Figure 65. Secondary loop flow diagram.

Throughout the following pages we use two terms to define system capacity and equipment size:

1. Design: Design conditions are those needed to supply an amount of heat equal to that specified in original building designs.
2. Estimated (or expected): Estimated (or expected) conditions are those needed to supply an amount of heat equal to that actually used in the various buildings, based on our work in Task I.1.

In general, estimated duties and flow rates are 50 to 60 percent of design values, indicating conservatism in original design. Our approach has been to use an equal amount of conservatism in specifying all equipment. In terms of estimating annual fuel savings and utility costs for the geothermal system, however, we use the lower "estimated" values. We believe this approach to be most conservative in that it will tend to overestimate equipment sizes and costs and may underestimate fuel savings.

B. Load Matching

As we found in Task I.1, heating load requirements vary considerably from building to building and vary with weather. We first combined historical weather data and building design data to obtain design level heat loads as functions of daily average outside air temperature. Table XLIII shows the weather distribution for the winter of 1978-79, one slightly more severe than average. Individual building design loads are given in Appendix A (Tables A-1 to A-7).

Estimated actual heat loads were determined using results of Task I.1. Overall for the entire Redondo East segment, estimated duties are 55 percent of design duties.

Because of the requirement to integrate our system with existing building systems, the returning secondary loop temperature is fixed as a function of outside air temperature (see Section G, below).

Using a secondary supply temperature of 160°F, we then determined secondary loop flow conditions as functions of outside air temperature for both design and expected heating loads. We then calculated primary (geothermal fluid) process conditions needed to match the

TABLE XLIII

OUTSIDE AIR TEMPERATURE FREQUENCY
(Daily Averages, 1978-79)

Temperature Range (°F)	Design Temperature (°F)	Frequency (Days/Year)
<u><5</u>	0	0
6-15	10	1
16-25	20	8
26-35	30	29
36-45	40	67
46-55	50	67
56-65	60	52
66-75	70	82
76-85	80	56
<u>>86</u>	90	3

secondary loop requirements. The geothermal supply temperature used is 190°F, shown earlier to be near optimum, with a 10°F cold end approach on the primary-to-secondary exchangers.

Design and estimated process conditions are summarized in Tables XLIV and XLV and in Figures 66 to 68. The large drop-off in geothermal energy supply and associated flow rates for outside air temperatures below 20°F is due to the requirement to use the steam peaking system to maintain high enough temperatures in individual building circulating systems.

Equipment is designed to provide design-level flows (Table XLIV and Figure 66). Energy savings and pumping costs for our economic analyses, however, are based on estimated actual flow conditions (Table XLV and Figure 67).

C. Production Well System

The production well will be approximately 8300 feet deep, perforated for the bottom 300 feet. Figure 69 shows a suitable configuration for such a well. The top 1000 feet is drilled with a 15 inch bit and cased with a 13-3/8 inch surface string. The next 3500 feet is drilled with a 12-1/4 inch bit and cased with a 10-3/4 inch string. The bottom 3800 feet is drilled with a 9-7/8 inch bit and cased with an 8-5/8 inch string.

Drilling will be done with a light water-base mud to about 7500 feet. Below that, just water will be used (if feasible) to lessen possible migration of mud solids into the producing reservoir.

Flow requirements for the well, both design and estimated basis, are shown in Tables XLIV and XLV and Figures 66 and 67.

The production well pump will be a multistage 480 HP downhole pump. Design level and estimated actual level pump power requirements are shown in Figure 70. In order to meet maximum design conditions with a positive suction head at the pump inlet, the pump must be located approximately 1000 feet below the surface. This provides for friction (99 psi) losses, water table depth (210 feet), drawdown (450 feet) and 15 psig available surface pressure. Since the pump must

TABLE XLIV
DESIGN OPERATING CONDITIONS

Outside Air Temp. °F	<u>0</u>	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>	<u>50</u>	<u>60</u>	<u>70+</u>
Total Heat Load*, 10 ⁶ Btu/hr	53.41	47.67	42.97	37.33	31.80	27.20	21.90	5.59
Geothermal Heat Load, 10 ⁶ Btu/hr	17.48	25.33	36.18	37.33	31.80	27.20	21.90	5.59
Steam Heat Load, 10 ⁶ Btu/hr	35.93	22.34	6.79	-	-	-	-	-
Sec. Loop Return Temp. °F	111	141	131	119	108	98	93	93
Sec. Loop Flow, GPM	720	2651	2527	1851	1220	882	639	167
Primary Loop ΔT, °F	69	39	49	61	72	82	87	87
Primary Loop Flow, GPM	522	1289	1508	1270	901	684	504	129

*Includes domestic hot water in Rondondo East Segment

TABLE XLV
ESTIMATED ACTUAL OPERATING CONDITIONS

Outside Air Temp. °F	<u>0</u>	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>	<u>50</u>	<u>60</u>	<u>70+</u>
Total Heat Load, 10^6 Btu/hr	29.53	26.38	23.79	20.69	17.65	15.12	12.20	3.23
Geothermal Heat Load, 10^6 Btu/hr	9.77	14.09	20.06	20.69	17.65	15.12	12.20	3.23
Steam Heat Load, 10^6 Btu/hr	19.76	12.29	3.73	-	-	-	-	-
Sec. Loop Return Temp. °F	111	141	131	119	108	98	93	93
Sec. Loop Flow, GPM	402	1475	1400	1026	677	490	357	96
Primary Loop ΔT , °F	69	39	49	61	72	82	87	87
Primary Loop Flow, GPM	292	717	829	704	500	380	281	74
Days/Year	<u>0</u>	<u>1</u>	<u>8</u>	<u>29</u>	<u>67</u>	<u>67</u>	<u>52</u>	<u>141</u>
Sec. Loop Yearly Flow, 10^6 gal	-	2.1	16.1	42.8	65.3	47.3	26.7	19.5
	Yearly Total = 219.8×10^6 gal							
Primary Loop Yearly Flow, 10^6 gal	-	1.0	9.6	29.4	48.2	36.7	21.0	15.0
	Yearly Total = 160.9×10^6 gal							
Geothermal Load, 10^9 Btu	-	0.34	3.85	14.40	28.38	24.31	15.23	10.93
	Yearly Total = 97.44×10^9 Btu

Figure 66. Design process conditions.

Figure 67. Estimated actual process conditions.

Figure 68. Process flow temperatures.

Figure 69. Production well configuration.

Figure 70. Production pump power requirements.

must operate over a wide range of average flows, a variable-speed unit is required. A fully submersible pump and motor could be used, but they are usually less efficient over a wide flow range than are shaft-connected units. It may not be feasible, however, to use a 1000 ft shaft pump. A spare pump and motor should be available for rapid replacement if necessary.

The well should be drilled in an open area within the Redondo East segment. During drilling operations, a plot of ground approximately 100 by 150 ft will be used. After drilling is complete, the well-head and pump will occupy only a few square feet. A light-duty portable building, approximately 10 by 10 ft should be placed over the well-head and pump to provide security while still permitting access for maintenance.

D. Surface System Facilities

The surface facilities for the primary loop are shown in the flow diagram in Figure 64.

We expect to inject small amounts of chemicals into the brine to aid in scale and corrosion control. A typical requirement would be 20 ppm of Na_2SO_3 for oxygen scavenging and 10 ppm of a scale inhibitor (e.g., Nalco 7317), (Norman, 1978). The required equipment is simple: one or two metering pumps feeding from a bank of 55-gallon drums.

A 15,000 gallon surge tank (approximately 12 ft diam by 20 ft high) provides a surge capacity of ten minutes (maximum design flow rate) or more. Under more typical operating conditions, it will provide 30 to 40 minutes capacity. This should be adequate time for simple emergency service on pumps or time to bring up the steam system to a higher level if the geothermal system must be shut down. The tank should be of steel or fiberglass-reinforced polyester construction. The tank must have facilities for maintaining an inert atmosphere above the water level.

The brine pump moves the geothermal brine from the surge tank through the primary heat exchangers and to the disposal well. Design and estimated flow rates are shown in Figures 66 and 67. Design

pressure increase is 90 psi. The pump will be a 100 HP centrifugal unit with remote start/stop capability. It will have an installed spare. The pump should have brass or stainless steel in contact with the brine.

The primary heat exchanger system is shown in Figure 71. For high-duty operation all three exchangers are used. For moderate levels, exchangers 1 and 2 are used in series. For low levels, only exchanger 3 is used. Process conditions shown in Figure 71 are for limiting case design conditions (approximately 25°F outside air temperature). All other design operating conditions can be met with the three exchangers specified. Exchanger materials are brass on the tube side (brine) and carbon steel on the shell side (secondary loop).

The exchangers were designed using a total fouling factor of $0.003 \text{ hr ft}^2 \text{ }^\circ\text{F/Btu}$. This accounts for roughly 60 to 70 percent of the total heat transfer resistance. System performance, especially early in its operation, should therefore be considerably better than indicated. It is possible to use three identical heat exchangers in place of the three slightly different ones we have specified. Each would require about 3500 square feet of area. The specified set, however, will provide slightly lower pressure drops for equivalent heat transfer.

E. Disposal Well System

A typical disposal well configuration for the proposed system is shown in Figure 72. We have assumed reinjection to 5000 feet, where the temperature will be about 141°F. The actual depth must be determined by agreement with local and state regulatory agencies.

The first 1000 feet is drilled with a 15 inch bit and cased with a 13-3/8 inch surface string. The remaining 4000 feet is drilled to 9-7/8 inches and cased with an 8-5/8 inch string. The bottom 340 feet must be perforated to permit gravity feed operation of the well, as shown in Task I.7.

The reinjection well, ideally, should be located 2000 feet or more away from the production well in a horizontal direction.

	EXCHANGER 2	EXCHANGER 1	EXCHANGER 3
TUBES:	Brass, 4-Pass	Brass, 8-Pass	Brass, 8-Pass
SHELL:	CS, 2-Pass	CS, 4-Pass	CS, 4-Pass
DUTY:	12.44×10^6 Btu/hr	12.44×10^6 Btu/hr	12.44×10^6 Btu/hr
AREA:	2389 ft ²	4104 ft ²	3797 ft ²
LMTD:	24.7°F	14.4°F	18.2°F
U:	227 Btu/ft ² hr°F	217 Btu/ft ² hr°F	193 Btu/ft ² hr°F
F:	0.94	0.975	0.94

Figure 71. Primary heat exchangers (limiting case design process conditions).

Figure 72. ReInjection well configuration.

F. Secondary Loop System

The secondary loop distributes 160°F water to the various buildings. It is shown schematically in Figures 65 and 73. Design and estimated actual total loop flow rates are shown in Figures 66 and 67 and in Tables XLIV and XLV.

Maximum flow rates in each segment of the secondary loop are tabulated in Table XLVI, along with corresponding process temperatures, pressures and pressure drops. The table also includes a listing of pipe sizes needed for various parts of the loop.

A total of four pumps, each with an installed spare, is required for the secondary loop. (In principle, a single pump is adequate; the four pump system is more economical, however, since it avoids excessively high pressures and provides pressure boosts to only part of the loop.

The exchanger pump and distribution pump (Figure 65) are identical 70 HP centrifugal pumps with a common spare. Iron or steel is adequate for these pumps since the water quality in the secondary loop can be much more carefully controlled and monitored than that in the primary loop.

The COE pump (which boosts pressure on the lines to College of Education buildings) is a 12 HP pump providing a pressure boost of 20 psi. The Gym pump (which boosts pressure to the Gymnasium and downstream buildings) is a 40 HP unit providing a 41 psi boost. Both locations use centrifugal pumps. Iron or steel construction is adequate; though brass may give longer life.

A 32,000 gallon surge tank is used on the secondary loop, sufficient for over 20 minutes surge at peak design flow rates. It is about 15 feet in diameter by 25 feet high. Like the primary surge tank, it could be steel or fiberglass-reinforced polyester. It, too, must be provided with inert gas blanketing.

Small accumulators should be located just upstream of the exchanger pump, the COE pump and the Gym pump. These small tanks, about 150 gallons each, provide positive liquid head for pump

Figure 73. Secondary loop flow conditions.

TABLE XLVI

SECONDARY LOOP DESIGN PROCESS CONDITIONS

Stream Number	Design Outdoor Air Temp. (°F)	Flow		Temp. (°F)	Pressure		Pipe Size	
		10 ⁶ lb/hr	GPM		Drop (psi)	Average (psig)	Diam. (in.)	Schedule
1	7	68	140	160	2.2	30	2-1/2	40
2	7	68	140	155	2.2	26	2-1/2	40
3	7	84	171	155	1.2	30.5	3	40
4	7	84	171	160	1.2	25	3	40
5	7	152	311	160	3.6	33	4	40
6	7	152	311	155	3.6	23	4	40
7	7	50	102	160	1.4	34	2-1/2	40
8	7	50	102	155	1.4	19	2-1/2	40
9	7	202	413	160	3.2	36.5	5	10
10	7	202	412	155	3.2	14.5	5	10
11	7	133	272	155	2.8	20	4	40
12	7	247	504	155	4.5	18.5	5	10
13	7	133	272	160	2.8	29.5	4	40
14	7	247	504	160	4.5	29	5	10
15	7	380	776	155	7.0	15.5	6	10
16	7	380	776	160	7.0	34.5	6	10
17	7	582	1187	155	0.9	11.5	8	10
18	7	582	1189	160	0.9	38.5	8	10
19	0	16	32	160	5.2	46.5	1-1/2	40
20	0	16	31	120	5.2	37	1-1/2	40
21	0	16	31	120	4.3	38	1-1/2	40
22	0	16	32	160	4.3	47	1-1/2	40
23	0	16	31	120	3.1	42.5	1-1/2	40

TABLE XLVI (continued)

Stream Number	Design Outdoor Air Temp. (°F)	Flow		Temp. (°F)	Pressure		Pipe Size	
		10 ⁶ lb/hr	GPM		Drop (psi)	Average (psig)	Diam. (in.)	Schedule
24	0	16	32	160	3.1	50.5	1-1/2	40
25	0	31	63	160	2.4	50.5	2	40
26	0	31	63	120	2.4	33	2	40
27	0	47	95	160	2.4	53	2-1/2	40
28	0	47	94	120	2.4	30.5	2-1/2	40
29	0	48	96	120	3.0	22	2-1/2	40
30	0	48	96	160	3.0	46.5	2-1/2	40
31	0	34	70	120	3.5	37.5	2	40
32	0	34	70	160	3.5	46.5	2	40
33	0	82	166	120	5.1	18	3	40
34	0	82	166	160	5.1	50.5	3	40
35	0	44	89	160	1.2	52.5	2	40
36	0	44	88	120	1.2	27.5	2	40
37	0	126	254	120	0.7	15.5	4	40
38	0	126	257	160	0.7	53.5	4	40
39	0	21	42	120	5.2	38.5	1-1/2	40
40	0	21	42	160	5.2	55	1-1/2	40
41	0	193	390	120	1.9	14	5	10
42	0	193	395	160	1.9	36	5	10
43	0	15	30	160	2.7	36	1-1/2	40
44	0	15	29	120	2.7	29.5	1-1/2	40
45	0	208	419	120	1.5	12	5	10
46	0	208	425	160	1.5	38	5	10
47	7	87	179	160	4.2	56	3	40
48	7	87	178	155	4.2	35	3	40

TABLE XLVI (continued)

Stream Number	Design Outdoor Air Temp. (°F)	Flow		Temp. (°F)	Pressure		Pipe Size	
		10 ⁶ lb/hr	GPM		Drop (psi)	Average (psig)	Diam. (in.)	Schedule
49	7	54	111	160	5.1	59.5	2-1/2	40
50	7	54	111	155	5.1	43.5	2-1/2	40
51	7	142	290	160	3.5	60	4	40
52	7	142	289	155	3.5	31	4	40
53	7	54	111	160	2.4	61	2-1/2	40
54	7	54	111	155	2.4	46	2-1/2	40
55	7	196	400	160	2.2	63	5	10
56	7	196	400	155	2.2	28	5	10
57	7	117	239	160	3.8	62	3-1/2	40
58	7	117	239	155	3.8	24	3-1/2	40
59	7	160	324	126	2.3	32	4	40
60	7	160	324	160	2.3	69	4	40
61	7	41	83	91	5.1	32.5	2	40
62	7	41	84	160	5.1	67.5	2	40
63	7	201	407	119	5.4	27.5	5	10
64	7	201	412	160	5.4	72.5	5	10
65	7	313	639	155	11.0	21.5	6	10
66	7	313	640	160	11.0	69.5	6	10
67	7	514	1045	141	4.7	13.5	8	10
68	7	514	1051	160	4.7	75	8	10
69	7	1304	2640	127	-	10	12	10
70	7	1304	2640	127	-	40	12	10
71	7	1304	2665	160	-	17	12	10
72	7	1304	2665	160	-	40	12	10

operation and room for thermal expansion and contraction in various parts of the secondary loop. They should be built of steel and provided with inert gas caps. Alternatively, they could be glass-lined steel.

G. Building Systems

A wide variety of heating equipment is used in the Redondo East segment. Table XLVII presents a brief summary of the heating systems contained in each building. Appendix A contains design details and equipment specifications.

A typical water system is illustrated in Figure 74. It is essentially a constant-flow loop within the building. As heating demand increases, loop temperature is raised. When the loop return temperature reaches about 140°F, the 160°F secondary supply is no longer adequate, and steam must be turned on to boost the supply to the loads above 160°F. Under extreme conditions (less than 7°F outside air daily average temperature), the loop supply must exceed 180°F, the loop return exceeds 160°F, and the geothermal secondary loop is of no value. This, of course, happens very rarely.

Controls are designed to maintain a constant flow of water in the building loop at the desired temperature. This temperature is usually set manually by operators or maintenance staff. In some buildings it is controlled from the central power plant.

A typical forced-air system is shown in Figure 75. Such units are used in the College of Education complex. Geothermal secondary water can supply all necessary heat in these buildings. The steam unit is kept as a back-up only. Each building has banks of finned-tube heat exchange coils located in ventilation ducts. Heat is now provided by steam-fed tubes; chilling by chilled-water-fed tubes. In the proposed system, additional banks of hot water tubes would be added.

The secondary loop can also be used to heat domestic hot water for all the buildings in the Redondo East segment. Table XLVIII lists the domestic hot water systems now installed in these buildings. It also lists our estimate of needs for geothermally-heated domestic hot

TABLE XLVII

BUILDING HEATING SYSTEMS

<u>Building</u>	<u>Type</u>	<u>Loads</u>
58	Water	Convectors, Unit Heater, Radiators, Booster Coils, Heating Coils
59	Water	Radiant Floor Heaters, Heating Coils, Cabinet Heaters, Pool Heaters, Convectors
61	Water	Convectors, Cabinet Heaters, Heating Coils
63	Air	Forced Convection
64	Air	Forced Convection
65	Air	Forced Convection
66	Air	Forced Convection
67	Air	Forced Convection
68	Air	Forced Convection
69	Air	Forced Convection
70	Air	Forced Convection
71	Water	Cabinet Heaters, Heating Coils
74 & 75	Water	Convectors, Heating Coils
77	Water	Heating Coils
155	Water	Convectors, Cabinet Heaters
156	Water	Convectors, Radiators, Heating Coils
157	Water	Cabinet Heaters, Heating Coils

Figure 74. Typical circulating water system.

Figure 75. Typical forced-air system.

TABLE XLVIII

DOMESTIC HOT WATER SYSTEMS

Building	Storage (gal)	Present System Design			Geothermal System Estimates		Storage (gal)
		Recovery Rate (10^6 Btu/hr)	Daily Load (average 10^6 Btu/hr)		Daily Load (average 10^6 Btu/hr)	Recovery Rate (10^6 Btu/hr)	
58	1325	1.083	0.090	:	0.188	0.376	2700
59	950	4.582	0.382	:	0.198	0.396	1425
61	1000	0.850	0.071	:	0.040	0.080	575
63	30	0.019	0.002	:	0.003	0.007	40
64	15	0.008	0.001	:	0.001	0.003	15
65	30	0.017	0.001	:	0.005	0.010	75
66	70	0.075	0.006	:	0.002	0.003	30
67	30	0.019	0.002	:	0.003	0.006	40
68	30	0.009	0.001	:	0.001	0.003	15
69	15	0.007	0.001	:	0.001	0.001	15
70	70	0.075	0.006	:	0.001	0.003	15
71	1070	0.891	0.074	:	0.042	0.084	600
74 & 75	2000	1.666	0.139	:	0.088	0.176	1250
77	127	0.093	0.008	:	0.040	0.080	600
155	3000	2.132	0.178	:	0.094	0.188	1350
156	1400	1.206	0.101	:	0.041	0.082	600
157	1070	0.891	0.074	:	0.041	0.082	600
Total		13.62	1.14	:	0.79	1.58	

water. Several buildings would need additional storage capacity since recovery time would be longer. A typical hot water installation is shown in Figure 76, making use of geothermal heat, when available, with steam as a back-up. The system would be quite simple, composed of double-pipe exchangers and a storage tank. Since total domestic hot water represents only about 4 percent of the geothermal system load, and since the systems are simple, we have not made detailed building-by-building designs for domestic hot water.

H. System Controls

A complete control system for both primary and secondary loops is shown in Figures 77, 78 and 79.

The primary loop flow rate must be controlled to meet system energy demand (Figure 77). The level in the surge tank should be allowed to fluctuate ± 25 percent of capacity. Outside this range, a level controller will adjust the speed on the well pump to meet demand. Chemical addition is done by metering pumps controlled by brine flow rate. Oxygen intrusion into the surge tank is prevented by maintaining a slight positive pressure of nitrogen, or other inert gas, in the tank.

The temperature on the secondary loop flow leaving the primary exchangers controls brine flow through the exchangers (Figure 78). A small by-pass around the control valve insures that there will always be a minimum brine flow. Brine and secondary fluid are split between exchangers 1 and 2 and exchanger 3 by proportioning flow valves. When not all exchangers are in use, these controls are deactivated and out-of-use exchangers isolated by block valves.

The secondary circulating loop must be maintained at constant pressure regardless of flow rate (Figure 79). This is accomplished with pressure controls downstream of the distribution pump. A small recycle is provided to avoid dead-heading the pump. Except for gas caps on the surge tank and accumulators, the secondary system runs liquid-full and should be easy to control. Note that a common spare pump serves both the exchanger and distribution pumps.

Figure 76. Typical domestic hot water system.

Figure 77. Primary loop controls, supply.

Figure 78. Primary loop controls, exchangers.

Figure 79. Secondary Loop Controls.

I. Mechanical Lay-out

Adequate equipment space must be provided for exchangers, pumps, controls and other equipment. A separate satellite utilities building could be used, or the equipment could be put in a new, large mechanical room in one of the buildings.

Figure 80 shows a typical equipment lay-out. Room inside is provided for exchangers, pumps and controls. There is also room to pull the tube-bundle from each exchanger for cleaning or inspection. A total area of about 1650 square feet is needed. The well, well pump and large surge tanks are located outside. The tanks could be either aboveground or belowground. All equipment must be insulated for personnel protection as well as for energy conservation.

J. Equipment Summary

Table XLIX presents a summary of all new equipment required for the proposed geothermal heating system.

K. Alternative Designs

Several alternative design features were identified in the course of this study. Due to lack of time or data, we did not examine them in detail. Each should be examined by project engineers before fixing the final design.

1. Consider using concrete/asbestos (Temptite) piping instead of carbon steel. In other New Mexico applications it has proved more economical.

2. Consider using plate heat exchangers rather than shell-and-tube units. Design procedures are straightforward, but there is little published cost data. In many industrial applications with close approach temperatures, plate exchangers are favored for liquid-liquid systems.

3. Consider using steam drive for the pumps instead of electricity, especially for the well pump, brine pump, exchanger pump and distribution pumps. If high pressure steam were available, steam drive would definitely be advantageous. If only 40 psig steam is available, the answer is not clear without further detailed study.

Figure 80. Possible mechanical equipment layout.

TABLE XLIX

EQUIPMENT SUMMARY

I. WellsA. Production Well

8300 ft

Surface casing, 1000 ft, 13-3/8 in.

Secondary casing, 4500 ft, 10-3/4 in.

Production casing, 8300 ft, 8-5/8 in.

Perforations, 300 ft

B. Injection Well

5000 ft

Surface casing, 1000 ft, 13-3/8 in.

Secondary casing, 5000 ft, 8-5/8 in.

Perforations, 340 ft

II. Pumps

	Number	Type	Size HP	Flow GPM	P psi	Discharge P psig	Material
Well	2*	Down-hole	480	1400	440	460	Brass or Stainless
Brine	2	Centrifugal	100	1400	90	100	Brass
Exchanger/Dist.	3	Centrifugal	70	2640	30	40	Steel
COE Booster	2	Centrifugal	12	425	20	55	Steel
Gym Booster	2	Centrifugal	40	1050	41	75	Steel

*Spare not installed.

III. Heat Exchangers

	Duty 10 ⁶ Btu/hr	Area ft ²	Shell		Flow GPM	P psi	Tubes		Flow GPM	P psi
			Passes	Mat'l.			Passes	Mat'l.		
Primary 1	12.44	4104	4	CS	1417	11	8	Brass	900	49
Primary 2	12.44	2389	2	CS	1417	13	4	Brass	900	34
Primary 3	12.44	3797	4	CS	708	3	8	Brass	450	16
Gym Pool	0.20	32*	1	CS	10	-	1	CS	7	-
Training Pool	0.46	74*	1	CS	22	-	1	CS	16	-
Olympic Pool	4.64	737	1	CS	222	-	1	CS	155	-

*Double pipe exchanger.

TABLE XLIX (continued)

IV. Finned Tubing for Water-to-Air Heat Transfer (1/2 in. OD copper with aluminum fins)

<u>Building</u>	<u>Ft of Tubing</u>	<u>Return Bends</u>
63	1566	102
64	1126	125
65	1946	98
66	965	107
67	1996	222
68	978	109
69	978	109
70	978	109

V. Piping (carbon steel, insulated)

<u>Pipe Size (in.)</u>	<u>Schedule</u>	<u>Total Length Required (ft.)</u>
1-1/2	40	340
2	40	280
2-1/2	40	500
3	40	480
3-1/2	40	200
4	40	745
5	10	1290
6	10	1495
8	10	100
12	10	1115

VI. Tanks and Vessels

	<u>Capacity (gal)</u>	<u>Pressure (psig)</u>	<u>Material</u>
Primary Surge	15,000	0.5	Steel or FRP
Secondary Surge	32,000	0.5	Steel or FRP
Accumulators (3)	100	50	Steel

TABLE XLIX (continued)

VII. Instrumentation (approximate)

Flow controllers or recorders	18
Flow indicators	20
Pressure controllers or recorders	6
Temperature controllers or recorders	45
Temperature indicators	46
Level controllers or recorders	1
Level indicators	5
Alarms	15

VIII. Valves (approximate)

Control valves	70
Block valves	86
Relief valves	14

IX. Chemical Injection

2 metering pumps, 0 to 2 gal/hr

X. Domestic Hot Water Equipment

Double-pipe exchanges, various sizes	20
New storage tanks, 500 gallons	2
1400 gallons	1

IX. Mechanical Equipment Building or Room

Approximately 30 by 55 feet

4. Consider using multiple pumps in parallel for the brine pump and secondary loop. More units would be required, but they could operate closer to peak efficiency by shutting off spare capacity when not needed.

Task III.2 Final Costs

Total capital and annual operating costs were estimated for the project.

Capital costs are summarized in Table L. They are distributed over three years, in accord with the program plan outlined in Task III.7. Individual item estimates were made as follows:

- A. Wells: Equation 15, Task I.6
- B. Primary Exchangers: Equation 17, Task I.6
- C. Surge Tanks: Equation 16, Task I.6
- D. Chemical Injection: from Norman (1978)
- E. Accumulators: from Guthrie (1969)
- F. Pumps: from Figure 37, Task I.6
- G. Building Equipment: from individual estimates for each building, ranging from \$13,000 for the smaller air-system buildings to \$87,000 for the gym complex
- H. Instrumentation and controls: \$1000 for each new control loop, \$500 for each modified existing control loop
- I. Piping: based on Marshall and Brandt (1974)
- J. Mechanical Building: from Peters and Timmerhaus (1980)

All capital costs are adjusted to mid-1980 dollars. A conservative 25 percent contingency is incorporated in the total capital costs, along with an engineering fee of 7 percent of the identified capital.

Annual operating costs, exclusive of electric power, are given in Table LI. Labor costs assume one operator over and above those now used for the campus utility system. Maintenance costs are estimated at 6 percent of non-well capital (pumps, pipelines, exchangers, etc.) per year plus 1 percent of well costs. Chemical costs assume the addition of a corrosion/scale inhibitor to the brine at a rate of 10 ppm, costing \$1.35 per pound, plus addition of Na_2SO_3 for oxygen scavenging at \$0.34 per pound.

Fuel savings and electric power usage are presented in Table LII. By the third year of operation, fossil fuel savings amount to 135×10^9 Btu/yr, equivalent to 135 million standard cubic feet of natural gas or about 940,000 gallons of fuel oil.

TABLE L
CAPITAL COST ESTIMATE
(1980 \$ in \$1000)

	<u>Total</u>	<u>Year 0</u>	<u>Year 1</u>	<u>Year 2</u>	<u>Year 16*</u>
Prod. Well	1030	1030	-	-	-
Disp. Well	376	376	-	-	-
Primary Exchangers	234	80	154	-	-
Primary Surge Tank	20	20	-	-	-
Secondary Surge Tank	38	38	-	-	-
Chemical Injection	5	5	-	-	-
Accumulators	3	2	1	-	-
Well Pumps	193	193	-	-	193
Brine Pumps	9	9	-	-	9
Secondary Pumps	23	23	-	-	23
Building Equipment	437	100	215	122	-
Inst. & Control	35	20	10	5	-
Piping	450	250	100	100	-
Mechanical Building	66	60	6	-	-
	<u>2919</u>	<u>2206</u>	<u>486</u>	<u>227</u>	<u>225</u>
Contingency 25%	730	551	122	57	56
Engineering 7%	<u>204</u>	<u>154</u>	<u>34</u>	<u>16</u>	<u>16</u>
TOTAL	3853	2911	642	300	297

*Replacements not included in original total.

TABLE LI
ANNUAL OPERATING COST ESTIMATE
(1980 \$ in \$1000)

	<u>Year 1</u>	<u>Year 2</u>	<u>Year 3+</u>
Operating Labor	25	25	25
Maintenance	62	91	105
Chemicals Cost	7	15	27
	<u>94</u>	<u>131</u>	<u>157</u>

TABLE LII
ANNUAL UTILITIES USE AND SAVINGS

	<u>Year 0</u>	<u>Year 1</u>	<u>Year 2</u>	<u>Year 3+</u>
Fuel Saved (10^6 Btu)	-	25,000	69,000	135,000
Electricity Used (kW-hr)				
Well Pump	36,000	180,000	364,000	696,000
Brine Pump	-	41,000	83,000	158,000
Secondary Pumps	-	47,000	96,000	183,000
	<u>36,000</u>	<u>268,000</u>	<u>543,000</u>	<u>1,037,000</u>

Task III.3 Overall Economics

In order to make a proper evaluation of the worth of a project such as the proposed geothermal heating system, it is necessary to use a technique which accounts for both initial and continuing costs and savings. One common approach is the use of discounted cash flow to reduce all costs and savings to the same base point in time.

For the proposed geothermal system, we anticipate a total three-year construction period and thirty years of operation. The first fuel savings occurs in the year following initial construction. For convenience, the first year of construction is defined as year zero and the first year of partial operation as year one. Full operation is achieved by year three.

Present values for all project cash flows have been calculated, using interest rates of 0, 6, 8 and 10 percent. These are defined as true value interest rates; i.e., the required interest rate over and above the general national rate of inflation.

A benefit:cost ratio is defined as:

$$\frac{\text{Present value of fuel cost savings}}{\text{Present value of (equipment + annual operation costs)}} \quad (21)$$

Clearly, this ratio must be greater than 1.00 for the project to be attractive.

A unit energy cost (\$/10⁶ Btu of fossil fuel saved) is defined as

$$\frac{\text{Present value of (equipment + annual operating costs)}}{\text{Discounted total fuel saved}} \quad (22)$$

where the denominator represents the "present energy value" in Btu of all fossil fuel saved, discounted at the appropriate interest rate.

For the overall economic studies, capital and operations costs are taken from Tables L and LI in Task III.2. The values to use for electricity and natural gas, however, are more complex. For each, we have assumed that energy costs will escalate faster than the general national rate of inflation. For electricity, the unit cost is assumed

to escalate at 2.7 percent annually through the end of project year 10, and at 2.0 percent annually thereafter. For gas, rates of 6.6 percent through year 10 and 5.0 percent thereafter are used. These escalation rates are considerably lower than those experienced in the past five years, but they are in line with those often used in energy studies in New Mexico (New Mexico Energy Institute, 1980). Actual rates for the future are, of course, subject to great uncertainty. Utility costs for 1979-80 at UMM are used to get initial values for electricity and gas prices. These costs, based on actual billings from July 1979 to June 1980, are \$0.0500 per kW-hr of electricity and \$2.53 per 10⁶ Btu for natural gas.

Present worth factors for the various cash flow configurations involved in this project were calculated and are given in Appendix C.

A discounted cash flow on a year-by-year basis for the base-case design and schedule is presented in Table LIII. Numbers in parentheses are costs (negative cash flows). Using 1980, non-inflating dollars, the project breaks even in Year 11. It reduces total gas bills by \$33 million at a cost of \$11 million, giving a benefit:cost ratio very close to 3. On a discounted basis, however, the ratio decreases considerably since much of the cost is early in project life and the greatest benefits are near the end of project life.

The first column of Table LIV presents total costs, benefits, benefit:cost ratios and equivalent energy cost for 1980 dollars (0 percent interest) and dollars discounted at 6, 8 and 10 percent. The benefit:cost ratios are still attractive. It is necessary, however, to examine them in more detail by seeing how sensitive they are to the assumptions in the analysis. This is done by considering nine variations of the base case. Slight differences in the discounted cash flow totals between Table LIII and Table LIV are due to round off error and to use of discrete year-by-year discounting in Table LIII while continuous discounting is used in Table LIV.

Cases 2 and 3 (Table LIV) illustrate the effect of higher and lower energy cost escalation, respectively. For case two, the escalation rates, relative to general inflation are double those of the base case (13.2 percent for gas and 5.4 percent for electricity through

TABLE LIII

BASE CASE DISCOUNTED CASH FLOW ANALYSIS
(10³ dollars)

		1980 Dollars				Cumulative	Discounted Dollars		
Year		Capital	Operations	Electricity	Gas	Total	6%	8%	10%
81-82	0	(2911)	-	(2)	-	(2913)	(2913)	(2827)	(2772)
82-83	1	(642)	(94)	(15)	80	(671)	(3584)	(613)	(578)
83-84	2	(300)	(131)	(30)	235	(226)	(3810)	(195)	(176)
84-85	3	-	(157)	(59)	491	275	(3535)	223	194
85-86	4	-	(157)	(61)	525	307	(3228)	234	196
86-87	5	-	(157)	(63)	560	340	(2888)	244	196
87-88	6	-	(157)	(64)	599	378	(2510)	256	197
88-89	7	-	(157)	(66)	639	416	(2094)	265	197
89-90	8	-	(157)	(68)	683	458	(1636)	275	196
90-91	9	-	(157)	(70)	730	503	(1133)	284	195
91-92	10	-	(157)	(71)	780	552	(581)	294	193
92-93	11	-	(157)	(73)	826	596	15	299	189
93-94	12	-	(157)	(74)	868	637	652	301	183
94-95	13	-	(157)	(76)	913	680	1332	303	176
95-96	14	-	(157)	(77)	960	726	2058	304	170
96-97	15	-	(157)	(79)	1009	773	2831	305	164
97-98	16	(297)	(157)	(80)	1061	527	3358	196	101
98-99	17	-	(157)	(82)	1115	876	4234	307	152
99-00	18	-	(157)	(84)	1172	931	5165	307	146
00-01	19	-	(157)	(85)	1232	990	6155	307	141
01-02	20	-	(157)	(87)	1295	1051	7206	307	135
02-03	21	-	(157)	(89)	1362	1116	8322	307	130
03-04	22	-	(157)	(91)	1432	1184	9506	307	125
04-05	23	-	(157)	(92)	1505	1256	10762	307	120
05-06	24	-	(157)	(94)	1582	1331	12093	306	115
06-07	25	-	(157)	(96)	1663	1410	13503	305	110
07-08	26	-	(157)	(98)	1749	1494	14997	305	106
08-09	27	-	(157)	(100)	1838	1581	16598	304	101
09-10	28	-	(157)	(102)	1933	1674	18252	303	97
10-11	29	-	(157)	(104)	2032	1771	20023	302	93
11-12	30	-	(157)	(106)	2136	1873	21896	300	89
TOTAL		(4150)	(4621)	(2338)	33005	21896	4422	2170	681

TABLE LIV

ALTERNATE CASE DISCOUNTED CASH FLOW ANALYSES

Case	1 Base	2 High Utilities	3 Low Utilities	4 High Maint.	5 Low Maint.	6 Zero Cont.	7 Deep Drawdown	8 10% Fuel Oil	9 Fast Const.	10 Present System
1980 Dollars (thousands)										
Capital	(4150)	(4150)	(4150)	(4150)	(4150)	(3364)	(4326)	(4150)	(4150)	-
Operations	(4621)	(4621)	(4621)	(5999)	(3089)	(4621)	(4711)	(4621)	(4710)	-
Electricity	(2387)	(3940)	(1881)	(2387)	(2387)	(2387)	(4012)	(2387)	(2414)	-
Gas	33004	131155	17568	33004	33004	33004	33004	38900	33579	(33004)
Net	21846	118444	6916	20468	23378	22632	19955	27742	22305	(33004)
Total Cost	(11158)	(12711)	(10652)	(12536)	(9626)	(10372)	(13049)	(11158)	(11274)	(33004)
Total Benefit	33004	131155	17568	33004	33004	33004	33004	38900	33579	-
B/C	2.96	10.32	1.65	2.63	3.43	3.18	2.53	3.49	2.98	-
10 ⁶ Btu	2.88	3.28	2.75	3.24	2.48	2.68	3.37	2.88	2.78	8.52
Discounted Dollars (thousands)										
6% Cost	(6679)	(7164)	(6511)	(7140)	(6023)	(5963)	(7460)	(6679)	(6855)	(11350)
Benefit	11350	38741	6626	11350	11350	11350	11350	13377	11893	-
B/C	1.70	5.41	1.02	1.59	1.88	1.90	1.52	2.00	1.73	-
/10 ⁶ Btu	4.15	4.44	4.04	4.43	3.74	3.70	4.63	4.15	3.88	7.05
8% Cost	(5968)	(6312)	(5848)	(6292)	(5448)	(5269)	(6586)	(5968)	(6160)	(8362)
Benefit	8362	26848	5042	8362	8362	8362	8362	9856	8891	-
B/C	1.40	4.25	0.86	1.33	1.53	1.59	1.27	1.65	1.44	-
/10 ⁶ Btu	4.72	4.99	4.62	4.97	4.31	4.17	5.21	4.72	4.35	6.61
10% Cost	(5445)	(5696)	(5356)	(5676)	(5022)	(4761)	(5945)	(5445)	(5656)	(6316)
Benefit	6316	19031	3929	6316	6316	6316	6316	7444	6831	-
B/C	1.16	3.34	0.73	1.11	1.26	1.33	1.06	1.37	1.21	-
/10 ⁶ Btu	5.36	5.61	5.28	5.59	4.95	4.69	5.86	5.36	4.87	6.22

Year 10, 10.0 percent for gas and 4.00 for electricity thereafter). Even these high levels are lower than those experienced in the last few years. As would be expected, the benefit:cost ratios are much more attractive for Case 2 than for the base case. Case 3 uses escalation rates half as large as those for the base case. The benefit:cost ratio is then much poorer, dropping below 1.00 for 8 and 10 percent discount factors. Clearly, the overall attractiveness of the geothermal project is highly dependent on future energy prices.

Cases 4 and 5 show the effects of higher and lower maintenance charges. For Case 4, these charges escalate 2 percent per year from the base-case value at Year 3. This would provide for higher maintenance charges as equipment ages. For Case 5, maintenance charges are one-half those of the base case. The benefit:cost ratios and equivalent energy costs are not significantly different from base case values. Maintenance assumptions, then, are not very critical.

The influence of using only identified costs and not including any contingency for unexpected capital expense is shown in Case 6. The total cost is significantly reduced; so the benefit:cost ratio increases somewhat and long-term costs of energy decrease.

One major system uncertainty is the pumping drawdown for the production well. Case 7 illustrates the effect of increasing drawdown from about 450 feet to about 1500 feet, essentially doubling the well pump power requirements. This corresponds to a reservoir permeability of about 0.035 darcies. Electric power costs are significantly higher, and the project becomes much less attractive. The benefit:cost ratio for the 8 percent discount factor decreases from 1.40 to 1.27.

The University normally uses natural gas as a boiler fuel. In times of curtailment, however, fuel oil is used instead, usually a middle distillate such as No. 2 fuel oil. If 10 percent of the UNM heat had to be supplied by oil, then the annual fuel bill would increase considerably since fuel oil costs about 2.8 times as much as natural gas, based on recent price quotations. Case 8 illustrates

this effect on project economics. The benefit:cost ratio increases significantly.

A "crash" program committing all initial construction and equipment at the start of the project would gain greater fuel savings earlier. The overall economic effect, however, as shown in Case 9, is relatively small.

One obvious alternative must also be considered: continued use of natural gas. Benefits and costs, as previously used, are meaningless in this instance. Case 10, however, shows the net discounted fuel cost associated with this alternative. Note that in every case it exceeds the cost for a geothermal system. That is to say, using the same economic assumptions, continued use of natural gas is more expensive than installing a geothermal system.

In summary, the overall economics of a hot-water geothermal heating system for the University of New Mexico are favorable. They are also highly dependent on the assumptions made regarding the escalation of fossil fuel costs over the project lifetime. The price and availability of natural gas are both factors which can have a major impact on the economics of this project. Some recent projections by DOE estimate escalation factors for natural gas in this part of the country to be close to our "low utilities" case. On the other hand, escalation of gas price (over and above general inflation) has been more than 20 percent per year for the past eight years, a value much higher than our estimate. Any required switch to fuel oil for all or part of the campus load will also raise fossil fuel prices drastically.

Task III.4 Net Energy Ratio

Analysis of energy-related projects by net energy, rather than by dollars alone, is a relatively new concept. There have been many publications in the field, but there is not yet universal agreement on methods or data sources.

Much of the basis for net energy analysis was laid in the early 1970s by Herendeen (1973) and Gilliland (1975 and 1978). The "classic" approach has been to use econometric models to determine energy-to-dollar ratios for transfers from one segment of the economy to another. This approach has been criticized for sometimes comparing apples and oranges. Weisz (1980), for instance, points out that theoretically all net energy ratios must be equal to 1.000 to satisfy the first law of thermodynamics. What should really be compared is the net ratio of one or more particular types of energy.

We elected to use two different methods of net energy analysis in our studies. The first method is an intuitive engineering approach; the second uses econometric factors coupled to our cost estimates.

In the engineering approach, we made independent estimates of the fossil fuel equivalents of all major pieces of equipment, construction operations, etc. For example, well drilling for wells in our size range typically proceeds at about 10 ft/hr and requires a 650 HP diesel engine running at 20 to 25 percent efficiency (fossil fuel basis). The well energy, however, must also include allowances for casing, cement, drilling, mud, transportation, energy depreciation of the drilling rig, and labor. By making reasonable estimates for each factor, we arrived at the totals shown in Table LV. The total energy "capital" is estimated to be 62.21×10^9 Btu. Annual "operating" energy, tied back to fossil fuel requirements, is 16.82×10^9 Btu. Annual fossil fuel savings are 135×10^9 Btu. We thus arrive at an energy payout period:

$$\begin{aligned} N &= \frac{\text{Capital energy}}{\text{Fuel savings/yr} - \text{operating fuel/yr}} \\ &= \frac{62.21}{135 - 16.82} = 0.53 \text{ yr.} \end{aligned} \tag{23}$$

For a 30-year project life, the net ratio of fossil fuel saved to fossil fuel expended is:

$$R = \frac{30 \text{ (fuel savings/yr)}}{30 \text{ (operating fuel/yr)} + \text{capital energy}} \quad (24)$$

$$= \frac{(30)(135)}{30(16.82) + 62.21} = 7.15$$

The second approach we used involved the use of econometric energy factors and our cost estimates, taken from Task III.2. Factors (Btu/\$) were taken from Herendeen (1973) and from Carlson and Underhill (1976) and adjusted to 1980 values. These are given in Table LV, along with the associated energy values for the project. Using this approach, the energy capital estimate is 89.68×10^9 Btu, 44 percent higher than the first estimate. Annual operating energy, however, is slightly lower. The energy payout period is 0.75 years, and the net fossil fuel energy ratio is 7.10.

Both these approaches to net energy evaluation reach the same conclusion: the proposed project is extremely attractive as a means of saving fossil fuel energy. Even if our ratio were high by a factor of 2.0 (which is very unlikely), the project would still be attractive from an energy standpoint.

TABLE LV

NET ENERGY TABULATION

	Engineering Estimate 10 ⁹ Btu	NER Factor 10 ⁴ Btu/\$(1980)	Factor Estimate 10 ⁹ Btu
Initial Items			
Production Well	21.91	3.136	32.30
Disposal Well	9.44	3.136	11.79
Production Pump	3.13	2.521	4.87
Brine Pump	0.20	2.521	0.23
Secondary Pumps	0.20	2.521	0.58
Distribution Piping	4.99	3.009	13.54
Primary Tank	0.95	4.717	1.79
Heat Exchangers	3.10	3.009	7.23
Water Treatment Systems	0.50	2.521	0.13
Building Systems & Controls	16.00	3.009	16.28
Total	62.21	-	89.68
Annual Expenditures			
Production Pump	7.92	-	7.92
Brine Pump	1.80	-	1.80
Secondary Pumps	2.10	-	2.10
Labor	0.80	1.087	0.27
Maintenance	3.20	3.060	3.12
Supplies	1.00	3.00	0.81
Total	16.82	-	16.02
Annual Fossil Fuel Savings	135.00	-	135.00
Energy Payout Period	0.53	-	0.75

Task III.5 Institutional Procedures

Three areas must be considered in order to define the procedures necessary to carry out this geothermal program and to identify the appropriate institutional responsibilities. First, it is necessary to define a program plan. Second, it is necessary to identify the program management structure needed to carry out such a plan. Third, it is necessary to fit that structure into the existing UNM organizational structure. (Note that there is a close relationship between this task and Task III.7, Implementation.)

A. Program Plan

An ordered geothermal energy development program plan is outlined in Table LVI. Specific dates and task durations are not included; instead, a "minimum duration" is estimated for each phase. If a minimum duration time schedule is followed, initial use of geothermal heating would take place in the fall of 1982, with the full system in use by fall of 1984.

Phase I of the plan involves planning and project organization on the part of the University. It includes complete financial and technical reviews, permit approvals, financial planning and approval.

Phase II of the plan involves drilling and testing both the production well and the disposal well. It also includes surface facility installation and modification of the first group of buildings to receive geothermal heat.

Phase III of the plan involves expanding the system to the full complement of buildings. Phase IV represents full operational use of the system. At this time, plans could be developed for adding additional well systems.

B. Management Structure

In order to carry out a moderate-sized energy and construction plan such as this one, it is necessary that a single individual be identified to have primary responsibility for the project. This project manager would carry out planning and scheduling, obtain permits, supervise and coordinate contractor activities, and be responsible

TABLE LVI
PROGRAM PLAN

Phase I - Organization, Approval, Financing and Planning

Minimum Duration - 1 year

Program Tasks

- Concept approval
- Project assignment
- Project organization
- Financial planning
- Detailed program preparation
- Technical review
- Financial review
- Permit approvals
- Program approvals

Phase II - Drilling, Testing and Initial Installation

Minimum Duration - 1 year

Program Tasks

- Production well drilling and testing
- Disposal well drilling and testing
- Initial building modifications
- Surface facility construction

Phase III - Initial Operation and Expansion

Minimum Duration - 2 years

Program Tasks

- Continued building modifications
- Expanded use to full capacity

Phase IV - Full Use

Expected Duration - 28 years (approximate)

Program Tasks

- Continued full use
- Consideration of additional systems

for smooth interfacing of the system with existing University utility systems and operations. He would be responsible for reports to the regents and to any agencies which may be sharing the development costs. The ideal person for such a job would be an engineer with experience in oil and gas drilling operations plus a reasonable knowledge of building heating systems. He must be able to work closely with a wide variety of people and institutions.

The actual engineering, drilling, testing and construction should be carried out by contractors reporting to the project manager. Two primary contractors would be required. The first is a drilling contractor, who would have full responsibility for drilling, casing and testing the wells and production pumps. This contractor would probably be selected from among major oil and gas drilling contractors. They are used to handling such jobs on a turn-key basis.

The second contractor would be a heating/ventilating/air-conditioning (HVAC) specialist. This contractor would be responsible for surface facilities and tie-ins to the existing building systems. There are several such contractors in the Albuquerque area, and the University traditionally uses them for major HVAC work.

It is our opinion that this arrangement, using a University-paid project manager and two prime contractors, would work best. It is unlikely that we could find a single prime contractor able to handle both drilling and HVAC systems.

C. The University Structure

Figure 81 shows the existing UNM management structure as it applies to utility systems. The logical location for the geothermal system project manager would be within the Physical Plant organization, reporting either to the Physical Plant Director or the Assistant Director for the Utilities Division. Clearly, however, the manager would have to maintain close working relationships with the University Architect and his staff and with the Comptroller's staff.

Up to the present time, this study project has been carried out by academic staff and graduate students. Implementation, however, must obviously be carried out by the business and physical plant

Figure 81. UNM Utilities Operations Organization

organizations. The project would be much too large, in terms of both time and money, to be carried out within the research function of the academic program, which reports to the Provost. It would be our hope, however, that the investigators involved in the past could continue to participate in the program at a low level of effort.

D. External Responsibilities

Several state agencies would have to be involved to a greater or lesser degree in a geothermal development program at UNM.

1. The Board of Educational Finance is charged with overall coordination and planning of expenditures by all state colleges and universities.

2. The Energy and Minerals Department has responsibility for effective development of the state's extensive energy and mineral resources. Among other activities, it promotes new energy development by coordinating and/or funding energy research and demonstration projects in the state.

3. The State Engineer has overall responsibility for water resources development and use. Though the proposed project would not be a net user of water, the hydrologist within the State Engineer's office would have to be consulted and would certainly be interested in the operation of the system.

4. The Environmental Improvement Agency's Water Quality Division has primary responsibility for water discharges, reinjection wells, emergency planning, etc. They would have to provide approval for the geothermal brine disposal wells and auxiliary equipment.

Task III.6 Overall Environmental and Energy Impacts

A. Environmental Evaluation

This section reviews the environmental aspects of the proposed geothermal heating system for the University of New Mexico campus. To the extent practicable, it follows the "Environmental Guide" outlined as an appendix to the DOE contract under which this study was carried out.

1. The proposed project is a geothermal hot-water heating system to provide a portion of the space heating and domestic hot water energy requirements on the campus of the University of New Mexico. The proposed system would supply energy equivalent to the burning of 135×10^9 Btu annually using hot water from a single production well. Energy would be transferred to buildings using a closed secondary water circulating system. Cooled produced water would be reinjected using a single well.

The proposed project is located in the City of Albuquerque, Bernalillo County, New Mexico. All facilities would be on land now owned by UNM.

Potential environmental effects are small. There would be some noise and local air pollution during drilling and construction. There would be a small decrease in air pollution during operation due to decreased local combustion of fossil fuels.

2. Description of Proposed Activity

- a. Location: Maps are shown in sections of this report covering Tasks I.2, II.1 and III.1.
- b. Project Objectives: The objective of the project is to provide energy for space heating and domestic hot water for a portion of the UNM campus.
- c. Geophysical Exploration:
 - (1) Test Wells: Test data have already been obtained from shallow gradient holes and local water wells (Jiracek and Callender, 1980). No major test drilling program except the actual project production and disposal wells is anticipated.

(2) Other Geophysical Activity: Except for local surface reconnaissance, no major additional geophysical exploration is anticipated.

- d. Drilling Description: Two wells must be drilled using rotary drilling rig equipment. The production well will be 8300 feet deep. The disposal well will probably be about 5000 feet deep. (Depth will depend on final agreements reached with state and local regulatory agencies.) Typical hole sizes and casing programs are given under Task III.1 (see Figures 69 and 72). Drilling will require the use of a light, water-based drilling mud. The University of New Mexico owns surface rights and shallow produced water rights in the area of the project. It is assumed, but not known in a strict legal sense, that the University also has title to the geothermal energy rights from deep wells. Similar precedence has been established elsewhere in the state.

During drilling operations, an area approximately 100 by 150 feet must be set aside for the rig and associated equipment. The drilling operations for both wells together should not exceed about 110 days. Normal steel mud tanks will be used. Waste mud and drill cuttings will amount to about 13000 bbl (2100 m³), wet basis, and about one-tenth of that, dry basis. Final drilling plans must be approved by local regulatory agencies. We would expect, however, that lined pits would be used to receive waste mud and cuttings. Net evaporation in Albuquerque's desert climate would rapidly reduce the volume to an amount that could be easily managed. Once dry, or nearly dry, the cuttings and mud would be used locally as fill material. We expect very limited use of drilling mud builders and thinners (bentonite clays and lignosulfonates); so the dried residue will be relatively stable and inert.

The project area is an urban/suburban university campus already containing an extensive network of roads.

No new roads are required.

- e. Description of Operations: Most piping will be located in existing campus utility tunnels. Additional required piping, such as that from the heat exchange facilities to the disposal well site, will be buried 3 to 5 feet below the surface if tunnels are not available. New equipment and retrofit equipment are described in Task III.1. The Utilities Division of the University Physical Plant Department will be responsible for system operations and maintenance.
- f. Project Costs and Schedules: Costs are presented in Task III.2. A proposed project program schedule is given in Task III.7.

3. Description of Existing Environments

- a. General: The proposed project is located at an urban/suburban university campus in Albuquerque, New Mexico. The city is located in the Rio Grande Valley, has a high altitude (approximately 5000 feet at the campus) and a desert climate.
- b. Physical Environment: The nearest continually-flowing surface water is the Rio Grande, which flows about two miles west of the campus. The campus and city are laced with storm ditches and canals which flow into the Rio Grande. The Rio Grande is used as a major source of irrigation water. Domestic water supplies are taken from the same broad aquifer proposed for the geothermal project. It is described in considerable detail in Tasks I.2 and I.4. Recharge is partly by rainfall (which averages less than 10 inches per year), but largely by a steady north-to-south underground flow.

The basin is composed principally of alluvial fill from mountains to the east and north. There is considerable seismic activity of a very low energy scale, but little evidence of major activity (Jiracek and Callender, 1980, and Kelley, 1977). Although groundwater has been

used for many years for domestic water and some irrigation, there is no evidence of subsidence, or even of any significant drop in the water table (Bjorklund, 1961). Local soil ranges from sand to coarse sand mixed with gravel.

Albuquerque fails to meet national ambient air quality standards in only two categories: particulates and carbon monoxide. Virtually the entire state of New Mexico fails to meet particulate standards because of dust from winds and traffic on dirt roads. Carbon monoxide in excess of ambient standards has been measured many times in the winter near areas of heavy traffic. Except in times of natural gas curtailment, SO₂ emissions are extremely low. Two local 350 MWe electric power plants (used primarily for peaking) and several industrial size boilers (including the University) must occasionally switch to fuel oil in severe winters. (This occurred in 1978-79.)

Albuquerque has frequent moderate to heavy winds. During the winter months, however, stable inversions frequently form in the valley. These usually break by noon. Typically, two to five times a year, however, the inversions persist for the whole day.

- c. Biological Environment: The proposed geothermal system would be located in an urban/suburban campus setting. Nearly all vegetation in the area is domestically cultivated. The areas have many grassy fields and lawns, shade trees and shrubbery. Animals living in the area are those common to southwestern desert cities: numerous species of wild birds, lizards, and insects; small scattered populations of field mice and squirrels; and large numbers of domestic pets. A flock of semi-wild ducks lives in a pond on the campus west of the proposed application area. To our knowledge, there are no threatened or endangered species in the immediate area.

- d. Human Environment: The campus is occupied during the day by up to 20,000 students and 4,000 faculty and staff. The area immediately surrounding the University is mixed residential and light commercial. There are several buildings on campus which have been designated historical landmarks.

All the land required for the proposed project is currently owned by the University of New Mexico.

4. Potential Environmental Impacts

- a. Geology: Since wells would penetrate only alluvium and loose overfill layers, there will be no danger from induced seismicity. There are numerous small seismic events in the area (less than 1.0 on the Richter scale). These would not be strong enough to damage production or injection wells sufficiently to cause environmental damage. There is no record of local water wells ever being affected by seismic events.

The entire basin, down to and below the depths proposed for production, is hydraulically pressured (normal pressure gradient), not geopressed. Subsidence, therefore, is extremely unlikely. Again, there has been no record of any subsidence due to many decades of production from local water wells.

- b. Soils: Since we plan to reinject all produced water, there should be no impact on local soil.
- c. Water Resources: So long as reinjection is used, there should be no impact on water resources, either quantitatively or qualitatively. There would be no net loss of water from the reservoir. Without reinjection, there would be a loss of up to one million gallons per day, with an average of about one-third that amount. If dissolved solids levels are as high as expected (3000 to 4000 ppm), a discharge of this magnitude would noticeably increase salinity of the Rio Grande. With reinjection, however, this will not be the case.

- d. Air Quality: As outlined in Task I.8, air quality for the area would improve slightly (though not enough to be significant) due to decreased use of natural gas.
- e. Noise: Noise would be a problem only during drilling and construction phases. Even then, its impact would be limited to a small area within the campus.
- f. Flora and Fauna: So long as reinjection is practical, there should be no deleterious effects on flora or fauna. Surface discharge of geothermal waters, however, could seriously affect plants due to expected high sodium and other species.
- g. Human Environment: Care must be taken to build attractive facilities which blend well with the campus architecture and landscaping. The facilities will not be large enough, however, to have a major impact on campus land use.

The most probable harmful "accident" would be a break in the primary geothermal loop. Since the steam system would be available as a back-up, the response would be to shut down the geothermal system until repairs are completed. Under worst-case conditions, a break might be undetected or uncontrolled for an hour, resulting in discharge of 40,000 gallons of water, at most. This could contain up to 1400 pounds of dissolved salts, an insignificant amount compared to what is now used for ice control in winter and fertilizer in summer.

5. Effluent Monitoring Program

Effluent monitoring requirements for the injection well would be set by state regulatory agencies. Expected requirements would include daily reporting of amount injected and less frequent reporting of chemical analyses of that water and on injection well pressure/flow characteristics.

6. Alternatives

Clearly, as shown in Task I.8, geothermal space heating would

be more favorable environmentally than any of three available alternatives: continued use of natural gas (which is subject to interruption), use of fuel oil or use of coal. In the long run, passive and semi-active solar heating coupled with better insulation may be best for new buildings. The proposed system, however, is aimed at existing buildings which will be in use for many decades to come.

B. Energy Evaluation

The impact on the campus for this initial demonstration project will be to reduce fossil fuel needs about 20 percent, or 135 billion Btu/yr. Electrical use would increase slightly. Total fossil fuel impact, then, would involve significant savings of natural gas at the expense of a much lesser amount of coal (the principal energy source for electricity in New Mexico).

Possible later expansions of geothermal heating on the campus or at other locations in Albuquerque would further reduce dependence on fossil fuels.

For the initial system, it is essential to have a back-up system with adequate capacity. Such a steam system is already in existence at the University. Presumably, reliability will increase as more geothermal systems are built and operated. Complete back-up capability may not always be necessary.

Widespread use of geothermal heating would result in some shifts in energy use patterns in the state. We have identified some likely trends, but we have not attempted to quantify them. That would require a major economic study of its own. Note that these same effects would follow expanded use of solar energy, which is perhaps the principal competitor to geothermal heating.

1. Total natural gas use would drop, putting less pressure on reserves, but possibly resulting in higher unit costs due to the capital intensive nature of gas distribution.

2. Installed electrical capacity would be as large as at present, possibly larger if electric heat is used for peaking. On-line factors, however, would drop. Again, this might result in higher unit costs.

3. Reduced reliance on fossil fuels in the state might decrease state revenues from severance taxes and from income taxes on public utilities.

Task III. 7 Implementation

A. Schedule

A great number of engineering tasks, reviews, approvals and actual facility construction tasks must be carried out in order to put geothermal energy to use on the UNM campus. Table LVII outlines an optimistic, but possible, schedule for these tasks, running from the present through full system operation in the fall of 1984.

Within the schedule, the area most likely to encounter delay is Phase I. We have assumed general concept approval at the Board of Regents level by the end of 1980. We have also assumed that a project manager would be named early in 1981, and would work on the project on a 50 to 75 percent basis from January to June. Barring major hurdles, this should be adequate time. Experience with other projects in the state, however, shows that delays are common at this stage. It is always easier to continue spending at a very low level than it is to make major commitments.

The schedule for Phases II and III is quite realistic, once the program is approved and funding commitments are made. Highly favorable initial well tests and first-year operating experience might lead to combining the second and third buildings sets to put the total system in operation sooner.

B. Responsibilities

UNM, through the Vice President for Business and Finance, must have overall responsibility for the project. A project manager within that organization would have day-to-day charge of the project. Initially, he would be responsible for planning, financial arrangements, obtaining permits, etc. As the project progresses, he would be responsible for supervising and coordinating the work of the drilling and HVAC contractors. He would have to work on the project 50 to 75 percent of his time from January to June, 1981; 100 percent from July 1981 to September 1982; and about 50 percent from then till September 1984.

A drilling contractor would be selected to drill, case and complete the two wells. He would also be responsible for well testing

TABLE LVII

IMPLEMENTATION SCHEDULE
(Minimum Duration Basis)

Task	Responsibility	Time
Phase I		
Concept approval	UNM	9-80 to 12-80
Project manager (PM) appointment	UNM	1-81
Technical review - drilling	PM, consultant	2-81 to 4-81
Technical review - HVAC	PM, consultant	2-81 to 4-81
Financial planning, resources	PM	2-81 to 5-81
Economic review	PM, UNM	4-81 to 5-81
Permit approvals	PM, agencies	4-81 to 6-81
Program go-ahead approval	UNM	6-81
Phase II		
Contractor selection - drilling (I)	PM, UNM	9-81
Contractor selection - HVAC (II)	PM, UNM	9-81
Detailed engineering	Contractors I & II	9-81 to 12-81
Production well drilling	Contractor I	3-82 to 5-82
Production well testing	Contractor I, PM	5-82
Disposal well drilling	Contractor I	5-82 to 6-82
Disposal well testing	Contractor I, PM	6-82
Surface facility construction	Contractor II	5-82 to 8-82
Initial building modifications	Contractor II	5-82 to 8-82
Phase III		
Initial operation	PM, UNM	9-82
Detailed engineering, 2nd buildings	Contractor II	12-82 to 3-83
Second building modifications	Contractor II	4-83 to 8-83
Second building operations	PM, UNM	9-83
Detailed engineering, 3rd buildings	Contractor II	12-83 to 4-84
Third building modifications	Contractor II	4-84 to 8-84
Third building operations	PM, UNM	9-84

and production pump installation. In accord with normal oil and gas practice, he would be responsible for subcontracting mud services, logging services, casing purchase, etc. Normal contracting arrangements are on a cost-plus-daily-fee basis.

A heating (HVAC) contractor would be selected to design and construct surface facilities and building modifications. Both contractors would report to UNM's project manager.

C. Project Funding

In addition to normal University funding sources, such as bond issues, there are at least three other potential sources of funds which should be considered. If these sources look attractive and feasible, it would be the responsibility of the project manager to submit appropriate requests and/or proposals.

1. U.S. Department of Energy. DOE has a program at the present time to encourage geothermal energy development by accepting much of the project risk associated with drilling and well testing. On selected projects, DOE will pay from 20 to 90 percent of the cost of drilling and testing initial production wells, up to a maximum of \$3.6 million. The fraction paid by DOE depends on the success of the project; they pay less for successful wells, more for ones which are unsuccessful. Thus, they reduce the risk to the user.

2. New Mexico Energy and Minerals Department. In the past two years, EMD has had available limited amounts of money for "matching fund" use in geothermal energy development projects. UNM could be a prime contender for some of those funds.

3. Private industry sources. Since this project could lead to reduced gas use and to further geothermal energy development, some private industries may be willing to support it, either on a grant or loan basis. Gas Company of New Mexico would be a prime candidate since the project could have long-term implications for their supply/demand picture. Union Oil Geothermal Company, active in geothermal drilling for electric power in the Baca project, is another prospect. One other possibility is the establishment of a consortium or limited partnership of local developers, industries and banks to finance the

project, with the University agreeing to pay a reasonable price for the energy as it is used.

D. Initial Steps

No major commitment of time or resources can be made until the basic concept is approved by top University administration (the Vice President for Business and Finance, the President and the Regents). To obtain this approval, we propose the following steps:

1. Publication of final report under the current DOE contract. (This would be the last step funded under that contract.)
2. Preparation of a short management summary by the present principal investigators and the campus energy conservation engineer.
3. Presentation of this summary, in written and/or oral form to appropriate UNM officials, state boards, etc.
4. Recommendation to the Regents that a project manager be appointed.

Once a project manager is appointed, he should review our report in detail. He should further obtain outside consulting review from both a drilling contractor and an HVAC contractor. He should coordinate permit approvals, financing, engineering and construction schedules, and all other aspects of the program.

CONCLUSIONS

We conclude that geothermal energy can provide effective, economical space heating and domestic hot water heating for a portion of the campus of The University of New Mexico. The deep, moderate temperature geothermal resources can be tapped and applied using existing technology and can be competitive with fossil fuel energy sources.

Specifically, we have reached the following conclusions:

1. Building heat loads are highly variable, depending on use and construction. Original design estimates and more recent estimates based on allocation of total known heat are adequate for most purposes. A detailed computer model is available for more precise load estimations.

2. The large, deep, interconnected aquifer below Albuquerque should be a good source of hot water in the 170 to 210°F range, using wells roughly 6500 to 9000 feet in depth. Well drawdowns are expected to be small, about 450 feet or less for 600 to 700 gal/min, typical for a single production well. Limited use of the resource (one to five producing wells) will have virtually no impact on the reservoir.

3. Carbon steel may be used for well tubulars and pipelines, provided care is taken to exclude oxygen from the system. Stainless steels, brasses and copper are all corrosion-resistant to the expected brine and can be used for pumps, valves and heat exchanger tubing. Under certain conditions, an iron-silica scale can develop on carbon steel pipe.

4. Geothermal fluids must be reinjected into the aquifer below the levels which might be used for domestic water wells.

5. Air conditioning using hot geothermal water as an energy source is not competitive with the existing cooling systems or with evaporative cooling.

6. The most attractive portion of the UNM campus for geothermal heating includes the College of Education, dormitories on the east side of the campus, and the gymnasium complex.

7. The best design for an initial system uses a large heat exchanger to supply the geothermal heat to a closed circulating hot water loop. The existing steam system is maintained for peak loads and as an emergency back-up.

8. A single production well geothermal system can replace 135 billion Btu per year in fossil fuels when used to heat the recommended portion of the campus. Detailed building-by-building designs show that the system is workable and can be easily tied to existing building systems.

9. The estimated total capital cost for the complete system is \$3.85 million.

10. The system is economically competitive with use of fossil fuels. Assuming a 30-year life and moderate energy cost increase, the benefit:cost ratio at a 6 percent discount rate is 1.70

11. On a net-energy accounting basis, one year of operation of the system would more than make up for the energy expended in building and operating the system.

12. Overall energy and environmental impacts are favorable.

13. The project could best be implemented under a University project manager using two primary contractors, one for drilling and testing and one for surface and building systems.

RECOMMENDATIONS

We recommend that a low-temperature (195°F) geothermal hot-water system be designed and installed to provide space and hot water heating for a portion of the campus of the University of New Mexico.

Specifically, we recommend the following:

1. The basic system concepts presented in this report should be accepted and approved by UNM administration and regents.
2. A project manager should be appointed to implement the project.
3. Various University, State, Federal and private funding sources should be considered.
4. The system should be designed for a capacity of about 25 million Btu/hr to serve a major portion of the campus.
5. The system should be built to use the existing steam system for peak loads and emergency back-up. It should be designed for minimum interference with the existing system and for minimum environmental disruption.
6. For at least the initial system, a separate secondary closed circulation loop should be used.
7. Geothermal brine should be disposed of by reinjection below the level of any present or possible withdrawal for domestic water.

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APPENDIX A

**DESIGN DETAILS
AND
BUILDING EQUIPMENT
ANALYSIS**

1. Design Details

Tables A-I through A-VII contain summaries of process conditions (design basis) for each building heating system at various outdoor daily average temperatures.

2. Equipment Analysis

The following pages contain heating design details and equipment analyses for the various buildings in the Redondo East segment. In the figures, dotted lines indicate equipment or piping to be added for the geothermal system. Solid lines indicate existing equipment. Letters on the figures correspond to individual pieces of equipment described in the text.

TABLE A-1

BUILDING HEAT LOADS AT 0°F OUTSIDE AIR TEMPERATURE

Building No.	Flow Rate lb/hr	Return Temp. °F	Building Loop Temp. °F	Geothermal Heat 10 ⁶ Btu/hr	Steam Heat 10 ⁶ Btu/hr	Total Heat 10 ⁶ Btu/hr
East & West 58	-----	-----	200	-----	14.10	14.10
59	125,800	97	130 - Gym Panel 200 - Pool Panel 120 - Pools	7.97	2.79	10.80
61	-----	-----	200	-----	1.84	1.84
63	47,900	120	160	1.93	-----	1.93
64	20,600	120	160	0.83	-----	0.83
65	43,600	120	160	1.76	-----	1.76
66	14,400	120	160	0.58	-----	0.53
67	34,400	120	160	1.38	-----	1.38
68	15,500	120	160	0.63	-----	0.63
69	15,500	120	160	0.63	-----	0.63
70	15,500	120	160	0.63	-----	0.63
71	-----	-----	200	-----	2.01	2.01
74/75	-----	-----	200	-----	3.10	3.10
77	-----	-----	200	-----	2.52	2.52
155	-----	-----	200	-----	4.33	4.33
156	-----	-----	200	-----	3.23	3.23
157	-----	-----	200	-----	2.01	2.01
Total	333,200	111	---	16.34	35.93	52.26

TABLE A-II

BUILDING HEAT LOADS AT 10°F OUTSIDE AIR TEMPERATURE

Building No.	Flow Rate lb/hr	Return Temp. °F	Building Loop Temp. °F	Geothermal Heat 10 ⁶ Btu/hr	Steam Heat 10 ⁶ Btu/hr	Total Heat 10 ⁶ Btu/hr
East & West 58	380,100	151	183	3.42	8.75	12.20
59	201,300	117	130 - Gym Panel 200 - Pool Panel 120 - Pools	8.65	1.74	10.40
61	49,800	151	183	0.45	1.15	1.60
63	32,000	107	160	1.65	----	1.65
64	12,600	105	160	0.70	----	0.70
65	30,000	107	160	1.60	----	1.60
66	10,800	110	160	0.54	----	0.54
67	28,600	115	160	1.29	----	1.29
68	11,700	112	160	0.56	----	0.56
69	11,700	112	160	0.56	----	0.56
70	11,700	112	160	0.56	----	0.56
71	54,300	151	183	0.49	1.25	1.74
74/75	83,900	151	183	0.76	1.93	2.69
77	68,100	151	183	0.61	1.57	2.18
155	116,900	151	183	1.05	2.69	3.74
156	87,300	151	183	0.79	2.01	2.80
157	54,300	151	183	0.49	1.25	1.74
Total	1,245,100	141	---	24.17	22.34	46.52

TABLE A-III

BUILDING HEAT LOADS AT 20°F OUTSIDE AIR TEMPERATURE

Building No.	Flow Rate lb/hr	Return Temp. °F	Building Loop Temp. °F	Geothermal Heat 10 ⁶ Btu/hr	Steam Heat 10 ⁶ Btu/hr	Total Heat 10 ⁶ Btu/hr
East & West 58	380,100	139	167	7.98	2.66	10.60
59	201,300	113	130 - Gym Panel 200 - Pool Panel 120 - Pools	9.56	0.53	10.10
61	49,800	139	167	1.05	0.35	1.40
63	25,300	100	160	1.53	----	1.53
64	9,400	95	160	0.62	----	0.62
65	22,500	97	160	1.42	----	1.42
66	7,800	100	160	0.47	----	0.47
67	21,000	105	160	1.16	----	1.16
68	8,500	102	160	0.50	----	0.50
69	8,500	102	160	0.50	----	0.50
70	8,500	102	160	0.50	----	0.50
71	54,300	139	167	1.14	0.38	1.52
74/75	83,900	139	167	1.76	0.59	2.35
77	68,100	139	167	1.43	0.48	1.91
155	116,900	139	167	2.46	0.82	3.28
156	87,300	139	167	1.83	0.61	2.44
157	54,300	139	167	1.14	0.38	1.52
Total	1,207,500	131	---	35.03	6.80	41.82

TABLE A-IV

BUILDING HEAT LOADS AT 30°F OUTSIDE AIR TEMPERATURE

Building No.	Flow Rate lb/hr	Return Temp. °F	Building Loop Temp. °F	Geothermal Heat 10 ⁶ Btu/hr	Steam Heat 10 ⁶ Btu/hr	Total Heat 10 ⁶ Btu/hr
East & West 58	264,800	127	150	8.74	----	8.74
59	178,400	106	130 - Gym Panel 150 - Pool Panel 120 - Pools	9.73	----	9.73
61	34,100	127	150	1.15	----	1.15
63	19,300	95	160	1.27	----	1.27
64	8,100	90	160	0.57	----	0.57
65	19,000	93	160	1.28	----	1.28
66	5,900	90	160	0.42	----	0.42
67	15,200	94	160	1.01	----	1.01
68	6,500	93	160	0.44	----	0.44
69	6,500	93	160	0.44	----	0.44
70	6,500	93	160	0.44	----	0.44
71	37,800	127	150	1.25	----	1.25
74/75	58,400	127	150	1.93	----	1.93
77	47,400	127	150	1.57	----	1.57
155	81,500	127	150	2.69	----	2.69
156	60,800	127	150	2.01	----	2.01
157	37,800	127	150	1.25	----	1.25
Total	888,600	119	---	0.36	----	36.18

TABLE A-V

BUILDING HEAT LOADS AT 40°F OUTSIDE AIR TEMPERATURE

Building No.	Flow Rate lb/hr	Return Temp. °F	Building Loop Temp. °F	Geothermal Heat 10 ⁶ Btu/hr	Steam Heat 10 ⁶ Btu/hr	Total Heat 10 ⁶ Btu/hr
East & West 58	151,700	115	133	6.83	----	6.83
59	156,000	100	130 - Gym Panel 200 - Pool Panel 120 - Pools	9.33	----	9.33
61	19,900	115	133	0.90	----	0.90
63	16,800	92	160	1.15	----	1.15
64	5,900	76	160	0.52	----	0.52
65	15,500	87.5	160	1.13	----	1.13
66	4,900	82	160	0.39	----	0.39
67	11,800	86	160	0.88	----	0.88
68	5,000	84	160	0.38	----	0.38
69	5,000	84	160	0.38	----	0.38
70	5,000	84	160	0.38	----	0.38
71	21,700	115	133	0.98	----	0.98
74/75	33,500	115	133	1.51	----	1.51
77	27,200	115	133	1.23	----	1.23
155	46,700	115	133	2.10	----	2.10
156	34,900	115	133	1.57	----	1.57
157	21,700	115	133	0.98	----	0.98
Total	583,300	108	---	30.65	----	30.65

TABLE A-VI

BUILDING HEAT LOADS AT 50°F OUTSIDE AIR TEMPERATURE

Building No.	Flow Rate lb/hr	Return Temp. °F	Building Loop Temp. °F	Geothermal Heat 10 ⁶ Btu/hr	Steam Heat 10 ⁶ Btu/hr	Total Heat 10 ⁶ Btu/hr
East & West 58	93,200	103	117	5.31	----	5.31
59	144,300	98	130 - Gym Panel 200 - Pool Panel 120 - Pools	9.03	----	9.03
61	12,200	103	117	0.70	----	0.70
63	14,600	87	160	1.08	----	1.08
64	4,900	74	160	0.43	----	0.43
65	11,300	79	160	0.92	----	0.92
66	4,100	76	160	0.35	----	0.35
67	9,600	81	160	0.76	----	0.76
68	4,000	79	100	0.33	----	0.33
69	4,000	79	160	0.33	----	0.33
70	4,000	79	160	0.33	----	0.33
71	13,300	103	117	0.76	----	0.76
74/75	20,500	103	117	1.17	----	1.17
77	16,700	103	117	0.95	----	0.95
155	28,700	103	117	0.76	----	0.76
156	21,400	103	117	1.22	----	1.22
157	13,300	103	117	0.76	----	0.76
Total	420,100	98	---	26.05	----	26.05

TABLE A-VII

BUILDING HEAT LOADS AT 60°F OUTSIDE AIR TEMPERATURE

Building No.	Flow Rate lb/hr	Return Temp. °F	Building Loop Temp. °F	Geothermal Heat 10 ⁶ Btu/hr	Steam Heat 10 ⁶ Btu/hr	Total Heat 10 ⁶ Btu/hr
East & West 58	49,500	91	100	3.42	----	3.42
59	135,700	97	130 - Gym Panel 200 - Pool Panel 120 - Pools	8.65	----	8.65
61	6,400	91	100	0.45	----	0.45
63	13,300	82	160	1.05	----	1.05
64	3,600	72	160	0.33	----	0.33
65	9,900	76.5	160	0.84	----	0.84
66	3,900	71	160	0.35	----	0.35
67	7,400	80	160	0.60	----	0.60
68	3,500	75	160	0.30	----	0.30
69	3,500	75	160	0.30	----	0.30
70	3,500	75	160	0.30	----	0.30
71	7,000	91	100	0.49	----	0.49
74/75	10,900	91	100	0.76	----	0.76
77	8,800	91	100	0.61	----	0.61
155	15,200	91	100	1.05	----	1.05
156	11,300	91	100	0.79	----	0.79
157	7,000	91	100	0.49	----	0.49
Total	300,400	93	---	20.75	----	20.75

Building Name: Hokona (West mechanical room)
 Building Number: 58
 Refer to Figure A-1

- A. Steam-to-water heat exchanger: Capacity to heat 270 GPM water from 180 to 200 F using steam at 40 psig, 0.002 fouling factor, 7 ft. head maximum water pressure drop.
- B. Pumps: 270 GPM capacity at 50 ft. head, 5 hp, 72% efficient, 30 psig discharge pressure, 21 psig suction pressure.
- C. Condensate Cooler: 4 pass, 10" diameter X 54" length, 48.5 sq. ft. surface, 5.5 ft. maximum pressure drop with 40 GPM cooling water.

Building Name: Hokona (East mechanical room)
 Building Number: 58
 Refer to Figure A-1

- A. Steam-to-water heat exchanger: Capacity to heat 500 GPM water 20 F using 5,200 lb/hr steam at 40 psig.
- B. Pumps: 270 GPM capacity at 50 ft. head, 5 HP, 72% efficient, 30 psig discharge pressure, 21 psig suction pressure.
- C. Condensate cooler: No information

Heat Loads

	Name	# Units	Fan HP	Capacity (Btu/hr)
I.	<u>Convectors</u>	161	--	438,610
II.	<u>Unit heater</u>	1	1/30	12,000
III.	<u>Radiators</u>	390	--	1,152,460
IV.	<u>Booster Coils</u>	27	--	---
V.	<u>Heating Coils (West)</u>			

Area (ft ²)	<u>Tube Rows</u>		CFM	Air Temp (°F)		GPM	Water Temp (°F)	
	Length	Depth		in	out		in	out
15.0	120"	2"	12,000	55	70	17	190	170
15.0	120"	2"	12,000	55	69	15	190	170

Figure A-1. Schematic for building 58
(Hokona, East and West).

VI. Heating Coils (East)

Area (ft ²)	<u>Tube Rows</u>		CFM	Air Temp (°F)		GPM	Water Temp (°F)	
	Length	Depth		in	out		in	out
15.0	120"	2"	12,000	55	70	190	170	

In each case the air friction loss is 0.25 in. head and the water friction loss is 1 ft. head.

Building Name: Johnson Gymnasium
Building Number: 59
Refer to Figure A-2

- A. Steam-to-water heat exchanger (panel heating): Capacity to heat 133 GPM from 90 to 130 F with steam at 60 psig.
- B. Steam-to-water heat exchanger (swimming pool): Capacity to heat 10 GPM from 80 to 120 F using steam at 5 psig, 0.001 fouling factor
- C. Water-to-water heat exchanger (swimming pool): Capacity to heat 10 GPM from 80 to 120 F (209,000 Btu/hr) using water entering at 160 F and leaving at 100 F. (New equipment requirement)
- D. Pump (panel heating): Pump presently disconnected from this point.

Heat Load

- I. Natatorium Radiant Floor Panel Heating System: This panel heating system consists of a number of pipes located under the pool deck.

Building Name: Olympic Pool
Building Number: 59
Refer to Figure A-3

- A. Steam-to-water heat exchanger (training pool): Maximum capacity of 480 lb/hr steam at 2 psig.
- B. Water-to-water heat exchanger (training pool): Capacity to heat 22.2 GPM from 80 to 120 F (463,900 Btu/hr) using water entering at 160 F and leaving at 100 F. (New equipment requirement)
- C. Steam-to-water heat exchanger (Olympic pool): Maximum capacity of 4,800 lb/hr steam at 2 psig.
- D. Water-to-water heat exchanger (Olympic pool): Capacity to heat 222 GPM from 80 to 120 F (4,649,000 Btu/hr) using water entering at 160 F and leaving at 100 F. (New equipment requirement)
- E. Steam-to-water heat exchanger: Capacity to heat 153 GPM water from 170 to 200 F, 3 ft/sec water velocity, 2 psig steam in tubes, 0.0005 for fouling factor in shell and 0.001 fouling factor in tubes, 226 ft.² minimum heating surface.

Figure A-2. Schematic for building 59 (Johnson Gym).

Figure A-3. Schematic for building 59 (Olympic Pool).

- F. Pump: Circulating water pump, centrifugal, 153 GPM capacity at 37 ft. head, 2 HP, 1750 rpm, discharge pressure 59 psig, suction pressure 37 psig.

Heat Load

- I. Cabinet unit heater: Quantity 1, 90,000 Btu/hr capacity using 9 GPM water entering at 200 F and circulating 1,800 CFM air
- II. Heating Coil: Quantity 1, 280,000 Btu/hr capacity using 18 GPM water entering at 190 F and circulating 9,000 CFM air entering at 75 F and leaving at 110 F.
- III. Heating Coils: Quantity 2, Aluminum fins with 5/8" O.D. copper tubes

CFM (@5,000 ft)	E.A.T. (°F)	L.A.T. (°F)	E.W.T. (°F)	L.W.T. (°F)	Total Heat (Btu/hr)
35,500	53	99	200	161	1,450,000

GPM	Water Friction	Total Face Area	Minimum Water Velocity
74	3'	70 ft ²	3 ft/sec

IV. Heating Coils (West)

Area (ft ²)	Tube Length (in.)	Rows Depth	CFM	Air Temp (°F)		GPM	Water Temp (°F)	
				In	Out		In	Out
15.0	120	2	12,000	55	70	17	190	170
15.0	120	2	12,000	55	69	15	190	170

V. Heating Coils (East)

Area (ft ²)	Tube Length (in.)	Rows Depth	CFM	Air Temp (°F)		GPM	Water Temp (°F)	
				In	Out		In	Out
15.0	120	2	12,000	55	70	17	190	170

In each case the air friction loss is 0.25 in head and the water friction loss is 1 ft head.

Building Name: Santa Clara
 Building Number: 61
 Refer to Fig. A-4

A. Steam to Water Heat Exchanger: Capacity to heat 101 GPM water from 153 to 190°F (1,919,000 Btu/hr) using 2,000 lb/hr steam at 40 psig, 54 ft² minimum heating surface, 0.0005 steam fouling factor, 0.0005 water fouling factor.

B. to D. Pumps:

	Capacity (GPM)	Head (ft)	HP	Suction Pressure (psig)
B	15	36	1/2	18
C	14	36	1/2	19.5
D	72	28	1	23.5

Heat Load

I. Convectors: Quantity 102, 4,515 Btu/hr capacity using 0.5 GPM at 170°F with a 20°F average temperature drop.

II. Cabinet Unit Heater: Quantity 1, Cabinet type, centrifugal fan, ceiling mounted, 7,440 Btu/hr capacity using 0.8 GPM water at 170°F, 20°F average temperature drop, approximately 210 CFM air, 1/40 HP fan.

III. Heating Coils

Floor	CFM	Face Area	E.A.T.	L.A.T.	
<u>Serviced</u>	<u>Air</u>	<u>(ft²)</u>	<u>(°F)</u>	<u>(°F)</u>	<u>10³ Btu/hr</u>
3rd	8,200	10.5	55	120	481.4
2nd	5,900	11.1	55	120	343.3
1st	9,400	20	55	120	550.1
Basement	800	2.1	55	120	39.4

Floor		E.W.T.	L.W.T.	Head Loss
<u>Serviced</u>	<u>GPM</u>	<u>(°F)</u>	<u>(°F)</u>	<u>(water, ft)</u>
3rd	24	190	150	2
2nd	17	190	150	2
1st	28	190	150	2
Basement	2	190	150	1

Figure A-4. Schematic for building 61 (Santa Clara) and 156 (Ocate).

Building Name: College of Education Complex
Building Numbers: 63-70

I. Unit A, Building Number 63 (Refer to Fig. A-5)

- A. Steam to Air Heat Exchanger: Capacity to heat 41,700 CFM air from 67.5 to 120°F using 1,950 lb/hr steam (1,950,000 Btu/hr) at 40 psig, 0.15 in. air pressure drop, 770 ft/min face velocity, 41.25 ft² face area.
- B. Fan: 43,010 CFM discharge, 30 HP, airfoil type.
- C. Water to Air Heat Exchanger: Capacity to heat 41,700 CFM air from 67.5 to 120°F using 91 GPM water entering at 160° and leaving at 120°F, 1,566 ft of finned tubing required, 23.5 psi maximum water pressure drop (NEW EQUIPMENT REQUIREMENT).

II. Unit B, Building Number 64 (Refer to Fig. A-6)

- A. Steam to Air Heat Exchanger: Capacity to heat 18,000 CFM air from 35 to 102°F using 1,060 lb/hr steam at 40 psig (1,060,000 Btu/hr), 0.4 in. air pressure drop.
- B. Steam to Air Preheat Coil: Capacity to heat 18,000 CFM air from 0 to 35°F using 562 lb/hr steam at 40 psig (562,000 Btu/hr), 0.4 in. air pressure drop, 1000 ft/min face velocity, 23.25 ft² face area.
- C. Fan: 18,000 CFM discharge, 1,786 ft/min outlet velocity, 10 HP, centrifugal type.
- D. Water to Air Heat Exchanger: Capacity to heat 18,000 CFM air from 67.5 to 120°F using 39 GPM water entering at 160° and leaving at 120°F (830,600 Btu/hr), 1,126 ft of finned tubing required, 8.23 psi maximum water pressure drop (NEW EQUIPMENT REQUIREMENT).

III. Unit C, Building Number 65 (Refer to Fig. A-7)

- A. Steam to Air Heat Exchanger: Capacity to heat 38,000 CFM air from 67.5 to 120°F using 1,760 lb/hr steam at 40 psig, 0.25 in. air pressure drop, 690 ft/min face velocity, 41.25 ft² face area.
- B. Fan: 34,660 CFM discharge, 20 HP, airfoil type.

Figure A-5. Schematic for buildings 63, 66, 68, 69 and 70 (Education A,D,F,G and H).

Figure A-6. Schematic for building 64 (Education B).

Figure A-7. Schematic for building 65 (Education C).

- C. Water to Air Heat Exchanger: Capacity to heat 38,000 CFM air from 67.5 to 120°F using 83 GPM water entering at 160° and leaving at 120°F (1,760,000 Btu/hr), 1,946 ft of finned tubing required, 25.3 psi maximum water pressure drop (NEW EQUIPMENT REQUIREMENT).

IV. Unit D, Building Number 66 (Refer to Fig. A-5)

- A. Steam to Air Heat Exchanger: Capacity to heat 12,600 CFM air from 67.5 to 120°F (583,000 Btu/hr), 22.5 ft approximate face area.
- B. Fan: 16,710 CFM discharge, 7.5 HP, centrifugal type.
- C. Water to Air Heat Exchanger: Capacity to heat 12,600 CFM air from 67.5 to 120°F using 27.5 GPM water entering at 160° and leaving at 120°F (583,000 Btu/hr), 965 ft of finned tubing required, 3.54 psi maximum water pressure drop (NEW EQUIPMENT REQUIREMENT).

V. Unit E, Building Number 67 (Refer to Fig. A-8)

- A. Steam to Air Heat Exchanger: Capacity to heat 14,500 CFM air from 60 to 110°F using 660 lb/hr steam (660,000 Btu/hr), 0.13 in. air pressure drop.
- B. Steam to Air Heat Exchanger: Capacity to heat 17,650 CFM air from 60 to 110°F using 706 lb/hr steam (706,000 Btu/hr), 0.13 in. air pressure drop.
- C. Fan: 22,080 CFM discharge, 25 HP, centrifugal type.
- D. Fan: 24,680 CFM discharge, 25 HP, centrifugal type.
- E. Water to Air Heat Exchanger: Capacity to heat 15,000 CFM air from 67.5 to 120°F using 65 GPM water entering at 160 and leaving at 120°F (830,000 Btu/hr), 998 ft. finned tubing required, 5.9 psi maximum water pressure drop (NEW EQUIPMENT REQUIREMENT).

VI. Units F, G and H, Building Numbers 68, 69, 70 (Refer to Fig. A-5)

- A. Steam to Air Heat Exchanger: Capacity to heat 14,000 CFM air from 67 to 120°F (625,000 Btu/hr), 22.5 ft² approximate face area.

Figure A-8. Schematic for building 67 (Education E).

- B. Fan: 16,000 CFM discharge, 15 HP, centrifugal type.
- C. Water to Air Heat Exchanger: Capacity to heat 14,000 CFM air from 67 to 120°F using 32 GPM water entering at 160 and leaving at 120°F (625,000 Btu/hr), 958 ft of finned tubing required, 4.5 psi maximum water pressure drop (NEW EQUIPMENT REQUIREMENT).

Building Name: Santa Ana Hall
Building Number: 71
Refer to Fig. A-9

- A. Steam to Water Heat Exchanger: Shell and tube, capacity to heat 110 GPM in shell from 177.5 to 200°F (1,240,000 Btu/hr) using 1,345 lb/hr steam in tubes at 40 psig (283°F), minimum 58 ft² heating surface, 0.001 fouling factor, 125 psig working pressure ASME certified, 6 ft head maximum water pressure drop.
- B. Pump: Centrifugal, end suction, mechanical seal, 110 GPM capacity at 40 ft head, 1,750 rpm, 3 HP, 70 psig discharge pressure, 50 psig suction pressure.

Heat Load

- I. Cabinet Unit Heater: Quantity 1, concealed ceiling mounted, centrifugal fan, 16,330 Btu/hr capacity using 1.6 GPM water entering at 200°F and leaving at 180°F.
- II. Heating Coil: Quantity 1, capacity to heat 18,200 CFM air from 53 to 120°F (1,083,000 Btu/hr) using 108 GPM water entering at 200°F and leaving at 180°F, 0.33 in. head maximum air friction, 10 ft head maximum water pressure drop, 26 ft² minimum coil face area, 144 by 33 in. approximate face dimensions.

Figure A-9. Schematic for buildings 71 and 157 (Santa Ana and Alvarado).

Building Name: Laguna/DeVargas
 Building Number: 74/75
 Refer to Fig. A-10

- A. Steam to Water Heat Exchanger: Capacity to heat 170 GPM from 158 to 203°F (4,240,000 Btu/hr) using 4,600 lb/hr steam at 40 psig (283°F), 0.001 fouling factor, 105 ft² heating surface, 4 ft head maximum water pressure drop.

Reset Schedule:	Outside Air	Discharge
	<u>(Temp.°F)</u>	<u>(Temp.°F)</u>
	0	200
	60	110

- B. Pumps: Centrifugal, end suction, mechanical seal, 170 GPM capacity at 51 ft head, 1,750 rpm, 5 HP.

Heat Load

- I. Convectors: Quantity ?, free standing, sloping top, 36 by 32 in. height by 4 in. depth, 3,800 Btu/hr capacity using 0.4 GPM water entering at 190°F and leaving at 170°F.

II. Heating Coils:

Reset Schedule:	Outside Air	Discharge
	<u>(Temp.°F)</u>	<u>(Temp.°F)</u>
	0	125
	60	95

	CFM Total <u>Ventilation</u>
Laguna	6,590 <u>2,060</u>
	9,800 <u>3,060</u>
	6,610 <u>2,070</u>
DeVargas	6,810 <u>2,130</u>
	9,700 <u>3,010</u>
	6,720 <u>2,100</u>

Figure A-10. Schematic for buildings 74, 75 and 77 (Laguna, DeVargas and LaPosada).

Building Name: La Posada
 Building Number: 77
 Refer to Fig. A-10

- A. Steam to Water Heat Exchanger: Capacity to heat 138 GPM water from 160 to 200°F (2,760,000 Btu/hr) using 2,930 lb/hr steam at 40 psig (283°F), 0.001 fouling factor, approximately 26 ft² surface area, 6 ft/sec maximum water velocity, 8 ft head maximum water pressure drop.

Reset Schedule:	Outside Air	Discharge
	(Temp. °F)	(Temp. °F)
	0	200
	60	100

- B. Pumps: Centrifugal, end suction, mechanical seal, 137 GPM capacity at 43 ft head, 1,750 rpm, 3 HP, 42 psig discharge pressure, 23 psig suction pressure (by observation).

Heat Load

I. Heating Coils:

Heating Coil	Discharge	
CFM, air	Schedule	
Total	Design Dry	Outside Air
Ventilation	Bulb (°F)	(Temp. °F)
40,780	95	60
25,620	125	0

Building Name: Coronado Hall
 Building Number: 155
 Refer to Fig. A-11

A. Steam to Water Heat Exchanger: Capacity to heat 237 GPM from 178.5 to 201.5°F with 2,930 lb/hr steam at 30 psig, 1.85 ft head water pressure drop.

B.-F. Pumps: Each pump in the figure represents four or five pumps in parallel with each other.

	B ₁	B ₂	B ₃	B ₄	C ₁	C ₂	C ₃	C ₄	D ₁	D ₂	D ₃
HP	1/4	1/4	1/4	1/4	1/3	1/3	1/3	1/3	1/2	1/2	1/2
Rated GPM	9.25	9.1	7.4	8.8	9.4	9.8	16.5	17.6	9.2	9.9	17.6

	D ₄	E ₁	E ₂	E ₃	E ₄	F ₁	F ₂	F ₃	F ₄	F ₅
Rated GPM	16.4	9.5	8.8	15.75	14.7	8.5	9.1	6.8	4.0	19.3
HP	1/2	1/2	1/2	1/2	1/2	1/4	1/6	1/6	1/6	1/3

Heat Load

- I. Convectors: Quantity 293, each varies in capacity. Based on 200°F entering water temperature, a 20°F temperature drop, and 65°F entering air temperature, the total capacity is 2,230,000 Btu/hr.
- II. Cabinet Unit Heater: Quantity 6, each varies in capacity. Based on 200°F entering water temperature, a 20°F temperature drop, and 60°F entering air temperature, the total capacity is 231,000 Btu/hr.

Figure A-11. Schematic for building 155 (Coronado Hall).

Building Name: Onate Hall
Building Number: 156
Refer to Fig. A-4

A. Steam to Water Heat Exchanger: Shell and tube, capacity to heat 177 GPM water from 181 to 200°F (1,679,600 Btu/hr) using 1,750 lb/hr steam at 40 psig (283°F), minimum of 58 ft² heating surface, 2 ft head maximum water pressure drop.

B.-D. Pumps:

<u>ID No.</u>	<u>Capacity (GPM)</u>	<u>Head (ft)</u>	<u>Discharge Pressure (psig)</u>	<u>Suction Pressure (psig)</u>	<u>HP</u>
B	75.1	48	43	32	2
C	75.1	48	43	34	2
D	26.0	22	42	35	1/2

Heat Load

- I. Convectors: Quantity 89, 660,000 Btu/hr capacity.
- II. Radiators: Quantity 7, 64,600 Btu/hr capacity.
- III. Heating Coil: Quantity 1, capacity to heat 8,700 CFM air from 35 to 100°F (509,500 Btu/hr), 14.0 ft² minimum coil face area, 620 FPM face velocity, 3 ft head water pressure drop.

Building Name: Alvarado Hall
Building Number: 157
Refer to Fig. A-9

- A. Steam to Water Heat Exchanger: Shell and tube, capacity to heat 110 GPM in shell from 177.5 to 200°F (1,240,000 Btu/hr) using 1,345 lb/hr steam in tubes at 40 psig (283°F), minimum 58 ft² heating surface, 0.001 fouling factor, 125 psig working pressure, ASME certified, 6 ft head maximum water pressure drop.
- B. Pump: Centrifugal, end suction, mechanical seal, 110 GPM capacity at 40 ft head, 1,750 rpm, 3 HP, 70 psig discharge pressure, 50 psig suction pressure.

Heat Load

- I. Cabinet Unit Heater: Quantity 1, concealed ceiling mounted, centrifugal fan, 16,330 Btu/hr capacity using 1.6 GPM water entering at 200°F and leaving at 180°F.
- II. Heating Coil: Quantity 1, capacity to heat 18,200 CFM air from 53 to 120°F (1,083,000 Btu/hr) using 108 GPM water entering at 200°F and leaving at 180°F, 0.33 in. head maximum air friction, 10 ft head maximum water pressure drop, 26 ft² minimum coil face area, 144 by 33 in. approximate face dimensions.

APPENDIX B

BUILDING HEAT LOAD MODEL

1. Internal Heat Sources

A. Lighting (LIGHT)

Heat supplied by persons, lights and equipment in the heated space should be ascertained in institutional as well as commercial buildings. In general, the instantaneous rate of heat gain from electric lighting in Btu per hour can be calculated from

$$Q_{LT} = 3.4 \times 10^3 W_{LT} F_{LT} \quad (B-1)$$

where

W_{LT} = total light wattage, kw

F_{LT} = ratio of the wattage in use, dimensionless

B. Occupancy (OCCUP)

Heat given off by human beings in different states of activity, modes of dress and environmental condition is tabulated in the ASHRAE Handbook (1977). The internal heat gain due to people can be expressed as:

$$Q_{pp} = F_p N_p Q_p \quad (B-2)$$

where

Q_p = rate of heat gain per person, adjusted values based on normal percentage of men, women, and children for various conditions are recommended, Btu per hour

N_p = maximum number of persons

F_p = average ratio of persons hourly, dimensionless

C. Equipment (EQUIP)

For heat generated from equipment in the space, a similar expression to Equation B-1 is used.

$$Q_{eq} = 3.4 \times 10^3 W_{eq} F_{eq} \quad (B-3)$$

where

W_{eq} = total equipment wattage, kw

F_{eq} = ratio of the wattage in use, dimensionless

2. External Sources and Sinks

A. Solar Input (SUNLIT)

Solar radiation has an important effect on the heat gain of a building. This effect depends to a great extent on both the location of the sun in the sky and the clearness of the atmosphere, as well as on the nature and orientation of the building. It is useful at this point to discuss ways of predicting the variation of the sun's location in the sky during the day and with the seasons for various locations on the earth's surface. It is also useful to know how to predict irradiation of a surface by solar radiation at any given time and location on the earth.

The total radiation, I_t , reaching a terrestrial surface is the sum of the direct solar radiation, I_D , the diffuse sky radiation, I_d , and the solar radiation reflected from surrounding surfaces, I_r . The intensity of the direct component is the product of the direct normal irradiation, I_{DN} , and the cosine of the angle of incidence, θ , (refer to Figure B-1) between the incoming solar rays and a line normal (perpendicular) to the surface:

$$\begin{aligned} I_t &= I_D + I_d + I_r \\ &= I_{DN} \cos\theta + I_d + I_r \end{aligned} \tag{B-4}$$

a. Direct Normal Solar Intensity

At the earth's surface on a clear day, I_{DN} is well represented by:

$$I_{DN} = \frac{A}{\exp(B/\sin\beta)} \tag{B-5}$$

where

A = apparent solar irradiation at air mass = 1

B = atmospheric extinction coefficient

β = solar altitude (Figure B-1).

Figure B-1. Solar angles for vertical and horizontal surfaces.

Values of A and B vary during the year because of seasonal changes in the dust and water vapor content of the atmosphere, and because of the changing earth-sun distance. Values in Table B-I, which take account of these effects, were derived from results of research at the University of Minnesota by Threlkeld (1958) and reprinted in the ASHRAE Handbook.

For locations where clear, dry skies predominate, and at high elevations, values found by using Equation B-5 and Table B-I should be multiplied by the clearness factors given by Threlkeld (1958) reproduced here as Figure B-2.

Table B-I lists, as function of date, five variables related to solar radiation. These variables are declination angle, d ; the equation of time, ET; the apparent solar constant, A; the atmospheric extinction coefficient, B; the sky diffuse factor, C.

TABLE B-I
VALUES OF d , ET, A, B AND C

Date	d degrees	ET hours	A Btu per (hr)(sq ft)	B air mass ⁻¹	C
Jan. 21	-20.0	-.190	390	0.142	0.058
Feb. 21	-10.8	-.230	385	0.144	0.060
Mar. 21	0.0	-.123	376	0.156	0.071
Apr. 21	11.6	.020	360	0.180	0.097
May 21	20.0	.060	350	0.196	0.121
June 21	23.45	-.025	345	0.205	0.134
July 21	20.6	-.103	344	0.207	0.136
Aug. 21	12.3	-.051	351	0.201	0.122
Sep. 21	0.0	.113	365	0.177	0.092
Oct. 21	-10.5	.255	378	0.160	0.073
Nov. 21	-19.8	.235	387	0.149	0.063
Dec. 21	-23.45	.033	391	0.142	0.057

Figure B-2. Clearness numbers of non-industrial atmosphere in United States.

b. Diffuse Sky Solar Radiation

The diffuse radiation falling on any surface consists of radiation from the sky and part of the reflected solar radiation from adjacent surfaces, particularly the ground lying south of the surface in question. There has been considerable research to determine the amount of diffuse solar radiation falling on horizontal and vertical surfaces from a clear sky. The radiation does not come uniformly from all parts of the sky, and the ratio of diffuse radiation incident on a vertical surface to that falling on a horizontal surface has been related approximately to the sun's incident angle for the vertical surfaces (Threlkeld, 1962). This ratio of vertical-to-horizontal radiation from the sky varies from a low of about 0.45 for the sun behind the surface at high incident angles, up to about 1.2 with the sun coming at very low angles. The Y term given below is a curve fit for this ratio for vertical surfaces only (Figure B-3).

Figure B-3. Ratio of diffuse sky radiation incident upon a vertical surface to that incident upon a horizontal surface during clear days.

$$I_{dH} = CI_{DN} \quad (B-6)$$

$$I_{dV} = I_{dH}Y \quad (B-7)$$

$$Y = 0.55 + 0.437 \cos \theta + 0.313 \cos^2 \theta \quad (B-8)$$

if $\cos \theta > -0.2$, otherwise $Y = 0.45$

where C , the diffuse radiation factor, is given in Table B-I. I_{dH} is the diffuse sky radiation falling on a horizontal surface, and Y is the ratio of diffuse sky radiation incident upon a vertical surface, I_{dV} , to that incident upon a horizontal surface during clear days.

c. Ground-Reflected Radiation

Ground-reflected radiation includes the diffuse sky and direct solar radiation incident on a horizontal surface. The intensity of the total solar radiation falling on the ground, I_g , is given by Equation B-9:

$$I_g = I_d + \sin \beta I_{DN} \quad (B-9)$$

where β is the solar altitude again and $I_{DN} \times \sin\beta$ is the direct radiation falling on the ground. This ground-reflected diffuse radiation incident on any surface may be estimated by:

$$I_r = I_g \times \rho_g \times F_g \quad (B-10)$$

where ρ_g is the reflectance of the foreground (dimensionless), and F_g is the angle factor between the surface and the ground (dimensionless). The sum of the angle factors equals 1.0, and the angle factor for the surface to ground is:

$$F_g = (1 - \cos\Sigma)/2 \quad (B-11)$$

where Σ is tilt angle (Figure B-1).

d. Time

Time measured by the apparent daily motion of the sun is called solar time. The relation between local solar time and standard time is

$$t_{sol} = t - N_s + ET - (L - 15N_z)/15 \quad (B-12)$$

where

t_{sol} = local solar time, hours after midnight

t = standard time hours after midnight

N_s = daylight saving time index, one or zero

N_z = time zone number, integer (See Figure B-4 and Table B-II)

ET = equation of time, hours

L = longitude, degrees

Figure B-4. Time zones in the United States.

TABLE B-II
TIME ZONE NUMBERS IN U.S. FOR STANDARD TIME

Time Zone	TZN
Atlantic	4
Eastern	5
Central	6
Mountain	7
Pacific	8

e. Solar Angles

Any point on the surface of the earth can be described in relation to the sun's rays at any instant if three fundamental quantities are known. Figure B-5 shows a point P located on the surface of the earth in the northern hemisphere.

f. Latitude, Hour Angle, and Declination Angle

The latitude λ is the angle between the line OP and the projection of OP on the equator plane. This is the same latitude that is commonly used on globes and maps to describe the location of a point with respect to the equator.

The hour angle h is the angle between the projection of OP on the equatorial plane and the projection on that plane of a line from the center of the sun to the center of the earth. Fifteen degrees of hour angle correspond to one hour of time. The hour angle varies from zero at local solar noon to a maximum at sunrise or sunset. Solar noon occurs when the sun is at the highest point in the sky, and hour angles are symmetrical with respect to solar noon. Thus, the hour angles of sunrise and sunset on a given day are identical. The hour angle of each specific time could be derived as:

$$h = (12 - T_{sol}) \pi/12 \quad \text{in radians} \quad (B-13)$$

The sun's declination is the angle between a line connecting the center of the sun and earth and the projection of that line on the equatorial plane. In Table B-I we will find how the sun's declination varies throughout a typical year. On a given day in the year the declination varies slightly from year to year, but for typical HVAC calculations, the values from any year are sufficiently accurate.

g. Solar Altitude, Solar Azimuth, Surface-Solar Azimuth

It is convenient in HVAC computations to define the sun's position in terms of the solar altitude β , and the solar azimuth ϕ , which depend on λ , h , and d .

Figure B-5. Latitude, hour angle and sun's declination.

The solar altitude β (sun's altitude angle) is the angle between the sun's ray and the projection of that ray on a horizontal surface (Figure B-1). It is the angle of the sun above the horizon. It can be shown by analytic geometry that the following relationship is true (Threlkeld, 1962).

$$\sin \beta = \cos \lambda \cos \delta \cos h + \sin \lambda \sin \delta \quad (\text{B-14})$$

The sun rise angle h is the hour angle when solar altitude is zero. Sun rise angle is gotten by setting $\beta = 0$, and solving for $h = h'$.

$$h' = \cos^{-1} (-\tan \lambda \tan \delta) \quad \text{in radians} \quad (\text{B-15})$$

The solar azimuth angle ϕ is the angle in the horizontal plane measured between south and the projection of the sun's rays on that plane, Figure B-1. Again by analytic geometry (Threlkeld, 1962), it can be shown that

$$\sin \phi = \frac{\cos \delta \sin h}{\cos \beta} \quad (\text{B-16})$$

$$\cos \phi = (\sin \beta \sin \lambda - \sin \delta) / (\cos \beta \cos \lambda) \quad (\text{B-17})$$

The solar position angles and incident angles for horizontal and vertical surfaces are shown in Figure B-1, where line OQ leads to the sun, the north-south line is SON and the east-west line is EOW. Line OV is perpendicular to the horizontal plane in which the solar azimuth, angle HOS(ϕ), and the surface azimuth, angle POS(ψ), are located. Angle HOP is the surface-solar azimuth, γ . Table B-III gives values in degrees for several surface azimuths and values of γ from Equation B-18.

TABLE B-III
SURFACE ORIENTATIONS AND AZIMUTHS, MEASURED FROM SOUTH

Orientation	N	NE	E	SE	S	SW	W	NW
Surface Azimuth, deg	180	135	90	45	0	315	270	235

$$\begin{aligned}\gamma &= \phi - \psi \text{ am} \\ \gamma &= \phi + \psi \text{ am}\end{aligned}\tag{B-18}$$

h. Angle of Incidence

The angle of incidence, θ , for any surface is defined as the angle between the incoming solar rays and a line normal to that surface. For the horizontal surface in Figure B-1, the incident angle θ_H is QOV; for the vertical surface, the incident angle θ_V is QOP. For any surface, the incident angle θ is related to β , γ , and the tilt angle of the surface Σ by:

$$\cos\theta = \cos\beta \cos\gamma \sin\Sigma + \sin\beta \cos\Sigma\tag{B-19}$$

where

Σ = tilt angle of the surface from the horizontal.

When the surface is horizontal, $\Sigma = 0$ deg, and:

$$\cos\theta_H = \sin\beta\tag{B-20}$$

For a vertical surface, $\Sigma = 90$ deg, and:

$$\cos\theta_V = \cos\beta \cos\gamma\tag{B-21}$$

i. Calculation Sequence

1) Determine d , ET , A , B , and C from Table B-I. Table B-I could be stored in the computer memory, but this would necessitate an interpolation procedure. In order to avoid such a problem and to save computer core, d , ET , A , B and C are expressed in Fourier Series form and the values are calculated as a function of the day of the year, d , from the following truncated Fourier Series (Atkinson, 1978).

$$\left. \begin{array}{l} d \\ ET \\ A \\ B \\ C \end{array} \right\} = \begin{array}{l} A_0 + A_1 \cos(wd') + A_2 \cos(2wd') + A_3 \cos(3wd') \\ + B_1 \sin(wd') + B_2 \sin(2wd') + B_3 \cos(3wd') \end{array}$$

where

$$w = 2\pi/366$$

d' = day of the year, 1 to 366

The proper Fourier coefficients are given in Table B-IV.

TABLE B-IV
FOURIER COEFFICIENTS

	A_0	A_1	A_2	A_3	B_1	B_2	B_3
d	.302	-22.93	-.229	-.243	3.851	.002	-.55
ET	-.0002	.4197	-3.2265	-.0903	-7.351	-9.3912	-.3361
A	368.44	24.52	-1.14	-1.09	.58	-0.18	.28
B	.1717	-.0344	.0032	.0024	-.0043	0.0	-.0008
C	.0905	-.0410	.0073	.0015	-.0034	.0004	-.0006

2) Calculate the local solar time, hour angle for each standard time (Equation B-12 and B-13).

3) Calculate solar altitude (Equation B-14) and the hour angle h at sunrise time (Equation B-15). If $|h| > |h'|$ skip all remaining calculations.

4) Calculate all the solar angles: solar azimuth ϕ , surface-solar azimuth γ , and incident angle θ from Equation B-16 to Equation B-19.

5) Calculate direct normal intensity I_{DN} , sky diffuse radiation I_d and ground-reflected radiation, I_r .

B. Window Gains and Losses (WINDOW)

At any instant, total solar radiation, I_t , falling on a window must equal the sum of radiation which is transmitted ($I_{t\tau}$), reflected outward ($I_{t\rho}$), and absorbed ($I_{t\alpha}$):

$$\tau + \rho + \alpha = 1$$

(B-22)

Values of the three solar-optical properties (transmissivity, reflectivity, and absorptivity) depend on: (1) thickness and physical properties of the glazing material; (2) any film of coating applied to its surfaces; and (3) the incident angle, θ .

The calculation of transmissivity and absorptivity are quite involved. Stephenson (1967) has precalculated for various values of $\cos\theta$ and expressed as polynomial function of $\cos\theta$. The polynomial coefficients are shown in Table B-V for standard 1/8 inch thick double strength glass and the equations are as follows:

Direct radiation transmission:

$$\tau_D = \sum_{j=0}^5 t_j (\cos\theta)^j \quad (B-23)$$

$$\alpha_D = \sum_{j=0}^5 a_j (\cos\theta)^j \quad (B-24)$$

Diffuse radiation transmission:

$$\tau_d = 2 \sum_{j=0}^5 t_j / (j+2) \quad (B-25)$$

$$\alpha_d = 2 \sum_{j=0}^5 a_j / (j+2) \quad (B-26)$$

TABLE B-V

POLYNOMIAL COEFFICIENTS FOR USE IN CALCULATION OF TRANSMISSIVITY AND ABSORPTIVITY OF STANDARD 1/8" THICK DOUBLE STRENGTH GLASS

j	a_j	t_j
0	0.01154	-0.00885
1	0.77674	2.71235
2	-3.94657	-0.62062
3	8.57881	-7.07329
4	-8.38135	9.75995
5	3.01188	-3.89922

The Shading Coefficient, SC, is defined as the ratio of the solar heat gain through a glazing system under a specific set of conditions to the solar gain through a single light of double strength sheet glass under the same conditions. This ratio, a unique characteristic of each type of fenestration, is represented by:

$$SC = \frac{\text{Solar Heat Gain of Fenestration}}{\text{Solar Heat Gain of Double Strength Glass}} \quad (B-27)$$

Once the value of SC is given, transmissivity and absorptivity needed are for the standard 1/8 inch thick double strength glass regardless of the type of glass used.

Routine for the calculation of transmissivity and absorptivity in this report is only for the standard single pane of double strength glass. Solar heat through the window could be expressed by:

$$I_w = SC \times CCM \times [I_D(\tau_D + \alpha_D) + (I_d + I_r)(\tau_d + \alpha_d)] \quad (B-28)$$

Heat loss from window could be calculated by the simple steady-state heat transfer equation:

$$Q_w = \frac{1}{1/h_o + 1/h_{in} + 1/U_w} (T_{in} - T_o) - I_w \quad (B-29)$$

a. Input

$\cos\theta$ = Cosine of angle of incidence of direct solar radiation.
(calculated in SUNLIT)

SC = Shading Coefficient.

I_D, I_d, I_r = Direct, diffuse, ground-reflected solar radiation, respectively. (calculated in SUNLIT)

h_{in} = Inside heat transfer coefficient of glass.
(calculated in HIN)

h_o = Outside heat transfer coefficient of glass.
(calculated in HOUT).

U_w = Thermal conductance of window.

CCM = Cloud cover modifier (calculated in CLOUD).

T_{in}, T_o = Indoor, outdoor temperature, respectively.

b. Output

Q_w = Heat loss from window.

c. Floor Slabs, Below Grade Floors and Walls (BASFLR)

Heat loss through basements below grade is based on floor and wall U-values for surfaces in contact with the soil, and on proper ground temperature. Latta and Boileau (1968, 1969) showed that heat loss through the soil surrounding a house basement can be calculated on the basis of steady state heat flow around concentric circular paths centered on the intersection of the ground surface and the basement wall. For the floor, these paths are continued around circular arcs centered on the intersection of the baselfloor and wall (Figure B-6). The ASHRAE Handbook (1977) recommends some overall thermal conductances for concrete-constructed basement walls at different depths (Table B-VI). The values for heat loss through each square foot of below grade walls are selected from Table B-VI, added together, and the total multiplied by the perimeter of the house. The overall heat loss from the basement walls is

$$Q_{BW} = P_{BW} F_{BW} (T_{in} - T_g) \quad (B-30)$$

where

F_{BW} = overall thermal conductances at different depth.

P_{BW} = perimeter of basement walls.

T_g = ground surface temperature at the depth of 4 inches.

It is known that ground surface temperatures fluctuate about a mean value by an amplitude A, which will vary with geographic location. Values for mean annual air temperature, $\bar{T}_a$, can be obtained from meteorological records. Chang (1958) prepared a map for the lines of constant amplitude in the U.S.A. at an underground depth of 4 inches and the map was reprinted in ASHRAE Handbook (1977)(Figure B-7).

The user must provide the mean annual air temperature which can be found from the local Weather Bureau, local ground temperature

Figure B-6. Heat flow from basement.

TABLE B-VI
HEAT LOSS BELOW GRADE IN BASEMENT WALLS

Depth (ft)	Path Length through Soil (ft)	Heat Loss			
		Uninsulated	Insulation		
			1-in.	2-in.	3-in.
0-1 (1st)	0.68	0.410	0.152	0.093	0.067
1-2 (2nd)	2.27	0.222	0.116	0.079	0.059
2-3 (3rd)	3.88	0.155	0.094	0.068	0.053
3-4 (4th)	5.52	0.119	0.079	0.060	0.048
4-5 (5th)	7.05	0.096	0.069	0.053	0.044
5-6 (6th)	8.65	0.079	0.060	0.048	0.040
6-7 (7th)	10.28	0.069	0.054	0.044	0.037

Figure B-7. Lines of constant amplitude.

amplitude, and annual high and low extreme outdoor temperatures [5 percent and 97.5 percent values tabulated in ASHRAE Handbook (1977) are recommended]. The current ground surface temperature at the depth of 4 inches can be linearly interpolated as a function of outdoor temperature.

It is possible to calculate heat loss through the basement floor for each square foot in the same way as for the walls, using longer heat flow paths around the arcs of two inches. With the much longer heat flow paths, the loss through each square foot of basement floor rapidly becomes a negligible part of the total basement heat loss. The ASHRAE Handbook (1977) also tabulates the average thermal conductance of basement floors at different depths of foundation, as well as various house widths (Table B-VII). Heat loss through each square foot of basement floor is easily calculated by:

$$Q_{BF} = C_{BF} (T_{in} - T_g) \quad (B-31)$$

where

C_{BF} = thermal conductance of basement floor.

TABLE B-VII
HEAT LOSS THROUGH BASEMENT FLOORS

Depth of Foundation Wall below Grade (ft)	Width of House			
	20 (ft)	24 (ft)	28 (ft)	32 (ft)
5	0.032	0.029	0.026	0.023
6	0.030	0.027	0.025	0.022
7	0.029	0.026	0.023	0.021

Experiments (Dill and Robinson, 1945) with the type of unheated concrete floor slabs in basementless houses indicate that heat loss from a concrete slab floor on grade is more nearly proportional to perimeter than to area of the floor, and that the heat loss can be estimated by means of:

$$Q_{FL} = F_{FL} P_{FL} (T_{in} - T_o) \quad (B-32)$$

where

Q_{FL} = heat loss of floor

F_{FL} = heat loss coefficient

P_{FL} = perimeter or exposed edge of floor.

The ASHRAE Handbook (1977) recommends the value of F_{FL} ranged from 0.81 Btu per hour per linear foot per degree F for a floor with no edge insulation to 0.55 for a floor with 1 inch of edge insulation.

D. Walls and Roof (WALROF)

Referring to Figure B-8, a ceiling or wall consists of several parallel panels with different materials and an air space existing within. In winter, heat flows from inside of the building upward through the ceiling. Heat transfer as heat conduction happens in each parallel panel, or zone 1, 2, 3, 5 and surface 2 to 5. Heat convection happens at the very inside surface of the ceiling and the very outside surface, or surfaces 1 and 6. Surface 6 takes the credit of air film resistance and surface 1 takes the wind speed into account. The stronger the wind speed is, the larger the surface conductance is. The sun adds heat on the very outside surface in the daytime. Surface 1 absorbs a certain amount of radiation and reradiates a small amount of heat.

a. Finite Difference Methods for Heat Conduction

Consider the solid slab shown in Figure B-9. The differential equation (Carslaw and Jaeger, 1959) for one-dimensional unsteady state heat flow is:

Figure B-8. Heat transfer in a typical roof.

Figure B-9. Unsteady-state conduction in solid slab.

$$\frac{\partial T}{\partial t} = \frac{k}{\rho C_p} \frac{\partial^2 T}{\partial x^2} = \alpha \frac{\partial^2 T}{\partial x^2} \quad (\text{B-33})$$

where

T = temperature

t = time

x = distance

k = thermal conductivity of the material

ρ = density of the material

C_p = heat capacity of the material

General "exact" solutions of unsteady-state conduction equation are available only for certain simple shapes with certain boundary conditions. As either the boundary conditions or the geometry becomes more complex, the solutions become much more complex, or even unobtainable. Hence, for practical purposes, there is a great need for approximate methods of solution. One approximate method is that of finite differences, frequently referred to as numerical methods.

The principle for solving one-dimensional unsteady-state heat transfer problems by finite difference equations is dividing the element into many subdivisions and making a heat balance on each one. The density, conductivity and heat capacity of each panel are supposed to be independent of temperature. The heat transfer occurring in the air space and the material whose density and heat capacity are not available are considered to heat as steady-state. The temperature at one position in the element, e.g., the center, is used to approximate the temperature throughout the element. These positions are referred to as nodes. These nodes lie along a single curved or straight line, or may be considered to so lie, as illustrated in the Figure B-10. The solid lines connecting the nodes form a pattern termed a grid, mesh, or net. The broken lines show the internal boundaries between the elements.

The temperature gradient between the nodes representing adjacent elements is usually assumed to be linear. The area through which heat flows between two adjacent nodes is usually taken to be the area of the

Figure B-10. Subdivision of a slab.

boundary between the nodes to which the direction of heat flow is orthogonal. Thus, the rate of heat transfer through a boundary area A from node j to an adjacent node $j+1$ a distance Δx away is given by the expression $\frac{kA}{\Delta x} (T_j - T_{j+1})$ where k is the thermal conductivity and $kA/\Delta x$ is termed thermal conductance.

b. Explicit Difference Equation

As an example of the manner in which finite difference equations are derived by this approach, consider a solid in which a transient one-dimensional heat conduction process is occurring (Figure B-10). Suppose that the system is subdivided into right parallelepiped elements such that the distance between adjacent nodes is Δx in the x direction. Attention is directed to an element located in the interior of the body at $j\Delta x$, whose temperature at time $n\Delta t$ is denoted by T_j^n . An energy balance is stated by

$$\begin{array}{ccccc} \text{Rate of conduction} & & \text{Rate of energy} & & \text{Rate of increase} \\ \text{into element} & + & \text{generation in} & = & \text{of sensible} \\ & & \text{element} & & \text{internal energy} \\ & & & & \text{in element} \end{array}$$

The model used in this report does not have energy generation in the element. Therefore, the energy balance is derived as:

$$\frac{kA}{\Delta x} (T_{j-1}^n - T_j^n) - \frac{kA}{\Delta x} (T_j^n - T_{j+1}^n) = \rho C_p \frac{A\Delta x}{\Delta t} (T_j^{n+1} - T_j^n)$$

or

$$T_j^{n+1} = \left(1 - 2 \frac{\alpha \Delta t}{(\Delta x)^2}\right) T_j^n + \frac{\alpha \Delta t}{(\Delta x)^2} (T_{j+1}^n + T_{j-1}^n) \quad (\text{B-34})$$

An equation such as this applies to all the nodes representing elements which are not on the surface of the body. Since this equation is an explicit expression for one unknown, it is termed an explicit finite difference equation. To arrive at Equation B-34, the rate of conduction into the element was evaluated at the "present" time increment, $n\Delta t$, in terms of known temperatures. This led to an explicit expression for the temperature at the "next" increment in time, $(n+1)\Delta t$.

One of the basic problems in using finite differences is to determine when one is converging on a solution. Unfortunately, it is found that with explicit finite difference equations, unless a certain ratio is maintained between the space increments and the time increments, the solution becomes meaningless (Richtmyer, 1957).

c. Implicit Difference Equation

It is equally reasonable from a physical standpoint, and it may be of considerable advantage from a calculational standpoint, to evaluate the rate of conduction at $(n+1)\Delta t$. Doing so, and also evaluating the energy generation at $(n+1)\Delta t$ produces the following equation:

$$\frac{k}{\Delta x} (T_{j-1}^{n+1} - T_j^{n+1}) - \frac{k}{\Delta x} (T_j^{n+1} - T_{j+1}^{n+1}) = \rho C_p \frac{\Delta x}{\Delta t} (T_j^{n+1} - T_j^n)$$

or

$$-\frac{\alpha \Delta t}{(\Delta x)^2} T_{j+1}^{n+1} + \left(1 + 2 \frac{\alpha \Delta t}{(\Delta x)^2}\right) T_j^{n+1} - \frac{\alpha \Delta t}{(\Delta x)^2} T_{j-1}^{n+1} = T_j^n \quad (\text{B-35})$$

where all the unknown quantities appear on the left side. This equation contains a number of unknowns, so it cannot be used to solve explicitly for any one of them. It is termed an implicit difference equation.

In order to evaluate the temperatures at $(n+1)\Delta t$, one must, in principle, solve simultaneously a set of equations equal in number to all the nodes in the body and on the surface, excepting those whose temperatures are specified by boundary conditions. This statement may appear to contradict the earlier statement that the implicit type of equation may have advantages relative to the explicit type from a calculational standpoint. However, it will be shown later that sets of implicit equations can be solved by a simple technique and that the total number of calculations they require to solve some types of problems is much smaller than that required by explicit equations. When the system is linear and one-dimensional, a simple recursion relation can be obtained which permits calculation of the unknown values without actual simultaneous solution of the set of equations. This technique can be adapted to two- and three-dimensional problems (Douglas, 1961).

For a system with a one-dimensional temperature distribution along the x-coordinate, Equation B-35 may be represented by the simpler form:

$$-A_j T_{j+1}^{n+1} + B_j T_j^{n+1} - C_j T_{j-1}^{n+1} = D_j \quad (B-36)$$

where

$$\begin{aligned} A_j &= C_j = \alpha \Delta t / \Delta x^2 \\ B_j &= 1 + 2 \alpha \Delta t / \Delta x^2 \\ D_j &= T_j^n \end{aligned} \quad (B-36.1)$$

There is an equation of this form for each internal node. The equations for the nodes on the boundaries may also be represented by Equation B-36, since they are of same general form.

d. Heat Transfer at the Boundary

Referring to Figure B-10, let the nodes be numbered 1 through J, starting at the left-hand boundary. The energy balance in terms of implicit equation on the half-element at the left-hand boundary (Figure B-8, surface 6) gives

$$h_{in} (T_{in}^{n+1} - T_j^{n+1}) - \frac{2k}{\Delta x} (T_j^{n+1} - T_{j+1}^{n+1}) = \rho C_p \frac{\Delta x}{2\Delta t} (T_j^{n+1} - T_j^n) \quad (B-37)$$

Rearranged equation gives the general form:

$$-A_j T_{j+1}^{n+1} + B_j T_j^{n+1} - C_j T_{j-1}^{n+1} = D_j$$

where

$$\begin{aligned} A_j &= 4\alpha\Delta t/(\Delta x)^2 \\ B_j &= 1 + \frac{2 h_{in} \Delta t}{\rho C_p \Delta x} + \frac{4\alpha\Delta t}{(\Delta x)^2} \\ C_j &= 0 \\ D_j &= \frac{2 h_{in} \Delta t}{\rho C_p \Delta x} T_{in} + T_j^n \end{aligned} \quad (B-37.1)$$

Equations similar to Equation B-37 apply at the surfaces adjacent the air space and within the materials for which only resistance data are available. For the half-element at the left-hand side of the air space (Figure B-8, surface 5), the energy balance gives

$$-A_j T_{j+1}^{n+1} + B_j T_j^{n+1} - C_j T_{j-1}^{n+1} = D_j$$

where

$$\begin{aligned} A_j &= 2\Delta t/(\rho C_p \Delta x R) \\ B_j &= \frac{4\alpha\Delta t}{(\Delta x)^2} + \frac{2\Delta t}{\rho C_p \Delta x R} + 1 \\ C_j &= 4\alpha\Delta t/(\Delta x)^2 \\ D_j &= T_j^n \end{aligned} \quad (B-38)$$

For the half-element at the right-hand side of air space (Figure B-8, surface 4):

$$- A_j T_{j+1}^{n+1} + B_j T_j^{n+1} - C_j T_{j-1}^{n+1} = D_j$$

where

$$A_j = 4\alpha\Delta t/\Delta x^2$$

$$B_j = \frac{4\alpha\Delta t}{(\Delta x)^2} + \frac{2\Delta t}{\rho C_p \Delta x R} + 1 \quad (B-39)$$

$$C_j = 2\Delta t/(\rho C_p \Delta x R)$$

$$D_j = T_j^n$$

The heat balance at the very outside surface of the wall or ceiling (Figure B-8, surface 1) becomes more complicated:

$$Q = h_o(T_s - T_o) - \alpha I \quad (B-40)$$

where

α = absorptivity of outside surface of wall to radiation in solar spectrum, dimensionless

I = total solar radiation incident on the surface, Btu/hr-ft²

h_o = overall film coefficient for the outside surface of wall, Btu/hr-ft²-°F

T_s, T_o = surface temperature and outdoor temperature, respectively, °F

The heat balance at the outer surface is

$$B_j T_j^{n+1} - C_j T_{j-1}^{n+1} = D_j$$

where

$$B_j = \frac{4\alpha\Delta t}{(\Delta x)^2} + \frac{2\Delta t}{\rho C_p \Delta x} h_o^{n+1} + 1 \quad (B-41)$$

$$C_j = 4\alpha\Delta t/(\Delta x)$$

$$D_j = \frac{2\Delta t}{\rho C_p \Delta x} \left(\alpha I^{n+1} + h_o^{n+1} T_o^{n+1} \right) + T_j^n$$

The heat balance at the surface between two different panels of different materials (Figure B-8, surfaces 2 and 3) is derived as:

$$-A_j T_{j+1}^{n+1} + B_j T_j^{n+1} - C_j T_{j-1}^{n+1} = D_j$$

where

$$A_j = 4k_2 \Delta t / \Delta x_2$$

$$B_j = \rho_1 C_{p1} \Delta x_1 + \rho_2 C_{p2} \Delta x_2 + \frac{4k_1 \Delta t}{\Delta x_1} + \frac{4k_2 \Delta t}{\Delta x_2}$$

(B-42)

$$C_j = 4k_1 \Delta t / \Delta x_1$$

$$D_j = \rho_1 C_{p1} \Delta x_1 + \rho_2 C_{p2} \Delta x_2$$

e. Scheme for Solving Equations

A complete set of equations for a one-dimensional problem, written in matrix form, looks like

$$\begin{bmatrix} B_1 & -A_1 & 0 & 0 & - & - & - & - & - & 0 \\ -C_2 & B_2 & -A_2 & 0 & - & - & - & - & - & 0 \\ 0 & -C_3 & B_3 & -A_3 & - & - & - & - & - & 0 \\ 0 & - & - & - & - & - & - & - & - & - \\ - & - & - & -C_j & B_j & -A_j & - & - & - & - \\ - & - & - & - & - & - & - & - & - & - \\ - & - & - & - & - & - & - & - & 0 & 0 \\ - & - & - & - & - & 0 & -C_{j-2} & B_{j-2} & -A_{j-2} & 0 \\ 0 & - & - & - & - & - & 0 & -C_{j-1} & B_{j-1} & -A_{j-1} \\ 0 & - & - & - & - & - & - & 0 & -C_j & B_j \end{bmatrix} \begin{bmatrix} T_1^{n+1} \\ T_2^{n+1} \\ T_3^{n+1} \\ - \\ T_j^{n+1} \\ - \\ - \\ T_{j-2}^{n+1} \\ T_{j-1}^{n+1} \\ T_j^{n+1} \end{bmatrix} = \begin{bmatrix} D_1 \\ D_2 \\ D_3 \\ - \\ D_j \\ - \\ - \\ D_{j-2} \\ D_{j-1} \\ D_j \end{bmatrix} \quad (B-43)$$

The scheme used to solve the set of equations (B-43) takes advantage of the fact that there are, at most, two unknowns in the equations for the nodes at the boundaries. Starting at either the right-hand or left-hand boundary, the difference equation for the boundary node either specifies the value of the temperature at that node at time $(n+1)\Delta t$, or it can be solved for this temperature in terms of the other (unknown) nodal temperature which appears in the equation. Supposing one starts at the left-hand boundary, the above procedure gives either a value for T_1^{n+1} or an expression for T_1^{n+1} in terms of T_2^{n+1} . When this value or expression is substituted into the equation for the next node to the right, namely, $j=2$, it results in an equation in terms of two unknowns, T_2^{n+1} and T_3^{n+1} . This equation may be solved for T_2^{n+1} in terms of T_3^{n+1} , and substituted into the next equation to obtain an equation in two unknowns. This process may be repeated until one arrives at an expression for T_{j-1}^{n+1} in terms of T_j^{n+1} by use of the equation for node $j-1$, the last internal node on the right side of the body.

When this expression is solved for T_{j-1}^{n+1} in terms of T_j^{n+1} and substituted into the equation for the boundary node, J , and explicit equation for T_J^{n+1} is obtained, the value of T_J^{n+1} obtained from this equation may in turn be substituted into the expression (either the reworked equation for node $J-1$ or the boundary condition) for T_{J-1}^{n+1} . This substitution process may be repeated for successively smaller values of j until all the T_j^{n+1} have been evaluated. If T_j^{n+1} is specified explicitly by the boundary condition, a similar procedure may be utilized. Substitution of the known value for T_j^{n+1} starts the process of evaluation of the T_j^{n+1} for successively smaller values of j , starting at $J-1$.

This scheme is utilized mathematically by noting that upon substitution for T_{j-1}^{n+1} in Equation B-36 in terms of T_j^{n+1} and various constants, one obtains an equation of the general form

$$T_j^{n+1} = E_j T_{j+1}^{n+1} + F_j \quad \text{or} \quad T_{j+1}^{n+1} = (T_j^{n+1} - F_j)/E_j \quad (\text{B-44})$$

where the quantities E_j and F_j are as yet unknown. To obtain recursion relations for E_j and F_j , it is noted that if Equation B-44 is written for node $j-1$, it becomes

$$T_{j-1}^{n+1} = E_{j-1} T_j^{n+1} + F_{j-1}$$

Substituting for T_{j-1}^{n+1} in Equation B-36 produces

$$T_j^{n+1} = \frac{A_j}{B_j - C_j E_{j-1}} T_{j+1}^{n+1} + \frac{D_j + C_j F_{j-1}}{B_j - C_j E_{j-1}} \quad (B-45)$$

Comparison of Equations B-44 and B-45 produces the desired recursion relations:

$$\begin{aligned} E_j &= \frac{A_j}{B_j - C_j E_{j-1}} \\ F_j &= \frac{D_j + C_j F_{j-1}}{B_j - C_j E_{j-1}} \end{aligned} \quad (B-46)$$

These relations are utilized by noting that comparison of Equation B-44 for $j=1$ with the difference equation for node 1 results in expressions for E_j and F_j in terms of known quantities, namely

$$E_1 = A_1/B_1, \quad F_1 = D_1/B_1 \quad (B-47)$$

Substitution of these values, along with the known values of A_2 , B_2 , C_2 , and D_2 , into Equation B-46 permits evaluation of E_2 and F_2 . This process is repeated until the right-hand boundary is reached. If the temperature of node J is specified explicitly, the process may be stopped when E_{J-1} and F_{J-1} have been evaluated. If the boundary condition at the right-hand boundary is in terms of heat transfer, the evaluation should be carried out until F_J has been evaluated. This follows from the fact that if Equation B-44 is written for $j = J-1$ and substituted into Equation B-41, one obtains

$$T_J^{n+1} = \frac{D_J + C_J F_{J-1}}{B_J - C_J E_{J-1}} \quad (B-48)$$

Comparison of this result with Equation B-46 shows that

$$T_J^{n+1} = F_J \quad (B-49)$$

Once T_J^{n+1} is known, its value may be substituted into Equation B-44 with $J = J-1$ to evaluate T_{J-1}^{n+1} . This process may be repeated until all the T_j^{n+1} have been evaluated. The process described above for solving implicit finite difference equations for one dimensional systems may be summarized as follows:

- 1) Specify values of the properties k , ρ , and C_p .
- 2) Specify values of the increments Δx and Δt .
- 3) Specify an initial temperature distribution, i.e., values for T_j^0 , $1 \leq j \leq J$.
- 4) Evaluate A_j , B_j , C_j , and D_j for $n = 1$.
- 5) Evaluate E_1 and F_1 from Equation B-47, then utilize Equation B-46 to evaluate the E_j and F_j for $1 \leq j \leq J$ or for $2 \leq j \leq J-1$, depending on the particular problem.
- 6) Solve for T_J^{n+1} from Equation B-49, or utilize the known value of T_J^{n+1} , and substitute successively into Equation B-44 to evaluate the remaining T_j^{n+1} . Then repeat Step 4 with $n = 2$, and so on, until the temperature distribution has been evaluated at the desired value of time.

It should be noted that the coefficients A_j , B_j , and C_j in Equations B-36, B-37.1 and B-41 are the same for any value of n , if the properties are independent of temperature, and if the values of Δx and Δt are not changed with n . D_j in Equations B-36, B-37.1, and B-41 necessarily depends on n . This presents no difficulty in carrying out the calculations; it is pointed out to emphasize that provision should be made, in writing a computer program, to recompute at each time increment those coefficients which depend on n .

f. Heat Loss from the Ceiling

For the unsteady-state heat transfer problem, transient heat loss from a slab varies from point to point. It is best to choose the transient heat loss of Q_L^n as the product of temperature difference between indoor temperature T_{in}^n and inside surface temperature T_1^n of the slab and inside surface heat transfer coefficient h_{in}^n :

$$Q_L^n = h_{in}^n (T_{in}^n - T_1^n) \quad (B-50)$$

E. Infiltration and Ventilation (INFIL and VENT)

Heat losses due to infiltration and ventilation of outside air can be divided into sensible and latent heat. The energy quantity associated with having to raise the temperature of outdoor air up to indoor air temperature is the sensible component. The energy quantity associated with net loss of moisture from the space is classified as the latent component.

a. Sensible Heat Loss

The energy required to warm outdoor air to the temperature of the room is given by:

$$Q_{INF} = 0.24 F_{INF} V_R \rho (T_{in} - T_o) \quad (B-51)$$

$$Q_{VENT} = 0.24 F_{VENT} \dot{V}_{VENT} \rho (T_{in} - T_o) \quad (B-52)$$

where

Q_{INF} , Q_{VENT} = sensible heat loss due to infiltration and ventilation, respectively.

0.24 = heat capacity of air.

V_R , $\dot{V}_{VENT}$ = volume of the room and maximum ventilation capacity, respectively.

F_{INF} , F_{VENT} = air change rate per room or building volume (Table IV) and ratio of ventilation capacity in use, respectively.

ρ = density of air at temperature T_o .

The air change rates are estimated two ways in the ASHRAE Handbook (1977). Table IV lists their estimates.

b. Latent Heat Loss

When addition of moisture to the indoor air is required to maintain winter comfort conditions, it is necessary to determine the energy needed to evaporate an amount of water equivalent to what is lost by infiltration and ventilation. This energy may be calculated by:

$$Q_L = \dot{V} \rho (H_{in} - H_o) h_{fg} \quad (B-53)$$

where

Q_L = latent heat loss.

$\dot{V}$ = volume rate of outdoor air entering building.

H_{in}, H_o = humidity of indoor and outdoor air, respectively.

h_{fg} = latent heat of vapor.

The value of latent heat of vapor, h_{fg} , is recommended to be 1060 Btu per pound of water. The humidity of outdoor air is easily calculated from relative humidity and outdoor air temperature reported by local Weather Bureau:

$$H_o = 0.62 H_R P_w / (P_{atm} - H_R P_w) \quad (B-54)$$

where

H_R = relative humidity divided by one hundred.

P_w = saturated water pressure at outdoor temperature.

P_{atm} = local atmosphere pressure outdoors.

0.62 = molecular weight ratio of water to air.

3. Auxiliary Functions

A. Cloud Coverage (CLOUD)

On a cloudy day, the total radiation intensity should be corrected by the cloud cover modifier, CCM. Values of CCM as a function of solar altitude angle, β , cloud type and total cloud amount, N_{tc} , are given in Table B-VIII, which is derived from Boeing Company Report (1964).

TABLE B-VIII
CLOUD COVER MODIFIER

Cloud Type N_{cld}	Stratus		Cirrus, Cirrostratus	
	$\beta \leq 45^\circ$	$\beta > 45^\circ$	$\beta < 45^\circ$	$\beta > 45^\circ$
1	.60	.88	.84	1.00
2	.60	.88	.83	1.00
3	.58	.88	.83	1.00
4	.58	.87	.82	1.00
5	.57	.85	.80	0.99
6	.53	.83	.77	0.98
7	.49	.79	.74	0.95
8	.43	.73	.67	0.90
9	.35	.61	.60	0.84
10	.27	.46	.49	0.74

The values in Table B-VIII are curve fitted and the coefficients calculated in the computer program. Values for cloud type between cirrus, cirro-stratus, and stratus clouds use average value of CCM of two values.

a. Input

β = Solar Altitude Angle

N_{tc} = Weather Bureau Total Cloud Amount

I_{ct} = Cloud Type Index: 0 = Cirrus, Cirrostratus

1 = Stratus

2 = Other

b. Output

CCM = Cloud Cover Modifier.

B. Internal Heat-Transfer Coefficient (HIN)

ASHRAE (1977) tabulated various inside surface heat transfer coefficients as function of direction of heat flow and surface emittance. Values of these coefficients for still air could be approximated by:

$$h_i = C_{hi} + 1.02 E \quad (B-55)$$

where

C_{hi}	=	.712	Upward heat flow
		.542	Horizontal heat flow
		.162	Downward heat flow

a. Input

E = Emittance of the surface, dimensionless

I_{dir} = Heat flow direction, index, 1, 2, and 3 for upward, horizontal and downward heat flow, respectively

b. Output

h_i = Inside surface heat transfer coefficient, Btu/hr-sq ft-°F

C. External Heat-Transfer Coefficient (HOUT)

The convective surface conductance is affected by air movement. Figure B-11 shows results of tests made on 12 inch square samples of different materials for wind velocities up to 40 mph (Rowley, 1930). Curves on Figure B-11 could be fitted by Equation B-56 and values in Table B-IX. Wind speed reported in knots is converted into mph.

$$V = 1.153V' \quad (B-56)$$

$$HOUT = C_1 V^2 + C_2 V + C_3$$

Figure B-11. Surface conductance for different 12-inch square surfaces as affected by air movement.

TABLE B-IX
VALUES FOR CALCULATION OF OUTSIDE HEAT TRANSFER COEFFICIENTS

IOUT	C_1	C_2	C_3
1	0	0.464	2.04
2	0.001	0.320	2.20
3	0	0.330	1.90
4	-0.002	0.315	1.45
5	0	0.244	1.80
6	-0.001251	0.262	1.45

a. Input

V' = Wind Speed, knots

IOUT = Outside surface index

1 Stucco

2 Brick and Rough Plaster

IOUT = 3 Concrete

4 Clear Pine

5 Smooth Plaster

6 Glass

b. Output

HOUT = Outside surface heat transfer coefficient,

Btu/hr-sq ft-°F

D. Day and Month Identifier (DAYMON)

A calendar subroutine which identifies the day of the month and the month of the year.

a. Calculation Sequence

1. If $IDOY < 31$, MONTH = 1 and IDAY = IDOY
2. If $31 < IDOY \leq (59 + LEAP)$, MONTH = 2, IDAY = IDOY - 31
3. If $(59 + LEAP) < IDOY \leq (90 + LEAP)$, MONTH = 3,
IDAY = IDOY - 59 - LEAP
4. If $(90 + LEAP) < IDOY \leq (120 + LEAP)$, MONTH = 4,
IDAY = IDOY - 90 - LEAP
5. If $(120 + LEAP) < IDOY \leq (151 + LEAP)$, MONTH = 5,
IDAY = IDOY - 120 - LEAP
6. If $(151 + LEAP) < IDOY \leq (181 + LEAP)$, MONTH = 6,
IDAY = IDOY - 151 - LEAP
7. If $(181 + LEAP) < IDOY \leq (212 + LEAP)$, MONTH = 7,
IDAY = IDOY - 181 - LEAP
8. If $(212 + LEAP) < IDOY \leq (243 + LEAP)$, MONTH = 8,
IDAY = IDOY - 212 - LEAP
9. If $(243 + LEAP) < IDOY \leq (273 + LEAP)$, MONTH = 9,
IDAY = IDOY - 243 - LEAP
10. If $(273 + LEAP) < IDOY \leq (304 + LEAP)$, MONTH = 10,
IDAY = IDOY - 273 - LEAP
11. If $(304 + LEAP) < IDOY \leq (334 + LEAP)$, MONTH = 11,
IDAY = IDOY - 304 - LEAP
12. If $(334 + LEAP) < IDOY$, MONTH = 12 IDAY = IDOY - 334 - LEAP

b. Input

LEAP : Leap year index = $\begin{matrix} 0 & \text{Non-leap year} \\ 1 & \text{Leap year} \end{matrix}$

IDOY : Day of the year, from start of year

c. Output

IDAY : Day of the month

MONTH : Month of the year

E. Daylight Saving Time Identifier (DAYSAV)

An Algorithm for Determining the Dates of the Daylight Savings Time

a. Calculation Sequence

1. If MO is less than 4 or greater than 10, DST = 0
If MO is greater than 4 and less than 10, DST = 1
2. If MO = 4, DAY is less than 25, DST = 0
If DAY is greater than 23, call WKDAY subroutine
If DAY is Sunday, DSTX = DAY
If DAY is less than DSTX, DST = 0, otherwise DST = 1
3. If MO = 10, DAY is less than 25, DST = 1
If DAY is greater than 24, call WKDAY subroutine
If DAY is Sunday, DSTY = DAY
If DAY is less than DSTY, DST = 1, otherwise DST = 0

b. Input

YR: Year AD

MO: Month of the year (calculated in DAYMON)

DAY: Day of the month (calculated in DAYMON)

c. Output

DSTX: The day when daylight savings time commences

DSTY: The day when standard time resumes

DST: The daylight savings time indicator

DST: = 0 during the standard time period
= 1 during the daylight savings time period

F. Day of the Week Identifier (WKDAY)

An Algorithm Used to Identify the Day of the Week for Any Given Date of the Year from 1901 to 2000

a. Calculation Sequence

1. Let FSDAY(1) = 31, FSTDAY(2) = 59, FSTDAY(3) = 90,
FSTDAY(4) = 120, FSTDAY(5) = 151, FSTDAY(6) = 181,
FSTDAY(7) = 212, FSTDAY(8) = 243, FSTDAY(9) = 273,
FSTDAY(10) = 304, FSTDAY(11) = 334, FSTDAY(12) = 365.

2. Let $N = \text{Integer part of } YR/4$
 $ND = N - 485$
 $IY = 2, IADD = 2$
 If $ND = 0$, Go to (4)
 If ND is less than 0, $ND = -ND$ and $IADD = -2$
3. Repeat the following steps for ND times
 $IY = IY - IADD$
 If IY is greater than 7, $IY = IY - 7$
 If IY is equal to 0, $IY = 7$
 If IY is less than 0, $IY = IY + 8$
4. Let $MD = YR - N * 4$
 If MD is equal to 0 $IWK = IY$
 If MD is equal to 1 $IWK = IY + 2$
 If MD is equal to 2 $IWK = IY + 3$
 If MD is equal to 3 $IWK = IY + 4$
 If IWK is greater than 7, $IWK = IWK - 7$
 If MD is not equal to 1, Go to 5
 $TDAY = DAY - 1$
 Go to 7
5. Repeat the following for $j = 2$ through 12
 If MD is equal to j , let $TDAY = FSTDAY(j-1) + Day - 1$
 Otherwise, Go to 6
6. If MD is equal to 0 and MD is greater than 2,
 $TDAY = TDAY + 1$
7. Let $NTX = \text{Integer part of } TDAY/7$
 $NDX = TDAY - 7 * NTX + IWK$
 If NDX is greater than 7, let $NDX = NDX - 7$
8. Let $WKDAY = NDX$
9. If this routine is going to be applied for the period outside 1901-2000, the following additional algorithms must be added:
 $KV = \text{First two digits of } YR$
 $KTEST = \text{Last two digits of } YR$
 If $MD \leq 2$ or $KTEST = 0$, $KV = KV - 1$

$LTEST = \text{Remainder of } KV/4$

$KV = 4*LV + LTEST$

If $LTEST = 2$, $WKDAY = WKDAY + 1$

$= 1$, $WKDAY = WKDAY + 2$

$= 0$, $WKDAY = WKDAY + 3$

Otherwise $WKDAY = WKDAY - 3*(LV - 4)$

If $WKDAY < 0$, $WKDAY = WKDAY + 7$

If $WKDAY > 7$, $WKDAY = WKDAY - 7$

b. Input

YR: Year AD

MO: Month of the year (calculated in DAYMON)

DAY: Day of the month (calculated in DAYMON)

c. Output

1. if Sunday

2. if Monday

3. if Tuesday

$WKDAY = 4$ if Wednesday

5 if Thursday

6 if Friday

7 if Saturday

APPENDIX C

DISCOUNTED PRESENT WORTH FACTORS

I. Discounted present worth factors for \$1.00 spent uniformly over a one-year period during year N.

N	0%	6%	8%	10%
0	1.00000	0.97059	0.96105	0.95163
1	1.00000	0.91407	0.88716	0.86107
2	1.00000	0.86084	0.81895	0.77913
16	1.00000	0.37163	0.26721	0.19213

II. Discounted present worth factors for \$1.00 per year spent uniformly in the period starting in year N and ending at the end of year 30.

N	0%	6%	8%	10%
0	31.00000	14.07212	11.45321	9.54951
1	30.00000	13.10153	10.49216	8.59788
2	29.00000	12.18746	9.60501	7.73682
3	28.00000	11.32663	8.78606	6.95769

III. Discounted present worth factors for \$1.00 per year escalating at 2% annually spent uniformly in the period starting in year N and ending at the end of year 30.

N	0%	6%	8%	10%
0	42.94640	18.03216	14.32211	11.67821
1	41.10594	16.69363	13.06547	10.48303
2	39.30192	15.43910	11.90876	9.40342
3	37.53363	14.26355	10.84424	8.42832

IV. Discounted present worth factors for \$1.00 per year escalating at i_1 % annually through year 10 and at i_2 % annually thereafter spent uniformly in the period starting in year N and ending at the end of year 30.

i_1	i_2	N	0%	6%	8%	10%
1.35	1.00	0	37.54351	16.26455	13.05378	10.74825
		1	36.53673	15.28085	12.07837	9.78130
		2	35.51626	14.34231	11.16622	8.89498
		3	34.48193	13.44690	10.31326	8.08262
2.70	2.00	0	45.90323	18.97881	15.01156	12.19669
		1	44.88961	17.98087	14.02048	11.21298
		2	43.84825	17.01646	13.08176	10.29972
		3	42.77839	16.08447	12.19269	9.45194
5.40	4.00	0	70.51564	26.61701	20.42224	16.12528
		1	69.48815	25.58657	19.39508	15.10280
		2	68.40365	24.56542	18.39763	14.12965
		3	67.25897	23.55349	17.42910	13.20360
3.3	2.5	0	50.56669	20.44661	16.05737	12.96069
		1	49.55001	19.44195	15.05885	11.96901
		2	48.49922	18.46553	14.10776	11.04318
		3	47.41317	17.51661	13.20191	10.17892

(continued)

6.6	5.0	0	87.19038	31.56163	23.85838	18.56960
		1	86.15664	30.51466	22.81273	17.52719
		2	85.05237	29.46581	21.78637	16.52440
		3	83.87277	28.41504	20.77898	15.55986

13.2	10.0	0	297.70329	90.06699	63.32729	45.73170
		1	296.63429	88.89510	62.13995	44.53530
		2	295.41444	87.65535	60.91058	43.32176
		3	294.02246	86.34251	59.63671	42.09025

APPENDIX D

RESERVOIR PERMEABILITY ESTIMATE

Since there are no permeability test data available for the immediate vicinity of the proposed project, it is necessary to estimate permeability indirectly. Sonic log data for a deep well in the same formation, but located several miles away, are used to estimate porosity as a function of depth. A published, but by no means universally accepted, correlation for permeability and porosity is then used to estimate permeability (Chilingar, 1963).

Sonic log data (reciprocal sonic velocities from a Schlumberger borehole compensated sonic log) for a nearby deep well are presented in Table D-I for depths up to 11200 feet. Using these data, porosities are estimated by three variations of the Wyllie formula:

$$\phi = \frac{\Delta t - \Delta t_m}{\Delta t_f - \Delta t_m} \quad (D-1)$$

where

ϕ is the porosity

Δt is the measured formation transit time

Δt_m is the matrix transit time

Δt_f is the fluid (water) transit time.

We estimated Δt_m to be 55 $\mu\text{sec/ft}$, typical for loosely compacted sands, and Δt_f to be 200 $\mu\text{sec/ft}$, typical for water. The most straightforward analysis, therefore, gives:

$$\phi = \frac{\Delta t_{\max} - 55}{200 - 55} \quad (D-2)$$

where $\Delta t_{\max}$ is the highest value of Δt in a particular interval. Since we are interested in long-range permeabilities, the maximum values should be representative of reservoir performance. Local minima will have little effect. Results for the nearby well are shown in Figure D-1 as circles.

A more conservative (lower permeability) approach arises if we assume that the local minima represent the dry matrix rock. Equation D-1 then becomes:

TABLE D-I
RIO GRANDE BASIN WELL - SONIC LOG DATA

DEPTH (ft)	Δt RANGE (μ sec/ft)	ESTIMATED POROSITY		
		Eq. D-1	Eq. D-2	Eq. D-3
500-1000	40-85	0.21	0.28	0.31
2100-1100	115-140	0.59	0.29	0.17
3100-3200	90-115	0.41	0.22	0.17
4100-4200	95-120	0.45	0.24	0.17
5100-5200	95-120	0.45	0.24	0.17
	peaks to 245			
6100-6200	85-115	0.41	0.26	0.21
	peaks to 125			
7100-7100	85-110	0.38	0.22	0.17
	peaks to 120			
8100-8100	140-155	0.69	0.25	0.10
	troughs to 95			
9100-9200	70-140	0.59	0.54	0.48
	wide scatter			
10100-10200	70-130	0.52	0.46	0.41
	wide scatter			
11100-11200	75-80	0.17	0.04	0.03
	very narrow band

Figure D.1. Porosity vs Depth for Typical Basin Well.

$$\phi = \frac{\Delta t_{\max} - \Delta t_{\min}}{200 - \Delta t_{\min}} \quad (D-3)$$

Results using this approach are plotted in Figure D-1 as squares.

A method which is even slightly more conservative assumes a constant denominator, as in Equation D-2, with the numerator established as in Equation D-3. Results using this approach are plotted in Figure D-1 as triangles.

We next conservatively fit a porosity vs depth curve to the well data. We believe this curve, as shown in Figure D-1, is quite conservative. At 8000 feet, production depth, we estimate 10 percent porosity. At the surface, we estimate 26 percent.

We next used correlations by Chilingar ([963]) to relate permeability to porosity. Values near the surface fall on his "coarse and medium-grained" curve, as shown in Figure D-2, circle A. Moving down the curve to a 10 percent porosity yields a permeability of 80 millidarcies, circle B. This will be our design point. We consider the circle C region to represent a minimum lower bound on permeability, with a value of about 13 millidarcies. This value is used as an extreme limit for parametric studies.

Figure D-2. Permeability vs Porosity (Chilingar, 1963).