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PHASE III

FINAL TECHNICAL REPORT

Conceptual Design Study of Geothermal District Heating of a Thirty-House Subdivision in Elko, Nevada, Using Existing Water-Distribution Systems

Report Number DOE/CS/31744-~~A002~~ T2

Contract Number: DE-AS07-78CS31744
Amendment Number: Modification No. A002

Principal Investigator: Donald R. Pitts

Design Team: Clemson University
Clemson, South Carolina

Chilton Engineering
Elko, Nevada

Period of Report: October 1, 1979 - September 30, 1980

Submitted To: United States Department of Energy
Idaho Operations Office
Idaho Falls, Idaho

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EXECUTIVE SUMMARY

This report consists of a conceptual design study for district heating of a 30-home subdivision located near the southeast extremity of the city of Elko, Nevada. While a specific residential community was used in the study, the overall approach and methodologies contained in the report are believed to be generally applicable for a large number of communities where low temperature geothermal fluid is available.

The proposed district heating system utilizes moderate temperature, clean domestic water and existing community culinary water supply lines. The culinary water supply is heated by a moderate temperature geothermal source using a single heat exchanger at entry to the subdivision. The heated culinary water is then pumped to the houses in the community where energy is extracted by means of a water supplied heat pump. The use of heat pumps at the individual houses allows economic heating to result from supply of relatively cool water to the community, and this precludes the necessity of supplying objectionably hot water for normal household consumptive use. Each heat pump unit is isolated from the consumptive water flow such that contamination of the water supply is avoided. The community water delivery system is modified to allow recirculation within the community, and very little rework of existing water lines is required.

The entire system coefficient of performance (COP) for a typical year of heating is 3.36, exclusive of well pumping energy. This relatively high COP results from the use of recently designed, high efficiency heat pumps at the houses. The annual energy savings that would result from the proposed retrofit during a typical year are 14,647 kW-h per house. Assuming a typical fossil fuel electric power plant efficiency of 33 percent, the conversion from electric resistance heating to the proposed district system would save 30 barrels of oil per year per house, or a yearly equivalent of 900 barrels of oil saved in this small subdivision.

Using a single geothermal well adjacent to the subdivision as the heat source, the proposed design appears to be economically attractive under current electric power rates in Nevada, having a payback period of about seven years. The total projected system cost in current dollars is approximately $228,000.

A major part of this cost is due to retrofit of the individual house heating systems which are baseboard electric units, the least adaptable system for conversion to district heating. For communities where homes have forced warm air systems, the cost would be decreased on the order of 20 percent from the above total cost. Further, for communities already having warm potable water, a condition existing in many western states, the total cost of the heating system would be much lower -- perhaps as low as 50 percent of the cost projected from the current design study.

Considering the high retrofit cost for conversion from electric baseboard to forced air distribution house systems in the single community studied and the existence of many western communities having 70°-80°F drinking water delivered to residences, it is recommended that further evaluations be made of communities which exhibit high potable water supply temperatures. The evaluation methodology of this report can be applied in an effort to rank prospective communities on both economic and technical feasibility scales for implementation of this concept of district heating.

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1. INTRODUCTION

1.1 Project Overview

This document represents the final Conceptual Design Report for a residential district heating system for a 30-home community in the city of Elko, Nevada, using a geothermal resource coupled with the existing culinary water distribution system in the community. The work has been performed under the auspices of the U.S. Department of Energy (USDOE) according to a contract with Clemson University, Contract Number DE-AS07-78CS31744, Modification Numbers A002 and M003. Chilton Engineering acted as subcontractor to Clemson University and provided engineering input and all community specific data including geologic and environmental information.

This conceptual design effort constitutes Phase III of a general study entitled "Feasibility Study of Existing Water Supply Systems." Phases I and II involved basic engineering feasibility and economic feasibility, respectively, of a general approach to district heating using the existing potable water distribution system to supply heated water; this water is also suitable for all other houeshold uses. The previously obtained results of Phases I and II were used to establish general techniques employed in the study reported herein.

The conventional approach to district heating involves distribution of heated water (or steam) through insulated piping to buildings to be heated. The sources of energy for most district heating systems in current use are, in order of decreasing usage, fossil fuel thermal plants, garbage incineration, cogeneration of electric power and thermal power, and geothermal resources. Only a few--waste heat, cogeneration, and geothermal systems--are in operation; the preponderance of district heating systems are in Europe and are fossil fuel supplied. Among geothermal systems, perhaps the largest and most widely publicized is that in Reykjavik, Iceland. A more complete discussion of existing district heating worldwide is given in Appendix A.

The concept embodied in the present design is unique in that district heating would be accomplished without installation of an insulated thermal fluid distribution system within the using community. While this is very attractive from a first cost viewpoint, it is only practical for either (i) low-cost waste heat or (ii) low-cost geothermal heat, since approximately 50-60% of the thermal energy is lost in the uninsulated distribution system. Nonetheless, the concept of dual-usage of the existing culinary water distribution system is felt to offer a simple, workable, low-cost approach to geothermal district heating. Further, the concept is believed to be adaptable to many communities where either low temperature hydrothermal geothermal resources or low-grade waste heat is readily available.

In keeping with other DOE sponsored demonstration projects, the conceptual design includes on-site data aquisition and monitoring capabilities. This equipment will permit verification of system performance and provide a data base for use in future similar projects.

The remaining sections in this chapter are intended to familiarize the reader with the existing community site and its heating requirements. The final section presents a brief description of the proposed district heating system. Chapter 2 describes the geologic/geothermal site setting, and Chapter 3 outlines the various heating system approaches considered and describes advantages and disadvantages of each. Chapter 4 presents details of the final design including engineering analysis techniques. The economic analysis of the proposed system is the subject of Chapter 5, whereas Chapter 6 is devoted to environmental considerations. A summary of the proposed design and recommendations for implementation are presented in Chapter 7.

1.2 Description of Site

1.2.1 General

A new but already completed subdivision consisting of 30 homes located near the southeast extremity of the city of Elko, Nevada, is the target community for this district heating design. Elko, a city of 9,600, is located in the Humbolt River Valley of northeastern Nevada, and it is at an elevation of approximately 5000 feet. Several mountain ranges with many peaks near or exceeding 10,000 feet in height dominate the landscape; notable among these are the Ruby Mountains. The immediate terrain of Elko, however, consists of sagebrush-covered valleys and low foothills, the highest of which are approximately 2500 feet above the valley floor. A few areas, mostly in the higher mountains, are covered with juniper, pinion pine and spruce.

Due to the high city elevation and proximity of the mountains, there are wide annual and daily temperature ranges. High nighttime radiation results in cool nights, even during the summer. The annual growing season averages about 90 days, but freezing temperatures have occurred during every month of the year.

Precipitation is light, averaging 9 inches annually with the majority of this occurring during the winter months as snow. For the forty year period 1939-40 through 1978-79, the record mean snowfall was greatest during January followed in order by December and February--

these are usually the three coldest months in the same order. During the present year, however, total precipitation exceeded 10 inches prior to mid-May. The amount of precipitation influences the thermal conductivity of the soil, and this has a significant bearing on the thermal losses from uninsulated buried hot water piping.

The heating requirement is relatively high due to the severe winter weather. The average number of heating degree-days during the twenty-year period 1958-59 through 1978-79 was 7112°F-day/year. The minimum heating requirement during this perid was 5914°F-day/year in 1978-79; the maximum requirement was 7990°F-day/year in 1963-64.

Air conditioning is not a significant factor; the average cooling requirement during the past ten year period was 375°F-day/year. The worst month is usually July, and the maximum July requirement during this period was 220°F-days--an average of only 7°F-day/day during the hottest month of the past ten years.

1.2.2 Water System

Chilton engineering of Elko, Nevada, completed an in-depth study of the Elko municipal water system in November, 1979. A complete description of the existing water system is included in their report of that date; the following briefly summarizes a description of the existing culinary water supply system.

The city water is supplied by eleven wells in service, one of which is not suitable for domestic water and is used only at the golf course. The peak-season production rates for these wells range from 160 GPM (gallons per minute) for the poorest flowing well to 770 GPM for the best well. The total maximum production, excluding the non-culinary water well, is approximately 6270 GPM or 9.03 MGD (million gallons per day), with the maximum summer production being 7.69 MGD.

Water storage is provided by four tank-type reservoirs at three sites with a total capacity of 6.4 million gallons. These provide gravity supply to the city. The tanks and wells are interconnected with a network of 10 to 18-inch mains, with future improvement intended to divide the area into two pressure zone service areas utilizing gravity feed. Street mains vary from 4-inch to 8-inch in general, with through-mains being 10-inch to 18-inch size.

The water from the wells is of generally high quality having total dissolved solids ranging from 240 to 481 PPM (parts per million) excluding one low flow rate well scheduled for phase-out. The largest contaminates are, in descending order, Bicarbonate, Alkalinity, Sulfate, and Calcium. Chlorination of the water supply is presently on an "as-needed" basis.

Individual house consumption of water is relatively high. This may be partially attributed to the present non-metered billing system. General practice in residential areas is currently to provide 1-inch diameter water lines to individual houses. This is somewhat larger than that used in most parts of the United states having metered water billing systems.

1.3 Brief Description of Proposed District Heating System

A district heating system is proposed which will utilize low temperature clean domestic water and existing community culinary water supply lines. The culinary water supply is heated by a moderate temperature geothermal source using a single heat exchanger at entry to the subdivision. The heated culinary water is then pumped to the houses in the community where energy is extracted by means of a water supplied heat pump. The use of heat pumps at the individual houses allows economic heating to result from supply of relatively cool water to the community, and this precludes the necessity of supplying objectionably hot water for normal household consumptive use. Each heat pump unit is isolated from the consumptive water flow such that contamination of the water supply is avoided. The community water delivery system is modified to allow recirculation within the community, and very little rework of existing water lines is required. The design study is for a 30-house residential subdivision in Elko, Nevada, using a single geothermal well adjacent to the subdivision as the heat source.

2. GEOLOGIC/GEOTHERMAL SITE SETTING

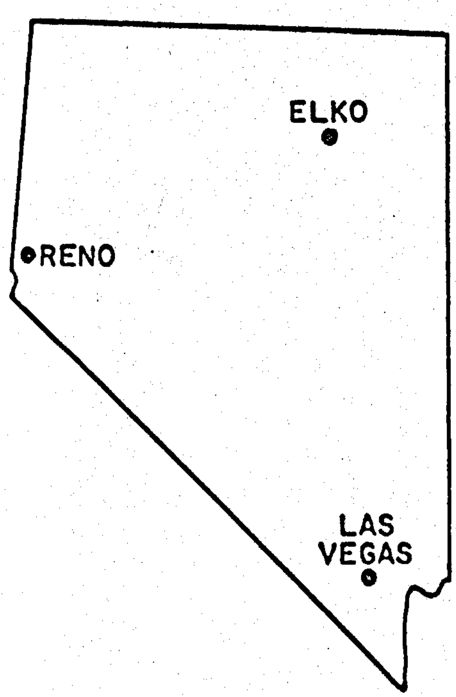
2.1 Summary

The City of Elko, Nevada, (Figure 2.1) lies above and adjacent to 8,960 acres of land designated as a known geothermal resource area. The geothermal system is assumed to be hot water based with convective mass transfer occuring along an as yet not fully described major fault line trending northeasterly beneath the City of Elko. This section describes recent investigations conducted concerning this geothermal resource and the base of experience that leads the contractor to feel that a suitable geothermal reservoir exists for the purposes of this study and the applications contemplated.

2.2 Introduction

2.2.1 General Statement

The following discussion presents the results and conclusions from a geological and geophysical assessment of the geothermal resources available for direct use in the vicinity of Elko, Nevada. The assessment was performed by Geothermal Surveys, Inc. (GSI), South Pasadena, California, in conjunction with the City of Elko and the Elko Heat Company. This work comprised a part of the resource assessment phase of the program outlined in a proposal to the U.S. Department of Energy entitled "Field Experiments for Direct Uses of Geothermal Energy: Elko, Nevada," dated July 18, 1979. The assessment resulted in a report prepared by GSI entitled "Direct Use Geothermal Investigations, Elko, Nevada: Phase I - Resource Assessment, Geological and Geophysical Surveys," dated November 16, 1979, which is included, in part, below. The report is available in its entirety from Geothermal Surveys, Inc., the Elko Heat Company, or Chilton Engineering, if required.



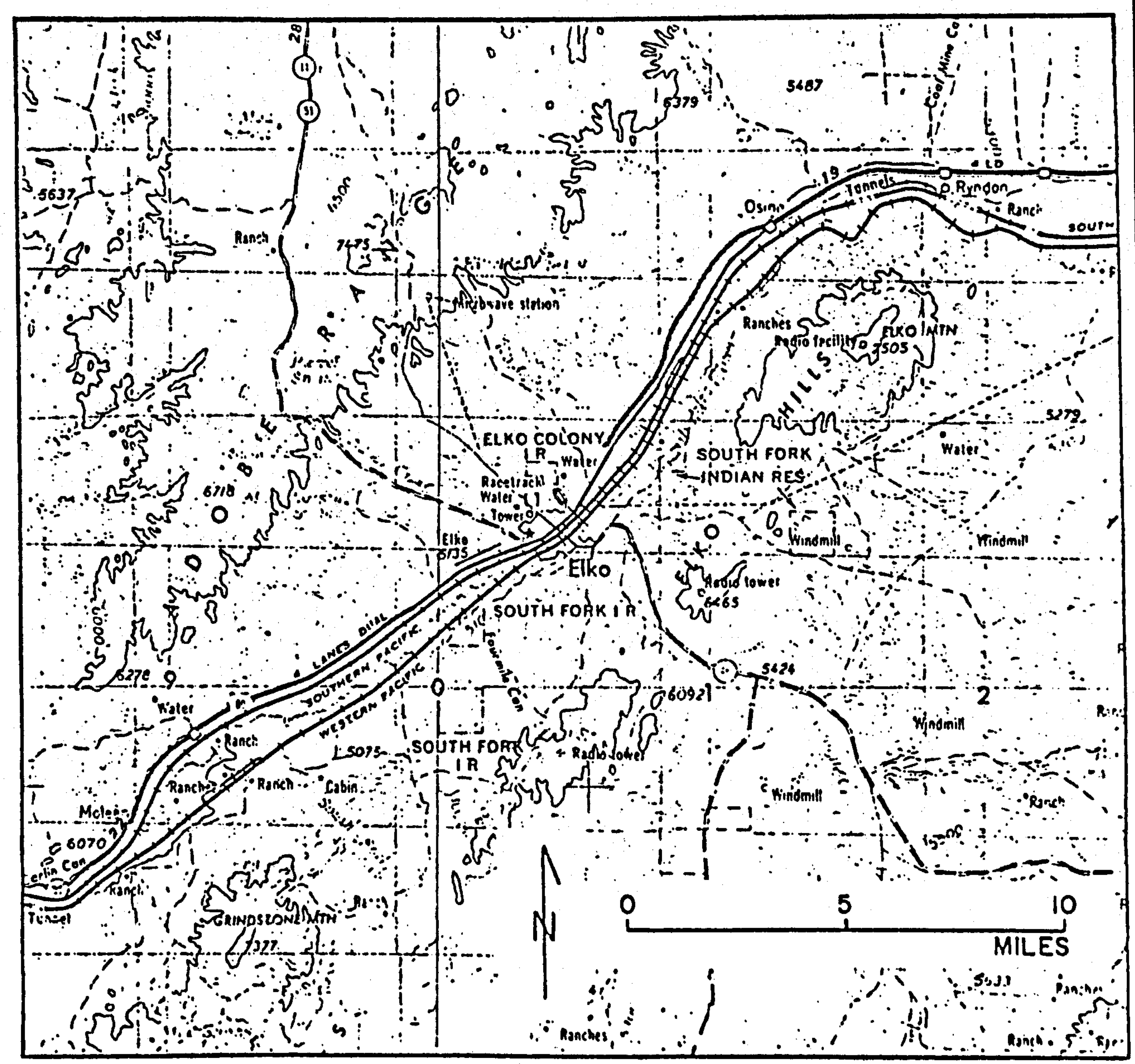


FIGURE 2.1

LOCATION MAP

ELKO, NEVADA

The objectives of the Resource Assessment Phase were threefold:

1) to locate the sites most favorable for drilling hot water wells;

2) to assess sufficiently that portion of the reservoir being produced to assure long-term continuance; and

3) to develop information that can be used to assess the characteristics of the entire reservoir.

Attainment of these goals involved an evaluation of the geologic and geohydrologic characteristics of the geothermal reservoir.

The work described herein consisted of reconnaissance geological mapping, geochemical analyses of water from springs and wells, and a number of geophysical surveys. Reconnaissance geologic mapping was conducted to examine exposed rock types and geologic structures that relate to the distribution and control of the hot water systems. Water samples were collected and analyzed to estimate possible source temperature and to characterize the chemical constituents of the geothermal waters. Thermal, direct-current electrical, and electromagnetic geophysical surveys were carried out to obtain further information on the extent of the thermal resource.

2.2.2 Background

In June, 1977 Geothermal Surveys, Inc. conducted a thermal exploration survey for the City of Elko. The purpose of the survey was to locate favorable sites for drilling municipal water wells. The results of the early work revealed an anomalous trend of higher temperatures extending northeast beneath the city from a group of well-known hot springs. This zone of high temperatures was interpreted as an extension of a mapped fault to the southwest. This discovery encouraged further interest in the local geothermal resources which lead to the development of an exploration and utilization program for the purposes of assessing, developing and using the available geothermal energy.

2.3 Geologic Setting

2.3.1 General Statement

The City of Elko is located on and along the floodplain of the Humboldt River as shown in Figure 2.1 The river flows in an alluvial valley from northeast to southwest through the study area, between the Adobe Range to the northwest and the Elko Hills to the southeast.

The Humboldt River valley divides the area into two different terrains. To the northwest are exposures of Late Tertiary Humboldt Formation, a continental sedimentary deposit (Sharp, 1939). A series of northwest trending cuestas, with the longer slopes to the northeast, rise gently from the valley floor to the Adobe Range.

South of the river the Elko Hills rise rather abruptly from the valley floor. Some units of the Humboldt Formation occur locally in this area but outcrops of the Tertiary Elko Formation, which underlies the Humboldt Formation, are most abundant. The Elko Formation also consists of continental sediments. Higher ridges in the area are composed of very resistant Paleozoic rocks which unconformably underlie the Humboldt and Elko Formations.

Tributary streams to the Humboldt River from the north flow southeasterly. From the south, the tributaries flow almost due north. The Humboldt valley, which is somewhat constricted at Elko, opens more widely upstream and downstream where broad terraces and fans of older alluvium occur.

Thermal activity in the Elko area is indicated by hot springs and seeps, by local alteration, and by abnormal temperatures encountered in some of the water wells. Faulting occurs in at least two northeasterly sets and provides some control for rising geothermal fluids.

2.3.2 Stratigraphy

Paleozoic Rocks - The oldest rocks exposed in the study area are Late Paleozoic quartzites and marine sediments consisting of shale, sandstone and carbonates (Sharp, 1939). These sediments are strongly indurated and make up the higher and more rugged topographic elements in the mountains flanking the Humboldt River Valley. The oil well shown on Plate 1 (Section 16) reportedly encountered Paleozoic rocks at a depth of 5,490 feet. Primary porosity of the Paleozoic rocks is very low due to induration; however, the rocks are generally brittle and closely fractured.

Elko Formation - This unit consists mainly of fine-grained sediments including light-colored shales and sandstones with lesser amounts of conglomerate, limestone, chert, rhyolite, tuff and oil shale. It unconformably overlies the Paleozoic rocks. Recent work on sediments by Smith and Ketner (1976) indicates that the oil shales are Eocene or Oligocene in age. Smith and Ketner therefore renamed this unit the Elko Formation, which had been originally described by Sharp as the lower member of the Miocene Humboldt Formation.

Humboldt Formation - This formation is widely exposed in the study area north and south of the Humboldt River. It consists largely of clastic sediments ranging from fine conglomerate near the base to weakly consolidated silts, clays, sands and gravels near the top. The lower portion is characterized by abundant rhyolitic tuff and ash.

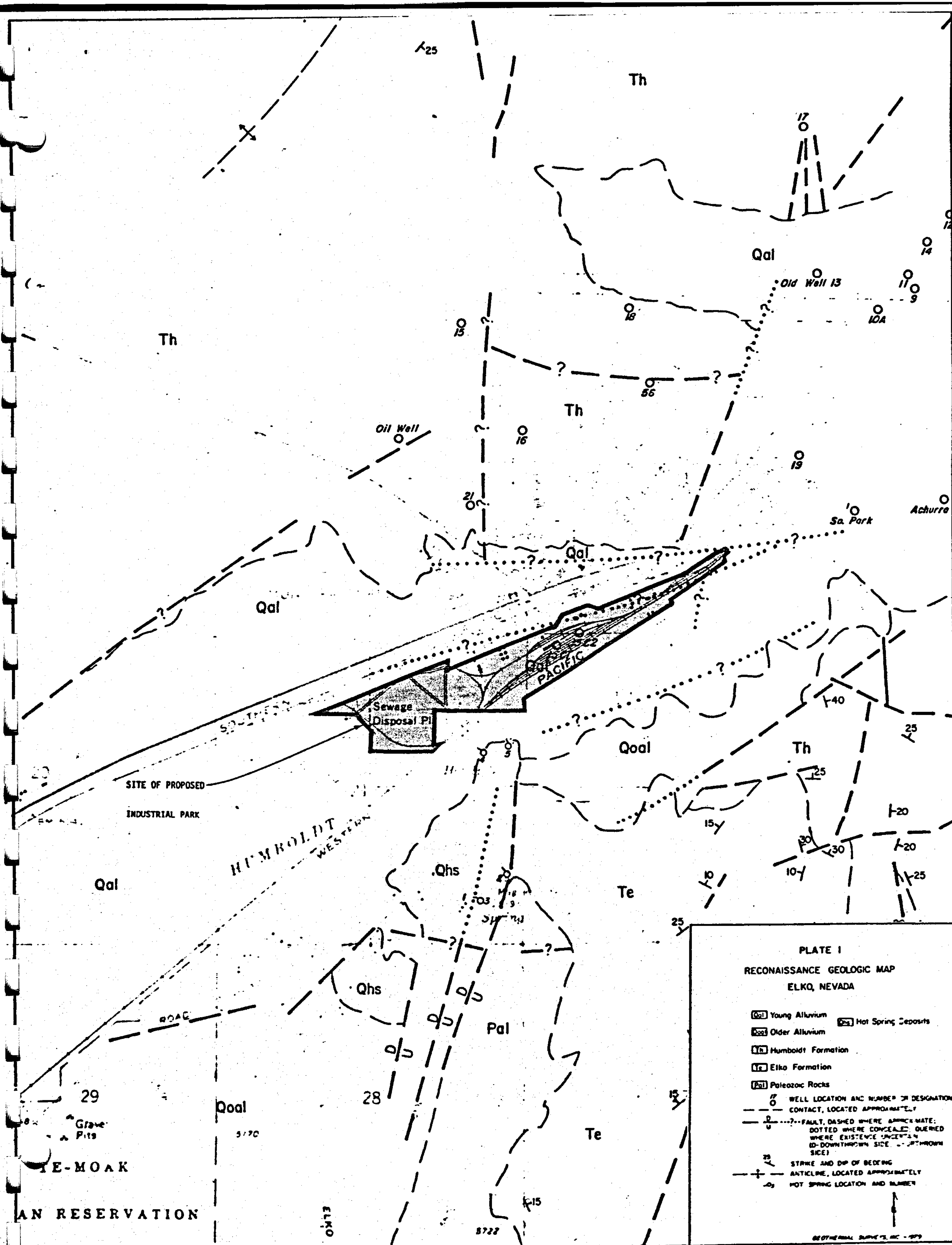


PLATE I
RECONAISSANCE GEOLOGIC MAP
ELKO, NEVADA
Qal Young Alluvium
Qoal Older Alluvium
Th Humboldt Formation
Te Elko Formation
Pal Paleozoic Rocks
Qhs Hot Spring Deposits
WELL LOCATION AND NUMBER OR DESIGNATION
CONTACT, LOCATED APPROXIMATELY
FAULT, DASHED WHERE APPROXIMATE; DOTTED WHERE CONCEALED; QUERIED WHERE EXISTENCE UNCERTAIN (D-DOWNTHROWN SIDE, U-UPTHROWN SIDE)
STRIKE AND DIP OF BEDDING
ANTICLINE, LOCATED APPROXIMATELY
HOT SPRING LOCATION AND NUMBER
Th
Qal
Old Well 13
Oil Well
Sa. Park
Achurra
Sewage
Disposal Pl
SITE OF PROPOSED
INDUSTRIAL PARK
HUMBOLDT
WESTERN
PACIFIC
Qoal
Qhs
Te
Pal
ROAD
29
28
Gravel
Pits
TE-MOAK
AN RESERVATION
ELKO

The age of the Humboldt Formation is presently known from vertebrate and plant remains. The lower portion is not older than late Miocene and the youngest sediments may have been deposited into lower Pliocene time (Sharp, 1939, p. 154). A sample of rhyolitic tuff from a locality immediately south of the river at Elko has been submitted for radioactive age dating. At the time of this writing the results are not yet available.

The Humboldt Formation is fluviatile and lacustrine in origin and unconformably overlies the Elko formation. The log of the oil well shown on Plate 1 indicates that the Humboldt Formation is at least 3,400 feet thick at that locality.

Quaternary Deposits - The alluvial fill of the Humboldt River Valley consists of unconsolidated deposits of silts, sands and gravels. These sediments overlie the Humboldt Formation unconformably. According to Fredericks and Loelts (1947, p. 9) the alluvium is not more than 75 feet thick. Based on GSI observations related to water wells, it is believed the Quaternary deposits may be at least 200 feet thick away from the valley edges. The exposed width in the immediate vicinity of Elko is about 3,500 feet. Northeast and southwest of Elko, the exposed width of Quaternary alluvial deposits is about one mile.

Older alluvium occurs outside of and stands higher than the present Humboldt River floodplain. It is only slightly more compact than the younger alluvium, but it is locally dissected, 20 to 50 feet.

Hot Spring Deposits - These deposits occur in the vicinity of Hot Hole and several other hot springs to the southwest. They consist of buff colored tufa mounds a few feet to about 20 feet thick. The reconnaissance geologic mapping did not reveal these deposits away from known hot springs. However, more detailed examination would be necessary in order to determine whether or not other hot spring deposits occur within the older formations.

If such deposits are restricted to existing hot springs, this would imply that the surface geothermal activity is geologically recent in the area of Elko.

2.3.3 Structure

A significant number of faults are shown on Plate 1. Their existence and locations were based largely on air-photo interpretation, the results of the ground temperature surveys, and some field observation. Detailed geologic mapping would undoubtedly eliminate some of the suspected faults, reveal others, and clarify their age relationships.

Faulting occurs primarily in northeasterly and east-northeasterly trending sets. Although there may be some overlap in age, present observations suggest that the youngest faulting is the more easterly trending set. Both sets displace the Humboldt and older formations. Whether they displace alluvial deposits is not clear from surface observations.

A number of northeast trending faults, here called the Hot Hole Fault Zone, occur along the western base of a ridge formed of Paleozoic rocks in Section 28. The Hot Hole Fault Zone appears to be a few hundred to almost 1,000 feet wide. Hot Hole and several other hot springs occur along and within the zone. Revealed as a ground temperature anomaly, the Hot Hole Fault Zone can be traced northeasterly across the Humboldt river alluvium into the southwest quarter of

Section 15. There, exposures in bluffs just north of U.S. Highway 40 do not show evidence of northeasterly continuation of the zone.

Based on topography and the ground temperature data, it is believed that the bluffs are controlled by an easterly trending fault along which the Hot Hole Fault Zone is displaced about 1,500 feet to the east. The Hot Hole trend then continues northeasterly through Section 15 and the southeastern part of Section 10. The fault is well-exposed in new highway roadcuts in the eastern part of Section 10.

South and southeast of the city of Elko the southern margin of the Humboldt River Valley appears to be fault controlled, separating the rugged topography and older formations to the south from the more gentle topography and younger formations to the north. GSI has tentatively interpreted the indicated faulting along the southern margin of the valley as normal faulting, along which the block to the north has been rotated downward and the block to the south has been rotated upward exposing the older, more resistant formations. At a locality in the northwest quarter of Section 23, about 500 feet south of the southernmost part of Highway 46, a measured dip on the fault is 60 degrees to the northwest.

The linear configuration of the temperature anomaly in the alluvium suggests that much of this faulting is young. Unless the aluvium is extremely thin the linear shape suggests that the faulting cuts the alluvium and controls the rise of hot fluids to or near the surface. Another indication that the faulting is young is that it appears to influence the older alluvial surface in Sections 28 and 29.

Exposures in the steep faces of the cuestas northwest of the Humboldt River do not show the type of outcrop pattern that would allow the cuestas to be explained as a product of differential erosion. They may be due to northwest trending faults, although in this case one must accept a large number of curving, subparallel faults rather equally spaced over a distance extending many miles up-river and down-river from Elko. If these faults are present they do not cross the northern margin of the Humboldt River valley but are cut off by the east-northeasterly trending fault set.

Another explanation of the cuesta topography is that the area is being tilted progressively toward the northeast, thus causing the southeast-flowing tributaries to cut their left banks. If so, tectonic activity is still going on in a regional sense.

In the Northwestern part of the mapped area, in Section 4 and in Sections 33 and 34 to the north, the cuesta faces expose a gently folded unit of volcanic ash within the Humboldt Formation. This expresses a broad anticline with a northeast trending axis.

2.4 Geothermometry

Hot Hole and four neighboring springs were sampled in May 1979 for quantitative analysis of the major cations. The results were used to estimate reservoir temperatures using standard geothermometric techniques.

The results of the geothermometric analysis are shown in Table 2.1.

TABLE 2.1

Estimated Source Temperatures

from Geothermometric Analysis

	Na-K-CA with MG correction Temp. °C	Silica Calculated Temp. °C
Hot Hole	150	114
Spring 2	163	114
Spring 3	166	111
Spring 4	161	111
Spring 5	163	111

The silica-calculated temperature for Hot Hole is in excellent agreement with that given by White and Williams (1975, p. 42). They give an assumed source temperature of 115°C, based on the silica geothermometer, and also show the Na-K-Ca values higher than the silica calculated temperature. The Na-K-Ca temperature may be high due to deposition of travertine by the thermal waters (White and Williams, 1975). All of the sampled springs show values very close to those for Hot Hole and indicate that they probably arise from a single source.

2.5 Geophysical Surveys

2.5.1 General Statement

In this study, four geophysical methods were applied to the evaluation of the Elko geothermal resource. Two of these were temperature techniques, one was a direct-current electrical method, and a few selected lines of ground electromagnetic data were also acquired.

Each survey was run with one or more specific objectives, either to detect localized presence or effects of hot water and/or structures such as faults controlling its distribution, or to gain more information on subsurface stratigraphic and structural conditions. A significant factor affecting the geophysical surveys is that the area of interest lies directly beneath the city of Elko which is a strong source of electrical and, to some extent, thermal noise unrelated to the geothermal resource.

2.5.2 Temperature Methods

The temperature methods employed by GSI were ground temperature surveying and downhole thermal logging. Both of these methods were also employed in their 1977 survey. In the present study the objectives were to specifically investigate the hot water regime and to obtain more detailed information than previously acquired.

2.5.3 Ground Temperature Surveying

Purpose - This survey was conducted to delineate the ground temperature anomaly associated with occurences of hot fluid and to more fully understand the interaction between the hot and cold water systems.

Results - The temperature pattern seen in Plate 2 is in excellent agreement with that revealed by the 1977 thermal survey. Except locally, the same pattrn of interpreted cold water flow routes and the distinct N 20° E trend of higher temperatures is present.

The most recent work revealed two distinct, high temperature anomalies entered at probe stations 51-A and 80-A. One of these is in the vicinity of Hot Hole; the measurement was made approximately 150 feet to the north. The second anomaly is located within the city of

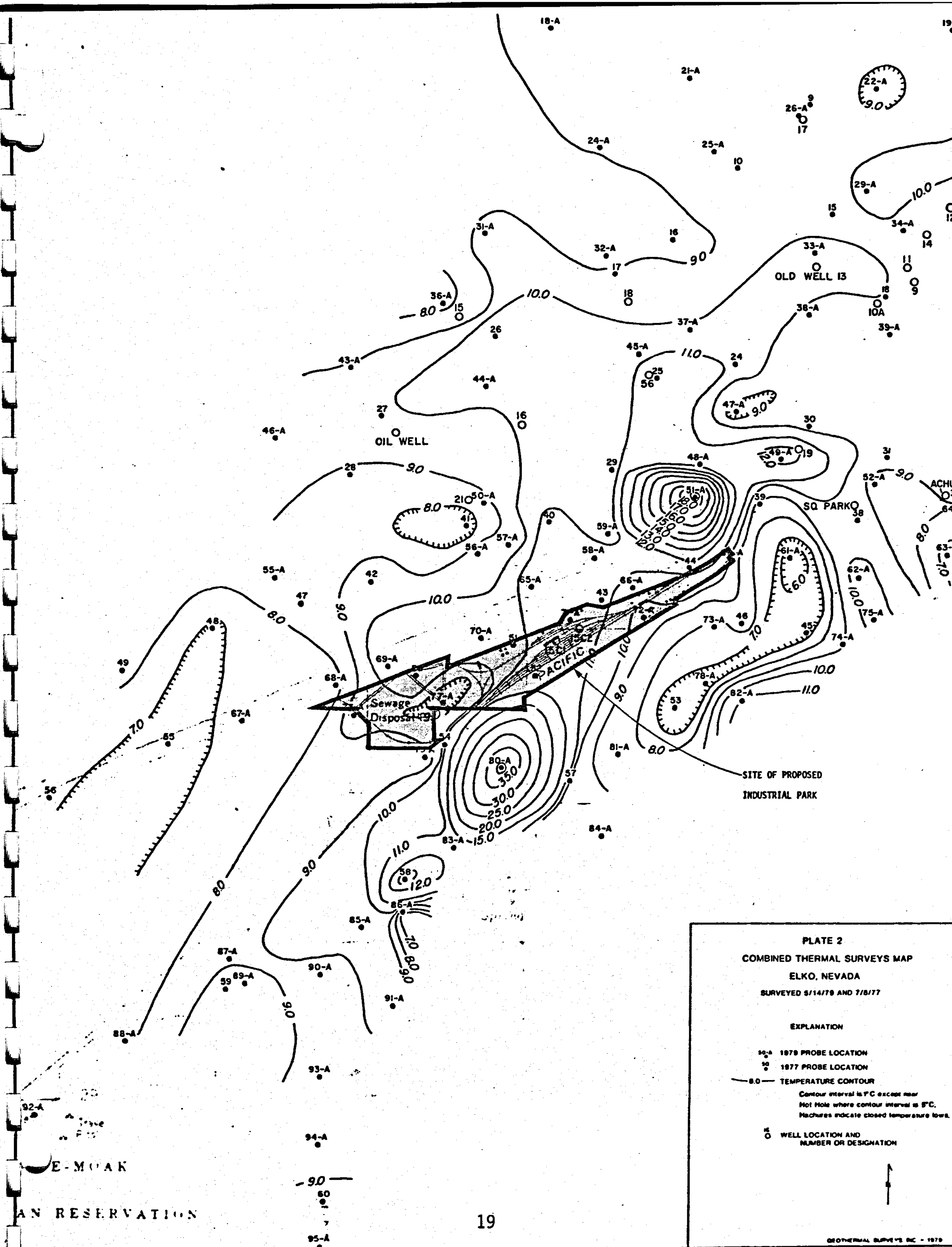


PLATE 2
COMBINED THERMAL SURVEYS MAP
ELKO, NEVADA
SURVEYED 5/14/79 AND 7/8/77
EXPLANATION
1979 PROBE LOCATION
1977 PROBE LOCATION
8.0 TEMPERATURE CONTOUR
Contour interval is 1°C except near Hot Hole where contour interval is 5°C. Hachures indicate closed temperature lows.
WELL LOCATION AND NUMBER OR DESIGNATION
GEOTHERMAL SURVEYS INC - 1979
OLD WELL 13
OIL WELL
SQ. PARK
Sewage Disposal
PACIFIC
SITE OF PROPOSED INDUSTRIAL PARK
E-MOAK
AN RESERVATION

Elko, on Court Street between Third and Fourth Streets. The extreme magnitude of the second anomaly should be treated with caution. Because of its local setting it may be an artifact in part. These two zones of anomalously high temperature are interpreted as being caused by heated ground water ascending from depth to the near-surface along faults or fractures in the underlying rocks.

2.5.4 Downhole Temperature Logging

Purpose - The primary objective of this logging was to identify areas with higher-than-normal geothermal gradient, suggesting the presence of hot fluids at depth. As part of GSI's work in 1977, six holes were thermally logged. Although an average geothermal gradient for this area is about 1.5°C per 100 feet, several of the logged holes showed geothermal gradients greater than 2°C per 100 feet and Well No. 56 showed a gradient greater than 4°C per 100 feet.

2.5.5 Vertical Electrical Resistivity Soundings

Purpose - This method was employed to examine the vertical resistivity distribution at each sounding location. Resistivity of subsurface earth materials is determined primarily by their water content. The quantity, quality, and temperature of the water affects the measured value as does the lithology, texture, and fabric of the rock in that these parameters determine the porosity of the rock. The quantity measured in the field is apparent resistivity, dependent not only on the true bulk resistivity of the material under investigation but also on the electrical properties of the surrounding environment and on the geometry of the measuring array.

Soundings were conducted to gain more information on subsurface stratigraphy and to identify anomalously low resistivity areas and zones at depth which may be saturated with hot water.

Results - As shown in Plate 3, the Humboldt Formation northwest of the Humboldt River is marked by moderate resistivities of 20 to 50 ohm-meters. In the vicinity of Hot Hole and other suspected fault zones measured resistivities range from 3 to 10 ohm-meters. This effect may be explained by water saturation or by the presence of clays in the fault zones. The alluvium is comparatively moderate-to-high in resistivity, 30 to 150 ohm-meters, owing to its coarser-trained composition, and appears to be up to a few hundred feet thick. In the eastern and southeastern portions of the surveyed area low to moderate resistivities occur at depths below the alluvium which are believed to be typical of the lower portion of the Humboldt Formation.

2.5.6 Horizontal-Loop Electromagnetic Profiling

Purpose - This technique was employed in an attempt to precisely define the position and width of some of the faults and fractures believed to be related to the near-surface expression of the geothermal resource.

Results - Lines SL 1 and SL 2 were run in an area southwest of Hot Hole, across and along the Hot Hole Fault trend. Both of these lines do reveal anomalously conducting zones related to the faulting. The response may be caused by the presence of warm water along the fault and/or by the presence of clay materials in the fault zones.

Although the possibility of acquiring interpretable Max-Min data within the city was considered small, Line SL 3 was run down Fifth Street

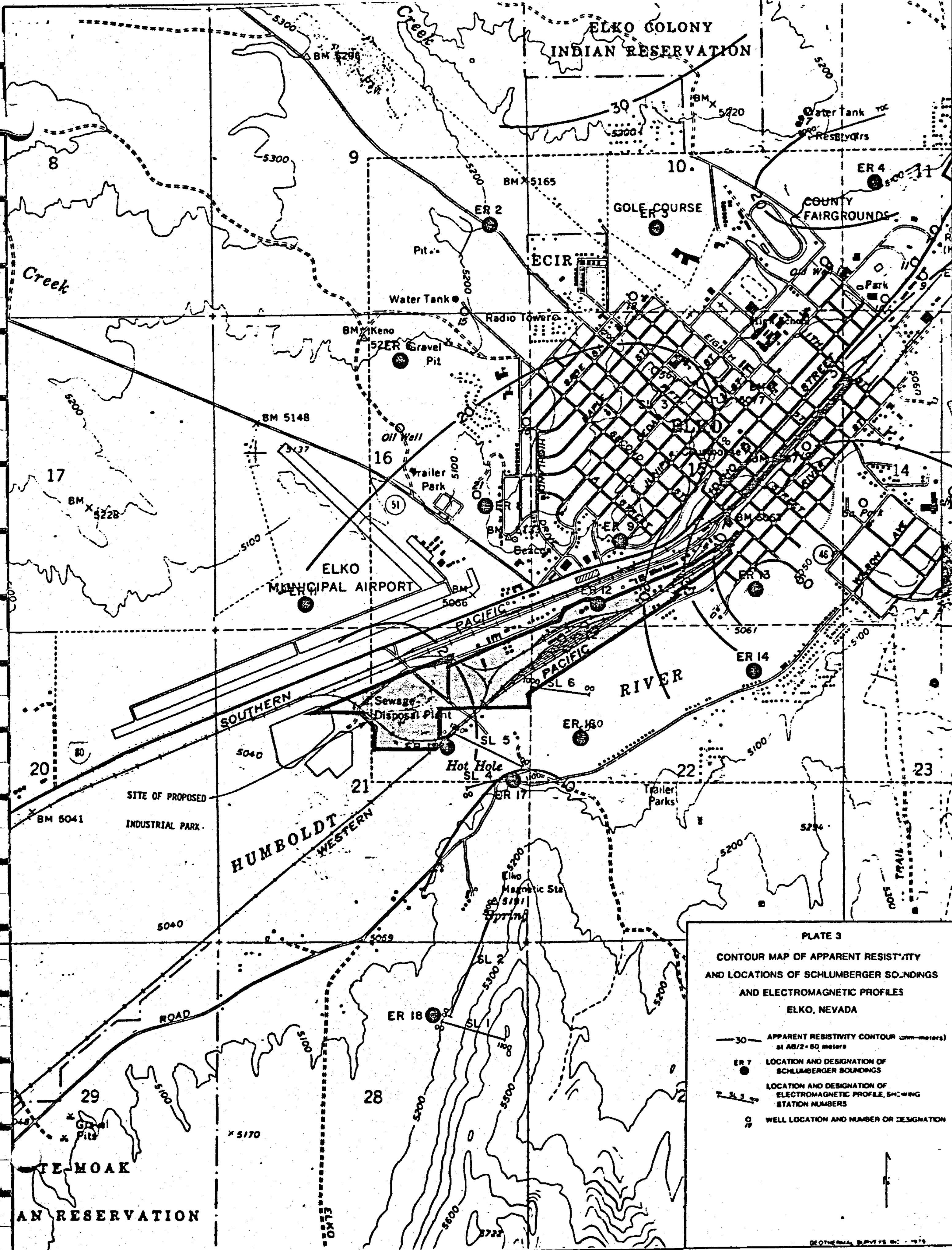


PLATE 3

CONTOUR MAP OF APPARENT RESISTIVITY AND LOCATIONS OF SCHLUMBERGER SOUNDINGS AND ELECTROMAGNETIC PROFILES

ELKO, NEVADA

in an effort to identify the position of the Hot Hole Fault Zone. As expected, the presence of many power lines and buried pipelines render the data uninterpretable.

Lines SL 4, 5 and 6 were run near and slightly northeast of Hot Hole. Interpretation of the data from lines SL 4 and SL 6 is difficult due to the short profile lengths. SL 5 shows a clear anomaly, identifying an anomalously conducting zone approximately 500 feet wide. This is interpreted as the Hot Hole Fault Zone.

Line SL 7 was run across new freeway road cuts northeast of the city that reveal several faults. An approximately 750 feet wide anomalously conductive zone is indicated by the data.

2.6 Conclusions

The present geological, geophysical, and geochemical investigations support the earlier indications that a hot water resource extends northeasterly beneath the city of Elko as shown by Figure 2.2. This is based on several sets of areally distributed ground temperature surveys, downhole temperature gradient logging in water wells, electrical resistivity and electromagnetic surveys, chemical geothermometry, and reconnaissance geologic mapping.

There appears to be strong control of thermal fluids by faults and considerable mixing of the hot fluids and cold ground water.

Temperatures observed at the hot springs are on the order of 60°C and original source temperatures, indicated by chemical geothermometry, are on the order of 110°-150°C.

The strong control of the near-surface thermal anomaly by faulting and the relatively low salinity of the thermal fluids indicates a

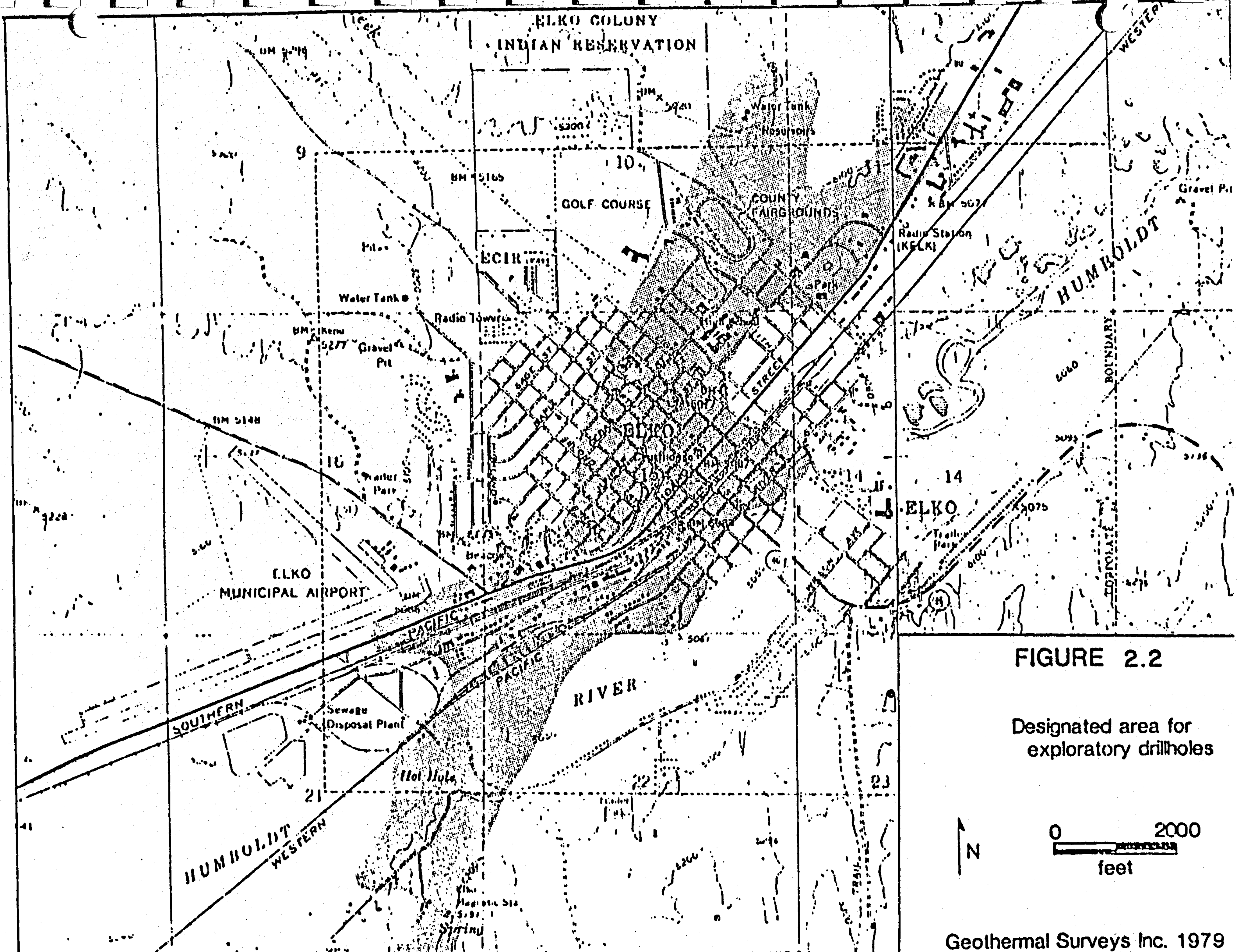


FIGURE 2.2

Designated area for exploratory drillholes

Geothermal Surveys Inc. 1979

convective geothermal model. It appears at this time that at least some of the Elko thermal resource is provided by ground water occurring or migrating deep enough to become heated by a temperature source still unknown and rising to the surface along some of the faults in the Elko area.

This model does not preclude the possibility that higher temperature geothermal fluids occur at greater depths than so far investigated by the present study.

Moreover, the thermal trend shown in Figure 2.2 shows only the zone of the maximum near-surface thermal anomaly supported by the electrical resistivity work. Extensions and/or thermally active faults occur outside the zone indicated in Figure 2.2. This is known from some of the thermal gradients and anomalous temperatures observed in water wells east of the Hot Hole thermal trend.

In general, water wells are of better quality east (up-drainage) of the Hot Hole Fault. Hot water rising along fractures in the bedrock enters the alluvium of the Humboldt River Valley and mixes with the shallow ground water. Thus, wells west (down-drainage) of the Hot Hole Fault are of poorer quality.

Water wells drilled in the general vicinity of Elko have encountered hot caving mud and higher-than-normal gradients a few hundred feet or less beneath the surface. Well 34/55-15C1 drilled by Western Pacific Railway Co. in 1911 at their roundhouse (in the approximate center of present proposed industrial park) encountered a supply of "warm water" between 345 and 360 feet which flowed at the surface at the rate of 7 gallons per minute. Another well, 34/55-15C2, was drilled approximately

50 feet away from 15C1 and encountered "hot caving mud" at a depth of 280 feet (see Plate 3, page 22, for location of 15C1 and 15C2). It is likely that in the upper few hundred feet the transmissivity of the young valley alluvium is high enough that cold water flushing is dominant. In the older, less permeable formations, hot water and high temperatures are not quickly removed by the ground water.

It appears at this time that geothermal reservoir potential may occur in the brittle, highly fractured Paleozoic quartzites and carbonates (especially if solution cavities are present) and in the coarser sediments of the Humboldt Formation. Calcareous tufa around some of the hot springs suggests that some of the geothermal fluids may be passing through Paleozoic carbonates. The fine-grained shaly nature of the Elko Formation suggests poor reservoir conditions and the Quaternary alluvium is probably not able to store hot fluids because of flushing by ground water.

Low-to-moderate temperature thermal fluids are probably available at depths of 500 to 1,000 feet within the Humboldt Formation. Higher temperature fluids may be available at significantly greater depths in the Paleozoic formations.

Exploratory drilling should be concentrated within but not limited to the shaded area shown in Figure 2.2. Additional exploratory drilling may be done outside the shaded area to test the additional extent of the thermal resource.

GSI believes that the thermal fluids are controlled mainly by the faults, which are numerous in the Elko area. To the extent that fluids rising along faults have migrated into adjacent formations of high permeability, this would increase the target area and the volume of the available geothermal resource. Until the lateral extent of such migration is known, further exploration should be undertaken with the expectation that production may have to be limited to the zones of favorable permeability caused by faulting or extensive jointing.

The shaded area shown in Figure 2.2 is not meant to represent the entire area within which there may be viable geothermal potential. There may be further extension northeasterly along U.S. Highway 40, northerly beyond the city water tanks, and southwesterly along the airport and the highway. The producing city water wells are along the margin of the northeasterly extension of the indicated anomalous zone. If these had been drilled deeper, thermal fluids or anomalous temperatures might have been encountered.

2.7 List of References (Chapter 2)

1. Fredericks, J. C. and Loeltz, O. J., 1947, Ground Water in the Vicinity of Elko, Nevada, U. S. Geological Survey.
2. Sharp, R. D., 1939, Miocene Humboldt Formation in Nevada, Jour. Geol., Vol. XLII, pp. 133-160.
3. White, D. E. and Williams, D. L., eds., 1975, Assessment of Geothermal Resources of the United States: U. S. Geological Survey Circular 726.

3. SYSTEM APPROACHES CONSIDERED

A number of possible system designs were considered for district heating of the Sunrise Subdivision. These design options along with the advantages and disadvantages of each are discussed in the following subsections.

3.1 Common Features

All design approaches considered in the design study include

- a single point for heating the culinary water within the subdivision, with a single geothermal well,
- increased water flow through the subdivision since the consumptive flow of culinary water cannot supply sufficient thermal energy (at a reasonable water temperature) for winter heating of the homes, and
- continuous throughflow of water at each house.

3.2 Design Options

The design concept options considered in the study were those pertaining to the main water supply system, the individual house supply/return piping and the heating system used in each house.

3.2.1 Main Water Supply System

The options evaluated were (a) the Open System Concept and (b) the Isolated Loop Concept as illustrated schematically in Figures 3.1 and 3.2, respectively. Since the water flow rate through the community must be several times as great as the consumptive water flow requirement (see paragraph 4.2.4), the open system concept requires a significant water usage downstream of the community. This use rate must either be consistently high, or the use pattern downstream must coincide with the heating cycle requirements of the subdivision. In the present case,

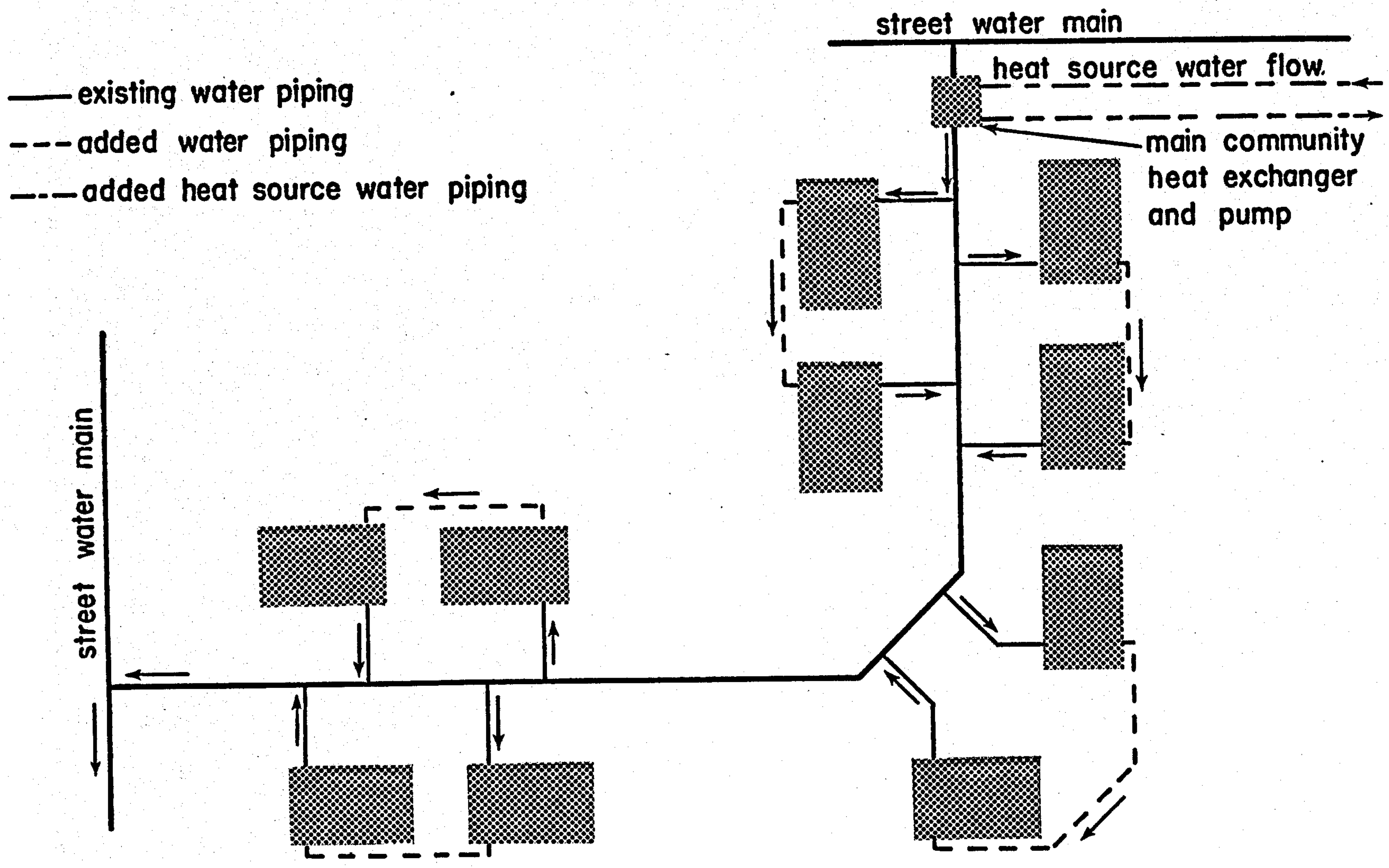


FIGURE 3.1 OPEN SYSTEM CONCEPT

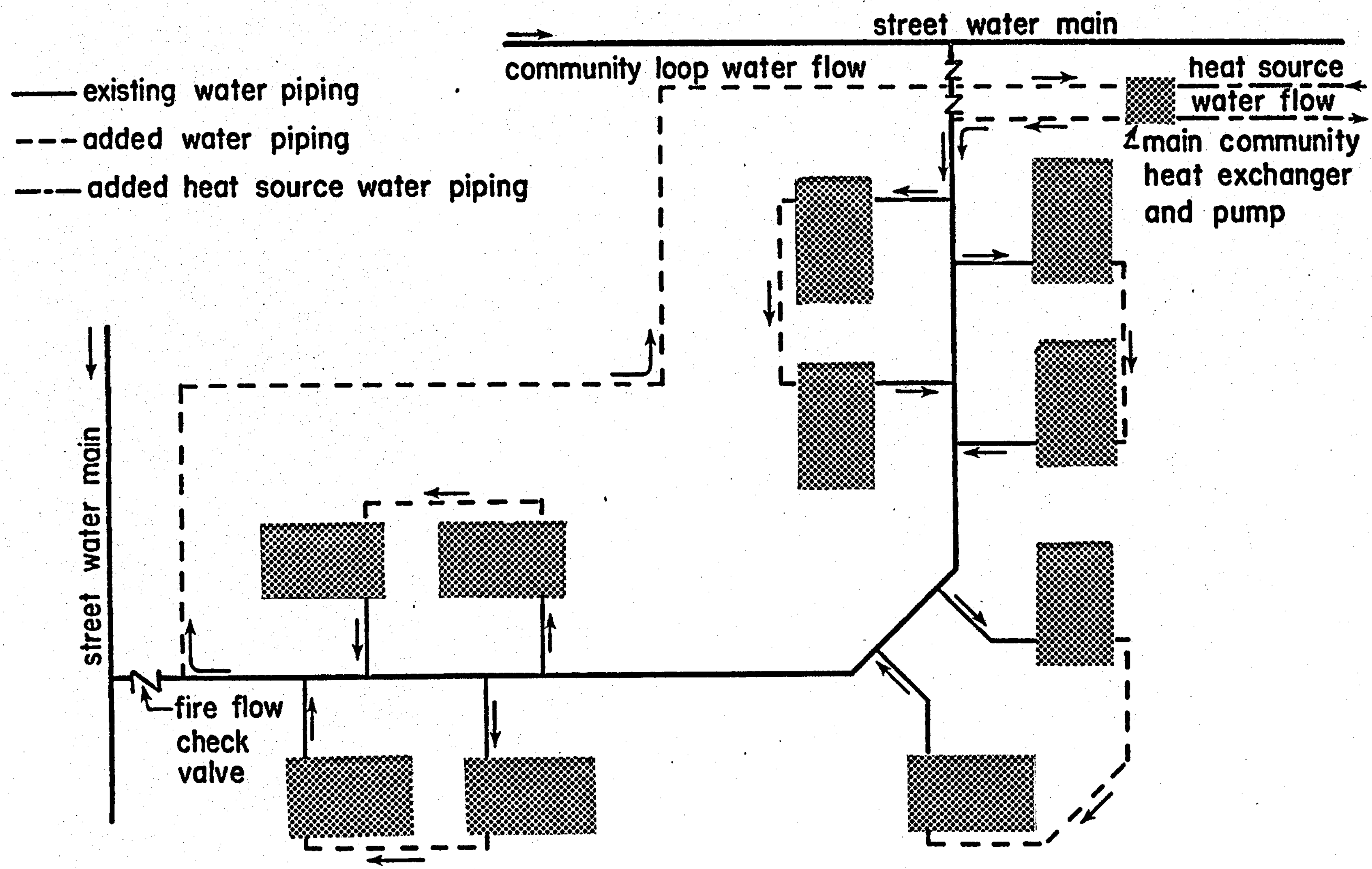


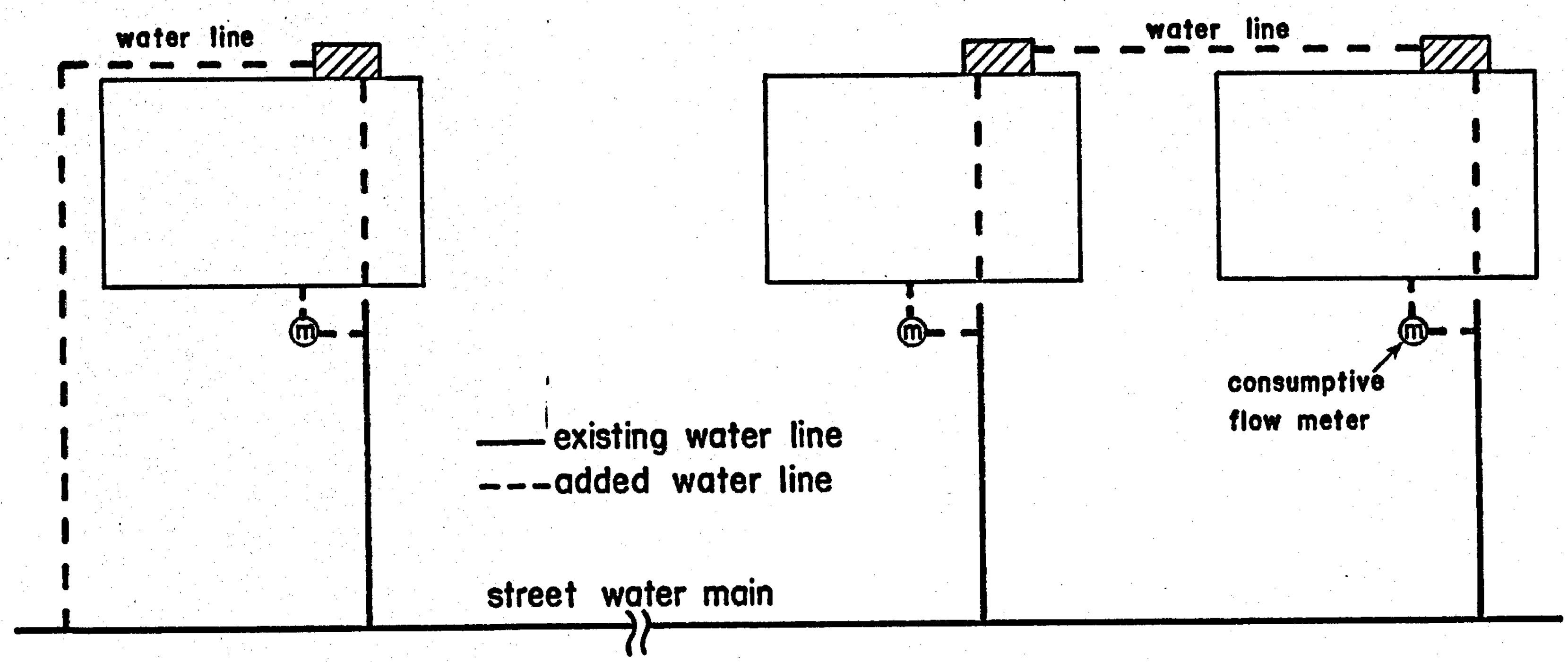
FIGURE 3.2 ISOLATED LOOP CONCEPT

there is no constant large flow demand downstream, and this effectively precludes selection of the Open System. It should also be noted that the Open System concept can also be wasteful with regard to the thermal energy supplied and can impose excessive main heat exchanger requirements. If, however, the discharge water from the subdivision is reheated for cascaded usage, this would render the Open System a more attractive option.

The Isolated Loop Concept for the subdivision requires the addition of a return main line and additional pumping throughout the life of the system. The return main, even if installed around the perimeter of the subdivision to minimize street damage and repair, is nonetheless a significant cost item and is easily the most visible and probably the most objectionable of all construction activities proposed. The Open System on the other hand, is simply not feasible for the subdivision under study for the reason previsouly stated.

3.2.2 Individual House Water Supply

Two approaches were considered for delivery and return of heated water from the street main water line to individual houses. The first of these utilizes the existing 1-in.-diameter water line to each house for supply and an added 1-in.-diameter line for return. This is shown schematically in Figure 3.3, part A; the dashed line in this schematic represents added piping and the cross-hatched block represents the heat exchange unit for the house. The second approach considered in the study is to "pair" two houses and use the two existing 1-in.-diameter supply lines, one for supply and one for return as shown schematically in Figure 3.3, part B.



A) SINGLE HOME SYSTEM

B) PAIRED HOME SYSTEM

FIGURE 3.3 SINGLE HOME-PAIRED HOME WATER SUPPLY SCHEMATICS

The first approach (i.e., single house system) requires more total piping and considerably more costly and disruptive construction. This is especially true since the Sunrise Subdivision has new asphalt streets with new concrete curbs and sidewalks. Each added line connected to the street main would require "cutting" of the street pavement and possibly require "cutting" of the sidewalk.

The "paired-house" approach, on the other hand, would require only a connecting 1-in.-diameter line between houses, and this could be added with less cost then the added lines for the single house concept. The "paired-house" approach, however, requires a bypass piping system at each house to permit full-flow to the other house of the pair. This is discussed in Section 4.1.3.

3.2.3 Housing Heating System

In general, the choices for heating the systems at the houses in a retrofit district heating system are

- modification of existing forced air system by addition of a heat exchanger,
- use of individual room convectors or space heaters,
- modification of existing forced air system by addition of a water supplied heat pump, or
- installation of a completely added central forced air system and heat pump.

The first and second of these approaches lend themselves more readily to use of a relatively high temperature heating fluid, generally on the order of 110°F and higher at the individual houses. Water at this temperature must be cooled by some means (refrigeration, holding tank, etc.) prior to use for kitchen and other consumptive purposes. It also results in higher thermal losses than lower temperature water. A rather complete generic study using high temperature water with a modified forced air heating system (existing) was undertaken in phases I and II but is not included in this report.

The last two approaches, which feature the use of heat pumps, allow the use of moderately heated water, say at temperatures of 90°F or less, supplied to the individual houses. Water at this temperature level should be suitable for kitchen, bath and other household consumptive use without further cooling. This is a prime factor in choosing a system design incorporating a heat pump for each house. A heat pump system, however, is the most costly type with regard to initial installation costs.

In the Sunrise Subdivision, the existing house heating system consists of electric baseboard heaters in each house. Consequently, a completely new or separate heating system is required, regardless of the type chosen, for each house. The use of a heat pump approach in this community also requres retrofit of an air-duct system which is a very high cost item in comparison with modification of an existing furnace system.

4. CONCEPT DEVELOPMENT, ANALYSIS AND OPTIMIZATION

4.1 General Concept

A district heating system is proposed which consists of a centralized plant to elevate the temperature of clean domestic water which is then pumped through existing potable water piping to the buildings in the community. At each building heat is given up to the living space via a water source heat pump connected to a central air distribution system. Since the design uses clean domestic water as the heating medium, all components in the system, as well as the system design, must be selected such that contamination of the water supply is avoided.

4.1.1 Central Heating Plant

The centralized plant in this design consists of a water-to-water heat exchanger, a water circulating pump, and the associated control equipment. Thermal energy is supplied to the heat exchanger from a nearby geothermal well. This thermal energy is transferred through the heat exchanger to the potable water supply. The potable water flow will be many times the normal consumptive flow rate in order to provide enough thermal energy for heating the houses and to account for thermal losses without excessive water temperature degradation. Since the power required to supply the needed heat to the house through the heat pump depends upon the temperature of the water supplied to the heat pump, it is desired to keep the difference between the water temperature extremes in the community at a minimum. One of the major objectives is to determine the community flow rate which will minimize the system operating cost based on the cost of heat pump operation and the cost of pumping the needed through-flow.

4.1.2 Distribution Through Community

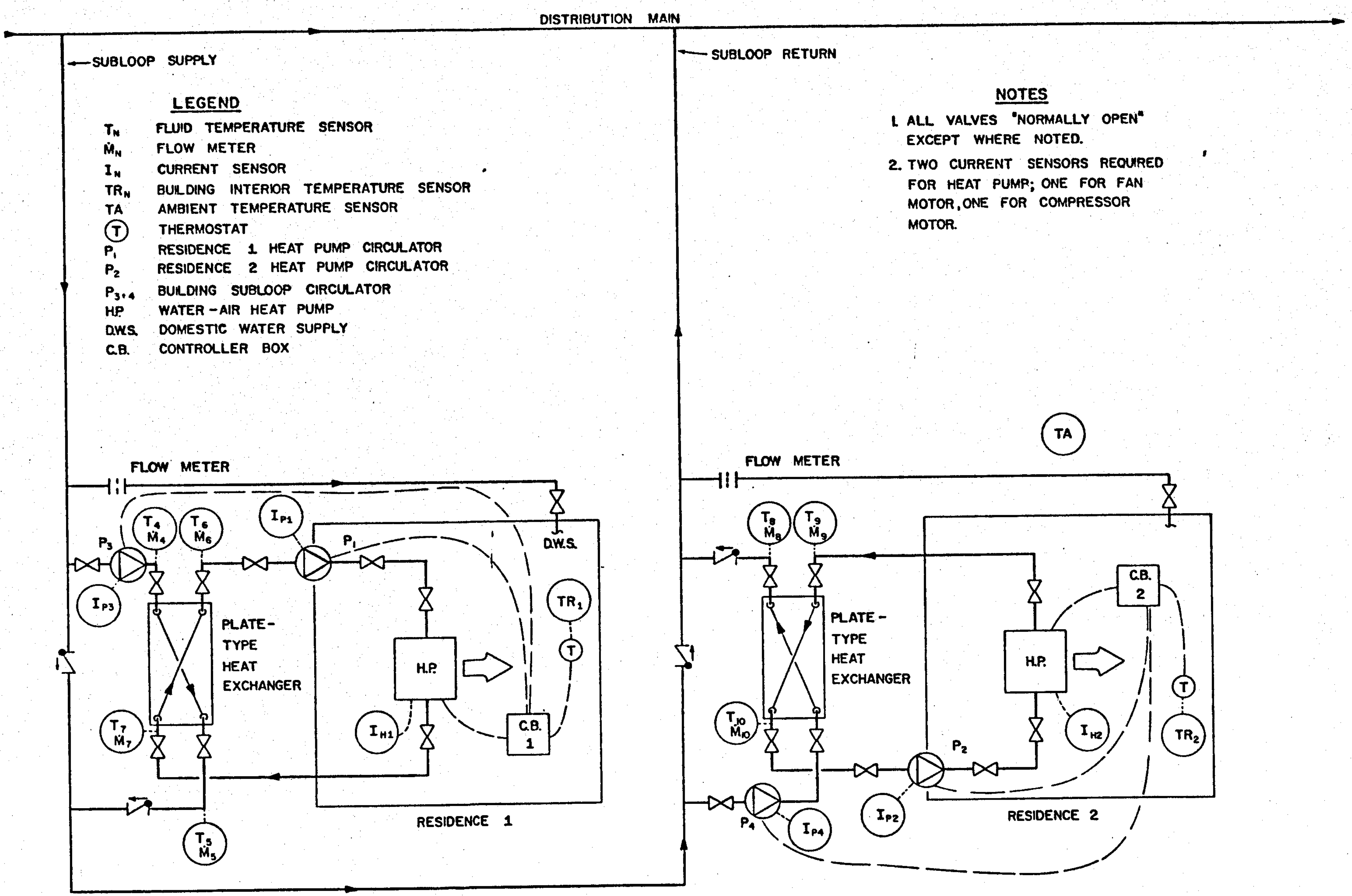
The proposed design concept uses the Isolated Loop Concept in which the potable water is heated to a moderate temperature (80-100°F) and then pumped through the community. The pump used has variable speed with controls to maintain the community water supply temperature within a specified range. The water flows through the community losing heat by conduction through the soil, losing heat through water consumption, gaining heat from the pumping frictional effects, and transferring heat to each home through a heat pump isolation loop. The water flowing through the community is returned to the main heat exchanger to be reheated and recirculated as discussed in Section 3.2.1. Prior to the water being returned to the main heat exchanger, some low temperature make-up water is added to the system to replace that which is consumed at the homes.

The proposed system concept makes use of the existing culinary water supply lines in the community. Using these uninsulated lines saves excavation and resulting surface repair costs associated with laying new heating pipes. Some additional piping, however, is required in order to form a closed loop through the community which thermally isolates the heated section of the community. After selecting a location for the heating plant, supply and return lines for the community are installed. These lines form a closed loop through which the greatly increased water flow will pass. The design of the added lines provides for supplying the make-up water needed to replace the water consumed at the houses and also ensures that adequate water flow for fire protection is available to the community.

4.1.3 Supply To Individual Houses

The proposed system design features the "paired house" approach. In this design a pair of adjacent houses make up a single heated water supply loop as discussed in Section 3.2.2. The existing potable water line for one house serves as the supply line for both houses. A new line is installed between the two houses to transmit the heating fluid. The existing potable water line for the second house serves as the return line for the two houses. This design requires only the excavation and refill costs for the connecting piping and causes no street damage. The two-house design also requires less pipe than the individual house design. For these reasons the two-house system design was chosen.

The house loop proposed contains small circulating water pumps which operate continuously to provide hot water to the heat pump isolation system. The continuous flow keeps the system piping and heat exchange devices at operating temperature which improves the system performance. The heat pump isolation loop isolates the water source heat pump from the culinary water supply so that the clean water is protected from contamination in the event of heat pump failure. The isolation loop consists of a water-to-water heat exchanger, a small water circulating pump, a water source heat pump package, a small amount of connecting piping, and the necessary control equipment (see Figures 4.1 and 4.1.a). The hot culinary water passes through the heat exchanger transferring heat to the water flowing in the isolation loop. The water in the isolation loop then passes through the heat pump which provides heat to the living space through a central air distribution



DISTRIBUTION TO HEAT PUMP SCHEMATIC WITH PROPOSED INSTRUMENTATION POINTS

FIGURE 4.1

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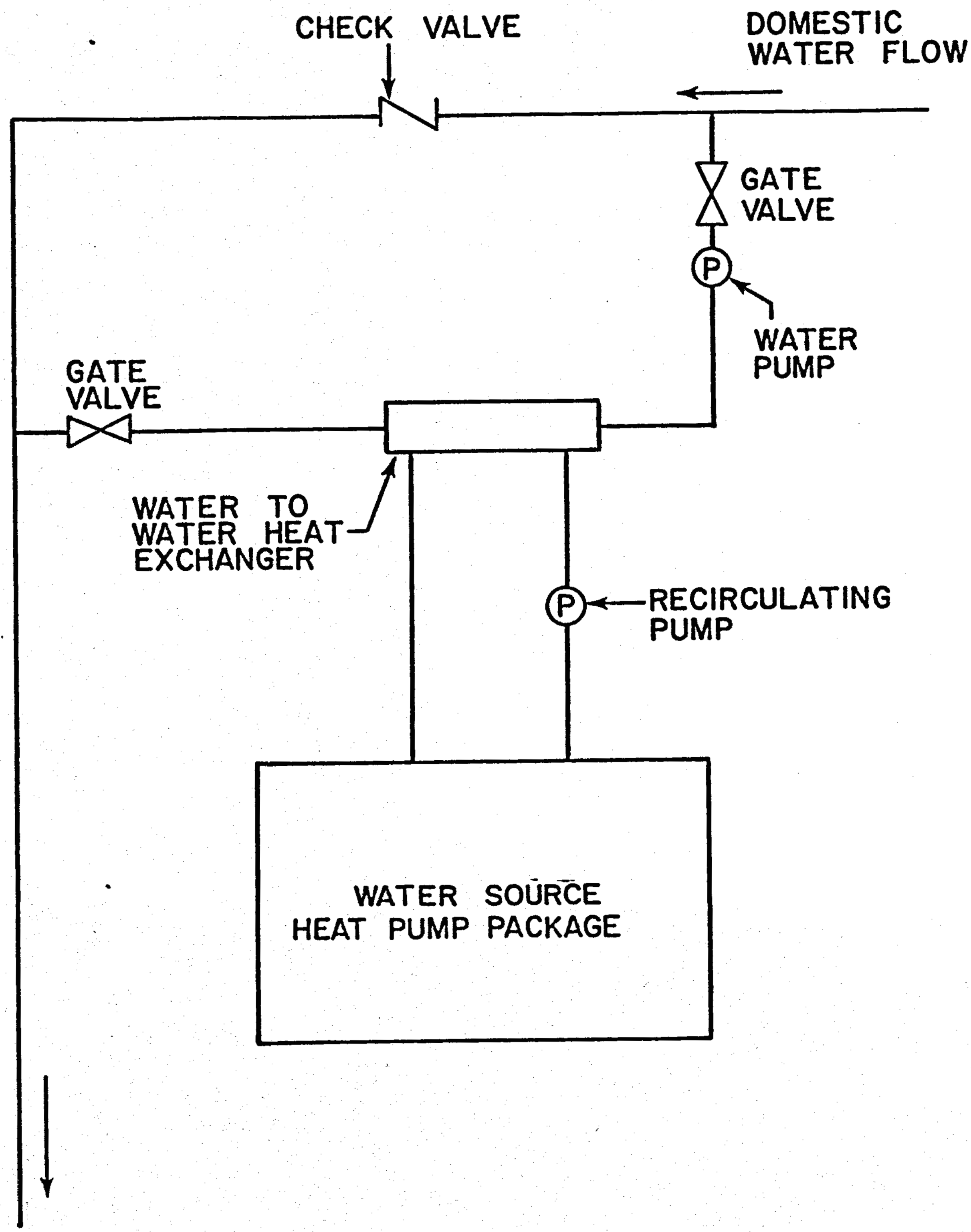

FIGURE 4.1a SIMPLIFIED SCHEMATIC OF HEAT PUMP WATER ISOLATION LOOP

system. The controls on this loop will indicate excessive increase or decrease in loop pressure which would be caused by failure of one of the loop components. A large flow requirement of the downstream house of the pair can be accommodated by flow through the bypass check valve.

4.2 System Analysis

4.2.1 General

In order to begin the design and analysis of the community heating system, data regarding existing piping and other factors are needed. Required detailed information on the existing community potable water piping includes:

- the location of all piping within the community,
- the length and diameter of all piping,
- the type of pipe used (pipe relative roughness),
- the location and angle of all pipe bends,
- the location of any flow obstructions (tees, valves, etc.), and
- the buried depth of all piping.

Information about the community in general, such as

- the approximate thermal conductivity of the soil in the area,
- the average consumptive water flow per house in the community,
- thermal design data for the houses in the community,
- local climatological data for the community, and
- the location, temperature, and flow rate of the heat source

must also be available. With this information in hand, the system design process may begin.

The design of a system to supply heat to an existing 30-house residential community in the town of Elko, Nevada, is presented. The design and analysis of this system are discussed in the following subsections.

4.2.2 Description of the Community/Subdivision

Elko, Nevada, is a town of approximately 9600 located in the northern part of the state at an elevation of 5050 feet. The 30-house community under consideration for the proposed district heating system is called the Sunrise Addition and is shown in Figure 4.2 with its existing potable water piping layout. The average daily consumptive water flow for this community is 575 gallons per home. The entire city of Elko is located in an area having known geothermal resources which could be used as a heat source for the proposed system. The thermal conductivity of the soil in the area[1] was assumed to be 0.5 BTU/hr.ft.°F. Local climatological data for the last 20 years indicate an average of 7112 degree-days of heating per year. All houses in the Sunrise Addition are essentially identical prefabricated units, and thermal design data from the manufacturer indicate a design heat load of approximately 250 BTU per hour (BTUH) per degree of temperature difference between the living space and the surrounding environment. The units were designed for a 77°F temperature difference (the design temperature for Elko is -7°F) which would require 19250 BTUH. The houses are currently equiped with electric baseboard heaters having a maximum output of 28150 BTUH. The proposed system is designed to totally replace the existing system and will actually deliver approximately 1.8

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1. The town of Elko is in an arid region having annual total precipitation of approximately 9 inches. Soil thermal conductivity values are very dependent on soil moisture content and range from 0.4 to 1.0 BTU/hr.ft.°F according to [8]. The aridity of Elko would indicate a low value of soil thermal conductivity.

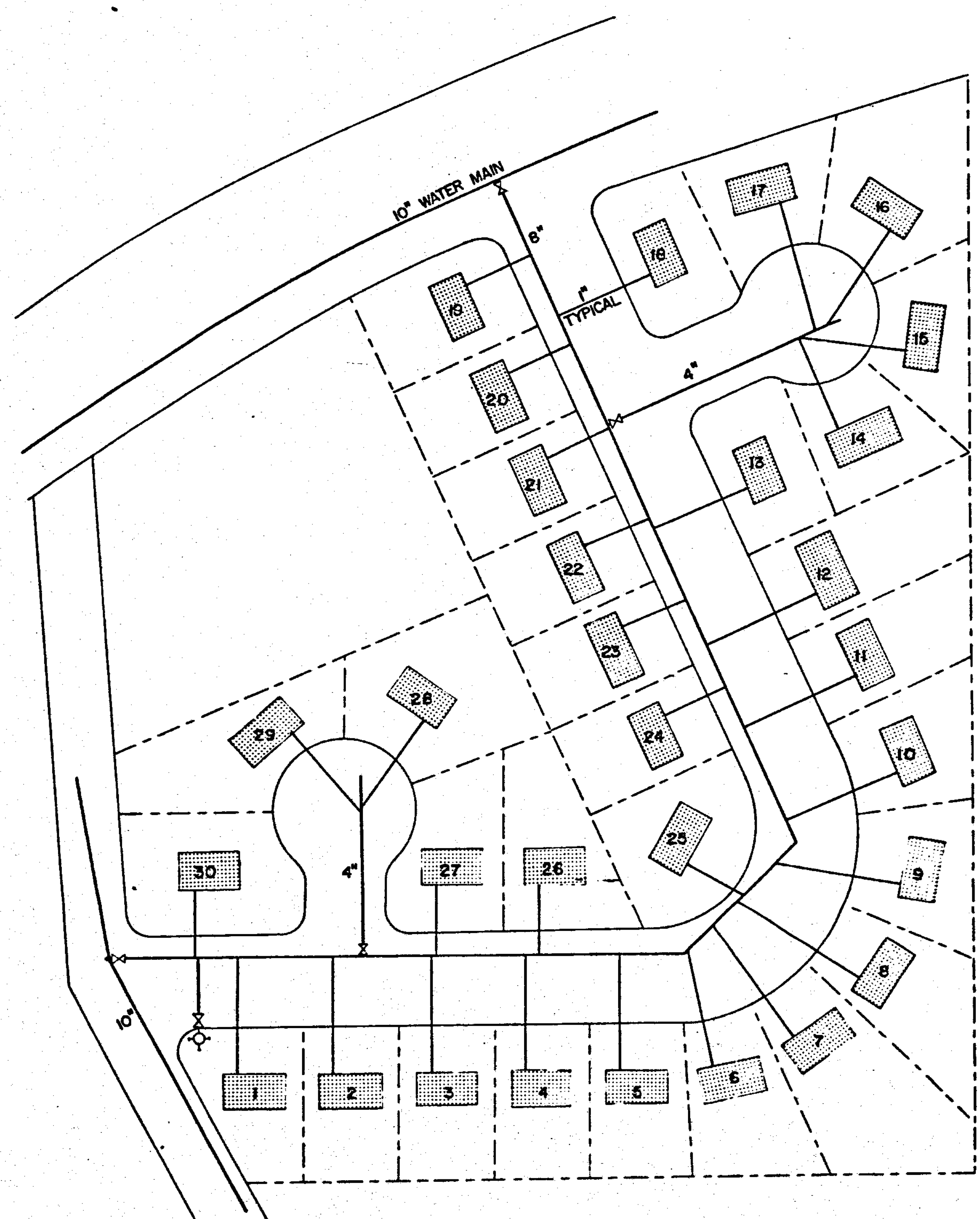


FIGURE 4.2 LAYOUT OF SUNRISE ADDITION SUBDIVISION WITH EXISTING POTABLE WATER PIPING

times the stated design heat load. Detailed study of the thermal design data obtained from the house manufacturer indicates that the effects of air infiltration were not accounted for in their analysis. The proposed design will supply enough heat to compensate for the infiltration effect and also ensure adequate capacity for heating from a cold-start condition.

4.2.3 Location of the Main Heating Plant and Added Community Piping

The present location of all existing piping in the community is shown in Figure 4.2. The first system design consideration is the determination of a location for the system main heating plant. The plant should be located as near as possible to the community main flow supply line in order to minimize the amount of additional piping needed. Excessive amounts of piping not only increase initial system costs but also increase system operating costs through increased thermal losses and added fluid frictional pressure drops. In the proposed design the heating plant is placed in the corner of lot number 16 approximately 300 feet from the main supply line as shown in Figure 4.3. The proposed site consists primarily of city right-of-way land with only a small portion on lot 16.

After choosing the location of the heating plant it is next necessary to determine the routing of the additional community main piping required to thermally isolate the heated section of the community. A supply line from the heating plant to the main distribution line and a return line from the end of the distribution line back to the heating plant are required. The lines will be run through community right-of-way property bordering the lots. The design of the piping layout must

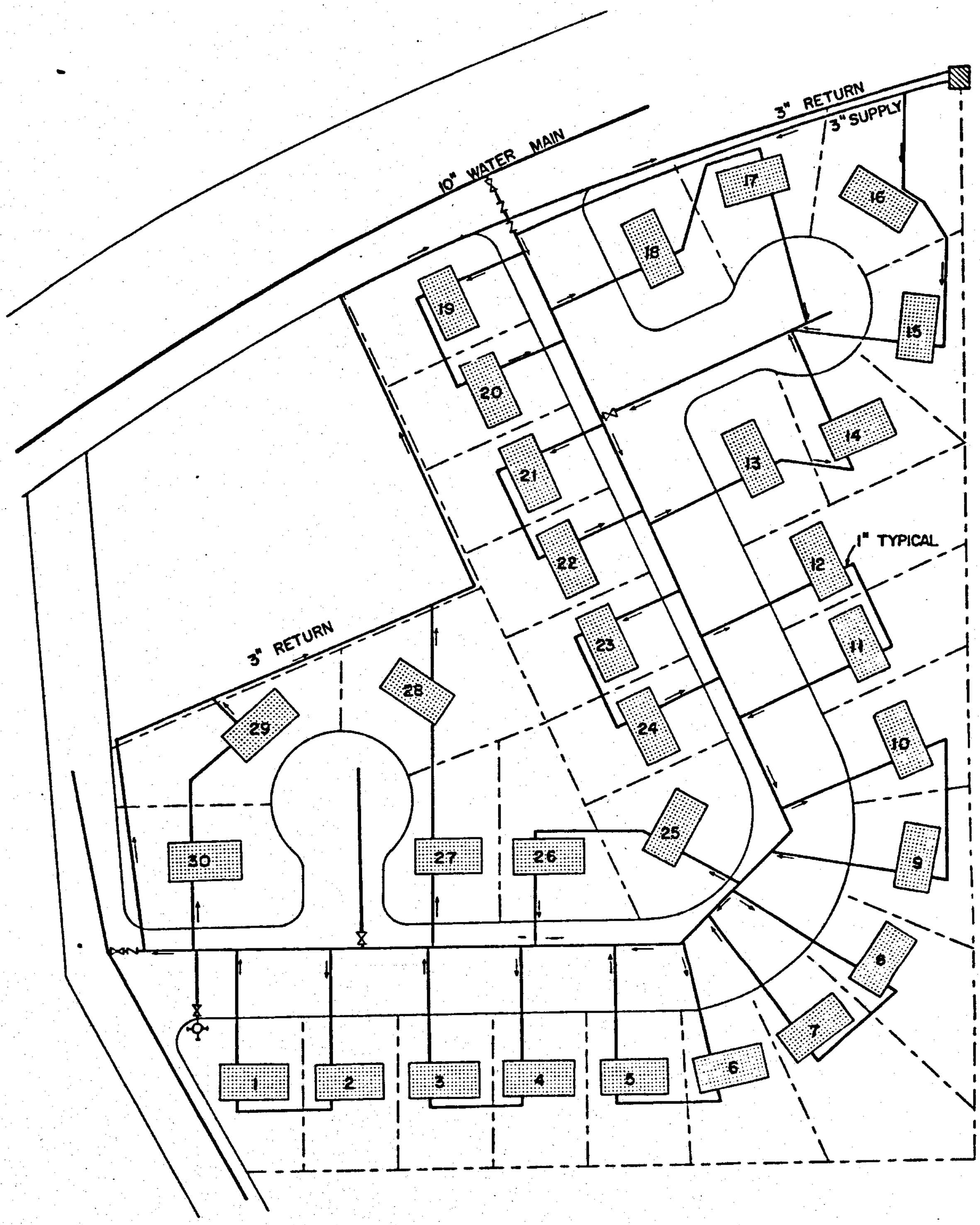


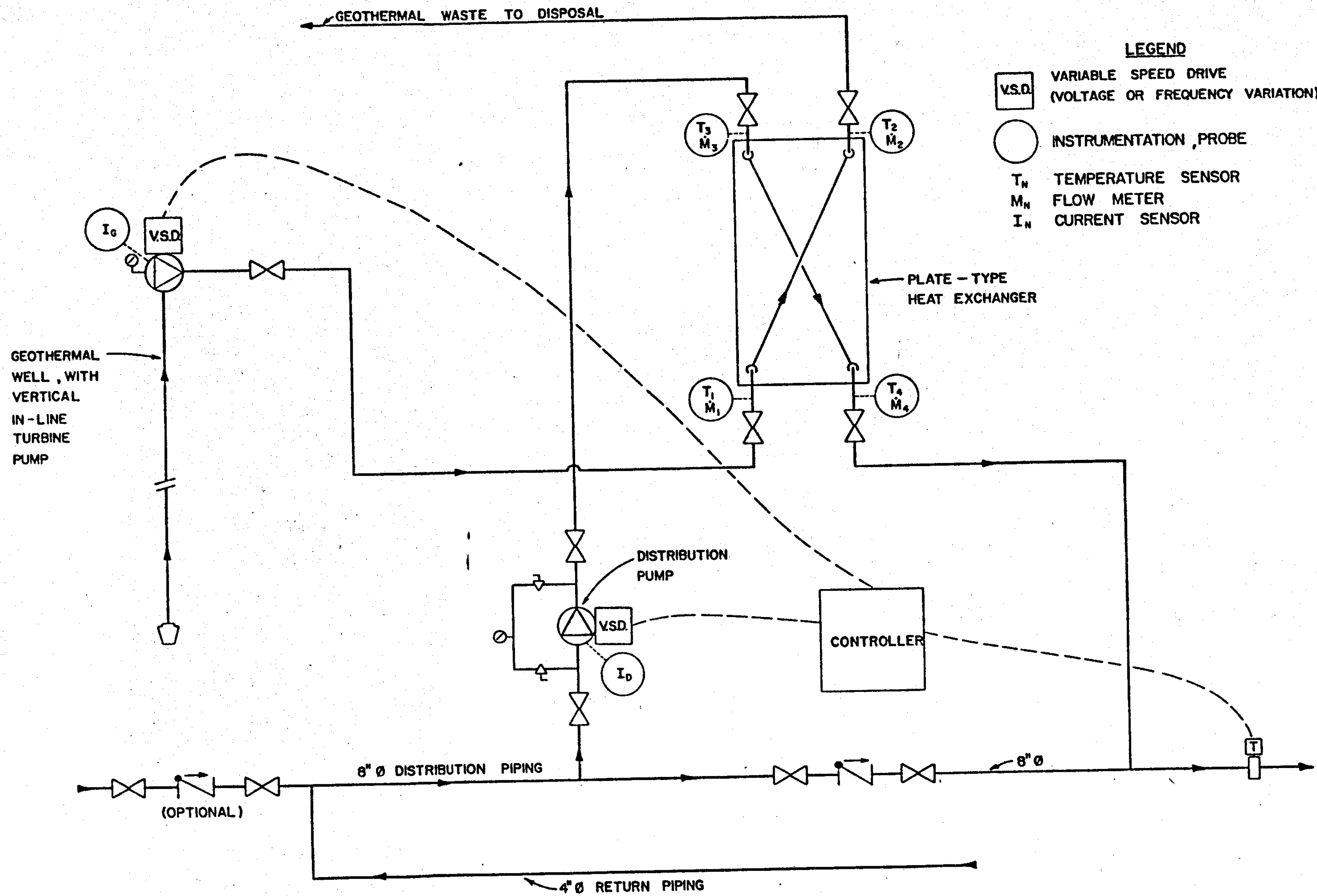
FIGURE 4.3 LAYOUT OF PROPOSED MAIN HEATING PLANT AND ADDED COMMUNITY PIPING FOR SUNRISE ADDITION SUBDIVISION

provide adequate water flow for fire protection throughout the community, and the return line must provide for the addition of make-up water needed to replace the water consumed at the houses. The check valves installed to accomplish these tasks and the location of the added main piping are shown in Figure 4.3, and in the detailed well head schematic and site plan of Figures 4.3.a and 4.3.b, respectively.

Adjacent houses in the community are paired for the two-house-loop system design and have a connecting pipe installed between them. In some cases a water supply or return line is installed to connect the house to the added main lines. This occurs only if the existing street-to-house line cannot be used. Since there is additional piping of some form connected to each house, there will be some trenching and back-filling of each yard. The proposed routing of the added piping at the houses is also shown in Figure 4.3.

4.2.4 Heat Pump Isolation Loop Component Selection and Flow Rate Determination

In order to analyze the heat pump isolation loop (Figure 4.1), thermal load data for the houses in the community are needed. The data set for a given residence indicates the size of water source heat pump package which must be used. For the sunrise addition subdivision (in which all houses are thermally similar), a heat pump which will deliver approximately 1.8 times the design thermal load of 19250 BTUH was chosen. This extra capacity ensures adequate heating and allows for a possible "cold-start" condition of the system. It also should prolong the life of the unit since continuous operation is not required. After considering several water-source heat pump packages capable of supplying the necessary heat output, the Friedrich model 803/804-024 unit was



WELL HEAD SCHEMATIC WITH PROPOSED INSTRUMENTATION POINTS FIGURE 4.3a

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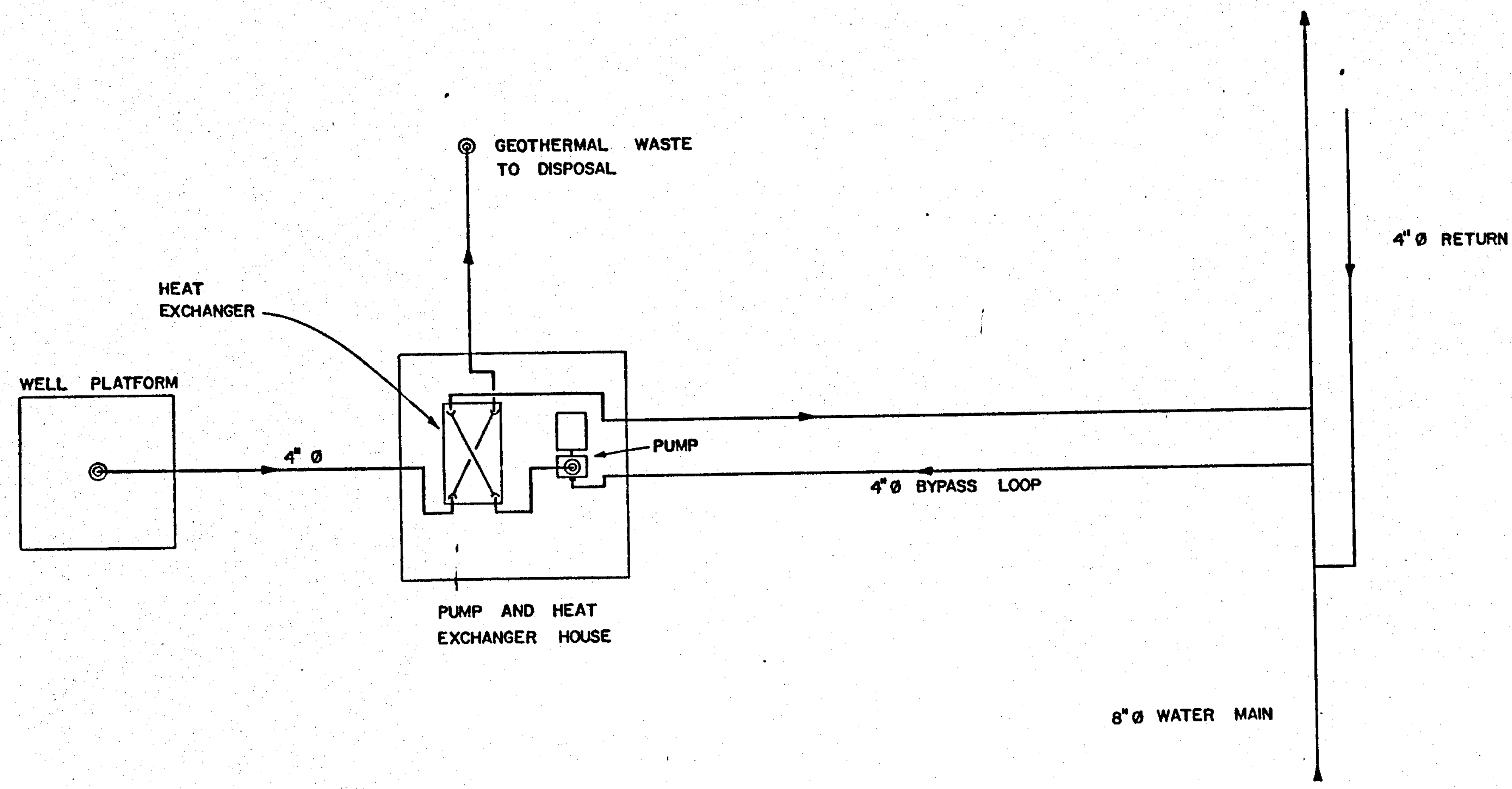

WELL HEAD SITE PLAN FIGURE 4.3b

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chosen because of its high coefficient of performance (COP) and low initial cost.

Having selected the heat pump package to be used, it is next necessary to choose the water-to-water plate-type heat exchanger which is the thermal interface between the potable water supply and the heat pump. Since the selected heat pump is designed for a water flow rate of 4 to 8 gallons per minute (GPM), a heat exchanger must be chosen which will deliver the heat pump's required heat of absorption (23000 to 28000 BTUH) in this flow range. Based on a hot side inlet water temperature of approximately 85°F and a cold side temperature drop of approximately 10°F (obtained from the heat pump performance curves) the Alfa-Laval type P01VL heat exchanger was chosen. This unit has stainless steel plates with an effective area of 4.5 square feet. Since the plates will not corrode, there will be minimal problems with contamination of the clean water supply, blockage of the fluid flow passages, or decreased unit heat transfer coefficient.

Determination of the isolation loop flow rate and selection of the circulating pump are possible once the heat pump and heat exchanger have been chosen. Expressions relating the pressure drop to fluid flow rate are obtained for the heat pump and the heat exchanger by a least squares fit of data obtained from the manufacturers. The pressure drop of the fluid flowing through the small amount of connecting piping is obtained from the Darcy-Weisbach equation

$$h_f = f \frac{L}{D} \frac{V^2}{2g} \tag{4-1}$$

which may be found in any introductory fluid mechanics text. The friction factor, f, in equation (1) is obtained using the Colebrook Equation

$$\frac{1}{\sqrt{f}} = -2 \log \left[\frac{\varepsilon}{3.7D} + \frac{2.51}{Re\sqrt{f}} \right] \tag{4-2}$$

assuming galvanized iron pipe is used having an equivalent sand roughness of 5×10^{-4} feet [1]. The curve representing the combined head requirement of the flow loop consisting of the heat pump, heat exchanger and connecting piping is plotted verses flow rate on a pump performance curve to determine the loop operating point. A Grundfos 1/20 horsepower pump model UP 25-42 SF was selected as the pump which delivers the required heat pump flow rate with a minimum power input. This pump in the isolation loop delivers approximately 10.6 feet of head at a flow rate of 5.25 GPM (see Figure 4.4). Knowing the exact isolation loop water flow rate, functions are obtained from the heat pump performance curves which relate COP, heat of absorption, heating capacity, required power input, and fluid temperature drop to the temperature of the water entering the heat pump. These expressions will be used in the thermal analysis of the heating system.

4.2.4.1 Two-House Loop Flow Determination

In order to analyze the overall community heating system, the flow rate in the two-house loop must be determined. The flow rate is chosen such that there is an approximate 5°F temperature drop across the heat exchanger. This choice ensures that the heat pump entering water temperatures for the two homes are close, and consequently the required power inputs do not vary significantly between the two adjacent houses.

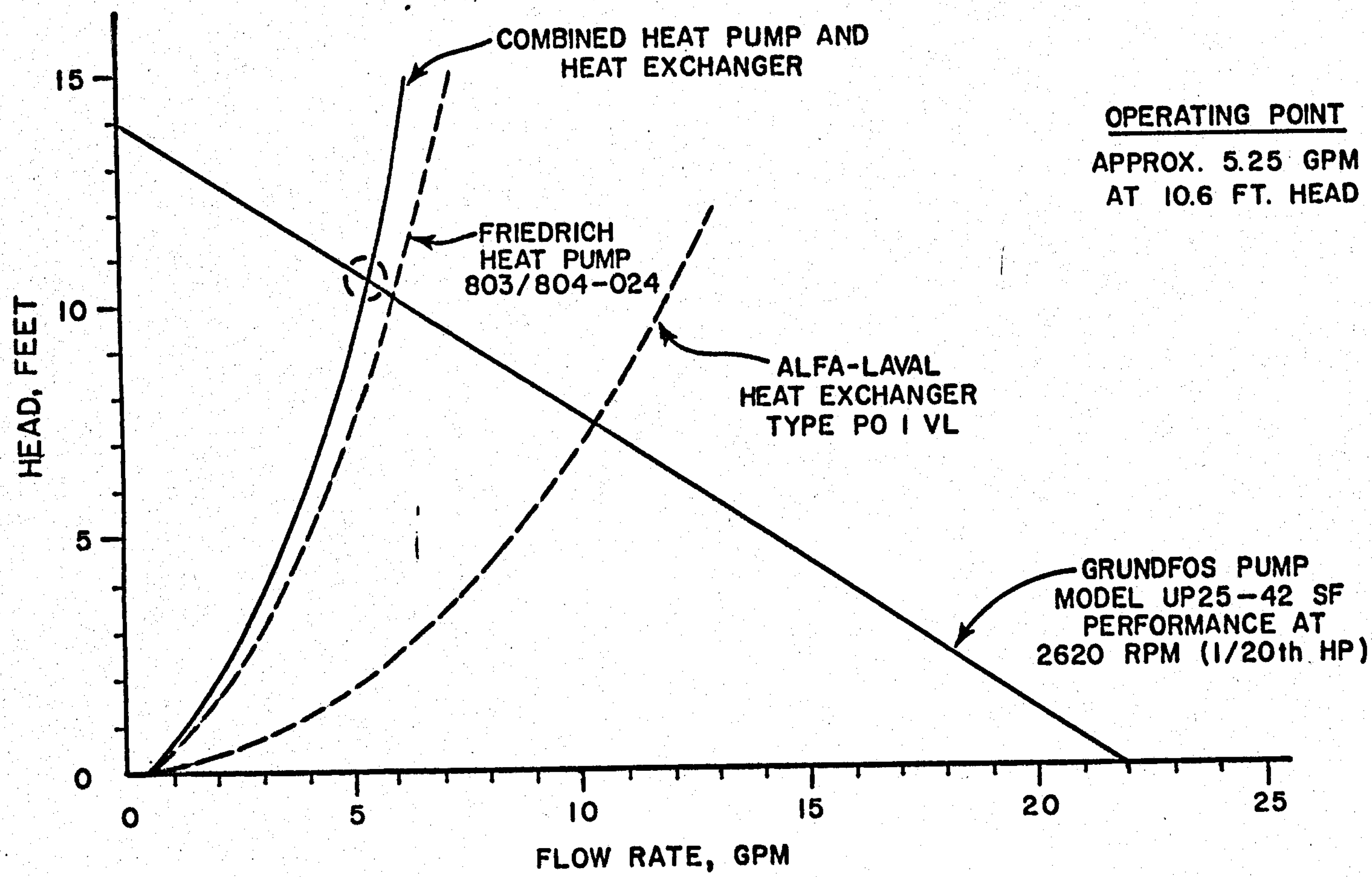

FIGURE 4.4 HEAT EXCHANGER WATER ISOLATION LOOP PUMP OPERATING POINT DETERMINATION CURVE

Since the flow rate in the heat pump isolation loop is known to be just over 5 GPM and there will be approximately 10°F temperature drop across the cold side of the heat exchanger, the two-house loop should have a flow rate of approximately 10 GPM.

The proposed piping layout of the two-house loop is shown in Figure 4.5. It is assumed that all the house-loops have the same number of pipe bends, valves, etc., with the only difference being the length of loop piping. The pressure drop across the various pipe fittings is found by the equivalent length method using

$$h_f = K \frac{V^2}{2g} \qquad (4\text{-}3)$$

and data in reference [2]. Assuming 1 inch diameter pipe fittings throughout, a value of 14.2 represents the total equivalent loss coefficient, K, for the pipe fittings in the two-house loop (see Appendix B). The expression relating the pressure drop across the heat exchanger as a function of flow rate will also be used for the loop analysis. The head loss through the loop piping will be computed using equations (4-1) and (4-2). For this analysis it is assumed that all loop piping is 1 inch diameter galvanized iron and the consumptive flow rate is zero so the loop flow is the same throughout. The loop is designed to have two circulating pumps (one per house) operating simultaneously. A computer program was written (see Appendix C) which computes the head required per pump for the loop at various flow rates. Values of the average length, the maximum length, and the minimum length of the loop piping in the community were used in the program. Plotting these results on circulating pump performance curves indicates an average, a maximum, and a

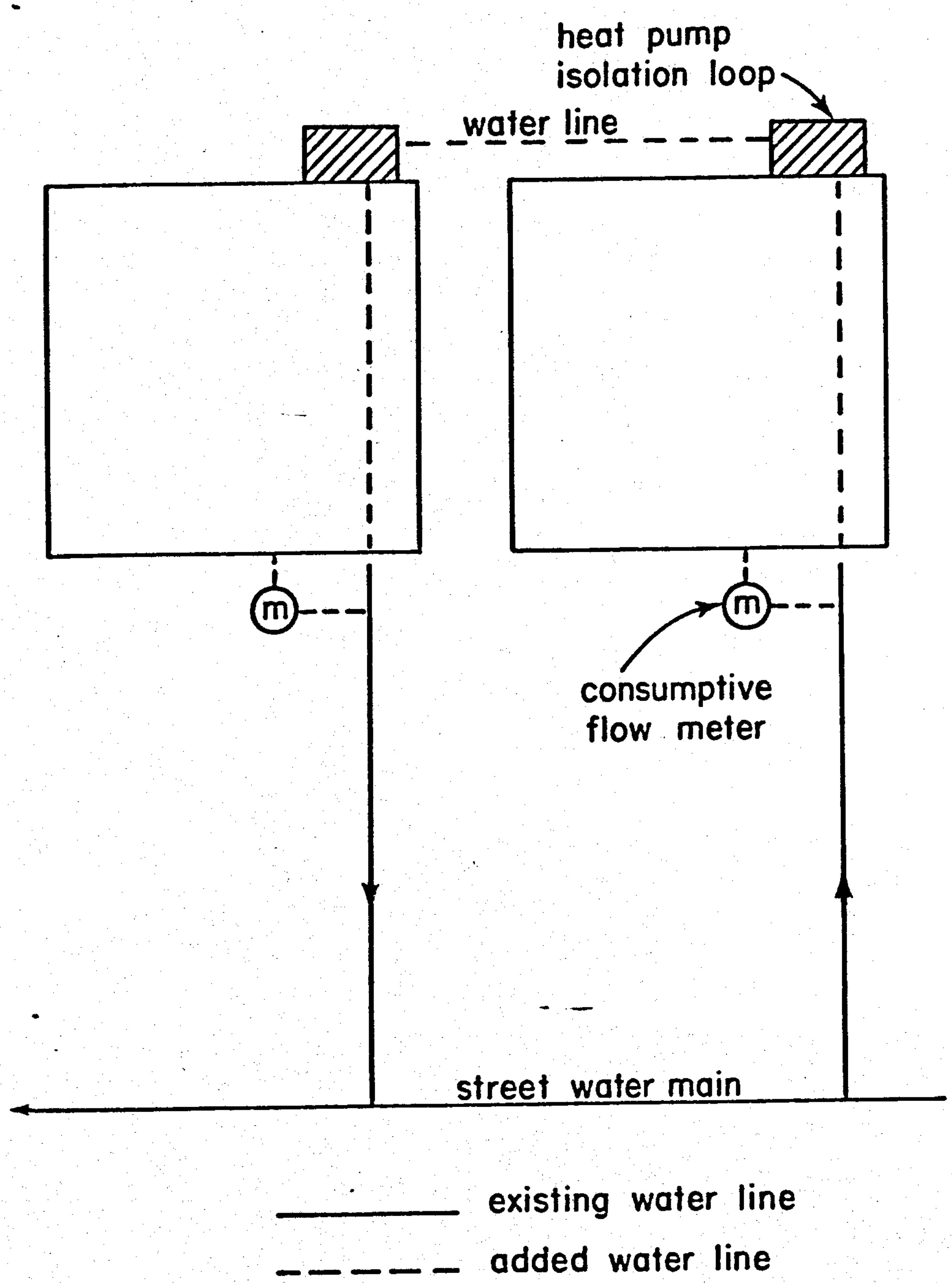

FIGURE 4.5 SCHEMATIC OF PROPOSED TWO-HOUSE LOOP WATER PIPING

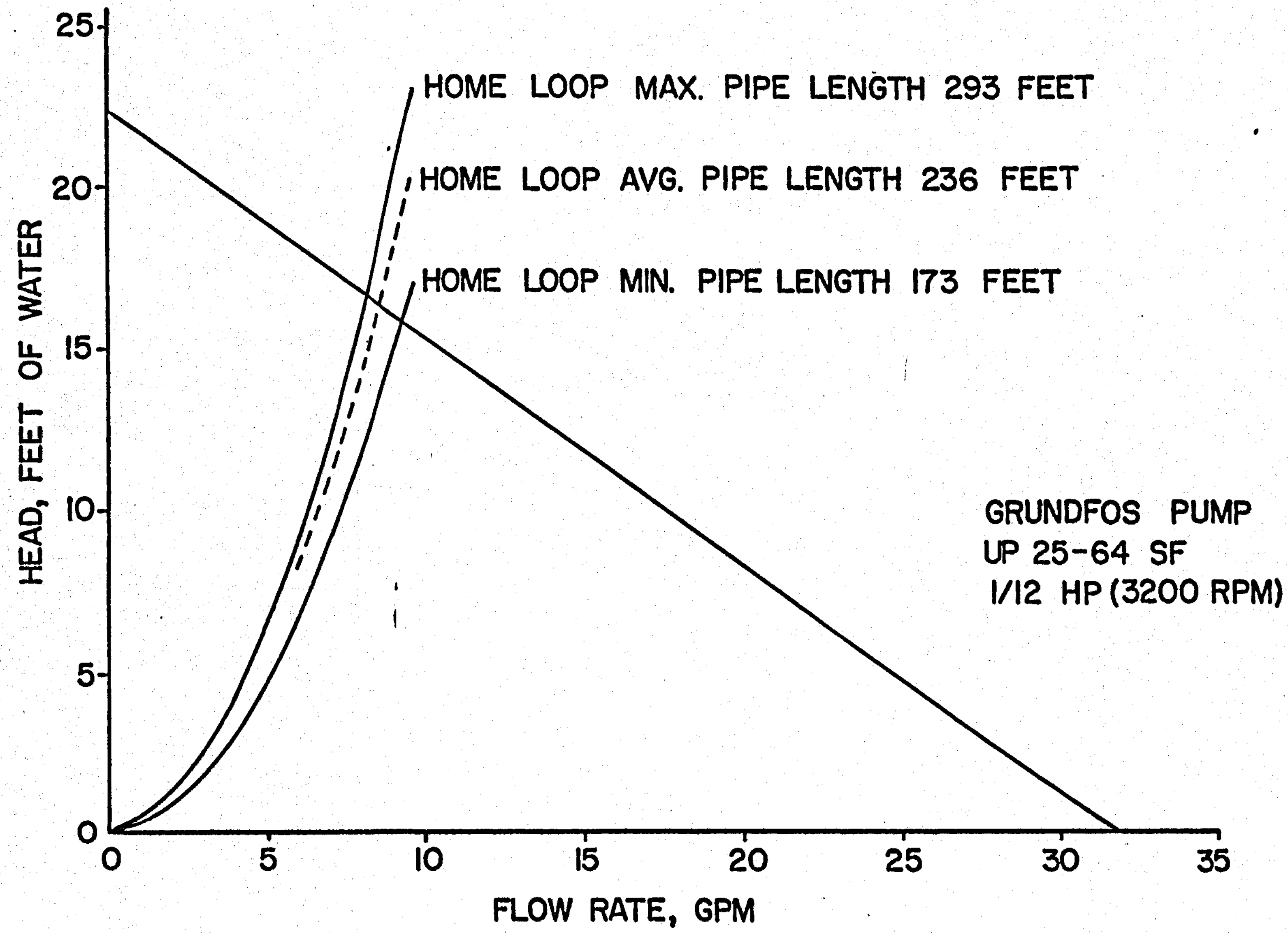

FIGURE 4.6 TWO-HOUSE LOOP WATER PUMP OPERATING POINT DETERMINATION CURVE

minimum loop operating point. In this manner, the Grundfos 1/12 horsepower pump model UP 25-64 SF was chosen as the pump which could deliver an adequate flow rate with minimum power required. Using this pump the average two-house loop flow rate is approximately 8.5 GPM (see Figure 4.6). Although the two-house loop flow varies slightly from loop to loop, this variation will not significantly affect system performance.

4.2.5 Computer Analysis of System

A computer program has been developed which completely analyzes the proposed district heating system. A listing of the program along with details of data input, a listing of program nomenclature, and a sample program output are included as Appendix D. The following information must be supplied to the program:

- detailed data on the proposed community piping system,
- performance characteristics of system components,
- average daily consumptive water flow for the houses,
- the consumptive flow factor (time average),
- the heating water flow per two-house loop,
- the community main piping flow factor,
- the initial supply water temperature,
- the ground surface temperature, and
- the soil thermal conductivity.

The program is designed to work its way step-by-step through the community piping network computing flow and thermal losses as well as the amount of heat delivered to each house. The frictional head loss for each pipe segment is calculated using equations (4-1) and (4-2). The frictional head loss across pipe fittings, valves, etc., is calcu-

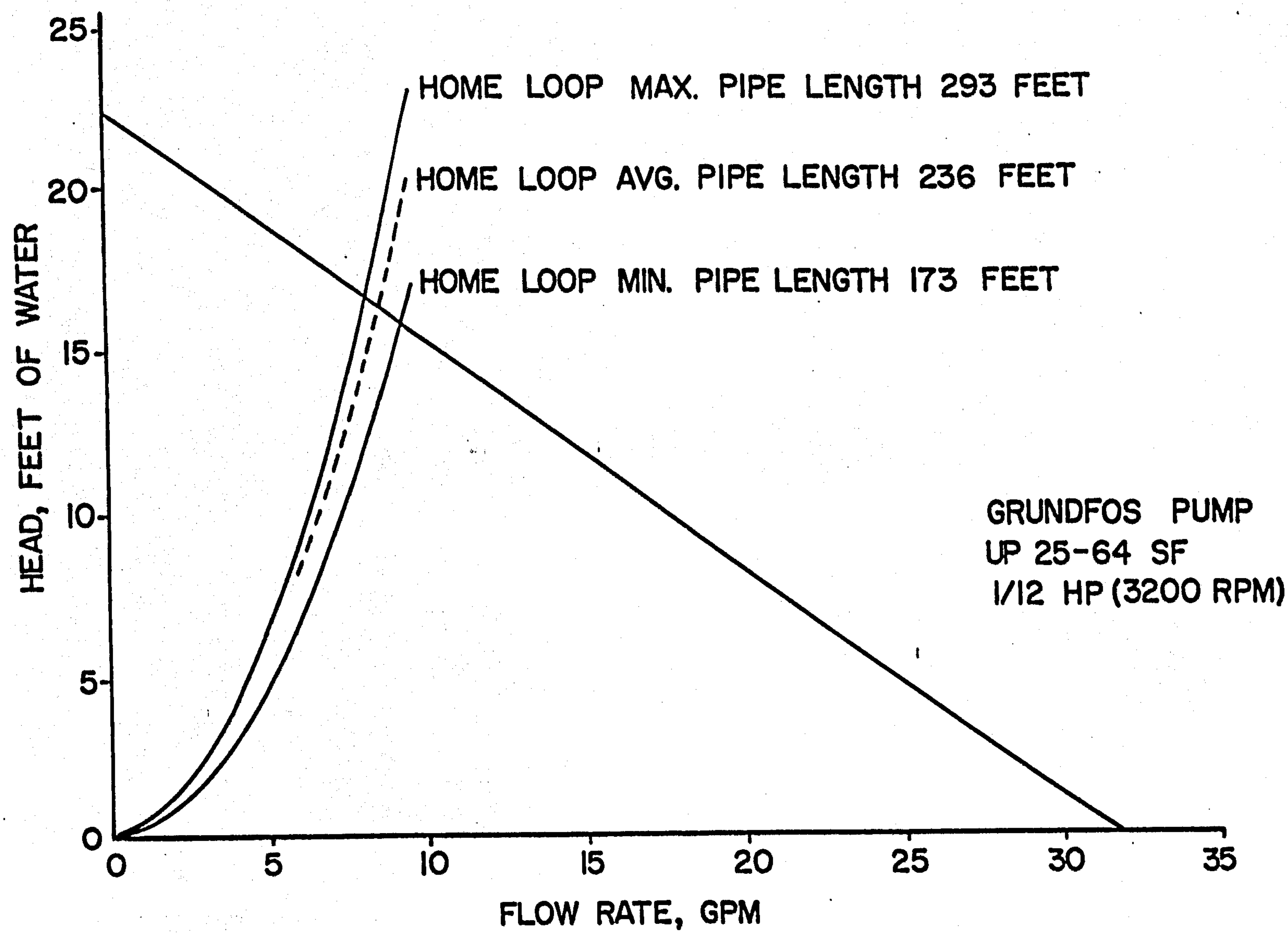

FIGURE 4.6 TWO-HOUSE LOOP WATER PUMP OPERATING POINT DETERMINATION CURVE

lated using equation (4-3) and data in [2]. The head loss across an abrupt pipe contraction or expansion is calculated from a least squares curve fit of data presented in [3]. The density and dynamic viscosity of water, which are used in the preceeding calculations, are obtained from least squares fit equations expressing them as functions of temperature based on data in [4]. The pressure drop across the house loop heat exchanger is calculated using the equation obtained from analysis of the manufacturer's data. The theoretical head loss through combining or dividing tees is obtained using equations from [5]. The sum of the required heads for all components, excluding the two-house loops, is used to determine the size of the community main flow pump. This total head will depend upon the community main piping flow factor and the size of the added main piping which will be considered in the section on system optimization.

The heat loss by conduction from the flowing fluid in the buried piping through the soil to the ground surface is calculated by the conduction shape factor method, i.e., from the equation

$$q = k_e \, S \, \Delta T \qquad (4\text{-}4)$$

where the shape factor for conduction through a homogeneous medium having constant thermal conductivity k_e between an isothermal surface and a horizontal cylinder of length L and diameter D buried with its axis a distance Z below the surface is

$$S = \frac{2\pi L}{\mathrm{Cosh}^{-1}(2Z/D)} \qquad (4\text{-}5)$$

according to [6]. This heat loss can also be expressed in terms of the fluid temperature drop for the pipe segment by

$$q = m \, C_p \, \Delta T_f \qquad (4\text{-}6)$$

where C_p for water is approximately 1 BTU/lbm°F. Equation (4-6) may be solved for the fluid temperature drop using equations (4-4) and (4-5) along with the definition of the inverse hyperbolic cosine resulting in

$$\Delta T_f = \frac{2\pi k_e L(T_1 - T_2)}{\rho Q \, Ln[(2Z/D) + \sqrt{(2Z/D)^2 - 1}]} \quad (4\text{-}7)$$

where the mass flow rate, m, has been expressed as the product ρQ. Since the conduction equation (4-4) for the buried pipe segment assumed a constant value of T_1 over the pipe length, a more accurate value of the heat loss is obtained if a new $\bar{T}_1$ is calculated as $t_i - \Delta T_f/2$. The new T_1 is used to calculate a new ΔT_f which is then used to find a new T_1. This process is repeated until successive values of ΔT_f agree within a specified amount. The frictional pumping power required to move the fluid through each pipe segment is assumed to be transformed into heat which is absorbed by the flowing fluid. This relatively small temperature increase is added back to the fluid exit temperature found by equation (4-7) for the pipe segment. The thermal loss by conduction from pipe fittings in the community is assumed to be negligible. However, the frictional heating effects are accounted for.

In the computer analysis the flow through each two-house loop is analyzed. For this analysis it is assumed that the flow rate in all two-house loops is the same. This flow rate has already been determined and is specified as part of the program input. Since the house loop pumps were chosen as part of the flow rate determination, the actual loop pumping power delivered is also known. The program, however, computes the theoretical pumping power required for each loop based on the specified flow rate. The primary function of the house loop analysis is to compute the thermal losses through the loop and determine the thermal operation of the heat pump isolation loop.

After computing the flow and thermal losses for the pipe from the street to the house, the consumptive flow of the first house is extracted. This flow rate is obtained by multiplying the consumptive flow factor by the average consumptive flow per house. The consumptive flow factor may be varied to model operation during various periods of water consumption. The heat loss due to water being consumed at the house is calculated by assuming a make-up water temperature of 40°F and using equation (4-6). The flow remaining after extraction of the consumptive flow for the first house is then passed through the heat exchanger of the heat pump isolation loop for that house.

The heat exchanger in the heat pump isolation loop shown in Figure 4.1 is a single pass, counterflow unit for which the heat transfer rate is given by

$$q = \xi C_{min} (T_{hi} - t_{ci}) \tag{4-8}$$

where the effectiveness obtained from [7] is

$$\xi = \frac{1-\exp[-NTU(1-C)]}{1-C\exp[-NTU(1-C)]} \tag{4-9}$$

The heat exchanger is the thermal interface between the potable water supply and the heat pump. Assuming there is negligible temperature loss in the lines connecting the heat pump and heat exchanger and that the pump does not significantly affect the fluid temperature, the outlet temperature of the heat exchanger cold side fluid, t_{co}, will be the heat pump entering water temperature. Similarly, the heat pump exiting water temperature will be the heat exchanger cold side fluid inlet temperature, t_{ci}. The temperature drop across the heat pump, or the heat exchanger cold side, is a function of the heat pump entering water temperature. The actual temperatures of the heat exchanger cold side fluid must be determined by trial and error.

At this point in the analysis both fluid flow rates and the hot side fluid inlet temperature, T_{hi}, are known for the heat exchanger. Assuming a value of t_{ci}, the heat exchanger heat transfer rate is determined using equations (4-8) and (4-9). This heat is transferred to the cold side fluid so t_{co} may be calculated from

$$q = C_{min} (t_{co}-t_{ci}) \qquad (4\text{-}10)$$

which is equation (4-6). The value of t_{co}, which is the heat pump entering water temperature, is used to calculate the temperature drop across the heat pump. Knowing the temperature drop, a new estimate of t_{ci} is obtained. This process is repeated until successive values of t_{ci} agree within a specified amount. The final value of t_{ci} is then used to find the actual heat pump entering water temperature which is used to determine the heat pump operation.

After determination of the operating data for the first house heat pump,the two-house loop analysis continues. The fluid temperature increase due to the power dissipated to overcome the pressure drop across the heat exchanger is added in, and then the pipe between the two houses is analyzed as previously outlined. The heat pump isolation loop at the second house is analyzed in the same manner as the isolation loop at the first house. Then the second house consumptive flow is extracted and the return pipe flow analyzed. This return flow is added to the street main flow and the temperature and flow effects computed. This two-house loop analysis is performed on all house loops in the community.

Simultaneous operation of all heat pumps in the community is not expected under normal conditions because of the excess capacity of each heat pump. An approximate heat pump capacity may be obtained once the temperature of the water leaving the main heating plant (community entering water temperature EWT) has been specified. (For the temperature range under consideration the heat pump will deliver approximately 35,000 BTUH.) The amount of heating required for each house is computed as 250 times the difference between the living space temperature and the ambient air temperature. An additional 30 percent of this amount is then added to compensate for air infiltration. Using the ratio of this total required heat load to the estimated heat pump capacity, the percentage of heat pump run time is obtained. Multiplying this percentage by the total number of houses in the community yields the average number of heat pumps which should be in operation at any given time. The program has the capability to randomly select which heat units are operating and which ones are not in operation using equal spacing between those units operating. The units in operation are then analyzed as previously described. The actual hourly power requirements for the heat pumps in operation are obtained by using the calculated percentage of run time (calculated using actual heat pump capacity) for each unit. This modified random selection method will more accurately model actual system performance.

Using the preceding outlined methods of analysis, the computer program will determine the operation of the entire community heating system subject to a specified set of conditions. Several of these conditions may be varied in order to determine the optimal system operating point. Details concerning these factors and the optimal system design will be presented in the section on system optimization.

4.3 System Optimization

At this point in the analysis all system components except the main flow pump, the main heat exchanger, and the added main piping have been selected. A system design optimization must be performed in order to choose these components. This optimization will be based upon system total cost which includes both initial cost and system operating cost. The design condition for the community at any given ambient air temperature will be for (1) the average number of heat pump units operating at any given time based upon the calculated percentage of run time for each unit, (2) all flow circulating pumps operating continuously, and (3) each house having the average consumptive water flow rate for the community. The design load condition for the community is for a -7°F ambient air temperature with the added constraint that the maximum variation in heat pump power input between any two houses cannot exceed 10 percent. At this ambient air temperature 22 of the 30 house heat pumps should be operating at any given time with each unit operating approximately 43 minutes out of each hour. Based upon the performance of the system at this maximum design condition, the final system components may be selected and the design completed.

4.3.1 Entering Water Temperature

First the temperature of the water being supplied to the community from the main heat exchanger (EWT) must be specified. Increased water temperature yields a higher heat pump COP and requires a lower water through-flow rate to prevent excessive water temperature degradation. Excessive water temperature, however, would create a need for some type of water cooling device at the houses for the consumptive flow. In order to avoid the need for a water coolng system, a maximum permissible system water temperature of 95°F (EWT) was chosen. At this temperature the water feels cool to the touch and should be acceptable to all residents of the community. Depending upon the available community heat source, a lower system operating temperature could be chosen.

4.3.2 Energy Analysis-Maximum Design Load

For this analysis EWT's of 90°F, 85°F, and 80°F were selected, and the computer program was run for several water flow rates at each of these temperatures coupled with a -7°F ambient air temperature. Although 95°F was chosen as the maximum permissible water temperature, it was assumed that the control equipment on the main flow pump would result in a ± 5°F temperature variation range. The computer runs for a 90°F EWT are assumed to be the minimum attained when an EWT of 95°F is desired. Multiple computer program runs were required in order to determine the flow rate necessary at each EWT to result in a heat pump power input variation of not more than 10 percent between any two units in the community. Figure 4.7 shows the resulting heat pump power requirements as a function of system flow rate for each EWT considered at the -7°F ambient air temperature design condition. Each plot presents the minimum, the average, and the maximum heat pump power input required in the community along with the 10 percent above minimum cutoff line for each EWT. It should be noted that while there is an

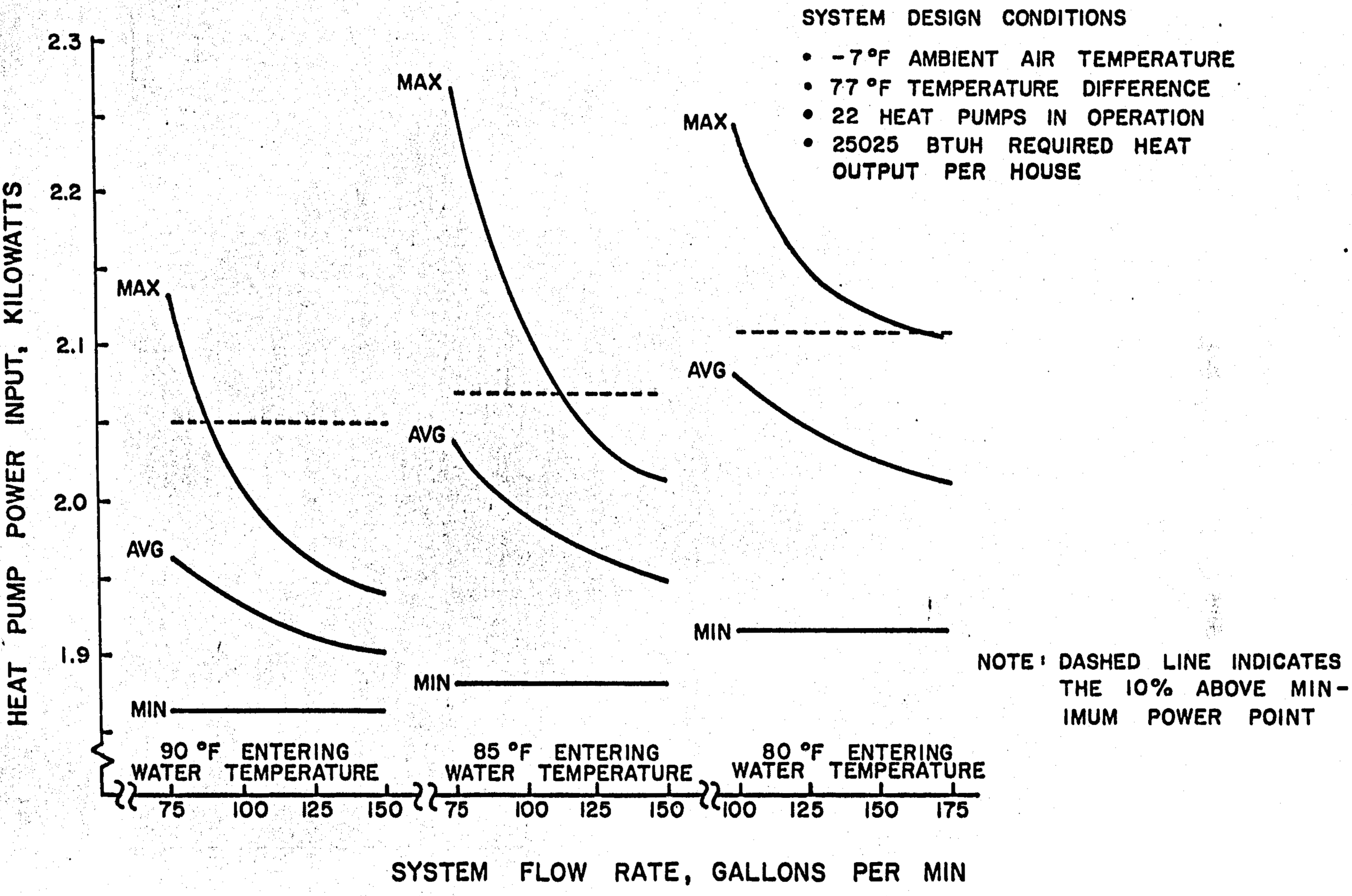

FIGURE 4.7 - HOUSE HEAT PUMP POWER REQUIREMENT AS A FUNCTION OF ENTERING WATER TEMPERATURE AND FLOW RATE FOR -7°F AMBIENT AIR TEMPERATURE

approximate 10 percent variation in average heat pump power input requirement for the 10°F EWT variation, the flow rate required to maintain the 10 percent limit between minimum and maximum heat pump power input varies from 88 to 166 GPM. It should be further noted that the minimum heat pump power input is independent of community water flow rate since this is the power required by the first house served by the water supply system, and the water temperature is essentially independent of flow rate at the first house in this community.

4.3.3 Energy Analysis-Average Design Load

The resulting flow requirement at the -7°F ambient air temperature design condition will be the maximum operating flow rate for the main flow pump. The pump is to be equipped with a variable speed drive such that at the high speed of the drive unit the maximum system flow rate will be attained. The mid-range of the pump operation was chosen to be the flow rate which will yield a 5 percent maximum variation between heat pump power inputs within the community for a 25°F ambient air temperature design condition. (This is the average January temperature in Elko for a typical year.) Once again the program was run at EWT's of 90°F, 85°F, and 80°F for various flow rates; however, the objective of this set of runs was to determine the flow requirement to result in a maximum variation between heat pump power inputs of 5 percent. The results are presented in Figure 4.8 using the same format as used in Figure 4.7. As in the previous runs, the required flow rate varies significantly with EWT while the average heat pump power input variation is approximately 10 percent for an EWT variation of 10°F; the required flow

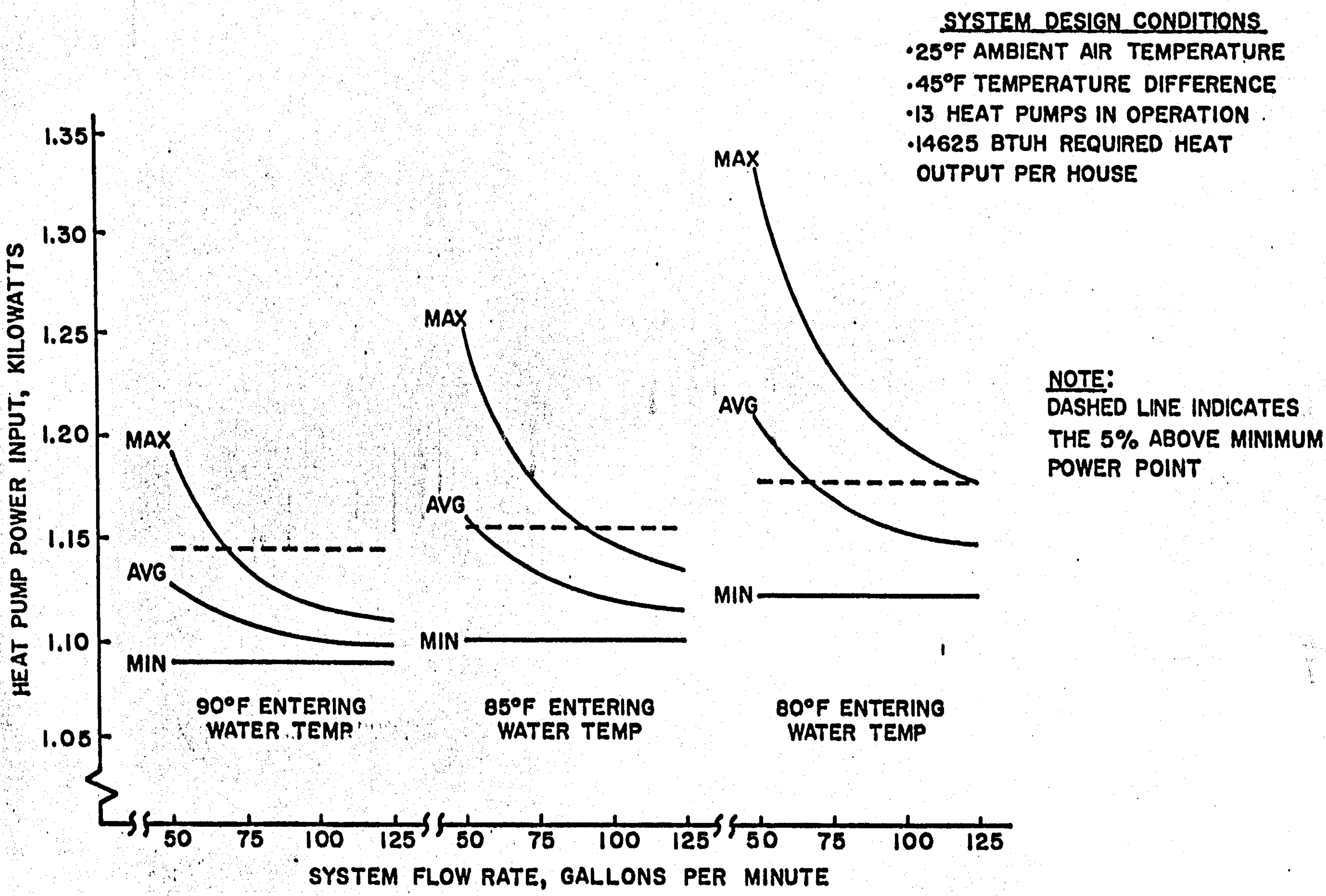

FIGURE 4.8 HOUSE HEAT PUMP POWER REQUIREMENT AS A FUNCTION OF ENTERING WATER TEMPERATURE AND FLOW RATE FOR 25°F AMBIENT AIR TEMPERATURE

rate at the 25°F ambient air temperature design condition ranges from 70 to 125 GPM.

4.3.4 Added Return Water Main Piping

Although the flow rate required to result in a particular heat pump performance level at a given set of temperatures is independent of the added return main piping size, the size of the main pump which can deliver this flow rate is very dependent upon the pipe size. Since the existing community water piping is 8-in.-diameter, the major portion of the main flow frictional losses will occur in the added main piping, which will be much smaller than 8-in.-diameter. The actual size of the added pipe must be chosen such that the needed flow rate may be obtained with minimum pumping power. The computer program was run for added main pipe sizes of 2-, 3-, and 4-in.-diameter at the flow rate needed to yield an approximate 5 percent maximum variation in heat pump power requirements for each of the three EWT's at the 25°F ambient air temperature design condition. The results of the computer program include the head required to pump the given flow rate through the community piping system for each of the different pipe sizes. (In the computer analysis the nominal pipe size was taken as the pipe inner diameter to allow for scale build-up in the pipe.) In order to obtain the total head which the pump must deliver, the head requirement of the main heat exchanger must also be determined at the needed flow rate.

For each EWT, a system flow rate was determined which would result in a 10 percent maximum variation in heat pump power input at the -7°F ambient air temperature design condition. This design condition corresponds to the maximum flow rate through the community and the maximum community design heat load. For the present analysis it is assumed that the geothermal well will supply adequate water flow at 120°F. Assuming that the temperature drop of the geothermal fluid and the temperature rise of the community water flow are both approximately 20°F, an appropriate water-to-water tube-and-shell heat exchanger was selected for the needed community flow rate at each system EWT for the -7°F ambient air temperature design condition. Having selected the heat exchanger, the head requirement of the heat exchanger at the flow rate corresponding to the mid-point of main pump operation (25°F ambient air temperature design condition) may be evaluated. Adding this head to that required for pumping through the community using various sizes of added piping results in a total head requirement for each pipe size (see Table 4.1).

Using the flow rate and the total head requirement for the different sizes of return pipe at each EWT, a pipe size was selected for each EWT which corresponds most closely with manufacturer's pump operating curves for the given flow rate. Having chosen a return pipe size, the system flow rate and total head requirement are known, and so a community main flow pump may be selected. The selection is made at the 25°F ambient air temperature design condition for pump operation at 1750 revolutions per minute (RPM). The main flow pump is to be equipped with a variable speed drive in the range of 1100 to 3000 RPM with the maximum system flow rate occurring in the upper end of the variable speed drive unit range. The size of motor required for the main flow pump is that which will allow the unit to deliver the flow rate necessary to result in a 10 percent maximum variation in heat pump power input at the -7°F ambient air temperature design condition. A pump motor is selected to deliver this required flow rate based upon the pump operation at the 1750 RPM selection point. (A sample pump operation calculation is included in Appendix E.) The resulting maximum speed of the pump at full power is then evaluated to ensure that it is below the upper limit of the variable speed drive unit. Since pump motors come in discrete horsepower (hp) increments, the actual maximum system flow rate will be somewhat greater than that required by the design condition. After the maximum system flow rate has been determined, the performance of the heat exchanger must be evaluated to ensure that the unit chosen is adequate. The minimum flow rate obtainable with the variable speed drive is calculated along with the corresponding minimum pump power requirement. The results of this analysis yield the optimal system components for each EWT. A summary of these results is presented in Table 4.1.

From the results presented in Table 4.1 it appears that the optimal system design will be that having the maximum value of EWT. Comparison of the 90°F EWT and 85°F EWT cases indicates that for each only the 3-in.-diameter added pipe corresponds with feasible pump performance curves. For the 2-in.-diameter added pipe subcase a pump could be chosen which would deliver the required head, but the necessary power input would be unreasonable. For the 4-in.-diameter added pipe subcase the required head at the desired flow rate is so small that no pump could be chosen. Comparison of these two EWT cases clearly shows the 90°F EWT case to be superior. Since each case requires the same size of added piping and the same main flow pump, the initial cost of these components will be the same for each case. The 85°F EWT case, however,

Table 4.1 Pumping Requirements and Component Selection

	Case 1			Case 2			Case 3		
System EWT, °F		90			85			80	
25°F Ambient Air Temp. Design Flow Rate, GPM		70			92			125	
Size of Added Pipe, in.-dia.	2	3	4	2	3	4	2	3	4
Approx. Head Req'd, Feet									
1. Main Piping System	150	17	3.5	280	26	6.5		51	12
2. Main Heat Exchanger	6	6	6	7	7	7		8.5	8.5
3. Total	156	23	9.5	287	33	13.5		59.5	20.5
Pump Model Selected (Bell & Gossett Series 1510)		1 1/2" AB			1 1/2" AB			1 1/2" BB	2" AB
Maximum System Flow Rate Req'd (-7°F), GPM		88			110			166	166
Pump Motor Size, hp		2			3			10	3
Max. Pump Speed, RPM		2385			2258			2515	2390
Max. System Flow Rate, GPM		95			119			180	171
Min. System Flow Rate, GPM		44			58			79	79
Min. Pump Power Input, hp		0.20			0.35			0.84	0.29
Heat Exchanger Selected (Bell & Gossett Type "WU")		WU105-4			WU106-4			WU125-4	

requires a larger pump motor and a larger heat exchanger than the 90°F EWT case. Also, the average heat pump power input requirement for the 85°F EWT case is greater than that for the 90°F EWT case. So, not only does the 85°F EWT case require greater initial capital expenditure than the 90°F EWT case, but it also requires greater operating power input. Clearly, the 90°F EWT case is superior to the 85°F EWT case.

For the 80°F EWT case either the 3- or 4-in.-diameter added pipe size appears to be feasible with only the 2-in.-diameter added pipe having an excessive head requirement for the desired flow rate. In order to determine which of the two feasible pipe sizes is to be used, the initial and operating costs of the associated components for each pipe size must be determined. However, it is clear that either pipe size selection for the 80°F EWT case will require a greater capital expenditure than either the 85°F EWT case or the 90°F EWT case since all the components for the 80°F EWT case are larger than those for either of the other two cases. Also, since at best the main pump motor for the 80°F EWT case is the same size as that for the 85°F EWT case while the average heat pump power input for the 80°F EWT case is considerably larger than that for the 85°F EWT case, the operating costs for the 80°F EWT case will be greater than the operating cost for either of the other two cases. Based upon these results, the 90°F EWT case with the added 3-in.-diameter main piping and associated components was selected.

4.3.5 System Water Flow Rate and Power Requirements

Since all the system components have been selected and the main flow entering water temperature chosen, the only variable remaining is the system water flow rate at a given ambient air temperature. The system water flow rate at any given ambient air temperature was selected as that which would yield a maximum heat pump power input variation of 5 percent between any two houses within the community. It is believed that this small amount of heat pump power input variation will ensure that all residents of the community will have similar electric power requirements. Figure 4.9 presents the results of multiple computer program runs to determine the flow rate at which the 5 percent power input variation occurs for ambient air temperatures in 5°F increments from 0°F to 65°F in addition to the -7°F maximum design condition[1]. The vertical lines in the figure indicate the 5 GPM flow range within which the 5 percent maximum power input variation occurs. The variation in average total power required per house in this 5 GPM flow range was found to be negligible for any given ambient air temperature. This indicates that a margin of at least 5 GPM may be allowed on the system flow rate without significantly affecting the average total power requirement per house. It should be noted that the system flow rate attainable is bounded by the limits on the main flow pump package (44 to 95 GPM). The results indicate that for ambient air temperatures below 10°F the pump will be operating at a maximum flow; for ambient air temperatures greater than 45°F the pump will be operating at minimum flow.

Listed just above each ambient air temperature in Figure 4.9 is the average number of heat pump units which should be in operation at any given time based upon the calculated percentage of run time for each unit. It should be noted that the worst possible operating condition

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1 The controls on the pump variable speed drive should be such that the system flow rate may be adjusted based upon ambient air temperature to obtain the flow rate corresponding to a maximum variation of 5 percent in heat pump power input.

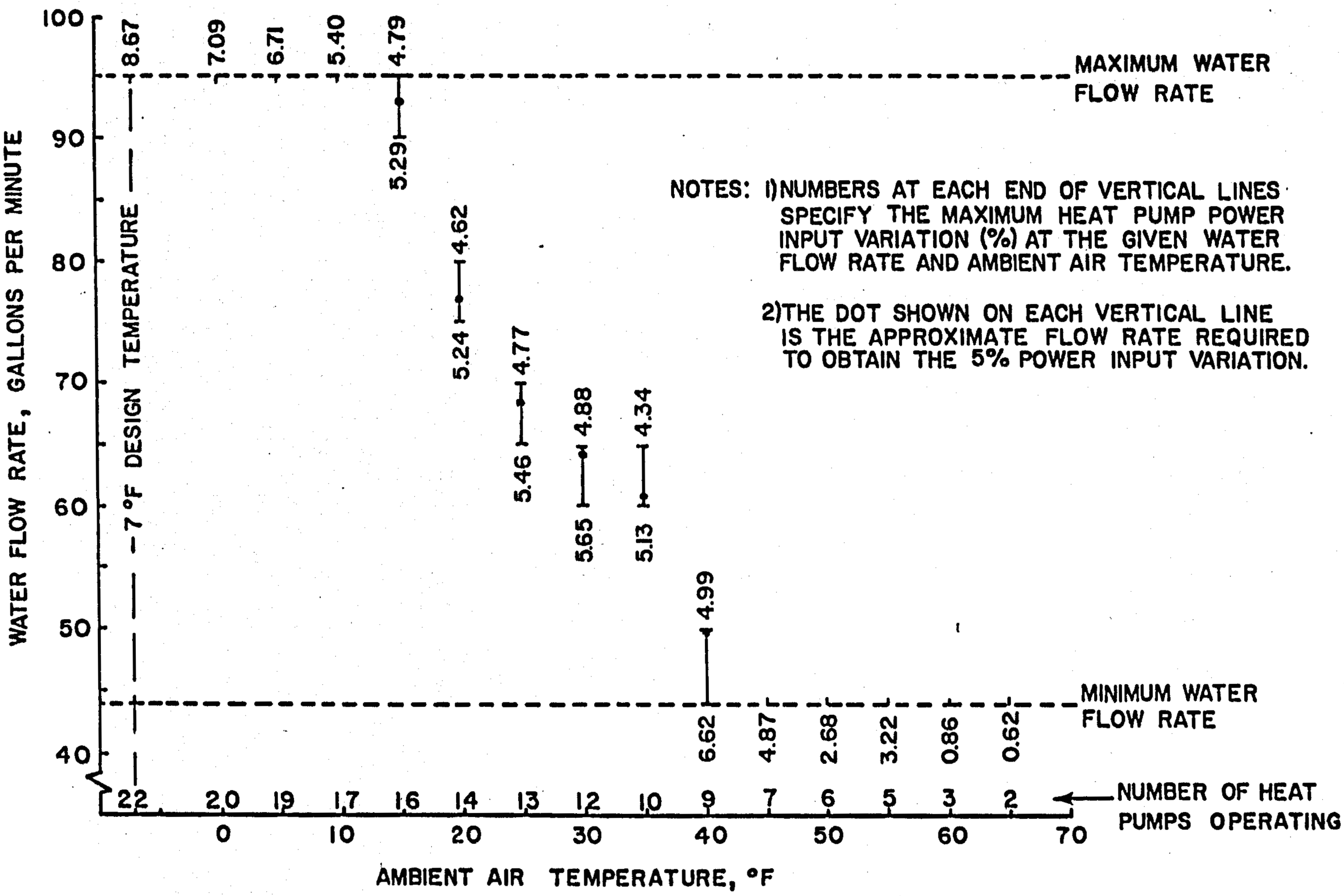

FIGURE 4.9 REQUIRED SYSTEM WATER FLOW RATE AS A FUNCTION OF AMBIENT AIR TEMPERATURE TO YIELD A MAXIMUM HEAT PUMP INPUT POWER VARIATION OF FIVE PERCENT

for the proposed system would be at the -7°F ambient air temperature design condition with all heat pump units operating simultaneously. At this maximum flow condition the maximum variation in heat pump power input throughout the community is 18.55 percent. Only after a prolonged electrical power outage when all units would start up simultaneously should this condition exist.

A plot of the total average hourly power required per house is presented versus ambient air temperature in Figure 4.10. These power values are based upon system performance at the water flow rate at each ambient air temperature which corresponds to the approximate 5 percent maximum variation in heat pump power input, or the flow rate corresponding to the limit of main flow pump operation (either maximum or minimum). The total average power required per house is a sum of the average heat pump power input per house (with the average number of heat pump units in operation at any given time), the per house actual power input to the main flow pump, the power requirement of the heat pump isolation loop pump (1/20 hp), and the power requirement of one of the two-house loop circulating pumps (1/12 hp). (For the worst possible operating condition described in the preceding paragraph the total average power required per house is 2.12 kilowatts.) Since the plot in Figure 4.10 is very nearly linear, a mathematical expression relating the total average hourly energy input required per house to the ambient air temperature may easily be obtained. This expression is used to obtain the total average hourly energy input required per house at any given ambient air temperature.

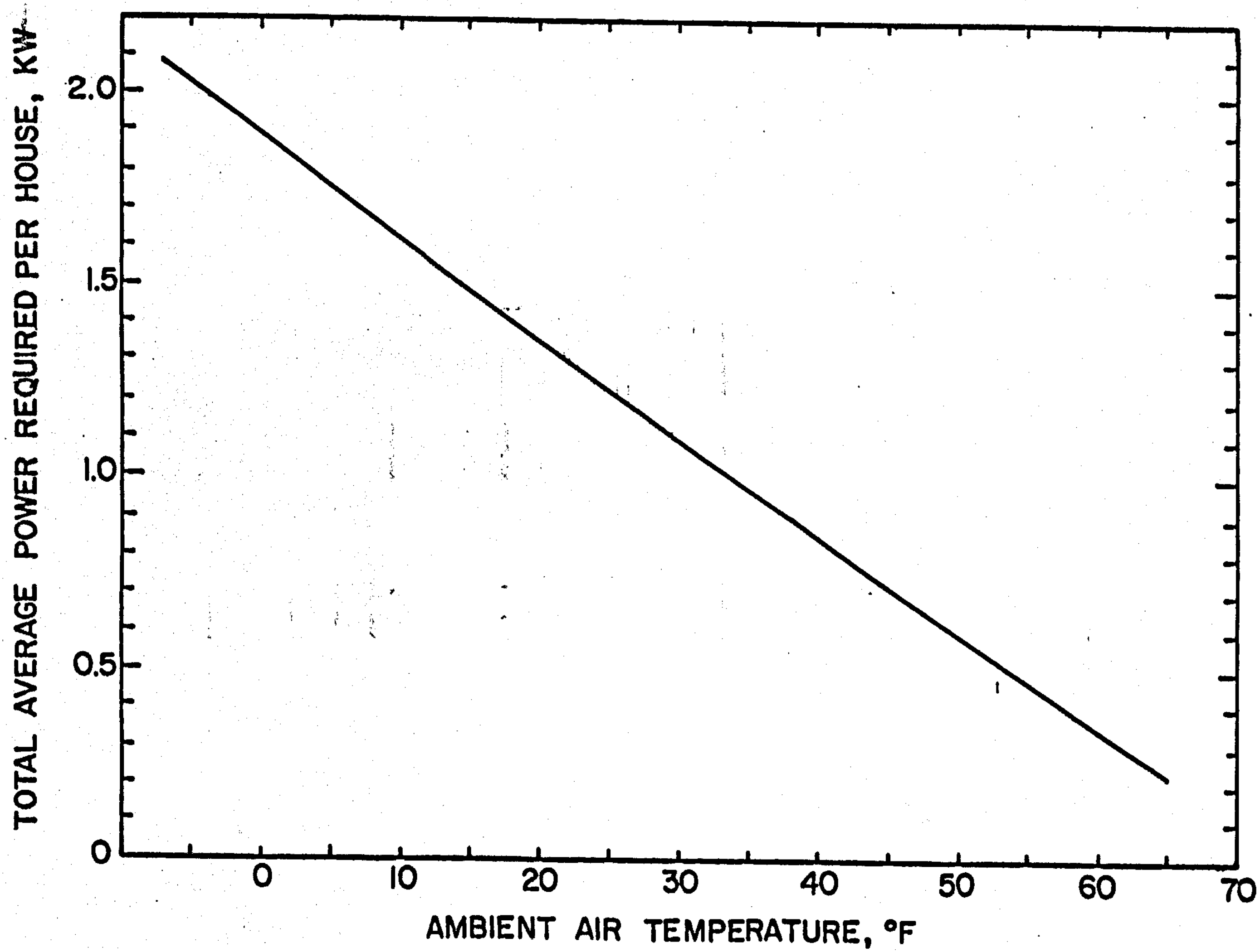

FIGURE 4.10 TOTAL AVERAGE ELECTRIC POWER PER HOUSE AS A FUNCTION OF AMBIENT AIR TEMPERATURE

4.4 List of References (Chapter 4)

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4.5 Nomenclature (Chapter 4)

C heat capacity ratio of heat exchanger fluids (minimum/maximum)

C_{min} minimum heat capacity of heat exchanger fluids, BTU/hr-°F

C_p specific heat of water, BTU/lbm-°F

D nominal pipe diameter, inches

f pipe friction factor

g local acceleration of gravity, ft/sec^2

h_f frictional head loss, feet

K loss coefficient for flow through fittings

k_e soil thermal conductivity, BTU/hr-ft-°F

L length of pipe segment, feet

$\dot{m}$ water mass flow rate, lbm/hr

NTU number of heat transfer units

Q water flow rate, ft^3/hr

Re Reynolds number based on pipe diameter

S conduction shape factor

ΔT temperature difference between T_1 and T_2, °F

ΔT_f fluid temperature drop, °F

T_1 temperature of surface of pipe, °F

T_2 ambient air temperature (ground surface), °F

T_{hi} heat exchanger hot side fluid inlet temperature, °F

T_{ho} heat exchanger hot side fluid outlet temperature, °F

t_{ci} heat exchanger cold side fluid inlet temperature, °F

t_{co} heat exchanger cold side fluid outlet temperature, °F

t_i temperature of water entering pipe segment, °F

V	fluid velocity in pipe segment, ft/sec
Z	buried depth of pipe centerline, feet
π	constant, 3.1415926
ε	equivalent sand roughness of pipe, feet
ξ	heat exchanger effectiveness
ρ	density of water, lbm/ft^3

5. ECONOMIC ANALYSIS

5.1 General Approach

The first step in performing the economic analysis of the proposed system is to determine the system operating cost for a typical year. Annual weather summary data obtained from the National Oceanic and Atmospheric Administration (NOAA) indicate that the average number of heating degree-days per year for Elko, Nevada, during the last 20 years is approximately 7112, and the year 1975-1976 with 7166 heating degree-days is a recent year having heating requirements close to this average value. Using monthly averaged daily temperature profiles for the year July 1975 through June 1976, the required heat load for a typical year may be calculated. Using this heating load, the energy requirements of the proposed heating system, as well as that for the existing electric baseboard heaters, may be determined. By comparing the energy required for the proposed system with the energy required for the existing electric baseboard heating system, the average yearly energy saving obtainable with the proposed system may be determined.

5.2 Annual Operational Cost

In order to determine the performance of the proposed system during a typical year, the performance at several ambient air temperatures must be evaluated. Detailed NOAA data for Elko were obtained for the year July 1975 through June 1976: these data include the daily ambient air temperature at three-hour intervals for each month. Using these, an average daily temperature profile for each month was obtained. Assuming that each three-hour temperature data point represents the mean temperature during the associated three-hour time period, the required heat load per house during each three-hour time period of the average day in each month was calculated. Summing these three-hour incremental energy requirements for the average day in each month yields the average daily energy required per house. Since the existing electric baseboard heaters in each house are assumed to be 100 percent efficient, the required heat load per house will also be the energy required to operate the existing heating system. The total average energy presently required per house for each month is obtained by multiplying the average daily energy requirement by the number of days in the corresponding month. Summing these monthly totals, the total average yearly energy requirement for the existing heating system during the typical year considered is approximately 20,866 kilowatt hours (kW-h) per house.

By a similar procedure, the total average yearly energy requirement for the proposed system was calculated. Table 5.1 presents the total average hourly energy requirement for the proposed system as a function of ambient air temperature. Again using the NOAA data for the year July 1975 through June 1976 and assuming that each three-hour temperature data point represents the mean temperature during the associated three-hour time period, the required energy input per house using the proposed system was calculated for each three-hour increment of the average day for each month. Summing these incremental results yields the average daily energy requirement for each month. Multiplying each month's average daily energy requirement by the number of days in that month and summing the resulting monthly totals yields a total average yearly energy requirement of 6,219 kW-h for the proposed system. Comparing this result with the energy required by the existing heating system

Table 5.1 Energy Requirements of the Proposed System for a Typical Year

Hour	July 1975 Ambient Air Temperature °F	July 1975 Required Heat Load per House kwh	July 1975 Proposed System Energy Input kwh	August 1975 Ambient Air Temperature °F	August 1975 Required Heat Load per House kwh	August 1975 Proposed System Energy Input kwh	September 1975 Ambient Air Temperature °F	September 1975 Required Heat Load per House kwh	September 1975 Proposed System Energy Input kwh	October 1975 Ambient Air Temperature °F	October 1975 Required Heat Load per House kwh	October 1975 Proposed System Energy Input kwh	November 1975 Ambient Air Temperature °F	November 1975 Required Heat Load per House kwh	November 1975 Proposed System Energy Input kwh	December 1975 Ambient Air Temperature °F	December 1975 Required Heat Load per House kwh	December 1975 Proposed System Energy Input kwh
01	61	2.58	0.96	52	5.13	1.62	44	7.44	2.22	39	8.85	2.61	26	12.57	3.63	25	12.87	3.69
04	55	4.29	1.41	47	6.57	2.01	39	8.85	2.61	35	9.99	2.91	25	12.87	3.69	23	13.44	3.87
07	66	1.14	0.60	55	4.29	1.41	46	6.87	2.07	35	9.99	2.91	24	13.14	3.78	22	13.71	3.93
10	81	-	-	73	-	-	68	0.57	0.48	50	5.70	1.77	35	9.99	2.91	31	11.13	3.24
13	88	-	-	81	-	-	79	-	-	58	3.42	1.20	43	7.71	2.31	39	8.85	2.61
16	86	-	-	83	-	-	78	-	-	58	3.42	1.20	43	7.71	2.31	38	9.15	2.70
19	79	-	-	72	-	-	62	2.28	0.90	46	6.87	2.07	32	10.86	3.15	28	12.00	3.48
22	68	0.57	0.48	59	3.15	1.11	51	5.43	1.71	41	8.28	2.46	29	11.70	3.39	25	12.87	3.69
Daily Total	(31)	8.58	3.45	(31)	19.14	6.15	(30)	31.44	9.99	(31)	56.52	17.13	(30)	86.55	25.15	(31)	94.02	27.21
Monthly Total		266	107		593	191		943	300		1752	531		2597	755		2915	844

Hour	January 1976 Ambient Air Temperature °F	January 1976 Required Heat Load per House kwh	January 1976 Proposed System Energy Input kwh	February 1976 Ambient Air Temperature °F	February 1976 Required Heat Load per House kwh	February 1976 Proposed System Energy Input kwh	March 1976 Ambient Air Temperature °F	March 1976 Required Heat Load per House kwh	March 1976 Proposed System Energy Input kwh	April 1976 Ambient Air Temperature °F	April 1976 Required Heat Load per House kwh	April 1976 Proposed System Energy Input kwh	May 1976 Ambient Air Temperature °F	May 1976 Required Heat Load per House kwh	May 1976 Proposed System Energy Input kwh	June 1976 Ambient Air Temperature °F	June 1976 Required Heat Load per House kwh	June 1976 Proposed System Energy Input kwh
01	19	14.58	4.17	27	12.27	3.54	25	12.87	3.69	35	9.99	2.90	45	7.14	2.16	48	6.30	1.92
04	17	15.15	4.32	26	12.57	3.63	23	13.44	3.87	30	11.43	3.30	40	8.58	2.55	42	8.01	2.40
07	17	15.15	4.32	25	12.87	3.69	25	12.87	3.69	36	9.72	2.85	50	5.70	1.77	55	4.29	1.41
10	26	12.57	3.63	34	10.29	3.00	38	9.15	2.70	48	6.30	1.92	65	1.44	0.69	69	0.30	0.39
13	35	9.99	2.91	40	8.58	2.55	45	7.14	2.16	53	4.86	1.56	71	-	-	76	-	-
16	37	9.42	2.76	42	8.01	2.40	46	6.87	2.07	54	4.56	1.47	71	-	-	76	-	-
19	27	12.27	3.54	33	10.56	3.09	36	9.72	2.85	46	6.87	2.07	63	2.01	0.84	70	-	-
22	22	13.71	3.93	30	11.43	3.30	29	11.70	3.39	40	8.58	2.55	51	5.43	1.71	55	4.29	1.41
Daily Total	(31)	102.84	29.58	(29)	86.58	25.20	(31)	83.76	24.42	(30)	62.31	18.63	(31)	30.30	9.72	(30)	23.19	7.53
Monthly Total		3188	917		2511	731		2597	757		1869	559		939	301		696	266

indicates that the proposed system would enable the residents of the community to realize an energy savings of approximately 14,647 kW-h per year per house. Since the energy required by the existing heating system corresponds to the amount of heat delivered by the proposed system, the proposed system has an effective COP of 3.36 (energy output/ energy input). Although the COP of the proposed system is high, the feasibility of applying this design must be determined based upon system costs.

5.3 Annual Savings

The proposed system would enable the residents of the Sunrise Addition subdivision to realize a yearly energy savings of 14,647 kW-h per house. Residents of this community currently have very inexpensive electric power rates, a situation that is to change drastically in the near future. The present electrical power distribution system serving this area has become obsolete and is scheduled to be replaced within the next two years. The new distribution system will be serviced by Sierra Pacific which plans to impose uniform rates statewide and currently (Sept., 1980) charges residents of Reno, Nevada, 7.52 cents per kW-h. It is inevitable that the residents of Elko will soon be charged this same amount. At this present energy rate of 7.52 cents per kW-h, the proposed system could save each house in the Sunrise Addition approximately $1,101.45 (1980 dollars) per year in electrical power costs. (Based upon a national average electrical power rate of 4.5 cents per kW-h, the proposed system could save each house owner approximately $659.12 per year.)

5.4 Capital Cost

In order to determine the payback period for the proposed system, the total initial cost must be determined. A detailed listing of the proposed system components and their approximate costs is presented in Appendix F. For the proposed system a single geothermal well would be the heat source. The cost factors for the community are grouped into three categories: (1) the geothermal well and wellhead facility, (2) the community added main piping and heating plant, and (3) the two-house loop component costs per house. A well and wellhead facility up to the main community heat exchanger which could supply adequate water flow at 120°F will cost approximately $29,900, assuming that the well is very close to the community main heating plant. The total cost of the components needed for the main heating plant and the components of the added community main piping is approximately $40,600. The total cost of the components necessary to form the two-house loop system design is approximately $4,800 per house[1] or a total of approximately $144,600 for the entire community. Summing these costs yields a total initial capital cost of approximately $215,000. Allowing 6 percent of this amount for engineering costs results in a total adjusted initial system cost of approximately $228,000 or $7,600 per house.

5.5 Payback Period

In order to determine the feasibility of the proposed system design, it is advantageous to examine the length of time required for the energy savings of the proposed system to offset the initial system cost. Assuming a yearly maintenance cost of approximately 0.5 percent of the initial system cost (in 1980 dollars), the yearly savings at the

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1. It should be noted that the two-house loop costs could possibly be reduced by as much as $700 per house by using a tube-and-shell heat exchanger in the heat pump isolation loop and by buying the house-loop components in quantity from a single supplier.

current energy rate ($1,101.45 per house) less the yearly maintenance cost ($38.00 per house) yields a net yearly savings of $1,063.45 per house for the proposed system. The savings realizable by the proposed system during a given year will be the net yearly savings (in 1980 dollars) projected to the year in question using the anticipated energy escalation rate. The present worth of each of these yearly savings may then be determined using the interest rate on borrowed money. The payback period will be the time required for the sum of the present worths of the yearly energy savings to equal the initial system cost of $7,600 per house. Table 5.2 presents the payback period (in years) of the proposed system as a function of energy escalation rate and the interest rate on borrowed money for a current energy cost of 7.52 cents per kW-h. This analysis assumes that the energy escalation rate remains constant over the time period in question. Details of the payback period calculations are included in Appendix E. For the case when the energy escalation rate equals the interest rate on borrowed money, the payback period may be found by direct division to be just over 7 years (for a current energy rate of 4.5 cents per kW-h a payback period of just over 12 years is obtained).

Table 5.2 System Payback Period

Annual energy cost escalation rate, percent	Annually compounded interest rate on borrowed money, percent: 5	6	7	8	9	10	11	12	13	14	15
5	7.1	7.4	7.7	8.1	8.5	8.9	9.4	10.0	10.7	11.5	12.5
6	6.9	7.1	7.4	7.7	8.1	8.4	8.9	9.4	10.0	10.6	11.4
7	6.6	6.9	7.1	7.4	7.7	8.1	8.5	8.9	9.4	9.9	10.6
8	6.4	6.6	6.9	7.1	7.4	7.7	8.1	8.4	8.9	9.3	9.9
9	6.2	6.4	6.6	6.9	7.1	7.4	7.7	8.1	8.4	8.8	9.3
10	6.0	6.2	6.4	6.6	6.9	7.1	7.4	7.7	8.0	8.4	8.8
11	5.9	6.0	6.2	6.4	6.7	6.9	7.1	7.4	7.7	8.0	8.4
12	5.7	5.9	6.0	6.2	6.4	6.7	6.9	7.1	7.4	7.7	8.0
13	5.6	5.7	5.9	6.1	6.3	6.4	6.7	6.9	7.1	7.4	7.7
14	5.4	5.6	5.7	5.9	6.1	6.3	6.5	6.7	6.9	7.1	7.4
15	5.3	5.4	5.6	5.7	5.9	6.1	6.3	6.5	6.7	6.9	7.1

6. ENVIRONMENTAL ANALYSIS

The following material provides a summary of the existing environment in which the project will be carried out. Special attention is paid to the aquatic environment since we feel it may be the most sensitive in terms of potential impacts, both beneficial and adverse.

A description of the human environment along with land use patterns, site history, and archeology is included to complete the definition of the existing environment. Potential environmental impacts are described in Section 6.3. Requirements for effluent and environmental monitoring programs are discussed in Section 6.4 and a statement on restoration is provided in Section 6.5.

6.1 Existing Conditions

Baseline data sample points are available both upstream and downstream from the Elko sewage treatment plant. The flow of the river during mid August, 1979, was well under 10 cubic feet per second, compared to the June flow of approximately 800 cubic feet per second. By the end of August, several areas of the river within the region of Elko were dry.

In the August, 1979, study, major differences were apparent in the liminological characteristics of the river upstream and downstream from the sewage treatment plant. Upstream from the sewage treatment plant Humboldt River plankton during the low water/high temperature/slower current stages of the river were probably produced endogenously; the primary substrates for production were algae masses in static water (primarily Spirogyra) or attached to rocks (primarily Cladophora). The major changes in river organisms in August compared to June can be attributed to reduced current rates which allow algae to gain a foothold on substrates, and which decrease water turbidity to allow sunlight to reach the bottom; and higher water temperatures which cause increased growth and reproductive rates.

The low water levels during August exposed bottom environments of mud or coarse sand in places, and in many places, rocks. Rock bottoms were usually productive; sand and mud bottoms were almost uniformly negative. Two general types of habitats were examined: lotic or running water habitats which exhibited different characteristics compared to static water habitats. Both habitat types were moderately productive for several types of macro-organisms, mostly immature insects: caddisfly larvae, mayfly nymphs, dipteran larvae, and beetle larvae. Caddisfly larvae which require well aerated water were found in abundance in lotic situations, but greatly reduced in number or absent in static water. Mayfly nymphs were found in both situations. Dipteran larvae were mostly confined to static water.

Among the micro-organisms associated with bottom conditions were many which are normally found associated with filamentous algae or with stagnant situations. They included diatoms, protozoans, rotifers, gastrotrichs, a few roundworms, several forms of algae, and a few micro-crustaceans. A greater variety and abundance of micro-organisms was found in static water compared to lotic water.

The river takes on different biological characteristics downstream from the sewage treatment plant. The primary algae found in the river was Scenedesmus denticulatus which had its origin in the effluent from the treatment plant. In response to the increased organic material entering the river, and probably to modifications of several chemical factors, populations of rotifers, protozoans, blue-green algae, gastrotrichs, and chironomid larvae were found. These populations differed qualitatively and quantitatively from those upstream. Many of the forms found were typical for stagnant or polluted water.

In areas of running water downtream from the treatment plant, populations of micro-organisms were not changed significantly compared to points upstream; apparently the running water where found is suitable for several insect larvae and nymphs.

6.1.1 Fish

The main fishery resources of the project area are the Humboldt River itself and some ponds within the area. The most significant of the ponds are the old gravel pits near the Twelfth Street overpass currently under construction. Some are periodically connected to the river while others are not. These contain water all year round and are stocked periodically with blue gill, bass and catfish.

At one time the Humboldt River supported cut-throat trout and produced excellent fishing when the white man first traveled the country in the 1840's. Since 1900 fishing conditions have deteriorated and cutthroat have not been found in the main river since the 1930's. Trout have been eliminated by many years of deteriorating watersheds, poor water quality, and primitive irrigation practices.

"Bull head catfish were planted and established in the Humboldt River early in this century. In about 1956 initial attempts were made to establish warm water fish species such as smallmouth bass, white crappie, large-mouth bass, channel catfish, white catfish, blue gill, white bass, and also bull frogs along the river. Sporadic attempts to establish gamefish along the Humboldt River have been attempted every two or three years since this date, but it is just in recent years that evidence indicates some of the activity has been successful in attempts to establish these warm water fish."* Best successes in these stockings were returned by the channel catfish and blue gill sunfish.

The river is not presently a good fishery resource in the Elko area. The section within the urbanized area of the city, which is confined by dikes constructed in the 1940's and 1950's, particularly is lacking in desirable fish habitat. The channeling of the river in the city will probably not change this situation.

In the project portion of the Humboldt River the more common species are carp, Lahontan tuichub, speckled dace, Redshine shiner and the mountain sucker, all of which are non-game fish.

The sewage treatment plant at this time does not appear to be a limiting factor on fish life, but this may be attributed to the flushing action during periods of high flow. In theory, the effluent should be detrimental to game fish. It is probably harmful to some bass, but appears to attract catfish.

There are no threatened or endangered fish within the immediate project area. Fish found in the area are listed in Table 6.1.

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* Source: Nevada Fish and Game Department, "Stream Survey - Humboldt River, Elko, Eureka and Lander Counties." February 1974.

Table 6.1

Fishes Found in the Humboldt River System

In the Vicinity of Elko

Common Name	Scientific Name
Minnows and Carps:	
Carp	Cyprinus carpio
Lahontan Tui Chub	Gila bicolor obesus
Lahontan Speckled Dace	Rhinichthys osculus robustus
Lahontan Redside	Richardsonius egregius
Suckers:	
Mountain Sucker	Catostomus platyrhynchus
Freshwater Catfishes:	
White Catfish	Ictalurus catus
Black Bullhead	Ictalurus melas
Channel Catfish	Ictalurus punctatus
Sunfishes:	
Bluegill	Lepomis macrochirus
Smallmouth Bass	Micropterus dolomieui
Largemouth Bass	Micropterus salmoides

6.1.2 Amphibians, Reptiles and Mammals

The bottom lands of the Humboldt River Valley have some significance as a mule deer range. Deer from adjoining winter ranges seek feed and shelter during late winter and early spring, but in small numbers. The activities normally associated with a growing community the size of Elko and the livestock in the area preclude any abundance of these animals.

Other mammals which have been historically reported in the project vicinity, but seldom seen, include: racoon, badger, spotted skunk, coyote, bobcat, beaver, muskrat, marmot, black-tailed jack rabbit, cottontail rabbit and an assortment of small rodents.

There are no threatened or endangered amphibians, reptiles or mammals within the immediate project area.

6.1.3 Birds

The area has a rich bird life including shore birds, waterfowl, birds of prey, a variety of scavengers and song birds.

Of the other bird species known to be in the Elko region, at least seasonally, some of the more conspicuous include: great blue heron, Canadian goose, mallard, American coot, killdeer, barn swallow, raven, robin, waxwing, starling, meadowlark, Bullock oriole, Brewer blackbird, western tanager, house finch, Oregon junco, and sparrows. Almost the entire above list is absent during winter, returning on migratory flights for breeding and nesting.

The Peregrine Falcon and the Bald Eagle are classified as threatened or endangered species and are found in Elko County. However, they do not frequent the immediate Elko area.

6.2 Human Environment

6.2.1 General

The city of Elko is a relatively large rural community in the state of Nevada. The city has an active retail business which serves the surrounding ranch and farm trade areas. The economy is primarily based on the gambling and tourist enterprises within the city, although ranching and agricultural enterprises play an important role in the community's economy. The community does have a few large commerical establishments, but no manufacturing industries presently exist. It is anticipated that light industry and manufacturing could possibly move into the area in the future.

There are three elementary, one junior high, and one high school serving the community and surrounding farm area. The Northeastern Nevada Community College also serves the city of Elko and the northeastern part of the state. There is also one General Hospital and a new facility for the elderly serving the city and vicinity. City officials presently etimate Elko's population at approximately 9,600.

In addition to growth within the city, development is taking place in areas south of Elko, notably at Spring Creek and Pleasant Valley. The community of Spring Creek was founded in 1971. The mobile home estates are located about 7 miles from Elko and the housing section about 12 miles south of Elko. Spring Creek includes 5,362 lots to accommodate primarily single family mobile homes and houses. Using a factor of 2.8 persons per household, Spring Creek could reach an eventual population of over 15,000 people; however, due in part to such factors as the present economic situation and the availability of jobs in Elko, growth has been relatively slow and Spring Creek has an estimated current population of 450 people.

Elko city is one of the few urbanized areas within northeastern Nevada. Elko County is considerably less urbanized and more sparsely populated than the state or the nation.

Anticipating a population of 15,500 by the year 1998, the first goal selected by the Community Development Committee is "to continue orderly growth. . . within the range of available resources." To accomplish this, Elko officials are calculating and encouraging a growth rate of 3 percent per year.

Elko's population is supported generally by jobs related to tourism, ranching and mining. The railroad also accounts for a certain percentage of basic jobs. Additionally, governmental agencies - local, state, and federal - employ many Elko residents. Agricultural employment (mostly ranching) is substantially greater and manufacturing substantially less than state or national norms. White collar and wholesale and retail trade compare with state norms.

As a result of many federal government grant programs, several projects are currently underway in the area of Elko which may provide employment and business opportunities. The relocation plan of the Southern Pacific and Western Pacific railroads will open up a larger area for the commercial growth of the city and has resulted in plans for a downtown redevelopment area. The State Highway Department is currently constructing Interstate 80 highway to bypass Elko to the north. There will be three interchanges offering easy access into the city when the highway is complete. The recently completed Elko Airport

Master Plan calls for the expansion of the airport to better commercial air carrier jet service. The proposed plan calls for the construction of an extended runway, an extended taxiway, aprons, and eventually, new terminal buildings.

All of the above are indications that Elko is growing and will continue to do so. Another factor is the migration of people out of the congested cities to rural areas such as Elko. Current economic indicators show that Elko is capable of growing at the desired 3 percent annual growth rate. It is felt that housing and employment can keep pace with this growth rate.

6.2.2. Land Use

Elko's major residential areas lie north of the central business district extending to the proposed location of Interstate 80. This area consists predominantly of moderate to higher income single family homes with scattered small apartment complexes.

The second major residential area is the area south of the river which consists of single family homes and mobile homes, the latter being on both single lots and in trailer courts due to the fact that much of the area south of the river is zoned for mobile homes. Since the national economic and housing conditions make such homes attractive for a significant section of the population, development of this area has been taking place rapidly in recent years.

Between the central business district and the river, there is a third concentration of residential development. It differs from the other main residential areas of the city in two important respects; it has a fairly high proportion of substandard housing; and in parts, the housing is intermixed with other land uses. The small area west of Second Street, between Commercial and River Streets, is largely single family homes with a new trailer court presently being developed. Between Second and Eighth Streets the residential development is interspersed with scattered small commercial and industrial establishments; while east of Eighth Street, between Commerical and River Streets, the area again becomes predominantly residential in nature.

Elko's main commercial area is still largely confined to the downtown area, consisting of two blocks north and two blocks south of the Southern Pacific railroad tracks. Idaho Street, which carries the U.S. Route 40 designation, is the main street in town and most of the convenience stores, such as supermarkets, drug stores, jewelry stores, sporting goods, and clothing stores are located along this thoroughfare. Commercial Street, fronting on the Southern Pacific railroad tracks, traverses the second major commercial area and together with Railroad Street form a center for tourism and gambling. Some smaller cafes and retail stores are located along River and Silver streets, south of the tracks. On the extreme east end of town, on U.S. 40 (I-80 alternate), is a newer shopping center, Elko Shopping Plaza, which contains, among other stores, a large supermarket and "junior" department store.

The Elko Central Business District Plan states that the major disruptive and incompatible use in the Central Business District are the Southern Pacific and Western Pacific railroad tracks. The two tracklines are scheduled to be removed from the downtown area. The area thus freed from usage by the railroad will be available to the city to upgrade the Central Business District. It also states that "Downtown Elko's major strength lies in the wide range of services and activities available. Retail stores, casinos, hotels, motels, and offices are all found in the Central Business District."

Two other major categories of existing land use are of significance in this analysis: industrial land and park land. Elko's main industrial area is the Western Pacific Railroad yard located in the Southwest portion of the city. This area consists of approximately 132 acres. This yard is scheduled for relocation to the east of the city as a part of the Railroad Relocation Demonstration Project. The land will then be developed as an Industrial Park. Other industrial areas lie on the south side of the railroads, generally in the area between Fifth and Twelfth Streets, although there is a small industrial district between River and Douglas west of First Street. There are no industries in Elko which can be considered "heavy industry"; most of the industrial area consists of bulk oil storage units, warehouses, and coal and lumber yards, several of which depend on access to the railroad for daily operations.

City Park (34 acres) located in the north side of the city at College and Fourteenth Streets, and Southside Park (five acres) just south of the river between Seventh Street and Lamoille Road, are Elko's two parks. The Southside Park is scheduled to be relocated in the same general area as part of the Railroad Relocation Project.

6.2.3. History

Elko's history started in 1868 when the Central Pacific Railroad was completed. The first growth occurred when Elko was a railroad construction camp. It held a strategic location when the Central Pacific opened in 1868. With the Nevada mining camps located to the northward and to the southward and the gold and silver camps located in southwest Idaho, Elko became the principal departure point for miners as well as the transfer point for their freight and supplies. This encouraged the establishment of roads to the north and south. In 1907 the Western Pacific railroad came through Elko and stimulated a new growth boom. This railroad based transportation system encouraged the development of the Victory Highway, one of the nation's first transcontinental highways, and the development of the airport, a station on the first transcontinental air mail route. As can be seen, Elko's past has been closely related to the development of transportation systems which connect it to the rest of the nation.

The only building in the Elko area that is on the National Register of Historic Places is at the Northeastern Nevada Museum. The bulding was at the Ruby Valley Pony Express Station and was moved to its present site in 1960.

The Elko Hot Hole has been a local curiosity for many years with various attempts being made to use the waters. These attempts have all been failures primarily due to scaling problems caused by the mineral content in the water. A swimming pool was operated with these waters in the 1920's and 1930's. This was the most successful of the attempted uses and it lasted only 10 years.

6.2.4. Archeology

The archeological significances of sites in the Elko area result from proximity to the Humboldt River. The westward flowing river has probably served as a major transportation route across the northern Great Basin since earliest human penetration into the area. The river was reported to be the site for winter encampments for many of the Numic-speaking Indians who occupied the Great Basin for centuries before white contact. Fish and other resources from the river supported a relatively dense population. Occupation was apparently intermittent from 2410 to 1370 B.C., according to radiocarbon dates from deposits in the South Fork Shelters, located just southwest of Elko. Projectile point types suggest that occupation was permanent after A.D. 1200. The mouth of the South Fork was preferred as a site for winter encampment and was named "Punodungahnivain," meaning "place where the house is," by the Numic people. However, small encampment sites could be found every mile or so along the river.

The Humboldt River Valley near Elko has been the scene of human activity for at least 4,500 years, and probably much longer. At the time of Anglo-American entry, the area supported a denser population than most other areas of the Great Basin. Human activity became progressively more intense in the 1870's, following mining booms in the White Pine mining district in the south. Elko served as a major communication-transportation center serving mining districts to the south and as far north as Idaho. The flood plain and terraces of this river bear the scars of over a century of mechanized transportation, farming and urban construction. The traces of earlier occupation which can be expected to have survived are rare and provide a source of knowledge about the area's prehistoric and early historic heritage.

6.3 Potential Environmental Impacts

The development of geothermal resources in the Humboldt River Valley may result in a variety of environmental impacts, none of which are considered to be significantly adverse.

6.3.1. Geology

Seismicity - Geothermal areas have often been associated with areas of seismic activity and the Elko area is designated as a moderate seismic risk zone as previously noted in this report. The geologic data available for the Elko area indicates that a fault zone is associated with the "Hot Hole" and hot springs in the city. Development of the resource may result in increased occurrence of microseismic events. Should an increase in seismic activity occur following development of the geothermal resource, surveys will be initiated to monitor such activity.

Subsidence - Whenever large quantities of fluids are withdrawn from unconsolidated sediments or when declining reservoir pressures reduce the support for overburden, subsidence may result. However, Elko has been pumping ground water for domestic uses from aquifers at a depth of 100 feet to 400 feet for many years and no subsidence has occurred. It is reasonable to not expect any subsidence to result from pumping water out of deeper aquifers.

6.3.2. Soils

There will be no impact on soils as result of this project since the area of the project is completely developed.

6.3.3. Water Resources

Deleterious impacts to surface and ground water systems are of major concern during both drilling of the wells and operation of the facility. It is critical that domestic and irrigation aquifers not be contaminated with geothermal fluids should the water quality of the latter be determined to be poor. Preliminary indications are that the geothermal fluids are of a relatively "clean" nature and this would not be a problem.

The well bore will be cased to avoid thermal contamination of the geothermal fluids by colder ground waters and this casing will not allow the geothermal fluids to contaminate the colder ground waters which are used for domestic supplies. The holding pond used for development and testing of the well can be lined if required to prevent seepage. A second user of the spent fluids will be found if possible. Second uses could be warm water irrigation of crops, aquaculture, or other similar uses. If this cannot be done, due to poor water quality, reinjection of the waters into the geothermal aquifer would avoid contamination of surface waters.

Blowout preventers will be installed during drilling and will remain until the well head equipment is installed upon completion of the well. The distribution lines will be designed to prevent leakage or rupture and will be checked periodically.

The water quality (including bacterial counts, TDS, temperature, pH, turbidity, chemical contaminants and dissolved gases) of the geothermal resource will then determine final disposal. In all cases, state and federal water standards will be considered and met. No solid wastes will be generated which will impact surface or ground water.

6.3.4 Air Quality

Expected sources of air pollution from geothermal development in the valley include vehicle emissions during drilling and dissolved gases in the geothermal fluids. The major dissolved gas emitted from most geothermal fluids is hydrogen sulfide; however, levels are expected to be low, since there is no indication of gasses in the "Hot Hole" waters. As mentioned previously, if the water quality is poor, reinjection of the used geothermal fluids will be done and air quality will not be affected.

6.3.5 Noise

The noise generated by this project will occur during the well drilling and construction phases. The noise associated with these operations will be typical of urban construction operations. The noise will be generated only during normal working hours.

The noise during operation will be minimal. This noise would be generated by well pumps and heat exchangers. The noise levels at the location of use will not be changed by the use of a different energy source.

6.3.6 Flora and Fauna

There will be no impact on the flora and fauna of the area. The immediate vicinity of the project is currently developed and impacts will be too small to affect the general area.

Aquatic life could be affected by the final disposal of the used geothermal fluids. However, as previously stated, if the water quality is poor, reinjection will be used.

6.3.7 Human Environment

The land use in Elko will not be affected in any way by the project. No locations of historical or archeological interest are in the project.

The project should not have a significant impact on the economics of Elko since it is a relatively small program. However, should the use of geothermal energy prove economical, the possibility of future economic impact on other energy types in Elko could be great.

Some potential exists for industrial accidents whenever personnel work around equipment and use moving vehicles. These types of potential industrial accidents will be reduced to a minimum through the implementation of OSHA safety policies, procedures, and regulations.

The geothermal fluids produced from the wells could possibly be at temperatures above the boiling point of water. Therefore, the pipelines and heat exchange equipment will be insulated for safety reasons as well as for reduction of heat loss. Equipment design and operating procedures will meet standards required for steam systems. The geothermal fluid has no inherent hazard other than the elevated temperature.

An accident such as a transfer line rupture or leakage around a well casing might lead to short-term and localized contamination of surface water or soils. In theory, leakage can be avoided through the use of established well casing and cementing procedures. At the relatively low temperatures and pressures expected to be encountered in the geothermal resource in Elko, the potential for leakage from the casing or for a well blowout is very low, even if reasonable procedures were not followed.

6.4 Effluent and Environmental Monitoring Programs

No environmental baseline programs will be conducted specifically for this project. Detailed baseline information will be available from several sources, including the Bureau of Land Management, the Nevada Division of Environmental Protection, and the "Elko, Nevada, Railraod Relocation Demonstration Project Environmental Impact Statement". Monitoring programs will include water quality and gas content of geothermal fluids from exploration wells or production wells.

If it appears that either induced seismicity or subsidence are occurring as a result of the production or injection of geothermal fluids, monitoring programs will be established. Data will be used to predict the long-term occurrence of either and to determine what subsequent mitigation efforts might be required.

6.5 Restoration

Upon completion of drilling and testing of the well drilled, all equipment and structures not necessary for testing or production will be removed from the drill site and, where necessary, disposed of at an approved disposal area. Future land requirements at the well site will be determined and the disturbed area reduced to meet those requirements. The holding pond will be backfilled upon completion of testing and the land graded and contoured. If the well is to be abandoned, it will be plugged in accordance with state requirements.

7. SUMMARY AND RECOMMENDATIONS FOR IMPLEMENTATION

7.1 System Design Summary

A geothermally supplied district heating system for a 30 house community in Elko, Nevada, has been conceptually designed. This system consists primarily of 5 major elements summarized in the following sections.

7.1.1 Main Water Supply System

The existing community water supply system shown in Figure 4.2, page 42, was modified such that the heated water flows in a closed loop as shown in Figure 4.3, page 44. The modifications include installation of flow isolation, valves and check valves such that ample fire flow is available to all areas of the community. The piping design also allows for the addition of make-up water to replace that which is consumed at the houses within the community. The added main piping passes through community right-of-way property bordering the lots. An added pipe size of 3-inch diameter was selected as the optimum. The water supply system modification consists of approximately 1308 ft of added 3-inch diameter pipe along with required pipe fittings and valves.

7.1.2 Well Head and Main Heating Plant System

The community will be supplied with water from a single geothermal well adjacent to the community. A schematic of the well head facility including instrumentation points is given in Figures 4.3a and 4.3b, pages 46 and 47. The well must be approximately 1000 ft deep in order to obtain 120°F water in the area where the community is located. The main heating plant consists of a Bell & Gossett tube-and-shell heat exchanger type WU 105-4 which is supplied ample water flow at 120°F from the geothermal well. The domestic water flow is heated to approximately 90°F and then pumped through the community with a Bell & Gossett series 1510 centrifugal pump, model 1 1/2" AB, having a 2 hp motor connected through a variable speed drive. The community water flow rate is adjusted based upon ambient air temperature to obtain the desired flow rate given in Figure 4.9, page 71.

7.1.3 <u>Two-House Loop</u>

The houses were paired for the two-house loop design such that minimal amounts of water piping must be installed. The layout of a typical loop is shown in Figure 4.5, page 52. Each loop is connected to the heat pump isolation loop at each house such that either heat pump may be taken out of service without interrupting the water flow to the other house. The loop contains two Grundfos 1/12 hp pumps model UP 25-64 SF, one per house, which operate simultaneously and continuously. The loops also contain added piping with fittings and valves.

7.1.4 <u>Heat Pump Isolation Loop</u>

An isolation loop was designed for the heat pump unit to ensure that failure of the heat pump would not contaminate the domestic water flow. A Friedrich heat pump model 803/804-024 unit was chosen based upon the design heat load for the houses in this community and the performance specifications of this heat pump. The other components of the isolation loop shown in Figures 4.1 and 4.1a, pages 38 and 39, are an Alfa-Laval plate-type heat exchanger model P01VL, a Grundfos 1/20 hp water circulating pump model UP 25-42 SF, a small amount of connecting piping, and required pipe fittings and valves.

7.1.5 House Modifications

Each house in the community must be modified by installing a central air distribution system (ductwork/blower) to be used with the heat pump unit. The proposed system is designed to completely replace the existing electric baseboard heaters of these houses. A housing for the heat pump isolation system must be provided at each house either in the crawl space below the house or as an addition outside the house.

7.2 Recommendations for Implementation

While the project described in this report exhibits technical and economic feasibility it suffers from a high building retrofit expense (i.e., electric baseboard to forced air distribution). There is also a concern about the acceptability of having warm (70-90°F) drinking water available at the residence in a community where average potable water supply temperatures have historically been below 55°F.

However, the concept and the technical evaluation methodology described will have general applicability to a number of communities in Nevada and the Western United States where municipal water systems already exhibit greatly elevated water supply temperatures. As an example, the community of Gabbs, Nevada has a primary municipal water well supply temperature of 112°F. This water is presently delivered to an elevated storage tank for cooling and then delivered to residential holding tanks for further cooling. While this condition is extreme it is by no means unique. The State of Washington Department of Energy has identified 89 communities in that state where municipal water systems operate at elevated temperatures, temperatures consistent with the requirements desribed in this report.

For these reasons it is our recommendation that further evaluations be made of communities which exhibit high potable water supply temperatures. This effort should rank those communities on an economic and technical feasibility scale for implementation of the concept.

APPENDICES

Appendix A

Traditional District Heating System

The concept of district heating has been applied for many years. It is believed that the first district heating plant was built at Lockport, New York, in 1877, and the first European plant started in Hamburg, Germany, in 1893 [1]. American Hydrotherm Corporation designed the first high temperature water cascade heating system in the United States, which was installed at Loring Air Force in 1950, and the first forced circulation heating system, which was installed at Lockbourne Air Force Base in 1952 [2]. A number of countries have been using district heating for many years. See Figure A.1, adapted from Scholten [3]. In this figure years denotes time period of use of district heating, and GDR and FRG are abbreviations for the Germany Democratic Republic and the Free Republic of Germany, respectively. Some Communist countries are trying to provide district heating as a public utility service similar to electrical power. In the USSR some two-thirds of all buildings in cities were supplied by district networks by 1976 [4]. Poland has been rapidly developing heating networks to serve industrial and municipal complexes in towns, making use of combined heat/power plants. District heating facilities are being extended to virtually all towns in the Scandinavian countries. Denmark has the highest proportion of district-heated dwellings in Europe, amounting to approximately one-third of its two-million homes, whereas Sweden has about one-sixth of its buildings on district heating [5]. The largest district heating system in the world, which is operated by Consolidated Edison Company of New York, Inc., provides some of New York City with heat and air conditioning. This system accomodates some of the largest buildings in the world, such as the Empire State Building, the Rockefeller Center, the Chrysler Building, the United Nations Building,

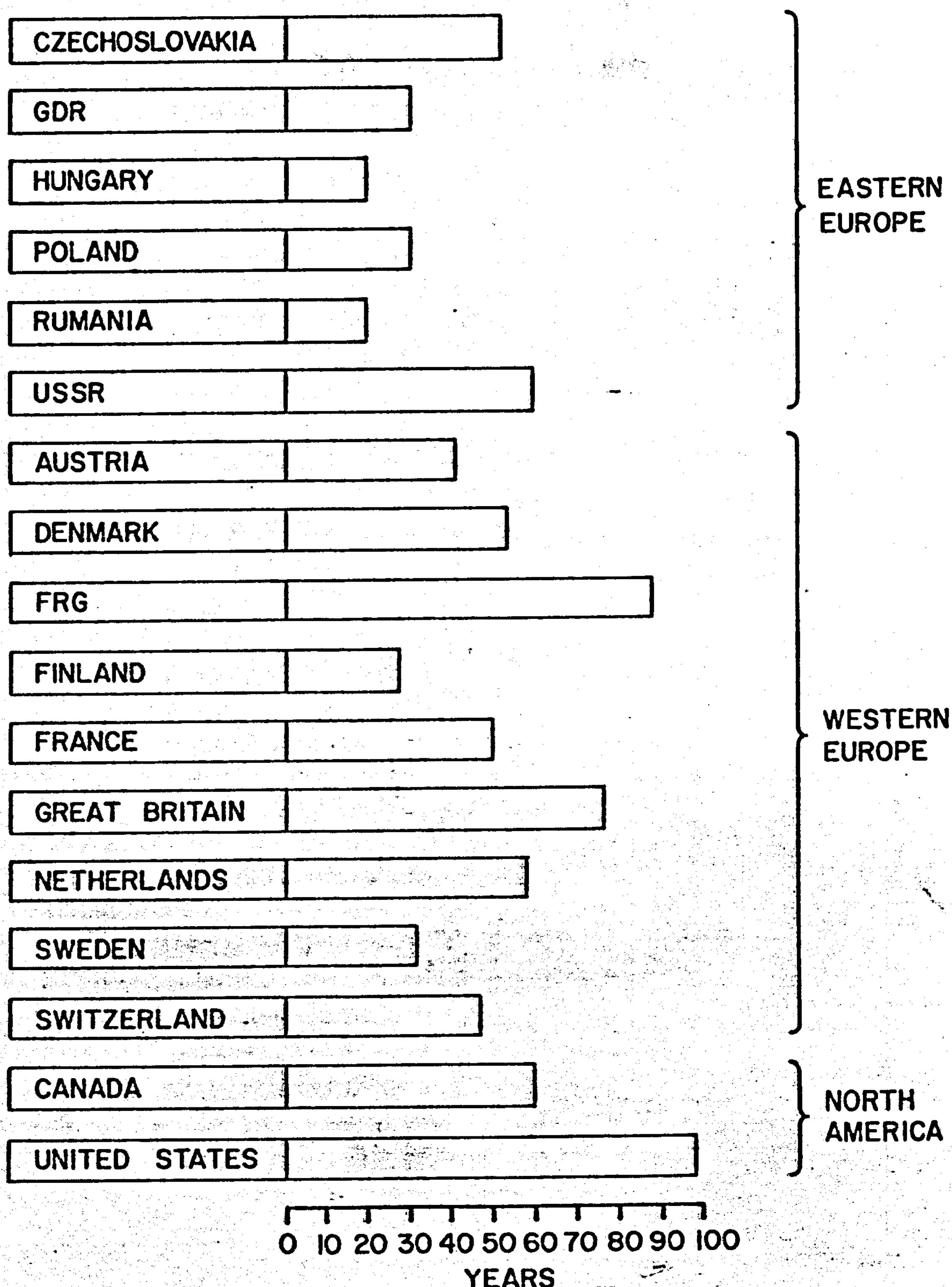


Figure A.1. Global History of District Heating as of August 1980 (adapted from Scholten [3]) etc., in addition to vast residential suburbs. Other major U.S. cities, such as Detroit, Cleveland, Boston and Pittsburgh, are served by district heating systems [5].

A traditional district heating system consists of a centralized plant to elevate the temperature of the heating medium which is then pumped through insulated pipes to the buildings where heat exchangers are used to provide room-heating and domestic water heating. The centralized plant may be designed to either supply the heating medium only, or produce both the heating medium and electricity (cogeneration). Most district heating plants at present are fueled by coal, oil, natural gas, or waste energy. In addition, geothermal energy may be used as a heat source and has for many years been used to supply the district system in the city of Reykjavik, Iceland. Nuclear energy may also be used as a heat source for the district system, although at present there are no nuclear powered systems in operation. Many of the larger European cities use waste incineration to provide heat to a district network. Paris, for example, receives approximately 1.2 million pounds of steam per hour from incinerators which rid the city of 90 percent of all its refuse [4]. The Netherlands, Denmark, Germany, Sweden, Switzerland, and the USSR, all treat waste incineration coupled with waste heat recovery as an essential part of the services for large cities. Even so, coal, oil, and gas make up the major portion of fuels used for district heating (see Figure A.2 from Scholten [3]).

The heating medium used in district systems is either steam or hot water. Both steam and hot water are used in Europe, whereas in North America, steam is almost exclusively used as the heating medium.

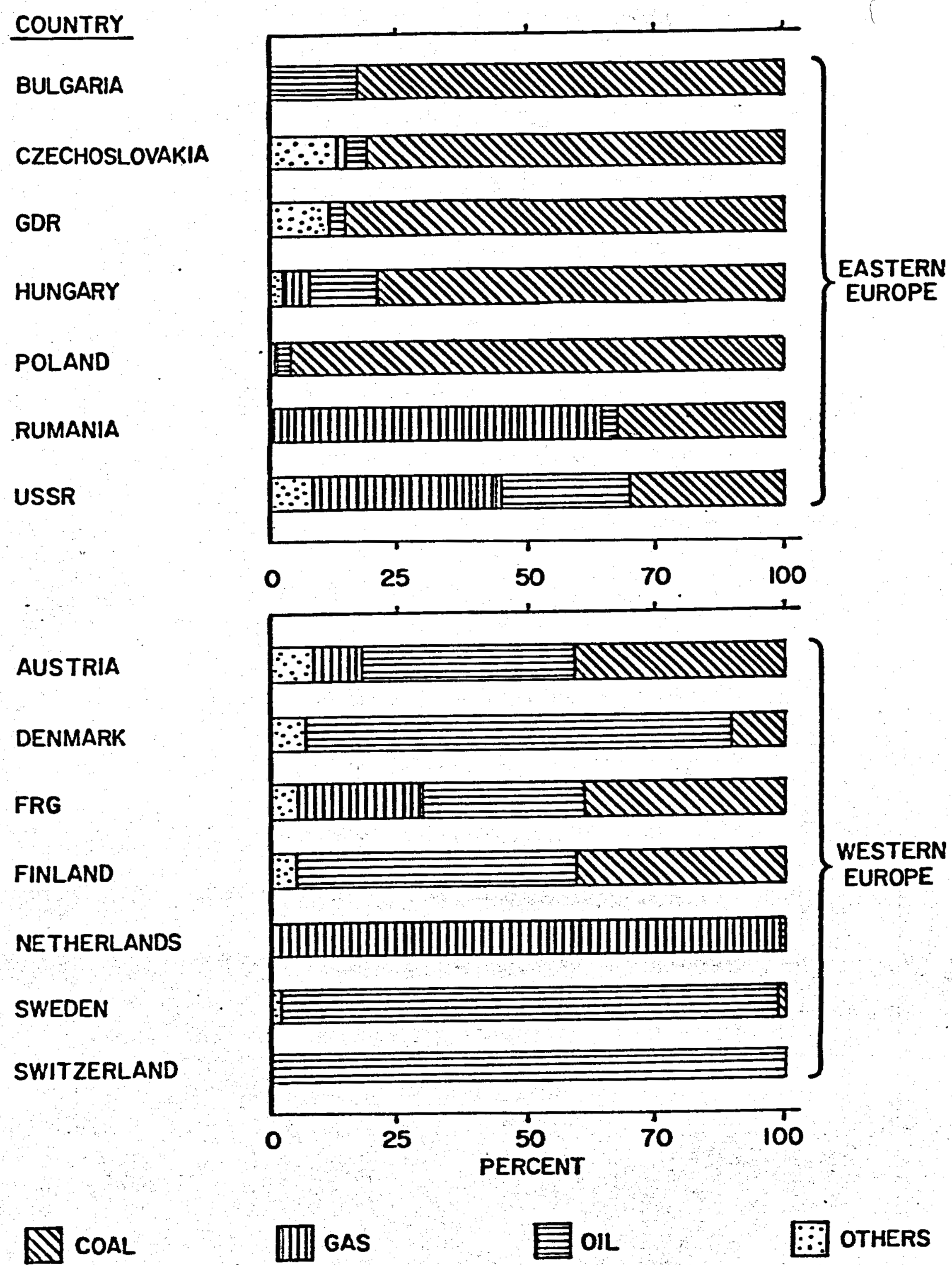


Figure A.2. Fuels Used in District Heating (adapted from Scholten [3])

Generally, hot water is considered to be superior to steam as the heating medium for a district system in heating applications requiring moderate temperatures (not exceeding 212-392°F) [1]. In steam systems, great care must be taken to insure that the temperature and pressure are such that condensation does not occur. Similarly, the hot water system must be pressurized so that flashing is avoided. In the hot water system, booster pumps may be provided when it is necessary to move the heating fluid over large distances. In the steam system, however, all of the pumping power must be provided at the heating plant. Clearly, when the heating medium must be transported over great distances, hot water is desired.

One of the major expenses, and perhaps the most vulnerable part of a district heating system, is the buried piping network. The hot water distribution system requires both a forward supply line and a system return line. Sometimes a second forward pipe for the production of domestic hot water is added. The pipelines normally consist of steel pipes covered with insulation and a protective sheath. The pipes are laid below street level in the same concrete incasement. In Sweden, a country which has many district systems, a trend in the type of piping used has emerged [1]. For district heating pipes larger than 12 inches in diameter, concrete culverts are used with the thermal expansions of the pipes being absorbed by compensators or expansion loops. For pipes up to 12 inches in diameter, prefabricated steel district heating culverts with polyurethane insulation and protective sheaths of polyethylene and PVC are used. The pipe is guided by the pressure of the earth so the material will absorb any movement due to thermal expansion. For pipes less than 3 inches in diameter, copper has been used where thermal expansions are taken up by the pipes being laid in a sinusoidal curve pattern. It should be noted that the water flowing in these systems is around 165-250°F [6].

A major problem with these piping networks is keeping the insulation dry. Wet insulation not only greatly increases the thermal losses but also promotes pipe corrosion. The traditional district system requires a great deal of excavation and resulting surface repair in order to run the large amounts of insulated piping needed.

List Of References
(Appendix A)

1. Lindeberg, Lennart, "District Heating Distribution Systems", technical paper presented at Swedish District Heating Workshop, Chicago, Ill., October 10-20,1978.

2. Geiringer, Paul L., High Temperature Water Heating, John Wiley and Sons Inc., New York, 1973.

3. Scholten, Volker, and Manfred Timm, "Survey of Existing District Heating Systems", Nuclear Technology, Vol.38, Mid-April 1978.

4. Field, A. A., "District Heating and Total Energy", Energy World, n13, February 1975.

5. Mackenzie-Kennedy, District Heating, Pergammon Press, New York, 1979.

6. Lind, Carl-Erik, "Setting the Stage", technical paper presented at Swedish District Heating Workshop, Chicago, Ill., October 10-20, 1978.

Appendix B

Two-House Loop Loss Coefficient Determination

Each two-house flow loop was assumed to contain the same number of pipe fittings, valves, etc. The following is a listing of loop components and their associated flow pressure loss coefficients, K, as obtained from reference 2 of Chapter 6 for use in the equation

$$h_f = K \frac{V^2}{2g} .$$

Quantity	Item	K each	K total
1	Pipe entry region	0.50	0.50
2	Flow through run of tee	0.46	0.92
4	Flow through branch of tee	1.38	5.52
8	90° pipe elbows	0.69	5.52
4	Gate valves	0.18	0.74
1	Pipe exit region	1.00	1.00
		TOTAL	14.20

As an approximation a K value of 7.1 per house is used.

Appendix C

Two-House Loop Computer Program

The following is a listing of the computer program to analyze the frictional flow losses through the two-house flow loop. Also included is a sample output from this program. All two-house loops are assumed to have the same number of pipe bends, valves, etc., and the loss coefficients used are those given in Appendix B. The sample output is for a two-house loop pipe length of 260 ft.

```
$JOB              P=20                 RICK PELFREY
            REAL MU,LI
      C** OPERATING AT 80 DEGREES F
            RHO=62.22
            MU=5.764E-4
            CFS=7.4805*60.
            G=32.174
            PI=3.1415926
      C** HOUSE PIPING IS 1 IN. DIAMETER
            DFT=1./12.
      C** TOTAL LENGTH OF HOUSE PIPING
            LI=260.
            AREA=PI*DFT**2/4.
            PRINT 50
         50 FORMAT('1')
            Q=6.
       1000 Q=Q+1.
            V=Q/(CFS*AREA)
            VV=V**2/(2.*G)
            RE=RHO*V*DFT/MU
      C** GALVANIZED IRON PIPE
            E=5.0E-4
            F=0.019
          1 B1=-2.*ALOG10(E/(3.7*DFT)+2.51/(RE*SQRT(F)))
            A=(1./B1)**2
            IF(ABS(A-F).LT.0.0001) GO TO 2
            F=(F+A)/2.
            GO TO 1
          2 HF=F*LI/DFT*VV
            QA=Q*RHO/(CFS*550.)
      C** 90-DEGREE ELBOWS
            CKEL=0.69
            ELS=8.
      C** ENTRY REGION (SHARP EDGED)
            CKI=0.5
      C** EXIT REGION (SHARP EDGED)
            CKE=1.0
      C** GATE VALVE
            CKV=0.184
            GVS=4.
      C** FLOW THRU RUN OF TEE
            CKTR=0.46
            TEER=2.
      C** FLOW THRU BRANCH OF TEE
            CKTB=1.38
            TEEB=4.
      C** HEAT EXCHANGER (ALFA-LAVAL TYPE P01VL)
            DP=0.032332-0.0035109*Q+0.032623*Q**2-1.8784E-4*Q**3
            HFHEX=DP*144./RHO
            PHEX=HFHEX*QA
            PRINT 100,Q
        100 FORMAT(' ',///////,10X,'RUN WITH FLOW OF ',F3.0,' GPM',//
           $T5,'ITEM',T15,'NO.',T25,'HF EA.',T35,'HF TOT.',T45,'PTOT',/)
            PRINT 110,CKI*VV,CKI*VV,QA*CKI*VV
        110 FORMAT(T4,' ENTRY',T16,'1',T25,F5.3,T35,F5.2,T45,F5.3,/)
            PRINT 120,LI,HF/LI,HF,QA*HF,F,RE,V
        120 FORMAT(T4,' PIPE',T14,F4.0,T25,F5.3,T34,F6.2,T45,F5.3,T55,'F=',F6.
           $4,T70,'RE=',F8.0,T85,'V=',F6.3,/)
            PRINT 125,ELS,CKEL*VV,CKEL*VV*ELS,CKEL*VV*ELS*QA
        125 FORMAT(T4,' ELBOWS',T15,F3.0,T25,F5.3,T35,F5.2,T45,F5.3,/)
```

```
      PRINT 130,TEER,CKTR*VV,CKTR*VV*TEER,CKTR*VV*TEER*QA
  130 FORMAT(T4,' TEES(R)',T15,F3.0,T25,F5.3,T35,F5.2,T45,F5.3,/)
      PRINT 135,TEEB,CKTB*VV,CKTB*VV*TEEB,CKTB*VV*TEEB*QA
  135 FORMAT(T4,' TEES(B)',T15,F3.0,T25,F5.3,T35,F5.2,T45,F5.3,/)
      PRINT 140,GVS,CKV*VV,CKV*VV*GVS,CKV*VV*GVS*QA
  140 FORMAT(T4,' VALVES',T15,F3.0,T25,F5.3,T35,F5.2,T45,F5.3,/)
      PRINT 145,HFHEX,2.*HFHEX,PHEX
  145 FORMAT(T4,' HT.EXCH.',T16,'2',T25,F5.3,T35,F5.2,T45,F5.3,/)
      PRINT 150,CKE*VV,CKE*VV,QA*CKV*VV
  150 FORMAT(T4,' EXIT',T16,'1',T25,F5.3,T35,F5.2,T45,F5.3,/)
      HFTOT=(CKI+CKE+CKEL*ELS+CKV*GVS+CKTR*TEER+CKTB*TEEB)*VV+HF+HFHEX*2
      PRINT 160,HFTOT,QA*HFTOT,HFTOT/2.
  160 FORMAT(/,T4,' TOTAL',T34,F6.2,T45,F5.3,T60,'HFTOT/2 ',F6.2)
      IF(Q.EQ.10) GO TO 200
      GO TO 1000
  200 CONTINUE
      STOP
      END

C$ENTRY
```

RUN WITH FLOW OF 7. GPM

ITEM	NO.	HF EA.	HF TOT.	PTOT			
ENTRY	1	0.064	0.06	0.000			
PIPE	260.	0.053	13.88	0.024	F=0.0350	RE= 25723.	V= 2.859
ELBOWS	8.	0.088	0.70	0.001			
TEES(R)	2.	0.058	0.12	0.000			
TEES(B)	4.	0.175	0.70	0.001			
VALVES	4.	0.023	0.09	0.000			
HT.EXCH.	2	3.568	7.14	0.006			
EXIT	1	0.127	0.13	0.000			
TOTAL			22.82	0.040	HFTOT/2 11.41		

RUN WITH FLOW OF 8. GPM

ITEM	NO.	HF EA.	HF TOT.	PTOT			
ENTRY	1	0.083	0.08	0.000			
PIPE	260.	0.069	17.95	0.036	F=0.0347	RE= 29397.	V= 3.268
ELBOWS	8.	0.115	0.92	0.002			
TEES(R)	2.	0.076	0.15	0.000			
TEES(B)	4.	0.229	0.92	0.002			
VALVES	4.	0.031	0.12	0.000			
HT.EXCH.	2	4.619	9.24	0.009			
EXIT	1	0.166	0.17	0.000			
TOTAL			29.54	0.060	HFTOT/2 14.77		

RUN WITH FLOW OF 9. GPM

ITEM	NO.	HF EA.	HF TOT.	PTOT			
ENTRY	1	0.105	0.11	0.000			
PIPE	260.	0.087	22.54	0.051	F=0.0344	RE= 33072.	V= 3.676
ELBOWS	8.	0.145	1.16	0.003			
TEES(R)	2.	0.097	0.19	0.000			
TEES(B)	4.	0.290	1.16	0.003			
VALVES	4.	0.039	0.15	0.000			
HT.EXCH.	2	5.800	11.60	0.013			
EXIT	1	0.210	0.21	0.000			
TOTAL			37.12	0.084	HFTOT/2 18.56		

RUN WITH FLOW OF 10. GPM

ITEM	NO.	HF EA.	HF TOT.	PTOT			
ENTRY	1	0.130	0.13	0.000			
PIPE	260.	0.106	27.65	0.070	F=0.0342	RE= 36746.	V= 4.085
ELBOWS	8.	0.179	1.43	0.004			
TEES(R)	2.	0.119	0.24	0.001			
TEES(B)	4.	0.358	1.43	0.004			
VALVES	4.	0.048	0.19	0.000			
HT.EXCH.	2	7.109	14.22	0.018			
EXIT	1	0.259	0.26	0.000			
TOTAL			45.55	0.115	HFTOT/2 22.77		

Appendix D

Main Computer Program

The method of analysis used in this program has been previously described; this section is intended to describe the details of data input required by the program. Following this section are:

(a) a listing of the program nomenclature (pages D-10 - D-16),

(b) a listing of the main program (pages D-17 - D-26),

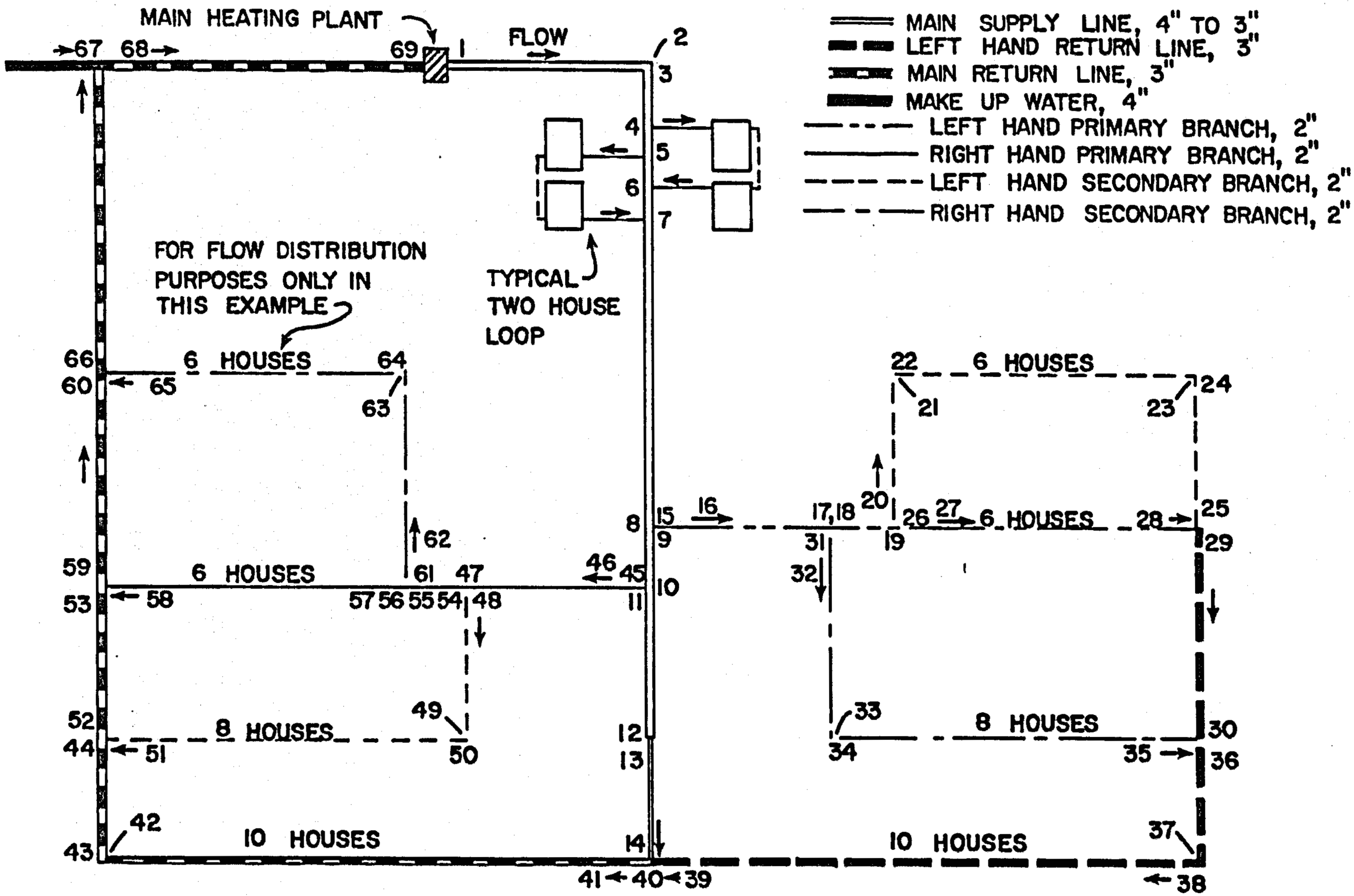
(c) a sample program input for the simplified community in the figure on the following page (pages D-27 - D-28),

(d) a sample program output for the simplified community in the figure on the following page (pages D-29 - D-31) and

(e) a sample program output for the Sunrise Addition subdivision (pages D-32 - D-38).

The sample program input and output for the simplified community in the figure on the following page is included only to demonstrate the analysis routing method and show the output at typical analysis steps. The sample output for the Sunrise Addition subdivision includes all information generated as output from the program for the -7°F ambient air temperature design condition.

In order to analyze the proposed community heating system, detailed information regarding the proposed system design must be supplied as input to the program. The program is designed to analyze the flow and thermal losses through a given community independently of the main heating plant. This enables the designer to choose a heat source, the corresponding heat exchanger, and a main flow pump. It is assumed that all houses in the community have similar heating requirements and a simple


MAIN HEATING PLANT
FLOW
MAIN SUPPLY LINE, 4" TO 3"
LEFT HAND RETURN LINE, 3"
MAIN RETURN LINE, 3"
MAKE UP WATER, 4"
LEFT HAND PRIMARY BRANCH, 2"
RIGHT HAND PRIMARY BRANCH, 2"
LEFT HAND SECONDARY BRANCH, 2"
RIGHT HAND SECONDARY BRANCH, 2"
FOR FLOW DISTRIBUTION PURPOSES ONLY IN THIS EXAMPLE
TYPICAL TWO HOUSE LOOP
6 HOUSES
6 HOUSES
8 HOUSES
10 HOUSES
6 HOUSES
6 HOUSES
8 HOUSES
10 HOUSES
67 68 69 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17,18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66

expression relating the house heat load to the outside ambient air temperature may be determined and input to the program as BTUREQ (BTUH). It is futher assumed that the components and flow rates of both the heat pump isolation loop and the two-house loop have been determined. The following loop information must be supplied as input:

QHP, the isolation loop water flow rate, GPM;

PHPILP, the heat pump isolation loop circulating pump power, hp;

AHEX, the heat exchanger effective area, ft^2;

U, the heat exchanger heat transfer coefficient, BTU/hr-ft^2-°F;

QH, the average two-house loop water flow rate, GPM; and

PTHLP, the two-house loop flow circulating pump power, hp.

In addition, the approximate heating capacity of the heat pump and the total frictional loss coefficient per house for flow through the two-house loop must be specified as input. The following performance characteristics of the heat pump based upon heat pump entering water temperature at the isolation loop flow rate must be provided:

FNCAP, the heat pump heating capacity, BTUH;

FNCOP, the heat pump coefficient of performance;

FNDT, the water temperature drop across the heat pump, °F; and

FNKW, the heat pump total power input, kW.

These will be functional relations from which the desired quantity may be determined for a given heat pump entering water temperature.

In addition to specifying input regarding the two-house loops and the heat pump isolation loops, the following information about the community must be provided:

KE, the approximate soil thermal conductivity, BTU/hr-ft-°F;

QD, the average consumptive water flow rate per house, gal/day;

Z, pipe centerline buried depth in the proposed piping network, ft;

E, the pipe relative roughness in the proposed piping network, ft;

D2, the diameter of two-house loop piping between the street and the house, in.;

DB, diameter of added two-house loop piping between houses, in.;

TN, the temperature of make-up water supplied to replace that consumed, °F; and

NH, the total number of houses in the community.

In addition to this general information, detailed information regarding the proposed piping network must also be provided.

The program is designed to proceed step-by-step through the community computing both frictional flow losses and thermal losses according to a path specified by the program data input. The analysis is divided into a number of computation steps, N, with a step occurring at each flow disturbance within the piping network. The steps through the community must occur in a prescribed order based upon the piping network as outlined in the following paragraphs. A simplified schematic of a typical community piping network which may be used for reference is given on page D-2.

A main flow supply line from the heating plant must be chosen from which a finite number of left-hand and right-hand (branch of tee is to the left or right, respectively, of the direction of flow in the main supply line) primary branches may be extracted. The system main flow supply line will terminate in a designated system return line. The initial sequence of steps must proceed from the main heating plant along the main supply line to its joining with the return line. Each of the left-hand and right-hand primary branch flow rates and the corresponding water temperatures are evaluated as part of this initial sequence of steps. The branch flow rate is determined as the initial system flow rate times the ratio of the number of houses served by the branch to the total number of houses in the community. It is assumed that flow control valves are installed as needed in the community branches such that the desired flow rate and direction of flow in each of the branches are obtained.

Upon reaching the end of the main supply line (computationally), the analysis shifts to the first (nearest the main heating plant) left-hand primary branch served by the main supply line. The analysis continiues along the left-hand primary branch until a secondary branch occurs or the primary branch terminates into the left-hand return main.

Whenever a branch occurs, the left-most branch is analyzed first. The analysis continues until another branch is encountered or a combination with an unknown flow is reached. When an unknown flow is to combine with the known flow, the analysis must proceed to evaluate the unknown flow. The case of not more than one right-hand and one left-hand secondary branch from a primary branch may be handled with ease. If multiple secondary branching occurs, caution must be exercised in the flow analysis routing.

If a left-hand secondary branch (branch of flow dividing tee to the left of the left-hand primary flow direction) occurs, the secondary flow rate and temperature are evaluated, and the water temperature and flow rate remaining in the primary branch are stored with the analysis proceeding along the secondary branch. The secondary analysis continues through the secondary branch until it joins the left-hand return line;

the return line analysis then proceeds until the end of the primary branch is encountered. At this point the analysis shifts back to the primary branch at the point where the left-hand secondary was extracted and the remaining primary branch flow is analyzed. The primary branch is joined with the left-hand return line and the analysis proceeds along the return line to the next flow disturbance.

If a right-hand secondary branch of a left-hand primary branch is encountered, the secondary flow rate and temperature are evaluated and stored with the analysis proceeding along the primary branch. The primary branch analysis continues until it joins the left-hand return line; the return line analysis continues to the point where the secondary branch joins. The analysis then shifts back to the right-hand secondary at its initialization point. The secondary is analyzed until joining the left-hand return line. The return line is then analyzed to the next flow disturbance. The analysis proceeds through all left-hand primary branches in the order which they appear following the direction of the main supply flow.

After all left-hand primary branches have been analyzed, the left-hand return line will be joined with the end of the community main supply line to begin the community main return line. The return main is analyzed until an unknown flow empties into it. At this point the right-hand branch nearest the end of the main supply line must be analyzed. The method of analysis of secondary branches is the same as outlined for the left-hand primary branch with branches now ending into the main return line rather than the left-hand return line. The right-hand primary branches are analyzed in reverse order (from the main supply line end, back to the heating plant) until all branches have been analyzed. The system return main is then analyzed until the main heating plant is reached. Somewhere before returning to the heating plant the system make-up water is added.

It must be noted that the outlined method of analysis is for a community piping layout such as the one shown in the figure on page D-2. If the system return line were located on the opposite side of the community, the roles of the left-hand and right-hand branch analyses would be interchanged. In that case the right-most branch would be analyzed first.

When laying out the pairing of the two-house loops, it is important to take care that the return from a particular two-house loop does not occur upstream (in the analysis chain of events) of the flow extraction for that two-house loop. If this situation does occur, some estimate of the temperature of the water entering the main flow from the two-house loop must be made; this estimate will introduce some error into the subsequent analysis.

Once the order of the piping network analysis has been determined, it is necessary to break the analysis into N computational steps. A step is required at each of the following types of flow disturbances:

(1) a smooth pipe bend,

(2) an abrupt pipe contraction,

(3) a two-house loop flow extraction,

(4) a two-house loop flow return,

(5) a flow dividing tee, or

(6) a flow combining tee.

The total number of analysis steps, N, must be provided as input as well as the following data at each step I:

L(I), the length of the pipe segment through the street, ft;

H(I), the number of houses served by the flow extraction;

D(I), the nominal diameter of the pipe segment through the street, in.;

L1(I), the length of the pipe from the street to the first house of the two-house loop, ft;

LB(I), the length of the added pipe between the two houses of the two-house loop, ft;

L2(I), the length of the return pipe from the second house of the two-house loop to the street, ft;

RET(I), the step to which the two-house loop flow returns; and

B(I), the calculation indicator.

These definitions will hold for each type of flow disturbance unless otherwise redefined below.

(1) For a smooth pipe bend, L(I) will be the negative of the angle of pipe bend in degrees with all other parameters except D(I) and B(I) zero.

(2) For an abrupt pipe contraction all parameters except D(I) and B(I) will be zero. D(I) will be the smaller diameter of the pipe contraction with the larger diameter given by D(I-1).

(3) For the two-house loop flow extraction only B(I) will be zero. The step begins at the point of flow extraction and extends along the street to the next flow disturbance. First the flow through the two-house loop is analyzed. The analysis then returns to the pipe segment from which the two-house loop flow was extracted, and this segment is analyzed.

(4) For the two-house loop flow return all parameters except L(I), D(I), and RET(I) will be zero. The step begins at the point where the flow returns and extends along the pipe through the street to the next flow disturbance. RET(I) will be the negative of the step from which the two-house loop flow was extracted.

(5) For a flow dividing tee, only H(I), D(I), and B(I) will be non-zero. D(I) will be the diameter of the branch of the tee.

(6) For a flow combining tee, D(I) is the diameter of the run of the tee and all other parameters except B(I) are zero.

In addition to the input parameters previously described, the following must be input and may be varied to model system performance at a variety of conditions: TII, the temperature of the water exiting the main heating plant and entering the community, °F; TES, the outside ambient air temperature, °F; and FF, the system flow factor (times 100 GPM).

Program Nomenclature

A	dummy variable used in subroutine FLOSS
ADJKW	adjusted average hourly power input to a heat pump, kW
AHEX	effective area of heat pump isolation loop heat exchanger, ft^2
ARATIO	ratio of tee branch area to tee run area
AREA	cross sectional area of pipe, ft^2
B(I)	indicator for type of calculation to be performed at step I
B1	dummy variable used in subroutine FLOSS
BTUREQ	heat load required per house, BTUH
C	heat capacity ratio of heat exchanger fluids (minimum/maximum)
CAP	heating capacity of the heat pump, BTUH
CET	dummy variable used in conduction shape factor equation
CFS	dummy variable to convert flow in GPM to ft^3/sec (cfs)
CMIN	minimum heat capacity of heat exchanger fluids, BTU/hr-°F
COP	heat pump coefficient of performance (COP)
COPAVG	average heat pump COP
COPTOT	sum of heat pump COP's
COSHI	inverse hyperbolic cosine
D(I)	diameter of pipe segment at step I, in.
D2	diameter of pipe segment between the house and street main, in.
D21	diameter ratio for evaluating head loss through contraction
DB	diameter of added pipe between houses for two-house loop, in.
DE	diameter of end section of main supply pipe, in.
DELTAP	total pressure drop of main flow through the community, psi
DFT	diameter of pipe in feet
DI	diameter of pipe segment being analyzed at a given step, in.

DPHEX	pressure drop across heat pump isolation loop heat exchanger, psi
DTF	temperature drop of flowing fluid, °F
DTFA	dummy DTF value used for comparison, °F
DTFAVG	average temperature drop across heat exchanger, °F
DTFTOT	sum of temperature drops across heat exchangers, °F
DTHP	sum of temperature drops across heat pumps, °F
DTHPAV	average temperature drop across the heat pumps, °F
E	pipe relative roughness, ft
EF	heat exchanger effectiveness
EFF	dummy variable used in EF calculation
FNCAP	function used to calculate heat pump capacity
FNCOP	function used to calculate heat pump COP
FNDT	function used to calculate temperature drop across heat pump
FNKW	function used to calculate heat pump power input
F	pipe friction factor calculated from the Colebrook Equation
FF	community main flow factor for adjusting system flow rate
FT	variable used in calculating head loss through pipe bend
FT1	dummy variable used in calculating FT
FT2	dummy variable used in calculating FT
G	local acceleration of gravity, ft/sec^2
H(I)	number of houses served by branch at I
HFL(I)	head loss through branch of tee for left-hand branch at I, ft
HFR(I)	head loss through branch of tee for right-hand branch at I, ft
HF	frictional head loss, ft
HF2	total head required for flow through two-house loop, ft

HFLS	tee head loss for flow into left-hand secondary branch, ft
HFRS	tee head loss for flow into right-hand secondary branch, ft
HFTOT	total head loss through main community piping, ft
I	incremental counter in main program
I1	incremental counter in two-house loop analysis
ICHK	heat pump spacing increment check value
IHP	average integer number of heat pumps operating
INC	spacing increment between heat pumps in operation
INCT	indicator for which heat pumps are to be operating
JL	counter for number of left-hand primary branches
JR	counter for number of right-hand primary branches
K	counter for analysis of right-hand primary branches
K13	loss coefficient for flow through branch of combining tee
K23	loss coefficient for flow through run of combining tee
K31	loss coefficient for flow through branch of dividing tee
K32	loss coefficient for flow through run of dividing tee
KA	dummy variable used in subroutine LOSSK (flow through tee branch)
KB	dummy variable used in subroutine LOSSK (flow through tee run)
KB	loss coefficient for flow through pipe bend in main program
KC	loss coefficient for flow through pipe contraction
KE	soil thermal conductivity, BTU/hr-ft-°F
KM	loss coefficient for flow through half of two-house loop
KW	heat pump power input, kW
L(I)	length of pipe segment at step I, ft
L1(I)	length of two-house loop pipe from street to house, ft

L2(I)	length of two-house loop pipe from house to street, ft
LB(I)	length of added two-house loop pipe between houses, ft
LI	length of pipe segment being analyzed, ft
M	dummy variable in transfer statement for B(I)
MU	dynamic vicosity of water, lbm/ft-sec
N	number of analysis steps
NH	total number of houses in the community
NTU	number of heat transfer units (heat exchanger analysis)
P	power required to overcome a certain frictional head, hp
PI	constant π
PHPILP	heat pump isolation loop pump power requirement, hp
PRCT	fractional run time for heat pump unit
PT	total community pumping power requirement, hp
PT2	total two-house loop pumping power requirement, hp
PT2AVG	average value of PT2 for all loops, hp
PT2I	number of two-house loops
PT2TOT	total power required for all two-house loops, hp
PTHLP	power required to operate two-house loop pump, hp
QIN(I)	flow to be added into main flow at step I, GPM
QL(I)	flow entering left-hand branch at step I, GPM
QR(I)	flow entering right-hand branch at step I, GPM
Q	flow rate being analyzed at a given step, GPM
QABS	heat pump heat of absorption, BTUH
QADIST	heat added due to flow disturbance friction effects, BTUH
QALOAD	community heat load calculated by energy balance, BTUH

QAPF	heat added due to pipe flow frictional effects, BTUH
QCFS	community water flow rate in cubic feet per second
QD	domestic water flow rate, GPM
QE	water flow rate exiting end of main supply, GPM
QEL	water flow rate exiting left-hand return line, GPM
QEM	water flow rate exiting main return line, GPM
QH	house loop heating water flow rate, GPM
QHEXT	sum of water flow rates through the heat exchangers, GPM
QHP	water flow rate through the heat pump, GPM
QI	initial community water flow rate, GPM
QIM	flow rate through main after extraction of house loop flow, GPM
QL1	dummy flow rate, GPM
QLCF	heat loss due to consumptive water flow, BTUH
QLHP	sum of heat pump QABS's adjusted for run time, BTUH
QLOAD	community heat load based upon temperature difference, BTUH
QLS	water flow rate entering left-hand secondary branch, GPM
QLSC	heat lost due to conduction through the soil, BTUH
QM	make-up water flow rate, GPM
QR1	dummy flow rate, GPM
QRATIO	ratio of tee branch flow rate to combined tee flow rate
QRS	water flow rate entering right-hand secondary branch, GPM
STEP	indicator of step at which the minimum heat exchanger EWT occurs
STEPHP	indicator of worst heat pump operating point
SUMH	sum of houses analyzed
SUMHP	sum of heat pumps analyzed
TIN(I)	temperature of water to be added into main flow at step I, °F

TL(I) temperature of water entering left-hand branch at step I, °F

TR(I) temperature of water entering right-hand branch at step I, °F

TA dummy temperature variable, °F

TAVG average heat exchanger entering water temperature, °F

TCI temperature of heat exchanger cold side inlet water flow, °F

TCI2 dummy temperature variable to check successive TCI values, °F

TCF temperature of consumptive water flow, °F

TCO temperature of heat exchanger cold side outlet water flow, °F

TE temperature of main supply exiting water flow, °F

TEE indicator for type of tee, 1 = dividing flow, 2 = combining flow

TEL temperature of water exiting left-hand return line, °F

TEM temperature of water exiting main return line, °F

TES ambient air temperature, °F

THETA angle of smooth pipe bend, degrees

THP sum of heat pump entering water temperatures, °F

THPAVG average heat pump entering water temperature, °F

TI temperature of water in component being analyzed, °F

TII temperature of water being supplied to the community, °F

TIM water temperature in main after house loop flow extraction, °F

TLS temperature of left-hand secondary branch water flow, °F

TM temperature of make-up water, °F

TMIN minimum heat exchanger entering water temperature, °F

TMINHP minimum heat pump entering water temperature, °F

TOTP average total power required per house, kW

TRS temperature of water entering right-hand secondary branch, °F

TTOT sum of heat exchanger entering water temperatures, °F

U heat exchanger heat transfer coefficient, BTU/hr-ft^2-°F

V velocity of water in pipe, ft/sec

VELC dummy velocity variable used in calculating loss through tees

W hourly power input to heat pump, hp

WAVG average heat pump power input, hp

WMAX maximum heat pump power input within the community, hp

WTOT sum of heat pump power inputs, hp

X consumptive water flow factor

Z distance pipe centerline is buried below the earth's surface, ft

```
$JOB            P=20              RICK PELFREY
      DIMENSION QL(20),QR(20),TL(20),TR(20),HFL(20),HFR(20)
      DIMENSION L(70),H(70),D(70),L1(70),LB(70),L2(70),RET(70),B(70)
      DIMENSION QIN(60),TIN(60)
      REAL L,L1,LB,L2,LI,MU,NH,KE,KW
      INTEGER STEP,STEPHP
C***********************************************************************
C***  NOTE: THESE FUNCTIONS ARE FOR A FRIEDRICH HEAT PUMP MODEL        ***
C***        803/804-024 WITH 800 SCFM AIR FLOW AT 70 DEGREES F         ***
C***        DRY BULB AND 5 GPM SUPPLY WATER FLOW (2500 LBM/HR)         ***
      FNCOP(T)=-14.663+0.64375*T-0.0074571*T**2+2.8889E-5*T**3
      FNCAP(T)=-104.06+4.4771*T-0.048078*T**2+1.7576E-4*T**3
      FNDT(T)=-46.43+1.8648*T-0.020416*T**2+7.5758E-5*T**3
      FNKW(T)=4.6369-0.099095*T+0.0014714*T**2-6.6667E-6*T**3
C***********************************************************************
      TI=TII=90.
      TES=-7.
      FF=1.00
      BTUREQ=1.3*250.*(70.-TES)
      KE=0.50
      READ,QD,NH,N,E,D2,Z,TM
      DB=D2
      X=1.
      QD=QD/1440.
      QH=8.5
C APPROXIMATE HEAT PUMP CAPACITY 35000 BTUH
      RUNT=NH*BTUREQ/35000.
      IHP=RUNT+1
      INCT=INC=NH/IHP
C***********************************************************************
C**  DENSITY (RHO) AND DYNAMIC VISCOSITY (MU) OF WATER                  **
C**  AS FUNCTIONS OF TEMPERATURE (TI)                                   **
      RHO=62.363+0.005252*TI-8.8518E-5*TI**2.
      MU=0.0017254-2.0277E-5*TI+7.4358E-8*TI**2.
C***********************************************************************
C* THE ISOLATION LOOP MAKES USE OF AN ALFA-LAVAL PLATE HEAT EXCHANGER **
C* TYPE P01VL WITH AN EFFECTIVE AREA OF 4.5 SQUARE FEET               **
C* AND A GRUNDFOS 1/20 HP PUMP MODEL UP 25-42 SF DELIVERING 5 GPM     **
C* THE TWO-HOUSE LOOP USES TWO GRUNDFOS 1/12 HP PUMPS (ONE PER HOUSE) **
C* MODEL UP 25-64 SF WITH AVERAGE TWO-HOUSE LOOP FLOW OF 8.5 GPM      **
      AHEX=4.5
      U=640.
      QHP=5.
      CMIN=500.*QHP
      C=QHP/QH
      NTU=U*AHEX/CMIN
      EFF=EXP(-NTU*(1.-C))
      EF=(1.-EFF)/(1.-C*EFF)
      PHPILP=1/20.
      PTHLP=1/12.
      PRINT 44,AHEX,U,QHP
   44 FORMAT('1',/////,5X,'THE ISOLATION LOOP USES AN ALFA-LAVAL HEAT EX
     $CHANGER TYPE P01VL WITH AN EFFECTIVE AREA OF ',F4.1,' SQ.FT.',/
     $,5X,'THE OVERALL U VALUE IS ',F5.0,' BTU/HR.SQ.FT.F',//
     $,5X,'A FRIEDRICH HEAT PUMP MODEL 803/804-024 IS USED WITH 800 SCFM
     $ AIR FLOW AT 70 DEGREES F DRY BULB',/
     $,5X,'THE ISOLATION LOOP WATER FLOW RATE IS ',F3.0,' GPM',/
     $,5X,'SUPPLIED BY A 1/20 HP GRUNDFOS PUMP MODEL UP 25-42 SF',//
     $,5X,'THE TWO-HOUSE LOOP IS SUPPLIED WITH TWO GRUNDFOS 1/12 HP PUMP
     $S (ONE PER HOME)',/,5X,'MODEL UP 25-64 SF DELIVERING AN AVERAGE LO
```

```
     $OP FLOW OF 8.5 GPM (SIMULTANEOUS OPERATION)',///)
      PRINT 50
   50 FORMAT(' ',5X,'VALUES OF PARAMETERS FOR THIS RUN',//)
      PRINT 51,RHO,MU,E,QD*1440.,QD,X,QD*1440.*X,QD*X,QH*1440.,QH,FF
   51 FORMAT(' ',4X,'DENSITY OF WATER, RHO=',F5.2,' LBM/CU.FT.',//
     $,5X,'DYNAMIC VISCOSITY, MU=',F8.6,' LBM/FT.SEC.',//
     $,5X,'RELATIVE ROUGHNESS, E=',F7.5,' FT.',//
     $,5X,'AVERAGE CONSUMPTIVE WATER FLOW, QD=',F4.0,' GAL/DAY/HOME   OR
     $    ',F5.3,' GAL/MIN/HOME',//
     $,5X,'CONSUMPTIVE FLOW FACTOR (TIMES AVG.), X=',F4.1,//
     $,5X,'DOMESTIC WATER FLOW, QD=',F4.0,' GAL/DAY/HOME   OR   ',F5.3,
     $' GAL/MIN/HOME',//
     $,5X,'HEATING WATER FLOW, QH=',F6.0,'GAL/DAY/HOME   OR   ',F5.3,
     $' GAL/MIN/HOME',//
     $,5X,'COMMUNITY MAIN PIPING FLOW FACTOR, FF=',F3.1,//)
      PRINT 52,D2,DB,BTUREQ
   52 FORMAT(' ',4X,'DIAMETER OF EXISTING HOUSE PIPING ',F4.2,' IN.',//
     $,5X,'DIAMETER OF ADDED HOUSE PIPING ',F4.2,' IN.',//
     $,5X,'REQUIRED HEAT LOAD/HOUSE, BTUREQ=',F6.0,' BTU/HR.',//)
      PRINT 53,TI,KE,TES,Z
   53 FORMAT(' ',4X,'INITIAL SUPPLY WATER TEMPERATURE, TI=',F4.0,' F',//
     $,5X,'THERMAL CONDUCTIVITY OF SOIL, KE=',F4.2,' BTU/HR.FT.F',//,5X,
     $'TEMPERATURE OF GROUND SURFACE, TES=',F4.0,' F',//,5X,'DISTANCE PI
     $PE IS BURIED BELOW GROUND SURFACE, Z=',F4.2,' FT.')
C***********************************************************************
      READ,(L(I),H(I),D(I),L1(I),LB(I),L2(I),RET(I),B(I),I=1,N)
      TTOT=WTOT=WMAX=COPTOT=DTFTOT=QHEXT=PT2TOT=PT2I=HFTOT=0.
      QAPF=QLSC=QLCF=QLHP=QADIST=THP=DTHP=0.
      TMIN=500.
      SUMHP=SUMH=0.
      PT=0.
      JR=JL=0
      G=32.1740
      PI=3.1415926
      CFS=7.4805*60.
C INITIAL SYSTEM WATER FLOW RATE
      QI=Q=FF*100.
      PRINT 60
   60 FORMAT('1',//,' ','STEP',T10,'PIPE LOCATION',T29,'PIPE',T36,'PIPE'
     $,T44,'TOTAL',T53,'EXIT',T62,'REYNOLDS',T73,'FRICTION',T84,'HEAD',
     $T92,'POWER',T101,'TOTAL',T110,'ENT.',T119,'TEMP.',T128,'EXIT')
      PRINT 61
   61 FORMAT(' ',2X,'N',T15,'AND',T29,'DIA.',T36,'LEN.',T44,'NUMBER',T53
     $,'FLOW',T63,'NUMBER',T74,'FACTOR',T84,'LOSS',T92,'REQD',T101,
     $'POWER',T110,'TEMP.',T119,'LOSS',T128,'TEMP.')
      PRINT 62
   62 FORMAT(T13,'BRANCHING',T30,'IN.',T37,'FT.',T44,'HOUSES',T52,'GAL/M
     $IN',T85,'FT.',T94,'HP',T103,'HP',T112,'F',T121,'F',T130,'F',//)
      PRINT 70,Q,TI
   70 FORMAT(' ', 7X,'MAIN SUPPLY',T50,F8.2,T127,F6.2)
C***********************************************************************
C***********************************************************************
      DO 10000 I=1,N
      M=B(I)
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17),M
C B(I)=0  ITERATE ALONG SELECTED PIPE SEGMENT
      TIM=TI
      QIM=Q-QD*X-QH
      IF(H(I).EQ.0) QIM=Q
      PT2=HF2=0.
```

```
      I1=0
      IF(H(I).EQ.0.) I1=3
C CALCULATE TEMP. LOSS IN PIPE FROM BRANCH TO HOUSE
  100 I1=I1+1
      GO TO (110,120,160,180),I1
C PIPE FROM STREET TO HOUSE
  110 LI=L1(I)
      DI=D2
      Q=QD*X+QH
      PRINT 115
  115 FORMAT(/,T13,'STREET TO HOUSE')
      GO TO 200
C PIPE BETWEEN HOUSES
  120 LI=LB(I)
      DI=DB
      Q=QH
      PRINT 125
  125 FORMAT(T13,'BETWEEN HOUSES')
      GO TO 200
C PIPE FROM HOUSE TO STREET
  160 LI=L2(I)
      DI=D2
      Q=QH-QD*X
      PRINT 165
  165 FORMAT(T13,'HOUSE TO STREET ')
      GO TO 200
  180 CONTINUE
      IF(RET(I).GE.0.) GO TO 190
      IF(ABS(RET(I)).LE.I) GO TO 182
C TWO-HOUSE LOOP FLOW RETURNS BEFORE IT IS INITIALIZED
C SPECIAL FUNCTION FOR THE SUNRISE ADDITION SUBDIVISION
      TIN(I)=0.5*(TIN(I-1)+TIN(I+1))
      QIN(I)=QIN(I-1)
C TWO-HOUSE LOOP FLOW RETURN INTO STREET MAIN
  182 Q=QIM+QIN(I)
      TI=(QIM*TIM+QIN(I)*TIN(I))/Q
      PRINT 185,-RET(I),QIN(I),TIN(I)
  185 FORMAT(T13,'RETURN FROM',F4.0,T50,F8.2,T127,F6.2)
C PIPE THROUGH STREET
  190 LI=L(I)
      DI=D(I)
      PRINT 195,I
  195 FORMAT(T2,I3,T11,'THROUGH STREET')
C CALCULATE TEMPERATURE LOSS
  200 DFT=DI/12.
      QCFS=Q/CFS
      DTF=0.
      TA=TI
      COSHI=ALOG((2.*Z/DFT)+SQRT((2.*Z/DFT)**2.-1.))
      CET=2.*PI*KE*LI/(RHO*QCFS*COSHI*3600.)
  210 DTFA=DTF
      DTF=CET*(TA-TES)
      IF (ABS(DTF-DTFA).LT.0.001) GO TO 220
      TA=TI-(DTF/2.)
      GO TO 210
  220 TA=TI
      CALL FLOSS(PI,DFT,QCFS,RHO,MU,E,LI,G,RE,F,HF,P)
C HEAT LOSS BY CONDUCTION THROUGH THE GROUND
      QLSC=QLSC+QCFS*RHO*DTF*3600.
      DTF=DTF-HF/778.16
```

```
      TI=TI-DTF
C HEAT ADDED DUE TO FRICTIONAL EFFECTS
      QAPF=QAPF+P*2545.
      PRINT 225,DI,LI,Q,RE,F,HF,P,TA,DTF,TI
  225 FORMAT('+',T29,F4.2,T35,F6.2,T50,F8.2,T62,F8.0,T73,F6.4,T82,F6.2,
     $T92,F6.4,T110,F6.2,T119,F5.2,T127,F6.2)
      PT2=PT2+P
      HF2=HF2+HF
      IF(I1.EQ.4) GO TO 350
      IF(I1.EQ.3) GO TO 300
C HEAT PUMP ISOLATION LOOP
      TCF=TI
      SUMH=SUMH+1.
      Q=QH
      DPHEX=0.032332-0.0035109*Q+0.032623*Q**2-1.8784E-4*Q**3
      HL=DPHEX*144./RHO
      P=HL*Q*RHO/(CFS*550.)
      PT2=PT2+P
      HF2=HF2+HL
      QAPF=QAPF+P*2545.
      QHEXT=QHEXT+Q
      IF(SUMHP.GT.RUNT) INCT=NH+1
      IF(SUMH.EQ.INCT) GO TO 226
C HEAT PUMP NOT OPERATING
      DTF=0.
      GO TO 230
C HEAT PUMP IN OPERATION
  226 TCI=TI-17.
      IF(INC.GE.2) GO TO 227
C CHECH CONDITION TO CHANGE INC FROM 1 TO 2
      ICHK=(NH+SUMH)/2.
      IF(RUNT.LT.ICHK) INC=2
  227 TCO=EF*TI+(1.-EF)*TCI
      TCI2=TCO-FNDT(TCO)
      IF(ABS(TCI2-TCI).LT.0.01) GO TO 228
      TCI=TCI2
      GO TO 227
  228 COP=FNCOP(TCO)
      KW=FNKW(TCO)
      CAP=FNCAP(TCO)*1000.
      PRCT=BTUREQ/CAP
      ADJKW=PRCT*KW
      QABS=EF*CMIN*(TI-TCI)
      DTF=QABS*7.4805/(Q*RHO*60.)
      DTF=DTF-HL/778.16
      QLHP=QLHP+QABS
      DTHP=DTHP+TCO-TCI
      THP=THP+TCO
      W=ADJKW/0.745712
      SUMHP=SUMHP+1.
      IF(W.LT.WMAX) GO TO 229
C FIND WORST OPERATING HEAT PUMP
      TMINHP=TCO
      WMAX=W
      STEPHP=I
  229 WTOT=WTOT+W
      COPTOT=COPTOT+COP
  230 PRINT 235,SUMH,QH,HL,P,TI,DTF,TI-DTF
  235 FORMAT(T15,'HEAT EXCH.',T45,F4.0,T53,F5.2,T82,F6.2,T92,F6.4,
     $T110,F6.2,3X,F5.2,3X,F6.2)
```

```
      IF(SUMH.LT.INCT) GO TO 250
      PRINT 240,COP,CAP,PRCT,W,TCO,TCO-TCI,TCI,QABS,KW,ADJKW
  240 FORMAT(T15,'HEAT PUMP',5X,'COP=',F5.2,7X,'CAPACITY=',F6.0,' BTUH',
     $7X,'PRCT=',F6.4,T91,F6.4,T109,F6.2,3X,F5.2,3X,F6.2,/,
     $T25,'QABS=',F6.0,' BTUH',7X,'KW=',F5.3,7X,'ADJKW=',F5.3)
      INCT=INCT+INC
  250 TTOT=TTOT+TI
      DTFTOT=DTFTOT+DTF
      IF(TI.GT.TMIN) GO TO 260
C FIND MINIMUM HEAT EXCHANGER ENTERING WATER TEMPERATURE
      TMIN=TI
      STEP=I
  260 TI=TI-DTF
      IF(I1.EQ.2) TCF=TI
      QLCF=QLCF+QD*X*RHO*(TCF-TM)*3600./CFS
      IF(H(I).EQ.1) I1=2
      GO TO 100
  300 QIN(RET(I))=Q
      TIN(RET(I))=TI
C MISCELLANEOUS PIPE BENDS, TEES, VALVES, ETC.
C LOSS COEFFICIENT OF 7.1 PER HOUSE COMPUTED FOR TWO-HOUSE LOOP
      KM=H(I)*7.1
      HF=KM*(QH*144./(CFS*PI*D2**2/4.))**2/(2.*G)
      P=QH*RHO*HF/(CFS*550.)
      QAPF=QAPF+P*2545.
      PRINT 310,HF,P
  310 FORMAT(T13,'PIPE BENDS,VALVES,ETC.',T82,F6.2,T92,F6.4)
      PT2=PT2+P
      HF2=HF2+HF
      TI=TIM
      Q=QIM
      PT2TOT=PT2TOT+PT2
      PT2I=PT2I+1.
      PRINT 325,RET(I),HF2,PT2
  325 FORMAT(T13,'ADD TO STREET AT STEP',F4.0,6X,'TOTAL LOOP PUMPING POW
     $ER (THEORETICAL)',T82,F6.2,T92,F6.4,/)
      GO TO 100
  350 PT=PT+P
      HFTOT=HFTOT+HF
      PRINT 360,PT
  360 FORMAT('+',T99,F7.3,/)
      GO TO 10000
C*********************************************************************
C B(I)=1  EVALUATE LEFT HAND BRANCH FLOW FROM MAIN SUPPLY
    1 DI=D(I)
      JL=JL+1
      QL(JL)=QI*H(I)/NH
      TL(JL)=TI
      QRATIO=QL(JL)/Q
      ARATIO=(DI/D(I-1))**2
      TEE=1.
      CALL LOSSK(DI,Q,CFS,PI,VELC,G,TEE,QRATIO,ARATIO,K31,K32)
      HFL(JL)=K31*VELC
      HF=K32*VELC
      Q=Q-QL(JL)
      PRINT 1010,I,JL
 1010 FORMAT(' ',I3,6X,'LB(',I2,') TEE-RUN')
      GO TO 900
C*********************************************************************
C B(I)=2  EVALUATE RIGHT-HAND BRANCH FLOW FROM MAIN SUPPLY
```

```
    2 DI=D(I)
      JR=JR+1
      QR(JR)=QI*H(I)/NH
      TR(JR)=TI
      QRATIO=QR(JR)/Q
      ARATIO=(DI/D(I-1))**2
      TEE=1.
      CALL LOSSK(DI,Q,CFS,PI,VELC,G,TEE,QRATIO,ARATIO,K31,K32)
      HFR(JR)=K31*VELC
      HF=K32*VELC
      Q=Q-QR(JR)
      PRINT 1020,I,JR
 1020 FORMAT(' ',I3,6X,'RB(',I2,') TEE-RUN')
      GO TO 900
C*********************************************************************
C B(I)=3  END MAIN SUPPLY LINE
    3 QE=Q
      TE=TI
      DE=D(I)
      K=JL=0
      Q=0.
      PRINT 1030,I,D(I),QE,TE
 1030 FORMAT(' ',I3,4X,'END MAIN SUPPLY',T25,F4.1,T50,F8.2,T127,F6.2)
      GO TO 10000
C*********************************************************************
C B(I)=4  INITIALIZE LEFT-HAND BRANCH
    4 JL=JL+1
      Q=QL(JL)
      TI=TL(JL)
      HF=HFL(JL)
      PRINT 1040,I,JL
 1040 FORMAT(' ',I3,4X,'LHB(',I2,') TEE-BRANCH')
      GO TO 900
C*********************************************************************
C B(I)=5  END LEFT-HAND BRANCH & INITIALIZE LH RETURN LINE
    5 K=K+1
      IF (K.EQ.1) GO TO 6
      PRINT 1050,I,D(I),Q,TI
 1050 FORMAT(' ',I3,4X,'END L.H. BRANCH',T25,F4.1,T50,F8.2,T127,F6.2)
      TI=(TEL*QEL+Q*TI)/(Q+QEL)
      QRATIO=Q/(Q+QEL)
      Q=Q+QEL
      ARATIO=(D(I)/D(I+1))**2
      DI=D(I+1)
      TEE=2.
      CALL LOSSK(DI,Q,CFS,PI,VELC,G,TEE,QRATIO,ARATIO,K13,K23)
      HF=(K13+K23)*VELC
      PRINT 1052,I
 1052 FORMAT(' ',I3,4X,'LH RETURN TEE-COMB.')
      GO TO 900
C*********************************************************************
C B(I)=6  END ITERATIONS ON LEFT-HAND RETURN LINE
    6 QEL=Q
      TEL=TI
      PRINT 1060,I,D(I),Q,TI
 1060 FORMAT(' ',I3,4X,'END LH RETURN  ',T25,F4.1,T50,F8.2,T127,F6.2)
      GO TO 10000
C*********************************************************************
C B(I)=7  EVALUATE AND INITIALIZE LEFT-HAND SECONDARY BRANCH FLOW,
C         EVALUATE REMAINING PRIMARY BRANCH FLOW
```

```
    7 DI=D(I)
      QLS=QI*H(I)/NH
      TLS=TI
      QRATIO=QLS/Q
      ARATIO=(DI/D(I-1))**2
      TEE=1.
      CALL LOSSK(DI,Q,CFS,PI,VELC,G,TEE,QRATIO,ARATIO,K31,K32)
      HFLS=K32*VELC
      HF=K31*VELC
      QL1=Q-QLS
      Q=QLS
      QLS=QL1
      PRINT 1070,I
 1070 FORMAT(' ',I3,4X,' LHSB TEE-BRANCH') _
      GO TO 900
C***********************************************************************
C B(I)=8  RETURN TO PRIMARY BRANCH WHERE LH SECONDARY BRANCH BEGAN
    8 Q=QLS
      TI=TLS
      HF=HFLS
      PRINT 1080,I
 1080 FORMAT(' ',I3,4X,'LHSB TEE-RUN')
      GO TO 900
C***********************************************************************
C B(I)=9  JOIN LH RETURN LINE TO MAIN SUPPLY, RETURN LINES
    9 Q=QE+QEL
      TI=(TEL*QEL+TE*QE)/Q
      QRATIO=QE/Q
      ARATIO=(DE/D(I+1))**2
      DI=D(I+1)
      TEE=2.
      CALL LOSSK(DI,Q,CFS,PI,VELC,G,TEE,QRATIO,ARATIO,K13,K23)
      HF=(K13+K23)*VELC
      PRINT 1090,I
 1090 FORMAT(' ',I3,4X,'RETURN MAIN TEE-COMB.')
      GO TO 900
C***********************************************************************
C B(I)=10  END ITERATIONS ON RETURN MAIN
   10 QEM=Q
      TEM=TI
      PRINT 1100,I,Q,TI
 1100 FORMAT(' ',I3,4X,'END RETURN MAIN',T50,F8.2,T127,F6.2)
      GO TO 10000
C***********************************************************************
C B(I)=11  INITIALIZE RIGHT-HAND BRANCH
   11 Q=QR(JR)
      TI=TR(JR)
      HF=HFR(JR)
      PRINT 1110,I,JR
 1110 FORMAT(' ',I3,4X,'RHB(',I2,') TEE-BRANCH')
      JR=JR-1
      GO TO 900
C***********************************************************************
C B(I)=12  EVALUATE RIGHT-HAND SECONDARY BRANCH FLOW, EVALUATE
C          AND INITIALIZE REMAINING PRIMARY BRANCH FLOW
   12 DI=D(I)
      QRS=QI*H(I)/NH
      TRS=TI
      QRATIO=QRS/Q
      ARATIO=(DI/D(I-1))**2
```

```
      TEE=1.
      CALL LOSSK(DI,Q,CFS,PI,VELC,G,TEE,QRATIO,ARATIO,K31,K32)
      HFRS=K31*VELC
      HF=K32*VELC
      Q=Q-QRS
      PRINT 1120,I
 1120 FORMAT(' ',I3,4X,' RHSB TEE-RUN')
      GO TO 900
C***********************************************************************
C B(I)=13  END RIGHT-HAND BRANCH & INITIALIZE RETURN MAIN
   13 PRINT 1130,I,D(I),Q,TI
 1130 FORMAT(' ',I3,4X,'END R.H. BRANCH',T25,F4.1,T50,F8.2,T127,F6.2)
      TEM=(TEM*QEM+TI*Q)/(QEM+Q)
      QEM=QEM+Q
      QRATIO=Q/QEM
      ARATIO=(D(I)/D(I+1))**2
      DI=D(I+1)
      TEE=2.
      CALL LOSSK(DI,Q,CFS,PI,VELC,G,TEE,QRATIO,ARATIO,K13,K23)
      HF=(K13+K23)*VELC
      Q=QEM
      TI=TEM
      PRINT 1132,I
 1132 FORMAT(' ',I3,4X,'RETURN MAIN TEE-COMB.')
      GO TO 900
C***********************************************************************
C B(I)=14  RETURN TO RH SECONDARY BRANCH AND INITIALIZE
   14 Q=QRS
      TI=TRS
      HF=HFRS
      PRINT 1140,I
 1140 FORMAT(' ',I3,4X,'RHSB TEE-BRANCH')
      GO TO 900
C***********************************************************************
C B(I)=15  EVALUATE LOSSES THRU A THETA-DEGREE PIPE BEND
C ****  THE FOLLOWING EQUATIONS WERE TAKEN FROM CRANE TECHNICAL
C ****  PAPER NO. 410  (CURVE FIT PERFORMED FOR FT)
   15 THETA=-L(I)
      FT1=0.027702-0.0048356*D(I)+6.124E-4*D(I)**2-3.2565E-5*D(I)**3
      FT2=5.9632E-7*D(I)**4
      FT=FT1+FT2
      KB=FT*(THETA*0.1297+3.823)
      AREA=(PI*D(I)**2)/(4.*144.)
      V=Q/(AREA*CFS)
      HF=(KB*V**2)/(2.*G)
      PRINT 1150,I,THETA
 1150 FORMAT(' ',I3,5X,F4.0,' DEGREE BEND')
      GO TO 900
C***********************************************************************
C B(I)=16  EVALUATE LOSSES THRU AN ABRUPT PIPE CONTRACTION
   16 D21=D(I)/D(I-1)
C THE FOLLOWING EQUATION WAS OBTAINED FOR 'KC' VALUES TABULATED
C IN ROBERSON/CROWE 'ENGINEERING FLUID MECHANICS' PAGE 304
      KC=.50008-.18499*D21+1.0212*D21**2.-3.0589*D21**3.+1.7228*D21**4.
      AREA=(PI*D(I)**2.)/(4.*144.)
      V=Q/(AREA*CFS)
      HF=(KC*V**2.)/(2.*G)
      PRINT 1160,I
 1160 FORMAT(' ',I3,5X,'CONTRACTION')
      GO TO 900
```

```
C*********************************************************************
C B(I)=17 ADD IN MAKE-UP WATER
   17 QM=NH*QD*X
      DI=D(I)
      TI=(TI*Q+TM*QM)/(Q+QM)
      Q=Q+QM
      QRATIO=QM/Q
      ARATIO=(DI/D(I-1))**2
      TEE=2.
      CALL LOSSK(DI,Q,CFS,PI,VELC,G,TEE,QRATIO,ARATIO,K13,K23)
      HF=(K13+K23)*VELC
      IF(X.EQ.0.) HF=0.
      PRINT 1170,I,QM,TM
 1170 FORMAT(' ',I3,4X,'ADD IN MAKE-UP WATER',T53,F5.2,T110,F6.2,/,8X,'C
     $OMBINATION')
C*********************************************************************
  900 P=(Q*RHO*HF)/(CFS*550.)
      QADIST=QADIST+P*2545.
      PT=PT+P
      TI=TI+HF/778.16
      HFTOT=HFTOT+HF
      PRINT 950,D(I),Q,HF,P,PT,TI
  950 FORMAT('+',T29,F4.1,T50,F8.2,T83,F5.2,4X,F6.4,2X,F6.3,T127,F6.2)
10000 CONTINUE
C*********************************************************************
C*********************************************************************
      DELTAP=HFTOT*RHO/144.
      TAVG=TTOT/SUMH
      WAVG=WTOT/SUMHP
      COPAVG=COPTOT/SUMHP
      DTFAVG=DTFTOT/SUMHP
      THPAVG=THP/SUMHP
      DTHPAV=DTHP/SUMHP
      PT2AVG=PT2TOT/PT2I
      PRINT 10010,TMIN,STEP,TAVG,DTFAVG,QHEXT/SUMH
10010 FORMAT('1',/,5X,'MINIMUM HEAT EXCHANGER ENTERING WATER TEMPERATURE
     $=',F6.2,' DEGREES F -  AT STEP ',I2,/
     $,5X,'AVERAGE HEAT EXCHANGER ENTERING WATER TEMPERATURE=',F6.2,' DE
     $GREES F',//
     $,5X,'AVERAGE TEMPERATURE DROP ACROSS THE HEAT EXCHANGER=',F5.2,' D
     $EGREES F',//
     $,5X,'THE AVERAGE QUANTITY OF WATER SUPPLIED TO THE HEAT EXCHANGER
     $=',F5.2,' GAL/MIN')
      PRINT 10020,TMINHP,STEPHP,THPAVG,DTHPAV,WMAX,STEPHP,WAVG,COPAVG
10020 FORMAT(//,5X,'MINIMUM HEAT PUMP ENTERING WATER TEMPERATURE=',F6.2,
     $' DEGREES F -  AT STEP ',I2,/
     $,5X,'AVERAGE HEAT PUMP ENTERING WATER TEMPERATURE=',F6.2,' DEGREES
     $ F',//
     $,5X,'AVERAGE TEMPERATURE DROP ACROSS THE HEAT PUMP=',F5.2,' DEGREE
     $S F',//
     $,5X,'MAXIMUM HEAT PUMP POWER INPUT REQUIRED=',F6.3,' HP -  AT STEP
     $ ',I2,/
     $,5X,'AVERAGE HEAT PUMP POWER INPUT REQUIRED=',F6.3,' HP',//
     $,5X,'AVERAGE HEAT PUMP COEFFICIENT OF PERFORMANCE=',F5.2,//)
      PRINT 10100,PT2AVG
10100 FORMAT(' ',4X,'THE AVERAGE THEORETICAL POWER REQUIRED TO PUMP THE
     $SUPPLY WATER FROM THE STREET TO THE HOUSE AND BACK IS ',F6.3,' HP'
     $,//)
      TOTP=PHPILP+WAVG+PTHLP+PT/(SUMH*.5)
      PRINT 10110,TOTP,TOTP*0.745712
```

```
10110 FORMAT(4X,' THE AVERAGE POWER REQUIRED PER HOME IS ',F5.3,' HP',
     $'    OR ',F5.3,' KW',/
     $,5X,'ASSUMING A 50% EFFICIENT MAIN FLOW PUMP',//)
      QALOAD=QLSC+QLCF+QLHP-QADIST-QAPF
      PRINT 10120,QLSC,QLCF,QLHP,QADIST+QAPF,QALOAD
10120 FORMAT(//,10X,' COMMUNITY HEAT FLOWS',//,4X,
     $'HEAT LOST BY CONDUCTION THROUGH SOIL ',F9.0,' BTU/HR',//,4X,
     $'HEAT LOST AS CONSUMPTIVE WATER FLOW  ',F9.0,' BTU/HR',//,4X,
     $'HEAT TRANSFERED TO HOME HEAT PUMPS   ',F9.0,' BTU/HR',//,4X,
     $'HEAT ADDED DUE PIPE FRICTION & FLOW  '/,4X,
     $'    DISTURBANCES (TEES,BENDS,ETC.)    ',F9.0,' BTU/HR',//,41X,
     $'*********',/,4X,
     $'TOTAL HEAT LOAD ON MAIN HT EXCHANGER ',F9.0,' BTU/HR',//)
      QLOAD=QCFS*RHO*(TII-TI)*3600.
      PRINT 10130,QLOAD
10130 FORMAT(3X,' LOAD USING M*CP*DT ACROSS MAIN HT.EX.',F9.0,' BTU/HR')
      PRINT 10140,Q,DELTAP,HFTOT,PT
10140 FORMAT(///,' ',T5,'MAIN PUMP: FLOW RATE ',F6.2,' GAL/MIN',/,T16,
     $'PRESSURE DROP ',F6.2,' PSI',/,T16,'REQUIRED HEAD ',F6.2,' FEET',/
     $,T16,'POWER REQUIRED ',F6.3,' HP')
      PRINT 10150
10150 FORMAT(//////)
      STOP
      END
C***********************************************************************

      SUBROUTINE FLOSS(PI,DFT,QCFS,RHO,MU,E,LI,G,RE,F,HF,P)
      REAL MU,LI
      AREA=(PI*DFT**2.)/4.
      V=QCFS/AREA
      RE=(RHO*V*DFT)/MU
      F=0.0190
C COLEBROOK-WHITE EQUATION
    1 B1=-2.00*ALOG10(E/(3.7*DFT)+2.51/(RE*SQRT(F)))
      A=(1./B1)**2.
      IF (ABS(A-F).LT.0.0001) GO TO 2
      F=(F+A)/2.
      GO TO 1
C DARCY-WEISBACH EQUATION
    2 HF=F*(LI/DFT)*(V**2/(2*G))
      P=(QCFS*RHO*HF)/550.
      RETURN
      END
C***********************************************************************

      SUBROUTINE LOSSK(DI,QI,CFS,PI,VELC,G,TEE,Q,A,KA,KB)
      DFT=DI/12.
      QCFS=QI/CFS
      AREA=(PI*DFT**2.)/4.
      V=QCFS/AREA
      VELC=(V**2.)/(2.*G)
C THEORETICAL HEAD LOSS COEFFICIENT EQUATIONS FOR FLOW THROUGH SHARP
C EDGED TEES AS OBTAINED BY BLAISDELL FOR CONVERGING FLOWS IN U.S.D.A.
C TECHNICAL BULLETIN NO. 1283 (1963) - THETA= 90 DEGREES
C    TEE=1.  FOR DIVIDING FLOW....CALCULATE K31,K32
C    TEE=2.  FOR COMBINING FLOW....CALCULATE K13,K23
      KA=-1.+4.*Q-(2.-1./A**2)*Q**2
      KB=2.*Q-Q**2
      RETURN
      END
```

STEP	L(I)	H(I)	D(I)	L1(I)	LB(I)	L2(I)	RET(I)	B(I)
1	175.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0
2	-90.0	0.0	4.0	0.0	0.0	0.0	0.0	15.0
3	50.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0
4	25.0	2.0	4.0	50.0	50.0	50.0	6.0	0.0
5	25.0	2.0	4.0	50.0	50.0	50.0	7.0	0.0
6	25.0	0.0	4.0	0.0	0.0	0.0	-4.0	0.0
7	250.0	0.0	4.0	0.0	0.0	0.0	-5.0	0.0
8	0.0	30.0	2.0	0.0	0.0	0.0	0.0	1.0
9	50.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0
10	0.0	20.0	2.0	0.0	0.0	0.0	0.0	2.0
11	125.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	3.0	0.0	0.0	0.0	0.0	16.0
13	100.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	3.0	0.0	0.0	0.0	0.0	3.0
15	0.0	0.0	2.0	0.0	0.0	0.0	0.0	4.0
16	150.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
17	0.0	8.0	2.0	0.0	0.0	0.0	0.0	12.0
18	50.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
19	0.0	6.0	2.0	0.0	0.0	0.0	0.0	7.0
20	125.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
21	-90.0	0.0	2.0	0.0	0.0	0.0	0.0	15.0
22	250.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
23	-90.0	0.0	2.0	0.0	0.0	0.0	0.0	15.0
24	125.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	2.0	0.0	0.0	0.0	0.0	5.0
26	0.0	0.0	2.0	0.0	0.0	0.0	0.0	8.0
27	250.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	2.0	0.0	0.0	0.0	0.0	5.0
29	125.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	3.0	0.0	0.0	0.0	0.0	6.0
31	0.0	0.0	2.0	0.0	0.0	0.0	0.0	14.0
32	175.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
33	-90.0	0.0	2.0	0.0	0.0	0.0	0.0	15.0
34	300.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
35	0.0	0.0	2.0	0.0	0.0	0.0	0.0	5.0
36	100.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
37	-90.0	0.0	3.0	0.0	0.0	0.0	0.0	15.0
38	450.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
39	0.0	0.0	3.0	0.0	0.0	0.0	0.0	6.0
40	0.0	0.0	3.0	0.0	0.0	0.0	0.0	9.0
41	450.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
42	-90.0	0.0	3.0	0.0	0.0	0.0	0.0	15.0
43	100.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
44	0.0	0.0	3.0	0.0	0.0	0.0	0.0	10.0
45	0.0	0.0	2.0	0.0	0.0	0.0	0.0	11.0
46	150.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0

47	0.0	8.0	2.0	0.0	0.0	0.0	0.0	7.0
48	125.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
49	-90.0	0.0	2.0	0.0	0.0	0.0	0.0	15.0
50	300.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
51	0.0	0.0	2.0	0.0	0.0	0.0	0.0	13.0
52	125.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
53	0.0	0.0	3.0	0.0	0.0	0.0	0.0	10.0
54	0.0	0.0	2.0	0.0	0.0	0.0	0.0	8.0
55	50.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
56	0.0	6.0	2.0	0.0	0.0	0.0	0.0	12.0
57	250.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
58	0.0	0.0	2.0	0.0	0.0	0.0	0.0	13.0
59	175.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
60	0.0	0.0	3.0	0.0	0.0	0.0	0.0	10.0
61	0.0	0.0	2.0	0.0	0.0	0.0	0.0	14.0
62	175.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
63	-90.0	0.0	2.0	0.0	0.0	0.0	0.0	15.0
64	250.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
65	0.0	0.0	2.0	0.0	0.0	0.0	0.0	13.0
66	250.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
67	0.0	0.0	4.0	0.0	0.0	0.0	0.0	17.0
68	275.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0
69	0.0	0.0	4.0	0.0	0.0	0.0	0.0	10.0

STEP N	PIPE LOCATION AND BRANCHING	PIPE DIA. IN.	PIPE LEN. FT.	TOTAL NUMBER HOUSES	EXIT FLOW GAL/MIN	REYNOLDS NUMBER	FRICTION FACTOR	HEAD LOSS FT.	POWER REQD HP	TOTAL POWER HP	ENT. TEMP. F	TEMP. LOSS F	EXIT TEMP. F
	MAIN SUPPLY				100.00								90.00
1	THROUGH STREET	4.00	175.00		100.00	105149.	0.0226	1.20	0.0303	0.030	90.00	0.28	89.72
2	90. DEGREE BEND	4.0			100.00			0.00	0.0000	0.030			89.72
3	THROUGH STREET	4.00	50.00		100.00	105149.	0.0226	0.34	0.0087	0.039	89.72	0.08	89.63
	STREET TO HOUSE	1.00	50.00		8.90	37430.	0.0323	3.98	0.0089		89.63	0.66	88.97
	HEAT EXCH.			1.	8.50			5.20	0.0111		88.97	6.42	82.56
	HEAT PUMP	COP= 3.90		CAPACITY=36426. BTUH			PRCT=0.6870		2.5007		80.18	10.88	69.30
			QABS=27201. BTUH		KW=2.714	ADJKW=1.865							
	BETWEEN HOUSES	1.00	50.00		8.50	35750.	0.0324	3.65	0.0078		82.56	0.64	81.92
	HEAT EXCH.			2.	8.50			5.20	0.0111		81.92	6.14	75.77
	HEAT PUMP	COP= 3.84		CAPACITY=35065. BTUH			PRCT=0.7137		2.5411		73.50	10.42	63.08
			QABS=26041. BTUH		KW=2.655	ADJKW=1.895							
	HOUSE TO STREET	1.00	50.00		8.10	34071.	0.0325	3.32	0.0068		75.77	0.62	75.15
	PIPE BENDS,VALVES,ETC.							2.62	0.0056				
	ADD TO STREET AT STEP 6.			TOTAL LOOP PUMPING POWER (THEORETICAL)				23.98	0.0514				
4	THROUGH STREET	4.00	25.00		91.10	95791.	0.0228	0.14	0.0033	0.042	89.63	0.04	89.59
	STREET TO HOUSE	1.00	50.00		8.90	37430.	0.0323	3.98	0.0089		89.59	0.66	88.93
	HEAT EXCH.			3.	8.50			5.20	0.0111		88.93	6.41	82.51
	HEAT PUMP	COP= 3.90		CAPACITY=36420. BTUH			PRCT=0.6871		2.5008		80.14	10.88	69.26
			QABS=27195. BTUH		KW=2.714	ADJKW=1.865							
	BETWEEN HOUSES	1.00	50.00		8.50	35750.	0.0324	3.65	0.0078		82.51	0.64	81.87
	HEAT EXCH.			4.	8.50			5.20	0.0111		81.87	6.14	75.73
	HEAT PUMP	COP= 3.84		CAPACITY=35055. BTUH			PRCT=0.7139		2.5415		73.46	10.41	63.05
			QABS=26032. BTUH		KW=2.655	ADJKW=1.895							
	HOUSE TO STREET	1.00	50.00		8.10	34071.	0.0325	3.32	0.0068		75.73	0.62	75.11
	PIPE BENDS,VALVES,ETC.							2.62	0.0056				
	ADD TO STREET AT STEP 7.			TOTAL LOOP PUMPING POWER (THEORETICAL)				23.98	0.0514				
5	THROUGH STREET	4.00	25.00		82.20	86434.	0.0231	0.12	0.0025	0.045	89.59	0.05	89.54
	RETURN FROM 4.				8.10								75.15
6	THROUGH STREET	4.00	25.00		90.30	94951.	0.0229	0.14	0.0032	0.048	88.25	0.04	88.21
	RETURN FROM 5.				8.10								75.11
7	THROUGH STREET	4.00	250.00		98.40	103469.	0.0227	1.67	0.0413	0.089	87.13	0.40	86.73
8	LB(1) TEE-RUN	2.0			51.53			0.00	0.0000	0.089			86.73
9	THROUGH STREET	4.00	50.00		51.53	54181.	0.0243	0.10	0.0013	0.090	86.73	0.15	86.57
10	RB(1) TEE-RUN	2.0			20.28			0.00	0.0000	0.090			86.57
11	THROUGH STREET	4.00	125.00		20.28	21322.	0.0279	0.04	0.0002	0.091	86.57	0.97	85.61
12	CONTRACTION	3.0			20.28			0.00	0.0000	0.091			85.61
13	THROUGH STREET	3.00	100.00		20.28	28429.	0.0274	0.14	0.0007	0.091	85.61	0.71	84.89
14	END MAIN SUPPLY	3.0			20.28								84.89
15	LHB(1) TEE-BRANCH	2.0			46.88			6.28	0.0740	0.165			86.74

16	THROUGH STREET	2.00	150.00	46.88	98577.	0.0260	8.34	0.0984	0.264	86.74	0.42	86.32
17	RHSB TEE-RUN	2.0		34.38			0.00	0.0000	0.264			86.32
18	THROUGH STREET	2.00	50.00	34.38	72290.	0.0265	1.52	0.0132	0.277	86.32	0.19	86.13
19	LHSB TEE-BRANCH	2.0		9.38			0.00	0.0000	0.277			86.13
20	THROUGH STREET	2.00	125.00	9.38	19715.	0.0305	0.33	0.0008	0.278	86.13	1.75	84.38
21	90. DEGREE BEND	2.0		9.38			0.00	0.0000	0.278			84.38
22	THROUGH STREET	2.00	250.00	9.38	19715.	0.0305	0.65	0.0015	0.279	84.38	3.40	80.98
23	90. DEGREE BEND	2.0		9.38			0.00	0.0000	0.279			80.98
24	THROUGH STREET	2.00	125.00	9.38	19715.	0.0305	0.33	0.0008	0.280	80.98	1.65	79.32
25	END LH RETURN	2.0		9.38								79.32
26	LHSB TEE-RUN	2.0		25.00			0.00	0.0000	0.280			86.13
27	THROUGH STREET	2.00	250.00	25.00	52574.	0.0272	4.14	0.0260	0.306	86.13	1.31	84.82
28	END L.H. BRANCH	2.0		25.00								84.82
28	LH RETURN TEE-COMB.	2.0		34.38			0.11	0.0010	0.307			83.32
29	THROUGH STREET	3.00	125.00	34.38	48193.	0.0256	0.48	0.0042	0.311	83.32	0.51	82.81
30	END LH RETURN	3.0		34.38								82.81
31	RHSB TEE-BRANCH	2.0		12.50			0.00	0.0000	0.311			86.32
32	THROUGH STREET	2.00	175.00	12.50	26287.	0.0293	0.78	0.0025	0.314	86.32	1.84	84.48
33	90. DEGREE BEND	2.0		12.50			0.00	0.0000	0.314			84.48
34	THROUGH STREET	2.00	300.00	12.50	26287.	0.0293	1.34	0.0042	0.318	84.48	3.07	81.41
35	END L.H. BRANCH	2.0		12.50								81.41
35	LH RETURN TEE-COMB.	2.0		46.88			0.00	0.0000	0.318			82.43
36	THROUGH STREET	3.00	100.00	46.88	65718.	0.0248	0.70	0.0082	0.326	82.43	0.30	82.14
37	90. DEGREE BEND	3.0		46.88			0.00	0.0000	0.326			82.14
38	THROUGH STREET	3.00	450.00	46.88	65718.	0.0248	3.14	0.0370	0.363	82.14	1.33	80.81
39	END LH RETURN	3.0		46.88								80.81
40	RETURN MAIN TEE-COMB.	3.0		67.15			0.00	0.0000	0.363			82.04
41	THROUGH STREET	3.00	450.00	67.15	94147.	0.0241	6.25	0.1057	0.469	82.04	0.92	81.12
42	90. DEGREE BEND	3.0		67.15			0.00	0.0000	0.469			81.12
43	THROUGH STREET	3.00	100.00	67.15	94147.	0.0241	1.39	0.0235	0.492	81.12	0.20	80.92
44	END RETURN MAIN			67.15								80.92
45	RHB(1) TEE-BRANCH	2.0		31.25			2.58	0.0203	0.513			86.58
46	THROUGH STREET	2.00	150.00	31.25	65718.	0.0267	3.80	0.0299	0.543	86.58	0.63	85.94
47	LHSB TEE-BRANCH	2.0		12.50			0.00	0.0000	0.543			85.94
48	THROUGH STREET	2.00	125.00	12.50	26287.	0.0293	0.56	0.0018	0.544	85.94	1.31	84.63
49	90. DEGREE BEND	2.0		12.50			0.00	0.0000	0.544			84.63
50	THROUGH STREET	2.00	300.00	12.50	26287.	0.0293	1.34	0.0042	0.549	84.63	3.08	81.56
51	END R.H. BRANCH	2.0		12.50								81.56
51	RETURN MAIN TEE-COMB.	2.0		79.65			0.00	0.0000	0.549			81.02
52	THROUGH STREET	3.00	125.00	79.65	111672.	0.0238	2.42	0.0484	0.597	81.02	0.21	80.81
53	END RETURN MAIN			79.65								80.81
54	LHSB TEE-RUN	2.0		18.75			0.00	0.0000	0.597			85.94
55	THROUGH STREET	2.00	50.00	18.75	39431.	0.0280	0.48	0.0023		85.94	0.35	85.59

56	.RHSB TEE-RUN	2.0		9.38			0.00	0.0000	0.599			85.59
57	THROUGH STREET	2.00	250.00	9.38	19715.	0.0305	0.65	0.0015	0.601	85.59	3.45	82.15
58	END R.H. BRANCH	2.0		9.38								82.15
58	RETURN MAIN TEE-COMB.	2.0		89.03			0.00	0.0000	0.601			80.95
59	THROUGH STREET	3.00	175.00	89.03	124815.	0.0236	4.20	0.0940	0.695	80.95	0.27	80.68
60	END RETURN MAIN			89.03								80.68
61	RHSB TEE-BRANCH	2.0		9.38			0.00	0.0000	0.695			85.59
62	THROUGH STREET	2.00	175.00	9.38	19715.	0.0305	0.46	0.0011	0.696	85.59	2.43	83.17
63	90. DEGREE BEND	2.0		9.38			0.00	0.0000	0.696			83.17
64	THROUGH STREET	2.00	250.00	9.38	19715.	0.0305	0.65	0.0015	0.697	83.17	3.36	79.81
65	END R.H. BRANCH	2.0		9.38								79.81
65	RETURN MAIN TEE-COMB.	2.0		98.40			0.00	0.0000	0.697			80.60
66	THROUGH STREET	3.00	250.00	98.40	137959.	0.0235	7.28	0.1803	0.878	80.60	0.34	80.26
67	ADD IN MAKE-UP WATER			25.56						40.00		
	COMBINATION	4.0		123.96			0.00	0.0000	0.878			71.96
68	THROUGH STREET	4.00	275.00	123.96	130340.	0.0223	2.86	0.0892	0.967	71.96	0.29	71.67
69	END RETURN MAIN			123.96								71.67

THE ISOLATION LOOP USES AN ALFA-LAVAL HEAT EXCHANGER TYPE P01VL WITH AN EFFECTIVE AREA OF 4.5 SQ.FT.
THE OVERALL U VALUE IS 640. BTU/HR.SQ.FT.F

A FRIEDRICH HEAT PUMP MODEL 803/804-024 IS USED WITH 800 SCFM AIR FLOW AT 70 DEGREES F DRY BULB
THE ISOLATION LOOP WATER FLOW RATE IS 5. GPM
SUPPLIED BY A 1/20 HP GRUNDFOS PUMP MODEL UP 25-42 SF

THE TWO-HOUSE LOOP IS SUPPLIED WITH TWO GRUNDFOS 1/12 HP PUMPS (ONE PER HOME)
MODEL UP 25-64 SF DELIVERING AN AVERAGE LOOP FLOW OF 8.5 GPM (SIMULTANEOUS OPERATION)

VALUES OF PARAMETERS FOR THIS RUN

DENSITY OF WATER, RHO=62.12 LBM/CU.FT.

DYNAMIC VISCOSITY, MU=0.000503 LBM/FT.SEC.

RELATIVE ROUGHNESS, E=0.00040 FT.

AVERAGE CONSUMPTIVE WATER FLOW, QD=575. GAL/DAY/HOME OR 0.399 GAL/MIN/HOME

CONSUMPTIVE FLOW FACTOR (TIMES AVG.), X= 1.0

DOMESTIC WATER FLOW, QD=575. GAL/DAY/HOME OR 0.399 GAL/MIN/HOME

HEATING WATER FLOW, QH=12240.GAL/DAY/HOME OR 8.500 GAL/MIN/HOME

COMMUNITY MAIN PIPING FLOW FACTOR, FF=0.9

DIAMETER OF EXISTING HOUSE PIPING 1.00 IN.

DIAMETER OF ADDED HOUSE PIPING 1.00 IN.

REQUIRED HEAT LOAD/HOUSE, BTUREQ=25025. BTU/HR.

INITIAL SUPPLY WATER TEMPERATURE, TI= 90. F

THERMAL CONDUCTIVITY OF SOIL, KE=0.50 BTU/HR.FT.F

TEMPERATURE OF GROUND SURFACE, TES= -7. F

DISTANCE PIPE IS BURIED BELOW GROUND SURFACE, Z=3.50 FT.

STEP N	PIPE LOCATION AND BRANCHING	PIPE DIA. IN.	PIPE LEN. FT.	TOTAL NUMBER HOUSES	EXIT FLOW GAL/MIN	REYNOLDS NUMBER	FRICTION FACTOR	HEAD LOSS FT.	POWER REQD HP	TOTAL POWER HP	ENT. TEMP. F	TEMP. LOSS F	EXIT TEMP. F
	MAIN SUPPLY				95.00								90.00
1	THROUGH STREET	3.00	45.00		95.00	133188.	0.0235	1.22	0.0293	0.029	90.00	0.07	89.93
	STREET TO HOUSE	1.00	63.00		8.90	37430.	0.0323	5.02	0.0112		89.93	0.83	89.10
	HEAT EXCH.			1.	8.50			5.20	0.0111		89.10	6.42	82.68
	HEAT PUMP	COP= 3.90		CAPACITY=36445.	BTUH		PRCT=0.6867		2.5003		80.30	10.89	69.41
	QABS=27216. BTUH			KW=2.715		ADJKW=1.865							
	BETWEEN HOUSES	1.00	90.00		8.50	35750.	0.0324	6.56	0.0140		82.68	1.15	81.52
	HEAT EXCH.			2.	8.50			5.20	0.0111		81.52	6.12	75.40
	HEAT PUMP	COP= 3.83		CAPACITY=34970.	BTUH		PRCT=0.7156		2.5448		73.13	10.38	62.75
	QABS=25956. BTUH			KW=2.652		ADJKW=1.898							
	HOUSE TO STREET	1.00	70.00		8.10	34071.	0.0325	4.65	0.0095		75.40	0.87	74.54
	PIPE BENDS,VALVES,ETC.							2.62	0.0056				
	ADD TO STREET AT STEP 11.			TOTAL LOOP PUMPING POWER (THEORETICAL)				29.26	0.0626				
2	THROUGH STREET	3.00	140.00		86.10	120711.	0.0237	3.15	0.0681	0.097	89.93	0.24	89.69
3	5. DEGREE BEND	3.0			86.10			0.00	0.0000	0.097			89.69
4	THROUGH STREET	3.00	113.00		86.10	120711.	0.0237	2.54	0.0550	0.152	89.69	0.20	89.49
5	93. DEGREE BEND	3.0			86.10			0.00	0.0000	0.152			89.49
6	THROUGH STREET	8.00	25.00		86.10	45267.	0.0232	0.00	0.0001	0.152	89.49	0.06	89.43
	STREET TO HOUSE	1.00	70.00		8.90	37430.	0.0323	5.58	0.0125		89.43	0.92	88.51
	HEAT EXCH.			3.	8.50			5.20	0.0111		88.51	6.40	82.11
	HEAT PUMP	COP= 3.90		CAPACITY=36356.	BTUH		PRCT=0.6883		2.5021		79.74	10.86	68.88
	QABS=27143. BTUH			KW=2.711		ADJKW=1.866							
	BETWEEN HOUSES	1.00	67.00		8.50	35750.	0.0324	4.89	0.0105		82.11	0.85	81.26
	HEAT EXCH.			4.	8.50			5.20	0.0111		81.26	6.11	75.15
	HEAT PUMP	COP= 3.83		CAPACITY=34903.	BTUH		PRCT=0.7170		2.5475		72.88	10.36	62.52
	QABS=25898. BTUH			KW=2.650		ADJKW=1.900							
	HOUSE TO STREET	1.00	70.00		8.10	34071.	0.0325	4.65	0.0095		75.15	0.86	74.28
	PIPE BENDS,VALVES,ETC.							2.62	0.0056				
	ADD TO STREET AT STEP 9.			TOTAL LOOP PUMPING POWER (THEORETICAL)				28.14	0.0603				
7	THROUGH STREET	8.00	37.50		77.20	40588.	0.0236	0.01	0.0001	0.153	89.43	0.10	89.34
	STREET TO HOUSE	1.00	90.00		8.90	37430.	0.0323	7.17	0.0161		89.34	1.18	88.15
	HEAT EXCH.			5.	8.50			5.20	0.0111		88.15	6.39	81.76
	HEAT PUMP	COP= 3.90		CAPACITY=36299.	BTUH		PRCT=0.6894		2.5034		79.39	10.84	68.56
	QABS=27096. BTUH			KW=2.708		ADJKW=1.867							
	BETWEEN HOUSES	1.00	65.00		8.50	35750.	0.0324	4.74	0.0101		81.76	0.83	80.94
	HEAT EXCH.			6.	8.50			5.20	0.0111		80.94	6.09	74.85
	HEAT PUMP	COP= 3.82		CAPACITY=34822.	BTUH		PRCT=0.7186		2.5508		72.59	10.33	62.26
	QABS=25826. BTUH			KW=2.647		ADJKW=1.902							
	HOUSE TO STREET	1.00	110.00		8.10	34071.	0.0325	7.31	0.0149		74.85	1.35	73.50
	PIPE BENDS,VALVES,ETC.							2.62	0.0056				
	ADD TO STREET AT STEP 13.			TOTAL LOOP PUMPING POWER (THEORETICAL)				32.25	0.0690				
8	THROUGH STREET	8.00	29.00		68.30	35909.	0.0242	0.00	0.0001	0.153	89.34	0.08	89.25

	RETURN FROM 7.				8.10								74.28
9	THROUGH STREET	8.00	51.00		76.40	40168.	0.0236	0.01	0.0001	0.153	87.66	0.13	87.53
10	END MAIN SUPPLY 8.0				76.40								87.53
	RETURN FROM 2.				8.10								74.54
11	THROUGH STREET	4.00	15.00		8.10	8518.	0.0339	0.00	0.0000	0.153	74.54	0.25	74.28
	RETURN FROM 19.				8.10								74.02
12	THROUGH STREET	4.00	5.00		16.20	17036.	0.0291	0.00	0.0000	0.153	74.15	0.04	74.11
	RETURN FROM 8.				8.10								73.50
13	THROUGH STREET	4.00	140.00		24.30	25553.	0.0271	0.07	0.0004	0.153	73.90	0.78	73.12
14	END LH RETURN 4.0				24.30								73.12
15	RETURN MAIN TEE-COMB.8.0				100.70			0.01	0.0002	0.153			84.06
16	THROUGH STREET	8.00	8.00		100.70	52945.	0.0226	0.00	0.0000	0.153	84.06	0.01	84.04
	STREET TO HOUSE	1.00	70.00		8.90	37430.	0.0323	5.58	0.0125		84.04	0.87	83.17
	HEAT EXCH.			7.	8.50			5.20	0.0111		83.17	6.20	76.97
	HEAT PUMP	COP= 3.86		CAPACITY=35356. BTUH			PRCT=0.7078		2.5304		74.67	10.52	64.15
			QABS=26294. BTUH	KW=2.666		ADJKW=1.887							
	BETWEEN HOUSES	1.00	60.00		8.50	35750.	0.0324	4.38	0.0094		76.97	0.72	76.25
	HEAT EXCH.			8.	8.50			5.20	0.0111		76.25	5.80	70.45
	HEAT PUMP	COP= 3.72		CAPACITY=33448. BTUH			PRCT=0.7482		2.6172		68.30	9.83	58.47
			QABS=24578. BTUH	KW=2.609		ADJKW=1.952							
	HOUSE TO STREET	1.00	70.00		8.10	34071.	0.0325	4.65	0.0095		70.45	0.81	69.64
	PIPE BENDS,VALVES,ETC.							2.62	0.0056				
	ADD TO STREET AT STEP 18.			TOTAL LOOP PUMPING POWER (THEORETICAL)				27.63	0.0592				
17	THROUGH STREET	8.00	60.00		91.81	48266.	0.0229	0.01	0.0003	0.154	84.04	0.12	83.92
	RETURN FROM 17.				8.10								69.64
18	THROUGH STREET	8.00	8.00		99.91	52525.	0.0226	0.00	0.0000	0.154	82.76	0.01	82.75
	STREET TO HOUSE	1.00	90.00		8.90	37430.	0.0323	7.17	0.0161		82.75	1.10	81.64
	HEAT EXCH.			9.	8.50			5.20	0.0111		81.64	6.13	75.52
	HEAT PUMP	COP= 3.83		CAPACITY=34999. BTUH			PRCT=0.7150		2.5436		73.24	10.39	62.85
			QABS=25983. BTUH	KW=2.653		ADJKW=1.897							
	BETWEEN HOUSES	1.00	35.00		8.50	35750.	0.0324	2.55	0.0055		75.52	0.41	75.10
	HEAT EXCH.			10.	8.50			5.20	0.0111		75.10	5.71	69.39
	HEAT PUMP	COP= 3.69		CAPACITY=33055. BTUH			PRCT=0.7571		2.6394		67.28	9.68	57.59
			QABS=24209. BTUH	KW=2.600		ADJKW=1.968							
	HOUSE TO STREET	1.00	87.00		8.10	34071.	0.0325	5.78	0.0118		69.39	1.00	68.40
	PIPE BENDS,VALVES,ETC.							2.62	0.0056				
	ADD TO STREET AT STEP 12.			TOTAL LOOP PUMPING POWER (THEORETICAL)				28.53	0.0612				
19	THROUGH STREET	8.00	50.00		91.01	47846.	0.0230	0.01	0.0002	0.154	82.75	0.10	82.64
	STREET TO HOUSE	1.00	70.00		8.90	37430.	0.0323	5.58	0.0125		82.64	0.86	81.79
	HEAT EXCH.			11.	8.50			5.20	0.0111		81.79	6.14	75.65
	HEAT PUMP	COP= 3.84		CAPACITY=35034. BTUH			PRCT=0.7143		2.5423		73.38	10.41	62.97
			QABS=26013. BTUH	KW=2.654		ADJKW=1.896							
	BETWEEN HOUSES	1.00	60.00		8.50	35750.	0.0324	4.38	0.0094		75.65	0.71	74.94
	HEAT EXCH.			12.	8.50			5.20	0.0111		74.94	5.70	69.24
	HEAT PUMP	COP= 3.69		CAPACITY=32998. BTUH			PRCT=0.7584		2.6428		67.13	9.66	57.47
			QABS=24157. BTUH	KW=2.599		ADJKW=1.971							

	HOUSE TO STREET	1.00	70.00		8.10	34071.	0.0325	4.65	0.0095		69.24	0.80	68.44
	PIPE BENDS,VALVES,ETC.							2.62	0.0056				
	ADD TO STREET AT STEP 22.			TOTAL LOOP PUMPING POWER (THEORETICAL)				27.63	0.0592				
20	THROUGH STREET	8.00	27.50		82.11	43167.	0.0234	0.00	0.0001	0.154	82.64	0.06	82.58
	STREET TO HOUSE	1.00	103.00		8.90	37430.	0.0323	8.21	0.0184		82.58	1.26	81.32
	HEAT EXCH.			13.	8.50			5.20	0.0111		81.32	6.11	75.21
	HEAT PUMP COP= 3.83			CAPACITY=34920. BTUH			PRCT=0.7166		2.5468		72.95	10.37	62.58
	QABS=25913. BTUH			KW=2.650		ADJKW=1.899							
	BETWEEN HOUSES	1.00	60.00		8.50	35750.	0.0324	4.38	0.0094		75.21	0.71	74.51
	HEAT EXCH.			14.	8.50			5.20	0.0111		74.51	5.66	68.84
	HEAT PUMP COP= 3.67			CAPACITY=32842. BTUH			PRCT=0.7620		2.6521		66.74	9.61	57.14
	QABS=24015. BTUH			KW=2.595		ADJKW=1.978							
	HOUSE TO STREET	1.00	103.00		8.10	34071.	0.0325	6.85	0.0140		68.84	1.17	67.67
	PIPE BENDS,VALVES,ETC.							2.62	0.0056				
	ADD TO STREET AT STEP 23.			TOTAL LOOP PUMPING POWER (THEORETICAL)				32.46	0.0696				
21	THROUGH STREET	8.00	32.50		73.21	38489.	0.0238	0.00	0.0001	0.154	82.58	0.08	82.50
	RETURN FROM 20.				8.10								68.44
22	THROUGH STREET	8.00	27.50		81.31	42748.	0.0234	0.00	0.0001	0.154	81.10	0.06	81.04
	RETURN FROM 21.				8.10								67.67
23	THROUGH STREET	8.00	65.00		89.41	47006.	0.0230	0.01	0.0003	0.154	79.83	0.13	79.69
	STREET TO HOUSE	1.00	100.00		8.90	37430.	0.0323	7.97	0.0178		79.69	1.18	78.51
	HEAT EXCH.			15.	8.50			5.20	0.0111		78.51	0.00	78.51
	BETWEEN HOUSES	1.00	90.00		8.50	35750.	0.0324	6.56	0.0140		78.51	1.10	77.42
	HEAT EXCH.			16.	8.50			5.20	0.0111		77.42	5.88	71.54
	HEAT PUMP COP= 3.75			CAPACITY=33825. BTUH			PRCT=0.7398		2.5972		69.36	9.97	59.39
	QABS=24920. BTUH			KW=2.618		ADJKW=1.937							
	HOUSE TO STREET	1.00	103.00		8.10	34071.	0.0325	6.85	0.0140		71.54	1.21	70.33
	PIPE BENDS,VALVES,ETC.							2.62	0.0056				
	ADD TO STREET AT STEP 27.			TOTAL LOOP PUMPING POWER (THEORETICAL)				34.40	0.0737				
24	THROUGH STREET	8.00	15.00		80.51	42328.	0.0234	0.00	0.0000	0.154	79.69	0.03	79.66
25	68. DEGREE BEND	8.0			80.51			0.00	0.0000	0.154			79.66
26	THROUGH STREET	8.00	15.00		80.51	42328.	0.0234	0.00	0.0000	0.154	79.66	0.03	79.63
	RETURN FROM 24.				8.10								70.33
27	THROUGH STREET	8.00	22.00		88.61	46587.	0.0231	0.00	0.0001	0.155	78.78	0.04	78.73
	STREET TO HOUSE	1.00	117.00		8.90	37430.	0.0323	9.32	0.0209		78.73	1.36	77.37
	HEAT EXCH.			17.	8.50			5.20	0.0111		77.37	0.00	77.37
	BETWEEN HOUSES	1.00	63.00		8.50	35750.	0.0324	4.59	0.0098		77.37	0.76	76.61
	HEAT EXCH.			18.	8.50			5.20	0.0111		76.61	5.82	70.79
	HEAT PUMP COP= 3.73			CAPACITY=33567. BTUH			PRCT=0.7455		2.6108		68.63	9.87	58.75
	QABS=24686. BTUH			KW=2.611		ADJKW=1.947							
	HOUSE TO STREET	1.00	113.00		8.10	34071.	0.0325	7.51	0.0153		70.79	1.31	69.47
	PIPE BENDS,VALVES,ETC.							2.62	0.0056				
	ADD TO STREET AT STEP 30.			TOTAL LOOP PUMPING POWER (THEORETICAL)				34.45	0.0739				
28	THROUGH STREET	8.00	25.00		79.71	41908.	0.0235	0.00	0.0001	0.155	78.73	0.06	78.68

	STREET TO HOUSE	1.00	65.00		8.90	37430.	0.0323	5.18	0.0116		78.68	0.76	77.92
	HEAT EXCH.			19.	8.50			5.20	0.0111		77.92	0.00	77.92
	BETWEEN HOUSES	1.00	75.00		8.50	35750.	0.0324	5.47	0.0117		77.92	0.91	77.01
	HEAT EXCH.			20.	8.50			5.20	0.0111		77.01	5.85	71.16
	HEAT PUMP	COP= 3.74		CAPACITY=33696. BTUH			PRCT=0.7427		2.6039		68.99	9.92	59.07
		QABS=24803. BTUH		KW=2.615		ADJKW=1.942							
	HOUSE TO STREET	1.00	70.00		8.10	34071.	0.0325	4.65	0.0095		71.16	0.82	70.34
	PIPE BENDS,VALVES,ETC.							2.62	0.0056				
	ADD TO STREET AT STEP 35.			TOTAL LOOP PUMPING POWER (THEORETICAL)				28.33	0.0606				
29	THROUGH STREET	8.00	25.00		70.81	37229.	0.0240	0.00	0.0001	0.155	78.68	0.06	78.62
	RETURN FROM 28.				8.10								69.47
30	THROUGH STREET	8.00	10.00		78.91	41488.	0.0235	0.00	0.0000	0.155	77.68	0.02	77.65
	STREET TO HOUSE	1.00	103.00		8.90	37430.	0.0323	8.21	0.0184		77.65	1.19	76.47
	HEAT EXCH.			21.	8.50			5.20	0.0111		76.47	0.00	76.47
	BETWEEN HOUSES	1.00	65.00		8.50	35750.	0.0324	4.74	0.0101		76.47	0.78	75.69
	HEAT EXCH.			22.	8.50			5.20	0.0111		75.69	5.75	69.94
	HEAT PUMP	COP= 3.71		CAPACITY=33261. BTUH			PRCT=0.7524		2.6276		67.81	9.76	58.05
		QABS=24394. BTUH		KW=2.604		ADJKW=1.959							
	HOUSE TO STREET	1.00	100.00		8.10	34071.	0.0325	6.65	0.0135		69.94	1.15	68.79
	PIPE BENDS,VALVES,ETC.							2.62	0.0056				
	ADD TO STREET AT STEP 34.			TOTAL LOOP PUMPING POWER (THEORETICAL)				32.62	0.0699				
31	THROUGH STREET	8.00	7.00		70.01	36809.	0.0241	0.00	0.0000	0.155	77.65	0.02	77.64
32	45. DEGREE BEND	8.0			70.01			0.00	0.0000	0.155			77.64
33	THROUGH STREET	8.00	44.00		70.01	36809.	0.0241	0.00	0.0001	0.155	77.64	0.11	77.53
	RETURN FROM 31.				8.10								68.79
34	THROUGH STREET	8.00	50.00		78.11	41068.	0.0236	0.01	0.0001	0.155	76.62	0.11	76.51
	RETURN FROM 29.				8.10								70.34
35	THROUGH STREET	8.00	10.00		86.22	45327.	0.0232	0.00	0.0000	0.155	75.93	0.02	75.91
	STREET TO HOUSE	1.00	100.00		8.90	37430.	0.0323	7.97	0.0178		75.91	1.13	74.78
	HEAT EXCH.			23.	8.50			5.20	0.0111		74.78	0.00	74.78
	BETWEEN HOUSES	1.00	60.00		8.50	35750.	0.0324	4.38	0.0094		74.78	0.70	74.08
	HEAT EXCH.			24.	8.50			5.20	0.0111		74.08	5.63	68.45
	HEAT PUMP	COP= 3.66		CAPACITY=32686. BTUH			PRCT=0.7656		2.6616		66.37	9.54	56.82
		QABS=23859. BTUH		KW=2.592		ADJKW=1.985							
	HOUSE TO STREET	1.00	100.00		8.10	34071.	0.0325	6.65	0.0135		68.45	1.13	67.32
	PIPE BENDS,VALVES,ETC.							2.62	0.0056				
	ADD TO STREET AT STEP 38.			TOTAL LOOP PUMPING POWER (THEORETICAL)				32.02	0.0686				
36	THROUGH STREET	8.00	52.50		77.32	40648.	0.0236	0.01	0.0001	0.155	75.91	0.12	75.79
	STREET TO HOUSE	1.00	70.00		8.90	37430.	0.0323	5.58	0.0125		75.79	0.79	75.00
	HEAT EXCH.			25.	8.50			5.20	0.0111		75.00	0.00	75.00
	BETWEEN HOUSES	1.00	117.00		8.50	35750.	0.0324	8.53	0.0182		75.00	1.37	73.64
	HEAT EXCH.			26.	8.50			5.20	0.0111		73.64	5.59	68.04
	HEAT PUMP	COP= 3.65		CAPACITY=32518. BTUH			PRCT=0.7696		2.6720		65.97	9.48	56.49
		QABS=23712. BTUH		KW=2.589		ADJKW=1.993							
	HOUSE TO STREET	1.00	27.00		8.10	34071.	0.0325	1.79	0.0037		68.04	0.30	67.74
	PIPE BENDS,VALVES,ETC.							2.62	0.0056				
	ADD TO STREET AT STEP 47.			TOTAL LOOP PUMPING POWER (THEORETICAL)				28.93	0.0623				

37	THROUGH STREET	8.00	7.50		68.42	35970.	0.0242	0.00	0.0000	0.155	75.79	0.02	75.77
	RETURN FROM 36.				8.10								67.32
38	THROUGH STREET	8.00	60.00		76.52	40228.	0.0236	0.01	0.0002	0.155	74.88	0.13	74.75
	STREET TO HOUSE	1.00	100.00		8.90	37430.	0.0323	7.97	0.0178		74.75	1.11	73.63
	HEAT EXCH.			27.	8.50			5.20	0.0111		73.63	0.00	73.63
	BETWEEN HOUSES	1.00	60.00		8.50	35750.	0.0324	4.38	0.0094		73.63	0.69	72.94
	HEAT EXCH.			28.	8.50			5.20	0.0111		72.94	5.54	67.40
	HEAT PUMP	COP= 3.62		CAPACITY=32247. BTUH			PRCT=0.7760		2.6893		65.35	9.39	55.96
	QABS=23485. BTUH			KW=2.584		ADJKW=2.005							
	HOUSE TO STREET	1.00	100.00		8.10	34071.	0.0325	6.65	0.0135		67.40	1.11	66.29
	PIPE BENDS,VALVES,ETC.							2.62	0.0056				
	ADD TO STREET AT STEP 40.			TOTAL LOOP PUMPING POWER (THEORETICAL)				32.02	0.0686				
39	THROUGH STREET	8.00	60.00		67.62	35550.	0.0242	0.01	0.0001	0.155	74.75	0.15	74.60
	RETURN FROM 39.				8.10								66.29
40	THROUGH STREET	8.00	30.00		75.72	39809.	0.0237	0.00	0.0001	0.155	73.71	0.07	73.64
	STREET TO HOUSE	1.00	70.00		8.90	37430.	0.0323	5.58	0.0125		73.64	0.77	72.87
	HEAT EXCH.			29.	8.50			5.20	0.0111		72.87	0.00	72.87
	BETWEEN HOUSES	1.00	83.00		8.50	35750.	0.0324	6.05	0.0129		72.87	0.95	71.93
	HEAT EXCH.			30.	8.50			5.20	0.0111		71.93	5.45	66.48
	HEAT PUMP	COP= 3.59		CAPACITY=31838. BTUH			PRCT=0.7860		2.7167		64.45	9.24	55.21
	QABS=23110. BTUH			KW=2.577		ADJKW=2.026							
	HOUSE TO STREET	1.00	20.00		8.10	34071.	0.0325	1.33	0.0027		66.48	0.22	66.25
	PIPE BENDS,VALVES,ETC.							2.62	0.0056				
	ADD TO STREET AT STEP 46.			TOTAL LOOP PUMPING POWER (THEORETICAL)				25.99	0.0560				
41	THROUGH STREET	8.00	37.00		66.82	35130.	0.0243	0.00	0.0001	0.156	73.64	0.09	73.55
42	86. DEGREE BEND	8.0			66.82			0.00	0.0000	0.156			73.55
43	THROUGH STREET	3.00	135.00		66.82	93679.	0.0241	1.86	0.0312	0.187	73.55	0.25	73.30
44	70. DEGREE BEND	3.0			66.82			0.00	0.0000	0.187			73.30
45	THROUGH STREET	3.00	75.00		66.82	93679.	0.0241	1.03	0.0174	0.204	73.30	0.14	73.16
	RETURN FROM 41.				8.10								66.25
46	THROUGH STREET	3.00	118.00		74.92	105036.	0.0239	2.03	0.0382	0.242	72.41	0.19	72.22
	RETURN FROM 37.				8.10								67.74
47	THROUGH STREET	3.00	58.00		83.02	116393.	0.0237	1.21	0.0254	0.268	71.78	0.08	71.70
48	90. DEGREE BEND	3.0			83.02			0.00	0.0000	0.268			71.70
49	THROUGH STREET	3.00	210.00		83.02	116393.	0.0237	4.40	0.0919	0.360	71.70	0.31	71.39
50	89. DEGREE BEND	3.0			83.02			0.00	0.0000	0.360			71.39
51	THROUGH STREET	3.00	116.00		83.02	116393.	0.0237	2.43	0.0507	0.410	71.39	0.17	71.22
52	4. DEGREE BEND	3.0			83.02			0.00	0.0000	0.410			71.22
53	ADD IN MAKE-UP WATER				11.98						40.00		
	COMBINATION	8.0			95.00			0.00	0.0000	0.410			67.28
54	THROUGH STREET	3.00	113.00		95.00	133188.	0.0235	3.07	0.0735	0.484	67.28	0.13	67.15
55	5. DEGREE BEND	3.0			95.00			0.00	0.0000	0.484			67.15
56	THROUGH STREET	3.00	185.00		95.00	133188.	0.0235	5.03	0.1203	0.604	67.15	0.22	66.93
57	END RETURN MAIN				95.00								66.93

MINIMUM HEAT EXCHANGER ENTERING WATER TEMPERATURE= 71.93 DEGREES F - AT STEP 41
AVERAGE HEAT EXCHANGER ENTERING WATER TEMPERATURE= 78.14 DEGREES F

AVERAGE TEMPERATURE DROP ACROSS THE HEAT EXCHANGER= 5.93 DEGREES F

THE AVERAGE QUANTITY OF WATER SUPPLIED TO THE HEAT EXCHANGER = 8.50 GAL/MIN

MINIMUM HEAT PUMP ENTERING WATER TEMPERATURE= 64.45 DEGREES F - AT STEP 41
AVERAGE HEAT PUMP ENTERING WATER TEMPERATURE= 70.85 DEGREES F

AVERAGE TEMPERATURE DROP ACROSS THE HEAT PUMP=10.06 DEGREES F

MAXIMUM HEAT PUMP POWER INPUT REQUIRED= 2.717 HP - AT STEP 41
AVERAGE HEAT PUMP POWER INPUT REQUIRED= 2.593 HP

AVERAGE HEAT PUMP COEFFICIENT OF PERFORMANCE= 3.76

THE AVERAGE THEORETICAL POWER REQUIRED TO PUMP THE SUPPLY WATER FROM THE STREET TO THE HOUSE AND BACK IS 0.065 HP

THE AVERAGE POWER REQUIRED PER HOME IS 2.766 HP OR 2.063 KW
ASSUMING A 50% EFFICIENT MAIN FLOW PUMP

COMMUNITY HEAT FLOWS

HEAT LOST BY CONDUCTION THROUGH SOIL	354497.	BTU/HR
HEAT LOST AS CONSUMPTIVE WATER FLOW	210366.	BTU/HR
HEAT TRANSFERED TO HOME HEAT PUMPS	553266.	BTU/HR
HEAT ADDED DUE PIPE FRICTION & FLOW DISTURBANCES (TEES,BENDS,ETC.)	4018.	BTU/HR
	*********	
TOTAL HEAT LOAD ON MAIN HT EXCHANGER	1114110.	BTU/HR
LOAD USING M*CP*DT ACROSS MAIN HT.EX.	1091920.	BTU/HR

MAIN PUMP: FLOW RATE 95.00 GAL/MIN
PRESSURE DROP 12.15 PSI
REQUIRED HEAD 28.17 FEET
POWER REQUIRED 0.604 HP

Appendix E

Sample Calculations

Pump performance calculations

For a given centrifugal pump, the performance of the pump changes as a function of the speed of rotation of the pump as follows [10]:

$$\frac{Q1}{Q2} = \frac{N1}{N2} \qquad \frac{H1}{H2} = \left(\frac{N1}{N2}\right)^2 \qquad \frac{P1}{P2} = \left(\frac{N1}{N2}\right)^3$$

where

H = the head developed by the pump, feet of fluid;

N = the speed of rotation of the pump, RPM;

P = the power input to the pump, hp; and

Q = the capacity of the pump, GPM.

For the 90°F system entering water temperature case using a 3-inch diameter system return line at the 25°F ambient air temperature design condition, a flow rate of 70 GPM and a head of approximately 23 feet of water are required. For this application, a Bell & Gossett series 1510 pump model 1-1/2 inch AB with a 5-1/2 inch diameter impeller was chosen. At a speed of 1750 RPM, the pump delivers the required head and flow rate and operates at 51 percent efficiency corresponding to a required power input of 0.79 hp. At the -7°F ambient air temperature design condition, the maximum system flow rate of 88 GPM is required. The motor size required to deliver this flow rate is

$$P2 = (Q2/Q1)^3\ P1 = (88/70)^3\ 0.79 = 1.57 \text{ hp.}$$

Choosing a 2 hp main flow pump motor, the actual maximum system flow rate obtained is

$$Q2 = (P2/P1)^{1/3}\ Q1 = (2/0.79)^{1/3}\ 70 = 95.4 \text{ GPM.}$$

The maximum pump speed is

$$N2 = (Q2/Q1)\ N1 = (95.4/70)\ 1750 = 2385\ \text{RPM},$$

and the maximum head delivered is

$$H2 = (Q2/Q1)^2\ H1 = (95.4/70)^2\ 23 = 42.7\ \text{ft}.$$

At the minimum pump speed of 1100 RPM, the performance of the pump is as follows:

$$Q2 = (N2/N1)\ Q1 = (1100/1750)\ 70 = 44\ \text{GPM},$$

$$H2 = (N2/N1)^2\ H1 = (1100/1750)^2\ 23 = 9.1\ \text{ft, and}$$

$$P2 = (N2/N1)^3\ P1 = (1100/1750)^3\ 0.79 = 0.20\ \text{hp}.$$

Payback period determination

The proposed system saves the residents of the community P per year in 1980 dollars. Based upon an energy escalation rate e, the system will save the residents

$$F = P\ (1+e)^n$$

in year n. The present worth of this future amount is given by

$$PW = F/(1+i)^n = P\ [(1+e)/(1+i)]^n,$$

where i is the annually compounded interest rate on borrowed money. The payback period is the length of time required for the summation of these yearly saving present worths to equal the total initial system cost PT. This equality may be written as

$$PT = \sum_{n=1}^{N} PW = \sum_{n=1}^{N} P\ [(1+e)/(1+i)]^n.$$

Using the geometric series with $x = (1+e)/(1+i)$

$$\sum_{n=1}^{N} x^n = x(1-x^N)/(1-x),$$

which holds for all cases except $x = 1$ $(e = i)$, one may obtain

$$PT = P\ x(1-x^N)/(1-x).$$

Solving for the payback period N yeilds

$$N = \frac{\ln\left[1 - \frac{PT}{P}\left(\frac{1-x}{x}\right)\right]}{\ln x} = \frac{\ln\left[1 - \frac{PT}{P}\left(\frac{i-e}{1+i}\right)\right]}{\ln[(1+e)/(1+i)]}.$$

Appendix F

System Components and Related Costs

Geothermal well facility costs

QTY unit	Item	cost/unit	Cost
	geothermal well 8-in. diameter X 1000 ft deep		$19,200
	well completion		10,000
30 ft	3-in. black steel pipe	$5.52/ft	166
4 ea	3-in. black steel elbows	14.40/ea	58
5 ea	3-in. black steel pipe flanges	25.88/ea	129
2 ea	3-in. malleable iron gate valves	153.00/ea	306
		subtotal	29,859

Community main piping and heating plant

1308 ft	3-in. iron pipe	3.50/ft	4,578
4 ea	8-in. X 3-in. ductile iron tees	104.33/ea	417
16 ea	3-in. ductile iron elbows	42.83/ea	685
3 ea	3-in. X 1-in. ductile iron tees	40.00/ea	120
4 ea	3-in. iron gate valves (flanged)	142.54/ea	570
8 ea	3-in. ductile iron pipe flanges	33.97/ea	272
6 ea	8-in. iron gate valves (flanged)	381.00/ea	2286
3 ea	8-in. iron swing check valves (flanged)	498.65/ea	1496
16 ea	8-in. ductile iron pipe flanges	89.29/ea	1429
90 ft	3-in. X 2-in. pipe insulation	5.58/ft	502
1 ea	3-in. strainer	240.75/ea	241
2 ea	pressure gauges	33.10/ea	66
2 ea	temperature sensors	22.78/ea	45

1 ea	Bell & Gossett pump with 2 hp motor		625.00/ea	625
1 ea	variable speed drive for main pump		1000.00/ea	1000
1 ea	Bell & Gossett main heat exchanger		1300.00/ea	1300
1 ea	main controls package		1000.00/ea	1000
100 yd^3	trenching and backfilling		22.00/yd^3	2200
20 yd^2	pavement repair		13.00/yd^2	260
150 ft^2	concrete block building including labor		50.00/ft^2	7500
330 Mhr	install pipe with fittings		30.00/Mhr	9900
48 Mhr	install insulation		30.00/Mhr	1440
24 Mhr	pump setting		30.00/Mhr	720
48 Mhr	heat exchanger setting		30.00/Mhr	1440
1 pkg	install main controls		500.00/pkg	500
			subtotal	40,592

Two-house loop component costs (per house)

1 pkg	added 1-in. loop piping with fittings, installed		400
1 ea	Grundfos 1/20 hp stainless steel pump		150
1 ea	Bell & Gossett 1/12 hp bronze pump		170
1 ea	Friedrich heat pump package		950
1 ea	Alfa-laval plate type heat exchanger		650
1 pkg	heat pump loop controls, installed		500
	heat pump and circulating pump installation		500
	house ductwork, installed		1,500
		subtotal per house	4,820
		subtotal	144,600

Total system initial cost	215,051
6 percent engineering cost	12,903
Total adjusted initial cost	227,954