Energy, Mines and Resources Canada
Earth Physics Branch

1 Observatory Crescent
Ottawa Canada
K1A 0Y3

Énergie, Mines et Ressources Canada
Direction de la physique du globe

1 Place de l'Observatoire
Ottawa Canada
K1A 0Y3

Geothermal Service of Canada

Service géothermique du Canada

MOOSE JAW GEOTHERMAL STUDY

Project Manager: R.J. Cousins, P. Eng.

ACRES INTERNATIONAL LIMITED
4th Floor, 845 Cambie Street
Vancouver, B.C.
V6B 2P4

Earth Phsyics Branch Open File Number 85-7
Dossier public de la Direction de la Physique du Globe No. 85-7

NOT FOR REPRODUCTION

REPRODUCTION INTERDITE

Department of Energy, Mines and
Resources Canada
Earth Physics Branch
Division of Gravity, Geothermics
and Geodynamics

Ministère de l'Energie, des Mines
et des Ressources du Canada
Direction de la'physique du globe
Division de la gravité, géothermie
et géodynamics

MOOSE JAW GEOTHERMAL STUDY

Prepared For:
ENERGY, MINES AND RESOURCES CANADA
Earth Sciences, Earth Physics Branch

Contract: 0SQ84-00256
Project Scientist: Dr. Alan Jessop

Prepared by:
ACRES INTERNATIONAL LIMITED
4th Floor, 845 Cambie Street
Vancouver, B.C.
V6B 2P4

Project Manager: R.J. Cousins, P.Eng

March, 1985
P7334.00

EXECUTIVE SUMMARY

The City of Moose Jaw is contemplating the development of a health spa using warm mineralized brine to be extracted from one of the geothermal reservoirs underlying the City. For a period of 25 years from 1932 the City operated a recreational indoor swimming pool, a natatorium, that was supplied with mineralized brine from a well originally drilled for natural gas.

In addition to providing an attractive amenity and therapeutic health centre for the City's growing senior citizen population, the City is also interested in encouraging the co-development of other geothermal opportunities including building heating and a possible centre for geothermal research.

The Earth Physics branch of Energy, Mines and Resources, Canada has been actively pursuing geothermal energy development for a number of years. This prefeasibility study is funded by EMR as a continuation of this effort.

A number of geothermal formations exist at depths from 900 to 2,300 m, and contain brines at temperatures of 30 to 60°C, and with salinities of 4,000 to 180,000 ppm. For pool and spa use, lower salinity brines are preferred.

The subject study identifies a practical and cost effective rationale for retrofitting existing heating systems to maximize the economic utilization of this low temperature energy resource.

As an addition to the basic brine restoration scheme, four central heat schemes were investigated. Each is progressively larger in terms of number of buildings connected and total heat load. The emphasis has been on the economic connection of City owned buildings. All schemes involve the use of heat pumps to

upgrade heating system temperatures from resource conditions of 38 and 44°C.

The costs for the four schemes including wells, central heat plant and distribution system vary from $1.2 million to over $5 million. As stand-alone heating projects, none are able to meet the City's minimum return requirements for investments of 6 to 7 percent, real (i.e. 12 to 13 percent nominal).

Co-development with the Spa facility, involving the sharing of expensive geothermal supply and disposal wells, substantially reduces the cost chargeable to heating to the point that Schemes 1 and 2 provide returns of over 10 percent real (i.e. 16 percent nominal). Capital assistance, potentially available through EMR's energy demonstration program (ENERDEMO), increases Scheme 1 returns to almost 14 percent, real (20 percent nominal) and with progressively lesser effect on the larger, more costly schemes.

The study concludes that both Schemes 1 and 2 are economic candidates for co-development with the restoration project and recommends further investigation in parallel with Spa development.

SOMMAIRE EXECUTIF

La ville de Moose Jaw est entrain de contempler le développement d'une institution de santé basée sur l'extraction d'eau tiède, salée et minérale d'un des réservoirs géothermiques de la ville. Depuis 1932, et pour une période de 25 ans, la ville a entretenu une piscine publique fermée en utilisant l'eau salée minérale d'un des puits creusé à l'origine pour le gaz naturel.

La création d'une centre attractif et thérapeutique pour une ville dont la population d'age d'or augmente m'était pas le seul but de Moose Jaw. D'autres projets géothermiques étaient en vue citant un projet de réchauffement d'immeubles et un centre de recherche.

La branche de la physique du globe du département d'Energie, Mines et Ressources, Canada a été active dans le développement et le financement de l'énergie géothermiques durant plusieurs années.

Plusieurs formations géothermiques existent à des profondeurs de 900 à 2300 m et contiennent de l'eau salée dont la température varie entre 30 et 60°C.

Leur pourcentage de salinité est entre 4000 et 180,000 ppm. Un bas pourcentage est préférable pour l'eau de piscine et pour l'institution de santé.

Cette étude consiste à trouver une méthode pratique et non coûteuse pour modifier l'ancien système de chauffage et faire un profit maximal de cette source à basse température.

En plus du plan d'origine pour le rétablissement de l'eau salée, quatre autres projets ont été étudiés. Le nombre d'immeubles reliés économiquement et la charge totale de chaleur augmentent avec chacun de ces projets. Vu que la température de l'eau provenant des ressources naturelles varie entre 38 et 44°C, des pompes à chaleur sont utilisées pour réchauffer l'eau du système de chauffage.

Le prix des quatres plans et celui des puits, de la central thermique et du système de distribution varie entre $1.2 million et plus de $5 million. Les projets de réchauffement individuels sont incapables de satisfaire aux besoins minimales d'investement de 6 à 7 pour cent, réel (i.e. 12 à 13 pour cent nominal).

Le co-développement avec les facilités de l'institution qui consiste à partager le matérial géothermique et les puits coûteux, réduit le prix de chauffage de tel façon que les plans 1 et 2 contribuent à 10 pour cent du rendement réel (i.e. 16 pour cent nominal). L'assistance financière disponible du programme d'énergie du EMR (ENERDEMO) augmente les profits du projet 1 de 14 pour cent, réel (20 pour cent nominal) et diminue graduellement l'effet des grands projets coûtant plus cher.

Cette étude conclut que les projets 1 et 2 sont économiques pour le co-développement du projet de restoration et recommende des recherches additionnelles pour le développement de l'institution.

COPYRIGHT NOTICE

PREFACE

This study has been undertaken by Acres International Limited as the principal consultant. Valuable support was provided by Nevin Sadlier-Brown Goodbrand Ltd., consulting geological engineers who undertook the assessment of geothermal resources, and by Interprovincial Corrosion Consultants Ltd., who were responsible for the corrosion analysis and materials selection aspects of the study.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS & SYMBOLS

COP - Coefficient of performance
DCF - Discounted cash flow
DHW - Domestic hotwater
DP - Design point (geothermal/heat pump supply system)
IRR - Internal rate of return
NPV - Net present worth
PDD - Pump (Hydrostatic) drawdown
TDF - Temperature drop factor; $(T_1-T_2)/(T_1-T_{si})$
UF - Utilization factor; $(\mathrm{TDF} \times \mathrm{LF}_s)$

Thermal Load and Annual Delivered Energy - q (GJ/h) and Q (GJ/yr)

q_b , Q_b - peaking boiler supply
q_p , Q_p - process demand
q_s , Q_s - geothermal/heat pump system supply
q_g , Q_g - geothermal system supply
q_1 , Q_1 - primary heat exchanger load (geofluid circuit)

Annual Load Factor - LF

LF_p - process demand load factor
LF_s - geothermal/heat pump system supply load factor

Heating System Temperatures - T (°C)
Primary Circuit (Geofluid)

T_1 - resource supply temperature
T_2 - resouce disposal temperature
T_{si} - reference geofluid sink injection temperature (0°C assumed)

Secondary Circuit (Process Heating)

T_s' - supply leaving primary exchanger
T_s - supply before boiler (leaving condenser)
T_p - supply to process (after boiler)
T_e - exit from convectors
T_r - return to geofluid exchanger

Heating System Flows - F (m^3/h)

F_g - geofluid supply flow (primary circuit)
F_p - secondary circuit flow (hydronic circuit)
F_c - central heat system (distribution circuit)

Unit Energy Cost (Levelized) - ϕ ($/GJ)

ϕ_s - geothermal/heat pump system
ϕ_g - geothermal supply system (excluding heat pumps)

Outdoor Temperatures - t (°C)

t_w - winter design (peak space load)
t_s - summer design (zero space load)

Coeffecient of Performance - (COP)

COP_{hp} - heat pumps only
COP_s - system or effective COP

Power - P (kW)

P_g - geothermal well pumping
P_c - CH system pumping

1.0 INTRODUCTION

The Natatorium indoor pool operated by the City of Moose Jaw was originally supplied with warm mineralized water from a deep well bored to explore for natural gas. This geothermal source of brine water, flowing under artesian pressure, supplied the Natatorium continuously from 1932 to 1957, when, following collapse of the wooden well casing, the supply ceased. Since that time the pool has been supplied by freshwater, heated with natural gas.

During the almost thirty years of operation, the brine pool provided a considerable attraction to the immediate population in the region and was a tourism feature of the City.

Following the City's initial interest in re-establishing the brine supply, other opportunities for using the geothermal heating potential came under consideration; in particular, the possibilities for using geothermal mineralized brine in a Health Spa development and also as a source for heating the Natatorium and perhaps other local buildings.

Energy Mines and Resources Canada, as part of its ongoing long-term interest in geothermal development has commissioned Acres International Limited to evaluate the issues of geothermal restoration and investigate various options, as appropriate, to utilize the geothermal capacity for heating purposes. These options are to properly reflect the City's preferences and wishes regarding the future of geothermal development in Moose Jaw.

1.1 City Requirements and Study Objectives

Natatorium Restoration and Spa Development

At the centre of the subject investigation is the proposed scheme to re-establish a geothermal brine supply to the Moose Jaw Natatorium and to serve a proposed Health Spa development. This is motivated by a variety of objectives not least of which is to re-create the unique recreational bathing facilities that previously existed at the Natatorium. The Health Spa development is to provide benefits in the form of improved amenities attractive to local inhabitants and also as an attraction promoting increased tourism. These provide indirect economic benefits to the City which are in addition to direct savings obtained by displacing consumption of natural gas by geothermal heating of the Natatorium and other buildings.

As an operational geothermal facility and the only one of its kind in Canada to involve the exploitation of deep warm-water brines, it would also offer a significant opportunity to develop a centre for continuing research into uses and long-term effects of geothermal operation. In view of the infancy of geothermal in Canada such a facility centered in Moose Jaw would offer considerable business and promotional potential.

Quantification of indirect and/or intangible benefits falls outside the terms and reference of this engineering pre-feasibility study. Nevertheless, the above possibilities bring. attention to some of the major features potentially available.

Co-Development with Geothermal Heating

Beyond re-establishing the brine supply is the potential for assisting the attractiveness of the scheme by co-developing with geothermal heating. An important observation derived from the 1982 study is that a major cost of geothermal heating lies in the development of the two wells required for supplying and re-injecting the fluid back to the reservoir formation. Furthermore, there is a least-cost size for the wells, a size that is capable of supplying a very large range of heating loads and involving, essentially, an incremental cost for pumping more or less of the fluid to suit the particular load. This is an important factor because it means that once a supply and return well system is established the cost for increasing well output is typically quite minimal. This consideration justifies examination of various schemes, each of increasing output potential, expanding to include buildings local to the Natatorium and Crescent Park. The limit to this approach is imposed by the finite output capability of a single supply well from any given reservoir formation. Predictably the economic limit will be reached when the increasing cost of distributing heat to increasingly remote buildings exceeds potential gas savings.

Adjacent to the Natatorium is the YMCA-YWCA building, the Library and Art Museum. These buildings, all located with Crescent Park, fall within the City's jurisdiction. A number of other buildings with the City's jurisdiction are located in proximity to the park including the City Hall and Senior Citizen apartment complexes. This gives rise to the possibility of extending the supply, in the form of a central heat distribution (CH) system, to serve these and also some of the large private building operations within economic proximity. Arranging with private owners to connect to such buildings could be mutually beneficial and helpful as a means of improving load demand on the system.

The City has indicated its willingness in principle (Meeting, November 19, 1984) to own and operate a central heat distribution system seeing in this a heat utility operation that would closely parallel similar utilities for which it is responsible (e.g., the town water supply). Single source responsibility involving installation by the City of a City-run central heat system to supply to buildings administered by the City offers significant and possibly unique institutional and economic advantages to CH development and operation, conditions not existing in conventional commercial relationships between supplier and user.

1.2 Background to Geothermal Energy

Earlier studies (Acres, 1983; Acres, 1984) have demonstrated the sensitive balance of design, performance and cost factors necessary to economically match low temperature, geothermal energy sources to space heating applications. For economic operation the studies have identified the need to:

1) select heating applications with large load demands;

2) engineer the heating system retrofits to properly accept lower-than-normal supply temperatures; and,

3) ensure a useful portion of the available energy is extracted from the geothermal supply throughout the year.

Most, if not all, of the conditions are essential for reasonable utilization of geothermal systems in order to achieve energy costs that are competitive with conventional energy sources (oil, gas, and electricity).

LT geothermal systems require a significant front-end investment for exploration, well development and testing, but they incur low to moderate costs to operate and maintain. This pattern of high investment and low operating cost is opposite to oil and gas fired energy systems where a relatively small investment is incurred for plant and equipment but operating costs are high because of the fuel costs.

These high geothermal investment costs are fixed and need to be amortized over the operating life of the project, probably 20 or 30 years. Typically, this is the major component of geothermal energy costs ($/GJ) so that the greater the amount of energy that can be taken by the load user(s), the smaller becomes the fixed component, lowering the unit cost and improving competitiveness, relative to other energy forms. Relative to those of oil and gas, geothermal costs are more stable so that competitiveness is further improved over time as a result of real increases that occur in conventional energy prices.

The technical, operational and cost aspects of LT geothermal applications, including unit energy cost comparisons with conventional energy, were comprehensively studied (1) in 1982. Little has occurred in the interim to modify the finding of that study which concluded that geothermal heating has the greatest potential in building space heating applications.

2.0 RESOURCE ASSESSMENT

2.1 Introduction

Water contained in deep, sedimentary bedrock aquifers of the Williston Basin (Figure 2-1) underlying Moose Jaw constitutes a low-temperature geothermal resource. The heat content of these waters is determined by the natural thermal gradient of the earth while the energy available for application at surface depends on the rate at which thermal water can be extracted.

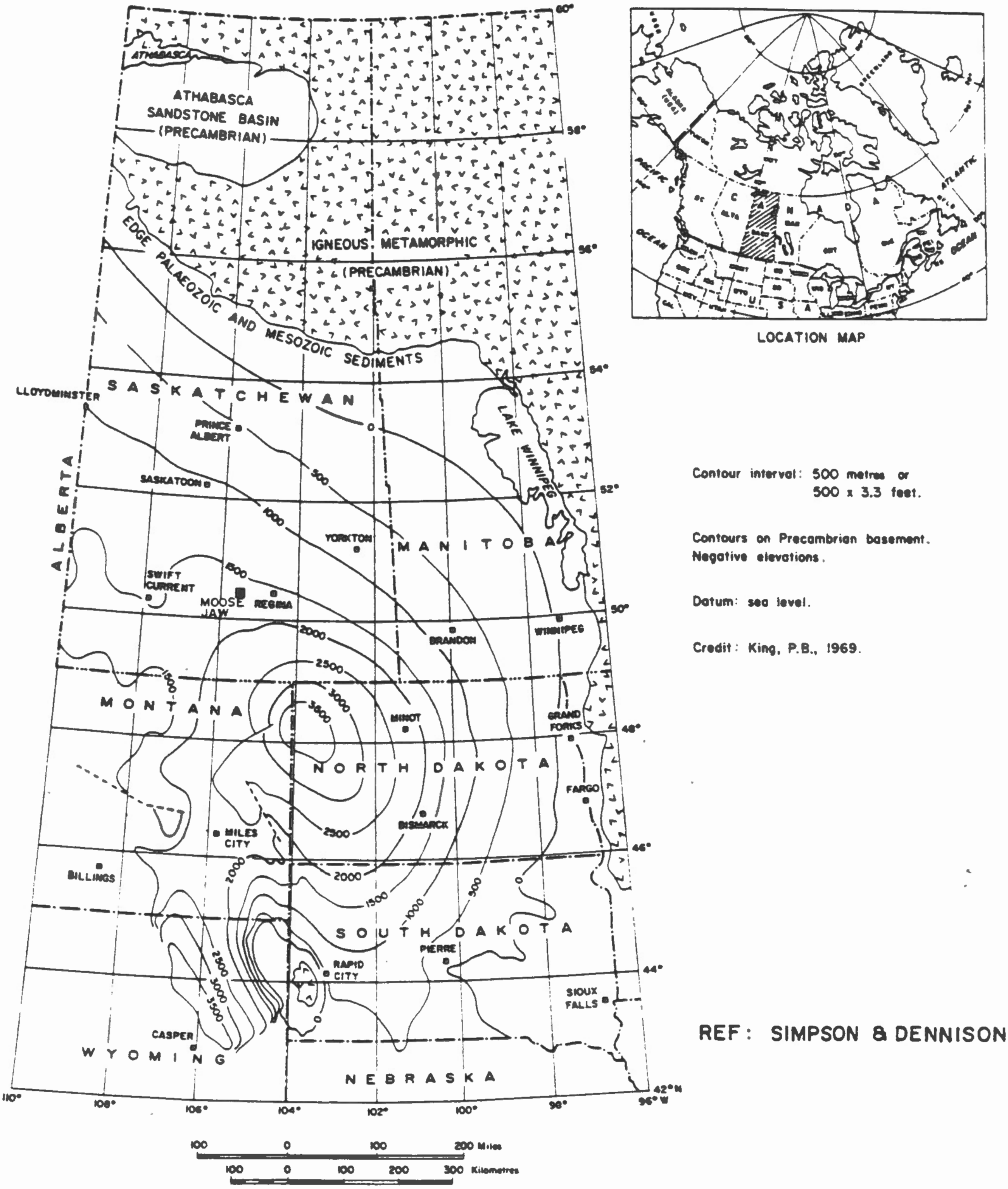
This section identifies prospective geothermal aquifers, reservoir characteristics, and thermal water production potential for the selected formations. The sedimentary succession overlying the Precambrian igneous-metamorphic basement at Moose Jaw is approximately 2237 m thick. The feasibility study considers two cases; firstly, relatively shallow reservoirs less than 1300 m deep with water temperatures between 27-50°C and secondly, reservoirs between 1978-2370 m deep immediately above basement with water or brine temperatures about 60°C.

Basic geothermal data was obtained from four main sources:

1) oil and gas industry well files for the area surrounding Moose Jaw;

2) historical records on the old "Moose Jaw Well" (Section 2.2);

3) a study by Vigrass, Kent and Liebel (1978) of the University of Regina, entitled "Low-Grade Geothermal



Contour interval: 500 metres or 500 x 3.3 feet.

Contours on Precambrian basement. Negative elevations.

Datum: sea level.

Credit: King, P.B., 1969.

REF: SIMPSON & DENNISON 1975

— Location map and structure contours on Precambrian surface, Williston basin proper and northern tectonic shelf, Saskatchewan, Manitoba, North Dakota, South Dakota and eastern Montana.

NSBG

FIG. 2-1

MOOSE JAW GEOTHERMAL STUDY
BASEMENT CONTOURS MAP WILLISTON BASIN

ACRES

Project, Geological Feasibiity Study, Regina-Moose Jaw Area, Saskatchewan"; and,

4) the geothermal test well experience at the University of Regina.

Vigrass et. al, (1978) is particularly useful as background information to the current study and their work is gratefully acknowledged.

Figure 2-2 shows the location, density and penetration depth of oil and gas industry wells that form the primary data base for the geothermal analysis. Well control in the project area, particularly for the deeper formations, is poor and in most instances data must be interpolated over distances greater than 10-20 km.

Certain problems inherent in geothermal reservoir mapping using oil and gas data are outlined in Sproule (1983). The following comments are relevant to the Moose Jaw area. Routine drill stem tests cover only short intervals of potential water production intervals, commonly at the upper section of the permeable strata where accumulations of hydrocarbons would be expected. The expense of thorough formation testing is not justified where no hydrocarbons are in evidence, as is commonly the case, hence data and bottom hole temperatures are often inaccurate and misleading. Temperature and water flow information available from the oil and gas industry is notoriously poor, largely because this information is of little importance to them. Details on the downhole conditions and elapsed time since last drill fluid circulation are often not reported with temperatures making it more difficult to distinguish good from bad data.

Notwithstanding the above problems, an adequate estimate of production potential is possible, considering the reasonably consistent stratigraphic sequence underlying the project area, by using a conservative approach and calibrating oil and gas data with the results from the Regina geothermal test and the old Moose Jaw well. It is emphasized that the reservoir parameters predicted are estimates only which must be proven by exploratory or development drilling.

2.2 Moose Jaw Well Historical Records

Records for the original 1042 m deep Moose Jaw well (Department of Mineral Resources, well files), believed to be reliable, are summarized below.

Location - Sec 32, Twp 16, Rge 26 W2nd Meridian

Elevation - 542 m

Depth - 1006 m in 1913-14 extended to 1042 m in 1931-32

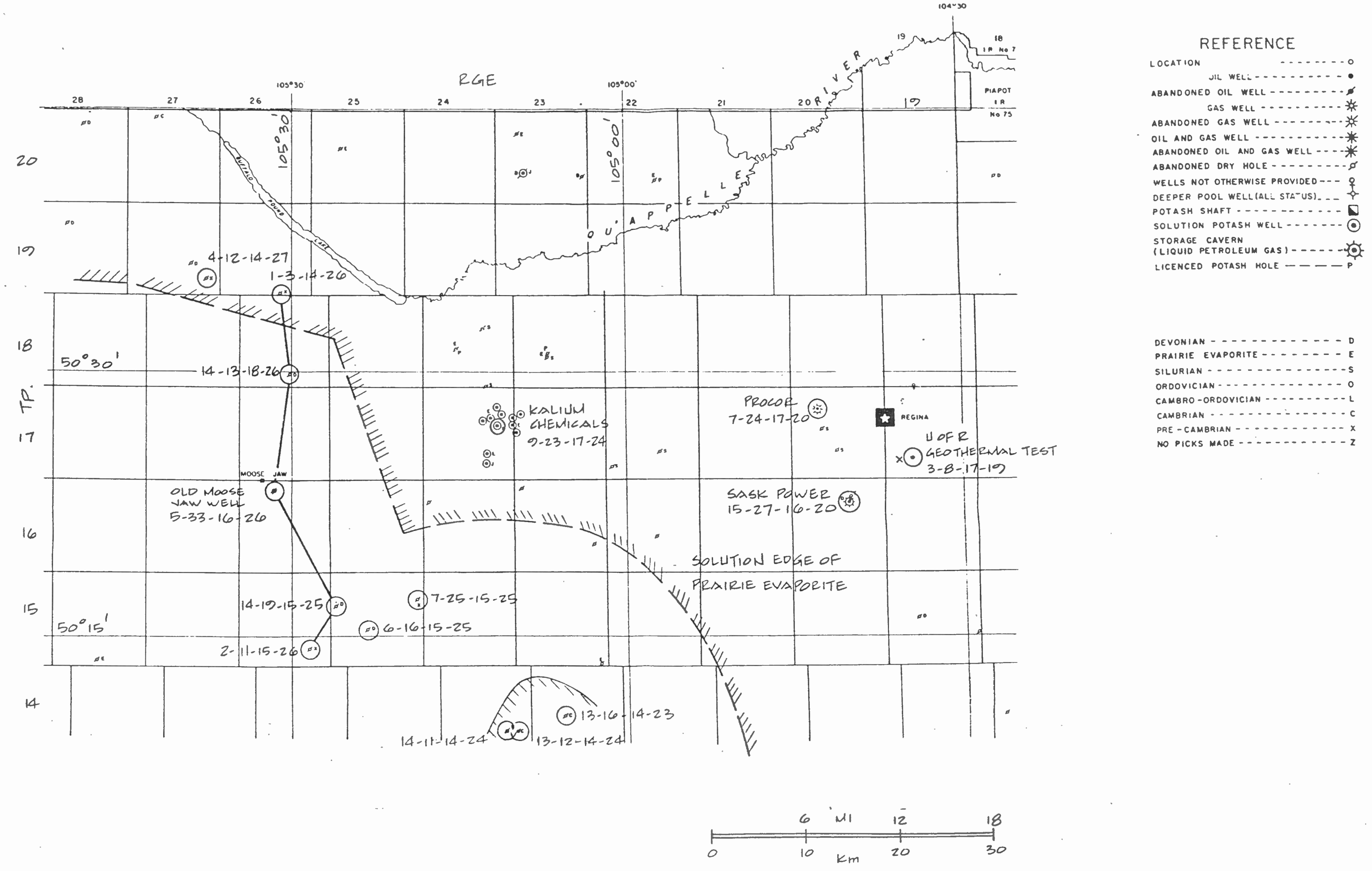
Casing - 49 m x 45.7 cm (18 in)

183 m x 36.5 cm (14 in)
358 m x 25.4 cm (10 in)
633 m x 20.3 cm (8 in) probably pulled
880 m x 15.2 cm (6 in) probably pulled
923 m x 12.1 cm (4 3/4 in)

Plug @ 1018 m
12 m slotted pipe placed above plug

Salt Water Intersections

279 m - 299 m, 18.2 m^3/h, 15.5°C
895 m, 6.8 m^3/h, 27.2°C

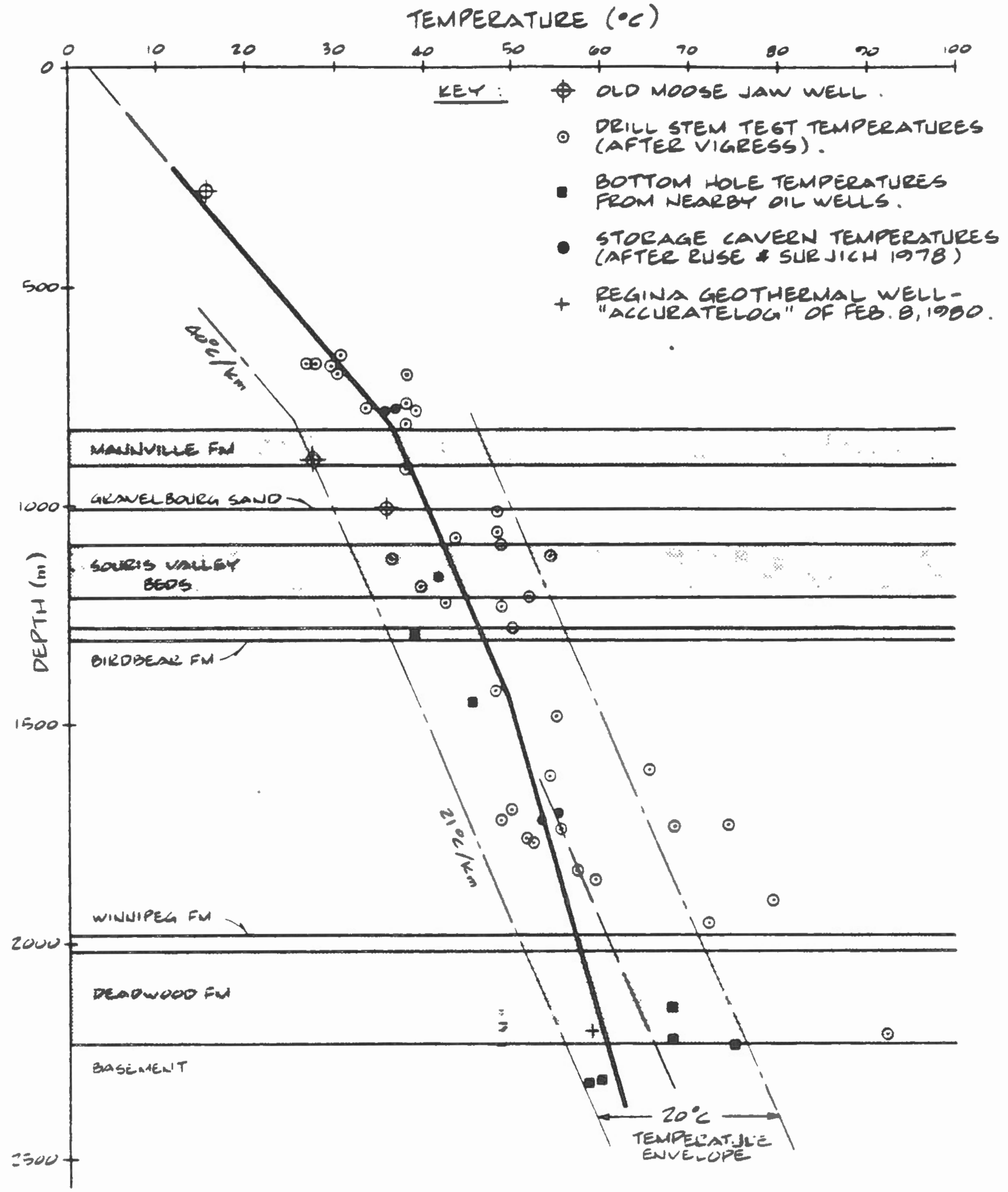


NSBG

FIG. 2-2

MOOSE JAW GEOTHERMAL STUDY
WELL PENETRATION MAP AND LOCATION KEY
MOOSE JAW - REGINA AREA

ACRES



NSBG

FIG. 2-3

MOOSE JAW GEOTHERMAL STUDY
TEMPERATURE PROFILE
REGINA MOOSE JAW AREA

ACRES

2.4 Well Prognosis

A north-south section of existing well (Figure 2-2) has been used to interpolate the depth and thickness of the sedimentary formations underlying Moose Jaw. The section is oriented so as to minimize the effects of E-W facies changes and complex structure at the Prairie Evaporite solution edge east of Moose Jaw. Moose Jaw is part of a salt free depression in southwestern Saskatchewan. The solution edge is delimited by a prominent scarp with younger strata draped over the present salt edge (Simpson and Dennison, 1975).

Table 2-1 shows formation top elevations for the wells in the section. Formation elevations at Moose Jaw (Moose Jaw Well Prognosis) are interpreted from the Old Moose Jaw Well and by interpolation from 14-3-18-26 W2 and 14-19-15-25 W2 for the incremental interval to -771 m elevation, and 1-3-19-26 W2 for the lowermost section to basement. Predicted formation top elevations in Table 2-1 are translated into depth below surface (at 545 m elevation) and formation thickness in Table 2-2.

2.5 Temperature Profile

Subsurface temperature data for the Regina-Moose Jaw area is shown on a temperature depth plot in Figure 2-3. The plot incorporates temperatures from the following sources:

1) drill stem test temperatures from Regina-Moose Jaw area (after Vigrass, 1978)

TABLE 2-2

MOOSE JAW WELL - GEOLOGICAL PROGNOSIS

FORMATION	Formation Tops Elev in (m)	Depth (m) (surface elev 545m)	Thickness (m)
1st specks	+54	491	-
2nd specks	-28	573	-
Viking Sand	-250	795	11
Mannville (Blairmore)	-278	823	88
Vanguard	-366	911	37
Upper Shaunavon	-403	948	17
Lower Shaunavon	-420	965	10
Gravelbourg	-430	975	73
Gravelbourg Sand	-459	1004	9
Upper Watrous	-503	1048	20
Lower Watrous	-523	1068	19
Souris Valley (Madison)	-542	1087	123
Bakken	-665	1210	10
Big Valley	-675	1220	9
Torquay	-684	1229	49
Birdbear	-733	1278	38
Duperow	-771	1316	126
Sourvis River	-897	1442	148
Dawson Bay	-1045	1590	82
Winnipegosis	-1127	1672	73
Ashern	-1200	1745	10
Middle Interlake	-1210	1755	66
Lower Interlake	-1276	1821	36
Stonewall	-1312	1857	23
Stoney Mountain	-1335	1880	35
Red River	-1370	1915	63
Winnipeg	-1433	1978	40
Deadwood	-1473	2018	219
Precambrian	-1692	2237	

TABLE 2-1

FORMATION TOPS (ELEVATIONS IN METRES) PROJECTED FOR MOOSE JAW AREA FROM SURROUNDING WELLS

LOCATION	1-3-19-26	14-3-18-26	5-33-16-26	MOOSE JAW WELL (PROGNOSIS)	14-19-15-25	2-11-15-26
T.D. (Total Depth)	2237	1299	1042	-	1463	2359
Datum K.B. (Kelly Bushing elevation)	596	595	542	545	580	590
Cretaceous						
1st specks	68	-9	+54	+54		
2nd specks	32	-46	-28	-28	-148	-127
Viking Sand Top		-164	-250	-250	-269	-251
Viking Sand Base		-178	-261	-261		-258
Blairmore (Mannville)	-134	-216	-278	-278	-320	-301
Jurassic						
Vangaurd	-201	-288	-366	-366	-409	-400
Upper Shaunavon		-325	-403	-403	-464	-459
Lower Shaunavon	-247	-349	-420	-420	-493	-485
Gravelbourg	-262	-362	-430	-430	-507	-524
Gravelbourg Sand - Top			-459	-459		
- Base			-468	-468		
Triassic						
Upper Watrous	-311	-425		-503	-581	-577
Lower Watrous (Red Beds)	-327	-444		-523	-602	-595
Mississippian						
Souris Valley (Madison)	-329	-457		-542	-626	-628
Devonian						
Bakken	-448	-560		-665	-770	-769
Big Valley	-455	-571		-675	-779	-779
Torquay	-473			-684	-789	-790
Birdbear	-516	-634		-733	-831	-832
Duperow	-554	-670		-771	-872	-873
Sourvis River	-751			-897		-1042
Dawson Bay	-921			-1045		-1170
Prairie Evaporite	-962					
Winnipegosis	-1123			-1127		-1211
Ashern	-1140			-1200		-1260
Silurian						
Middle Interlake	-1151			-1240		-1270
Ordovician						
Lower Interlake	-1223			-1276		-1329
Stonewall	-1258			-1312		-1366
Stoney Mountain	-1281			-1335		-1389
Red River	-1315			-1370		-1425
Cambrian						
Winnipeg	-1376			-1433		-1490
Deadwood	-1412			-1473		-1533
Precambrian						
Basement	-1623			-1692		-1760

gradient deceases from approximately 40°C/km to about 21°C/km. A second apparent decrease in the temperature profile occurs in the section of the hole at 1600 m depth and below 2050 m, the temperature gradient is further reduced to about 4°C/km (Jessop and Vigrass, 1984). It is considered that the thermal regime in the lower segments, and, particularly below the casing at 2034 m depth has been affected by convection in the wellbore and downward moving crossflow between the lower Winnipeg and Deadwood Formations. The conductive gradient of the middle segment of the Regina temperature profile has been extrapolated downward (dashed line in Figure 2-3) to approximate the in-situ temperature conditions prior to disturbance by well construction.

Reservoir temperature estimates for the Moose Jaw area are based on the Regina temperature profile, adjusted for the Old Moose Jaw well temperatures for the Mannville and Gravelbourg Formations, and discounting the effects of probably fluid movement in the lowermost section of well bore.

Mannville	30°C
Gravelbourg	37°C
Souris Valley	44°C
Birdbear	46°C
Winnipeg	60°C
Deadwood	63°C

2.6 Fluid Chemistry

Williston Basin formation waters are sodium chloride type with sodium, potassium, and chloride ions constituting 90-95 percent by weight of total dissolved solids. Fluid chemistry is facies and structure-dependent. In general, salinities increase with formation depth and range from

2) storage cavern temperatures (Ruse, 1978)

3) bottom-hole temperatures from wells near Moose Jaw (Dept. of Mineral Resources)

4) Regina geothermal well accurate log of February 8, 1980 (Energy, Mines and Resources, Canada)

5) Reported Moose Jaw well temperatures (Dept. of Mineral Resources).

Unfortunately, supporting information describing down hole conditions is unavailable for many of the temperature measurements and oil industry measuring techniques and equipment calibration are notoriously inaccurate. The Regina log and storage cavern test temperatures are reliable and in good agreement, but they are somewhat removed from Moose Jaw. Drill stem test temperatures are generally considered to be more representative than bottom hole temperatures (Sproule, 1983; Vigrass, 1978), however, they show considerable scatter especially in the deeper environment where they proved to be high compared to actual temperatures in the Regina test. Old Moose Jaw well water temperatures should be a good indicator of shallow subsurface conditions except that the reported temperatures are considerably lower than expected. It is probable that they represent artesian flows measured at surface as the wells were drilled. Reported fluid temperatures might therefore be cooled by drill fluid invasion of the reservoir formations.

The Regina well temperature profile (Jessop and Vigrass, 1984) is considered to give the best indication of subsurface temperature conditions. A marked temperature gradient inflection which occurs at 850 m depth is related to a change in thermal conductivity between the upper clastic unit and the middle carbonate-evaporite unit. The

14-11-14-24 40 km southeast of Moose Jaw (Figure 2-2). Reported pH is consistently between 6.5 - 7.5.

2.7 Reservoir Parameters

Net reservoir thickness, effective permeability, transmissibility, formation pressure and productivity index (flow rate per unit pressure drop) are estimated for each of the sandstone reservoirs. Similarly, a range of productivity indices are generated for each carbonate reservoir to illustrate the range of values to be expected depending upon variations in the degree and continuity fracture enhanced permeability. Reservoir productivity parameters were developed and are summarized in Table 2-3.

2.7.1 Mannville Formation

Water production of 6.8 m^3/h is reported at the old Moose Jaw well from a sandstone horizon correlated with the Mannville Formation.

Productivity index is calculated by estimating the artesian pressure associated with the natural flow. The fresh water head, or theoretical level to which a fresh water column in communication with the Mannville reservoir at Moose Jaw would rise, is estimated to be 640 m elevation based on an interpretation of regional potentiometric mapping by Vigrass et. al. (1978). The corresponding formation pressure is 9740 kPa at 355 metres below sea level. Natural water head, assuming 10,000 ppm TDS fluid with 1.007 specific gravity, is then at 634 m elevation, or 92 m above ground at the old well corresponding to 906 kPa artesian pressure. The productivity index for the Mannville Formation is calculated to be 0.0075 $m^3/h/kPa$.

TABLE 2-3

PROJECTED RESERVOIR PARAMETERS

Formation	Depth (m)	Temp (°C)	Total Thickness (m)	Net Reservoir Thickness (m)	Porosity	Permeabil (md.m)
Mannville	823	30	88	17	0.20	164
Gravelbourg Sandstone	1004	37	9	9		259
Souris Valley (Madison)	1087	44	123	30	variable	342
				30		104
				15		25
Birdbear	1287	46	38	10	0.11	350
				10	0.11	25
Winnipeg	1978	60	40	32	0.15	200
Deadwood	2018	63	219	150	0.13	132

Formation	Transmissivity (md.m)	Productivity Index (m^3/hr/kPa)	TDS Content (ppm)	Specific Gravity	Formation Pressure (kPa)	Natural Water head (m elev.)	Deptt elc (−) o Abc (+) Grounc (m)
Mannville	2780	0.0075	10,000	1.007	9740@-355m	634	+89*
Gravelbourg Sandstone	2330	0.0063	10,000	1.007	12100@-459m	771	+ 6**
Souris Valley (Madison)	10300	0.0277	20,000	1.014	13900@-635m	760	215
	3130	0.0084					
	375	0.0010					
Birdbear	3500	0.0095	35,000	1.025	14700@-733m	730	185
	250	0.0007					
Winnipeg	6400	0.0173	180,000	1.120	22000@-453m	554	+9
Deadwood	19800	0.0535	180,000	1.120	22300@-1582m	453	-92

Surface elevation for old Moose Jaw well = 542 m
Surface elevation for new well at Natatorium = 545 m

* +92 m at old Moose Jaw well
** +229 m at old Moose Jaw well

Written logs for the old well indicate 17 m of net sand in three zones separated by shale. Assuming a net reservoir thickness of 17 m and productivity index of 0.0075, the transmissibility and effective permeability are calculated to be 2780 md.m and 164 md respectively. Porosity is conservatively estimated at 0.20 from core analysis at 9-27-16-20 and 11-11-20-22.

2.7.2 Gravelbourg Sandstone

Water production from the old Moose Jaw well from a sandstone horizon at 1006 m depth, correlated to the Gravelbourg Formation, is reported at 14.2 m^3/h. Productivity index for the Gravelbourg sand is calculated using a similar procedure to that outlined above the Mannville Formation.

Analysis of two wells bracketing Moose Jaw (4-11-14-26 and 16-22-17-24) indicates increasing formation pressure from northeast to southwest and fresh water head of approximately 780 m elevation, corresponding to reservoir pressure of 12,100 kPa at 459 m elevation below sea level. Assuming reservoir fluid with total dissolved solid content of 10,000 ppm and specific gravity of 1.007, the natural water head is 771 m elevation or 229 metres above ground level at the old well. Artesian pressure associated with the reported natural flow of 14.2 m^3/h is therefore estimated to be 2260 kPa indicating a productivity index of 0.0063 $m^3/h/kPa$.

Geological logs of the old well cuttings show sand thickness of 9 m. Using the estimated productivity index and net reservoir thickness of 9 m, the indicated transmissibility is 2780 md.m and permeability is 259 md. Porosity is undetermined.

2.7.3 Souris Valley Beds

The old Moose Jaw well did not penetrate to the level of the Souris Valley Beds and therefore projections are based on data from other wells in the region. Favourable reservoir characteristics are indicated at storage cavern sites near Regina (Ruse, 1978) and at the Kalium Chemicals solution potash mine east of Moose Jaw (Simpson and Dennison, 1975) where the Souris Valley Beds are used for high volume disposal of brine. Drill stem tests of the Souris Valley recovered water to surface at several sites surrounding Moose Jaw (13-12-16-23 W2, 2-11-14-28 W2, 8-4-15-28 W2), for example, at 13-12-16-23 W2 water flowed to surface in 21 minutes at 12 m^3/h. Water production is typically from the lower section of the unit. A well known aquifer in the U.S. portion of the Willison Basin, known as the Madison Aquifer (Lodgepole Formation), and used at several locations for geothermal space heating is correlated to the Souris Valley Beds.

Injection wells typically display a long term pressure build up to a stabilized flow pressure, possibly indicating good close in permeability in combination with restricted reservoir (Ruse, 1978). Inconsistent permeability characteristics and pressure build up upon injection indicate permeabiilty enhancement due to fractures.

A wide variation in potential production rates from 0 to 100 m^3/h is possible from the Souris Valley; therefore, three scenarios are illustrated representing low, moderate, and high production rates. Long term production/ injection rates are expected to be less than initial rates indicated by drill stem tests, therefore data from injection experience at two operating brine disposal wells, namely Procor 7-29-17-20 W2 and Saskatchewan Power Corporation 15-27-16-20 W2 (Figure 2-2) (Ruse, 1978), are adapted for the medium and high production scenarios at Moose Jaw. This is conservative since a closed loop, affected by the production/injection well doublet, may lessen long-term pressure build up effects associated with the restricted reservoir condition.

The Procor well is used to illustrate the high productivity case. Net reservoir thickness is 30 m over the lowermost Souris Valley interval. Total thickness is 99 m. The long term productivity index, based on operating experience, is 0.0227 m^3/h/kPa compared to 0.198 m^3/h/kPa calculated from drill stem tests (Ruse, 1978). During the initial 6 months of operation, 200,000 m^3 of brine was injected at a rate of 68 m^3/h and injection pressure of 3500 kPa (gauge) (Simpson and Dennison, 1975). For comparison, injection rate at Kalium is 73 m^3/hr and injection pressure is 550 kPa (gauge). Total thickness of the Souris Valley Beds is interpreted to be 123 m at Moose Jaw versus 99 m at the Procor site, therefore it appears reasonable to use 30 m net reservoir thickness (as at Procor well) as a reference for Moose Jaw. Effective long term transmissibility and permeability corresponding to the reference productivity index of 0.0277 m^3/h/kPa are 10,300 md.m and 342 md respectively. Calculations are over simplified in this case, however, the resultant permeability/transmissibility values serve as a basis for comparison with the other prospective reservoir formations.

The Saskatchewan Power Corporation disposal well (15-27-16-20 W2), originally planned for a Birdbear completion, was completed in the Souris Valley Beds (and Torquay Formation) by perforating through cemented casing (Ruse, 1978). Remedial acid and repeated perforating jobs were required to overcome formation damage and bring the well up to its present injection capacity. The long term injectivity index is 0.00845 $m^3/h/kPa$. The peforated interval is 78 m; however, the net reservoir thickness is probably much less. 30 m is again used for a moderate production case at Moose Jaw and productivity index of 0.0084 $m^3/h/kPa$ is assumed. Resultant transmissibility is 3130 md.m and permeability is 104 md.

For the third, low productivity reference case, net reservoir thickness of 15 m and permeability of 25 md is assumed. Corresponding transmissibility is 375 md.m and productivity index is 0.0010 $m^3/h/kPa$.

Fresh water head at Moose Jaw is estimated at 780 m elevation considering values given by Vigrass et. al. (1978) at nearby wells 14-19-15-25 W2 and 11-30-16-24 W2 of 793 m and 773 m respectively. Reservoir pressure is then 13,900 kPa at 635 metres below sea level. Natural water head would be 760 m assuming fluid with 20,000 ppm TDS and 1.014 specific gravity, or 215 m above ground level. Artesian pressure for the Souris Valley Beds is approximately 2130 kPa which would result in sustained artesian flows of 2 m^3/h, 18 m^3/h, and 60 m^3/h for the three reference cases.

2.7.4 Birdbear Formation

Favourable reservoir porosity is indicated for the Birdbear Formation locally. For example, massive drill fluid circulation losses to the formation are reported in cavern wells 7-29-17-20 W2 and 15-27-16-20 W2 (Ruse, 1978) and water was recovered at or near surface on several drill stem tests (14-19-15-25 W2, 16-22-17-24 W2, 14-16-18-23 W2).

According to Vigrass et. al. (1978), the Birdbear Formation is comprised of a lower carbonate member about 29 m thick with good reservoir potential, and an upper evaporite member about 9 m thick with relatively poor reservoir potential. The favourable lower carbonate is further subdivided into two facies; a grain supported, porous, dolomitized carbonate and a relatively impermeable chalky micrite facies. The large water recoveries on drill stem tests normally correlate to areas underlain by the dolomitized carbonate facies. Mapping by Vigrass et. al. (1978) show the area around Moose Jaw to be dominated by the chalky micrite facies with limited reservoir potential.

Total thickness of the Birdbear Formation at Moose Jaw is about 38 m; 10 m of net permeability is assumed. High and low productivity reference cases are considered with 25 md and 350 md, however, 25 md is probably most representative. Corresponding transmissibilities are 250 md.m and 3500 md.m and productivity indices are 0.0007 and 0.0095 m^3/h/kPa.

Fresh water head is estimated to be 765 m elevation at Moose Jaw (Vigrass et.al., 1978). Reservoir pressure at

733 m subsea is then 14,700 kPa and the natural water head assuming 35,000 ppm TDS (specific gravity - 1.025) is approximately 730 m elevation or 185 m above ground. Artesian pressure is therefore about 1850 kPa and natural flows would be 1 m^3/h and 18 m^3/h for the two reference cases. The lower productivity is the most representative and hence the Birdbear Formation is not a favourable target zone at Moose Jaw.

2.7.5 Winnipeg Formation

Basal clastic reservoirs (Winnipeg and Deadwood Formations) are included in the study to determine the effect of higher reservoir temperature, higher water enthalpy, and greater formation depths and development costs on feasibility of relatively large scale space heating applications. Existing wells through these reservoirs are widely spaced (Figure 2-2), however, their characteristic is becoming increasingly well known through the work of the Energy Research Unit at the University of Regina and Energy, Mines and Resources, Canada. It is not the intention of the current study to repeat earlier work and the reader is referred to Vigrass et.al. (1978), Vigrass (1979, 1980) and Vigrass and Jessop (1984) for background geological and hydrological information.

The Winnipeg Formation is projected to occur at depth of 1978 m with a total thickness of 40 m. Net reservoir thickness (sandstone) is estimated to be 32 m (Vigrass et.al. 1978; Fyson, 1961).

Permeability estimates from drill stem tests in the Regina-Moose Jaw area vary between 331-3961 md and average 2000 md (Vigrass et.al. 1978), however, the most reliable estimate from the region is 70 md over 31 m at the Regina geothermal test site (Vigrass and Jessop, 1984). A permeable value of 200 md is predicted for Moose Jaw based on widely spaced data and porosity is predicted at 0.15 based on the Regina test. Transmissibility is calculated to be 6400 md and corresponding productivity index is 0.017 $m^3/h/kPa$.

Fresh water head, from reservoir maps by Vigrass et.al. (1978), is 790 m elevation; reservoir pressure is then 22,000 kPa at - 1453 m subsea. Reservoir fluid with 180,000 ppm TDS and 1.120 specific gravity would result in a natural water head of 554 m or approximately ground level. At the greater reservoir depths, large variations in salinity may have a significant impact on natural water head estimates. For example, water with 120,000 ppm TDS and specific gravity of 1.08 would result in a natural water level of 47 m above ground or artesian pressure of 500 kPa assuming the same reservoir pressure of 22,000 kPa.

2.7.6 Deadwood Formation

The Deadwood Formation, comprised of an upper, middle and lower unit, has an estimated total thickness of 219 m (Section 2.4) and net sandstone reservoir thickness of 150 m (Fyson, 1961) at Moose Jaw. Average porosity and effective permeability are predicted to be 0.13 and 132 md based on the Regina geothermal well (Vigrass and Jessop, 1984) and supported by core analyses from 2-11-15-16 W2 (Department of Mineral Resources). Transmissibility is 19,800 md and corresponding productivity index is 0.0535 $m^3/h/kPa$.

The Deadwood Formation is underpressured with respect to the Winnipeg Formation (Vigrass et.al. 1978; Vigrass and Jessop, 1984). Natural water head is estimated at 700 m elevation (compared to 790 m elevation for Winnipeg) and the formation pressure is approximately 22,300 kPa at 1582 m below sea level. Natural water with 180,000 TDS and specific gravity equal to 1.120 would stand at 453 m elevation or 92 m below ground.

2.8 Projected Production Rates

Table 2-4 summarizes production rates associated with various drawdowns below ground level projected from the natural water head, the pressure gradient of natural water, and the productivity index.

The Mannville, Gravelbourg, Souris Valley and Birdbear reservoirs have artesian pressures ranging from 875-2225 kPa. Natural water flows due to artesian pressure significantly enhance the geothermal potential of these formations (Table 2-4). The Souris Valley Beds have the greatest potential of the shallow formations considered, in terms of both the possible artesian flow rates and the productivity indices attainable. Souris Valley reservoir characteristics are variable because porosity and permeability is enhanced by fracturing of the carbonate rocks. The Mannville and Gravelbourg Formation sandstone reservoir projections indicate that natural flows would be adequate to supply the pool water for a spa development. Well pumping would provide moderate incremental gains in flow rates governed by the estimated productivity index. The Birdbear Formation is considered a poor geothermal prospect.

Table 2-4

Projected Flow Rates (m3/h) for Prospective Reservoirs at Moose Jaw

Reservoir	Natural Artesian Flow Rate	Pumped Flow Rate Drawdown Below Ground Level 100m	150m	200m
Mannville Fm.	6.8	14	18	22
Gravelbourg Sand	14.2	20	24	27
Souris Valley Beds				
low	2	3	4	5
moderate	18	26	31	35
high	60	88	102	115
Birdbear				
low	1	2	2	2
high	18	28	32	37
Winnipeg	2	21	31	40
Deadwood	-	5	35	64

Deep, basal clastic units, especially the Deadwood Formation, have good production potential. The natural water levels of Winnipeg and Deadwood waters are expected to be at approximately ground level and 90 m below ground level respectively, therefore, both formations would require pumping for production. The productivity index of the Winnipeg indicates only moderate flows would be available while the Deadwood has excellent flow potential. In combination, Winnipeg and Deadwood sandstone reservoirs should produce approximatley 80 m^3/hr with 100 m of drawdown.

2.9 Well Design Considerations and Costs

Cost analysis of a production/injection well system to the base of the Souris Valley beds is conducted for feasibility purposes. Detailed well design is beyond the scope of this study, however, some general design factors must be considered for the production test well. Total depth is estimated to be 1210 m. The Mannville, Gravelbourg, and Souris Valley reservoirs would be flow tested prior to casing. A multizone completion, with the Souris Valley Beds completed open hole, production casing set (cemented) to a depth of 1150 m or slightly above the carbonate production zone, and perforations to the upper Mannville and Gravelbourg sandstone reservoirs, is contemplated.

Casing size should be selected to optimize drilling costs since only moderate flow volumes are expected. A vertical turbine pump can be considered because of the minimal lifts required. Surface casing should be sized to meet pump requirements.

A cost estimate for a completed production well to the base of the Souris Valley Beds is given in Table 2-5. The estimated total cost of a production well completed to the base of the Souris Valley Beds at 1210 m depth is $426,000. An injection well to the same formation is estimated to cost $400,000 with savings due to lower engineering and testing costs for a second well.

Estimated costs are in reasonable agreement with historical geothermal well cost data (Figure 2-4, reported by Gross, 1983; Acres, 1983; Carson and Lin, 1981). Geothermal well costs are typically 2 to 3 times conventional oil industry wells based on extensive case history data. Added expense is due to a combination of factors including drilling program locations where detailed geology and drilling practices are not established, costs associated with drilling in urban areas, higher cementing costs to

TABLE 2-5

COST ESTIMATE FOR PRODUCTION WELL TO BASE OF SOURIS VALLEY

Item	Cost $
Site prep., survey, pad, access, roads, mud pit	7,000
Mob, demob, rig up, tear down	12,000
Drilling services - footage (1210 M)	82,000
- day rate (5 days)	25,000
Conductor pipe	2,000
Surface casing, 366 mm (12 in) x 150 m	9,000
Production casing 178 mm (7 in) x 1150 m	32,000
Rentals, blow out preventor, rotating head, etc.	12,000
Cement and cementing services	20,000
Drill fluid - water	4,000
- mud additives	8,000
Bits	10,000
Welding	1,000
Fuel	10,000
Freight	2,000
Communications	1,000
Well logs	15,000
Coring	3,000
Drill stem tests	10,000
Perforating and completion operations	5,000
Well head flange, valves	4,000
Well testing equipment rentals & direct costs	10,000
Drilling engineering and well design	24,000
Well site geologist and services	9,000
Reservoir engineering, testing	28,000
Travel and accommodation	6,000
Miscellaneous supplies	4,000
	$ 355,000
20% contingency	71,000
TOTAL PRODUCTION WELL	$ 426,000

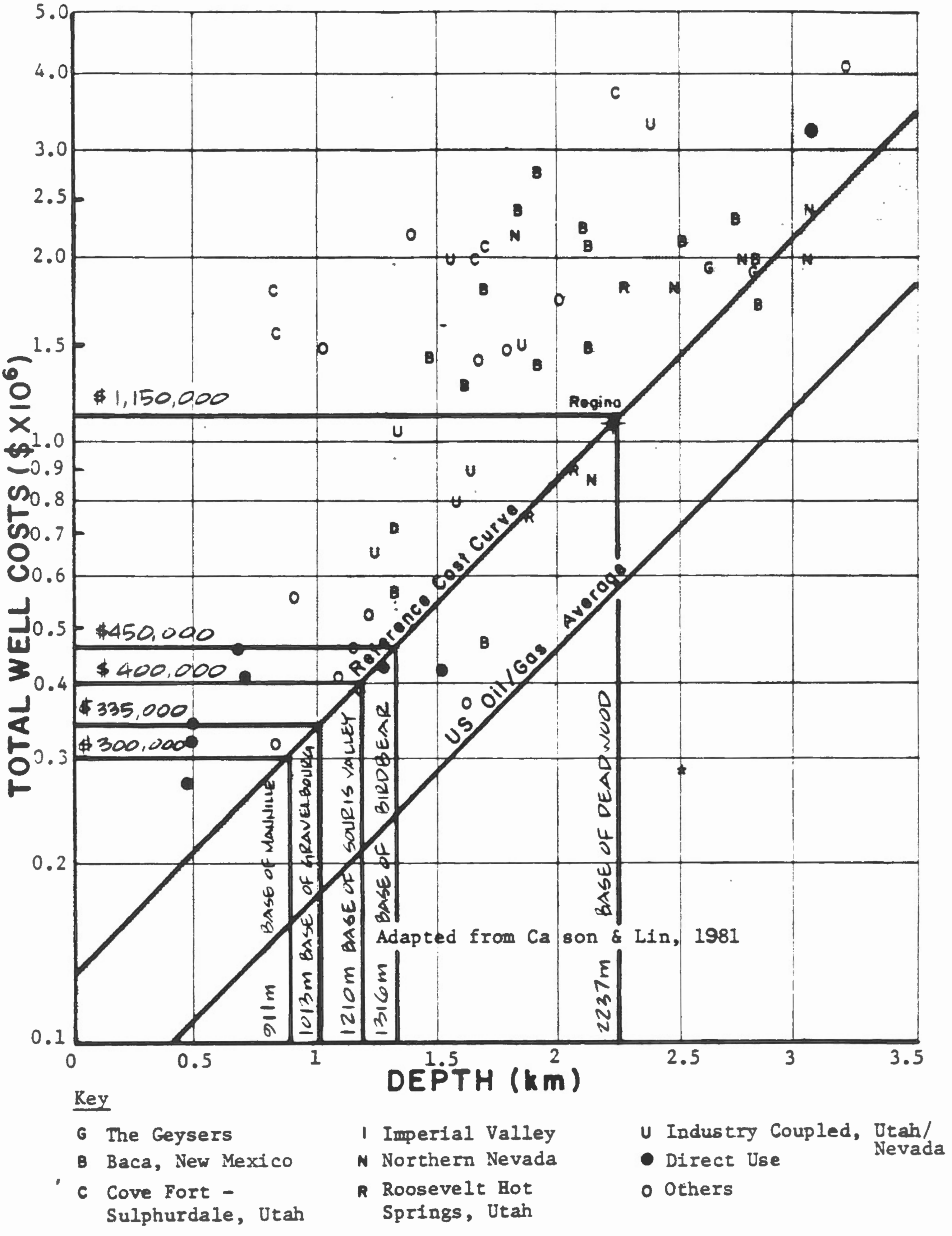


FIG. 2-4

MOOSE JAW GEOTHERMAL STUDY
INDICATIVE FORMATION WELL COSTS

ACRES

prevent casing problems associated with hot water production and thermal cycling, more thorough well testing requirements, and specialized engineering, operating and service personnel requirements.

The initial well at Moose Jaw must be considered exploratory and should be designed to test Souris Valley permeability. In view of the high costs of a new well, consideration might be given to re-entering the Old Moose Jaw well and deepening it to the level of the Souris Valley Beds. Re-entry is a controversial issue whose merits, in terms of potential risks and benefits, needs to be fully explored.

The cost of a production test well to the Deadwood and Winnipeg Formations is estimated to be $1,150,000 (Figure 2-4). A detailed cost breakdown and analysis has not been undertaken.

Well costs are a crucial component of total geothermal development costs and greatly influence energy economics. From discussions with the industry, the limited levels of well drilling and exploration work undertaken in recent years in the prairies could provide very competitive pricing and lead to lower costs than those indicated here.

3.0 BUILDING CANDIDATES - RETROFIT DESIGN, LOADS & COST

3.1 Candidates

The principal candidate for geothermal heating is the Natatorium, the geothermal brine suppling the indoor pool and also providing a source for heating the building, the domestic hot water (DHW) for showers and, in the summertime, for heating the outdoor swimming pool.

Because of the large load and energy potential of a producing geothermal well, even at relatively low temperatures of 30 to 40°C, and also the high cost of well development, it is appropriate to consider steps to maximize the benefits by heating other adjacent facilities where this can be shown to be economic. With this in mind, discussions were held with city council members and engineering staff which led to the identification of further heating candidates of interest to the City. Those located within a few blocks of the Natatorium were deemed to be the most appropriate, based on concerns for minimizing pipeline distances and installation costs.

The candidates selected for consideration are identified by name and location in Figure 3-1. The distinction between buildings owned privately and those within the City's jurisdiction is shown. In all heating schemes subsequently developed the first priority is given to serving city buildings subject to over-riding constraints imposed by remoteness, limited load demand and cost/ benefit considerations.

Connection of candidate buildings to a central heat network is indicated in Figure 3-1 by the dotted line.

The routing is provisional and intended to show a typical path that maximizes pipe burial runs within Crescent Park and minimizes the more expensive burial requiring road excavation. Schemes examined in detail in Section 7 show, except for the fourth scheme, a more limited distribution system serving fewer buildings.

Two candidates, the Cultural Centre (#9), and the Harwood Commercial Development (#13) are at the proposal stage. No details are available at the present time. They both offer the potential for inclusion at a later date.

Specific candidate buildings were visited to inspect the condition of equipment and the type of heating system employed, also any plans for upgrading or refurbishing the building and/or heating system. Appendix A contains building survey summary sheets compiled for the majority of candidates, data that includes brief details of heating systems and 12 months of monthly gas consumption data obtained from Saskatchewan Power Corporation records.

3.2 Geothermal Retrofit Considerations

The building survey summary sheets of Appendix A include brief outlines of geothermal retrofit opportunities. These have been identified on the basis of general guidelines and criteria now reviewed.

Existing buildings are provided with various means to achieve heating of internal spaces, ventilation make-up air and domestic hot water. It is common practice in many of the modern buildings such as the senior citizen apartments, the Harwood Inn and others to employ perimeter heating, comprising radiators or baseboard convector units

1006 m, 14.2 m^3/h, 35.5°C

Salinity 6000 ppm (chiefly NaCl)

Abandonment Program (from Application to Abandon)

- cement 35.6 cm (14 in) casing to 3 m;
- place 60 m cement plug above Blairmore (Mannville), i.e. 823-914 m through 10.2 cm (4 in)* casing; pull 10.2 cm casing;
- perforate 25.4 cm (10 in) and 35.6 cm (14 in)* casing at 305 m, place 600 m cement plug at perforation level; pull 25.4 cm (10 in) casing;
- perforate 35.6 cm (14 in) casing at 75 m; plug back to 30 m, squeeze outside 45.7 cm (18 in) casing if possible;
- cut casing 1 m below ground; put in 5 sks cement; weld on steel plate; clean up location

* discrepancy noted with reported casing

The abandonment plan would leave 35.6 cm (14 in) casing, the smallest diameter casing in the hole, to 183 m (601 feet) with cement plugs below the casing at about 300 and 780 m depth.

Lithologic logs and general geologic accounts by various geologists (G.S. Hurvey, R.T.P. Wickenden, F.J. Fraser, M. Mahoney) indicate that the depths reported for the lower two water production zones probably correspond to the Mannville (Blairmore) and Gravelbourg Formations respectively. Close inspection of written logs shows the Mannville occurs between 823-911 m depth with a total thickness of 88 m, including 55 m of sandy units, and 17 m of net sand. Precise water bearing levels are unknown. Similarly, the Gravelbourg Formation limestone/shale sequence occurs between 430-503 m depth and includes a 9 m sand interval at 1001-1010 m depth. The upper water production zone, corresponding to a thin sand and sandy shale interval within a thick shale sequence, was not evaluated in detail because of its low temperature (15.5°C).

2.3 General Stratigraphy, Selected Reservoir Formations

The sedimentary succession of the Northern Williston Basin consists of three important divisions, separated by major unconformities, as follows: 1) lowermost sandstone-shale clastic unit (Cambrian-Middle Ordivician) up to 500 m thick resting upon the Precambrian basement; 2) middle carbonate-evaporite unit (Middle Ordivician-Mississippian) up to 1500 m thick; and 3) an upper shale-sandstone clastic unit (Triassic to Holocene) up to 1600 m thick. Strata generally dip southwesterly in the Moose Jaw area. Basin sediments are 2200 m in the project area and thicken to 5100 m near the center of the basin in North Dakota.

Geothermal aquifers are expected at intervals throughout the sedimentary section. Prospective geothermal reservoirs selected for feasibility analysis are the Mannville, Gravelboug, Souris Valley, Birdbear, Winnipeg and Deadwood Formations. Of these, the Mannville, Gravelbourg, Winnipeg and Deadwood Formations are sandstone reservoirs with intragranular porosity and the Souris Valley Beds and Birdbear Formation are carbonate reservoirs with potential fracture porosity. The selected reservoirs represent two scenarios; deep reservoir development in the basal clastic unit (Winnipeg and Deadwood Formations) and relative shallow reservoirs (to 1300 m) represented by the other units.

Each of the selected formations has demonstrated reservoir potential. The Mannville and Gravelbourg supplied water to the former Moose Jaw well. The Mannville (Blairmore) Formation, in particular, is a well known aquifer in Southern Saskatchewan. The Souris Valley Beds are used for high volume brine disposal at Kalium Chemicals, located west of Moose Jaw (Simpson and Dennison, 1975), and at the Procor Limited and Saskatchewan Power Corp. storage cavern sites (Ruse, 1978) (Figure 2-2). Permeability within the Birdbear Formation is lesser known; it was selected because of its position in the section immediately below the Souris Valley Beds and reported indications of favourable, local permeability (Ruse, 1978; Saskatchewan Energy and Mines, well files). Other potential carbonate reservoirs, (e.g. Dawson Bay, Duperow, Interlake) were not included because of the relatively high cost associated with their increased depth in the section and high risk inherent with less consistent reservoir characteristics. These lower carbonate formations would be secondary targets if drilling for the basal clastic reservoirs were to be undertaken.

The Winnipeg and Deadwood Formations were included in the analysis because they are the deepest and hence highest temperature reservoir formations. They have reasonably consistent porosity-permeability characteristics and are the best known geothermal aquifers in southern Saskatchewan. The geothermal well at Regina was drilled to test the basal clastic formations which have been used extensively for brine disposal at Saskatchewan potash mining operations in the Saskatoon and Esterhazy areas.

2.4 Well Prognosis

A north-south section of existing well (Figure 2-2) has been used to interpolate the depth and thickness of the sedimentary formations underlying Moose Jaw. The section is oriented so as to minimize the effects of E-W facies changes and complex structure at the Prairie Evaporite solution edge east of Moose Jaw. Moose Jaw is part of a salt free depression in southwestern Saskatchewan. The solution edge is delimited by a prominent scarp with younger strata draped over the present salt edge (Simpson and Dennison, 1975).

Table 2-1 shows formation top elevations for the wells in the section. Formation elevations at Moose Jaw (Moose Jaw Well Prognosis) are interpreted from the Old Moose Jaw Well and by interpolation from 14-3-18-26 W2 and 14-19-15-25 W2 for the incremental interval to -771 m elevation, and 1-3-19-26 W2 for the lowermost section to basement. Predicted formation top elevations in Table 2-1 are translated into depth below surface (at 545 m elevation) and formation thickness in Table 2-2.

2.5 Temperature Profile

Subsurface temperature data for the Regina-Moose Jaw area is shown on a temperature depth plot in Figure 2-3. The plot incorporates temperatures from the following sources:

1) drill stem test temperatures from Regina-Moose Jaw area (after Vigrass, 1978)

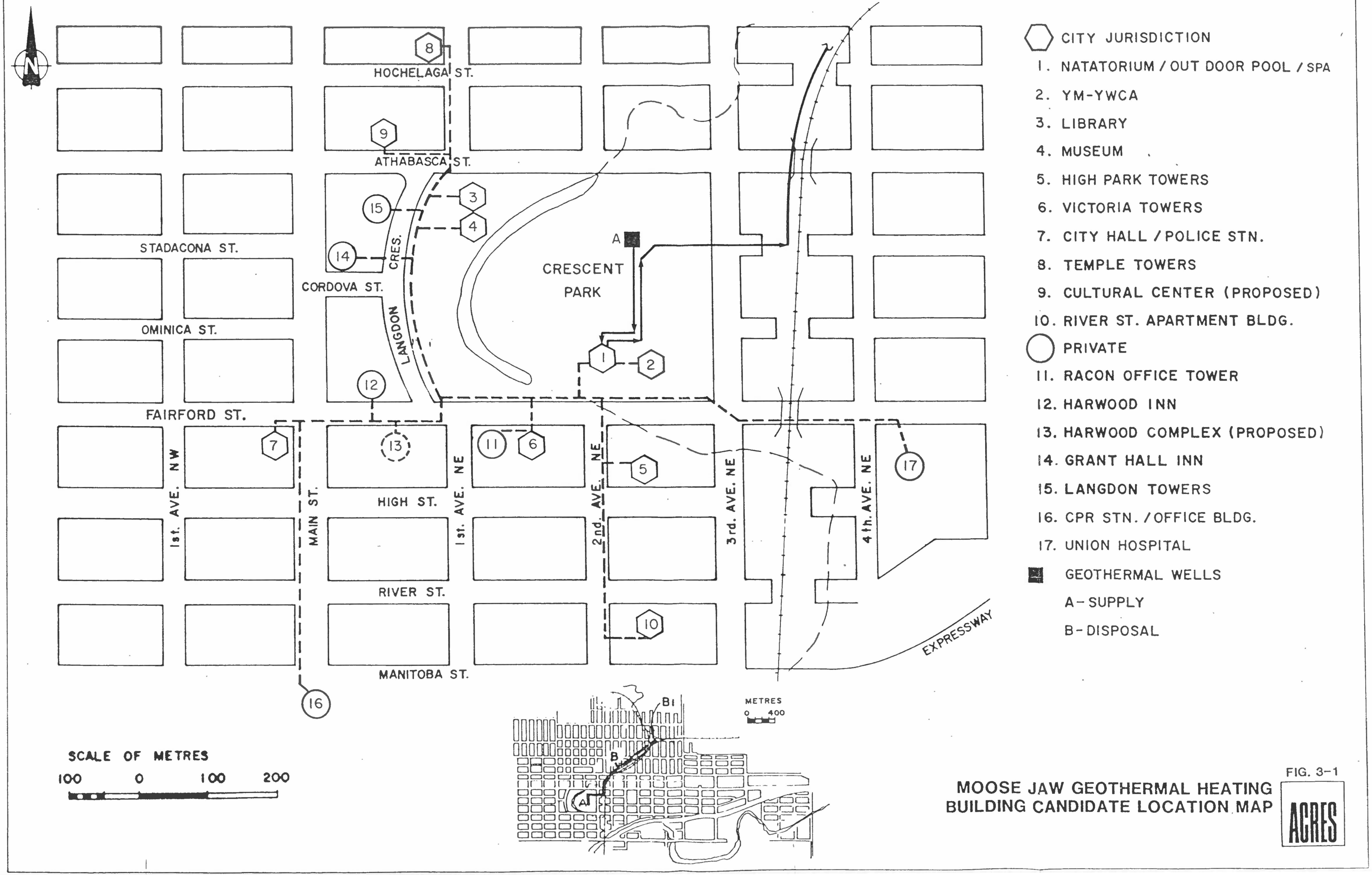


FIG. 3-1

MOOSE JAW GEOTHERMAL HEATING
BUILDING CANDIDATE LOCATION MAP

ACRES

located under windows and adjacent to outside doors. Within large open internal spaces, unit heaters-either gas fired, hydronic or steam - may be additionally employed to project heated air to occupant levels.

Ventilation make-up air is mandatory in buildings of modern design in order to pressurize and prevent uncomfortable in-leakage, also to remove odours and humidity build-ups, and meet normal air change criteria for occupied areas. The City Hall is a case of an old building retrofitted with modern sealed windows that has no ventilation air change facilities. Ventilation systems require a fresh air make-up supply to offset losses from extractor fans and leakage losses through doors, windows and other outdoor paths. For the buildings examined, ventilation air is either heated by gas fired burners or by steam coils.

Domestic hot water, traditionally circulated at 80°C and above, is now commonly regarded to be acceptable at temperatures of around 55°C for most general purposes, including washing and showers. The majority of buildings utilize gas fired heaters while some older buildings have steam heaters.

3.2.1 Equipment de-Rating with Temperature

With resource temperatures as low as 37°C the impact on conventional heat emitter performace, typically designed for 90-100°C would be drastic. This is evident from the tabulation below, showing capacity de-rating effects with temperature.

Typical Capacity Derating with Temperature

Supply (T_s°C)	Perimeter Baseboard Output (%)	Heating Coil Output (%)	Preheat Coil Output (%)
100	100	100	100
90	92	88	92
80	74	77	85
70	59	62	76
60	44	50	70
50	29	37	63
40	17(b)	23	52

Notes:

(a) Baseboard and heating coil entering air at 18°C; preheat coil entering air, -35°C.
(b) At 40°C, fan units improve output to 22%.
(c) At 50% design flow, the capacities given reduce by 10%.

From inspection, a 40°C supply would severely limit the load capability of existing heat emitters (i.e. baseboard and heating coils). For retrofit or new designs, the number and/or size of emitters would need to be increased accordingly. However, as described in Section 5.1, the impact of low resource temperatures can be avoided by using heat pumps to increase the temperature (T_s) above the resource temperature (T_1) to perhaps 55 or 60°C; thereafter to use conventional boiler heating to achieve conventional peak temperatures of 93°C, all according to load demand. Regulation of supply temperature with load is addressed later (Section 5.1). What is evident from the capacity de-rating table above is that a 60°C supply temperature is capable of meeting from 44 to 70 percent of design capacity relative to peak design of 100°C. For existing systems designed for 93°C (200°F), a common condition, emitter capacities at 60°C would be marginally better than this.

In short, with heat pump and boiler assistance, existing hydronic designs - or retrofit designs to replace existing steam systems, for example - do not need to incur a de-rating penalty on account of a low supply temperature. However, there is another important factor to be recognized, the need to achieve a low disposal temperature (T_2).

Two requirements are necessary to achieve this both of which contribute to lower the hydronic (or CH system) return temperature (T_r). They involve:

- increasing the hydronic temperature differential across each emitter;
- arranging emitters in cascading order of flow and temperature from perimeter baseboard units and reheat coils to DHW and ventilation make-up preheat coils at the lower end of the temperature scale.

3.2.2 Improved Temperature Differentials

To maximize direct heat output from the geothermal system it is most desirable to increase hydronic temperature differentials across heating equipment. With existing perimeter baseboards an increase from conventional levels of 10 degrees C or so up to 22 degrees C is within the range of conventional practice. For fan coil units an increase to 27 degrees is acceptable. These improvements can be achieved by reducing the hydronic flow to individual coils and baseboard units by around 50 percent which also reduces capacity (load) by 10 percent. This

10 percent reduction in the perimeter heat load is considered to have a negligible effect on comfort conditions, and can be expected to be absorbed within equipment performance margins. Alternatively, the load loss might be compensated for by upgrading existing ventilation system capacity by a similar amount.

Similar considerations apply to other hydronic equipment such as building ventilation air heating and make-up units. New units can be fitted with multi-row coil designs to achieve temperature differentials of 40 degrees C or so for a relatively small increase in cost.

3.2.3 Cascading

Previous studies (Acres, 1983; Acres, 1984) have demonstrated for new buildings the economic advantage of designing hydronic circuits to cascade flows from the higher to the lower temperature heat exchange processes, this to lower secondary circuit temperatures (T_r) returning to the primary exchanger. Accordingly, hydronic designs were developed where perimeter baseboard heaters are the first to be supplied with the warmest water, the outflow passing next to DHW pre-heaters and then finally to heat ventilation/make-up air.

For building retrofits the lowering of T_r remains still a principal objective but one that has to take into account the opposing influence of potentially higher retrofit costs. For the general case, it is judged to be too costly to attempt extensive re-routing changes to existing pipework other than those that can be made in the building Boiler Mechanical Room, and perhaps in building service shafts - where pipes are normally readily accessible.

In conventional heating systems, the high temperature (HT) supply leaving the boiler feeds to a manifold arrangement from where individual take-offs serve the building hydronic distribution system, this comprising vertical pipe risers supplying to each floor and from there to perimeter baseboards and reheat coils installed in ventilation air supply ducts. Hydronic returns from each floor ultimately all flow to a manifold prior to re-entry to the boiler.

With such an arrangement, the pipework changes that can be most readily accomplished at reasonable cost involve redirecting the return flows from baseboard and reheat coils to supply existing or new ventilation air make-up coils. The re-routed supply would go via the DHW heat exchanger given that the economics of DHW heating is justified (see later discussion).

The effect of cascading on the design and performance of existing baseboard and reheat coils would be negligible since, in general, they would continue to receive supply temperatures sufficient for the load demand, controlled in accordance with the reset schedule. Ventilation unit reheat and preheat coils, on the other hand, would experience supply temperatures lower than normal and a fall off in capacity unless retrofitted with new coils.

3.2.4 Perimeter Heating/Hydronic Circuits

Existing Steam Systems

The adaptation and/or retrofitting of extensive building perimeter heating systems is typically an involved costly undertaking. If existing steam distribution systems are in reasonably sound condition, replacing extensive concealed piping and radiators could be too costly to be an economic proposition for adapting to geothermal/hydronic operation.

Alterations to buildings extensively heated with steam would be restricted by cost considerations to replacing ventilation air and DHW coils, in the process taking the opportunity to increase the heat load contribution of the ventilation supply system and reduce perimeter heating steam loads.

On the other hand, the costs chargeable to geothermal retrofit are diminished where, because of deterioration and accelerating maintenance demands, steam boiler and piping systems are due for imminent replacement. In this case, the cost of replacement is not chargeable to geothermal energy other than, possibly, a small increment for upgrading the replacement hydronic design to suit increased temperature drop and cascading objectives. This imminent retirement situation prevails in the Natatorium, could quite possible apply in the case of the YM-YWCA system in the fairly near future, and has already occurred at City Hall with the replacement of the original steam system with hydronic. The avoidance of increasing labour costs to repair and maintain corroded systems and correct steam trap failures, provides sufficient economic justification in many cases.

3.2.5 Ventilation Systems

Ventilation make-up air heating systems are well suited to low temperature geothermal application since the leaving temperature requirements are, by and large, compatible with geothermal systems operating in the 40° to 60°C range. Of particular benefit to geothermal heating operations is the low entering temperature of make-up air which, for a considerable period of the year, ranges between -35°C to 15°C. This is an important area of geothermal retrofitting, typically requiring replacement of heating coils (or the complete units if necessary) with multi-row coil designs suited to lower-than-normal circuit temperatures. In the case of steam heated or gas fired ventilation units, complete unit replacement is required.

Generally speaking, retrofits involving installation or replacement of this equipment, which is frequently located and accessible within the Boiler/Mechanical Equipment Room, can be undertaken at reasonable cost. The cost of heating and ventilation equipment is traditionally inexpensive.

3.2.6 DHW Preheat/Storage Retrofit

Domestic water is presently heated with steam or gas heaters and operates in conjuction with storage tank facilities. The practical way to meet high demands of short duration with a hydronic system is to divert the full system flow to an instantaneous DHW heater. This approach is often used in schools, for example, where shower loads occur with 15 minutes after each class. At such times, other load demands on the heating system are starved and the building temperature is allowed to fall temporarily.

This approach is adopted for DHW retrofits considered in this study, subject to evaluation of cost/benefit aspects reviewed below.

Apartment buildings can experience instantaneous DHW demands equal to 50 percent of the total heating load while, on an annual basis, DHW heating may only represent 5 percent or so of the total heating energy consumption. In addition, in summer the supply temperature T_S will be insufficient to provide full heating and existing gas fired facilities will still be required. The costs for heat exchangers sized for the instantaneous demand including controls are expensive making it economic only in cases where hot water useage is substantial.

Where the costs can be justified, retrofitting typically involves a relatively simple modification within the Mechanical Room to incorporate the new DHW instantaneous exchanger in line ahead of the existing gas heater/storage facility.

3.3 System Retrofit Cost Estimates

Installation under retrofit conditions, incurs a premium cost to cover uncertainties, unforeseen difficulties with dis-assembly and re-assembly, customized fitting up, and to compensate for the limited scope of retrofit undertakings in relation to the responsibilities incurred for subsequent satisfactory operation. Nevertheless, such costs need not be extreme given adequate planning, reasonable access to equipment and some minimum space locally in which to install additional pumps, interconnecting piping and electrical/control panels, as applicable.

Table 3-1 presents indicative cost estimates for retrofitting existing building heating systems for geothermal based CH system supply. For systems subject to rehabilitation due to poor condition, the cost estimated for this

TABLE 3-1

INDICATIVE HEATING SYSTEM RETROFIT COSTS
($1000)

Bldg. No.	Bldg. Candidate	Perimeter and Unit Htrs.	Ventilation Air	DHW	Total	Rehabilitation Charge	Geothermal Charge
1	Natatorium	45	20	15	80	60	20
	o Indoor Pool	-	-	3	3	-	3
	o Outdoor Pool	-	-	25	25	-	25
2	YMCA-YWCA	16	7	-	23	10	13
3	Library	20	50	-	70	60	10
4	Art Museum	-	10	-	10	-	10
5	High Park Towers	20	5	7	32	-	32
6	Victoria Towers	20	5	7	32	-	32
7	City Hall	34	84	-	118	94	24
8	Temple Towers	15	4	6	25	-	25
9	Cultural Centre	5	-	-	5	-	5
10	River St. Apts.	12	4	5	21	-	21
11	Racon Office Bldg.	-	10	-	10	-	10
12	Harwood Inn	25	20	15	60	20	40
13	Harwood Centre	-	10	-	10	-	10
14	Grant Hall Inn	25	20	15	60	20	40
15	Langdon Towers	20	5	7	32	-	32
16	CPR - station	40	28	-	68	58	10
	- shops	-	40	-	40	-	40
17	Union Hospital	80	150	30	260	30	230

upgrading are separately itemized from charges incurred to adapt or replace the system or components to suit geothermal system use.

As shown the costs have been broken down into categories of perimeter, ventilation air and DHW heating system each covering replacement of coils, baseboard radiation units, and associated piping and controls as applicable.

3.4 Building Peak Load Estimates & Annual Gas Consumption

Gas consumption data and degree-day information for a number of candidates is shown plotted in Figure 3-2. In the typical case the demand in the summer months can be assumed to be attributable almost entirely to DHW heating. Consumption data for the Natatorium shows that summer heating of the outdoor swimming pool together with normal DHW demands produces the peak demand condition.

The estimated peak load demand for each candidate is shown in Table 3-2. These estimates are based on an appraisal of gas consumption records. The peak load distribution between perimeter, ventilation and DHW services is estimated on the basis of specific system data in some cases. In others, judgement is used based on a knowledge of the building age and typical heating pratice.

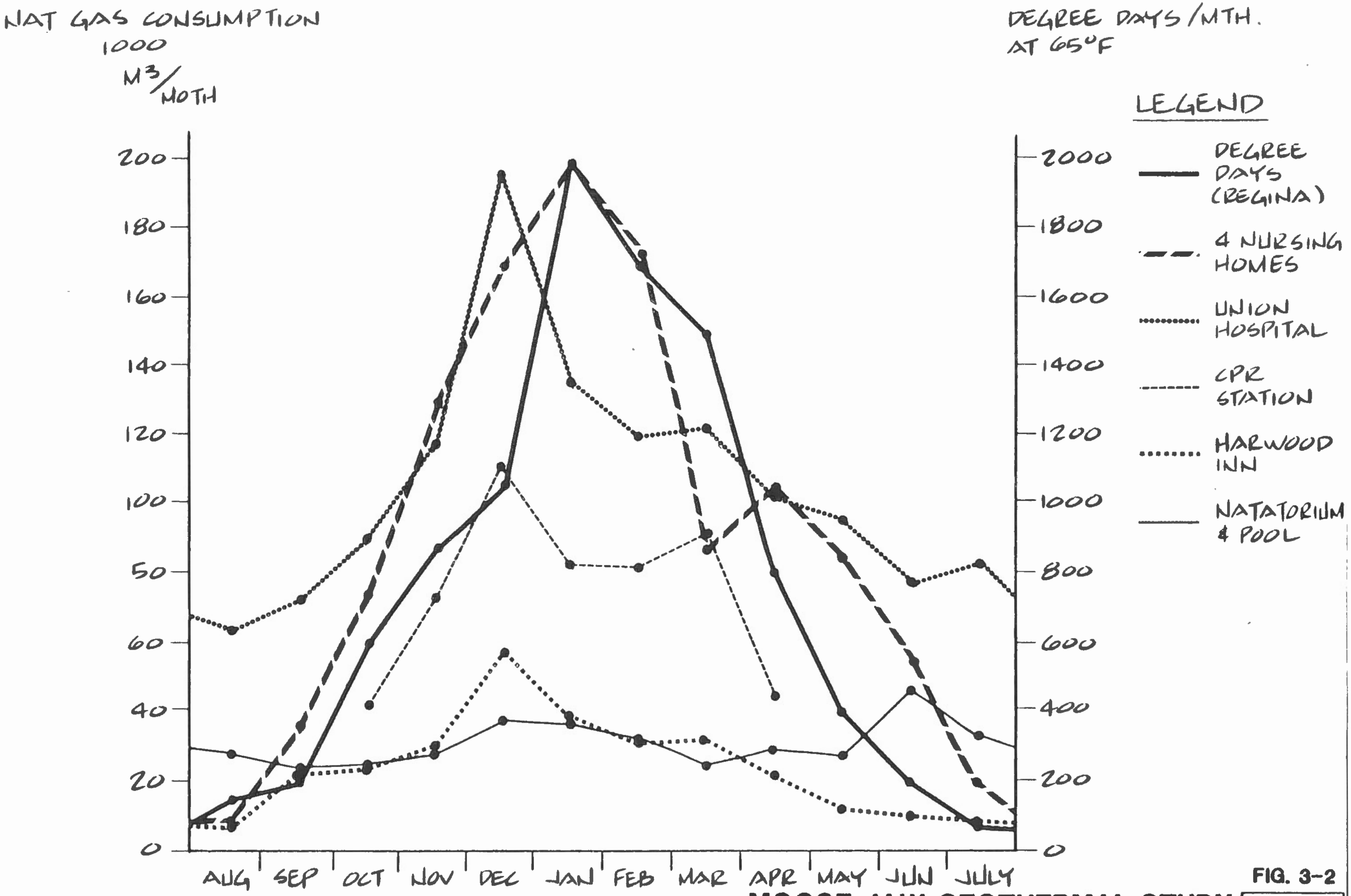


FIG. 3-2

MOOSE JAW GEOTHERMAL STUDY
BUILDING MONTHLY GAS CONSUMPTION PLOTS

ACRES

TABLE 3-2

BUILDING PEAK LOAD DEMANDS & ANNUAL GAS CONSUMPTION

Bldg. No.	Building Candidate	Annual Gas Consumption (1000 m^3/yr)	Perimeter Load GJ/h	Ventilation Load GJ/h	DHW Load GJ/h	Total Load GJ/h
1	Natatorium	242	0.15	0.55	0.23	0.9
	o Indoor Pool	60	n/a	n/a	0.30	0.3
	o Outdoor Pool	60	n/a	n/a	1.5	1.5
2	YMCA-YWCA	122	1.2	0.4	0.10	1.7
3	Library	31	0.4	0.3	neg.	0.7
4	Art Museum	39	0.2	0.1	neg.	0.3
5	High Park Towers	251	1.9	1.6	0.1	3.6
6	Victoria Towers	261	1.9	1.6	0.1	3.6
7	City Hall	99	1.0	1.0	neg.	2.0
8	Temple Towers	246	1.1	1.0	0.05	2.2
9	Cultural Centre	6	0.2	-	neg.	0.2
10	River St. Apts.	75	0.6	0.5	0.03	1.1
11	Racon Office Bldg.	350(est)	2.3	2.3	0.1	4.7
12	Harwood Inn	298	2.0	1.9	0.4	4.3
13	Harwood Centre	250(est)	1.0	1.0	-	2.0
14	Grant Hall Inn	345	2.0	1.9	0.4	4.5
15	Langdon Towers	101	1.9	1.6	0.1	1.4
16	CPR - station	521	4.2	4.2	neg.	8.5
	- shops	300(est)	1.3	1.3	-	2.6
17	Union Hospital	1278	5.3	3.2	2.1	10.6

Note:

1) DHW loads are 24 hour averages, not instantaneous peaks.

4.0 GEOTHERMAL PERFORMANCE ANALYSIS

4.1 Geothermal System - General Description

The geothermal energy system is expected to comprise the single doublet arrangement comprising one production (supply) and one disposal (re-injection) well connected by transmission piping at the surface. Additionally, the system incorporates wellhead facilities, the primary heat exchanger, production well pump and re-injection pump.

Figure 4-1 illustrates the current arrangement of buildings and proposed supply well location in Crescent Park.

The City has expressed a preference for locating the production well within Crescent Park at a site about 200 m north of the Natatorium. It is proposed that the production wellhead, supply pump and possibly the re-injection pump as well, be housed within a small building constructed at this site to contain all necessary electrical power supplies and control panels including variable speed control facilities required for pump output regulation.

Two disposal well site options have also been designated by the City, (sites B and B_1, Figure 3-1). The closest (B) is 700 m in a direct path from the production well site, while B_1 is approximately 1000 m away. The connecting disposal pipeline routes to both disposal well sites, developed in consultation with the City, run for the most part adjacent to the CNR rail track. From preliminary discussions with CNR an approval to route within the right-of-way can be expected. The Athabasca Street rail bridge will be necessary for supporting the pipe.

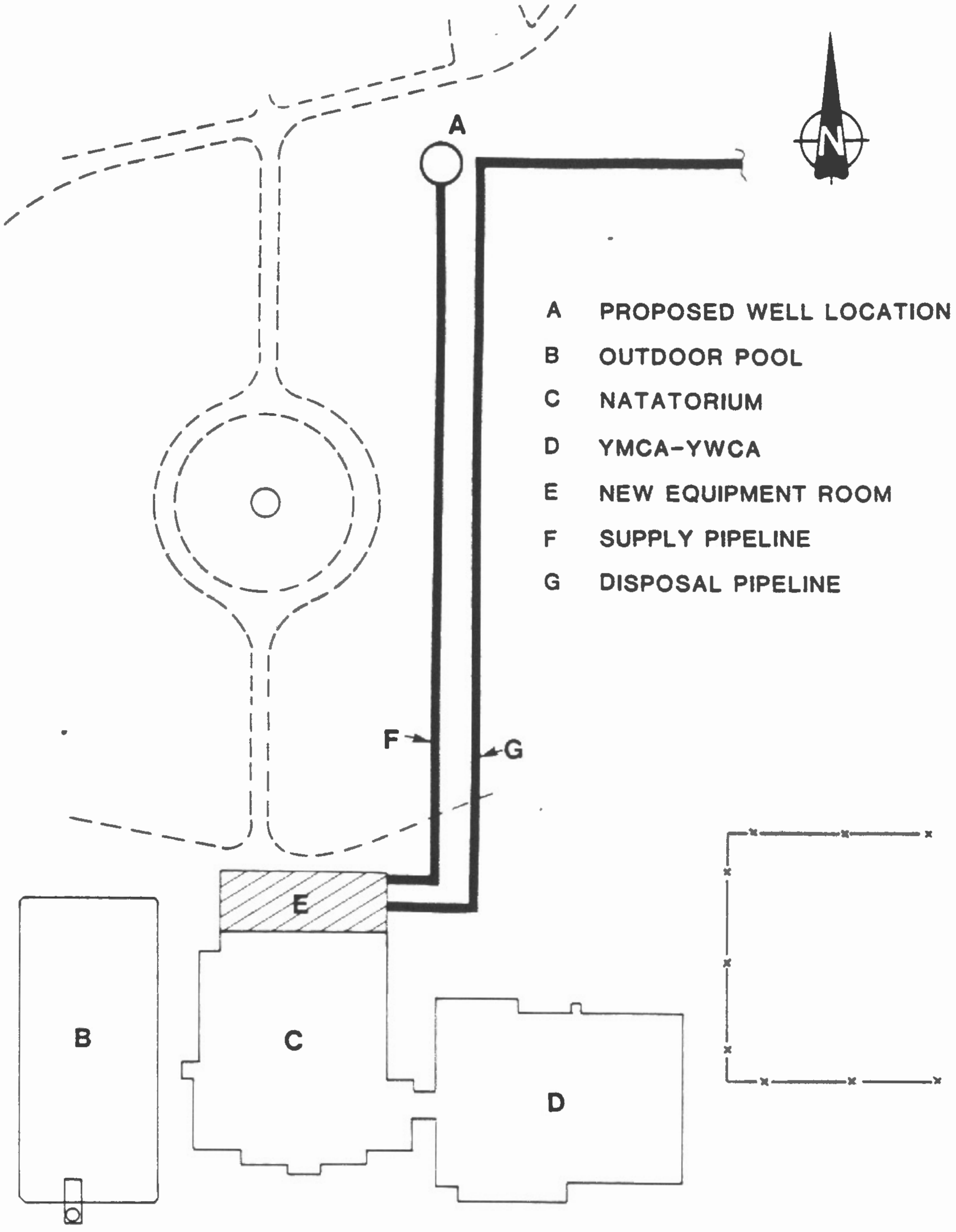


FIG. 4-1

MOOSE JAW GEOTHERMAL STUDY
CRESCENT PARK - NEW WELL LOCATION
AND BUILDING ARRANGEMENTS

ACRES

For limited flow applications including the Base Scheme and Scheme 1, locating the disposal well adjacent to the supply well (A) in Crescent Park is a valid possibility. Angle drilling would be necessary to achieve separation.

For the smaller load schemes proposed, space exists to locate the primary heat exchanger, heat pumps and other facilities in the basement of Natatorium. For large load systems Schemes 3 and 4, requiring large heat exchanger facilities, central system water circulation pumps, heat pumps and associated power supplies and controls, a building extension to the Natatorium is envisaged.

4.2 Production Flow Rates & Pumping Requirements

Referring to Section 2.0, the data well analysis indicates the presence of four candidate formations at shallower depths ranging from about 800 to 1200 m, namely the Mannville (30°C), Gravelbourg (37°C), Souris Valley (44°C) and Birdbear (46°C). Deeper, below 2 km, about 60°C can be expected from the Winnipeg/Deadwood formations. The shallow formations are noted to be under substantial artesian pressure (positive hydrostatic head) varying from 90 m to a high of 230 m above ground, while hydrostatic heads of the deeper formations varies from 9 m to 96 m below ground (reference Table 2-3).

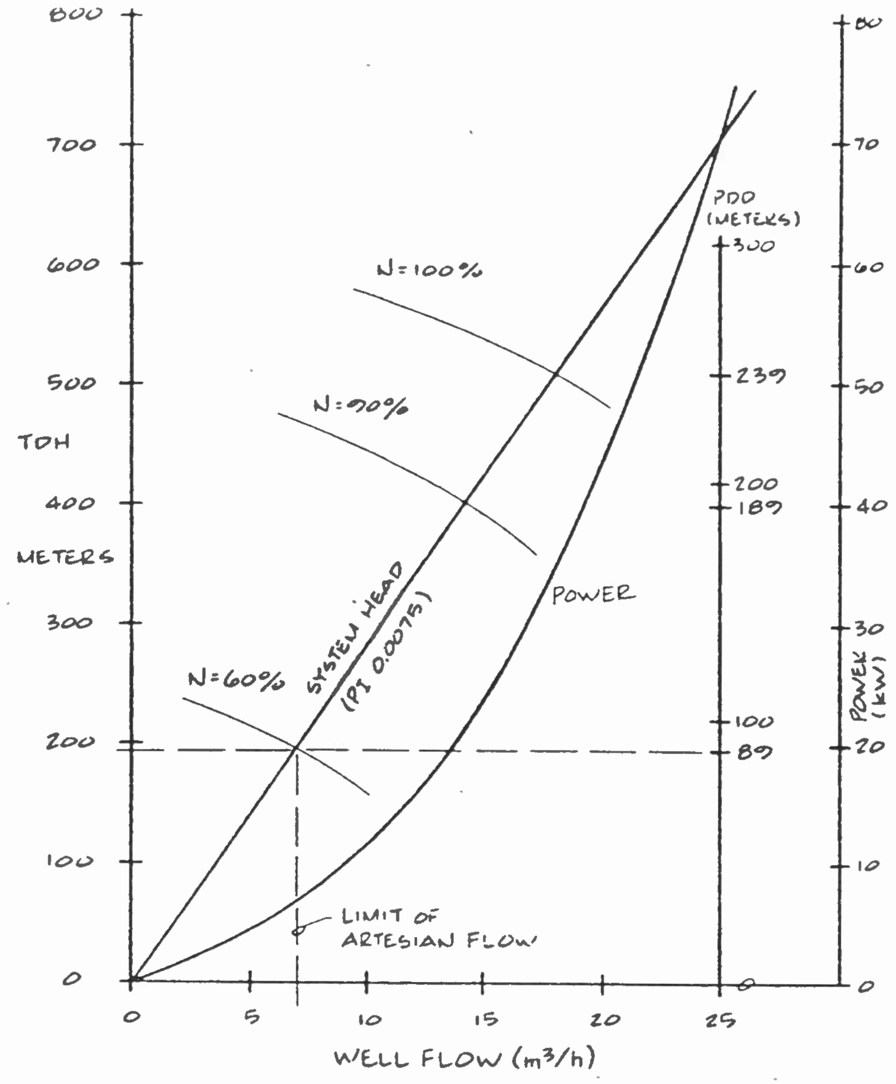
Applying productivity index data of Table 2-3 to the analysis of the geothermal pumping flow rate and power requirements shows a number of interesting results. Figure 4-2 illustrates plots for each of the formations showing system head-flow characteristics; total dynamic head (TDH) requirements for the production and disposal pumps; and pump power characteristics. Hydrostatic pump drawdown conditions (PDD) are also represented with drawdowns to grade level, and 100 m and 150 m below grade indicated.

The limit of well output flow under artesian pressure conditions is shown. This flow would be approximately obtained without the aid of a supply pump if allowed to flow from the open well. In practice, a pump will be required for returning the brine back to the formation. Pump power requirements can be determined from the point of intersection of the flow on the power demand curve.

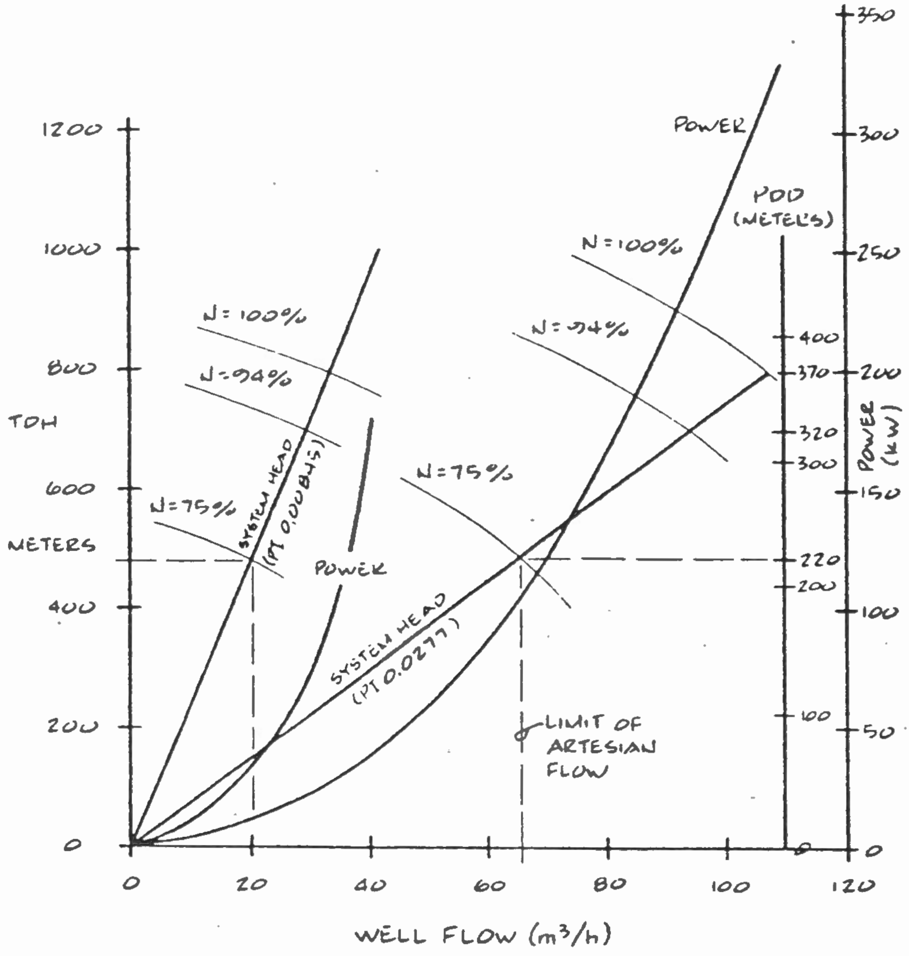
For larger supply flows both a supply and disposal pump are required. The combined power requirements for the two operating in series is obtainable,again from the flow intersection with the power demand curve. It should be noted that in many cases, subject to certain system hydraulic constraints, a supply pump will be able to handle the total pumping demand.

In Figure 4-2, curves of relative pump speed (N) expressed as percentages are also shown superimposed on system head-flow characteristics. The speeds correspond with hydrostatic drawdowns at grade, and at 100 m and 150 m below grade respectively. They serve to illustrate the potential flow and power variation available with pump speed regulation.

System head characteristics rise almost linearly with increasing flow so that pump power, as the product of both flow and head, increases as the square of the flow. The power savings available with variable speed control of the



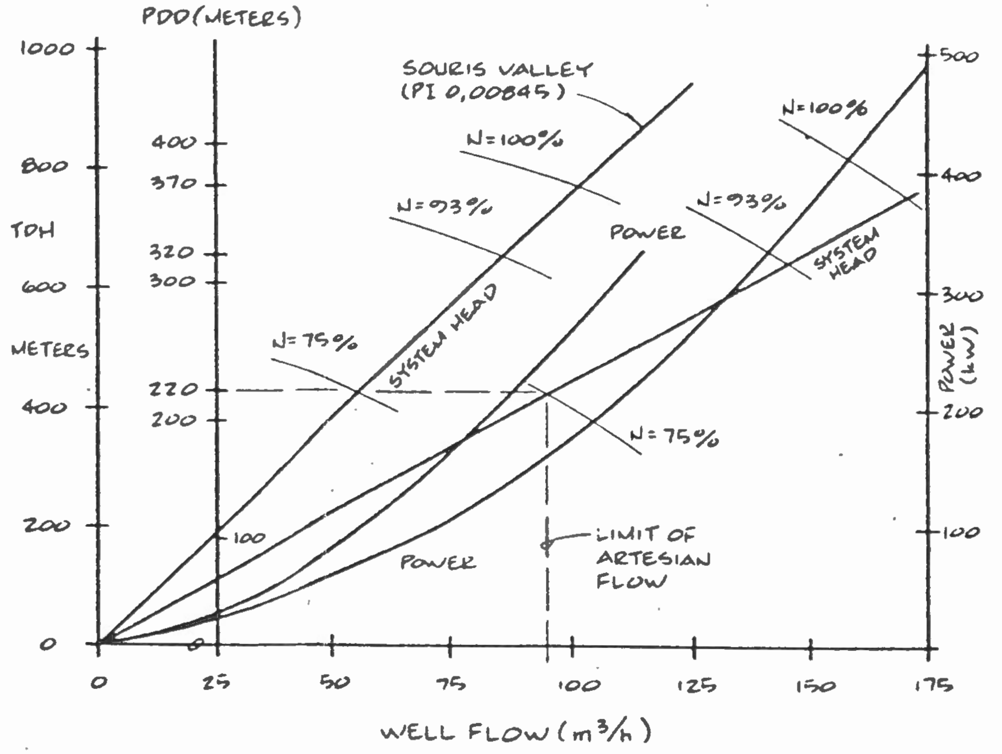
MANNVILLE



SOURIS VALLEY

PI (m³/h/kPa)

MANNVILLE	0.0075
GRAVELBOURG	0.0063
SOURIS VALLEY	0.00845 & 0.0277
BIRDBEAR	0.0095



MULT-ZONE COMPLETION

EXAMPLE : REFERENCE GRAVELBOURG CHARACTERISTICS

FLOW RATE REQUIRED	20.5 m³/h
GEOFLUID SYSTEM HEAD	700 m
TOTAL PUMP TDH	700 m
HYDROSTATIC DRAW DOWN	326 m
TOTAL POWER	52 kW

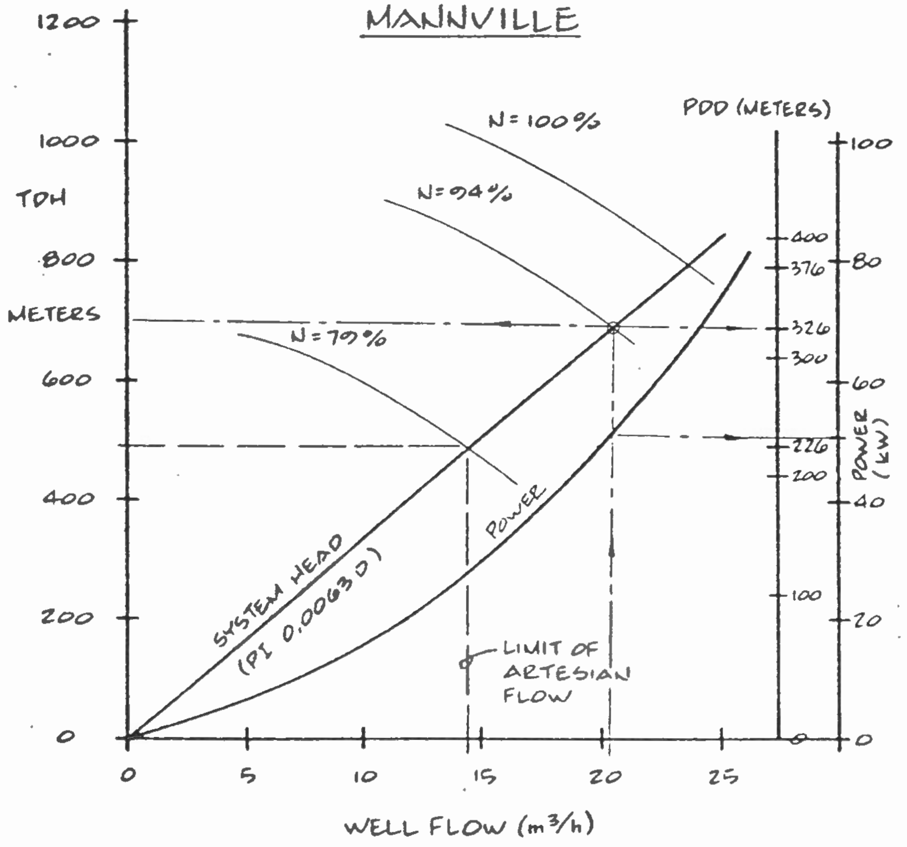
LEGEND

N - SPEED

PDD - PUMP DRAW DOWN

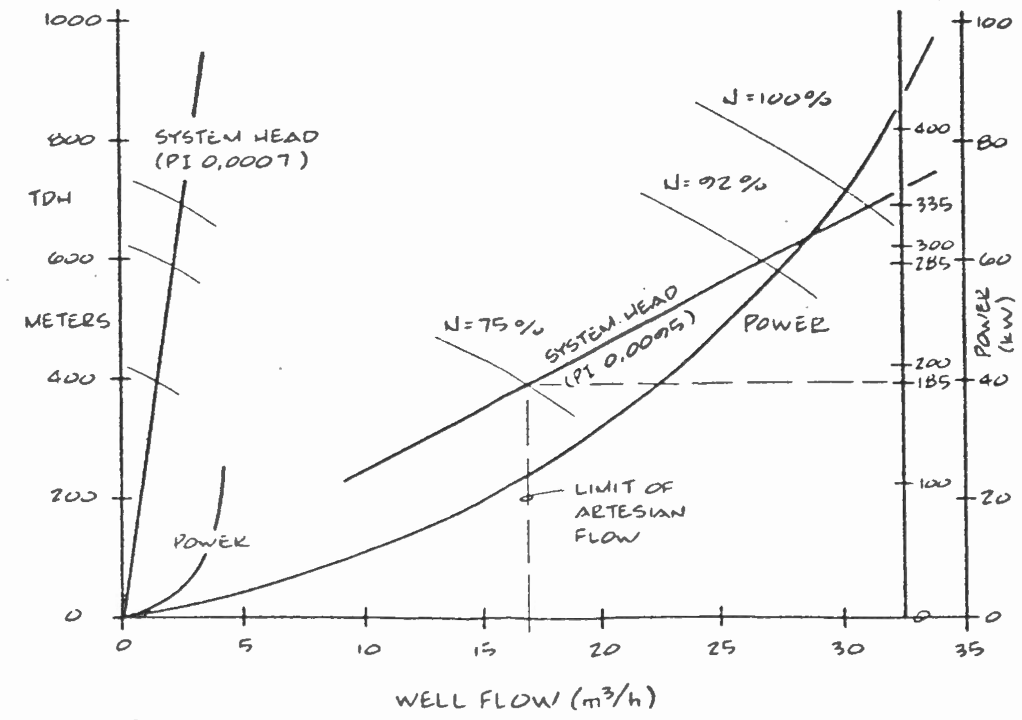
TDH - TOTAL DYNAMIC HEAD

PI - PRODUCTIVITY INDEX



NOTE: LIMIT OF ARTESIAN FLOW IS MAXIMUM NATURAL FLOW CASE WITHOUT REINJECTION.

GRAVELBOURG



BIRDBEAR

FIG. 4-2

MOOSE JAW GEOTHERMAL STUDY
FORMATION PUMPING CHARACTERISTICS
PUMP HEAD VS. FLOW

ACRES

pumps is evident, a feature particularly valuable for reduced flow/load conditions normal to summer periods of operation. As an example, a 70 percent reduction in flow achieved by speed regulation to 55 percent, reduces system head by 70 percent and power by 91 percent.

Pump operating data for the four shallow formations are presented in Table 4-1 for comparison. The output potentials of the Mannville, Gravelbourg and Birdbear formations are relatively poor and all require considerable pumping power. The Souris Valley offers the best potential for supplying the larger load schemes.

Also included in Table 4-1 to demonstrate power and flow rate improvements are data corresponding to a multi-zone well completion (reference Figure 4-2). If exploration and flow testing should indicate flow difficulties with the Souris Valley, a multi-zone completion could be beneficial.

Production Well Pumps

Production well pump options include the vertical turbine and the submerged downhole type. The maximum setting depth with the vertical pump is currently around 250 m. It comprises a motor mounted at the surface, an extended fixed casing and rotating inner shaft driving a multi-stage impellor assembly that requires to be submerged at some depth below the maximum drawdown level. The downhole type, specifically developed for pumping deep, hot water aquifers, is also a multi-stage unit that is suspended in the casing below the maximum drawdown level. The whole unit including the special oil cooled, small diameter motor is inaccessible for routine maintenance, a situation

TABLE 4-1

FORMATION PUMPING PERFORMANCE DATA

Formation	Hydrostatic Drawdown (PDD)	Pumping Head (TDH)	Flow (1)	Pump (1) Power
	(m)	(m)	(m^3/h)	(kW)
Mannville	89 (grade)	200	7	5
(PI 0.0075)	189	400	14	20
	239	500	18	33
Gravelbourg	226 (grade)	490	14	25
(PI 0.0063)	326	700	20	50
	376	800	23	66
Souris Valley	220 (grade)	460	20/66	33/110
(PI 0.0085/0.0277)	320	700	29/94	73/235
	370	800	33/107	95/310
Birdbear	185 (grade)	400	1.3/17	1.8/24
(PI 0.0007/0.0095)	285	590	1.9/27	4.0/57
	335	690	2.3/31	5.8/77
Multi Completion(2)	220 (grade)	450	55/95	90/154
	320	630	87/145	205/340
	370	770	102/172	270/470

Notes:

1. TDH and Power are totals for production and disposal pump (in-series)
2. Souris Valley PI 0.00845/0.0277; high PI values assumed for the other formations.

influencing motor maintenance and the reliability of the entire supply system. The vertical turbine unit is preferred, for reasons of lower cost and greater accessibility to the motor.

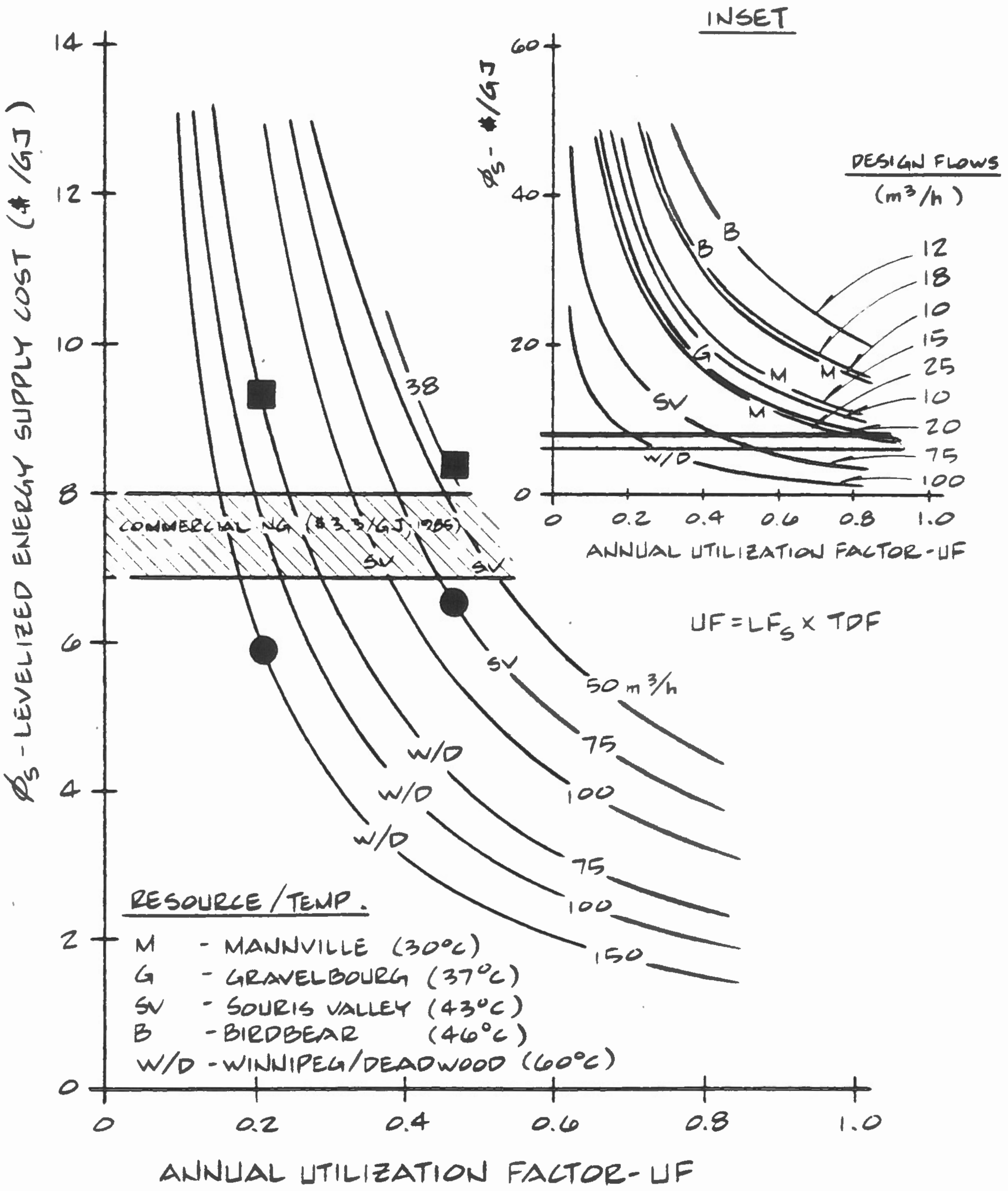
4.3 Corrosion Control and Materials Selection

Appendix B contains details of the geofluid chemistry, analysis of corrosion potential, and provisional material selection for components of the geothermal supply circuit. Table 4 of the Appendix identifies the geo-circuit materials assumed for this study.

4.4 Geothermal/Heat Pump System Performance & Costs

To direct development of the most cost effective heat scheme it is appropriate to generally examine the interactions of resource conditions, well costs, flow rates, pumping costs, and other factors on the potential for economic utilization of the geothermal resource. This review compares the economics of using the deep, more expensive but warmer (60°C) conditions of the Winnipeg/ Deadwood formation, with the cooler shallower formations requiring heat pumps to achieve effective utilization of the resource. The appraisal is preliminary and employs analytical methods presented in detail in earlier studies.

The inset, Figure 4-3, presents curves of unit energy costs versus geothermal system annual utilization for the various formations and range of design flow rates (F_g). Heat pumps are required for all formations, other than the Winnipeg/Deadwood: a maximum system supply temperature (T_s) of 60°C is assumed. The resource disposal temperature (T_2) is set at 10°C for the heat



1. REFERENCE SINK TEMPERATURE $T_{si} = 0°C$;
2. LEVELIZED N/GAS COST RANGE REFLECTS COMBUSTION LOSSES.

FIG. 4-3

MOOSE JAW GEOTHERMAL STUDY
INDICATIVE GEO-ENERGY SUPPLY COSTS
VS. ANNUAL UTILIZATION

ACRES

pump cases. The various system operating characteristics described later and illustrated in Figure 5-3 provide the basis for estimating typical annual patterns of power demand and annual energy requirements of well supply and heat pumps. Allowances were made to adjust for the different formation conditions and their impact on well flow potentials, supply temperatures, heat pump operating and pumping power requirements, and so on.

Costs for wells and above-ground supply system, including heat pump costs at various capacities, are based on data presented elsewhere in this report. From these, indicative capital and annual owning and operating (O & O) costs were constructed. Table 4-2 presents for reference, cost breakdowns including levelized annual O & O costs. All costs are in constant 1985 dollars. With labour and materials costs forecast to remain constant or to reduce only slightly in real terms, the primary increase in annual operating costs is for electrical power.

Referring to annual O & O costs, (Table 4-2) annualized capital costs are based on an assumed real cost of public sector borrowing of 6 percent. This rate, though real is noted to favour capital intensive operations and in particular, development of the Winnipeg/Deadwood wells.

To the curve data, Figure 4-3, has been added a band showing the range of levelized gas costs appropriate to: a 30 year operating life; a 65 to 70 percent combustion efficiency factor (annual average); and real long-term annual gas cost increases of 1 and 2 percent respectively.

The curves show the characteristic trend of reducing energy costs with improved annual utilization of the geo-

TABLE 4-2

TYPICAL GEOTHERMAL/HEAT SUPPLY SYSTEM CAPITAL AND O & O COSTS

INDICATIVE CAPITAL COSTS

FORMATION	Mannville	Gravelbourg	Souris Valley	Birdbear	Winnipeg Deadwood
Flow Rate m^3/h	15	25	75	20	150
Well Costs	670	700	740	900	2,100
Above Ground System	210	240	450	230	530
Heat Pumps	120	180	450	125	n/a
TOTAL CAPITAL COSTS	1,000	1,120	1,640	1,225	2,630

INDICATIVE ANNUAL OWNING & OPERATING COSTS

($1000/yr.)

Fixed Costs					
Annualized Cap. Cost	75	83	124	90	200
O & M Labour	40	40	70	40	40
Overhead Allowance	20	22	30	25	50
Equipt. Replacement Allowance	15	15	30	15	20
Sub-Total	150	160	254	170	310
Variable Costs					
Well Pumping Power	8	20	53	15	90
Heat Pumping Power	20	33	107	20	n/a
Sub-Total	28	53	160	35	90
Total O & O Costs	178	213	414	205	400
Levelized O. & O Costs	182	215	430	210	410

supply system. As a point of reference, regarding utilization factors values much above 0.5 are difficult to achieve for space heating applications. Previous studies have indicated values ranging from 0.4 to 0.5. By inspection, geothermal systems dependent solely on flows from the Gravelbourg or Mannville cannot hope to be competitive with natural gas. This is primarily the result of the thinness of the formations imposing constraints to the economic flow rate potential. (The analysis has not pursued the flow and load capability of each formation to its economic limit, i.e. the point when the next incremental increase in well pumping flow causes the power cost to outstrip the economic benefit from the further energy supplied.)

It should be noted that in developing Figure 4-3 no costs were included for the central heat system, building retrofits or for CH system operation. These cost factors all contribute to increase energy costs above those shown (Figure 4-3).

Comparison of Shallow vs. Deep Formations

Two example cases were developed in order to compare performance and energy costs for the Souris Valley with heat pumps, and the Winnipeg/Deadwood with direct heat exchange only. Energy cost points are shown superimposed on the sets of curves for these formations, shown to a larger scale in Figure 4-3. Employing the nomenclature developed in a previous study (Acres, 1984), the following tabulation presents performance assumptions and conditions for the worked examples.

For the same design load q_s, the Souris Valley flow (F_g) is only 50 percent of the flow required from

Performance Conditions & Assumptions

FORMATION		Souris Valley		Winnipeg/Deadwood	
Flow (F_g)	m^3/h	75	37.5	150	75
Resource Temp (T_1)	°C	43	43	60	60
Disposal Temp (T_2)	°C	10	10	38	38
TDF		0.77	0.77	0.37	0.3
Design Point COP_s		4.0	4.0	n/a	n/a
Load (q_p)	GJ/h	27.6	13.8	27.6	13.8
Load (q_s)	GJ/h	13.6	6.8	13.8	6.8
Load (q_g)	GJ/h	10.3	5.15	13.8	6.9
Load Factor (LF_p)		0.33	0.33	0.33	0.34
Load Factor (LF_s)		0.59	0.59	0.59	0.53
Utilization Factor (UF)		0.45	0.45	0.22	0.22
Unit Cost (Øs)	$/GJ	6.6	8.4	6.0	9.2

the Winnipeg/Deadwood, clearly indicating better utilization of the Souris Valley resource. This better utilization is provided entirely by the heat pumps which are able to depress the DP disposal temperature to 10°C: this compares to 38°C for the Winnipeg/Deadwood. Notwithstanding, the Winnipeg/Deadwood unit energy cost ($6.0/GJ) for the 150 m^3/h delivery system is less than for the Souris Valley (75 m^3/h; $6.6/GJ), a situation that is reversed at the lower flow rate condition. This and the relationship of the cost curves indicates the Winnipeg/Deadwood to have an inherently better economic potential than the Souris Valley (with heat pumps), a potential that is further enhanced where TDF improvements are obtainable through control of T_r.

The economics of both Winnipeg/Deadwood cases could be greatly enchanced with heat pumps which, by using the disposal geofluid at 38°C, could lower the disposal temperature further to 10°C or so. For the additional cost of heat pumping, the total heat supply (load) capability would be increased by 130-140 percent. (The problem becomes then, as found in previous studies, one of finding applications with high enough load demands to suit the enhanced supply capability).

Concluding, this general analysis of geothermal supply costs indicates that:

- for stand-alone heating applications to be economic, use of the lower cost, shallow formations will be restricted to the Souris Valley or, alternatively, will necessitate multi-zone completions to meet minimum flow rate requirements;
- for smaller loads, development of the shallow formation heat source(s) in combination with heat pumps, can be competative with natural gas on a stand-alone basis;
- for larger loads, development of the deep Winnipeg/Deadwood heat source in combination with heat pumps, offers improved economics compared to using the shallower formations.

As demonstrated later, if the cost of wells can be shared in co-development projects such as is proposed for Moose Jaw, the economics of heating with the lower flow, shallow sources can be greatly enhanced.

5.0 CENTRAL HEAT SYSTEMS

Overview

Central heat systems are similar to district heat (DH) systems, differing mainly in the smaller network size and typically designed to serve high, load-density areas, conditions found in the commercial core of large cities, for example. DH systems comprise much larger networks that extend outward from high-density commercial or industrial areas into medium and, in some cases, into low-density residential areas of a community. The justification for each is influenced by prevailing national, regional, economic and social factors.

In a number of European countries dependent on imported liquified natural gas and oil at world prices and, as a consequence, vulnerable to discontinuation of supplies, extensive DH systems have been developed as a matter of national policy. Significant capital subsidies of 35 percent or so have been made available to offset the high costs of installing extended network systems. High population densities and living conditions tend to assist DH system economics in many cases.

Essentially, none of these conditions prevail in Canada and, in the past, frequent attempts to justify the development of extended DH networks, even to use essentially no-cost waste heat available from thermal power plant exhausts, have been shown to be economic only under high cost escalation assumptions for the displaced fuels (i.e. oil and gas). Studies undertaken by Acres and others show the need for a rapid system growth to full capacity, large system loads, high annual energy utilization, a rapid schedule of hook-ups to customer connections and public utility levels of extended payback. No extensive DH systems are known of in Canada.

CH networks, on the other hand, are installed and operational in Canada. In Vancouver a commercially operated CH system supplies buildings in the downtown commercial core, including hotels and office complexes. In Fairbanks, Alaska, expansion of the present system to the downtown core is imminent. Such examples as these serve to indicate that CH systems, selectively supplying a few large load users, can be practical and economic in North America, under the right conditions.

In this study the basis for selecting candidate load users for CH schemes is directed at City-run buildings with private buildings considered if adjacent to the route. Residential and other relatively small load users adjacent to the distribution route are provisionally excluded. This is a subject for reconsideration at a later stage of investigation but, for the present, it is expected that the connection cost plus the cost of retrofitting individual small-building heating systems would be difficult to justify.

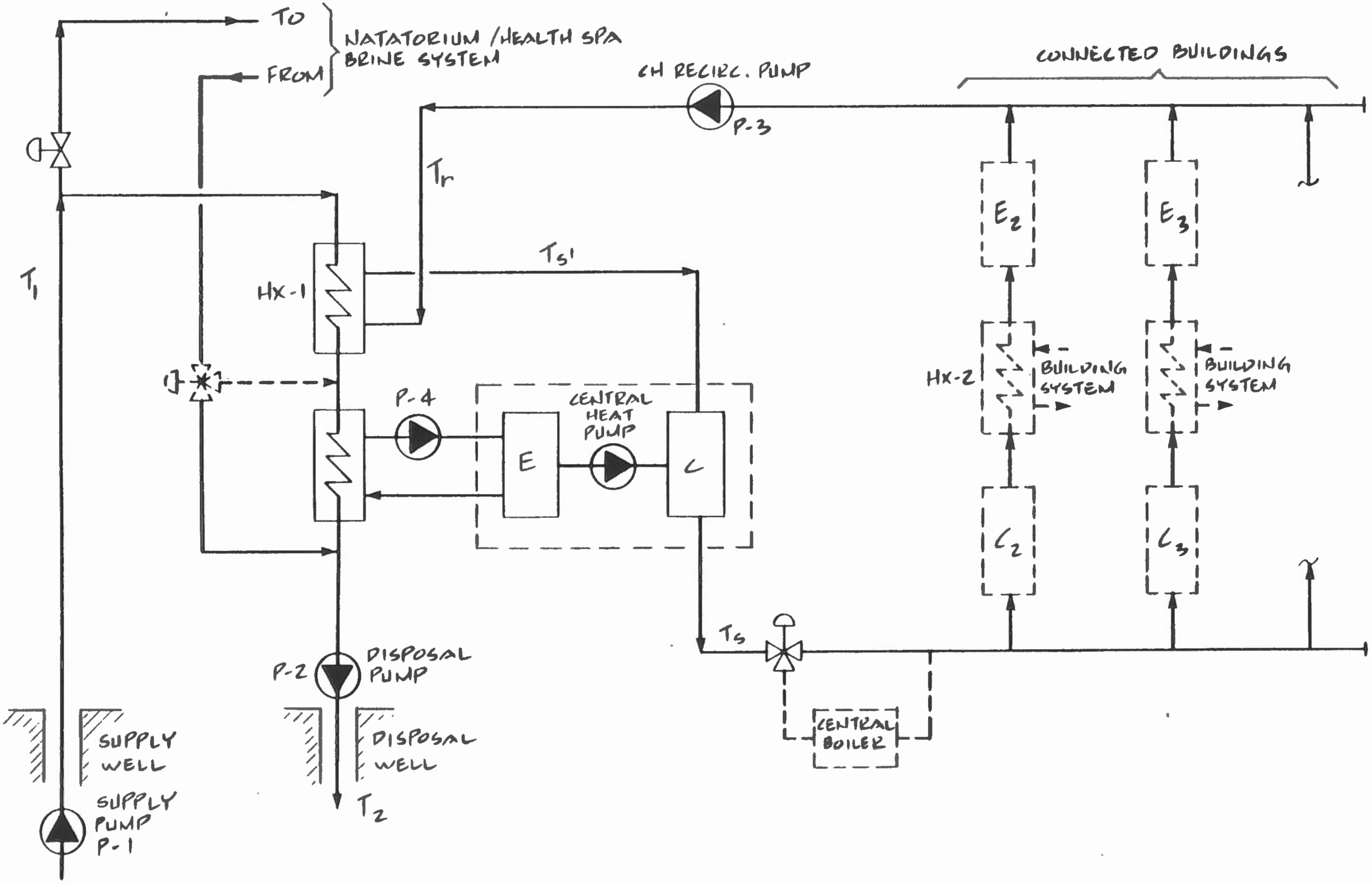
Encouraging large numbers of individual users to connect up to a central system is a major task, particularly where the economics makes it essential for the user, as a long-term beneficiary, to contribute to the initial cost of installation. As indicated previously, central system economics are greatly affected by the system connection (hook-up) rate. Where connection is not made a mandatory requirement, but is left to persuasion, the system's economic viability becomes strongly dependent on large numbers of small users and in those circumstances a rapid schedule of connections may be, realistically, difficult to achieve.

5.1 CH System Design Considerations

The essential elements of geothermally heated CH Systems proposed in this study are illustrated in the simple schematic, Figure 5-1. This shows the geothermal, or primary system, conveying heat by heat exchanger HX-1 to the independent secondary circuit. This circuit serves individual building loads via HX-2, HX-3, etc.

The geothermal supply system operates on the open or once-through principle where the geofluid brine from the producing formation, is pumped by the downhole pump (P-1) to the surface, passes in part or in total to the Natatorium pool, exchanges heat via HX-1, and then is returned to the same formation by means of reinjection Pump P-2. The highly corrosive nature of the brine makes it unsuitable for circulating through the secondary loop, notwithstanding the useful thermodynamic improvement and cost savings to be gained from eliminating exchanger HX-1.

The secondary loop is a closed recirculation system with buried distribution piping serving the various buildings. For freeze protection, a 50/50 glycol solution is proposed, to be recirculated via pump P-3. For conventional higher temperature heating systems, designed to supply hot water at 90° to 120°C, heat exchangers (HX-2, HX-3) are installed to interface with the building's hydronic systems, effectively keeping the CH and hydronic circuits independent. When energy supply temperatures are ade-



E - EVAPORATOR

C - CONDENSER

FIG. 5-1

MOOSE JAW GEOTHERMAL STUDY
CENTRAL HEAT SYSTEM
GENERAL SCHEMATIC ARRANGEMENT

quately above end-use temperatures this approach is preferred since it provides minimum interaction between the CH and building hydronic systems which, from the perspective of the central heating operation, is highly desirable.

To fully utilize the potential of low temperature geothermal energy sources the number of heat exchange processes between the geothermal supply and end-use points (i.e. ventilation air, domestic water, etc.) must be kept to a minimum. Accordingly, for this feasibility level of investigation, the intermediary heat exchange between the CH and building systems is dispensed with in the interest of improved performance and cost savings. At the detailed stage this approach requires further examination to weigh economic and performance advantages against practical considerations including operating and maintenance factors of feeding directly into existing older pipework systems.

An alternative to consider is to allow direct fluid transfer from the secondary circuit only to those buildings that are to be fitted with new or refurbished systems or equipment, and to separate other systems by intermediary heat exchangers. A further refinement is to allow direct fluid transfer to City-operated buildings and use intermediary heat exchangers to interface with other users on the system.

5.1.1 Standby/Peak Heating Source

A secondary source of heating independent of the principal geothermal source is required in order to provide for loss of the geothermal fluid and to meet periodic peak demands. Failure of the supply well pump (P-1), which if of the downhole type is completely inaccessible, is the most likely cause of failure. As has been demonstrated previously (1), providing a second, rarely used, geothermal source for back-up purposes is prohibitively expensive and selection of conventional, low-cost boiler equipment is the appropriate economic choice.

A central heat utility designed for future system expansion would almost certainly incorporate a central boiler plant probably in a common facility with the geothermal heating equipment. The potential for future system growth is not under consideration for the present. The high level of supply reliability required of a utility operation is not considered to be a mandatory requirement. All building candidates being considered have or, it is assumed, will have their own heating plants. These would supplement the CH system energy supply under peak demand conditions. In the event of CH system failure, these plants would also provide the necessary standby capability.

This approach is subject to later reconsideration, particularly where some of the existing boilers are in questionable condition so that replacement is imminent, a situation presently existing at the Natatorium.

New buildings soon to be constructed such as the Cultural Centre, Harwood Centre and Racon Office development that, due to large loads and proximity, are potential candidates for connection could add weight to the selection of a central system boiler plant. A fully independent CH system with back-up and peak load capability offers to commercial developers/owners the opportunity to dispense with boiler room/penthouse facilities (space that is non-revenue earning), thereby saving building costs and boiler supervision operation and maintenance costs.

5.1.2 CH System Temperatures

Supply Temperature Operating Range

Temperature reset controls are required to regulate supply temperatures (T_s) and recirculation flows (F_p) to follow system load demand, the latter being principally influenced by outdoor temperature (t). A linear reset characteristic produces a steadily increasing T_s with increasing demand and falling outdoor temperature.

For minimum retrofitting and cost for adapting building systems, the peak load temperature requires to be maintained at or close to conventional hydronic peak levels (90 to 95°C). The minimum load temperature, corresponding to summer operation, is maintained at a level consistent with direct heat exchange from the primary geo-supply system, a value close to T_1. Thus for a 40°C geothermal supply, the temperature schedule range would be from about 40° to 90°C.

Design Point Supply Temperature

A 40°C geothermal supply could provide about 20 percent of a building's peak load demand. The most useful contribution would be to DHW and ventilation air heating. However, as a CH system design point (DP) value, it is not adequate and heat pumps (or supplementary gas heating) must be used. (Refer also to Section 3.0 for discussion of temperature - capacity effects.)

Identifying the optimum setting for the DP temperature requires a system-wide economic evaluation of all elements of the integrated system including well, heat pump, CH distribution system and building retrofit capital and operating costs and performance interactions. System performance must address usage patterns (daily, seasonal, annual) and effect on design and part load operations and system temperature interactions. In France, where most of the "hands-on" experience in geothermal applications engineering resides, computer simulation of system physical and economic variables has been found necessary for proper optimization of these costs and performance factors and selecting of DP conditions. Such a procedure is reserved for a later stage of investigation.

For present purposes a DP of 60°C is provisionally selected. Higher temperatures adversely affect heat pump performance and costs; lower temperatures reduce the load contribution per building necessitating an increase in the number of buildings to be connected and retrofitted further adding to installation costs.

5.2 Heat Pumps

Heat pumps operating in conjunction with shallow, lower temperature resources have been shown (Acres, 1984) to offer considerable economic potential for a variety of space heating applications.

Heat pumps act to increase the supply temperature (T_S) and lower the brine disposal temperature (T_2) returning to the formation. The economic improvement is derived from:

1) very significant savings in drilling and well development costs for the shallower resources, savings which

for two wells more than offsets the capital cost of heat pumps; and

2) improved utilization of the geothermal energy system from depressing the reinjection temperature thereby increasing the delivered load.

For heating retrofit cases, higher supply temperatures also help to avoid extensive replacement of existing baseboard convectors and other heat exchanger components.

Heat Pump Placement

Referring to Figure 5-1, a central heat pump installation with condensers (C) and evaporators (E) located as shown in the CH system supply and geo-system reinjection lines, offers economies of scale in terms of cost and performance, and also the opportunity to optimize the system coefficient of performance (COP_S) by employing two or more stages of heat pumping. In practice, it is appropriate to separate evaporators from the brine circuit by means of a fresh water recirculation system. Installing condensers and evaporators on the secondary circuit avoids this, but this can be most detrimental to COP_S (Acres, 1984).

A central installation also lends itself to the use of natural gas, internal combustion engine drivers for the heat pumps with the potential for recapture of engine waste heat. This approach, increasingly adopted in Europe, provides the opportunity to improve both the supply temperature (T_S) and system economics by displacing costly electricity. It is a feature that justifies detailed research. For present study purposes electric motors are considered for heat pump drives.

The alternative is to use heat pump units installed at each building with condensers (C_2, C_3) and evaporators (E_2, E_3) in the supply and return lines as shown. The purpose, to raise the supply and lower the leaving temperature, is achieved but such an approach does not readily lend itself to performance and economic refinement. The central plant heat pump installation is considered to be the most appropriate choice.

Heat Pump Performance and Costs

In geothermal space heating applications, with condenser leaving temperatures T_s of 55 to 65°C, temperature differentials between evaporator and condenser (T_s-T_2) could range from 45 to 60 degrees C. Heat pump staging has been shown (Acres, 1984) to offer considerable improvement in COP_s. Arranging multi-stage heat pumps in series, each contributing to the total temperature lift, allows the most appropriate refrigerant to be selected for each stage to suit stage temperature regimes.

For overall economy the choice of the number of heat pump stages for larger load schemes is expected to vary between 2 and 3. Typical installed costs are illustrated in Figure 5-2. Analysis of typical operating conditions, from part load to full load, shows significant improvement in system and machine COP values from employing more stages. Operational flexibility is also enhanced. For total outputs of 10 GJ/hr or more, the value of annual energy savings is expected to justify the use of three stages.

With the large output ranges applicable to geothermal space heating operations, centrifugal (and screw type) machines are appropriate. Compared to reciprocating

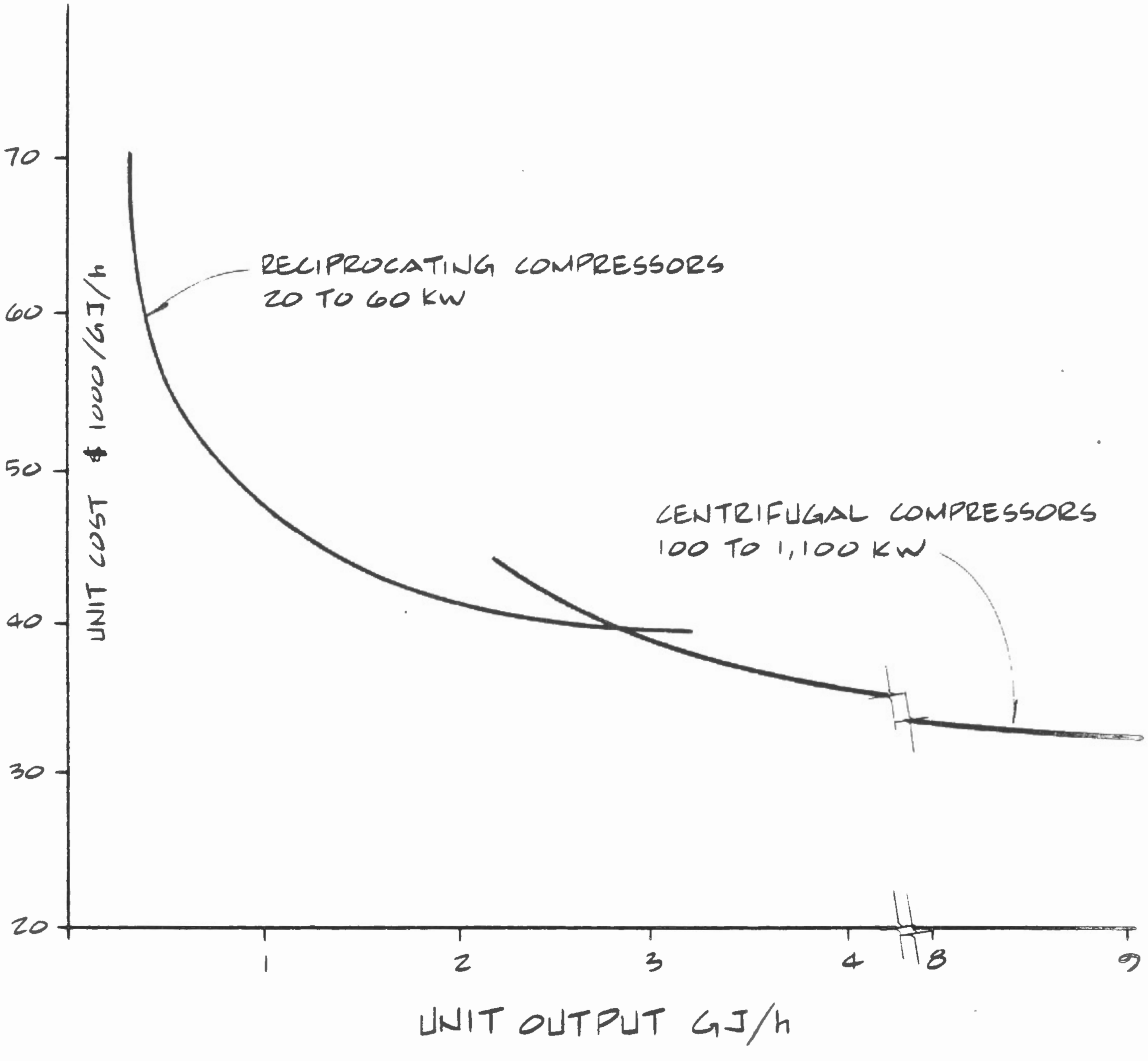


FIG. 5-2

MOOSE JAW GEOTHERMAL STUDY
INDICATIVE HEAT PUMP COSTS

units, centrifugals offer better COP and part-load turn down characteristics; also, less maintenance and improved reliability.

At the design point load (qzs), system COP_s values of 4 to 4.5 are achievable for a 50 degree C design temperature differential. At part load, the reduced differentials of each stage can be expected to improve COP_s to levels of 6 and better.

The improvement in system COP_s at part load does not adequately reflect the substantial savings in heat pump power demand that can be obtained with multi-staging. An illustration of COP_s and power demand variations for a three stage operation is shown in Figure 5-3. With the seasonal variation in space heating demands requiring protracted heat pump operation at part loads, these savings are important to the overall economics of geothermal system operation.

5.3 System Operating Characteristics

Figure 5-3 displays various system parameters and their variability with outdoor temperature and load demand. Temperature relationships, including the important CH system return temperature T_r, are developed to reflect probable building system retrofit conditions and performance assumptions as opposed to those for new buildings, employing custom designs specifically tailored to lower temperature geothermal energy.

Refering to the diagram showing system temperatures the system supply temperature (T_s) characteristic assumes a linear reset schedule.

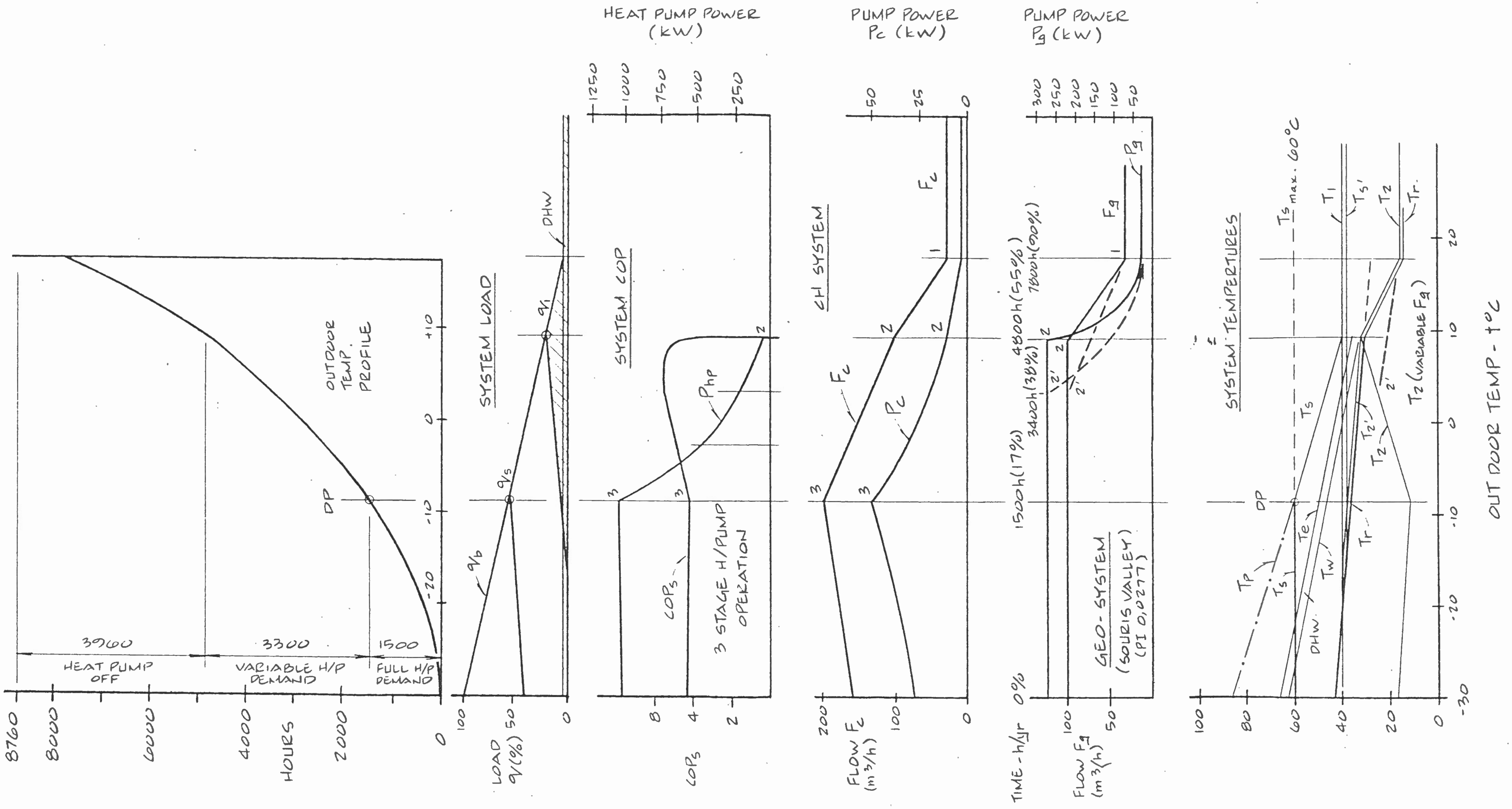


FIG. 5-3

MOOSE JAW GEOTHERMAL STUDY
TYPICAL SYSTEM OPERATING CHARACTERISTICS

ACRES

The advantages of cascading from perimeter heaters to ventilation make-up air coils in order to obtain minimum return temperature T_r has been addressed in Section 3.0. The increasing flare between the CH system supply and return temperatures, i.e. T_s-T_r, with rising load demand reflects a fairly equal load distribution between perimeter heating and ventilation air. A hydronic temperature drop of 20°C for each at peak load, has been assumed. Any improvement possible in temperature drop, particularly a greater contribution from ventilation air (and/or DHW heating), would be beneficial in lowering T_r. At the detailed investigation stage such improvements need to be pursued.

In the summer ($t>18°C$) the CH System supply temperature would be maintained as close as economically possible to the resource temperature (T_1) to maintain maximum heating of DHW. This is a low load demand period which permits the geo-system and CH flows to be cut back substantially with considerable savings in pumping power particularly for the well pumps.

Referring to the flow and power characteristics for the primary and secondary systems; as the space heat load demand commences (point 1) the CH/geo-system flows increase together during the process of direct heat transfer; at point 2, direct transfer is a maximum and further load demand requires the first stage heat pump to commence operation. There is a period of operation between point 1 and 2 where the combined power demands of the first stage heat pump and geo-system pumps can be optimized. It involves cutting back on well flow F_g, and increasing heat pump load to minimized total power demands. This process is represented by dotted characteristics connecting points 1 and 2. Because of the significant number of hours at part-load represented by these points, system energy savings from optimizing power usage can be expected to be substantial.

The system COP diagram illustrates the high COP_S values to be expected during the first stage of operation. With increasing second stage operation the COP_S falls steadily with increasing power demand until, at point 3, the COP_S is between 4 and 4.5 appropriate to three stage centrifugal operation.

Lowering the DP value of T_S to 55°C has the effect of moving the DP to the right corresponding to an outdoor temperature of around minus 5°C. This tends to improve the supply system load factor LF_S and certainly heat pump performance but reduces the geothermal utilization and contribution to the annual energy mix. Theoretically, to correct for this reduction, the CH system would be required to serve more buildings in an extended network; however, this incurs additional connection and retrofit costs. The total energy supply and distribution system has be to be considered as a whole so that improvements in one component need to be measured against performance and/or cost consequences resulting elsewhere.

5.4 Annual Energy Demand

The CH system annual energy utilization is a composite of individual building consumptions. To estabish a typical histogram pattern of annual demand, monthly gas consumptions for a representative number of candidate buildings were analyzed in conjunction with mean monthly temperatures and degree day data. For determining energy demands, gas consumption data was corrected for boiler combustion losses assumed at 70 percent on an annual basis.

Figure 5-4 illustrates a typical annual energy consumption profile presented in terms of percentage of total annual energy versus outdoor temperature. The profile is based on consumption data for 12 buildings, approximately those selected for Schemes 3 and 3A (see sub-Section 7.2).

When the outdoor temperature exceeds 18°C (65°F) the demand for space heating is assumed to cease. Referring to the intersection of this temperature point on the curve, it is seen that approximately 5 percent of the total annual energy is consumed in heating the two pools (and building DHW) in the summer months. With fewer buildings, the percentage energy contribution to pool heating would be greater i.e. for Schemes 1 and 2 pool heating becomes a more significant portion of the annual heating duty.

Also shown in Figure 5-4 is the familiar histogram, or load profile, constructed from the data derived for the annual consumption profile. The bottom part of the profile diagram shows DHW and pool heating. The abrupt increase in load with outdoor pool heating is typical. The total water heating demand for the 2 to 3 month pool heating period averages 8-10 percent of the total winter peak. Again, with fewer buildings (e.g. Schemes 1 and 2) the pool/hot water heating load would be a considerably higher percentage of the winter peak total.

The histogram shows, typically, the small area (Q_b) representing energy to be supplied by conventional heating

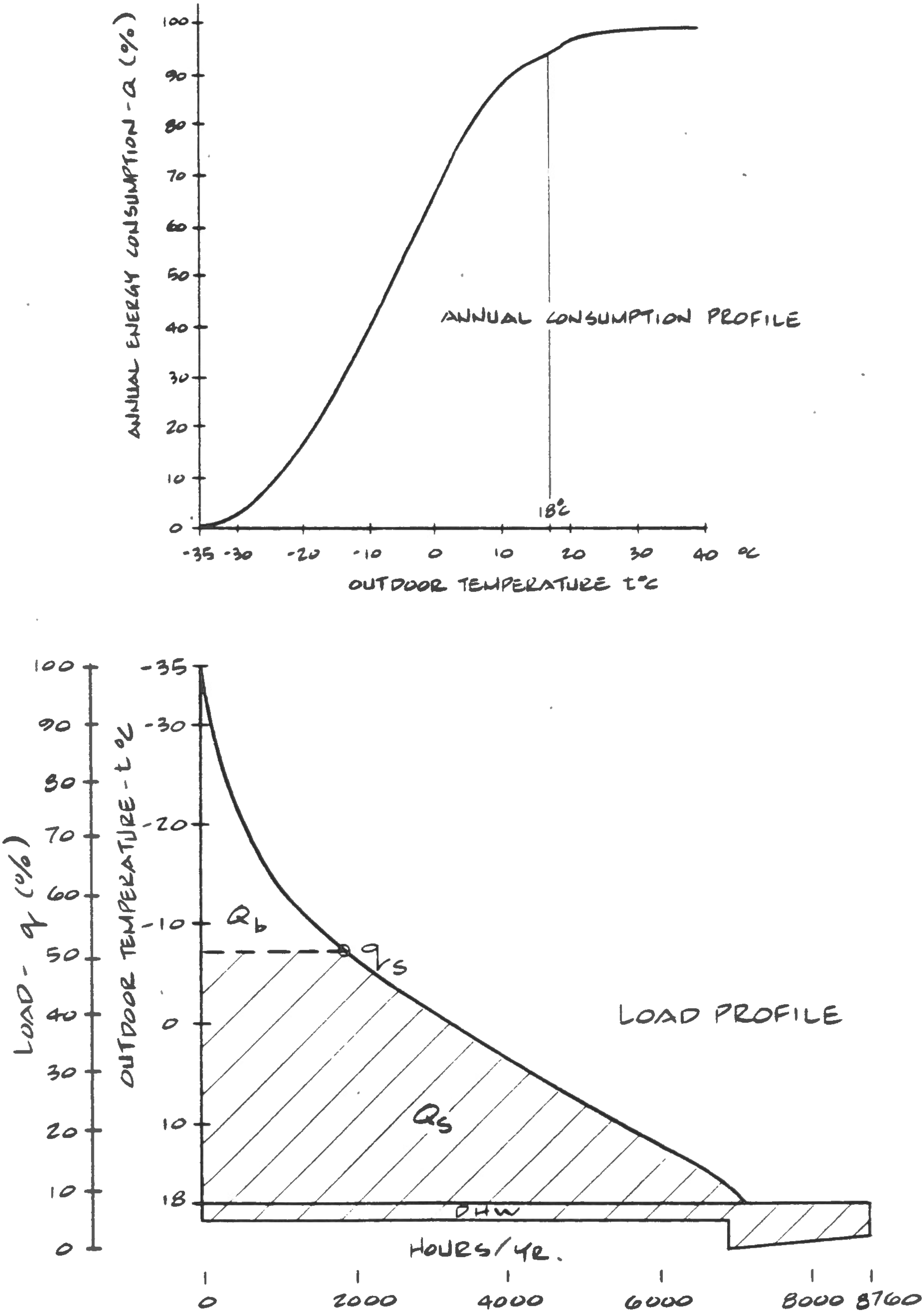


FIG. 5-4

MOOSE JAW GEOTHERMAL STUDY
TYPICAL ANNUAL CONSUMPTION & LOAD PROFILES

means (q_s equal to 50 percent of winter peak); the area Q_s, representing the geothermal/heat pump annual supply, is also shown.

5.5 Pipe Materials and Installation

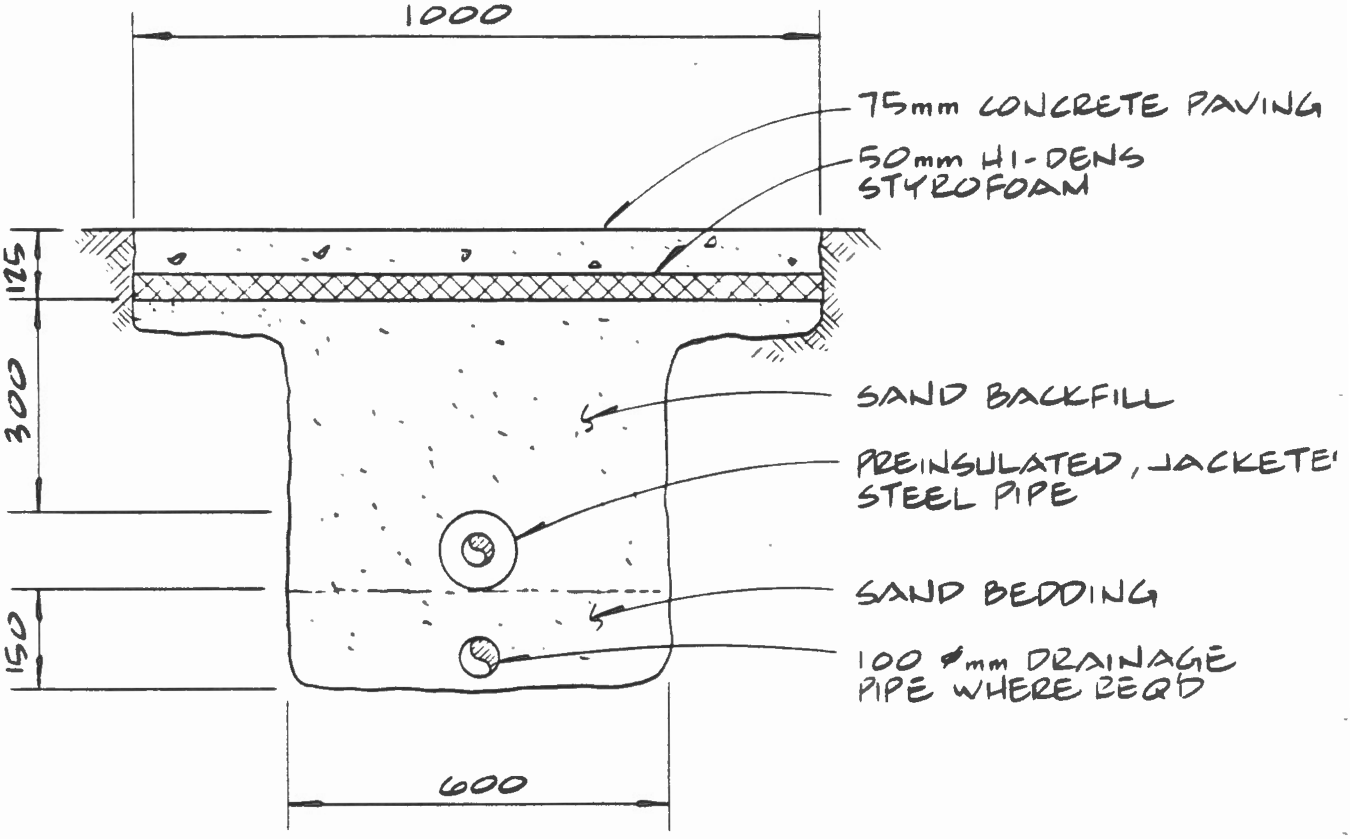
This section addresses both the geothermal supply and CH system.

CH system piping is subject to static pressure conditions imposed by the highest connected building which , combined with dynamic pressures could total 750 kPa (110 psig). At 60°C this is close to the limits of inexpensive plastic piping materials such as polyethylene or PVC. Higher strength fibreglass, polybutylene and others are available but at material prices not competitive with conventional steel. When ease of handling is taken into account the installed costs for higher strength "plastics" and jacketed steel are more comparable. For costing purposes the use of pre-insulated schedule 40 steel piping fitted with PVC jacketing is assumed.

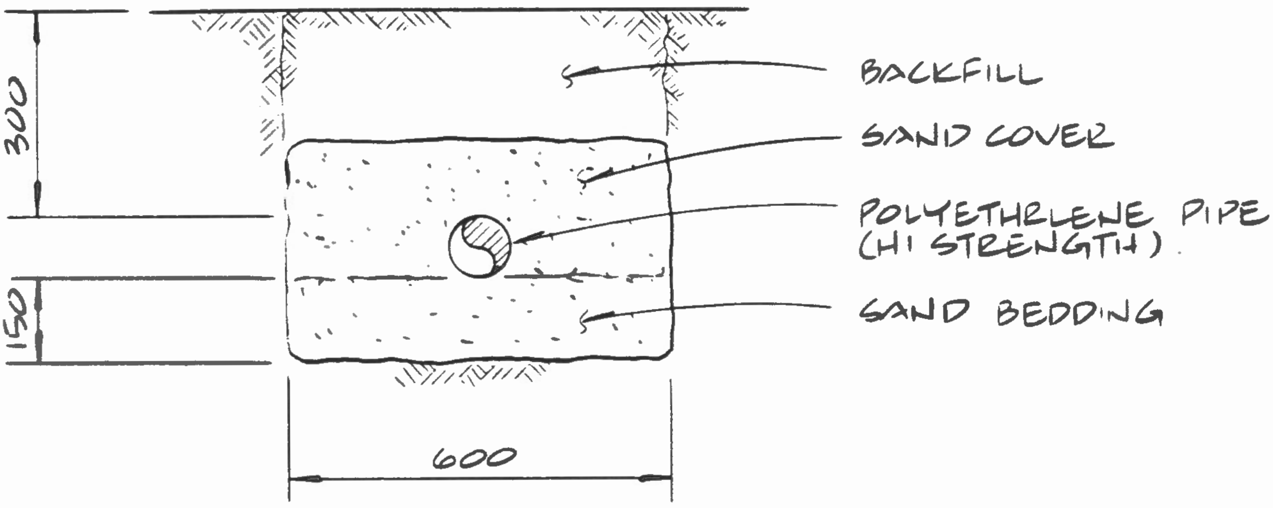
Installation

All pipelines are proposed for a burial depth of 1 m saving an estimated 30 percent in excavation costs when compared with a 2 m depth used by the City for cold water mains. The brine and recirçulation fluids of both circuits can be exposed to freezing temperatures at this depth without risk. Cathodic protection requirements will need to be reviewed with the City.

Paving and excavation costs were obtained from the City Engineering Department, which has also advised that



GEOFLUID SUPPLY



DISPOSAL PIPELINE

GEOFLUID PIPE LINE

FIG. 5-5

MOOSE JAW GEOTHERMAL STUDY
PIPELINE INSTALLATION DETAILS

ACRES

installations should be problem free with good soil conditions, free of rocks. The water table in the region of the proposed routings is well below the surface.

Since overall pipe run lengths are short, the need for manholes is not anticipated. Typical pipe trench conditions are illustrated in Figure 5-5. Piping will be surrounded by 300 m of sand to allow for expansion estimated to be 167 mm per 200 m. At this stage of design there appears to be no need for elaborate tunneling, valving or expansion compensators. Under roads, the piping is shown with additional protection comprising a double layer of styrofoam to help distribute concentrated vehicular traffic loads.

The use of a 50% ethylene glycol/water mixture for the secondary distribution system loop is considered a necessary precaution for freeze protection. Glycol has received wide acceptance on the prairies where exposure of piping and coils to freezing temperatures cannot be avoided. It introduces a 15 percent penalty in the heat transfer coefficient and a further penalty in pumping power, but allows unrestricted use and is essential for hydronic designs where large temperature drops are proposed for outdoor air heating equipment. It also permits a reduced depth of bury without risk of freezing the network in the event of pump failure.

Investigation of each building on a building-by-building basis would be necessary to assure that all materials including gaskets are compatible with glycol. Expansion tanks in individual buildings normally dump system excess water to drain, replenishing with city water for make-up purposes. For direct fluid exchange between hydronic and CH system this practice would require to be modified.

5.6 Installation Costs

Costs received from the City Engineering Department for excavation, backfilling and pavement repair are as follows:

Unpaved	$49/m
Paved	$131/m

Costs for supply and laying of welded steel pipe (Lansdowne Cost Manual, 1984) appropriate to Saskatchewan conditions are:

Pipe Size mm	Unit Cost ($/m)
50	29.5
100	75.4
150	144.0
200	220.4

Unit costs developed for 2-pipe system including insulation at 15 to $30/m and jacketing at 3-$6/m are tabulated below.

CH DISTRIBUTION PIPEWORK

2-Pipe, Unit Costs, Installed

Pipe (mm)	Paved ($/m)	Unpaved ($/m)
50	230	148
60	263	180
75	295	213
100	341	259
150	490	408
200	644	562

Unit costs estimated for single pipe, geothermal brine supply and disposal lines are as tabulated.

GEOTHERMAL SUPPLY/DISPOSAL

1-Pipe, Unit Costs, Installed

Pipe (mm)	Paved ($/m)	Unpaved ($/m)
50	180	98
75	215	133
100	240	158
150	350	268
200	410	328

The above assumes the installed cost of FRP insulated supply piping to be approximately the same as uninsulated steel disposal piping, with FRP lining.

The above unit costs have been used for study estimating purposes. They are high and contribute significantly to the cost of all schemes, but particularly the larger load ones. Further investigation of plastic materials and costs, and also impact of bulk ordering pre-fabricated, pre-insulated pipe, can be expected to show savings. Further savings should be achievable by reducing the depth of bury, particularly in un-paved areas. For all schemes, mobilization of contractor or city construction forces on a project basis should be able to achieve scale economies effectively lessening the unit cost of installation.

Regarding geothermal brine delivery and disposal piping costs, overall savings may be achievable from reducing the separation of the two wells at the surface (thereby reducing pipe lengths) and angle drilling one or both wells to achieve appropriate separation at the formation depth.

6.0 NATATORIUM RESTORATION & SPA DEVELOPMENT - BASE SCHEME

This section addresses the base scheme of restoring the brine supply to the Natatorium indoor pool and also to the proposed health spa development expected to adjoin the Natatorium building. The health spa development is a comparatively recent concept and no details are available as yet. Address is limited to issues concerned with the restored brine supply. Many of the observations are provisional and further work will be necessary to clarify the uncertainties affecting design that remain, particularly those related to health spa facilities and the kinds of therapeutic treatment that might be eventually proposed.

6.1 Natatorium Overview

The building housing the natatorium, i.e. indoor swimming pool, is a single storey structure with basement. The pool, of approximately 25 m x 13 m, is constructed above ground; the perimeter side and end walls are accessible from the basement of the building. For reference, the main and basement floor plans are reproduced in Figure 6-1. They show such features as lounge areas, kitchen, first aid, offices and other spaces on the main floor, and showers, locker rooms, washrooms and other facilities in the basement area. The basement houses the mechanical plant including the boiler, pumps, heat exchangers, and chlorination and filtration equipment.

Heating System

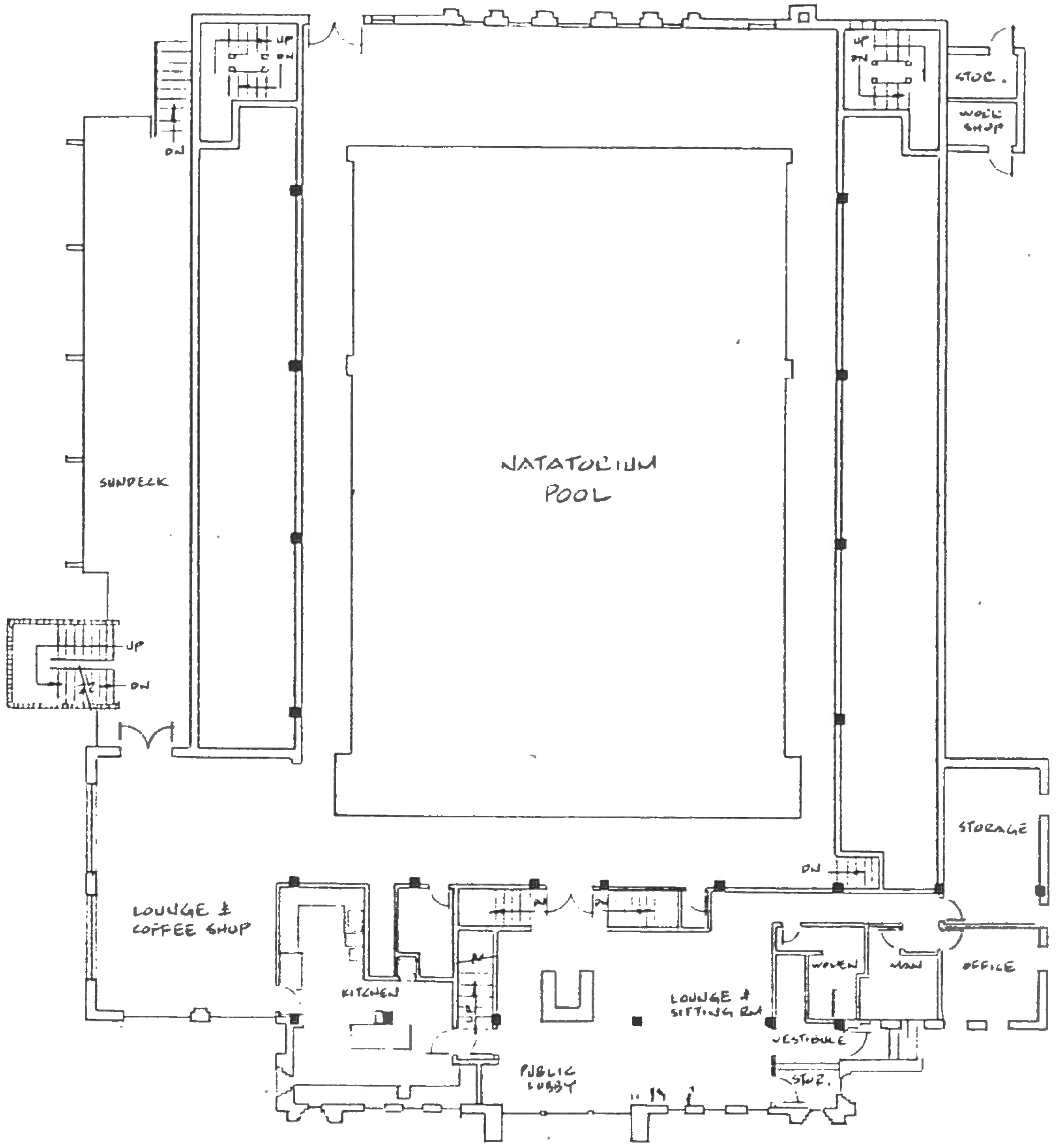
Details of the present system and its operation are presented in Appendix A (Data Sheet, Candidate #1). The low pressure steam distribution system serves perimeter radiators: interior and basement areas are served by steam unit heaters.

Following the original installation in 1932, a gas fired ventilation unit has since been mounted overhead above the natatorium area. The unit draws in outdoor air which, after heating, is ducted locally to assist distribution. This constant make-up supply, introduced to control humidity, is drawn through the building and expelled by exhaust fans located in the basement area. (A further ventilation unit in the basement appears to be intended to supply underseat heating in the Natatorium area. Its use is understood to have been discontinued).

The steam and condensate distribution piping has deteriorated significantly from internal corrosion and is due for imminent replacement along with the boiler. Quotations have been received by the City for undertaking the renovation work involving, essentially, re-instatement of the existing steam boiler and distribution system. This and other major work has been postponed to await the results of the present study in order to assess and incorporate, as appropriate, system features conducive to future geothermal use.

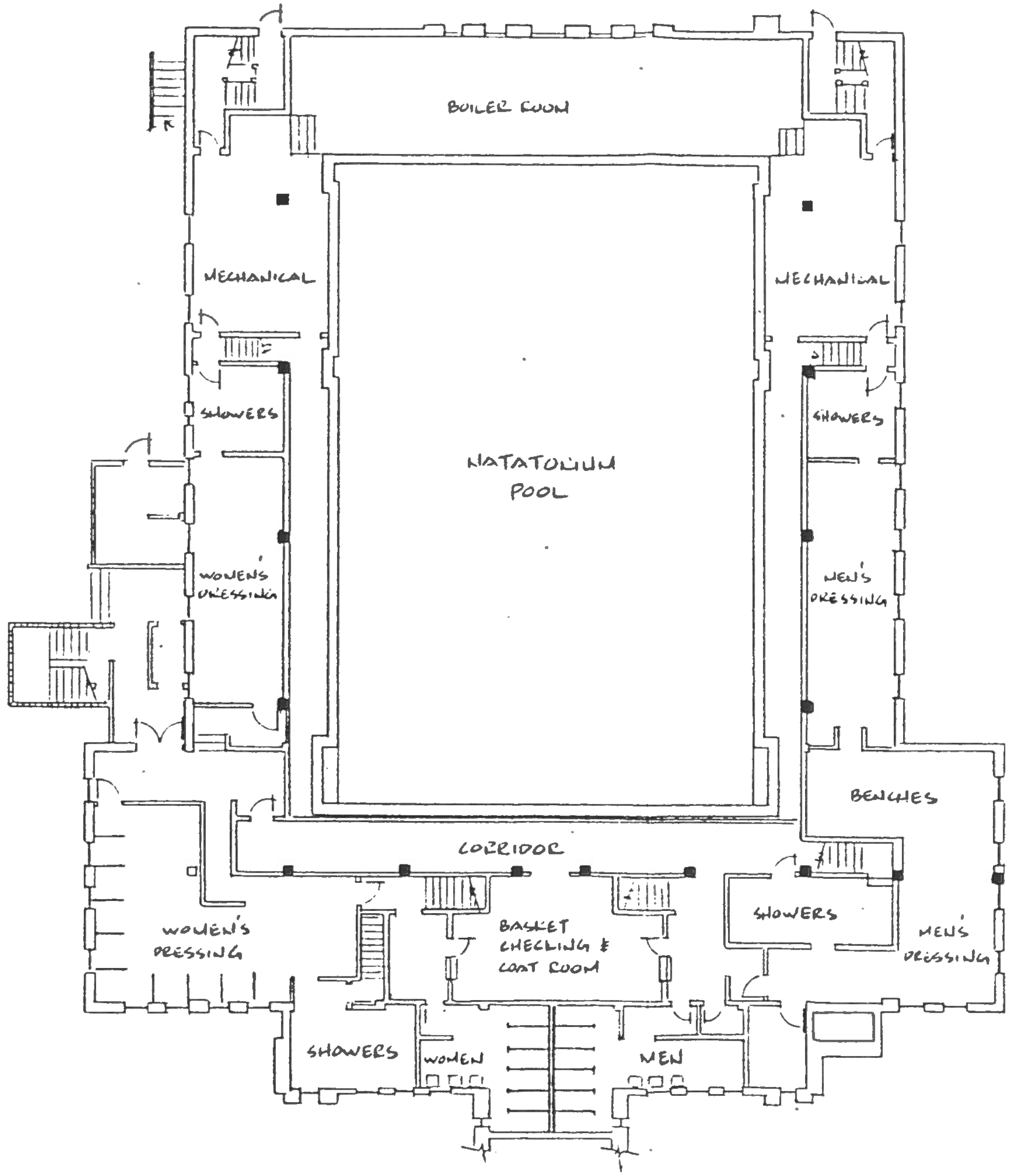
Natatorium Pool

The original brine supply to the pool originated from the Gravelbourg formation. The well, located south and east of the natatorium and almost a kilometre away, flowed under artesian pressure. Estimates of the flow rate are uncertain but 11 m^3/h (50 gpm) has been given as the possible order. This is consistent with the artesian



MAIN FLOOR PLAN

SCALE: 3/32" = 1'-0"



BASEMENT PLAN

SCALE: 3/32" = 1'-0"

FIG. 6-1

MOOSE JAW GEOTHERMAL STUDY
NATATORIUM FLOOR PLANS

ACRES

pressure and productivity index reported herein for the Gravelbourg. Other reports indicate that the temperature of the brine at the well was 35°C, cooling to 28°C by the time it reached the building: the total dissolved solids concentration (TDS) was given as 6,280 ppm, comprising mostly NaCl. This compares with 10,000 ppm predicted from well data for the area.

Articles indicate that the original operation included filtration and sterilization of the incoming brine supply, it entering and leaving the pool on a once-through basis. The leaving flow was directed to the city sewer system for disposal, avoiding the need for a re-injection well. Following a noticeable deterioration in the clarity of the brine and increasingly unpleasant odor emissions (not identified), the brine supply was discontinued in 1957 and replaced by water drawn from the city mains and heated.

The fresh water make-up supply is currently softened, prior to entry to the pool, and recirculated for heating and limited filtration. Chlorine levels (and consumption) necessary to meet public heath standards has been high with complaints being made by pool patrons of eye irritation and other side effects. Chlorine treatment is costing about $1200/year for materials at present.

Enquiries to pool designers and operators provisionally suggests that the need for high chlorine levels is due to inadequate filtration/recirculation. Inspection of pipework and filtration equipment indicates that the recirculation system is not capable of meeting the 4 to 6 pool changes/day that is necessary to meet modern standards of operation. This is not to construe that the present pool operation is failing to comply with public health standards. Simply put, low organic filtration/ recirculation increases the residence time for contamination and requires higher chlorine dosing levels to achieve a given chlorination residual, recommended level, 1 to 2 ppm.

6.2 Review of Mineral Spa and Salt Water Operations

A brief search was made of water conditions at a number of mineral spa operations in Canada and Europe. TDS levels and temperatures are compiled in Table 6-1. The ranges covered are considerable. The very high TDS levels found in a few of the German spa supply waters can be assumed to undergo significant salt removal prior to use in the resorts. The table provides a guide but is incomplete as to the relative proportions of NaCl and the other constituents in the waters.

A review of published mineral spa operations indicates that heavy brine concentrations are not used in recreational pools. Highly saturated water is used in small personal tubs where it is disposed of after use, thereby eliminating need for chlorination or other pre-treatment.

Mineral spa facilities that operate on a once-through flow basis i.e., without recirculation and treatment, appear to be designed so that the spring flow is sufficient to permit an effective change of water in 4 to 6 hours. For the natatorium pool this translates to a flow of 90 to 140 m^3/h (400 to 600 gpm).

Practical experience with operation of the Vancouver Aquatic Centre has shown that the use of sea water directly (35,000 ppm) caused users subject to prolonged

TABLE 6-1

TEMPERATURE & TDS CONTENT OF VARIOUS MINERAL SPA SUPPLY WATERS

	TEMP °C	TDS (ppm)	REMARKS
GERMANY			
Schoeningen	19	265,000	Resort & Salt Works
Eickel-Wanne	35	111,000	" "
Berniburg	26	268,000	" "
Oeynhausen	33	45,000	" "
Wiesbaden	65	9,000	Resort
Baden-Baden	68	3,000	
AUSTRIA			
Baden	40	2,000	Sanatorium
Mittendorf	-	26,000	Resort
ENGLAND			
Bath	47	2,000	
CANADA			
Jasper	49	1,800	Free H_2S
Banff	46	1,100	
Harrison	63	1,300	
Fairmont	45	1,200	
FRANCE			
Vichy	-	4,000	
St. Maurice	-	7,000	

exposure, e.g. under training conditions, to complain of eye irritation. The Centre now employs desalination to control concentrations.

From discussion with health authorities in B.C. concerning recreation pools, the opinion is that salt content alone is not sufficient to ensure control of bacteria introduced by the swimmers. Enquiries to the Saskatchewan Health Department in Moose Jaw (personal communications, L.E. Wright, Senior Public Health Inspector) indicate that no specific criteria have been prepared regarding the use of saline water in swimming pools. Public Health standards or guidelines need to be developed that would probably draw largely on experience from elsewhere.

6.3 Moose Jaw Brine Chemistry

For reference, Page 2-10 presents the projected chemical analysis for brines from the various formations. From the Mannville to the Birdbear, TDS values range from 10,000 to 35,000 ppm while for the deep Winnipeg Deadwood the projected TDS is 180,000 ppm. As noted in the text following Table 1 of Appendix B, total dissolved solids are "...determined largely by the sodium and chloride content, and the remaining ionic composition (calcium, magnesium, bicarbonate, sulphate) is remarkably constant." Excessive NaCl levels are deemed to be unnecessary and undesirable for both pool and spa operations; the choice therefore favours brine drawn from the shallowest formation. However, this will be also the coolest. From a geothermal heating perspective, the preference would be to select one of the deeper formations. In view of the excessive NaCl content of the Winnipeg/Deadwood, combined with the likely possibility of encountering H_2S, the use of this source can be rejected as unsuitable for pool and spa requirements.

Brine from the Birdbear likewise has a relatively high TDS and is also a likely source of H_2S. Combined with the thinness of the seam, making it a poor candidate for high flow and large load heating demands, these factors permit its rejection also for the present purposes.

The City has engaged a consultant from the University of Saskatchewan to examine brine chemistry from the perspective of spa and possible therapeutic uses. Provisional findings (personal communications, A. Gate, City of Moose Jaw) appear to support use of the shallower, lower NaCl content brines for such purposes i.e., the Mannville or Gravelbourg.

The Mannville could prove to be marginally too cool particularly if the original recorded well temperature of 28°C is realized. While for the base scheme, this could be overcome by reheating with gas, as a geothermal heat source it would be limited to small scale, localized heat pump applications.

The Gravelbourg, is the minimum choice from temperature considerations (35° to 38°C), particularly so if the original low TDS level of around 6000 ppm is reproduced. From the perspective of geothermal heating, however, the Gravelbourg is considered to be still somewhat cool and also restricted as regards its ability to provide large flows. Accordingly, the 44°C Souris Valley resource is preferred for the central heat schemes proposed later.

Should a conflict occur between the preferred chemistry for natatorium/health spa purposes and the preferred temperature for heating purposes, de-salination of the potentially small brine quantities required for direct use in the natatorium/health spa could prove a practical and economic compromise.

6.4 Base Scheme Arrangement & Pool Upgrading

Pool Treatment

From the preceeding, it is tentatively concluded that restoration of a brine supply to the natatorium will not eliminate the need for chlorination (or similar treatment). Upgrading of the present filtration-recirculation system, in combination with perhaps some level of desalination, might reduce chlorination treatment costs but some offsetting increases will be incurred as a result.

Ozonation maybe an alternative option to chlorination. Used extensively in Europe, it does not provide the unpleasant side effects to the user. However, the cost for ozonation equipment is high and approval by Public Health authorities in Canada is still awaited.

A specialist supplier familiar with the natatorium system has submitted a budgetary price estimate of $80,000 for upgrading the recirculation-filtration-chlorination system including pumps, piping and filtration plant. Upgrading would involve the installation of large collection and return headers to handle the much increased recirculation rates of 100 to 140 m^3/h.

Other pool improvements needed include replacement of submerged lights, which have rusted and been disconnected, and sealing of leaks in pool lining.

Pool/Spa Supply Scheme

The schematic, Figure 6-2, shows the brine supply/disposal arrangement proposed for serving the natatorium pool and future health spa facilities. The Gravelbourg is assumed to be the source of the brine: the shut-in or zero flow pressure is about 2.2 MPa (325 psig). From Figure 4-2 the maximum artesian flow to be expected is approximately 14 m^3/h (62 gpm); with pipe friction losses (which must be controlled) this flow will be reduced in proportion. This artesian flow potential should be adequate. It would be a beneficial simplification if pumping of the supply well can be avoided.

The arrangement (Figure 6-2) shows the base scheme without supply well pump. The well supply at 38°C is shown distributed to the natatorium pool and the health spa. The spa is assumed to comprise individual therapy baths and soaking pools of a size small enough to permit once-through flow without the need for filtration or chemical treatment. A pressure regulating valve (PRV) at inlet to the building is required to control the extreme pressure variations that would otherwise be transmitted through the supply system with variations in flow demand.

A continuously flowing brine system is strongly preferred both to mitigate increased corrosion effects in the well casings under stagnant flow conditions (see Appendix B) and also to avoid temperature degradation in non-flowing lines. A relatively constant supply to the natatorium of

7 m3/h (30 gpm) is sufficient to maintain pool temperature at 28°C.

Flow to the health spa could comprise a steady and variable flow demand component. If a steady load is not required a minimum continuous bypass flow should be maintained, discharging to drain.

Downstream of the PRV, a predominately plastic piping system can be employed for supply and drains disposal.

Drains

Overflow and drains from the natatorium pool and health spa are shown directed to a drains sump. Sump pump (P-3) delivers to the injection well pump (P-2) the discharge from which is shown regulated by level control of the drains sump.

Well Disposal

A disposal well has been assumed for the base and subsequent schemes, consistent with agreed approach established at the outset. The basis is tentative and arises from a provisional concern for formation fluid depletion and the salt-loading imposed on the city's sewage treatment plant if large brine flows, potentially 100 m3/h and greater, were disposed of to sewer.

For small flow rates there is the opportunity for considerable simplification and significant cost saving from disposing to sewer and eliminating the disposal well, disposal line and (P-2) pump. Reducing the make-up flow to the pool to compensate only for normal evaporative and

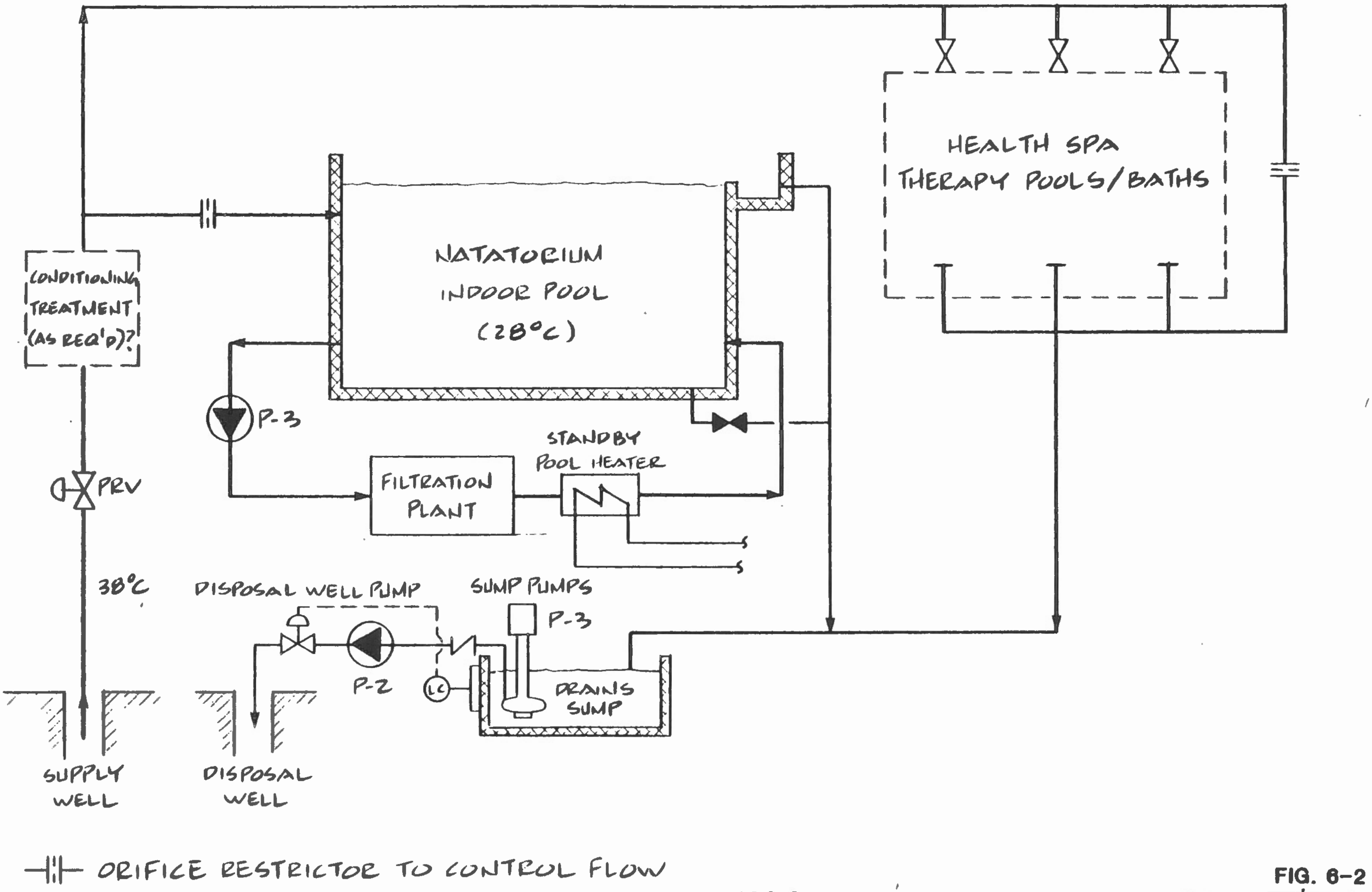


FIG. 6-2

MOOSE JAW GEOTHERMAL STUDY
NATATORIUM / HEALTH SPA DEVELOPMENT
BRINE SUPPLY / DISPOSAL-BASE SCHEME

ACRES

fluid losses, the average continuous disposal rate to the sewer system might be held to fairly low levels, e.g. 2 - 3 m^3/h, particularly if using a holding drains sump to even out surges.

The savings in capital of perhaps $400,000, and in pump (P-2) operating and maintenance costs provides a strong impetus to closely examine this possibility at a later stage. The penalties to be considered include the cost of pool heating by external means, any adverse impacts on the sewer system and sewage treatment plant, and also on the producing formation from the small net loss.

A further factor appears to favour the disposing of drains to sewer, rather than to the formation. This is the real possibility for oxygen contamination of the drains flow. Oxygen introduced to the disposal system could be a source of significant well casing corrosion (reference Appendix B) a possibility that will need serious consideration at a later stage.

6.5 Rehabilitation/Replacement of Heating System

The general poor state of the boiler and piping systems is such as to necessitate replacement. There does not appear to be any over-riding reason to remain with a low pressure steam heating system in the Natatorium. Conversion to a modern hydronic system would seem to be the most appropriate and cost effective approach, replacing radiators with wall fin type radiation units and re-plumbing unit heaters for hydronic service, the latter according to condition determined by a unit-by-unit examination. A hydronic replacement eliminates the need for boiler attendance by a certified operator.

The steam boiler is original equipment and appears to have a design capacity some 50 percent in excess of present system requirements, believed to be a consequence of the subsequent installation of the gas fired ventilation unit serving the natatorium area. For the base scheme, capacity requirements will be further reduced given a sufficient geothermal supply to the pool.

The indicative installed cost of a gas fired hydronic replacement for the existing steam system, including DHW heating facilities, reduced-capacity boiler (and with no changes to the ventilation air unit) is $60,000.

The alternative of rehabilitating to present standards, using energy saving methods applicable to heating new swimming facilities under prairie conditions, could be expected to involve:

- the addition of direct gas preheating of make-up air to the ventilation unit;
- refrigeration cycle de-humidification of exhaust air; and,
- recovery and return of reject heat back to the space.

Retrofitted to the existing building, this heat recovery modification would increase capital costs quite substantially and have to be justified by the trade-off in future fuel cost savings. If geothermal heating is adopted the cost of such a heat recovery system cannot be justified as the incremental energy cost for a simple 100 percent once-through make-up/exhaust air system will be negligible.

6.6 Indicative Base Scheme Costs

Table 6-2 presents indicative capital costs covering Natatorium building heating and brine restoration, excluding the health spa. Assumptions and conditons include:

- a supply and disposal well to the Gravelbourg;
- no allowance for health spa development costs and other costs covering general repairs or improvements to the existing facilities;
- an assumed well spacing separation of 200 m to suit 10-15 m^3/h maximum flowrate; and
- no allowance for brine pretreatment for pool or health spa use if required.

As raised in Section 5.6, a possibility for future consideration is to locate the well close to the supply and angle drill one or both wells to achieve the 200 or 300 m limited separation believed necessary with low flow rates. Well costs would increase but most or all of this could be offset by savings in disposal line installation costs. The principal advantages are: minimized disturbance to Crescent Park and roads for pipe crossings; compactness of well head arrangement, permitting a common housing; proximity of disposal pump and flow regulation valve to Natatorium and power supplies; and limited routing of power and control cables.

TABLE 6-2

INDICATIVE BASE SCHEME

CAPITAL COSTS

	$
Pool Modifications	
Filtration/Recirculation System	80,000
Pool Improvements (lining repairs, lights etc.)	allow 10,000
Drainage Collection, Sump and Pumps, including power supplies and controls	allow 20,000
50 m, 75 mm Ø, Brine Supply Piping internal to building including PRV and plastic pipe	5,000
Geothermal Supply/Disposal System	
Supply and Disposal Well, including cathodic protection	690,000
75 mm Ø, 200 m Supply/400 m Disposal Piping including 25 kW disposal pump, power supplies and cabling	90,000
Misc. Civil Works and Building Modifications	10,000
Heating System - Replacement	
Boiler/Hydronic (minimum scope)	60,000
Sub-Total	965,000
Engineering & Commissioning	60,000
Sub-Total	1,035,000
Contingency @ 10%	103,000
TOTAL	$1,138,000

Notes:

(1) Geothermal well engineering and commissioning is included in well costs.

(2) Geothermal supply/disposal system cost total, including contingency at 10 percent, is $880,000.

7.0 GEOTHERMAL HEATING SCHEMES

This section addresses heating schemes 1 to 4, each of increasing size, cost and heating load. All schemes are, in a sense, add-ons to the base scheme. Well capacities, stimulated at increasingly greater rates by supply well pumping, continue to serve the Natatorium/Health Spa but more and more of the output goes to primary heat exchangers and/or heat pumps for cooling prior to disposal by re-injection. With the greater flow rates use of the increasingly remote disposal well locations (reference B and B_1, Figure 3-1) becomes necessary.

7.1 Heating Scheme 1

The scope of this scheme covers the heating of the Natatorium, Health Spa and adjacent YM-YWCA buildings. At this stage the choice of geothermal sources is between the Gravelbourg (38°C) and Souris Valley (44°C) in combination with heat pumps. The winter peak heating load of these buildings in total could be around 3.5 GJ/h of which 2.9 GJ/h is the total estimated for the two existing facilities including DHW heating needs.

Summer Peak Load - Outdoor Pool Heating

In the summer months most of the heating demand will continue to come from the DHW and outdoor pool heating requirements. The pool is maintained at 24°C for the 3 months of operation: the initial high heating load to bring the pool up to operating temperature at the beginning of the season is evident from the gas consumption curves (Figure 3-2). Analysis shows the summer peak Natatorium demand currently to be in excess of 2 GJ/h, mostly for pool heating, and reducing somewhat as the summer progresses. With a 38°/44°C range of source temperatures,the geothermal flow required to directly heat i.e. without heat pumping, ranges between 50 to 60 m^3/h (with heat pump, this reduces by 50 percent). The additional cost for larger equipment and facilities (i.e. heat exchanger, pumps, piping etc.) necessary for direct heating, recognizing the limited heating period of perhaps 3 months, will predictably be difficult to justify.

Design and Performance Issues

A common hydronic recirculation system is proposed to serve all facilites. The steam boiler at the YM-YWCA would be retained for standby and steam room service. For economic sizing, the design point load for the geothermal/heat pump supply system is provisionally expected to be around 50 percent of the total winter peak, or 1.7 GJ/h; at this level the geothermal/heat pump system should, expectedly, meet 85 to 90 percent of the annual energy demand.

The system load is relatively small so that without the better economies of scale, heat pump and other equipment costs will be proportionately higher: a costly, multi-stage heat pump installation could be difficult to justify. With a single stage heat pump, selection of system temperatures must be reasonably matched to the capabilities, economics and performance limits of a single refrigerant, commercial heat pump unit. Proper analysis of these factors will be necessary at the detailed stage. The conditions provisionally selected, or calculated, are tabulated below. Heat pump performance is based on

Templifier equipment obtained from the manufacturer's published data.

Preliminary Design Conditions
Scheme 1

Winter Peak Load	(q_p)	3.5 GJ/h
Geothermal/Heat Pump Load	(q_s)	1.7 GJ/h
Geothermal Supply Temperature	(T_1)	44°C
Geothermal Disposal Temperature	(T_2)	15°C
Hydronic Supply Temperature		
- at Design Point	(T_s)	55°C
- at Peak	(T_p)	85°C
Heat Pump COP		4.5
Geothermal Flow Rate	(F_g)	13 m^3/h*
Annual Energy Demand	(Q_p)	16.9 TJ/yr
Annual Energy Supplied	(Q_s)	15.0 TJ/yr

*excluding Natatorium/Spa consumption

Assuming a linear characteristic chosen for the heating system temperature reset schedule, the maximum hydronic supply temperature from boiler at winter peak operation will be around 85°C, or about 10°C below conventional levels.

The geothermal flow indicated could almost be obtained by artesian means whether originating from the Gravelbourg, Souris Valley, or both (given a multi-zone well completion arrangement). For the present a supply well pump of the vertical turbine line shaft type is assumed.

From gas consumption records, and assuming a system annual efficiency factor for combustion and other losses of 70 percent, the current annual energy demand for Natatorium and YM-YWCA above is estimated at about 13 TJ/yr. The future Health Spa is assumed to experience similar forms of energy demand as the present Natatorium e.g. large ventilation make-up loads for dehumidification purposes. An annual energy demand equivalent to 40 percent of the Natatorium load has been arbitrarily assumed in ariving at the annual energy demand (Q_p) included in the above performance data tabulation.

The annual energy supplied by the geothermal/heat pump system (Q_s) is predicted on the basis of previous investigations (Acres, 1983; Acres, 1984) to be between 85 to 90 percent with the supply load q_s at 50 percent of q_p. Recognizing the useful summer load from outdoor pool heating and the fairly constant annual demand the higher value is provisionally favoured.

Heating System Schematic

A schematic of the proposed arrangement is presented in Figure 7-1. Flow from the supply well is divided, the main stream being directed to the primary exchanger HX-1. The stream to the pool and health spa need be only sufficient to meet liquid consumption needs. Heating/ reheating of the recirculating pool water is by indirect heat exchange (HX-4) with the secondary circuit.

The main geothermal circuit shows HX-1 served by its own fresh water loop and recirculation pump (P-4) conveying heat to the heat pump evaporator (E). A fresh water circuit is proposed to avoid the very considerable extra expense of corrosion resistant metallurgy for the evaporator. As shown here, all geothermal energy requires heat pumping to the secondary circuit.

The secondary (glycol) circuit is shown supplying perimeter heating, pool heating, DHW and ventilation/make-up air heating in cascading order. This arrangement is the most desirable for all three facilities. The need to cascade in order to minimize the return temperature (T_r) remains a feature of LT geothermal engineering though it is perhaps less critical with the heat pump interfacing between the geothermal and secondary circuits.

In the pool area it is proposed that only limited replacement of perimeter heaters be considered, with the load loss to be compensated by increasing the design output of the ventilation unit. Ductwork would need extending to the perimeter to achieve proper air distribution and comfort conditions.

The ventilation units in all of the facilities should have make-up air preheat coils connected at the lowest point in the cascade and their reheat coils served from the primary supply or, better still, from the perimeter heating collection header as illustrated. Careful attention will be necessary at the design stage to achieve a proper balance between the additional cost of piping, to conform to the cascading philosophy, and the cost benefit from better geothermal energy utilization.

The imminent need to replace the Natatorium heating system, provides the opportunity to design both it and the future Health Spa heating system to suit the cascade philosophy. The 85°C peak temperature, 10°C or so below conventional plus the capacity loss of 10 percent or so for improved hydronic temperature drop, will require the addition of more wall-fin radiation units to compensate for the fall off in capacity. Also controls and bypass facilities to meet temporary out-of-balance demands of downstream equipment will be more complicated and costly than for conventional heating systems. Overall, the cost of adapting the Natatorium and Health Spa to a geothermal energy source is expected to be an incremental one for larger piping, coils, ducting and so forth. The major chargeable cost will be for the heat pump installation.

The present low pressure steam heating system at the YM-YWCA can be largely retained with the exception of, essentially, the condensate piping which will require replacement. Pipe corrosion reported may make this work imminent in any case so that the cost of conversion might not be fully chargeable to geothermal. Replacement of ventilation unit coils and addition of new recirculation pumps is also required.

7.2 Heating Schemes 2 to 4

These schemes identify increasingly larger geothermal/ central heat distribution systems each growing outward from the Natatorium/YM-YWCA buildings. In their development recognition was given to the location and energy demands of each candidate building and the incremental cost of connecting and retrofitting. A simple payback ratio of incremental cost to annual gas cost provided a "best use" guide to the ordering of candidate selections and, potentially, the most economic system growth. This approach resulted in deferring connection to city build-

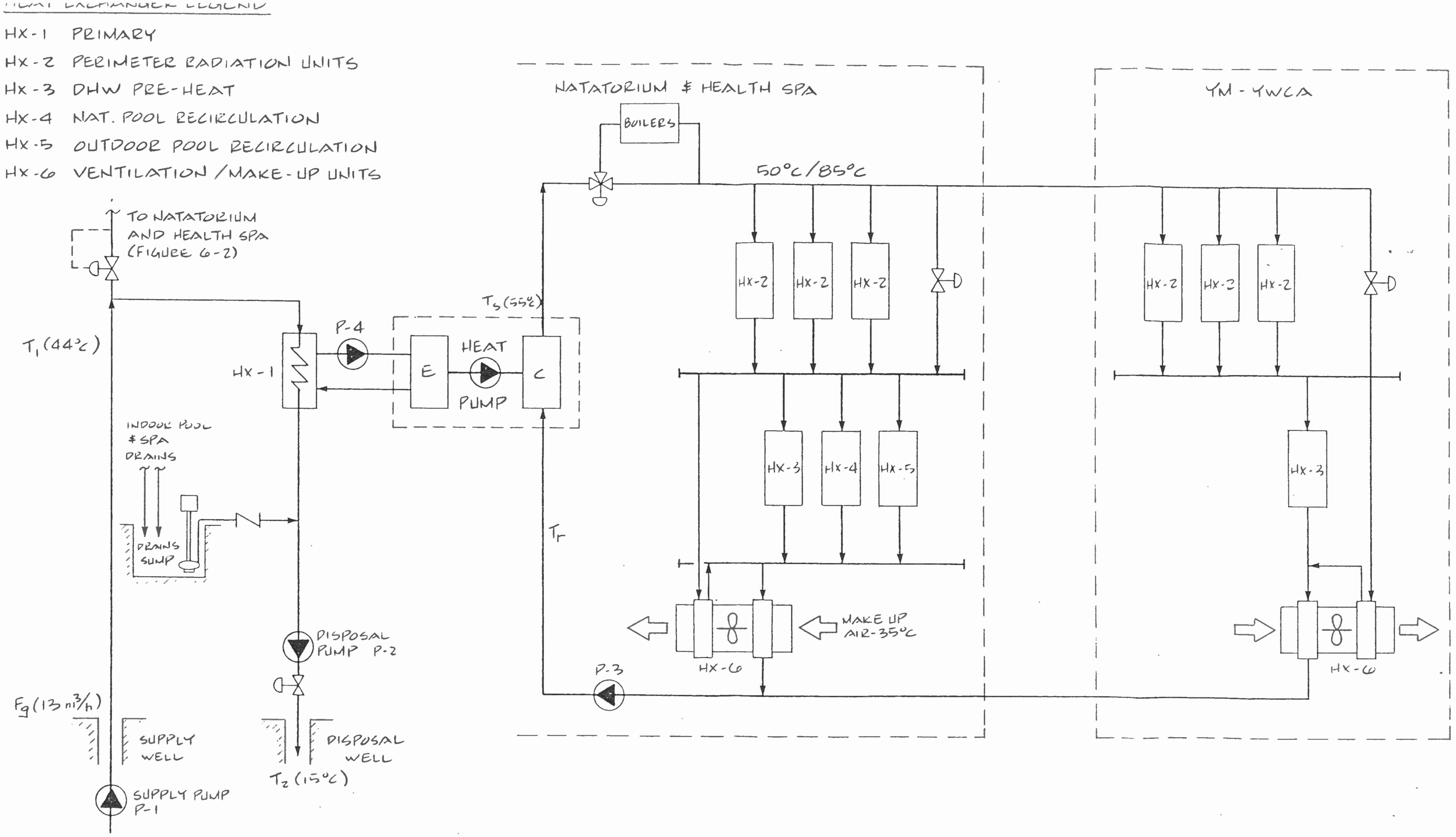


FIG. 7-1

MOOSE JAW GEOTHERMAL STUDY
SCHEMATIC OF HEATING SCHEME 1

ACRES

ings such as the Library, Art Museum and City Hall until such time as other buildings had been connected en route to these buildings. Clearly, many permutations are possible, particularly if additional criteria for connecting these city-run buildings are adopted.

The result of this selection process, in terms of candidate identification and peak load demands, is summarized in the following tabulation.

Scheme Candidates & Peakloads (GJ/h)

	Candidate	Scheme No. 2	3 & 3A	4
City/Public Jurisdiction				
1	Natatorium/Health Spa	1.8	1.8	1.8
2	YMCA-YWCA	1.7	1.7	1.7
3	Library		0.7	0.7
4	Art Museum		0.3	0.3
5	High Park Towers	3.6	3.6	3.6
6	Victoria Towers	3.6	3.6	3.6
7	City Hall		2.0	2.0
8	Temple Towers		2.2	2.2
9	Cultural Centre		-	0.2
10	River St. Apts.		1.1	1.1
Private Jurisdiction				
11	Racon Office Bld.	4.7	4.7	4.7
12	Harwood Inn		4.3	4.3
13	Harwood Centre		-	2.0
14	Grant Hall Inn		4.5	4.5
15	Langdon Towers		1.4	1.4
16	CPR Station		-	8.5
17	Union Hospital		-	10.6
	Totals (GJ/h)	15.4	31.6	52.9

Figure 7-2 shows the CH distribution routing for Schemes 2 to 4, the numbers attached indicating pipe sizes in millimeters.

With the exception of Scheme 3A, the others are assumed to use the 44°C Souris Valley resource in combination with multi-stage heat pumps. Scheme 3A, using the 60°C Winnipeg/Deadwood resource without heat pumps, is developed to provide economic comparison with Scheme 3.

The general analyses, presented in previous Sections 3.0 and 5.0 describe the technical considerations behind the development of the CH system and building retrofits designs for each of the schemes. The schematic arrangement of Figure 5-1 is typical for the schemes noting that all (except 3A) assume a central heat pump installation.

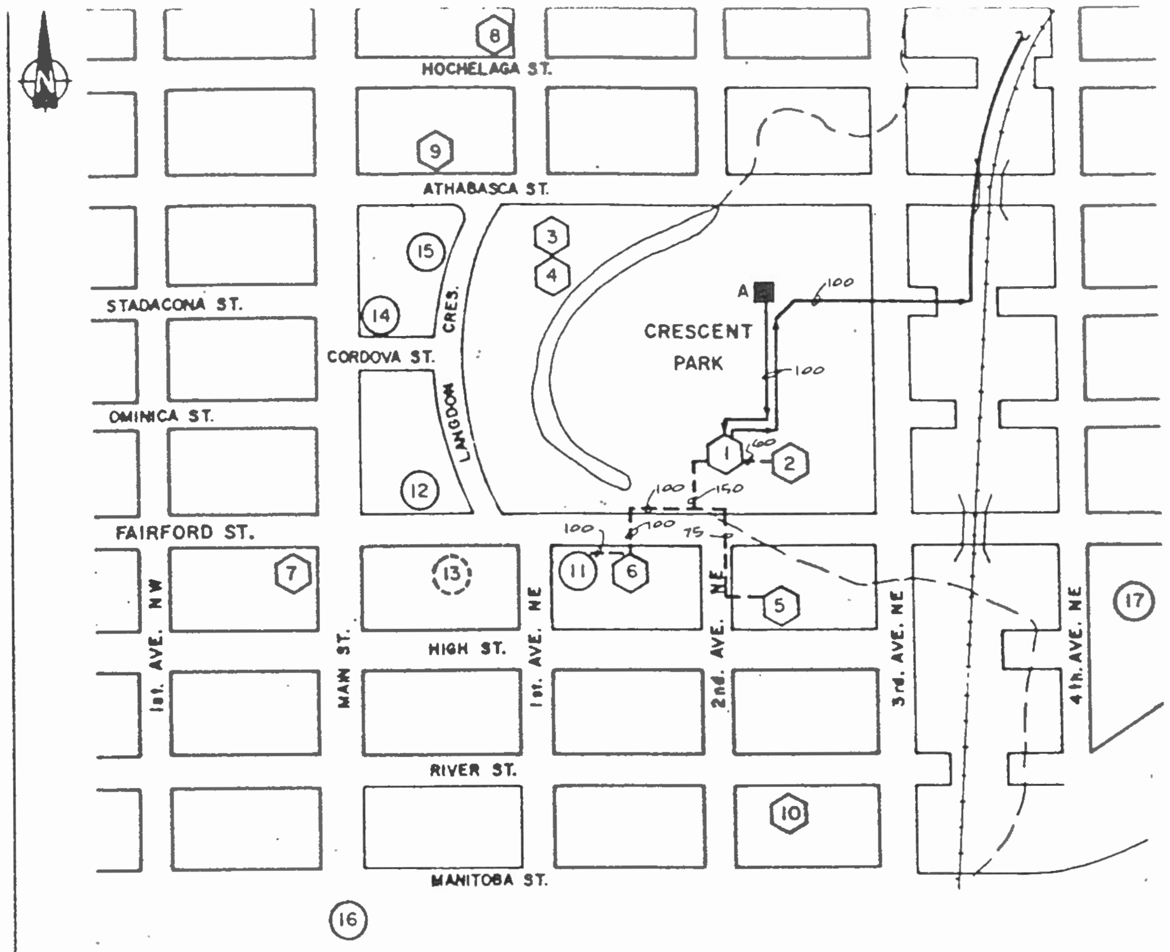
Preliminary performance and design data are tabulated below for reference.

Preliminary Design Conditions

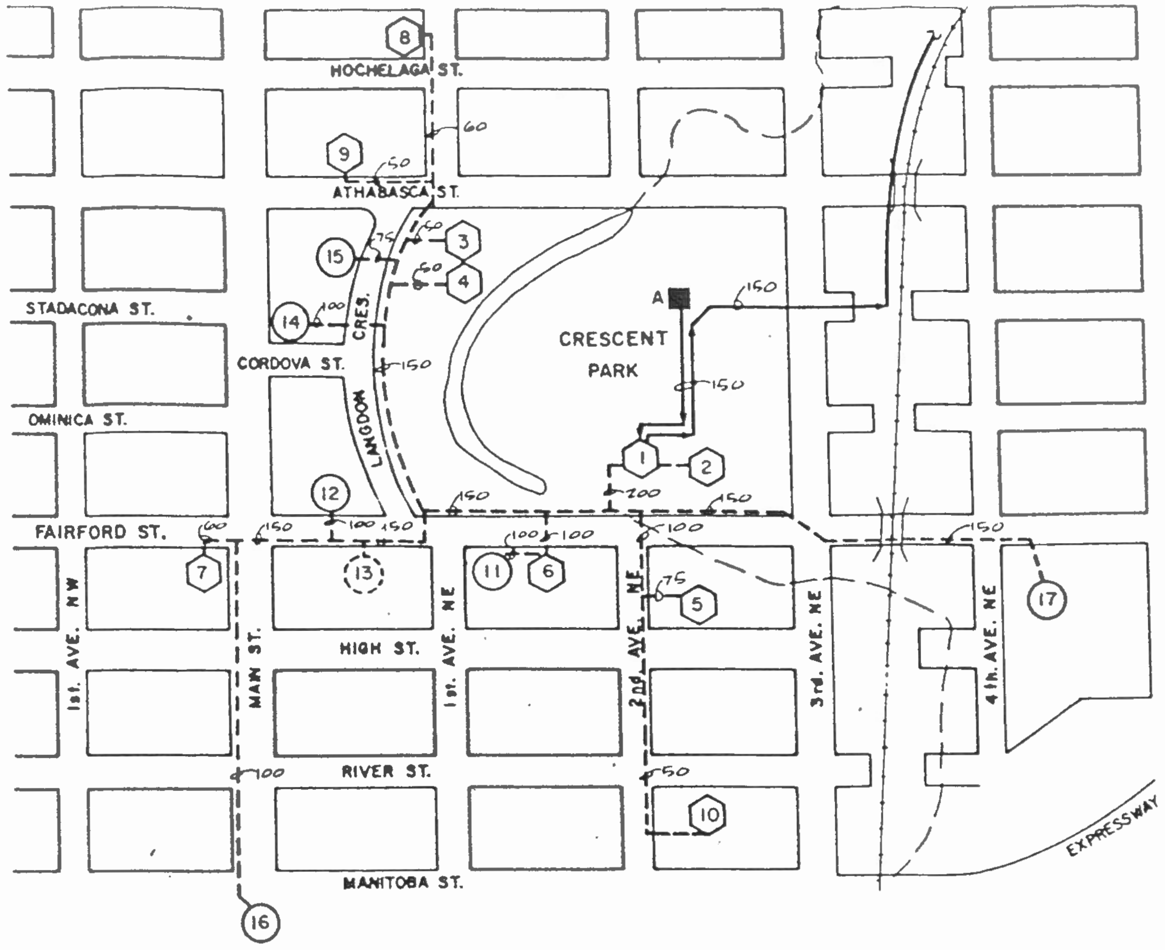
Schemes 2 to 4

SCHEME			2	3/3A	4
Winter Peak Load	q_p	(GJ/h)	15.4	31.6	52.9
Geothermal/Heat Pump Load	q_s	(GJ/h)	8	15.5	26
Geothermal Supply Temp.	T_1	(°C)	43	43	43/60
Geothermal Disposal Temp.	T_2	(°C)	10	10	10/38
Hydronic Supply Temp.					
- at Design Point	T_s	(°C)	60	60	60
- at Peak	T_p	(°C)	90	90	90
Heat Pump COP_s			4.5	4.5	4.5
Geothermal Flow Rate*	F_g	(m^3/h)	45	85/170	145
Annual Energy Demand	Qp	(TJ/yr)	40	69/69	128
Annual Energy Supplied	Qs	(TJ/yr)	35	60/60	114

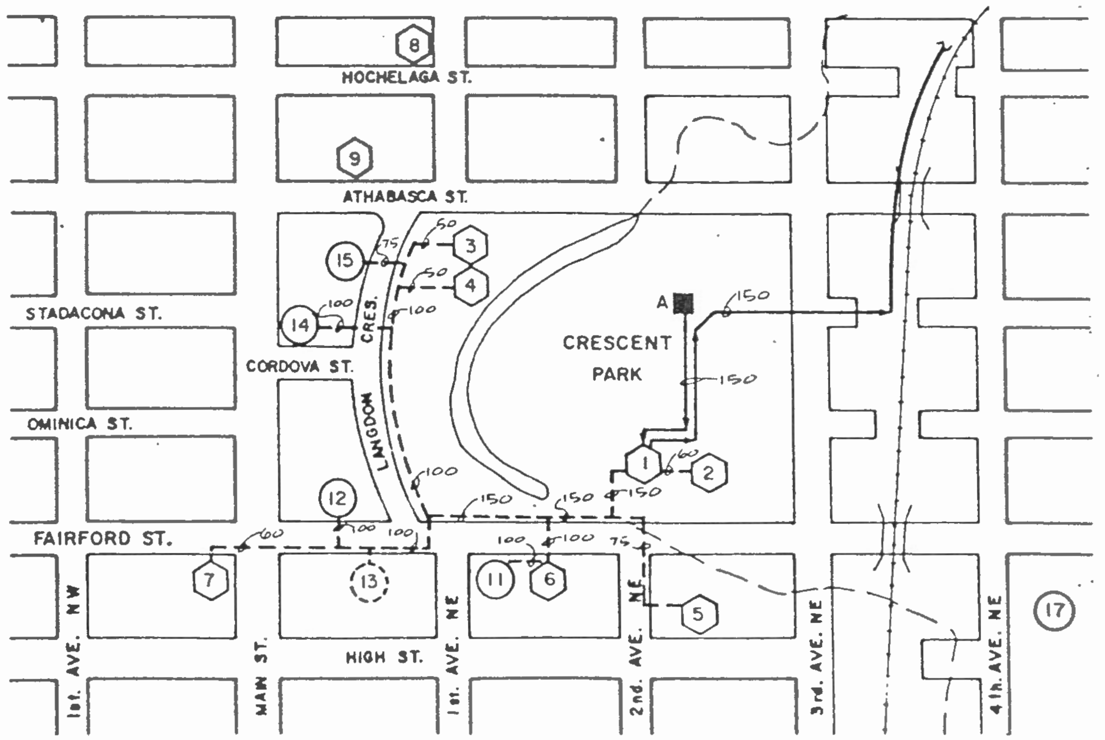
*excludes brine supply requirements to Natatorium pool and spa



SCHEME 2



SCHEME 4



SCHEME 3/3A

⬡ CITY JURISDICTION
1. NATATORIUM / OUT DOOR POOL / SF
2. YM-YWCA
3. LIBRARY
4. MUSEUM
5. HIGH PARK TOWERS
6. VICTORIA TOWERS
7. CITY HALL / POLICE STN.
8. TEMPLE TOWERS
9. CULTURAL CENTER (PROPOSED)
10. RIVER ST. APARTMENT BLDG.
○ PRIVATE
11. RACON OFFICE TOWER
12. HARWOOD INN
13. HARWOOD COMPLEX (PROPOSED)
14. GRANT HALL INN
15. LANGDON TOWERS
16. CPR STN. / OFFICE BLDG.
17. UNION HOSPITAL
■ GEOTHERMAL WELLS
A - SUPPLY
B - DISPOSAL

SCALE OF METRES
100 0 100 200

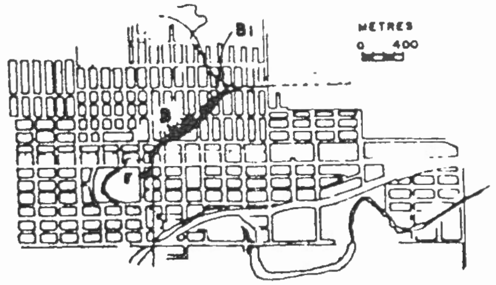


FIG. 7-2

MOOSE JAW GEOTHERMAL STUDY
C. H. SYSTEM LAYOUTS
SCHEME 2 TO 4

ACRES

A similar approach and assumptions as for Scheme 1 were adopted to determine estimates of annual energy demand (Q_p) and energy supplied annually (Q_s).

The larger the system the greater will be the impact of demand diversity, a factor which recognizes that peak demands are not coincident in time and hence not simply cumulative. This permits installation of either a smaller, less expensive supply system or, for a given size of system, can be assumed to result in both a better supply load factor and utilization. No attempt has been made to estimate the effect of diversity; on the larger schemes it is worth noting that a conventional district heat diversity factor of 10 to 15 percent could produce valuable savings in plant and piping size and costs.

7.3 Capital and Operating Costs - Schemes 1 to 4

Capital Costs

Scheme costs for geothermal wells, building retrofits and central system piping network have been developed in accordance with costing data presented in Sections 2.0, 3.0 and 5.0 respectively. The results are tabulated in Table 7-1.

In the case of Scheme 1, building retrofit costs are the incremental costs chargeable to the scheme for adapting or modifying conventional heating system designs to accommodate the cascade arrangement of equipment, the requirement for additional heat transfer surface, and more sophisticated control and regulation equipment.

TABLE 7-1

INDICATIVE CAPITAL COSTS ($1,000)

SCHEME	1	2	3	3A	4
Geo-Supply System					
Wells	820	820	820	2,300	820
Supply & Disposal Pumps	35	70	100	150	135
Supply & Disposal Piping	50	75	175	220	200
Geo-supply Totals	905	965	1,095	2,670	1,155
Central Heat Plant					
Primary Heat Exchangers	25	60	120	135	185
Heat Pumps	70	340	560	-	900
Pumps, Piping & Installation	25	105	150	30	250
Power Supplies & Controls	10	35	60	25	90
Building Extension, Civil Works	10	10	50	10	75
CH Plant Totals	140	550	940	200	1,500
Central Heat Network	-	165	385	385	1,200
Bldg. Retrofit/Adoption[a]	60	135	320	320	600
SUB-TOTAL	1,845	1,820	2,715	3,635	4,365
Engineering & Commissioning[a]	30	100	200	150	400
Sub-Total	1,135	1,915	2,940	3,725	4,855
Contingency Allowance 10%	115	190	300	370	490
CAPITAL COST TOTALS[b]	1,250	2,105	3,240	4,095	5,345
INCREMENTAL TOTALS[c]	370	1,225	2,360	3,215	4,465

Notes: (a) costs chargeable to geothermal

(b) heating scheme cost totals exclude pool restoration, spa and other renovation work

(c) additional cost for upgrading from Base Scheme geothermal supply at $880,000 (Table 6-2)

A building extension to the Natatorium is assumed to be necessary for Schemes 3 and 4. Otherwise, adequate space is expected to be available in the basement of the Natatorium. The costs reflect this.

Engineering and commissioning costs reflect charges for retrofitting existing or adapting new conventional designs to geothermal heating. Well engineering and supervision is included in well costs.

Annual Owning and Operating Costs

Annual owning and operating costs for the schemes are tabulated below.

Annualized O & O Costs ($1,000)

SCHEME	1	2	3	3A	4
Annualized Capital Cost	90	153	235	300	390
Well Pumping Energy	4	11	40	75	110
Network Pumping Energy	neg.	2	5	5	8
Heat Pumping Energy	37	58	110	-	180
Incremental O & M	10	15	30	15	40
Administration/Overhead	-	-	25	25	50
TOTAL	141	239	445	420	778

* Capital recovery factor at 6 percent, 30 years

For Scheme 1, heat pump operation is essentially constant, year round, since there is no provision for direct exchange between the primary and secondary circuits. With Schemes 2, 3 and 4 (where heating of the Natatorium, Spa and YM-YWCA would be supplied from the CH system as for any other candidate load) the Natatorium outdoor pool load can be met by direct exchange without heat pump assistance: well flow rates and exchange equipment, designed for winter load conditions are adequate for handling this smaller summer peak.

Conventional heating systems in each building incurs operating and maintenance (O & M) requirements and costs. The O & M component of cost in the above tabulation is incremental, representing the estimated additional cost chargeable to the geothermal/heat pump/CH system.

Heat pump systems require more maintenance and an allowance for conducting major overhaul and parts replacement every four or five years is necessary. This is in addition to annual inspections and interim part replacements.

For Schemes 3 to 4, a provisional sum has been included as an allowance for administration and overhead to cover billing and other costs of serving private building users.

8.0 ECONOMIC ASSESSMENT OF ENERGY PROJECTS

8.1 Basic Economic Assumptions

If geothermally heated waters are tapped to supply a health and recreation spa complex in Moose Jaw, it is also technically feasible to apply the same resource to provide heat energy to buildings in the area. The various heating schemes have been described in Section 7.0 which also provides capital and operating cost estimates and forecasts of the natural gas energy which could be displaced by each scheme. This data has been utilized to examine the economic and financial attractiveness of the four central heating options. Basically, the heating schemes would operate as extensions to the Base Scheme and involve the following categories of costs and benefits:

- incremental capital costs for larger geofluid supply and disposal system pumps and piping;
- incremental operating costs for geofluid pumps, heat pumps and network recirculation pumps;
- additional capital costs for heat exchange equipment, heat pumps, central heating plant, distribution network and building retrofits; and,
- benefits in the form of cost savings on future purchases of natural gas for space heating and domestic hot water uses.

The economic analysis presented here does not attempt to quantify the benefits accruing to the Natatorium restoration and development of the Health Spa, but rather, examines the variables affecting the economics of the energy projects alone. For the Spa, the expected benefits include increased visitor revenues, expanded tourism, any employment which would be created and the improved amenity value to Moose Jaw residents. It is, however, beyond the scope of this study to quantify these factors. For the present, it is assumed that Natatorium/Spa development is deemed desireable and central heating is an incremental investment option under consideration.

City Ownership Perspective

This analysis assumes that the City would be the sponsor, owner and operator of any central heat system which may be installed. Certainly other institutional arrangements could be considered such as formation of a regulated utility entity, a private corporation, a mixed ownership system and so on. However, in this case, it is considered appropriate to assume City ownership since the geothermal wells would be developed by the City to supply the Natatorium, the wells and related equipment would be on city property, and for the more practical size of central heat scheme, city buildings would represent the bulk of the connected load. As a result the City would be the chief beneficiary of the system in terms of energy savings.

A further implication associated with City ownership is that it would be expected that the cost of capital would be less than for a private developer and that income and other taxes would not apply. Thus, financially the City would be expected to be in a better position than a private developer to launch a central heating scheme in Moose Jaw.

Commercial Arrangements

Given the foregoing stance, it is appropriate that the entire economic analysis be conducted from the viewpoint of the City of Moose Jaw. It is assumed that all capital costs, including the retrofit of privately owned buildings connected to the system, will be incurred by the City. Principally, the rationale here is that it will be in the City's interest to encourage connections by helping private customers avoid initial high costs. Previous studies Acres, 1984 a; et al) have made it clear that a critical prerequisite for the success of geothermal heating systems is almost immediate load connection. The best way to accomplish this is for the project developer to finance the connection costs and amortize them through the rates charged.

The rate structure applicable to private customers will probably incorporate a fixed charge related to the size of connected load and/or the capital costs of building connection and retrofit. The rate will also incorporate an energy charge based on the amount of heat actually delivered.

For the financial analysis it is assumed that the combination of these rates will have to be lower than the operating costs building operators would face if they remained on natural gas heat. Charges to private customers have been assumed at 90 percent of the value of displaced gas. This 90 percent charge would incorporate both demand and energy portions of the rate structure. At a level of 90 percent there should be incentive for building connections and the actual amount of savings in years after 1988 will steadily increase given the assumption that gas prices will escalate at 2 percent.

From the standpoint of the City, it is therefore assumed that the project is not credited with the full amount of the gas savings. Rather, the cash inflows are the full amount of gas purchases avoided in city buildings and 90 percent of the gas purchases avoided in private buildings. As such, the economic analysis contained in this report does not capture the 10 percent of social benefit attributable to the project which would be enjoyed by private building operators.

A further implication following from the assumption that the City would be the owner/operator of the geothermal system is that no tax calculations have been included in the cash flow analysis. Net cash flows are taken simply as the gas purchases avoided in municipal buildings, plus 90 percent of the gas purchases avoided in private buildings, less total capital costs and total operating costs. Net present values for all schemes based on these cash flows are calculated at 6, 9, 12, 15, and 18 percent. In addition, an internal rate of return is provided. The significance of these investment ranking criteria is discussed in the following subsection.

8.2 Analytical Approach

Discounted cash flow analysis techniques have been employed to screen and rank the possible central heat schemes. Throughout the analysis, all cash flows are expressed in constant January, 1985 Canadian dollars and as such, there is no need to allow for general inflation in the calculations.

All schemes are assumed to have a useful life of 30 years with the initial capital costs projected to occur in 1987. The in-service date is assumed to be 1988. From 1988 onwards then, the principal annual cash flows are the cost savings on natural gas purchases and the system operating costs. Provision has also been made for certain capital equipment replacements and major overhauls at 5 year intervals over the life of the project. These recurring capital costs are assumed to be 25 percent of the original cost of the geothermal pumps and wellheads each 5 years and 20 percent of the original cost of heat pump systems.

Investment Criteria and Price Escalation

Since it is assumed that the projects would be undertaken by the City of Moose Jaw, the investment criteria of the City will determine the economic viability of proceeding with any particular scheme. For the purposes of this analysis, it is assumed that the alternative investment option for City funds is long-term Government of Canada bonds. These securities currently have a market yield of about 11.5 percent to 12 percent. If long-term inflation trends of between 4 percent and 5 percent are anticipated the City is obtaining a "real" return of close to 7 percent.

In general, the current level of real return is considered somewhat high in terms of long-run, historical levels. More typical required rates of return for public projects have been closer to 5 percent real. For this analysis, a value of 6 percent is taken as the average, long run opportunity cost of funds employed by the City for geothermal energy projects. Schemes which are expected to provide returns in excess of about 6 percent real, therefore, are considered worthwhile projects.

For each of the schemes analyzed in this section, various discount rates have been used to calculate net present values of the project cash flows. The discount rate is used to adjust downward the present value of cash flows occurring in the future in recognition of the expected rate of return on the initial investment. Basically, if the City requires a 6 percent real return on its money, then future cash flows should be decremented by 6 percent per annum to determine what they are worth now. If these discounted future cash flows sum to a value greater than the initial investment, then it can be said that the investor recovered the original investment, gained a 6 percent return on that investment, and earned some additional wealth as well. The amount of this gain is the difference between the present value of future cash inflows, less the original cash outflow. If this difference is positive when a 6 percent discount rate is used, then the net benefit to the City of Moose Jaw is the amount of this net present value.

To examine the sensitivity of project economics to various discount rates, net present values are calculated using real discount rates of 6, 9, 12 and 15 percent for each geothermal heating scheme. In addition, an internal rate of return is provided for each. This is defined simply as the discount rate at which the net present value would be zero. Thus, if the required rate of return, or hurdle rate, for investment projects is 6 percent, and a scheme provides an internal rate of return of 10 percent, then the project has a positive benefit for the investor.

Since all cash flows are stated in constant dollars and the discount rates employed are real rates, it is necessary to determine the extent to which any components of the cash flows will have price changes at variance with general inflation. Energy prices are an important possible source of such changes.

In the short term, natural gas prices are expected to increase from current levels of about $3.30 per GJ to a level based on a wholesale price of 65 percent of world oil prices on an energy equivalent basis. At current oil price levels this converts to a commercial rate of about $4.29 per GJ in Saskatchewan. This value is then adjusted for combustion efficiency of 70 percent to yield a net energy cost of $6.13 per GJ. This is the value ascribed to each gigajoule of geothermal system supply commencing with the in-service date in 1988. Beyond 1988, National Energy Board estimates of real price increases amounting to 2 percent per annum have been adopted.

Commercial electrical energy rates of 4.5¢ per kilowatt hour have been used in the analysis. The City of Moose Jaw may be able to reduce these costs through bulk rate price breaks. As with natural gas prices, it is assumed that electric energy costs will escalate at 2 percent "real" per year.

Other operating cost items such as labour, supplies and miscellaneous are held constant throughout the project life. In other words, real escalation is assumed to be 0 percent per year. (In practice most economic forecasts predict real costs declining by half percent or so with productivity gains).

Spa/Heat System Co-Development Approach

In general, the cash flow pattern associated with geothermal heating projects involves front-end capital costs which are relatively high in comparison to conventional heating systems. Annual operating costs are lower when compared to the purchase of conventional fuels avoided. In the case of the Moose Jaw schemes, this pattern is somewhat modified in that the heating projects are viewed as possible enhancements to Natatorium restoration and health spa development. The implication of this is that it is assumed that the supply well, disposal well, related piping and pumps suitable to the spa are, in the conceptual sense, already in place. To establish a central heat system, the only incremental capital costs are for upgrading the well systems, piping and pumping capacity to produce geofluid volumes greater than those required for the base scheme alone.

The principal additional costs for these schemes include the capital costs for heat pump systems, the central heating plant and distribution network, and the retrofit of suitable heating equipment in connected buildings, as well as the operating costs for the heat pumps in the form of electricity purchases. The scale of these items is roughly proportional to the number of buildings connected to the system and thus, the actual amount of capital costs chargeable to the heating schemes increases steadily as the size of the system increases.

As mentioned earlier, the Base Scheme Natatorium restoration and spa development project is deemed to be valuable to the City of Moose Jaw in its own right. Thus, to avoid double accounting of heat system benefits and costs, the approach taken here is to include only the incremental and additional costs chargeable to the heating schemes and only the energy benefits. If the benefits are found to exceed the costs for the heat scheme, these net benefits represent an additional positive impact accruing to the spa development.

ENERDEMO Capital Assistance

Another opportunity for increasing the net benefits of the heating schemes, from the viewpoint of the City, may be available in the form of grant assistance from the federal government.

Numerous federal and joint federal/provincial initiatives have been developed over the past few years designed to provide incentives for the development of alternative energy projects and to encourage energy self sufficiency. A comprehensive cataloging of these programs was conducted (Acres, 1984 a).

Discussions with the Conservation and Renewable Energy Office of Energy, Mines and Resources Canada in Saskatoon, (personal communication, L. Epp) suggest that ENERDEMO Program funds could be available for a geothermal heating project such as that contemplated in Moose Jaw. Recently, capital grants of up to $450,000 have been awarded to alternative energy demonstration projects through this program. For schemes in Moose Jaw, it is thought that grants ranging from $100,000 to $250,000 would be realistic allowances to make at this stage. To be eligible for an ENERDEMO grant, the scheme must incorporate a heating component. Spa development alone would not qualify for this assistance.

In the financial analyses, the schemes have been examined firstly without assuming any capital grants. Subsequently, the impact of grants of $100,000 for Scheme 1, $200,000 for Scheme 2 and $250,000 for Schemes 3 and 4 are examined.

8.3 Financial Results

Tables 8-1 to 8-5 provide the schedule of capital expenditures and cash flows for central heating schemes 1, 2, 3, 3A and 4. Although the projects are assumed to have 30-year useful lives, for brevity, annual cash flows to 1999 only are shown on the tables. The schemes themselves are described in detail in Section 7.0 of this report.

The first page of each table provides relevant particulars of the scheme and the estimated capital costs, which are assumed to occur in 1987. The system energy supply value is provided along with a breakdown of the distribution of this supply to city-owned and private buildings. These supply values are used to calculate the natural gas purchases displaced by the project.

Pumping power requirements are also indicated. These values are used to calculate the principal operating costs of the scheme. As noted earlier, the capital costs provided for well drilling and geofluid system are those necessary for upgrading these components of a health and recreation spa. The estimates for heat pump systems, central plant and network, and building retrofits are direct costs of the central heating system. Engineering and commissioning costs as well as contingency allowances

TABLE 8-1

MOOSE JAW GEOTHERMAL DEVELOPMENT-CASH FLOW ANALYSIS

CASE DESCRIPTION: SCHEME 1: INCREMENTAL CENTRAL HEAT SYSTEM

				CITY	PVT.
SYSTEM SUPPLY (TJ/A):	15.0				
HP WORK ENERGY (MWh):	820.0		BLDG LOADS (TJ/A)	15.0	0.0
WELL PUMP ENERGY (MWh)	90.0		CONNECTED BLDGS.	3.0	0.0
RECIRC. PUMP ENERGY (MWh):	25.0				

CAPITAL EXPENDITURES	YEARS 1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Well Drilling	130.0												
Geofluid System	40.0					9.6					9.6		
Heat Pump Systems	70.0					14.0					14.0		
Central Plant and Network	30.0												
Building Retrofits	60.0												
Sub-total	330.0	0.0	0.0	0.0	0.0	23.6	0.0	0.0	0.0	0.0	23.6	0.0	0.0
Engineering & Commissioning	30.0	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	2.4	0.0	0.0
Contingency	40.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	3.8	0.0	0.0
TOTAL CAPITAL COST	400.0	0.0	0.0	0.0	0.0	29.7	0.0	0.0	0.0	0.0	29.7	0.0	0.0

MOOSE JAW GEOTHERMAL SYSTEM CASH FLOW ANALYSIS

CASE DESCRIPTION: SCHEME 1-INCREMENTAL CENTRAL HEAT SYSTEM

CASH FLOWS	YEAR 1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
ANNUAL FUEL COST SAVINGS													
Municipal Buildings	0.0	92.0	93.8	95.7	97.6	99.5	101.5	103.6	105.6	107.7	109.9	112.1	114.3
Pvt. Buildings @ 90%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL CASH INFLOW	0.0	92.0	93.8	95.7	97.6	99.5	101.5	103.6	105.6	107.7	109.9	112.1	114.3
TOTAL CAPITAL COSTS	400.0	0.0	0.0	0.0	0.0	29.7	0.0	0.0	0.0	0.0	29.7	0.0	0.0
OPERATING COSTS													
Geofluid Pumping	0.0	4.1	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.7	4.8	4.9	5.0
Incremental O & M	0.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Heat Pump Energy	0.0	36.9	37.6	38.4	39.2	39.9	40.7	41.6	42.4	43.2	44.1	45.0	45.9
Distribution Pumping	0.0	1.1	1.1	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.4	1.4
TOTAL OPERATING COSTS	0.0	52.1	52.9	53.8	54.7	55.5	56.5	57.4	58.3	59.3	60.3	61.3	62.3
NET CASH FLOW	-400.0	39.9	40.9	41.9	42.9	14.3	45.1	46.2	47.3	48.4	19.9	50.8	52.0

NET PRESENT VALUE	@ 0%	@ 9%	@ 12%	@ 15%	@18%
	240.6	55.7	-56.6	-129.0	-175.[illegible]

INTERNAL RATE OF RETURN: 10.31%

TABLE 8-2

MOOSE JAW GEOTHERMAL DEVELOPMENT-CASH FLOW ANALYSIS

CASE DESCRIPTION: SCHEME 2: INCREMENTAL CENTRAL HEAT SYSTEM

			CITY	PVT.
SYSTEM SUPPLY (TJ/A):	35.5			
HP WORK ENERGY (MWh):	1280.0	BLDG LOADS (TJ/A)	27.2	8.3
WELL PUMP ENERGY (MWh)	215.0	CONNECTED BLDGS.	5.0	1.0
RECIRC. PUMP ENERGY (MWh):	53.0			

CAPITAL EXPENDITURES	YEARS 1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1996	1999
Well Drilling	130.0												
Geofluid System	83.0					16.6					16.6		
Heat Pump Systems	340.0					68.0					68.0		
Central Plant and Network	375.0												
Building Retrofits	135.0												
Sub-total	1063.0	0.0	0.0	0.0	0.0	84.6	0.0	0.0	0.0	0.0	84.6	0.0	0.0
Engineering & Commissioning	100.0	0.0	0.0	0.0	0.0	8.5	0.0	0.0	0.0	0.0	8.5	0.0	0.0
Contingency	120.0	0.0	0.0	0.0	0.0	15.3	0.0	0.0	0.0	0.0	15.3	0.0	0.0
TOTAL CAPITAL COST	1283.0	0.0	0.0	0.0	0.0	108.3	0.0	0.0	0.0	0.0	108.3	0.0	0.0

MOOSE JAW GEOTHERMAL SYSTEM CASH FLOW ANALYSIS

CASE DESCRIPTION: CASE 2-INCREMENTAL CENTRAL HEAT SYSTEM

CASH FLOWS	YEAR 1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
ANNUAL FUEL COST SAVINGS													
Municipal Buildings	0.0	166.7	170.1	173.5	176.9	180.5	184.1	187.8	191.5	195.4	199.3	203.3	207.3
Pvt. Buildings @ 90%	0.0	45.8	46.7	47.6	48.6	49.6	50.6	51.6	52.5	53.7	54.7	55.8	56.9
TOTAL CASH INFLOW	0.0	212.5	216.8	221.1	225.5	230.0	234.6	239.3	244.1	249.0	254.0	259.1	264.3
TOTAL CAPITAL COSTS	1283.0	0.0	0.0	0.0	0.0	106.3	0.0	0.0	0.0	0.0	108.3	0.0	0.0
OPERATING COSTS													
Geofluid Pumping	0.0	9.7	9.9	10.1	10.3	10.5	10.7	10.9	11.1	11.3	11.6	11.8	12.0
Incremental O & M	0.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Heat Pump Energy	0.0	57.6	58.8	59.9	61.1	62.3	63.6	64.9	66.2	67.5	66.8	70.2	71.6
Distribution Pumping	0.0	2.4	2.4	2.5	2.5	2.6	2.6	2.7	2.7	2.8	2.9	2.9	3.0
TOTAL OPERATING COSTS	0.0	84.7	85.1	87.5	88.9	90.4	91.9	93.4	95.0	96.6	98.3	99.9	101.6
NET CASH FLOW	-1283.0	127.9	130.7	133.6	136.6	31.3	142.7	145.9	149.1	152.4	47.4	159.2	162.6

NET PRESENT VALUE	@ 6%	@ 9%	@ 12%	@ 15%	@18%
	710.1	147.4	-195.3	-416.4	-566.9

INTERNAL RATE OF RETURN: 10.12%

TABLE 8-3

MOOSE JAW GEOTHERMAL SYSTEM CASH FLOW ANALYSIS

CASE DESCRIPTION: SCHEME 3-INCREMENTAL CENTRAL HEAT SYSTEM

CASH FLOWS	YEAR 1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
ANNUAL FUEL COST SAVINGS													
Municipal Buildings	0.0	190.0	193.8	197.7	201.7	205.7	209.8	214.0	218.3	222.7	227.1	231.6	236.3
Pvt. Buildings @ 90%	0.0	160.0	163.2	166.5	169.8	173.2	176.6	180.2	183.8	187.5	191.2	195.0	198.9
TOTAL CASH INFLOW	0.0	350.0	357.0	364.2	371.4	378.9	386.5	394.2	402.1	410.1	418.3	426.7	435.2
TOTAL CAPITAL COSTS	2408.0	0.0	0.0	0.0	0.0	196.7	0.0	0.0	0.0	0.0	196.7	0.0	0.0
OPERATING COSTS													
Geofluid Pumping	0.0	38.9	39.7	40.5	41.3	42.1	43.0	43.8	44.7	45.6	46.5	47.4	48.4
Incremental O & M	0.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Heat Pump Energy	0.0	109.1	111.3	113.5	115.8	118.1	120.5	122.9	125.4	127.9	130.4	133.0	135.7
Distribution Pumping	0.0	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6
Admin. & Overhead	0.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
TOTAL OPERATING COSTS	0.0	207.6	210.6	213.7	216.9	220.1	223.4	226.8	230.2	233.7	237.3	241.0	244.7
NET CASH FLOW	-2408.0	142.5	146.4	150.5	154.6	-38.0	163.0	167.4	171.8	176.4	-15.7	185.7	190.5

NET PRESENT VALUE	@ 6%	@ 9%	@ 12%	@ 15%	@18%
	-231.3	-860.0	-1238.6	-1480.3	-1643.1

INTERNAL RATE OF RETURN: 5.21%

MOOSE JAW GEOTHERMAL PROJECT-CASH FLOW ANALYSIS

CASE DESCRIPTION: SCHEME 3-INCREMENTAL CENTRAL HEAT SYSTEM

SYSTEM SUPPLY (TJ/A): 60.0

HP WORK ENERGY (MWh): 2425.0
WELL PUMP ENERGY (MWh) 865.0
RECIRC. PUMP ENERGY (MWh): 100.0

	CITY	PVT.
BLDG LOADS (TJ/A)	31.0	29.0
CONNECTED BLDGS.	8.0	5.0

CAPITAL EXPENDITURES	YEARS 1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Well Drilling	130.0												
Geofluid System	213.0					42.6					42.6		
Heat Pump Systems	560.0					112.0					112.0		
Central Plant and Network	765.0												
Building Retrofits	320.0												
Sub-total	1988.0	0.0	0.0	0.0	0.0	154.6	0.0	0.0	0.0	0.0	154.6	0.0	0.0
Engineering & Commissioning	200.0	0.0	0.0	0.0	0.0	15.5	0.0	0.0	0.0	0.0	15.5	0.0	0.0
Contingency	220.0	0.0	0.0	0.0	0.0	26.7	0.0	0.0	0.0	0.0	26.7	0.0	0.0
TOTAL CAPITAL COST	2408.0	0.0	0.0	0.0	0.0	196.7	0.0	0.0	0.0	0.0	196.7	0.0	0.0

TABLE 8-4

CASE DESCRIPTION: SCHEME 3A: INCREMENTAL CENTRAL HEAT SYSTEM
DEEP WELL DEVELOPMENT

			CITY	PVT.
SYSTEM SUPPLY (TJ/A):	60.0			
HEAT PUMP CAPACITY (MW):	0.0			
HP WORK ENERGY (MWh):	0.0	BLDG LOADS (TJ/A)	31.0	29.0
WELL PUMP ENERGY (MWh)	1585.0	CONNECTED BLDGS.	8.0	5.0
RECIRC. PUMP ENERGY (MWh):	100.0			

CAPITAL EXPENDITURES	YEARS 1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Well Drilling	1630.0												
Geofluid System	370.0					74.0					74.0		
Heat Pump Systems	0.0					0.0					0.0		
Central Plant and Network	585.0												
Building Retrofits	320.0												
Sub-total	2905.0	0.0	0.0	0.0	0.0	74.0	0.0	0.0	0.0	0.0	74.0	0.0	0.0
Engineering & Commissioning	150.0	0.0	0.0	0.0	0.0	7.4	0.0	0.0	0.0	0.0	7.4	0.0	0.0
Contingency	300.0	0.0	0.0	0.0	0.0	7.4	0.0	0.0	0.0	0.0	7.4	0.0	0.0
TOTAL CAPITAL COST	3355.0	0.0	0.0	0.0	0.0	88.8	0.0	0.0	0.0	0.0	88.8	0.0	0.0

MOOSE JAW GEOTHERMAL SYSTEM CASH FLOW ANALYSIS

CASE DESCRIPTION: CASE 3A

CASH FLOWS	YEAR 1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
ANNUAL FUEL COST SAVINGS													
Municipal Buildings	0.0	190.0	193.8	197.7	201.7	205.7	209.8	214.0	218.3	222.7	227.1	231.6	236.3
Pvt. Buildings @ 90%	0.0	160.0	163.2	166.5	169.8	173.2	176.6	180.2	183.8	187.5	191.2	195.0	198.9
TOTAL CASH INFLOW	0.0	350.0	357.0	364.2	371.4	378.9	386.5	394.2	402.1	410.1	418.3	426.7	435.2
TOTAL CAPITAL COSTS	3355.0	0.0	0.0	0.0	0.0	88.8	0.0	0.0	0.0	0.0	88.8	0.0	0.0
OPERATING COSTS													
Geofluid Pumping	0.0	71.3	72.8	74.2	75.7	77.2	78.7	80.3	81.9	83.6	85.2	86.9	88.7
Incremental O & M	0.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Administration/Overhead	0.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Heat Pump Energy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Distribution Pumping	0.0	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6
TOTAL OPERATING COSTS	0.0	115.6	117.3	118.9	120.5	122.1	123.7	125.4	127.1	128.8	130.6	132.4	134.3
NET CASH FLOW	-3355.0	234.2	239.7	245.3	251.0	168.0	262.7	268.8	275.0	281.3	198.9	294.3	300.9

NET PRESENT VALUE	@ 6%	@ 9%	@ 12%	@ 15%	@18%
	586.1	-529.4	-1210.6	-1651.3	-1951.4

INTERNAL RATE OF RETURN: 7.38%

TABLE 8-5

MOOSE JAW GEOTHERMAL PROJECT-CASH FLOW ANALYSIS

CASE DESCRIPTION: SCHEME 4-INCREMENTAL CENTRAL HEAT SYSTEM

			CITY	PVT.
SYSTEM SUPPLY (TJ/A):	114.0			
HP WORK ENERGY (MWh):	3990.0	BLDG LOADS (TJ/A)	42.0	72.0
WELL PUMP ENERGY (MWh)	2465.0	CONNECTED BLDGS	11.0	7.0
RECIRC. PUMP ENERGY (MWh):	165.0			

CAPITAL EXPENDITURES	YEARS 1967	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Well Drilling	130.0												
Geofluid System	273.0					54.6					54.6		
Heat Pump Systems	900.0					180.0					180.0		
Central Plant and Network	1800.0												
Building Retrofits	600.0												
Sub-total	3703.0	0.0	0.0	0.0	0.0	234.6	0.0	0.0	0.0	0.0	234.6	0.0	0.0
Engineering & Commissioning	400.0	0.0	0.0	0.0	0.0	23.5	0.0	0.0	0.0	0.0	23.5	0.0	0.0
Contingency	410.0	0.0	0.0	0.0	0.0	41.5	0.0	0.0	0.0	0.0	41.5	0.0	0.0
TOTAL CAPITAL COST	4513.0	0.0	0.0	0.0	0.0	299.5	0.0	0.0	0.0	0.0	299.5	0.0	0.0

MOOSE JAW GEOTHERMAL SYSTEM CASH FLOW ANALYSIS

CASE DESCRIPTION: SCHEME 4-INCREMENTAL CENTRAL HEAT SYSTEM

CASH FLOWS	YEAR 1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
ANNUAL FUEL COST SAVINGS													
Municipal Buildings	0.0	257.5	262.6	267.9	273.2	278.7	284.3	289.9	295.7	301.7	307.7	313.8	320.1
Pvt. Buildings @ 90%	0.0	397.2	405.2	413.3	421.5	430.0	438.6	447.3	456.3	465.4	474.7	484.2	493.9
TOTAL CASH INFLOW	0.0	654.7	667.8	681.1	694.8	708.7	722.8	737.3	752.0	767.1	782.4	798.1	814.0
TOTAL CAPITAL COSTS	4513.0	0.0	0.0	0.0	0.0	299.5	0.0	0.0	0.0	0.0	299.5	0.0	0.0
OPERATING COSTS													
Geofluid Pumping	0.0	110.9	113.1	115.4	117.7	120.1	122.5	124.9	127.4	130.0	132.6	135.2	137.9
Incremental O & M	0.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Administration/Overhead	0.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Heat Pump Energy	0.0	179.6	183.1	186.8	190.5	194.4	198.2	202.2	206.2	210.4	214.6	218.9	223.2
Distribution Pumping	0.0	7.4	7.6	7.7	7.9	8.0	8.2	8.4	8.5	8.7	8.9	9.1	9.2
TOTAL OPERATING COSTS	0.0	387.9	393.9	399.9	406.1	412.5	418.9	425.5	432.2	439.0	446.0	453.1	460.4
NET CASH FLOW	-4513.0	266.8	273.9	281.2	288.6	-3.3	303.9	311.8	319.8	328.0	36.9	344.9	353.6

NET PRESENT VALUE	@ 6%	@ 9%	@ 12%	@ 15%	@18%
	-324.5	-1520.2	-2255.6	-2721.7	-3036.7

INTERNAL RATE OF RETURN: 5.41%

have been incorporated in the total capital costs for all schemes.

The second page of each table summarizes the annual cash flows. Fuel cost savings represent cash inflows while capital costs and operating costs are cash outflows. Inflows less outflows yields the net cash flow for each year. At the bottom of the page, net present values at the indicated discount rates are provided along with the internal rate of return resulting from the stream of net cash flows over the 30-year project life.

Figure 8-1 plots these rate of return values for each of the schemes. Three development scenarios are indicated for each heating scheme. The "incremental" results are simply the financial returns based on development of the heating system as an adjunct to Natatorium/Spa development. The dark bars (with capital grant) show the improved return to the City if assistance in the amount of $100,000 is obtained for Scheme 1, $200,000 for Scheme 2 and $250,000 for Schemes 3 and 4. The last set of results, labelled "Stand-Alone Project", provides the economic results assuming no capital grant and no co-development with the spa complex. This latter case is discussed in a subsequent sub-section.

As noted earlier, projects with internal rates of return exceeding about 6 percent are considered worthwhile investments for the City. In the incremental case, Schemes 1 and 2, with IRR's of 10.3 and 10.1 percent meet this criterion. Schemes 3 and 4 fall short of this financial hurdle rate, although Scheme 3A shows a return of 7.4 percent.

There are two primary reasons for the relative non-attractiveness of the larger schemes. Firstly, there is the simple phenomenon that it is becoming more and more costly to extend the distribution system out to connect more buildings. The capital and operating costs are simply increasing faster than the additional gas cost savings. The other element mitigating against the larger systems is the assumption regarding revenues from private buildings. In the smaller schemes, the bulk of the connected load would be city buildings and the full amount of the fuel cost savings would accrue to the City. However, in Schemes 3 and 4, private building heating loads become more predominant. For these, it is assumed that the city is incurring the full cost of connection and retrofit but will only be able to recover about 90 percent of the economic value of the natural gas displaced.

The 90 percent value is somewhat arbitrary but it must be recognized that some price incentive has to be offered to private building operators to provide an adequate commercial inducement to subscribe to the system. Other rate structure formulae may be found to be more appropriate. For example, a combined demand charge and energy charge is common, but it must be assumed that the overall costs to the customer must be less than the expected costs for conventional heating. In reality, the overall savings available to building operators would be somewhat greater than the 10 percent allowance assumed here since maintenance and operating costs, and in in some cases necessary replacements, would also be avoided.

MOOSE JAW GEOTHERMAL ENERGY PROJECTS FINANCIAL RATES OF RETURN

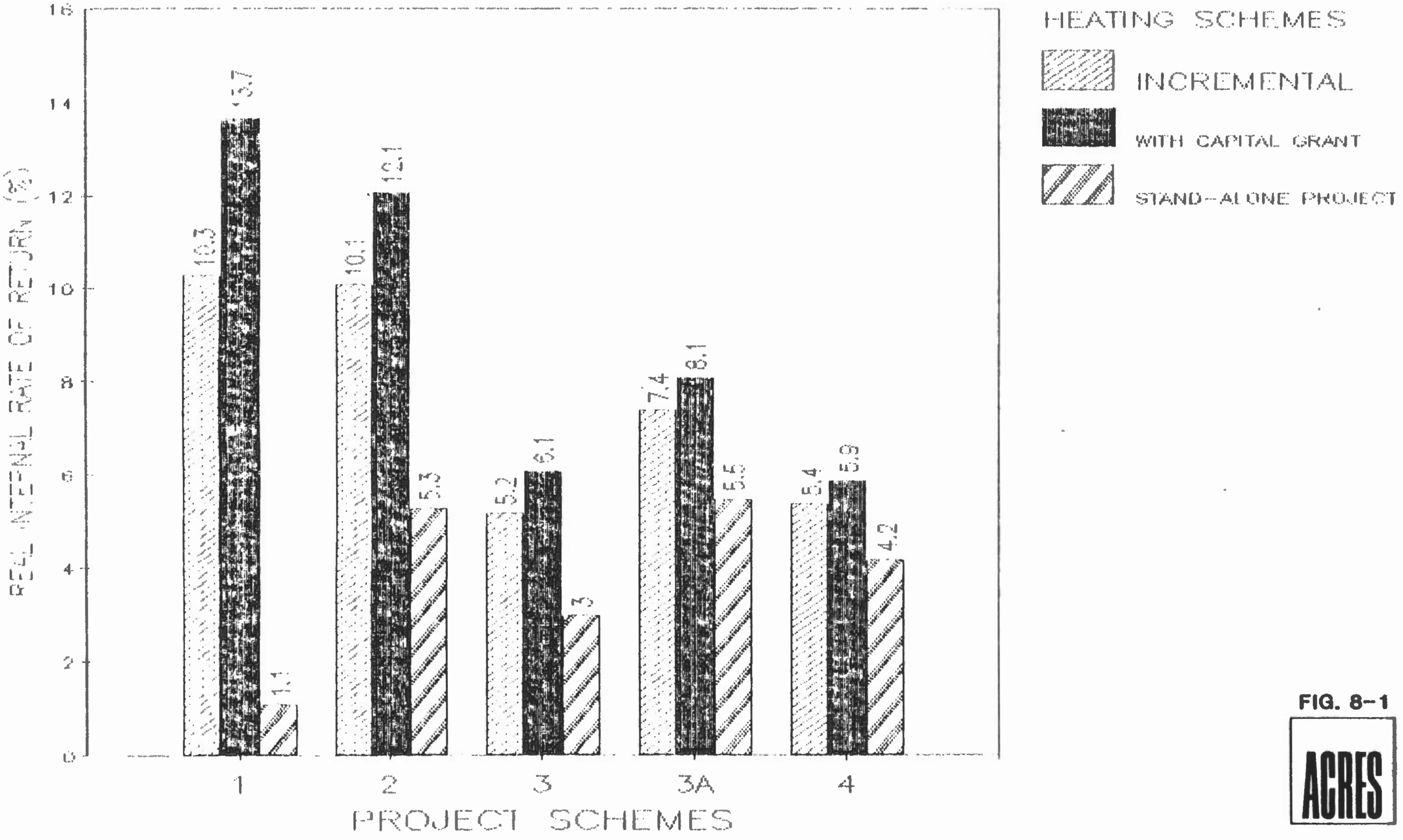


FIG. 8-1

ACRES

Scheme 3A - Deep Well Development

This Scheme is not directly comparable to the others in that it incorporates a deep well system and no heat pumps. The cost impact is an increase of $1.0 million in capital cost relative to Scheme 3. Operating costs are reduced by about $80,000 per year, primarily by the avoidance of heat pump energy costs. As can be seen, the rate of return of Scheme 3A is about 2 percent higher than for Scheme 3. However, it must be noted that the risks associated with Scheme 3A could be substantially higher also. As deeper resources are sought, the variability of costs will increase. Given the only slight increase in return, it must be concluded that pursuing deep well system configurations would not be warranted particularly since the well chemistry is incompatible with natatorium and health spa users. For the smaller heating schemes, the high cost and more limited utilization would make deep wells even less attractive source options.

Sewer Disposal Option

One further variation should be considered. It has been assumed throughout that, for the base scheme, the geofluid system associated with spa development would involve a geothermal supply well system and disposal well system. The potential for savings from disposal to sewer has already been referred to. The following looks at the economic implications of avoiding a disposal well system for Scheme 1.

Scheme 1 entails very little enhancement to the wells and geofluid system to supply energy for the Natatorium, Spa and YMCA buildings. The total geofluid flow would probably be of the order of 15 m^3/h (65 GPM). In terms of the total sewer flow and its dilution capability, this is a very small amount so that elimination of the disposal system could be considered as an option. The advantage is a reduction in capital cost for the combined spa and central heat system of Scheme 1 of some $350,000. The resulting capital cost for providing geothermal water for Scheme 1 is reduced to about $400,000 and the incremental cost of the central heat system would be on the order of $300,000. The social and economic benefits accruing to the spa would be unchanged and the $52,000 of annual energy savings through the heating system would also be realized.

The financial returns are obviously attractive since the rate of return on the heating system would be over 17 percent real. Further study would be required of the technical difficulties associated with this scheme but it does appear to offer a promising, least cost, minimal scale alternative.

8.4 Cost Sensitivities

The two principle areas where the financial results reported here would be significantly altered are in the capital and operating costs. As mentioned earlier, central heating schemes may benefit from capital grants through the federal ENERDEMO program. Figure 8-1 indicates the impact of such grants which basically have the effect of reducing capital costs by $100,000 in Scheme 1, $200,000 in Scheme 2 and $250,000 in Schemes 3 and 4.

Since the capital costs are relatively low in Schemes 1 and 2, the impact of the grant is dramatic, adding over

3 percent to the Scheme 1 rate of return and 2 percent to Scheme 2. Capital grants, or other forms of capital cost reduction, have less influence on Schemes 3 and 4, resulting in rate of return increases of less than 1.0 percent. They remain below the level of financial viability. Naturally, while a reduction in the effective capital cost adds to the rate of return, increased capital cost charges will reduce it a like amount.

The other major component of costs which affect the project are electric energy expenses for operating supply and disposal pumps, heat pumps, and heat network circulation pumps. In the financial analysis for the schemes discussed above, the standard commercial account electrical rate of 4.5¢/kWh has been used. However, if the City adds the geothermal system loads to existing loads, it may be able to obtain lower bulk rates. The impact of 4¢/kWh power has been examined in the context of Schemes 1, 2 and 3. Since electricity represents the bulk of operating costs, the effect of changes in electric prices have a direct impact on project cash flows.

In each case, the assumed reduction in electricity costs of about 10 percent resulted in an increase of the projected internal rates of return of about 1.0 percent. Based on these results, unless the changes in elements of operating costs are quite large, the overall viability of the schemes will not be affected significantly.

Stand-Alone Heating Schemes

Finally, one other set of assumptions was examined for comparative purposes. In locations other than Moose Jaw, where the "symbiotic" relationship between the Natatorium restoration/Spa development and central heat schemes can be used to advantage, the energy projects would stand alone as independent systems. In such cases, the costs of the full development would be charged to the heating scheme and the benefits associated with the spa would not be available. The rates of return associated with this scenario for each of the schemes are also presented in Figure 8-1 under the "stand-alone" category.

All of the schemes fail to meet the financial hurdle rate of 6 percent on this basis, but they do still provide positive returns. With the stand-alone configuration, the smallest scheme is by far the least attractive while the larger schemes show healthier returns. This is consistent with the findings of numerous other studies of geothermal heating systems where it has been noted that relatively modest system loads cannot begin to justify the system capital costs. Stand-alone geothermal heating systems must have very dense and intensive system loads so that the value of the energy delivered will be sufficient to overcome the high capital costs associated with such projects. The computerized cash flow runs for these stand-along cases are provided in Appendix "C".

8.5 Conclusions

Based on the analysis and assumptions presented here, Scheme 1 offers slightly greater returns than Scheme 2, and both well exceed the return of the various other heating schemes examined. However, Scheme 1 is not so effective as a representative geothermal project as Scheme 2. Scheme 2 incorporates elements which would be more characteristic of a prototype geothermal central heating project in Canada. It would clearly have greater demonstration value and would deserve greater capital funding assistance from the federal government, because it offers greater diversity of buildings and contains all the system components associated with central heating.

Scheme 2 also offers the flexibility to expand to Schemes 3 or even 4 at a later time, as operating experience is gained and should energy prices increase at a greater rate than forecast herein. For the present however, Scheme 2 is manageable in scale and all but one of the connected buildings would be city owned.

With ENERDEMO program support on the order of $200,000, the City would spend about $1.0 million on the Scheme 2 heating scheme to obtain annual returns on the order of $130,000. The simple payback period would be less than 8 years and the internal rate of return would be 12 percent real, which is the equivalent of about a 16 or 17 percent yield on investment at today's rates. This level of return substantially exceeds that available to the City on bond investments.

At a discount rate of 6 percent, Scheme 2 offers a net present value contribution to a combined Natatorium/Spa/Heat System Scheme of about $900,000 assuming federal assistance. However, it can be expected that the total contribution will be even greater if the potential secondary benefits are developed. As noted earlier, the Natatorium and Spa are expected to be self-supporting and beneficial on their own. Geothermal heat system development however will provide an additional interest focal point in central Moose Jaw with the potential for various research and development activities and the attraction associated with a demonstration project. The fortuitous circumstances presented by the possibility of co-developing the healh spa complex as well as a central heating scheme in a complementary arrangement provide the City of Moose Jaw with a potentially unique opportunity.

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

This investigation indicates that combining geothermal heating with Natatorium restoration and Spa development is practical and economically attractive for certain schemes.

The most limited scheme, Scheme 1, involving the heating of the Natatorium pool and building, new Spa facilities and the YM-YWCA, is seen to offer an economic return on the incremental investment that substantially exceeds the City's minimum return requirements. This provides a positive indication of the mutual economic benefit to be gained from combining restoration and heating.

Scheme 2, an extension to Scheme 1 that includes heating two adjacent apartment buildings and one office building, also offers a favourable economic return potential. However with this, as with the two larger Schemes 3 and 4 that were examined, the system costs required to connect to and retrofit increasingly remote buildings results in diminishing returns.

Both Schemes 1 and 2 are considered to provided realistic opportunities for economic heating with geothermal energy, Scheme 2 being perhaps more representative for demonstration project purposes because of the greater variety of buildings involved. It might therefore be regarded to be a more appropriate candidate for financial assistance, under the federal ENERDEMO program, and could gain further support as a geothermal research and development project from one or more levels of government including further assistance under the federal government's geothermal program.

Schemes 3 and 4, principally developed to investigate the potential benefits from achieving economies of scale and fullest utilization of the costly geothermal supply, show installation costs increasing at a greater rate than the improvements in earnings, i.e. the savings from displacing natural gas. They remain valid candidates for the long term, though probably not before operational experience has been gained with one of the smaller capacity schemes.

Development, ownership, installation and operation of either of the two largest Schemes is a significant undertaking and a long-term commitment. A thorough demonstration of the concept, its implementation, operation and economic advantages will be necessary both from the City's perspective and as a means of inducing increasing numbers of private building owners to connect to the central heat network. Accelerated gas price increases in the future, in excess of the 2 percent real assumed for this study, could provide the economic inducement component. With the pressure from the various levels of government to use energy as a revenue vehicle, accelerated increases may not be unrealistic.

For geothermal heating in general and where a choice exists, this work tends to support a preference for using shallower, lower temperature resources in combination with heat pumps, rather than deeper formations. Project investment costs are less and only the much smaller well cost portion of this initial investment is exposed to the risk of well failure e.g. inadequate flow rate potential or temperature. Heat pumps provide flexibility to adjust to less favourable well temperatures and, to some extent, flows. Central heat pump plant driven by natural gas engines fitted with heat recovery offer further advantages, reducing operating costs and increasing system temperatures.

A flexible project strategy is preferable, one which can adjust to the resource conditions actually encountered during the drilling and testing stage. Though not appropriate to the restoration/spa development program aspects of this study, for prairie based geothermal heating projects in general, the better known more dependable Winnipeg/Deadwood formation could provide a valuable second choice or fall back option should well testing show first choice shallower formations to be inadequate. Though more costly initially, the lifetime economics of using this deep formation for large heat load projects can be better in which case project economics is not compromised.

9.2 Recommendations

This study has not looked at the direct and secondary economic benefits from Natatorium restoration and Spa development. These include the potential benefits from enhanced tourism and employment. It has indicated that the favourable economics of Schemes 1 and 2 can provide a partial subsidy to the restoration/spa development program. It is recommended that Schemes 1 and 2 be pursued in parallel with the program.

Concerning the poor state of the Natatorium heating system, it can be expected that the time frame for bringing a geothermal project to fruition will be at least two years away. The replacement for the present boiler and steam system in the Natatorium and upgrading of the indoor pool cannot be delayed indefinitely. The heating system replacement should ideally be hydronic with consideration given to sizing and routing the piping to sensibly minimize the cost of adapting later to a cascade philosophy. Unless, or until such time as, the restoration/spa development program is committed, additonal investment in the replacement heating system to make provision for future adaptation should be kept to fairly minimal levels.

The immediate course of action for the City is to continue to pursue enquires regarding the sources and possible levels of financial assistance for all aspects of the proposed development. At the same time project impacts and benefits need researching, including an appraisal of the improved amenity value to the community based on the recreational and therapeutic needs of the various age groups and demographic growth projections for the City.

Other recommendations include undertaking preliminary engineering of Schemes 1 and 2 to firm up design, performance and cost criteria. For Scheme 2 in particular, the specifics of retrofitting High Park, Victoria Towers and the Racon office building will need to be more fully engineered and costed, this to be followed by preliminary discussions with all parties to assess the level of interest, possible commitment and necessary inducements. Connection of the Racon building might be abandoned if an impediment to the City's development program.

The impact of alternatively disposing relatively small brine flows (to 15 m^3/h) to the sewer should be explored further. The effect on capital requirements for the Base Scheme and Scheme 1 is profound.

REFERENCES

Acres, 1983. Low Temperature Geothermal Energy Applications, National Research Council

Acres, 1984. Survey of Geothermal Energy in the Maritime Provinces, National Research Council

Acres, 1984 a. Regulatory and Commercial Aspects of Geothermal Energy Development.

Carson, C.C. and Lin, Y.T., 1981. Geothermal Well Costs and Their Sensitivities to Changes in Drilling and Completion Operations. In Proceedings of the International Conference on Geothermal Drilling and Completion Technology, Alburquerque, New Mexico, Jan. 21-23, 1981.

Department of Mineral Resources, Province of Saskatchewan - Well files.

Dick, D.D., 1983 - "General Planning and Preparation for the Drilling of a Shallow Geothermal Well". Workshop on Shallow Geothermal Wells: Geothermal Resource Council, Reno, Nevada.

Francis, D.R., 1956. Jurassic Stratigraphy of the Williston Basin area, Dept. of Mineral Resources, Province of Saskatchewan, Rept. No. 18.

Fuzesy, L.M. 1983. Correlation and Subcrops of the Mississippian Stata in Southeastern and south-central Saskatchewan. Saskatchewan Energy and Mines, Report 51.

Fyson, W.K., 1961. Deadwood and Winnipeg Stratigraphy in South-Western Saskatchewan, Dept. of Mineral Resources, Province of Saskatchewan, Report No. 64.

Gross, J.T., 1983. "A Case History" in Workshop on Shallow Geothermal Wells: Geothermal Resource Council, Reno, Nevada.

Jessop, A.M. and Vigrass, L.W. 1984, The Regina Experiment - Thermal Aspects.

Kent, D.M., 1974. A Stratigraphic and Sedimentologic Analysis of the Mississippian Madison Formation; Department of Mineral Resources, Province of Saskatchewan, Rept. No. 141.

McLean, D.D., 1960. Deadwood and Winnipeg Stratigraphy in East Central Saskatchewan, Dept. of Mineral Resources, Province of Saskatchewan, Rept. No. 147.

Nichols, R.A.H., 1970. The Petrology and Economic Geology of the Upper Devonian Birdbear Formation in Southeastern Saskatchewan. Department of Mineral Resources, Province of Saskatchewan, Report No. 125.

REFERENCES

(continued)

Patterson, D.F., 1975. Computer Plotted Isopach and Structure Maps of the Lower Paleozoic Formations in Saskatchewan, Dept. of Mineral Resources, Province of Saskatchewan.

Paterson, D.F., 1971. The Stratigraphy of the Winnipeg Formation (Ordivician) of Saskatchewan, Dept. of Mineral Resources, Province of Saskatchewan, Rept. No. 140.

Ruse, D., 1978. Compilation of Industry-Derived Data on Formation Fluid and Reservoir Characteristics in the Regina Area, Vigrass et.al. 1978., Earth Physics Branch Open File 78.4

Simpson, F. and Dennison E.G., 1975. Subsurface Waste Disposal Potential for Saskatchewan, Department of Mineral Resources, Province of Saskatchewan.

Sproule Associates Ltd., 1983. "Report on Study of the Feasibility of Geothermal Reservoir Mapping in Deep Sedimentary Basins using Existing Data." Earth Physics Br., Open file 83-57.

Sproule Associates Ltd., 1977. "Report on Study of Geothermal Resources in Western Canadian Sedimentary Basins from Existing Data, Phase Two." Earth Physics Br., Open file 77-14.

Vigrass, L.W., 1979. "Final Well Report, University of Regina 3-8-17-19 (w.2nd.Mer.) Saskatchewan". Earth Physics Br. Open file 79-9.

Vigrass, L.W. and Jessop, A.M. 1984, The Regina Experiment - Geological and Hydrological Aspects.

Vigrass, L.W., Kent, D.M. and Leibel, R.J., 1978. "Low-Grade Geothermal Project, Geological Feasibility Study, Regina - Moose Jaw Area, Saskatchewan." Earth Physics Br. Open file 78-4.

Walker, C.T., 1957. Correlations at Middle Devonian Rocks in Western Saskatchewan, Department of Mineral Resources, Province of Saskatchewan, Report no. 25.

APPENDIX A - CANDIDATE DATA SHEETS

List of Candidate Data Sheets

#1 - Natatorium & Outdoor Pool
#2 - YMCA/YWCA
#3 - Library
#4 - Museum
#5 - High Park Towers
#6 - Victoria Towers
#7 - City Hall/Police Station
#8 - Temple Towers
#9 - Cultural Centre*
#10 - River Street Apartments
#11 - Office & Retail Tower, Racon Ltd.
#12 - Harwood Inn
#13 - Harwood Complex (proposed)*
#14 - Grant Hall Inn*
#15 - Langdon Towers*
#16 - CPR Station
#17 - Union Hospital

* Not included

CANDIDATE #1
NATATORIUM & OUTDOOR POOL

1. Approximate Floor Area: Main Floor 1,115 m^2
Basement 186 m^2

2. Heating Equipment: 100 kPa (15 psig) steam boiler, 2.8 GJ/h

2 outdoor pool heaters, each 2.2 GJ/h.

3. Heating System: Steam distribution to radiators, 25,500 m^3/h gas fired ventilation unit

4. Domestic Water Heating: Steam convertor

5. Occupancy: 12 h/day

6. Special Equipment: Indoor pool 50 ft X 75 ft,
Outdoor pool 50 m x 25 m

7. Gas Consumption (1983):

		(1000m^3)
(1)	January	37
(2)	February	30
(3)	March	31
(4)	April	24
(5)	May	22
(6)	June	44
(7)	July	29
(8)	August	37
(9)	September	17
(10)	October	25
(11)	November	28
(12)	December	38
	TOTAL	362

8. Heating Plant Condition:

Building heating is presently by low pressure steam boiler operating under 10 psig.

Steam is distributed to free standing radiators and unit heaters.

Heating of ventilation air is accomplished with a gas fired make-up air unit that experiences recurring problems with frost build up in winter.

Boiler has developed a crack and is due for replacement.

Local regulations require that certified operator be in attendance at steam heating plant (minimum attendance is once every 12 hours).

Ductwork in the pool area is of galvanized steel, rather than aluminum which is preferred.

Heating system operates 24 h/day at constant temperature.

Natatorium Geothermal Retrofit Potential

1. Convert to conventional hydronic system from existing steam system.

2. Ventilation unit to be left at present rate of 2,500 l/s maximum flow, converting from gas to hydronic with addition to preheat and reheat coils. Air requirement at -35°C is 1,500 l/s to maintain 50% RH. This constitutes a load of 0.4 GJ/h with 28°C discharge. Transferring the perimeter load of 0.15 GJ/h to ventilation increases required discharge temperature to 44°C. Note, total peak winter load decreased due to reduced ventilation rate.

3. Domestic hot water load represents showers and pool heating.

   Shower water to be generated at 45°C and up with instantaneous heaters: estimated daily rate, 2,000 litres; peak load, 0.23 GJ/h.

   Pool evaporative heat loss from surface at 28°C water and air temperature, and 50% RH is estimated at 0.3 GJ/h.

Indoor Pool

Heat loss from pool is mainly due to the evaporation from water surface.

Conventional standards call for re-circulating pool water at a rate equivalent to a complete change every 4 to 6 hours. Originally, Natatorium pool with brine supply provided a once-through flow rate equivalent to one change every 2 days.

Outdoor Pool

Enclosing the outdoor pool for winter operation is under consideration. A re-established geothermal supply would meet or assist with the summer heating load including both bulk heating and fresh water make-up duties. (Evaporative heat loss at a water temperature of 10°C higher than air temperature is 1.5 GJ/h.)

CANDIDATE #2
YMCA - YWCA

1. Area: 2 flrs. at 12,000 sq. ft. each

2. Heating Equipment: Steam at low pressure, 2 GJ/h

3. Heating System: Steam convectors

4. Domestic Water Heating: Steam converter

5. Occupancy: 1000 active membership

6. Special Equipment: Steam room

7. Gas Consumption (1983): (1000^3)

(1)	January	24
(2)	February	15
(3)	March	10
(4)	April	12
(5)	May	7
(6)	June	4
(7)	July	4
(8)	August	3
(9)	September	3
(10)	October	9
(11)	November	14
(12)	December (1983)	17
	TOTAL	122

8. Heating Plant Condition: Plant is 10 years old, annual pipe replacement cost approx. $3,000

9. Proposed Changes: None known

10. Comments: YMCA rents the building from the City and operates the swimming program at both indoor and outdoor pools. Heating plant maintenance has been limited in past due to lack of funding. Condensate return system shows signs of corrosion. Valves do not have a close shut-off. Increased maintenance costs are due to work not done in past years.

    Boiler has substantial life left.

    Steam is used for building heating, for domestic hot water and for steam rooms.

12. Geothermal Retrofit Potential: Building shows promise for geothermal system for following reasons:

    1. Large ventilation rate required for gym and high domestic water use both assisting to lower CH system return temperature.

2. Long hours of operation.

3. Proximity to Natatorium.

4. Municipal ownership.

Existing heating convectors and boilers could be changed to conventional hydronic system. Ventilation system would be equipped with a new hydronic heating coil selected for high temperature drop.

CANDIDATE #3
LIBRARY

1. Area: 930 m^2

2. Heating Equipment: steam boiler, 1.7 GJ/h

3. Heating System: steam radiators

4. Domestic Water Heating: -

5. Occupancy: -

6. Special Equipment: -

7. Gas Consumption (1983): ($1000m^3$)

(1)	January	5.2
(2)	February	3.2
(3)	March	3.5
(4)	April	2.0
(5)	May	.3
(6)	June	.1
(7)	July	.1
(8)	August	.1
(9)	September	1.8
(10)	October	(2.8) allowance
(11)	November	(4.0) allowance
(12)	December	7.7
	TOTAL	30.8

8. Heating Plant Condition: Plant is due for replacement as it has reached the limit of its expected life.

9. Proposed Changes:

10. Comments: Building is of heritage value. New ventilation system may have to conform to restrictions on internal appearance of the building. Future use as a museum is possible.

    It may be considered appropriate to retain existing convectors to preserve building authenticity.

11. Geothermal Retrofit Potential

    1. Relatively close to Natatorium and pipework can be layed in landscaped area without paving.

    2. Load demand is limited.

3. Discussion with museum personnel assigned to take over the operation of this building shows a strong preference for installation of a central HVAC system more suited to museum needs regarding proper humidity and temperature control.

   There is some reluctance to supply the museum with a steam or water heating distribution system in exhibit areas as this poses a potential threat of leaks and damage to the collection.

CANDIDATE #4
ART MUSEUM

1. Area: 930 m^2 total of 2 floors

2. Heating Equipment: Gas fired furnace 240 KJ/h output

3. Heating System: Forced Air

4. Domestic Water Heating: Gas fired.

5. Occupancy: -

6. Special Equipment: -

7. Gas Consumption (1983):

		$(1000\ m^3)$
(1)	January (1984)	3.1
(2)	February (1984)	4.3
(3)	March (1984)	4.0
(4)	April (1984)	3.3
(5)	May (1984)	1.3
(6)	June (1984)	.4
(7)	July (1984)	.1
(8)	August (1984)	.02
(9)	September (	2.9
(10)	October	2.8*Estimated
(11)	November	4.1*
(12)	December	7.9
	TOTAL	39.2

8. Heating Plant Condition: Installed in 1967. Humidification and outside air duct need upgrading to permit "free cooling".

9. Proposed Changes: -

10. Comments:

11. Geothermal Retrofit Potential

Heating & Ventilation System:

Existing gas fired furnace would be equipped with new outside air coils and reheat coils. Fans will be upgraded to compensate for larger pressure drop.

Furnace is rated at 240 MJ/h output which implies an airflow at normal conditions of 1,500 l/s total.

Expected outside air for winter ventilation would be limited to 10% for a load of 24 MJ/h.

From general examination of building, it appears that heating system capacity is abnormally low, probably in the order of 50% of expected capacity.

The records, annual gas consumption is extremely high for a heating plant of this size. With 300 MJ/h input, annual gas consumption of 39,000 m^3 is equivalent to almost 5,000 hrs of peak load operation which is not realistic. It is likely that gas metering equipment for this building is not correct.

A disparity in records also exists with the adjacent library building, which has been combined under common billing for some months in 1983/84.

CANDIDATE #5
HIGH PARK TOWERS

1.	Area:	Approx. 9,300 m^3
2.	Heating Equipment:	4.2 GJ/h Hydronic, gas fired boilers
3.	Heating System:	Conventional hydronic
4.	Domestic Water Heating:	1 GJ/h gas fired
5.	Occupancy:	150 Senior citizens apartment units.
6.	Special Equipment:	-

7. Gas Consumption:

			(1000 m^3)
(1)	January	(1984)	50
(2)	February	"	41
(3)	March	"	22
(4)	April	"	26
(5)	May	"	21
(6)	June	"	14
(7)	July	"	5
(8)	August	"	4
(9)	September	"	5
(10)	October	"	15
(11)	November	"	22
(12)	December	(1983)	26
	TOTAL		251

8. Heating Plant Condition: Building was constructed in 1980.

9. Geothermal Adaptation: Existing gas fired make-up air units are estimated to provide 100 l/s per apartment, for a total of 15,000 l/s. Existing gas burners will be replaced with a glycol coil.

CANDIDATE #6
VICTORIA TOWERS

1. Area: Approx. 9,300 m^3

2. Heating Equipment: 4.2 GJ/h Hydronic, gas fired boilers

3. Heating System: Conventional hydronic

4. Domestic Water Heating: 1 GJ/h gas fired

5. Occupancy: 151 Senior citizens apartment units

6. Special Equipment: -

7. Gas Consumption (1984):

		(1000 m^3)
(1)	January	56
(2)	February	38
(3)	March	30
(4)	April	33
(5)	May	23
(6)	June	12
(7)	July	5
(8)	August	2
(9)	September	3
(10)	October	17
(11)	November	30
(12)	December (1983)	12
	TOTAL	261

8. Heating Plant Condition: Building was built in 1982.

9. Geothermal Adaptation: Existing make-up air units are expected to provide 100 l/s per apartment, for a total of 15,000 l/s. Existing gas burners will be replaced with a glycol coil.

CANDIDATE #7
CITY HALL/POLICE STATION

1. Area: 2,800 m^2, 4 floors

2. Heating Equipment: L.P. steam boiler, 1.8 GJ/h

3. Heating System: Hot water radiation, no ventilation

4. Domestic Water Heating: Gas fired. 0.1 GJ/h

5. Occupancy: City hall office and police station staff

6. Special Equipment: -

7. Gas Consumption (1983):

		(1000 m^3)
(1)	January	17.0
(2)	February	12.0
(3)	March	11.0
(4)	April	8.0
(5)	May	0.7
(6)	June	0.4
(7)	July	0.4
(8)	August	0.4
(9)	September	3.0
(10)	October	8.0
(11)	November	11.0
(12)	December	27.0
	TOTAL	99.0

8. Heating Plant Condition: Good. Boiler retubed 1983

9. Proposed Changes: Building is being seriously considered for major renovation with boiler conversion to hot water. Police station will expand to new addition.

10. Geothermal Retrofit Potential:

Present heating system is a conventional hydronic and as such would be directly incorporated into geothermal/CH System.

Building requires a proper ventilation and air conditioning system that is expected to be installed as soon as renovation design is completed.

New Police Station will probably occupy a building addition to the present City Hall. If timing of construction is favourable, heating of a new addition could be matched to expected geothermal system at a marginal cost penalty over conventional heating systems.

CANDIDATE #8
TEMPLE TOWERS

1. Area: Approx. 5,800 m^3

2. Heating Equipment: 2.6 GJ/h Hydronic, gas fired boilers

3. Heating System: Conventional hydronic

4. Domestic Water Heating: 1 GJ/h gas fired

5. Occupancy: 93 Senior citizens apartment units

6. Special Equipment: -

		(1000 m^3)
(1)	January	44
(2)	February	41
(3)	March	27
(4)	April	29
(5)	May	21
(6)	June	12
(7)	July	4
(8)	August	1
(9)	September	1
(10)	October	11
(12)	December (1983)	33
	TOTAL	246

8. Heating Plant Condition: Building was constructed in 1974.

9. Geothermal Adaptation: Existing make-up air units are expected to provide 100 l/s per apartment, for a total of 9,000 l/s. Existing gas burners will be replaced with a glycol coil.

CANDIDATE #10
RIVER STREET APARTMENTS

1.	Area:	Approx. 2,900 m^2
2.	Heating Equipment:	1.3 GJ/h Hydronic, gas fired boilers
3.	Heating System:	Conventional hydronic
4.	Domestic Water Heating:	0.5 GJ/h gas fired
5.	Occupancy:	45 Senior citizens apartment units
6.	Special Equipment:	-

7. Gas Consumption (estimated) (1000 m^3)

(1)	January	15
(2)	February	12
(3)	March	7
(4)	April	8
(5)	May	6
(6)	June	4
(7)	July	2
(8)	August	1
(9)	September	2
(10)	October	4
(11)	November	7
(12)	December (1983)	8
	TOTAL	75

8. Heating Plant Condition: Building to be completed in 1985.

9. Geothermal Adaptation: Existing make-up air units are expected to provide 100 l/s per apartment, for a total of 4,500 l/s. Existing gas burners will be replaced with a glycol coil.

CANDIDATE #11
OFFICE & RETAIL TOWER, RACON LTD.

1. Area: 4,500 m^2, 5 floors

2. Heating Equipment: Hot water boilers, 4.8 GJ/h (est.)

3. Heating System: 83/93°C hydronic Wallfin

4. Domestic Water Heating: Gas (load negligible)

5. Occupancy: Offices 350 people, Retail 16,00 sq. ft.

6. Special Equipment: 48 cars below ground parking

7. Gas Consumption (estimated):

		(1000 m^3)
(1)	January	64
(2)	February	34
(3)	March	48
(4)	April	26
(5)	May	13
(6)	June	7
(7)	July	3
(8)	August	3
(9)	September	12
(10)	October	24
(11)	November	42
(12)	December	54
	TOTAL	350

Based on degree days

8. Heating Plant Condition: not applicable

9. Proposed Changes: not applicable

10. Comments:

11. Geothermal Opportunities;

Building construction is imminent, too late for incorporating geothermal heating design criteria in original design. Retrofit opportunities include: use of central ventiliation unit preheat coil;

CANDIDATE #12
HARWOOD INN

1.	Area:	Approx. 9,300 m^2
2.	Heating Equipment:	3 low pressure boilers, total 5.4 GJ/h
3.	Heating System:	Steam convectors and hot water fan coils
4.	Domestic Water Heating:	1.9 GJ/h gas fired
5.	Occupancy:	Mixture of hotel and residential
6.	Special Equipment:	0.15 GH/h Pool Heater-gas 50 MJ/h Whirlpool heater-electric
7.	Gas Consumption (1983):	(1000 m^3)

		(1000 m^3)
(1)	January	39
(2)	February	31
(3)	March	32
(4)	April	21
(5)	May	16
(6)	June	10
(7)	July	9
(8)	August	8
(9)	September	21
(10)	October	23
(11)	November	30
(12)	December	58
	TOTAL	298

8. Heating Plant Condition: Plant is old and requires substantial maintenance.

9. Proposed Changes:

10. Comments:

Complex is composed of number of independent heating plants constructed at different times.

Oldest part serves now as a residence and is heated with steam radiators.

New hotel rooms have air conditioning units in each room with a heating coil. Corridors and rooms are being overheated due to inadequate water flow control. Room units have individual outdoor air ducts. Windows are not sealed.

12. Geothermal Retrofit Potential: Existing steam system would be converted to hydronic. Ventilation system

requirements for this complex can be approximated as follows:

Coffee shop	1000 l/s
Tavern	3500 l/s
Pool area	1000 l/s
Corridors pressurization	3000 l/s
Restaurants	1000 l/s
Total	9500 l/s

Corresponding peak load capacity of a ventilation system is 1.9 GJ/h.

It is expected that new coils would have to be installed in existing gas fired ventilation units. In an old wing, a completely new corridor pressurization system would be needed as the area relies on natural ventilation.

CANDIDATE #16
CPR STATION

1. Area, Volume: 1,395 m^2 passenger terminal, 1,860 m^2 offices

2. Heating Equipment: Steam boiler

3. Heating System: Steam radiators

4. Domestic Water Heating:

5. Occupancy:

6. Special Equipment:

7. Gas Consumption (1983): (1000 m^3)

		(1000 m^3)
(1)	January	82
(2)	February	81
(3)	March	91
(4)	April	43
(5)	May	-
(6)	June	-
(7)	July	-
(8)	August	-
(9)	September	-
(10)	October	41 (estimated)
(11)	November	72 (estimated)
(12)	December	111
	TOTAL	633

8. Heating Plant Condition: Boiler replaced in 1980.

9. Proposed Changes: Proposed 465 m^2 new transportation centre to be used by the City, to include bus terminal facilities.

10. Comments: There is an indication that present plant operation is not efficient. Terminal area is fully heated but not utilized due to low traffic.

11. Geothermal Retrofit Potential:

    Office block radiation system would be converted to hydronic operation.

    Terminal and office building should, by today's standards, have a ventilation system of 12,000 l/s serving existing offices, telecommunications centre, locker rooms and training centre.

Existing high pressure steam in the building is also occasionally used to heat passenger trains, through direct coupling to the train heating systems.

Discussions between CPR and Via Rail seem to indicate that train steam heating system is under review and might not be used in the future.

Since the building does not have a ventilation system, most practical adaptation would be to pressurize the open terminal space with an outside air preheated with new make-up air unit and allow this tempered air to migrate into other areas.

Maintenance Facility

A new maintenance facility of 4,000 m^2 is being completed in 1985. The facility is equipped with gas fired infra red heaters that are not adaptable to hydronic type system. Gas fired ventilation systems of 40,000 l/s capacity can be expected that could easily be adapted to hydronic. Facility is located 250 m south west of Main Terminal and piping could be extended through unpaved yards.

CANDIDATE #17
UNION HOSPITAL

1. Area: 20,200 m^2 (patient area)

2. Heating Equipment: Central steam plant, 2-210 GJ/h boilers at 860 kPa (125 psig)

3. Heating System: Steam coils, hydronic radiation and induction units

4. Domestic Water Heating: Steam convertor, grey water laundry heat recovery

5. Occupancy:

6. Special Equipment: Steam sterilizers, heat recovery

7. Gas Consumption: 1983

		(1000 m^3)
(1)	January	136
(2)	February	120
(3)	March	122
(4)	April	102
(5)	May	96
(6)	June	78
(7)	July	83
(8)	August	64
(9)	September	71
(10)	October	90
(11)	November	118
(12)	December	198
	TOTAL	1,278

8. Heating Plant Condition: Plant was build in 1966 and is well maintained. Boiler exhaust employs waste heat recovery.

9. Proposed Changes:

10. Comments:
    - Boiler #2 is standby duty
    - Radiation system flow is 57m^3/h (2.6 GJ/h)
    - Induction system flow is 43 m^3/h (1.9 GJ/h)
    - Boiler #1 (7.5 GJ/h)
    - Old wing, 6,500 m^2 (4.75 GJ/h)
    - Hospital, 20,200 m^2 (14.5 GJ/h)
    - DHW, 3.8 GJ/h
    - Consumption data indicates plant efficiency below 50%

11. Geothermal Retrofit Potential:

    Distribution: New CH system piping would be installed in existing distribution network in the basement parallel to the steam mains.

Ventilation:	Steam preheat coils would be replaced with new glycol coils. New waste heat recovery system is reflected by 40% reduction in ventilation loads.
Heating:	Existing hydronic system would be directly connected to the geothermal network.
D.H.W.:	Contribution of recovery system is estimated at 10%.

APPENDIX B - CORROSION ANALYSIS & MATERIALS SELECTION

SOUTH SASKATCHEWAN GEOTHERMAL SYSTEMS:
WATER CHEMISTRY, CORROSION AND MATERIALS SELECTION

J. Postlethwaite,
Interprovincial Corrosion Consultants Ltd.

CONTENTS

March 1985

1. INTRODUCTION

Corrosion in the form of pitting, stress corrosion cracking, and hydrogen blistering is a major problem in the geothermal industry [Ref 1]. In liquid dominated systems such as the ones under discussion here, the hot water is often a brine with high chloride concentrations. Such brines can be very corrosive especially if they contain small amounts of dissolved hydrogen sulphide or oxygen. Hydrogen sulphide causes pitting [Ref 2] sulphide stress cracking (SSC) and hydrogen blistering [Ref 3]. Contamination of the brine with oxygen above ground by leakage through valve stems and at pumps during operation [Ref 1] and during shut down periods can lead to severe pitting corrosion [Ref 4]. Oxygen contamination in brines containing H_2S can result in drastic increases in corrosion rates by as much as two orders of magnitude [Ref 16]. The pH of these brines is usually on the acid side of neutrality.

The acidic pH relates to the partial pressure of dissolved carbon dioxide. A release of the pressure on the liquid at the wellhead can cause a rise in pH by as much as two units to less corrosive values. Unfortunately this rise in pH can cause the deposition of calcium carbonate scale on the walls of the pipes and heat exchangers and a liquid dominated system used for heating should be maintained under pressure and not flashed [Ref 1].

This corrosion engineering evaluation deals with the water chemistry; the impact of this chemistry on the corrosion of candidate construction materials; and the provisional selection of suitable materials of construction. Consideration is given to water taken from various formations within the three gross lithological divisions [Ref 5]: an Upper Clastic Unit (1000m) of shale and sandstone with minor limestone and anhydrite in the lower part; a Carbonate Evaporite Unit (1000m) of dolomite, limestone, salt (halite and potassium salts) and anhydride; and a Basal Clastic Unit (200m) of sandstone and shale.

2. WATER CHEMISTRY

The specific formations involved are listed below; along with the projected temperature and total dissolved solids for the Moose Jaw area which is one potential site for a future geothermal project.

Table 1. Water Sources

	Formation	Depth/m	Temp/°C	TDS/ppm
Upper Clastic	Mannville	855	35	10,000
	Gravelbourg-Sandstone	1,009	38	15,000
Carbonate Evaporite	Souris Valley	1,115	42	20,000
	Birdbear	1,320	45	35,000
Lower Clastic	Winnipeg/Deadwood	2,100	65	180,000

The projected analyses of these waters, Table 2, were prepared using the analyses assembled by Vigrass [Ref 6] taking into account the fact that,

> 'the waters from below the 650 m depth are sodium chloride waters of the Williston Basin type. Total dissolved solids are said to be determined largely by the sodium and chloride content, and the remaining ionic composition (calcium, magnesium, bicarbonate, sulphate) is remarkably constant.' [Ref 5].

The latter statement is supported by the accompanying Stiff diagrams [Fig 1] of subsurface water in the Regina-Moose Jaw area [Ref 5]. It should be emphasised that the analyses are for use only as a guideline for identifying potential corrosion problems and for preliminary materials selection purposes.

The major uncertainties in the projected water compositions are:

i) the dissolved H_2S content of the brines from the formations above the Winnipeg/Deadwood

ii) the dissolved oxygen content

iii) the pH

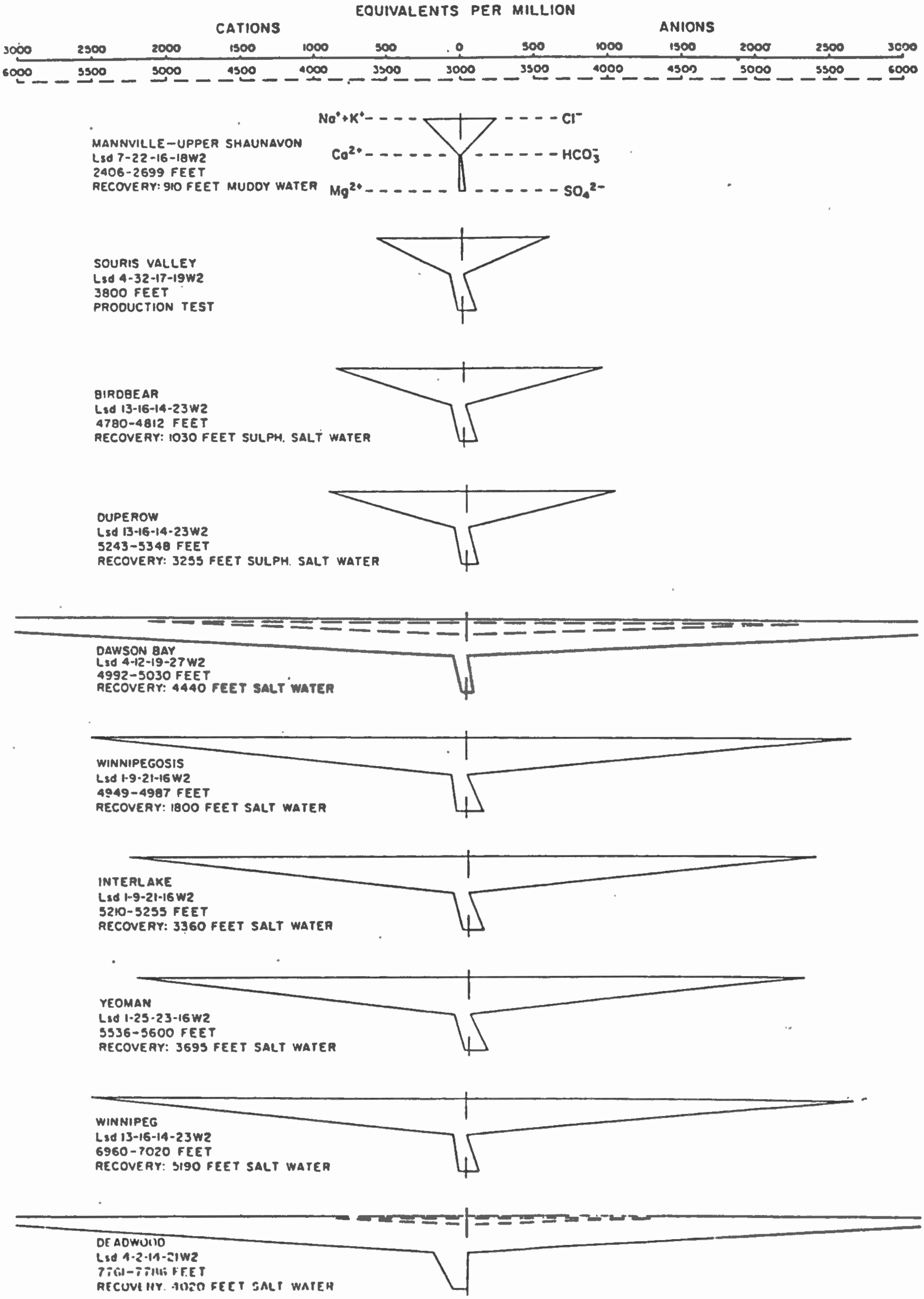


Fig 1. **Representative Stiff diagrams of subsurface waters in the Regina - Moose Jaw area.** [Ref 5]

Table 2. Projected Water Analyses - Moose Jaw.

FORMATION	TDS/ppm	CATIONS/ppm			ANIONS/ppm			H_2S ppm	O_2 ppm	pH
		$Na^+ + K^+$	Ca^{++}	Mg^{++}	Cl^-	HCO_3^-	$SO_4^=$			
MANNVILLE	10,000	2,927	401	255	4,806	122	1,488	NR*	NR	5.5-6.5
GRAVELBOURG	15,000	2,933	1,684	610	6,792	244	2,785	NR	NR	5.5-6.5
SOURIS VALLEY	20,000	4,600	1,805	547	8,722	244	4,083	NR	NR	5.5-6.5
BIRDBEAR	35,000	10,189	2,005	608	17,872	244	4,083	many reported sulphurous		5.5-6.5
WINNIPEG/ DEADWOOD	180,000	66,800	1,940	360	105,509	400	4,100	24	1.0	5.3**

* None reported

** This is an accurate well head value of the unflashed fluid. The fluid produced ca 2% gas when flashed [Ref 7]. Other values are corrected laboratory values for flashed fluid.

The dissolved H_2S content in the Winnipeg/Deadwood water was determined on-site at the Regina well [Ref 7] and the value is considered reliable.

The waters from the Carbonate-Evaporite Unit may all contain some H_2S since this Unit contains little iron which converts H_2S to pyrites, as is the case in the Upper-Clastic Unit. Many of the waters from the Birdbear formation have been reported [Ref 6] to be sulphurous indicating the presence of H_2S. The Souris Valley, which is at the top of the carbonate-evaporite zone, is the least likely of the formations in this zone to contain H_2S and indeed there are no reports [Ref 6] of waters from this formation containing H_2S. However the presence of traces of H_2S in these waters must be regarded as a possibility. The Gravelbourg and Mannville waters are unlikely to contain H_2S since these formations are in the Upper-Clastic unit which contains iron.

The reported presence of 0.9 - 1.2 ppm of dissolved oxygen [Ref 7] in the water from the Winnipeg/Deadwood formation is a contentious issue. Given sufficient time to react oxygen and hydrogen sulphide cannot co-exist in a brine and it is commonly assumed that freshly produced brines containing H_2S are free of O_2 [Ref 1,3,8]. They may of course be contaminated above ground by inleakage at valve stems and pumps. The reaction between dissolved O_2 and H_2S is slow [Ref 8] and it is conceivable that the co-existence could be attributed to waters being produced from different formations which were vertically separated by permeable or semi-permeable barriers [Ref 7]. The presence of oxygen at upper levels is more likely where there is little chance of H_2S as for example in the Mannville and Gravelbourg formations. Measurements of dissolved oxygen in these waters have not been reported. Syrett et al did consider that the Nowlin No 1 Heber, California [Ref 9] wellhead brine may naturally contain some oxygen as well as H_2S on the basis of the non-condensable gas composition, but did go on to suggest contamination as a source of this gas. Other geothermal waters contain dissolved oxygen [Ref 1] but this either occurs in the absence of H_2S or there are uncertainties about whether the oxygen relates to contamination at the well head.

The pH of the Regina water [Ref 7] from the Winnipeg/Deadwood formation was 5.3 prior to flashing after which it rose to 6.6. Such a rise is expected when brines containing carbon dioxide species are flashed. The projected values in Table 2 are the laboratory values with an approximate correction to allow for this change.

3. POTENTIAL CORROSION AND SCALING BEHAVIOUR

3.1 Corrosion

Hot brines are corrosive. The corrosion rate of carbon steel increases with a rise in the chloride concentration and temperature [Ref 1]. Such laboratory data should be treated with caution as it often does not permit sufficient time for protective scales to develop which eventually slow down the early rapid corrosion rate. And much of the data used to discuss brine corrosion is laboratory data. The present brines increase in chlorinity and temperature with increasing well depth and it can be assumed that higher uniform corrosion rates of carbon steel would obtain the deeper the well.

There is a rapid rise in the corrosion rate as the pH is reduced below 5 in solutions containing CO_2 [Ref 10]. The present brines are at the worst just above this value at 5.3. The presence of the CO_2 will undoubtably increase the uniform corrosion rate, but not to an unacceptable value at the temperatures involved in the present study.

The presence of H_2S will increase the uniform corrosion rate but more importantly may give rise to severe pitting, [Ref 1,2,3], sulphide-stress corrosion cracking (SSC) [Ref 1,3] and hydrogen blistering [Ref 1,3]. The concentration of H_2S required to crack high strength carbon steels is as low as 0.1 ppm, with a less chance of attack at temperatures above 66°C [Ref 3] which is coincidently the high temperature expected in the present waters. Fortunately sulphide stress cracking and hydrogen blistering can be controlled by the use of low strength metallurgically clean and void free steel [Ref 1].

The combination of hydrogen sulphide and carbon dioxide is more aggressive than hydrogen sulphide alone in terms of pitting corrosion and the presence of even minute quantities of oxygen have been stated to be disastrous [Ref 3].

The presence of oxygen would lead to severe pitting of carbon steel, stainless steels and other alloys by the produced brine [Ref 1]. Conventional wisdom in the oil industry is that 'water produced with oil, even when fresh, seldom contains dissolved oxygen' and 'that oxygen corrosion found in downhole equipment is usually caused by careless operating techniques or faulty equipment' [Ref 3]. Similarly in the geothermal industry, oxygen contamination by inleakage is considered to be the source of the severe oxygen corrosion that sometimes occurs [Ref 1,4]. Oxygen corrosion occurs in secondary oil recovery and cannot normally economically controlled by the inhibitors usually applied in primary oil production [Ref 11]. Inorganic inhibitors used in aerated water are too expensive and the concentrations of filming amine are similarly uneconomic and internally coated steel pipe is usually required to handle these brines. Oil of course is a high value product and as discussed later any inhibition with geothermal brines is much more relatively expensive.

The other constituent of the brine which may cause a corrosion problem is sulphate. Sulphate ions are less aggressive than chloride ions and by themselves do not constitute a problem. However in anaerobic conditions they can be reduced to H_2S by sulphate reducing bacteria which process leads to rapid pitting corrosion of steel. This for example is a common form of corrosion of buried water mains in heavy clay soil containing gypsum, and is also a problem in oil wells [Ref 12].

The waters from the Mannville and Gravelbourg formations, which are in the Upper Clastic Unit, would be the least corrosive. They have the lowest temperatures and salinities and are unlikely to contain any H_2S.

The water from the Souris Valley formation is predicted to be the next least corrosive with a somewhat higher temperature and salinity and no reported H_2S. As mentioned above however the presence of H_2S cannot be entirely discounted in water from this formation.

The water from the Birdbear formation is likely to contain H_2S and will be more corrosive. The most corrosive water will be that from the Winnipeg/ Deadwood formation, which contains H_2S as well as having the highest temperature and salinity.

3.2 Scaling

Scaling could interfere with the flow of the fluid and the heat transfer in the plate heat exchanger. The scales that could form on the pipe and other equipment are;

calcium carbonate,
calcium sulphate or
silica.

The solubility of calcium carbonate decreases with a rise in pH and decreases with a rise in temperature. Thus providing that the geothermal fluid is maintained under pressure and the pH not allowed to rise calcium carbonate scaling is unlikely. Calcium carbonate scaling is a problem in heat exchangers where the water is a coolant and undergoes a rise in temperature and not a drop as in this case.

Calcium sulphate has a higher solubility than calcium carbonate and similarly the solubility increases as the temperature decreases and calcium sulphate scaling is unlikely with the present brines. The solubility of calcium sulphate is not sensitive to pH changes in the pH range of geothermal fluids [Ref 1].

The solubility of silica increases with temperature, however it is considered that silica scaling should not be a major problem for resources with reservoir temperatures less than approximately 150°C provided no flashing occurs [Ref 1].

4. MATERIALS SELECTION

This provisional materials selection takes into account; the previous operating experience of geothermal systems [Ref 1]; the experience of the oil industry in handling brines during primary and secondary production [Ref 3,11,12] and brine disposal by reinjection [Ref 8].

Mechanical and thermal properties and the cost of corrosion resistant materials have been considered along with the projected costs of corrosion protection by inhibition and cathodic protection.

The geothermal system components considered are:-

- production well
- production pump
- piping, pre and post injection pump
- heat exchanger
- reinjection pump
- injection well

4.1 Production Well

Sour service API - J55 or similar low strength casing which is resistant to SSC is the recommended metallic material of construction for the production well casing. This mild steel has performed satisfactorily in sour brine geothermal service and is included in the NACE Standard for SSC resistant metallic material for oil field equipment [Ref 13] for tubing and casing for all temperatures. API J55 178 mm 8 mm thick casing would cost approximately $36.37/m FOB Moose Jaw.

Protection of the outside of the casing would require the application of an impressed cathodic protection system similar to that used for many oil well casings [Ref 3]. The ground around a well is sometimes saturated with brine left over from the initial drilling operations and the resulting soil may be very corrosive. Such a system has been installed at the U. of R. well [Ref 14]. Geothermal well casings at Wairakei have suffered severe external corrosion near the surface where they have been in contact with aerated ground water [Ref 1]. Multiple casings with careful cementing were used to solve this problem. Such multiple casings would not be required if an external cathodic protection system were in place. The cost of the cathodic protection system would be $15 - 25,000. This system could protect both wells.

The inside of the casing could be inhibited with weighted filming amine inhibitors [Ref 12]. The chemicals for an intermittent treatment on a monthly basis would cost $50 - 100/month depending on the well depth and casing size.

An alternative to using a metallic well casing would be to use fibre-glass-reinforced plastic (FRP) casing. One geothermal well in France with water temperatures of 60°C is a known to have such casing [Ref 15]. One problem with FRP casing is making sufficiently strong joints to join the sections together when casing deep wells. One standard FRP pipe system is said to be good for 1,000 m. Casing 203 mm OD, 11 mm thick sufficient to withstand the external collapse pressure during cementing would cost $150/m for the material. The cementing would have to be done in 300 m stages to avoid collapse. At the present time there does not seem to be a wealth of knowledge regarding the use of FRP well casing in the oil-industry and the recent materials selection guidelines for geothermal systems [Ref 1] does not include a single case of its use for casing. Extra casing with steel near the surface would protect the FRP from mechanical abuse. FRP is a brittle material. FRP with a vinyl ester resin would probably have the best combination of corrosion resistance and mechanical properties.

The FRP would be the most suitable from the corrosion standpoint for the deepest well where the most H_2S will be found. However the technology for wells deeper than 1,000 m is not well developed and FRP casing is not recommended for this project.

Epoxy coatings could be applied to the inside of the steel casing. However the life of these brittle coatings is doubtful. They could be damaged by rough handling of the casings during installation. The cost of such coated steel would be approximately 1.3 the cost of plain steel tube. These coatings are liable to failure by blistering and peeling [Ref 1].

4.2 Production Pump

This is a key component of the system and should be constructed from alloys likely to give good performance at a reasonable cost. Titanium and high nickel alloys (such as Hastelloy C 276 and Inconel 625) would perform very well but could triple the cost of a pump using more conventional materials. The cost of one particular pump which would handle 150 m^3/h, with a total dynamic head of 150 m would be in the $60 - 70,000 price range. This pump is used extensively in the oil industry and has a carbon steel housing, with external Monel flame spray; Ni Resist impellers and diffusers and a Monel shaft. Such a pump has been used to handle oil containing brine, SG = 1.07, with a high H_2S and CO_2 gas content, at 82°C.

The NACE Standard RP-04-75 [Ref 19] which deals with the selection of metallic materials to be used in all phases of water handling for injection into oil bearing formations is relevant. This standard includes lists of materials for both vertical submersible pumps (downhole motor driven) and vertical turbine pumps (shaft driven). Materials are listed for four environments aerated and non-aerated with and without H_2S. The selections are very similar for all environments. The original standard should be consulted for complete details, including alloy compositions.

The materials listed for all four environments for the vertical submersible pumps and for non-aerated environments with and without H_2S for the vertical turbine pumps are shown in Table 3.

Table 3. Production Pump Materials.

	Vertical Submersible	Vertical Turbine (Shaft driven)	
	All environments	non-aerated without H_2S	non-aerated with H_2S
Bowl, impeller stationary and rotating rings	316 stainless, $NiAl_{w\ \&\ ca}$ $AlBr_{ca}$ NiRe Hard Co,Hard Ni/316	316,316L $AlBr_{ca}$ 63Br NiRe	316,316L $AlBr_{ca}$
Shaft	316,K500	400M,K500,316	400M,K500,316
Bearings	C BrgBr, NiVBr	C NiVBr	C NiVBr
Cable Sheathing	NM		
Motor; case and protector	Fe_c		
Line Shaft Bushing	-	NM	NM
Head	-	Cl_cFe_c	Cl_cFe_c
Column	-	Fe_{2c}, Fe_c	Fe_{2c}, Fe_c

The materials having the greatest expected life are placed on the first line, the next longest life expectancy on the second line etc.

Potential corrosion problems with the alloys in Table 3 are that: 316 is subject to pitting and SCC cracking in chloride solution in the presence of small amounts of oxygen which would contaminate the brine during operation or shutdown; copper alloys are susceptible to severe corrosion when traces of sulphide are present [Ref 1] and should be avoided. $NiAl_{ca}$ and $NiAl_{w}$ are 80-81% copper alloys. $AlBr_{ca}$ is a 85% copper alloy, Ni Resist does not contain sufficient Cr to prevent pitting if oxygen enters the system. However as mentioned above these materials are used extensively in the oil industry where corrosive brines containing H_2S and CO_2 are handled and the use of a pump with standard materials is recommended for the present project. Materials recommended by the NACE Standard these should be chosen in consultation with the pump manufacturer when the pump has been designed.

Bimetallic corrosion effects should be carefully studied. Sometimes however a base metal such as iron can cathodically protect stainless steel for example and permit its use as pump and valve trim with a steel body [Ref 17].

The recommendation at this stage of the project is to use 316 stainless steel for the bowl and impellers and Monel or 316 for the shaft; and C for the bearings, with the objective of avoiding copper alloys which can cause problems when the H_2S concentration in geothermal fluids is as low as 7 ppb [Ref 1]. It has been suggested that virtually all geothermal fluids contain sufficient H_2S to damage copper alloys [Ref 1].

Stainless steel components should be drained and rinsed during shut down periods to avoid the initiation of localized corrosion. Stagnant conditions are to be avoided [Ref 1].

4.3 Pre-Injection Pump Line

FRP pipe is recommended for this line which is expected to have a pressure of 0.7 M Pa.

Many geothermal lines have suffered severe corrosion, especially when oxygen has infiltrated into the system [Ref 1]. The cost of inhibiting carbon steel lines on a continuous basis is expensive. One m^3 of brine cooled from 65 to 33°C liberates heat equivalent to 47¢ worth of natural gas. The cost of inhibiting this water to the level normally used in the oil-industry (ca. 20 - 30 ppm) would be 8 - 12 ¢ or for a $100m^3/h$ system, 70,080 to $105,129/annum, which would be approximately equal to the initial capital cost of the line for this project. Additional costs would be associated with the external coating and cathodic protection of a steel line.

The NACE Standard which applies to the selection of metallic materials to be used in water handling for injection into oil bearing formations is relevant. Gathering and injection lines for water which is non-aerated and aerated with and without H_2S are all recommended to be either internally coated steel or non-metallic. Mild steel line internally coated with epoxy and externally coated for protection against soil corrosion by yellow jacket or tape insulation costs approximately 1.5 - 1.8 plain mild steel when laid. There are problems with epoxy lined pipe if it is roughly handled during installation and it is doubtful whether a 20 - 30 year life could be assumed. Pitting corrosion at breaks in the coating could be a problem.

FRP pipe is being used in one geothermal project [Ref 1] where a line failed due to oxygen corrosion. Otherwise little data is available from geothermal experience. However FRP pipe was being successfully used for concentrated brines at 80°C in 1965 [Ref 18] in a caustic-chlorine plant and is presently being used in the oil fields to handle corrosive brines and FRP vinyl ester pipe is recommemded for this line. The cost would be approximately 1.2 the cost of mild steel pipe laid. Such pipe is very light and can be laid by a two man crew. The pipe can be glued or ball and spiggot joints can be used. The pipe could be insulated with styrofoam pipe insulation. One problem that has been encountered with buried FRP pipe in the oil inustry is stone breaks due to ground movement in the spring. The pipe should be laid on a 6" sand bed and covered by sand. ASTM A53 steel pipe could be used to join the buried pipe to the well head. The steel pipe would be much more robust and less liable to accidental damage. This short section of steel pipe could be internally coated with epoxy.

4.4 Plate Heat Exchanger

Plate heat exchangers have several advantages over the more standard shell and tube exchangers for use in geothermal applications. They are readily cleaned; the stamped plates are thin and can be made of expensive materials which may be required for corrosion resistance; and approach temperatures are smaller. The latter factor is important in low temperature geothermal applications.

Titanium preferably ASTM Grade 12 is preferred for this equipment. It has very good resistance to corrosion in hot brines aerated to deaerated as evidenced by the fact that it is one of the major contenders for the disposal of nuclear waste by deep burial, where ground water containing NaCl might occur. The ASTM Grade 12 has a better resistance to pitting and crevice corrosion in brine than commercially pure titanium [Ref 1]. In various field tests at geothermal sites and laboratory tests titanium has proven to have outstanding corrosion resistance. It is a strong, ductile metal and highly suitable for plate heat exchanger manufacture.

It is important not to have pitting or other localized corrosion in the heat exchanger. In-leakage of cooling water could cause severe oxygen corrosion of the injection well. Out-leakage of the brine containing the H_2S from the Winnipeg/Deadwood formation would pose an immediate health hazard [Ref 7].

4.5 Injection-Pump

The NACE Standard RP-04-75 [Ref 19] lists suitable materials for the construction of injection-pumps for aerated and non-aerated waters, with and without H_2S.

A multistage centrifugal pump, similar to that used by the potash industry in Saskatchewan for brine disposal, would be used. Positive displacement pumps have insufficient capacity for the flowrates under consideration.

It is recommended that materials for the present project be chosen from: casing, 316, 316L stainless steel; impellers, 316, 316L stainless steel; stationary rings, 316, 316L stainless steel; rotating rings, tungsten carbide, Hard Co, Hard Ni; shaft sleeves, tungsten carbide, Hard Co, Hard Ni; shaft, Monel K500, 17-4 PH stainless steel (wrought) or ACI Grade CB - 7 Cu (cast), 316 stainless steel; mechanical seal (316 + NonZnBr + C + WC - complete unit). The materials for the shaft are in order of ranking. These materials are recommended by the NACE standard for all the above mentioned environments. The NACE Standard should be consulted for full details.

The precautions relating to the use of stainless steel components mentioned earlier would also apply to this pump.

4.6 Post Injection-Pump Piping

The pressure on the line after the injection pump may be 2.4-4.0 M Pa. FRP pipe can be made to withstand this pressure, however it is considered that lined steel pipe would be preferable for this service. This line should be kept as short as possible. Some of the alternatives are: epoxy lined steel pipe - which is used widely in the oil industry for handling brines; FRP lined steel pipe; polyethylene lined steel pipe; PVC lined steel pipe.

The recommendation is to use mild steel pipe with a FRP lining. The couplings would contain corrosion barrier rings. The cost of the lining is approximately \$24.75/m for a 152 mm pipe and \$15.68/m for a 102 mm pipe.

4.7 Injection Well

It is assumed that the injection well will consist of a tube run into a casing and the tubing casing annulus closed off with a packer. The annulus can be filled with inhibited water to prevent internal casing corrosion.

API J55 or similar [Ref 1,13] would be suitable for the casing.

The tubing could be internally protected by: an epoxy coating; a cemented FRP lining; a cemented PVC lining. One such system for example at Midale, Saskatchewan is using PVC lined tube to a depth of 1,500 m. An FRP lined tube is recommended.

As discussed earlier the continuous addition of inhibitors to the produced water of a geothermal system would not be economical. This has also been pointed out elsewhere [Ref 1]. Oxygen scavengers, in particular sodium sulphite have been used in Iceland, but again continuous treatment may be uneconomic, and geothermal fluid pretreatment and post treatment if required are presently undefined [Ref 1].

4.8 Effect of Water Source on Materials Selection

The selection of API J55 or similar low strength mild steel well casing is recommended for all the well casings.

The water from some of the upper formations may not contain H_2S however because of the high chloride content and seemingly inevitable oxygen contamination, during operation or especially shut down, then the FRP pipe is considered the best selection for the pre-injection-pump piping and FRP lined mild steel pipe for the post-injection-pump piping. Similarly the water entering the reinjection well should be considered corrosive and the use of FRP lined steel tubing inside an unlined mild steel casing is recommended for all the fluids.

The plate heat exchanger with titanium plates is recommended for all fluids.

It is considered that standard pumps similar to those in use in the oil and potash industries could be used for the production and injection pumps for the waters from all the formations. The waters from the Mannville, Gravelbourg and Souris Valley formations would likely cause the least corrosion problems to the pump materials listed above.

5. SUMMARY OF MATERIALS SELECTION FOR CORROSION CONTROL

The materials selected for the various pieces of equipment are shown in Table 4 along with any necessary corrosion control measures.

Table 4. SUMMARY OF MATERIALS SELECTION FOR CORROSION CONTROL

EQUIPMENT	MATERIAL	COST	CORROSION CONTROL	
			SYSTEM	COST
Production Well Casing	API J55 or similar	$36.37/m FOB Moose Jaw 178 mm diameter 8 mm thick	External - Cathodic Protection	Capital Cost $15-25,000
			Internal - weighted filming amines	$50-100/month
Pumps Production and Injection	316 stainless Monel		Stainless steel components should be drained and rinsed during plant shutdown Avoid stagnant conditions	
Pre Injection-Pump Piping	FRP vinyl ester pipe with styrofoam pipe insulation, buried	Approx. 1.20 x mild steel laid.	none required	
Post Injection-Pump Piping	(ASTM A53, API 5L) with FRP vinyl ester lining	152 mm pipe - liner cost $24.75/m 102 mm pipe, liner cost $15.68/m. pipe - see below*	Corrosion barrier rings in coupling. External - cathodic protection - linked to casing cathodic protection	
Plate Heat Exchanger	plates and parts in contact with brine - titanium or or Ti - Code 12	2.5 cost of an equivalent stainless steel unit ?		
Injection Well Casing	API J55 or similar	see above	External - cathodic protection - linked with other system.	
Tubing	API J55 lined with FRP vinyl ester liner		Annulus inhibited water.	Inhibited water $50-100/treatment.

For comparison purposes mild steel pipe:

ASTM A53	102 mm (4" SCH 40)	$13.74/m;	ASTM A53	102 mm (4" SCH 80)	$23.58/m;
ASTM A53	203 mm (8" SCH 40)	$35.03/m;	ASTM A53	203 mm (8" SCH 80)	$70.78/m.

REFERENCES

1. Ellis, P.F. and Conover, M.F., 1981. Materials. Selection Guidelines for Geothermal Energy Utilization Systems.
2. Dvoracek, L.M., 1975. "Pitting Corrosion of Steel in H_2S Solutions". Corrosion, Vol 32, No 2, pp.64-68.
3. Corrosion Control in Petroleum Production, 1979, TPC Publication No 5, NACE, Houston, Texas.
4. Goldberg, A. and Owen, L.B., 1979. "Pitting Corrosion and Scaling of Carbon Steels in Geothermal Brine". Corrosion, Vol 35, No 3, pp.114-124.
5. Vigrass, L.W., Kent, D.M. and Leibel, R.J., Oct 1979. "Low Grade Geothermal Potential of the Regina-Moose Jaw Area, Saskatchewan." CIM Bulletin, pp.67-76.
6. Vigrass, L.W., Kent, D.M. and Leibel, R.J., 1978. "Low-grade Geothermal Project, Geological Feasibility Study, Regina-Moose Jaw Area." Tp.14-23. Rge.15-27 W 2nd Mer: DSS Contract No OSU 77-00125.
7. Postlethwaite, J., Vigrass, L.W., Gummadi, V., Neufeld, R. and Kybett, B.D., 1980. "Water Chemistry Testing on Western Canada Geothermal Waters." University of Regina, Report to Public Works Canada, 12 pp + appendix.
8. Ostroff, A.G., 1979. Introduction to Oilfield Water Technology, 2nd Ed, NACE, Houston, Texas.
9. Syrett, B.C., Macdonald, D.D. and Shih, H., 1980. "Pitting Resistance of Engineering Materials in Geothermal Brines-1. Low Salinity Brines." Corrosion, Vol 36, No. 3, March. pp.130-13.
10. Speller, F.N., 1951. Corrosion - Causes and Prevention, 3rd Ed, McGraw Hill.
11. Dunlop, A.K., 1973. Corrosion Inhibition in Secondary Recovery. Corrosion Inhibitors Ed. c.c. Nathan, NACE, Houston, Texas.
12. Nestle, A., 1973 Corrosion Inhibitors in Petroleum Primary Recovery. Corrosion Inhibitors Ed c.c. Nathan, NACE, Houston, Texas.
13. Sulphide Stress Cracking Resistant Metallic Material for Oil Field Equipment. NACE Standard MR-01-75 (1978 Revision), NACE, Houston, Texas.
14. Postlethwaite, J., 1982. Design and Installation of Cathodic Protection System for Geothermal Well Casing U. of R., Regina 3-8-17-19 W2M Appendix II, Report prepared for Govt. of Canada and Govt. of Sask. under Contract No 5001-1.
15. Ten Dam, ., 1978
16. Appendix 2 NACE Standard TM -01-77, 1977, Testing of Metals for Resistance to Sulphide Stress Cracking at Ambient Temperatures. NACE, Houston, Texas.
17. Fontana, M.G. and Green, N.D., 1967, Corrosion Engineering, p 272, McGraw Hill, New York.
18. Szymanski, W.A., April, 1965. "Reinforced Polyester Piping Systems." Chemical Engineering Progress, Vol 61, No.4, pp.53-56.
19. NACE Standard RP-04-75. Selection of Metallic Materials to be used in All Spheres of Water Handling for Injection into Oil Bearing Formations. NACE, Houston, Texas.

APPENDIX C - CASH FLOW ANALYSIS FOR INDEPENDENT HEATING SCHEMES

TABLE C-1

MOOSE JAW GEOTHERMAL DEVELOPMENT-CASH FLOW ANALYSIS

CASE DESCRIPTION: SCHEME 1

SYSTEM SUPPLY (TJ/A):	15.0		CITY	PVT.
HP WORK ENERGY (MWh):	920.0	BLDG LOADS (TJ/A)	15.0	0.0
WELL PUMP ENERGY (MWh)	90.0	CONNECTED BLDGS.	3.0	0.0
RECIRC. PUMP ENERGY (MWh):	25.0			

CAPITAL EXPENDITURES	YEARS 1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Well Drilling	820.0												
Geofluid System	85.0					17.0					17.0		
Heat Pump Systems	70.0					14.0					14.0		
Central Plant and Network	70.0												
Building Retrofits	60.0												
Sub-total	1105.0	0.0	0.0	0.0	0.0	31.0	0.0	0.0	0.0	0.0	31.0	0.0	0.0
Engineering & Commissioning	60.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	3.1	0.0	0.0
Contingency	115.0	0.0	0.0	0.0	0.0	4.5	0.0	0.0	0.0	0.0	4.5	0.0	0.0
TOTAL CAPITAL COST	1280.0	0.0	0.0	0.0	0.0	38.6	0.0	0.0	0.0	0.0	38.6	0.0	0.0

MOOSE JAW GEOTHERMAL SYSTEM CASH FLOW ANALYSIS

CASE DESCRIPTION: SCHEME 1-INCREMENTAL CENTRAL HEAT SYSTEM

CASH FLOWS	YEAR 1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
ANNUAL FUEL COST SAVINGS													
Municipal Buildings	0.0	92.0	93.9	95.7	97.6	99.5	101.5	103.6	105.6	107.7	109.9	112.1	114.3
Pvt. Buildings @ 90%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL CASH INFLOW	0.0	92.0	93.9	95.7	97.6	99.5	101.5	103.6	105.6	107.7	109.9	112.1	114.3
TOTAL CAPITAL COSTS	1280.0	0.0	0.0	0.0	0.0	38.6	0.0	0.0	0.0	0.0	38.6	0.0	0.0
OPERATING COSTS													
Geofluid Pumping	0.0	4.1	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.7	4.8	4.9	5.0
Incremental O & M	0.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Heat Pump Energy	0.0	36.9	37.6	38.4	39.2	39.9	40.7	41.6	42.4	43.2	44.1	45.0	45.9
Distribution Pumping	0.0	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.4	1.4
TOTAL OPERATING COSTS	0.0	52.1	52.9	53.8	54.7	55.5	56.3	57.4	58.3	59.3	60.3	61.3	62.3
NET CASH FLOW	-1280.0	39.9	40.9	41.9	42.9	5.4	45.2	46.2	47.3	48.4	11.2	50.8	52.0

NET PRESENT VALUE	@ 5%	@ 8%	@ 10%	@ 12%	@15%
	-651.5	-878.9	-939.3	-1022.5	-1052.7

INTERNAL RATE OF RETURN: 1.85%

TABLE C-2

CASE DESCRIPTION: CASE 2

			CITY	PVT.
SYSTEM SUPPLY (TJ/A):	35.0			
HEAT PUMP CAPACITY (MW):	15.0			
HP WORK ENERGY (MWh):	1280.0	BUILDING LOADS	27.2	8.3
WELL PUMP ENERGY (MWh)	250.0	CONNECTED BLDGS	6.0	1.0
RECIRC. PUMP ENERGY (MWh):	53.0			

CAPITAL EXPENDITURES	YEARS 1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Well Drilling	800.0												
Geofluid System	145.0					29.0					29.0		
Heat Pump Systems	340.0					68.0					68.0		
Central Plant and Network	395.0												
Building Retrofits	140.0												
Sub-total	1820.0	0.0	0.0	0.0	0.0	97.0	0.0	0.0	0.0	0.0	97.0	0.0	0.0
Engineering & Commissioning	100.0	0.0	0.0	0.0	0.0	9.7	0.0	0.0	0.0	0.0	9.7	0.0	0.0
Contingency	200.0	0.0	0.0	0.0	0.0	16.5	0.0	0.0	0.0	0.0	16.5	0.0	0.0
TOTAL CAPITAL COST	2120.0	0.0	0.0	0.0	0.0	123.2	0.0	0.0	0.0	0.0	123.2	0.0	0.0

MOOSE JAW GEOTHERMAL SYSTEM CASH FLOW ANALYSIS

CASE DESCRIPTION: CASE 2

CASH FLOWS	YEARS 1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
ANNUAL FUEL COST SAVINGS													
Municipal Buildings	0.0	166.7	170.1	173.5	176.9	180.5	184.1	187.8	191.5	195.4	199.3	203.3	207.3
Pvt. Buildings @ 90%	0.0	45.0	46.7	47.6	48.6	49.6	50.6	51.6	52.6	53.7	54.7	55.8	56.9
TOTAL CASH INFLOW	0.0	212.5	216.8	221.1	225.5	230.0	234.6	239.3	244.1	249.0	254.0	259.1	264.3
TOTAL CAPITAL COSTS	2120.0	0.0	0.0	0.0	0.0	123.2	0.0	0.0	0.0	0.0	123.2	0.0	0.0
OPERATING COSTS													
Geofluid Pumping	0.0	11.3	11.5	11.7	11.9	12.2	12.4	12.7	12.9	13.2	13.4	13.7	14.0
Incremental O & M	0.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Supplies and Misc.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heat Pump Energy	0.0	57.6	58.8	59.9	61.1	62.3	63.6	64.9	66.2	67.5	68.8	70.2	71.6
Distribution Pumping	0.0	2.4	2.4	2.5	2.5	2.6	2.6	2.7	2.7	2.8	2.9	2.9	3.0
TOTAL OPERATING COSTS	0.0	86.3	87.7	89.1	90.6	92.1	93.6	95.2	96.9	98.5	100.1	101.8	103.6
NET CASH FLOW	-2120.0	126.2	129.1	132.0	134.9	14.7	141.0	44.1	147.3	150.5	30.7	157.3	160.7

NET PRESENT VALUE	@ 6%	@ 9%	@ 12%	@ 15%	@18%
	-187.6	-7[illegible]	-1065.4	-1279.5	- 423.2

INTERNAL RATE OF RETURN: 5.2%

TABLE C-3

CASE DESCRIPTION: CASE 3

SYSTEM SUPPLY (TJ/A):	59.0		CITY	PVT.
HEAT PUMP CAPACITY (MW):	15.0		-----	-----
HP WORK ENERGY (MWh):	2425.0	BUILDING LOADS	31.0	29.0
WELL PUMP ENERGY (MWh)	700.0	CONNECTED BLDGS	9.0	4.0
RECIRC. PUMP ENERGY (MWh):	100.0			

CAPITAL EXPENDITURES	YEARS 1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Well Drilling	300.0												
Geofluid System	275.0					55.0					55.0		
Heat Pump Systems	558.0					111.6					111.6		
Central Plant and Network	762.0												
Building Retrofits	720.0												
Sub-total	2715.0	0.0	0.0	0.0	0.0	166.6	0.0	0.0	0.0	0.0	166.6	0.0	0.0
Engineering & Commissioning	200.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.0	16.7	0.0	0.0
Contingency	300.0	0.0	0.0	0.0	0.0	27.8	0.0	0.0	0.0	0.0	27.8	0.0	0.0
TOTAL CAPITAL COST	3215.0	0.0	0.0	0.0	0.0	211.1	0.0	0.0	0.0	0.0	211.1	0.0	0.0

MOOSE JAW GEOTHERMAL SYSTEM CASH FLOW ANALYSIS

CASE DESCRIPTION: CASE 3

CASH FLOWS	YEAR 1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
ANNUAL FUEL COST SAVINGS													
Municipal Buildings	0.0	190.0	193.8	197.7	201.7	205.7	209.8	214.0	218.3	222.7	227.1	231.6	236.3
Pvt. Buildings @ 90%	0.0	160.0	163.2	166.5	169.8	173.2	176.6	180.2	183.8	187.5	191.2	195.0	198.9
TOTAL CASH INFLOW	0.0	350.0	357.0	364.2	371.4	378.9	386.5	394.2	402.1	410.1	418.3	426.7	435.2
TOTAL CAPITAL COSTS	3215.0	0.0	0.0	0.0	0.0	211.1	0.0	0.0	0.0	0.0	211.1	0.0	0.0
OPERATING COSTS													
Geofluid Pumping	0.0	40.5	41.3	42.1	43.0	43.8	44.7	45.6	46.5	47.5	48.4	49.4	50.4
Incremental O & M	0.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Supplies and Misc.	0.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Heat Pump Energy	0.0	109.1	111.3	113.5	115.8	118.1	120.5	122.9	125.4	127.9	130.4	133.0	135.7
Distribution Pumping	0.0	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6
TOTAL OPERATING COSTS	0.0	209.1	212.2	215.4	218.5	221.8	225.2	228.6	232.0	235.6	239.2	242.9	246.6
NET CASH FLOW	-3215.0	140.9	144.8	148.8	152.9	-54.0	161.3	165.6	170.1	174.5	-32.0	183.8	188.6

NET PRESENT VALUE	@ 5%	@ 9%	@ 12%	@ 15%	@18%
	-1097.8	-1710.0	-2078.1	-2312.3	-2478.5

INTERNAL RATE OF RETURN: 1.97%

TABLE C-4

CASE DESCRIPTION: CASE 3A

				CITY	PVT.
SYSTEM SUPPLY (TJ/A):	60.0			-----	-----
HEAT PUMP CAPACITY (MW):	0.0				
HP WORK ENERGY (MWh):	0.0	BUILDING LOADS		31.0	29.0
WELL PUMP ENERGY (MWh)	1620.0	CONNECTED BLDGS		9.0	4.0
RECIRC. PUMP ENERGY (MWh):	100.0				

CAPITAL EXPENDITURES	Y E A R S 1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Well Drilling	2300.0												
Geofluid System	370.0					74.0					74.0		
Heat Pump Systems	0.0					0.0					0.0		
Central Plant and Network	605.0												
Building Retrofits	320.0												
Sub-total	3595.0	0.0	0.0	0.0	0.0	74.0	0.0	0.0	0.0	0.0	74.0	0.0	0.0
Engineering & Commissioning	150.0	0.0	0.0	0.0	0.0	7.4	0.0	0.0	0.0	0.0	7.4	0.0	0.0
Contingency	400.0	0.0	0.0	0.0	0.0	7.4	0.0	0.0	0.0	0.0	7.4	0.0	0.0
TOTAL CAPITAL COST	4145.0	0.0	0.0	0.0	0.0	88.8	0.0	0.0	0.0	0.0	88.8	0.0	0.0

MOOSE JAW GEOTHERMAL SYSTEM CASH FLOW ANALYSIS

CASE DESCRIPTION: CASE 3A

CASH FLOWS	Y E A R 1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
ANNUAL FUEL COST SAVINGS													
Municipal Buildings	0.0	190.0	193.8	197.7	201.7	205.7	209.6	214.0	218.3	222.7	227.1	231.6	236.3
Pvt. Buildings @ 90%	0.0	160.0	163.2	166.5	169.8	173.2	176.9	180.2	183.8	187.5	191.2	195.0	198.9
TOTAL CASH INFLOW	0.0	350.0	357.0	364.2	371.4	378.9	386.5	394.2	402.1	410.1	418.3	426.7	435.2
TOTAL CAPITAL COSTS	4145.0	0.0	0.0	0.0	0.0	88.8	0.0	0.0	0.0	0.0	88.8	0.0	0.0
OPERATING COSTS													
Geofluid Pumping	0.0	72.9	74.4	75.8	77.4	78.9	80.5	82.1	83.7	85.4	87.1	88.9	90.6
Incremental O & M	0.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Supplies and Misc.	0.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Heat Pump Energy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Distribution Pumping	0.0	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6
TOTAL OPERATING COSTS	0.0	117.4	118.9	120.5	122.1	123.8	125.5	127.2	128.9	130.7	132.5	134.4	136.2
NET CASH FLOW	-4145.0	232.6	238.1	243.6	249.3	166.3	261.0	267.0	273.2	279.4	[illegible]	292.3	299.0

NET PRESENT VALUE	@ 5%	@ 8%	@ 10%	@ 12%	@15%
	-220.9	-1075.3	-2015.4	-2457.0	-2751.2

INTERNAL RATE OF RETURN: 5.54%

TABLE C-5

CASE DESCRIPTION: CASE 4

			CITY	PVT.
SYSTEM SUPPLY (TJ/A):	110.0			
HEAT PUMP CAPACITY (MW):	0.0			
HP WORK ENERGY (MWh):	3990.0	BUILDING LOADS	42.0	72.0
WELL PUMP ENERGY (MWh)	2500.0	CONNECTED BLDGS	10.0	7.0
RECIRC. PUMP ENERGY (MWh):	165.0			

CAPITAL EXPENDITURES	YEARS 1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Well Drilling	600.0												
Geofluid System	335.0					67.0					67.0		
Heat Pump Systems	900.0					180.0					180.0		
Central Plant and Network	1755.0												
Building Retrofits	575.0												
Sub-total	4365.0	0.0	0.0	0.0	0.0	247.0	0.0	0.0	0.0	0.0	247.0	0.0	0.0
Engineering & Commissioning	350.0	0.0	0.0	0.0	0.0	24.7	0.0	0.0	0.0	0.0	24.7	0.0	0.0
Contingency	500.0	0.0	0.0	0.0	0.0	42.7	0.0	0.0	0.0	0.0	42.7	0.0	0.0
TOTAL CAPITAL COST	5215.0	0.0	0.0	0.0	0.0	314.4	0.0	0.0	0.0	0.0	314.4	0.0	0.0

MOOSE JAW GEOTHERMAL SYSTEM CASH FLOW ANALYSIS

CASE DESCRIPTION: CASE 4

CASH FLOWS	YEAR 1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
ANNUAL FUEL COST SAVINGS													
Municipal Buildings	0.0	257.5	262.5	267.9	273.2	278.7	284.3	289.9	295.7	301.7	307.7	313.8	320.1
Pvt. Buildings @ 90%	0.0	397.2	405.2	413.3	421.5	430.0	438.6	447.3	456.3	465.4	474.7	484.2	493.9
TOTAL CASH INFLOW	0.0	654.7	667.3	681.1	694.8	708.7	722.8	737.3	752.0	767.1	782.4	798.1	814.0
TOTAL CAPITAL COSTS	5215.0	0.0	0.0	0.0	0.0	314.4	0.0	0.0	0.0	0.0	314.4	0.0	0.0
OPERATING COSTS													
Geofluid Pumping	0.0	112.5	114.8	117.0	119.4	121.8	124.2	126.7	129.2	131.8	134.4	137.1	139.9
Incremental O & M	0.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Supplies and Misc.	0.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Heat Pump Energy	0.0	179.6	183.1	186.8	190.5	194.4	198.2	202.2	206.2	210.4	214.6	218.9	223.2
Distribution Pumping	0.0	7.4	7.6	7.7	7.9	8.0	8.2	8.4	8.5	8.7	8.9	9.1	9.2
TOTAL OPERATING COSTS	0.0	389.5	395.5	401.5	407.2	414.2	420.6	427.3	434.0	440.9	447.9	455.1	462.4
NET CASH FLOW	-5215.0	265.2	272.[illegible]	279.6	287.0	-19.9	302.2	310.0	318.0	326.2	20.[illegible]	343.0	351.[illegible]

NET PRESENT VALUE	@ 5%	@ 7%	@ 10%	@ 15%	@18%
	-1867.2	-2274.0	-2998.2	-3447.7	-3759.8

INTERNAL RATE OF RETURN: 4.22%