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Idaho Operations Office • Idaho National Engineering Laboratory

MASTER

Final Report Dickinson Geothermal Study

G. O. Fossum, K. L. Harris, D. J. Hassett,
D. V. Mathsen, and T. C. Owens
Engineering Experiment Station

June 1982

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Prepared for the
U.S. Department of Energy
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FINAL REPORT DICKINSON GEOTHERMAL STUDY

**G. O. Fossum, K. L. Harris,
D. J. Hassett, D. V. Mathsen,
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**Engineering Experiment Station
Box 8103, University Station
Grand Forks, North Dakota**

**Prepared for EG&G Idaho, Inc.
Under Subcontract No. K-7915
and the U.S. Department of Energy
Idaho Operations Office
Under DOE Contract No. DE-AC07-76ID01570**

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PREFACE

This report was prepared for EG&G Idaho by the Engineering Experiment Station, Box 8103, University Station, Grand Forks, North Dakota on Subcontract No. K-7915 under the Department of Energy's Outreach Program. It is now being

reissued without modification as an EG&G Formal report in order to make it available to others that may be interested in this geothermal application.

FOREWORD

The Geothermal Technical Assistance Program was developed under the premise that the majority of groups or individuals with available geothermal resources do not have the experience or manpower necessary to do a preliminary engineering and economic feasibility evaluation for geothermal energy projects. In order to disseminate technical information and to facilitate expanded use of geothermal energy resources, assistance was provided through FY-1981 in a consulting format on a first-come, staff-and-funds-available basis. Technical assistance can relate to conceptualization; engineering; economics; water chemistry implications for environmental, disposal, and material selection considerations; and planning and development strategies. This report is one of a series adapted from consultation provided to requesters either through in-house efforts or through limited efforts subcontracted to local engineering firms. The Geothermal Technical Assistance (GTA) Reports in this series, which are listed below, will be available for purchase early in 1982 by those with interest in specific geothermal applications from the U.S. National Technical Information Service:

U.S. Department of Commerce,
National Technical Information Service,
5285 Port Royal Road,
Springfield, VA 22161,
(703) 557-4650

<u>GTA</u> <u>Report Number</u>	<u>EG&G</u> <u>Report Number</u>	<u>Title</u>
1.	EGG-GTH-5512	<i>Aquaculture Facility Potential at Boulder Hot Springs, Boulder, Montana</i>
2.	EGG-GTH-5521	<i>Preliminary Geothermal Disposal Considerations, State Health Laboratory, Boise, Idaho</i>
3.	EGG-GTH-5573	<i>Geothermal Conversion at Veterans Hospital, Boise, Idaho</i>
4.	EGG-GTH-5574	<i>Geothermal Applications for Highway Rest Areas</i>
5.	EGG-GTH-5575	<i>Geothermal Applications for a Tannery</i>
6.	EGG-GTH-5599	<i>Preliminary Conceptual Design for Geothermal Space Heating Conversion of School District 50 Joint Facilities at Pagosa Springs, Colorado</i>
7.	EGG-GTH-5617	<i>Selected Geothermal Technical Assistance Efforts (comprising short descriptions of ten space heating projects, five district heating projects, and three heat exchanger projects)</i>
8.	EGG-2137	<i>Geothermal Source Potential and Utilization for Methane Generation and Alcohol Production (subcontractor report)</i>
9.	EGG-2138	<i>Geothermal Source Potential and Utilization for Alcohol Production (subcontractor report)</i>

<u>GTA Report Number</u>	<u>EG&G Report Number</u>	<u>Title</u>
10.	EGG-2139	<i>Potential Geothermal Energy Applications for Idaho Elks Rehabilitation Hospital (subcontractor report)</i>
11.	EGG-2144	<i>Technical Assistance Report on a Geothermal Heating Utility for Lemmon, South Dakota (subcontractor report)</i>
12.	EGG-2145	<i>Economic Analysis for Utilization of Geothermal Energy by North Dakota Concrete Products Company (subcontractor report)</i>
13.	EGG-2146	<i>Geothermal Feasibility Analysis II for Polo School District No. 29-2, South Dakota (subcontractor report)</i>
14.	EGG-2147	<i>Preliminary Feasibility Study of Heating and Cooling Alternatives for Nebraska Western College, Scottsbluff, Nebraska (subcontractor report)</i>
15.	EGG-2148	<i>Inventory of Thermal Springs and Wells Within a One-Mile Radius of Yucca Lodge, Truth or Consequences, New Mexico (subcontractor report)</i>
16.	EGG-2149	<i>Utilization of Geothermal Energy, Feasibility Study—Ojo Caliente Mineral Springs Company, Ojo Caliente, New Mexico (subcontractor report)</i>
17.	EGG-2150	<i>Geothermal Heated Office Building at Glenwood Springs, Colorado (subcontractor report)</i>
18.	EGG-2151	<i>Final Report—Dickinson Geothermal Study, Dickinson, North Dakota (subcontractor report)</i>
19.	EGG-2152	CANCELLED
20.	EGG-2153	<i>Comparison of Two Options for Supplying Geothermal Energy to the Veterans Administration Medical Center, Marlin, Texas (subcontractor report)</i>
21.	EGG-2154	<i>Geothermal Utilization at Castle Oaks Subdivision Castle Rock, Colorado (subcontractor report)</i>
22.	*EGG-2155	<i>Space Heating for Twin Lakes School Near Gallup, New Mexico (subcontractor report)</i>
23.	EGG-2156	<i>Pumping Tests of Well Campbell et al. No. 2, Gila Hot Springs, Grant County, New Mexico (subcontractor report)</i>
24.	EGG-GTH-5739	<i>Geothermal Deicing of Highways and Bridge structures</i>
25.	EGG-GTH-5740	<i>Assessment of a Geothermal Application at Tucson, Arizona</i>

<u>GTA Report Number</u>	<u>EG&G Report Number</u>	<u>Title</u>
26.	EGG-GTH-5741	<i>Heat Pump Systems for Spring Creek, Montana</i>
27.	EGG-GTH-5779	<i>Pipe Selection Guide</i>
28.	EGG-GTH-5804	<i>An Overview of Engineering and Agricultural Design Considerations of the Raft River Soil-Warming and Heat-Dissipation Experiment</i>
29.	EGG-GTH-5812	<i>Design of the Glenwood Springs Downhole Heat Exchanger</i>

*Not published as of 6/1/82.

ABSTRACT

The Inyan Kara Formation provides an abundant source of warm (54-71°C) but salty (7400 mg/l combined Na and Cl ions) water for much of southwestern North Dakota. The city of Dickinson, ND, overlies this aquifer at 1676-1768 meters. This study investigates the potential of using this hydrothermal resource as an energy source for a district heating system in a new undeveloped addition to Dickinson. In addition,

the use of a reverse osmosis system to desalinate the water is considered along with other water treatment processes necessary to allow use of this water in the existing city water supply. The results of the study indicate the economic requirements to make this concept feasible and outline the consideration to carry the project into the design phase.

FINAL REPORT
DICKINSON GEOTHERMAL STUDY
SUBCONTRACT K-7915--HYDROTHERMAL
TECHNICAL ASSISTANCE--GKA-153-81

By:

G.O. Fossum, K.L. Harris,
D.J. Hassett, D.V. Mathsen,
and T.C. Owens

To:

EG & G Idaho, Incorporated

Engineering Experiment Station
Box 8103, University Station
Grand Forks, North Dakota

EES Bulletin Number: 82-01-EES-04

January 29, 1982

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INTRODUCTION

The city of Dickinson, North Dakota, lies above several hydrothermal aquifers, the most promising of which is the Cretaceous-Dakota Group-Inyan Kara Formation aquifer at 1676-1768 m depths. Water from the Inyan Kara is soft, warm ($54-71^{\circ}\text{C}$), but high in salt content (7400 mg/l combined Na and Cl ions).

The city is also experiencing growth due to the oil and gas developments in the Williston Basin. Beginning in early 1982, a 2.35 km^2 (721 lot) addition to the city will undergo development. This addition, presently owned by the North Dakota State Board of Higher Education may, upon completion, contain up to 2000 living units with a population of 7500 residents. In addition, 24 lots are zoned for commercial use. With this level of development, the addition will have the following estimated energy and water requirements on an annual basis (See Appendix A):

Space Heating Requirement	$(8.80 \times 10^{10} \text{ KJ/Yr})$
Domestic Water Heating Requirement	$(4.21 \times 10^{10} \text{ KJ/Yr})$
Water Demand	$(1.56 \times 10^9 \text{ l/Yr})$

The purpose of this study is to determine the feasibility of extracting the thermal energy from water of the Inyan Kara Formation in meeting the future residential and commercial space and domestic water heating loads of the State Board of Higher Education addition. This study also investigates the process and operational requirements in desalinating, and otherwise treating, this water for delivery to the city water system.

The general system described herein was originally proposed by Mr. Bruce Gaugler of the North Dakota State Geothermal Office and developed to the extent of this report by the University of North Dakota Engineering Experiment Station, with the support of the North Dakota Geological Survey, under Subcon-

tract K-7915 with EG&G Idaho, Inc. Data relating to specific equipment items and costs are all derived from either telephone conversations or informal quotations from equipment manufacturers, suppliers, or contractors without the benefit of detailed engineering drawings or specifications. The specific objectives of the study which are addressed chronologically in the report are:

1. Define the equipment requirements of a combined geothermal district heating and water supply system.
2. Verify the availability, quality, and well requirements of the hydrothermal resource with respect to both supply and disposal.
3. Determine means of utilizing the thermal energy and design, in a preliminary sense, the distribution system of a district heating system for the Dickinson addition.
4. Select a desalination process and determine its capital and operating costs together with any accessory water conditioning requirements within the system.
5. Investigate the interface of the geothermal water system and its clean product water with the existing Dickinson city water system.
6. Identify the capital and operating costs of the combined district heating and water supply system at several levels of scale.
7. Define areas requiring further study and development.

THE CONCEPT

The concept in its general form is illustrated in Figure 1. Drawing water from the Inyan Kara formation at approximately 1707-1737 m, the supply well provides water at temperatures of up to (71°C) into a district heating distribution loop. Prior to entering the district heating loop, the water is treated with dilute sulfuric acid to drop the pH from 7.8 to 6.8 and reduce the potential for scaling in the pipe network. The water also passes through an iron filtration process to reduce contamination of the desalination process. A booster pump maintains pressure in the distribution loop. The distribution system delivers hot water to each residential living unit and commercial building where it is used for space and domestic water heating. Some commercial uses may also exist. Water may exit the distribution loop by either the return loop through Valve B or through Valve A at the end of the supply loop depending on the need for water in the residences and commercial buildings. Prior to entering the desalination unit, the water passes through a fan jet cooling tower where it is cooled to around 29°C . The cooled water then enters a reverse osmosis (R.O.) unit where desalination occurs. With the incoming water quality of 11,069 TDS, most of which is Na^{+} and Cl^{-} ions, a 50 percent water recovery rate can be expected in the R.O. unit. The concentrated brine is reinjected into the Cretaceous-Newcastle Formation at around 1585 m. The clean water is delivered to the city water supply with some acid (or base) treatment probably necessary to prevent pipe fouling and corrosion. Preliminary calculations indicate the amount of post-R.O. treatment to be very slight and best determined after the R.O. unit is operational. A booster pump will be required to feed the clean water into a nearby 12" city main.

The most expedient location of the equipment is shown in Figure 2, however, formal approval of these locations has not been sought. Figure 3 indicates the

Figure 1. Combined heating and water supply system.

Figure 2. Overall system layout.

Figure 3. Typical well and pump unit.

type of equipment required in the well and pump houses. Figure 4 identifies the main equipment items in the desalination and water control unit. Neither of the latter two figures indicates the control or accessory equipment necessary for the complete operation of the system.

Figure 4. Desalination and water control house.

THE HYDROTHERMAL RESOURCE

Assurance of water at known temperatures, quality, and flow rates is the most crucial element in determining the feasibility of the combined district heating and water supply system. Without a test drilling program on the site, any assessment of the resource will have some level of uncertainty. The study investigated past reports on wells in the Dickinson area, and a water sample was analyzed from one well approximately two miles northwest of the site. The data indicates the Inyan Kara Formation has water quality acceptable to desalination by reverse osmosis, but its actual temperature is uncertain without a test well. Water at 56°C was confirmed with the water sample obtained during the study, but other prior reports indicate water available at temperatures up to 73°C. Flow rates up to 5678 l/m appear to be possible. While the Inyan Kara Formation appears very promising as a supply aquifer, the Newcastle Formation shows promise as a disposal aquifer for the reverse osmosis concentrate stream. This section provides documentation of the hydrothermal resource from the available reports.

Potential Hydrothermal Aquifers

The city of Dickinson overlies a number of potential hydrothermal aquifers with sediments that range in age from the Cenozoic through the Paleozoic Eras (Figures 5 and 6). Water contained in these aquifers generally increases in temperature with depth, but water quality usually decreases with depth. Water quality requirements of this project make the Cretaceous Inyan Kara and Newcastle Formations (Figure 6) particularly interesting, since they are relatively shallow and contain water in a useful temperature range with reasonable water quality. A summary of the depth, thickness, expected water temperature and expected water quality for aquifers in these formations follows.

Figure 5. Cross section showing major unconformities in the North Dakota stratigraphic column (After: Carlson, C.G. and Anderson, S.B., 1966)

NORTH DAKOTA STRATIGRAPHIC COLUMN

		SYSTEMS	GROUPS	ROCK UNITS			BIG SNOWY GROUP	OTTER	
Cenozoic	QUATERNARY			GLACIAL	Paleozoic	MISSISSIPPIAN	MADISON GROUP	KIBBEY ●	
	TERTIARY	WHITE RIVER						INFORMAL INTERVALS	POPLAR INTERVAL
				GOLDEN VALLEY					RATCLIFFE INTERVAL ●
		FORT UNION GROUP		SENTINEL BUTTE					FROBISHER ALIDA INTERVAL ●
				BULLION CREEK					TILSTON INTERVAL ●
				SLOPE					
				CANNONBALL					
				LUDLOW					
									HELL CREEK
	Mesozoic	CRETACEOUS	MONTANA GROUP	FOX HILLS				DEVONIAN	
PIERRE				THREE FORKS ●					
					BIRDBEAR ●				
					DUPEROW ●				
					SOURIS RIVER				
				DAWSON BAY ●					
COLORADO GROUP			NIOBRARA	PRAIRIE					
			CARLILE	WINNIPEGOSIS ●					
			GREENHORN						
			BELLE FOURCHE						
		DAKOTA GROUP	MOWRY	SILURIAN		INTERLAKE ●			
NEWCASTLE ss			STONEWALL ●						
SKULL CREEK			STONY MTN.						
INYAN KARA			RED RIVER ● ☀						
MORRISON									
JURASSIC			SWIFT	ORDOVICIAN	BIG HORN GROUP	WINNIPEG GROUP	☀		
			RIERDON						
			PIPER				DEADWOOD ☀ ●		
TRIASSIC				SPEARFISH ●	CAMBRIAN			●	
PERMIAN				MINNEKAHTA	PRECAMBRIAN				
				OPECHE					
				BROOM CREEK					
PENNSYLVANIAN	MINNELUSA GROUP		AMSDEN						
			TYLER ●						

● OIL PRODUCTION

☀ GAS PRODUCTION

● OIL PRODUCTION
☀ GAS PRODUCTION

Figure 6. North Dakota stratigraphic column. Black dots and stars denote geologic horizons that produce oil or gas.

The Cretaceous Inyan Kara Formation

Information obtained from nearby oil wells (Figure 7) was used to construct geologic cross sections (Figures 8 and 9) that show the expected depth of these aquifers in the Dickinson area. The Inyan Kara is expected to be about 1676 m deep. Figures 8 and 9 show that there is little variation in the depth of these units in the Dickinson area.

Figure 10 shows a reproduction of a laterolog run in Union Oil Company, #1 State of North Dakota (#4288). This well is located about 152 m north of the northern boundary of the Experiment Station Addition (Figure 7). About 44 m of sand development is evident between 1699 m and 1756 m. This overall interval consists of a 30.5 - meter thick sand, a 7.6 - meter thick sand, and two 3 - meter thick sands.

The best information available on water temperature is contained in the Conoco report to the Water Commission (Figure 11). This report indicates 73°C water was produced from their Inyan Kara (Dakota) Formation well. No additional water temperature information is available.

Water quality information is available from three sources. First, a Continental Oil Company report submitted to the North Dakota State Water Commission, relative to an Inyan Kara Formation water supply well completed about two miles northwest of the Engineering Experiment Addition (Figure 7), reports a TDS of 8200 ppm, with a sodium chloride equivalent of 7900 ppm (Figure 11). The second source is a water analysis performed by the NDGS-EES on the same Inyan Kara well, which indicated a TDS of 11,069 ppm (Figure 12). The third source is electric log interpretations of Inyan Kara water resistivity and sodium chloride equivalent TDS from a nearby well, #4288 (Figure 7). The calculated water resistivity is .285 Ω -m which indicates a sodium chloride equivalent TDS of 9600 ppm at an assumed temperature of 73°C.

Figure 7. Location of wells and cross-sections used in this report.

Figure 8. East-West cross-section through area of interest.

Figure 9. North-South cross-section through area of interest.

SCHLUMBERGER		LATEROLOG	
COUNTY STARK, N.D. FIELD or LOCATION DICKINSON STATE OF N.D. WELL COMPANY UNION OIL OF CALIF.	COMPANY <u>UNION OIL COMPANY OF CALIFORNIA</u>		
	WELL <u>STATE OF NORTH DAKOTA #1 4388</u>		
	FIELD <u>DICKINSON</u>		
	COUNTY <u>STARK</u> STATE <u>NORTH DAKOTA</u>		
	LOCATION SW/SE <u>15</u> 510'N/S - 1980'W/E Other Services: <u>SLC</u>		
Sec. <u>32</u> Twp. <u>140N</u> Rge. <u>96W</u>		Elev.: K.B. <u>2495</u> D.F. <u>2492</u> G.L. <u>2453</u>	
Permanent Datum: <u>GL</u> Elev. <u>2483</u> Log Measured From: <u>KB</u> <u>12</u> Ft. Above Perm. Datum Drilling Measured From: <u>KB</u>			
Date	<u>7-19-67</u>		
Run No.	<u>ONE</u>		
Depth - Driller	<u>8009</u>		
Depth - Logger	<u>8007</u>		
2in. Log Interval	<u>8002</u>		
Top Log Interval	<u>676</u>		
Casing - Driller	<u>8-5/8" 676</u>		
Casing - Logger	<u>676</u>		
Bit Size	<u>7-7/8"</u>		
Type Fluid in Hole	<u>FRESH GEL</u>		
Dens.	Visc.	<u>9.8 60</u>	
pH	Fluid Loss	<u>9.5 10.2ml</u>	
Source of Sample <u>FLOWLINE</u>			
P ₁ Meas. Temp.	<u>1.30</u>	<u>73 °F</u>	<u>°F</u>
R ₁ Meas. Temp.	<u>5.14</u>	<u>71 °F</u>	<u>°F</u>
R ₂ Meas. Temp.	<u>-</u>	<u>-</u>	<u>°F</u>
Source R ₁ - R ₂	<u>4</u>	<u>-</u>	<u>°F</u>
P ₂ BHT	<u>558</u>	<u>170 °F</u>	<u>°F</u>
Time Since Circ.	<u>7 HOURS</u>		
Max. Rec. Temp.	<u>170</u>	<u>°F</u>	<u>°F</u>
Equip. Location	<u>4552 WLSIN</u>		
Recorded By	<u>SEVAN</u>		
Witnessed By	<u>MR. GUY-MR. LANSFORD - MR. ROSE</u>

Figure 10. A reproduction of a laterolog run in Union Oil Company, #1 state of North Dakota.

Production Department
Casper Division

Western Hemisphere Petroleum Division
Continental Oil Company
152 North Durbin
Casper, Wyoming 82601
(307) 234-7311

N. D. STATE WATER COMMISSION
ROUTE TO

Asst. Secy.		
Asst. Ch. E.		
Legal Coun.		
Plan. Comm.		
Office Dir.		
Const. Engr.		
C. W. E.		
Inv. Engr.		
Deputy Dir.		
Proj. Dir.		
Water Rights		
Chief Asst.		
Chief Supt.		
File		

December 13, 1973

North Dakota State Water Commission
900 East Boulevard, State Office Building
Bismarck, North Dakota 58501

Gentlemen:

Dickinson Heath Sand Unit Well No. 44
SWC Water Permit No. 1930
Stark County, North Dakota
File: PC-410-CF

Continental Oil Company has drilled and completed the subject well for water supply purposes in the Dickinson Heath Sand Unit waterflood. The following is the completion data for the well:

Location: 590' FSL, 439' FEL, Sec. 25, T140N, R97W, Stark Co., North Dakota. AFE 12-61-2291. API Well No.: None. TD 5850', PBTD 5700'. Elevations: GL 2544', KB 2555', RBM 11'. Spudded 7-31-73. Rig released 8-11-73. Completed 10-19-73. Dakota formation. Ran Schlumberger Gamma Caliper Neutron, FDC-CR and Collar Locator Logs. Perfs: 5302-5793', 5774-5758', 5750-41', and 5663-5558' with 2 JSPP. No treatment. Casing record: 13 3/8" set at 617'; 8 5/8" set at 5850'. Tubing record: 5 1/2" set at 2670'. Log tops: Greenhorn 4630'; Newcastle 5220'; Dakota 5469'. Pumped 15,500 EMPD on 10-19-73. Liquid level 960'. Wellhead surface press. 400 psig. Traces of H₂S and 48 ppm CO₂ were present. No sand was evident. Total dissolved solids were 8200 ppm with a sodium chloride equivalent of about 7900 ppm. Water temp. 164° F.

It is anticipated that beneficial use of water under the subject permit will commence on or about December 21, 1973.

Very truly yours,

J. A. Ubben
Administrative Supervisor

bjs

CC: North Dakota Industrial Commission

Figure 11. Continental Oil Company report submitted to North Dakota State Water Commission relative to Dickinson Heath Sand unit well no. 44.

Calcium	(ppm)	17
Iron	(ppm)	<.2
Magnesium	(ppm)	3.4
Sodium	(ppm)	3,200
Alkalinity	(ppmasCaCO ₃)	673
Chloride	(ppm)	4,225
pH		7.80
Sulfate	(ppm)	251
Total Dissolved Solids		11,069
Conductivity	mmhos/cm	17,600
Temperature	(°C)	56.0

Figure 12. Engineering Experiment Station Water Analysis Sample from Continental Oil Company, Dickinson Heath Sand Unit, Well Number 44 (November, 1981).

The Inyan Kara Formation consists of alternating sands and shales. The sands are of variable thickness (from 46-meter-thick to 3-meter-thick in #4288) and no doubt vary in their long term capacity to produce water. Water quality sources one and two, above, are based on water produced by the overall perforated interval in the Continental Oil Company water supply well. The two samples were taken nine years apart. It is likely that differences in these two samples can be attributed to: 1) a change in the relative proportions of water produced by the various sand units over time, or 2) sampling procedure, or 3) laboratory procedure. The third source, using calculated water resistivity and an assumed temperature of 73°C (164°F), was based on log responses in the best sand, 1487 to 1730 meters (4877 to 5677 feet) in Figure 10, and may not be representative of the quality of all water bearing units. In conclusion, the quality of the water produced from the Inyan Kara may be expected to vary somewhat with the sands selected to be completed, and perhaps with the location of the source wells, but it is expected to be in the range of 8,000 to 11,000 TDM.

The Cretaceous Newcastle Formation

Figures 8 and 9 indicate an expected depth of about 1585 m for the Newcastle Formation in the Dickinson area.

The laterolog from oil well #4288 (Figure 10) shows about 14 m of good sand development between 1590 and 1603 m.

The best information available on water temperature is an extrapolation based on the Conoco report to the North Dakota Water Commission (Figure 11). This report indicates a water temperature of 73°C for the Inyan Kara Formation water. The Newcastle is about 122 m shallower than the Inyan Kara. The apparent geothermal gradient, based on a mean annual surface temperature of 4.4°C and the Inyan Kara temperature of 73°C at 1707 m, is 40.4°C/Km . The Newcastle Formation then can be expected to contain water at about 68°C .

The only water quality information available is based on electric log interpretations of water resistivity and sodium chloride equivalent TDS from the nearby oil well, #4288 (Figure 7). The calculated water resistivity is $.195\Omega\text{-m}$ which indicates a sodium chloride equivalent TDS of about 15,000 ppm at an assumed temperature of 68°C .

Probable Aquifer Yields

Initial project guidelines called for source water at a rate of 4542 ℓ/m per well and waste fluid injection at a rate of 4542 ℓ/m per well. The yields of nearby Inyan Kara water supply wells used by the oil industry for oil field pressure maintenance are far less than 4542 ℓ/m . The Conoco well, Dickinson Health Sand Unit Well No. 44 (Figure 11) yielded about 2.46×10^6 ℓ of water per day or 1711 ℓ/m on its initial test. The Inexco Oil Company water supply well (T140N-R97W-S28 SE/SE), about eight km northwest of the Experiment Station Addition (Figure 7), is expected to yield about 2.38×10^5 ℓ/day or 163 ℓ/m . These Inyan Kara water supply wells are completed using standard oil well completion techniques, perforated casing rather than using well screens. Consequently, the yields of these wells are not a realistic evaluation of the aquifer's potential.

Information obtained from the North Dakota Water Commission and the United States Geological Survey, Water Resources Division (U.S.G.S.W.R.D.) in Bismarck, ND, indicates that the Inyan Kara Formation, in this area, probably has a permeability of about 9.1 m/day and a specific capacity of about 124.2 $\ell\text{pm}/\text{m}$ of drawdown, for a 30.5-meter screened interval. Consequently, a drawdown of 45.72 meter would theoretically result in a yield of 5678 ℓpm for each well. The static water level is predicted to be about 152 to 213 meters below the surface, according to the U.S.G.S.W.R.D. The Conoco well, 4.8 km to the northwest, reported a static water level of 293 meters below the surface. Regardless

of the actual fluid level it should be possible to place a suitable submersible pump 46 m below the static water level in order to provide the desired yield of about 4578 lpm.

Although a source well production rate of 5678 lpm is no doubt optimistic, when viewed in terms of actual well screen and pump performance, the Inyan Kara should be capable of producing water at a rate approaching the design figure of 4542 lpm.

Well spacing requirements have been estimated by the U.S.G.S.W.R.D. as in excess of 300 meters.

No known water supply wells in the area produce water from the Newcastle Formation. The U.S.G.S.W.R.D. supplied specific yield data for the aquifer in this area; it is about 37 lpm/m of drawdown, with a 13.7 m screened interval. Consequently, 122 m of drawdown would be required to provide a yield of 5678 lpm. Alternatively, 122 m of head would provide 5678 lpm of waste fluid injection. The static water level is expected to be about 152 m below the surface, so the waste fluid column should provide the head necessary for injection. In actual practice, some pressure will probably be necessary.

Although the injection well capacity of 4542 lpm is probably optimistic, due to practical problems involving well screen performance and formation pressure build-up, the Newcastle Formation should be capable of accepting waste fluids at an acceptable rate.

Approximate Well Costs

Installation of wells for the proposed project will require an oil well rig to do the drilling. Figures 13 and 14 outline well construction and costs. The costs listed here are best estimates; actual costs will depend on the availability of a drill rig, the type of rig used, and variations in the well design outlined here and unforeseen problems encountered during the drilling and

Figure 13. Source well configuration.

Drilling Costs:

Footage Charge: \$52.50/meter x 1737 meters	= \$91,200	
Standby Time Charge: \$6600/day x 3 days	= <u>20,000</u>	
		\$111,200

Drilling Mud Cost:

About \$8,000 unless there are problems	= 8,000	8,000
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Logging Cost:

Gamma-Ray and Porosity Logs	= 6,800	6,800
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Casing Cost:

0-671 meters; 34 cm (13-3/8") at \$94.16/meter	= 63,200	
671-1707 meters; 22 cm (8-5/8") at \$53.48/meter	= <u>66,500</u>	
		118,600

Cement Cost:

0-671 meters; 34 cm (13-3/8") casing with a 44.5 cm (17-1/2") hole: 671 meters x .0645 m ³ /m ÷ .0326 m ³ /sack x 2 x \$8.00/sack	= 21,200	
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671-1707 meters: 22 cm (8-5/8") casing with a 3 cm (9-7/8") hole; cemented up to about 1509 meters (198 meters): 198 meters x .012 m ³ /m ÷ 1.15 ft ³ /sack x 2 x \$8.00 sack	= 1,140	
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<u>Set-Up Charges:</u> 1. Surface hole--\$800 2. 13-3/8" casing--\$800 3. 8-5/8" casing--\$800	= <u>2,400</u>	
		24,740

Completion Cost:

Drill Bits	14,000	
Well Screen: \$160/ft x 100 ft	16,000	
Casing Handling	3,500	
Miscellaneous		
Sand Packing	5,000	
Pump Blowout	5,000	
Rig Stand-By: \$6,600/day x 2	13,200	
Pump	50,000	
Pump Installation	<u>50,000</u>	
		156,500
TOTAL SUPPLY WELL COST		<u>\$425,840</u>

Figure 14. Summary of estimated source well cost.

completion process. All cost estimates given here are based on telephone conversations with drilling contractors, hardware suppliers, and service companies active in the Williston Basin. The cost of a well will include charges for drilling footage, drilling mud, wireline logging services, casing, well screen, casing installation, cement, pump, and surface plumbing.

Drilling charges are estimated at \$52.50/meter for a 1768-meter deep hole. This amounts to about \$91,200. Standby time for the rig during casing installation, logging, and cementing is estimated at about \$6,600/day. It is likely that about three days of standby time will be required. Standby costs are minimally estimated at about \$20,000.

Drilling mud charges will be about \$8,000, excluding hole problems. A good mud program is necessary to maintain good hole conditions which are necessary for proper casing installation.

Logging services are estimated at about \$6,800. This would include a gamma-ray log for correlation and a porosity log for evaluating the aquifer and positioning the well screen.

Casing requirements, dictated by the permitting agency, require casing set 15 m below the Cretaceous Fox Hills Aquifer. Estimated cost is based on 34 cm casing being set at about 671 m, about 15 meters into the Cretaceous Pierre Formation which underlies the Fox Hills Aquifer. From 670 m to about 1372 m, 21.9 cm casing would be installed. About 30 m of 15.2 cm well screen would then be installed in the Inyan Kara Formation. The cost of surface casing is assumed to be comparable to the footage cost of the 34 centimeter casing. All casing footages should include an overlap of about 6 meters using an average 9 meter joint length. Estimated casing costs are: 670 m of 34 cm casing at \$88.6/m is about \$59,400; 1036 m of 22 cm (8-5/8") casing at \$53.48/m is about \$55,400; the total casing costs are about \$118,600.

Cementing costs are determined by the casing requirements, hole size and casing size. This estimate is based on cementing the 22 cm (8-5/8 in) casing at about 1707 m through the Newcastle to a footage of about 1509 meters. The cement float shoe could then be drilled out to the desired depth, and the well screen installed. The 34 cm (13-3/8 in) surface casing is cemented in place from about 671 meters to the surface. The cement charges are based on volume and rugosity factors supplied by a cement company and include three set-up charges (surface hole, surface casing, production casing). Estimated cementing costs are about \$2,395.

The well screen recommended is a high pressure, 15-24 cm well screen about 30.5 m in length. The cost of this type of well screen is \$525/meter or about \$16,000. Installation is probably best done by the oil well drilling rig to properly prepare the screened interval. Rig costs are estimated at about \$6,600/day for two days or \$13,200.

A turbine pump installed at about 45.7 meters below static water level is necessary for the desired yield of 4543-5678 lpm. The depth of the pump will probably be about 274 to 305 meters. The cost of the pump is estimated at about \$50,000.

The total cost per production well would be about \$425,895.

Summary

The well design discussed in this report is for an Inyan Kara Formation source well. The injection well, or wells, that will be required would be of a similar design but would not require the large diameter surface casing, needed to accomodate the high discharge lift pump (Figure 15).

Injection into the Cretaceous Newcastle Formation (Figure 10) is assumed to be institutionally and practically possible. Injection into the Newcastle would eliminate any possible problem of water circulating between the injection and source wells. Figure 16 shows the probable cost of such a well.

Figure 15. Injection well configuration.

Drilling Costs:

Footage Charge: \$52.50/meter x 1603 meters	= \$84,200	
Standby Time Charge: \$6600/day x 3 days	= <u>19,800</u>	
		\$104,000

Drilling Mud Cost:

About \$8,000 unless there are problems		8,000
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Logging Cost:

Gamma-Ray and Porosity Logs		6,800
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Casing Cost:

0-671 meters: 27.3 cm (10-3/4 in) at \$72.18/meter	= 48,400	
671-1603 meter: 22 cm (8-5/8 in) at \$53.40/meter	= <u>49,900</u>	
		98,300

Cement Cost:

0-671 meter: 27.3 cm (10-3/4 in) casing with a 34.6 cm (13-5/8") hole		
671 meter x .036 m ³ /m ÷ .0326 m ³ /sack x 2		
x \$8.00/sack	= 11,900	

671-1588 meter: 22 cm (8-5/8 inch) casing with a 25 cm (9-7/8 inch) hole		
183 meter x .012 m ³ /m ÷ .0326 m ³ /sack x 2		
x \$8.00/sack	= 1,100	

<u>Set-Up Charges:</u>	1. Surface hole--\$800	
	2. 10-3/4 inch casing--\$800	
	3. 8-5/8 inch casing--\$800	= <u>2,400</u>
		15,400

Completion Cost:

Drill Bits	14,000	
Standby Time Charge: \$6600/day x 1 day	6,600	
Casing Handling	3,500	
6 inch well screen: \$525/ft x 16.2 meter	<u>8,000</u>	
		<u>32,100</u>

TOTAL INJECTION WELL COST		<u>\$263,800</u>
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Figure 16. Summary of estimated injection well cost.

THE DISTRICT HEATING SYSTEM

In order to maximize the potential of the hydrothermal resource, energy utilization systems must be designed to extract the greatest possible amount of heat from the water and do so at a reasonable cost. Likewise, the delivery of the water to the point of use must be accomplished within a distribution system which provides an optimized balance between initial capital cost and annual operating costs. In addition, the water must be conditioned to reduce scale and corrosion assuring long life of the system.

The distribution system is considered as a complete installation in this study. It is understood that actual development of the site will be in stages. All costs are based on a per well basis and pipe costs are available on a per foot basis to permit economic extrapolation to various stages of development.

Energy Utilization Systems

In order to gain the maximum utilization of the hydrothermal resource, the space and water heating systems must be capable of extracting the maximum amount of heat from the well water. In addition, the water must be reduced to around 29°C for efficient desalination by reverse osmosis. These requirements imply at least three possible space heating systems:

1. Low temperature panel heating systems.
2. Fan-coil heating units with a low temperature panel heating system downstream.
3. Low temperature panel heating systems with a water-to-water or water-to-air heat pump downstream.

All three of these systems may achieve most of the domestic water heating requirement of water temperatures in the 65.6°C to 71°C range exist.

The first system appears to be the best suited for the majority of the installations as it extracts the most available heat per installed system cost (see Figure 17).

Figure 17. Typical panel heating installation.

Domestic water is heated in a tank with a copper coil at its base. Higher-priced, specially-equipped cupro-nickel coils may be required if H_2S is present in the water as observed in the Conoco well. The hot geothermal water passes directly through the coil whenever a tank temperature sensor indicates the need for additional heat. Figures 18 and 19 illustrate some of the details of a low temperature floor panel heating system. Water for the panel system is tempered to around $38^{\circ}C$ prior to circulating through the panels. Tempering the water with cooler recirculated water reduces the water consumption from the distribution loop and increases the amount of heat removal from each unit of water. A discharge temperature of $29.4^{\circ}C$ is desirable. The system is controlled by the house thermostat which opens a flow control valve and operates a small circulator pump. A low pressure relief or pressurized check valve maintains back pressure in the system to assure recirculation of water through the panel system. Pressure from the distribution supply loop will force cooled water from the panel system as the tempering valve allows hot water to be admitted into the circuit.

The second concept (Figure 20) has the potential of offering fast system response and flexibility in sizing a system. A fan coil offers almost instantaneous heat delivery in response to the building thermostat and coils can be sized to meet almost any heating load. Water tempered to between $49^{\circ}C$ ($120^{\circ}F$) and $60^{\circ}C$ ($140^{\circ}F$) is circulated through the fan-coil unit when the building calls for heat. This tempering is again performed to reduce water consumption and increase heat extraction. The discharge from the fan-coil unit may feed into a secondary low temperature panel heating system which works in the same manner as the first concept (Figure 17). This secondary panel system may be in the same building as the fan-coil unit or it may be in a separate building altogether. A combination fan-coil and panel system is perhaps best suited for commercial buildings where non-business hours are maintained at lower room temperatures

Figure 18. Concrete floor panel heating cross-section.

Figure 19. Wood floor panel heating cross-section.

Figure 20. Fan-coil unit with low-temperature panel heating system and domestic water heating.

by the panel system and quick warm-up periods are satisfied with the fan-coil unit just prior to and during business hours.

The third concept (Figure 21) enables the greatest amount of heat to be extracted from the hydrothermal resource. This system employs a heat pump to extract heat from the water after it has passed through a low-temperature panel system. The heat pump can extract anywhere from 5.6°C - 22°C Centigrade degrees (10-40 Fahrenheit degrees) from the water dependent on the flow rate through the heat pump. This flow rate is controlled by two balancing valves. At the present time, the cost of operating the electric water source heat pump in Dickinson is equivalent to providing the same output energy with a natural gas furnace and there is little incentive for its use. This balance may change in favor of the heat pump with the pending decontrol of natural gas.

Distribution and Auxiliary Cooling System Design

A preliminary layout of the distribution system is outlined in Appendix F. The mains and feeder lines are sized on the following estimated space and water heating flow requirements (See Appendix B):

Single Family Units	10.2 lpm (2.7 gpm/unit)
Multi-Family Units	7.6 lpm (2.0 gpm/unit)
Commercial Buildings	13.6 lpm (3.6 gpm/unit)

The above flows assume that 71°C (160°F) water is available and that a low-temperature floor panel is used as the main heating system. Domestic water heating is accomplished by a copper coil in a water heating tank. It is assumed that the average multi-family unit is an eight-plex.

The water would be neutralized to prevent scale build-up and iron would be removed by filtration at the well head. A booster pump would develop 552 KPa (80 psi) entering the supply main. With a maximum pressure drop through the system of approximately 207 KPa (30 psi), a minimum pressure of 345 KPa

Figure 21. Low temperature panel heating system with heat pump.

(50 psi) is provided in the system. The main supply and return lines are 25.4 cm (10") fiberglass reinforced thermosetting resin pipe with all feeder lines ranging in size from 5 cm (2") to 15.2 cm (6") and made of polybutylene. All supply lines are insulated, reducing the total piping system's heat loss to around 1.84×10^{10} KJ/Yr. All return lines are uninsulated. The feeder lines would contain taps at each lot for hook-up by the owner or plumbing contractor as the living units are constructed.

The system, as proposed, contains two supply wells at 4543 ℓ pm (1200 gpm) each for a total hydrothermal capacity of 9085 ℓ pm (2400 gpm). This flow rate would provide about 60 percent of the total space and water heating load under design conditions. This capacity, however, represents 100 percent of the space heating load under maximum design conditions with about 3407 ℓ pm (900 gpm) of reserve capacity to simultaneously handle 30 percent of the design water heating load. As a preliminary design, this 60 percent ratio of system capacity to design load is considered adequate as peak load conditions occur for only a few hours a year and during that time supplemental space or water heating can be provided electrically. During the non-heating season, the system is capable of providing 80 percent of the maximum possible instantaneous domestic water heating load. This level of capacity should be adequate to provide the average water heating load. Even with the above loads, the system has up to 7.07×10^{11} KJ/Yr of unused energy in bringing the well water down to 29.4°C.

Operating continuously, the water flow through the distribution system will be controlled by two 35.6 cm (14") flow control valves in the Desalination and Water Control House (Figure 4). These valves will respond to line pressure maintaining set supply and return side pressures. Therefore, a continuous flow will be provided to the reverse osmosis unit.

Only during peak heating loads will the geothermal water be sufficiently cooled (to 29.4°C) to allow efficient desalination without auxiliary cooling. This additional cooling may be provided by a number of different techniques, however, a small process-type cooling tower appears to be the most economical. One manufacturer's unit is shown in Figure 22 and referenced in Appendix D. This particular unit is capable of cooling 2271 lpm (600 gpm) from 71°C to 29.4°C at 35°C dry bulb and 24.4°C wet bulb ambient conditions. Two such units are required for each supply well.

Distribution System Capital and Operating Costs

The capital cost of the distribution system is assumed to cover everything from the completion of the well through the cooling towers. These items are summarized in Figure 23. Operational costs of the distribution system consist principally of the pumping costs and maintenance of the filtration and acid metering system. These costs in 1982 dollars are (per supply well):

Well Pumping Cost - 340 Kw Unit (456 HP)		
340 Kw x 8760 hr/yr x \$.03801/Kw-Hr	=	\$113,200
Booster Pumping Cost - 75 Kw Unit (100 HP)		
75 Kw x 8760 Hr/Yr x \$.03801/Kw-Hr	=	25,000
Demand Charges		
(340 + 75) HP x \$1.81/Kw-Mo x 12 Mo/Yr	=	9,000
Miscellaneous Operation and Maintenance Costs	=	<u>10,000</u>
TOTAL ANNUAL OPERATING COST		\$157,200/Yr/Well

The capital cost of the energy conversion system within each living unit will vary with the type of system selected and the layout of the building. It is assumed that a floor panel heating system is installed together with a coil-equipped water heating tank. These costs are estimated are follows:

Water Heating Tank 303 l (80 Gallon)	
with Copper Coil	\$ 500
Circulation Pump	125

Figure 22. Typical cooling tower.

Well Head Items (Per Supply Well):

Isolation Valves 24.5 cm (10") 2 x \$1500	\$ 3,000	
Booster Pump 75 Kw (100 HP)	8,000	
Iron Filtration Unit (See Appendix D)	120,000	
Installation	60,000	
Chemical Metering Pump	1,000	
Controls and Wiring*	30,000	
Well and Pump House Building (40'x 20') x \$30/ft ²	<u>24,000</u>	
		\$ 246,000

Distribution Line (Entire Addition):

Main and Feeder Line Labor and Materials (See Appendix C)		2,200,000
Flow Control Valves (14") 2 x 3500	7,000	
Valve Control Units	6,000	
Piping and Installation from 25.4 cm (10")	<u>10,000</u>	
Mains to Cooling Tower		23,000

Cooling Tower (Per Supply Well):

Cooling Towers, Controls, Pumps, and Auxiliary Equipment (See Appendix D)	<u>100,000</u>
TOTAL DISTRIBUTION AND COOLING COST (ONE WELL)	<u>\$2,569,000</u>

* Dependent on Connection Costs From
Electrical Power System

Figure 23. Capital costs of the distribution system.

Mixing Valve	100
Solenoid Valves (2)	100
Miscellaneous Valves and Fittings	175
Panel Coil and System Installation	<u>1,500</u>
TOTAL CAPITAL COST	\$2,500

A \$1000 per living unit cost for connection to the system is assumed. The annual operating cost to the homeowner is the cost of operating the circulating pump plus any maintenance requirements plus any electricity purchased for supplemental water heating. A typical situation may be:

$$\begin{array}{l} \text{Circulator Run Time (2,200 Hrs)} \\ 2200 \text{ Hrs/Yr} \times (.10 \text{ Kw}) \times \$.0654/\text{Kw-Hr} = \end{array} \quad \$14.38/\text{Year}$$

$$\begin{array}{l} \text{Maintenance (2\% of System Cost per Year)} \\ .02 \times \$2,500 = \end{array} \quad \$50.00/\text{Year}$$

$$\begin{array}{l} \text{Supplemental Water Heating Cost (15\% of} \\ \text{Total Demand)} \\ .15 \times (52,769 \text{ KJ/Day} \times 356 \frac{\text{days}}{\text{year}} \times \$.0654) \div \\ 3600 \frac{\text{Btu}}{\text{Kw-Hr}} = \end{array} \quad \underline{\underline{\$51.17/\text{Year}}}$$

$$\text{TOTAL HOMEOWNER OPERATING COST} \quad \underline{\underline{\$115.55/\text{Year}}}$$

THE DESALTING PROCESS

One alternative in considering the application of geothermal energy for the city of Dickinson would be to utilize only the heat energy and reinject the water into the Newcastle Formation just prior to the cooling tower. Because of the relative purity of the water, except for a high dissolved NaCl content, this study investigates the feasibility of desalinating the water and making it potable for distribution in the city water supply.

This section reviews the water treatment and equipment requirements for desalination by reverse osmosis. This method appears to be the most efficient and economical process for desalination of the type of water found in the Inyan Kara Formation.

During the course of this study, concern has been expressed regarding the reliability and long-term operability of reverse osmosis systems. The bases for the concerns are problems that have been experienced in the operation of two municipal reverse osmosis facilities in the state. No particular effort has been made to investigate the difficulties, and firm information is difficult to gather. In any case, it should be recognized that a reverse osmosis plant is an operation that requires continuous surveillance and maintenance. Preventive maintenance is necessary, and there must be provision for replacement of key components. For instance, reverse osmosis membranes, the heart of the unit, have an estimated life of three years. Deterioration in water quality and/or reduction in production rate will result when membranes have exceeded their service life. Close attention to chemical pretreatment and pre-filtering operations, located ahead of the reverse osmosis unit, are necessary because the membranes can be irreversibly damaged if precipitation results or if suspended solids enter the membrane system.

Before installing a desalting system, it must be recognized that trained operators and maintenance workers are essential. In addition, financial provision for timely equipment repair and replacement are necessary to insure satisfactory operation. The facility cannot be installed, then forgotten.

Pre-Conditioning of the Water

The water analysis, as shown in Figure 12, shows the water is highly mineralized, but very soft. That is, it contains relatively low concentrations of calcium and magnesium. The water can be characterized as a sodium chloride water. The temperature of the feedwater to the desalting unit is projected to be about 29.4°C (85°F), based on the maximum cooling level economically available with a cooling tower. This is somewhat higher than desired, but it is within the acceptable range for operation of reverse osmosis desalting systems. The sodium ions and chloride ions are not as efficiently rejected as are divalent anions and cations. Design rejection of the monovalent ions ranges from 96 percent to 99 percent depending on the membrane (and the vendor) being considered, while the rejection of divalent ions is in the 98 to 99 percent range. The actual rejection and recovery depend on the identity and the concentrations of the ions in the feedwater and they are also membrane dependent. Therefore, predictions of performance are not guarantees.

The feedwater should be pretreated prior to feeding the reverse osmosis unit. There is very little iron (and no detectable manganese) present in the water, but it needs to be removed because its presence may stimulate the growth of microorganisms, such as *Crenothrix*, which can clog processing equipment. Iron removal is accomplished in the pump house (Figures 1 and 3) before the geothermal energy is extracted to avoid problems in the circulating system. In addition, the water is filtered prior to circulation to remove suspended solids that may be present in the raw well water. In addition, a 10-micron

filter must be installed just upstream of the desalting unit to ensure that no particulate matter enters the membrane system.

Chemical pretreatment of the feedwater to avoid precipitation on the product water side of the membranes is also necessary. Preliminary indications are that adding acid to lower the pH will be sufficient; adding a stabilizing agent to prevent scaling and to avoid problems associated with the presence of small amounts of barium and strontium in the feedwater is also advised. More specific dosages can be determined only when the actual water analysis is available. Other tests (i.e. fluoride and radioactivity) need to be conducted upon completion of a test well.

Capital and Operating Costs

With the relatively high concentration of dissolved solids, the recovery (i.e. the fraction of the feedwater that is available as product) is estimated as 50 percent. For that recovery, the volume of product water from the water estimated to be available from one supply well 4543 lpm would be about 3.2×10^6 liters per day. Two wells will supply the domestic water needs in the proposed development with an additional reserve capacity of 2.27×10^6 liters per day based on 7,500 residents at 568 liters (150 gal.) per day. The water will meet EPA water quality standards for drinking water, and it will be a very soft water.

The estimated capital cost of the membrane system is \$400,000 per 4543 lpm (1200 gpm) supply well. With the addition of the necessary peripheral equipment, the total capital cost per well, exclusive of membranes, will be about \$650,000. The building to house the equipment and the necessary tankage will add about \$50,000 to the cost. The total reverse osmosis plant, therefore, will cost approximately \$1,100,000 per well. Operating and maintenance costs are estimated on a cost per 1,000 gallons (3785 l) of product water. The estimated costs are shown in the table following:

<u>Operating and Maintenance</u>	<u>\$/1,000 Gal. Product Water</u>
Electric power (3.801¢/kwhr + \$1.81/mo-Kw demand)	\$.42
Membrane replacement (3 year life)	.25
Maintenance labor and materials	.045
Pump reconditioning	.017
Chemicals	.10
Filter replacement	<u>.10</u>
TOTAL	\$ 0.93

Thus the total operating and maintenance costs will total about \$1.00 per 1,000 gallons (3785 l) of product water.

The capital cost associated with the membranes and the auxiliary equipment will be proportional to the water production rate because the desalting unit is modular. That is, doubling the product water rate will require twice as much membrane area (or twice as many modules). Economics of scale for anticipated expansion of the system will have to be designed in the first stage. In addition, the operating and maintenance costs per unit of water production will be only slightly reduced as the production is increased. Only the maintenance labor cost per unit will be lowered; the energy, membrane, and filter replacement, and pretreatment costs are directly proportional to the volume of water produced.

GEOTHERMAL - CITY WATER INTERFACE

Current Tap Water Quality

The city of Dickinson, North Dakota, currently uses Patterson Lake as its source of municipal water supply. This source of raw water is subject to considerable variation in quality, both seasonally and from year to year. Basically, the principal components of the water treatment system are coagulation, softening by the lime-soda process, recarbonation, filtration, disinfection, stabilization and fluoridation. Due to the algae problem in Patterson Lake it is also necessary to practice algae control both at the plant and the reservoir and to combat taste and odor of the finished water. Although considerable variation is evident in water quality data reported by the North Dakota State Department of Health in their 1980 publication and corresponding values received from the city of Dickinson for 1980 and 1981, the finished water has a hardness around 125 mg/l, an alkalinity around 175 mg/l, and a total dissolved solids of approximately 950 mg/l based on city data. At 10°C, the Langelier Index indicates that this water is slightly in the scale-forming range for either set of data; the Ryznar Index, however, tends to show a water that is in the corrosive range. Based on both of these values, it appears that the current tap water is very near the neutral point as to corrosivity or scale-forming tendencies.

Geothermal Water Quality

Exact values for the pertinent parameters of the finished water delivered by the reverse osmosis process are unknown at this time. Such values will not be determined until the quality of the water from the geothermal wells is known, and the expected reductions in the reverse osmosis treatment process can be predicted. However, certain assumptions can reasonably be made.

Based on the characteristics of the Dickinson Geothermal Dakota Sand Well #44, which is probably quite indicative of the raw water quality for the wells involved in this project, certain observations are projected. If total dissolved solids are reduced to the recommended value of 500 mg/l, the corresponding values of hardness, calcium, magnesium, alkalinity, sodium, chloride, and sulfate will apparently be reduced to nominal values. Iron concentrations will already have been reduced before reverse osmosis treatment.

In July, 1979, the Environmental Protection Agency (EPA) issued the National Secondary Drinking water Regulations to become effective January 19, 1981. These regulations specify maximum contaminant levels of 250 mg/l for chloride, 0.3 mg/l for iron, 250 mg/l for sulfate, and 500 mg/l for total dissolved solids (TDS). It is expected that the reverse osmosis finished water can readily meet these levels.

Quantity Requirements

At a current population of slightly less than 20,000, the annual average water consumption for Dickinson could be expected to approximate two million gallons per day. For maximum daily consumption this figure could be expected to double. Actual pumping figures for July 16, 1980, as given in the Water Processing Study by Ulteig Engineers in August, 1980, show an actual value of very close to four million gallons for that day. It is readily conceivable that future growth could increase the average and maximum values to 23.2 million liters per day and 26.5 million liters per day, respectively.

Two geothermal wells, pumping at 4543 liters (1,200 gallons) per minute each, would supply about 13.2 million liters per day. If the finished product water from the reverse osmosis process is taken to be 50 percent of the input water, this would supply about 6.62 million liters per day for public use. Thus, on an average day the two geothermal wells at maximum output would furnish

50 percent of the water demand, and 25 percent on maximum days. At the present consumption, these figures would be about 85 percent and 45 percent.

Distribution System Interface

Cooling

Water temperature in the city mains from the existing system can be expected to be around 10°C (50°F), with slight seasonal variations. The geothermal system will probably put out water in the vicinity of 25°C to 30°C (77°F to 86°F). Attempts to lower this temperature significantly during summer months would seem to be impractical. Consequently, if the geothermal wells are utilized to their full projected capacity of 9085 lpm, users would find that the tap water would be considerably warmer. This would be particularly noticeable near the junction of the two systems during summer months.

Stability

As mentioned earlier, the current tap water is very near the neutral point between corrosiveness and scale formation. It appears that the product water in the R.O. system will most likely be well into the corrosive range at a temperature of 10°C . Provisions will be necessary to make this water near neutral. As this water blends with the existing city water where the systems join, the tendency to corrosion will lessen. However, it appears that adjustments to the R.O. water system by chemical additions, pH adjustment, and the use of stabilizers will be advisable. Quantities of chemicals to be added will not be large, but will have to be rather closely controlled by metering equipment.

Disinfection and Fluoridation

Provisions for fluoridation and post-chlorination equipment will be required following the R.O. units. No large units are required because chemical additions are very small; however, a good monitoring system is essential because it is desirable that the residual fluoride and chlorine levels be very

nearly equal for both the city water and the R.O. water at their service junction.

Pressure

Maps show the overflow elevation of the elevated storage in the present system to be 786 meters. The average elevation of the new development area served by the geothermal wells is assumed to be about 750 meters (a figure obtained in a telephone conversation with Mr. Warren Hintz, Assistant City Engineer). To meet the static pressure from the present city system at this area requires that water from the R.O. system have a static pressure of approximately 344.7 KPa (50 psi) at the junction. A high service centrifugal pump with a capacity of 4542 lpm (1,200 gallons per minute) at a head of approximately 38 m (25 feet) would be required as the primary unit for delivering the R.O. water into the city system. Fire requirements dictate some sort of standby arrangement, whether from a second pump or from an elevated storage tank.

During the coldest weather of winter, the greatest demand will be placed on the geothermal wells for heating puposes, but this will coincide with a minimum demand for R.O. water. This will necessitate some means of controlling or storing the output from the R.O. units. Several alternatives will have to be considered, such as:

1. Pass water through the R.O. units only where the city system has a demand for water. At all other times the return flow from the heating system will be bypassed to the injection wells and the only benefit achieved from the geothermal wells will be heat.
2. Provide a fairly large clearwell for treated water, possibly 757,000 liters (200,000 gallons), and bypass the heating return flow only when there is no demand on the high service pump and

the clearwell is full. This system would waste less return flow water but will require a fairly substantial clearwell.

3. Reduce the size of the clearwell to perhaps 284,000 liters (75,000 gallons) and pump from it with a low-head pump to a ground storage reservoir with a capacity of three to four million gallons. The high service pump then would pump from the ground storage as required. This system required additional pumps, a smaller clearwell, but a large ground storage reservoir. However, all return flow from the heating system could probably be utilized for city water.

Equipment and Facilities

The following items will apparently be required between the R.O. units and the city distribution system:

1. pH adjustment equipment.
2. Chemical feeders for:
 - a. Stabilization
 - b. Disinfection
 - c. Fluoridation
3. Monitoring and control mechanisms for items 1 and 2.
4. High service pumps (two required).
5. Clearwell.

In addition, the following items will be required, dependent upon alternatives selected for design:

6. Low-head pumps (two required).
7. Ground storage reservoir.

A pump control and bypass system will also be required for any of the options.

AN ECONOMIC EVALUATION

The geothermal heating system must economically justify itself by offering a net operational savings over that of conventional space and water heating systems to the extent that the greater capital cost of the system can be recovered in a reasonable time frame. Likewise, the clean water from the R.O. unit must be produced at a total capital and operating cost equivalent to or less than that of alternative supplies. This section discusses the economics of a system sized to provide nearly all of the space and water heating load of the addition upon full development. Alternate combinations of system size are discussed with their respective economic status.

A complete system would consist of two supply wells producing 4542 gpm each. The total instantaneous heating capacity of 9085 gpm represents 95×10^6 KJ/hr for a 71°C to 29°F drop in temperature across the distribution system. The total anticipated instantaneous space heating load for the fully developed site is 58.9×10^6 KJ/hr. This load utilizes 62 percent of the total system hydrothermal capacity under a peak load condition. The remaining 38 percent or 3452 gpm is available for water heating. This amount of water is capable of supplying 30 percent of the theoretical peak water heating requirement simultaneously with the peak heating load (assuming a 71°C to 60°C temperature drop). During the non-heating season, two wells can supply 80 percent of the theoretical peak water heating load, a high enough load factor to virtually assure 100 percent water heating from the geothermal system during the summer. Additional energy is available in the $27\text{--}60^\circ\text{C}$ range if it can be effectively used.

Two supply wells will produce nearly 4542 gpm of potable water for delivery to the city water supply or 6.5×10^6 liters (1,728,000 gallons) per day, a quantity sufficient to handle the entire load of the new addition with a reserve

of 228,260 liters (60,300 gallons) per day. For the purposes of conservatism, it is assumed that two 4542 lpm injection wells will be required to permit system operation if all city water reservoirs are full and all system water must be reinjected.

A system theoretically capable of 100 percent of the space heating load and approximately 85 percent of the water heating load would consist of the following components:

Two Supply Wells	\$425,895 @	\$851,790
Two Injection Wells	\$263,800 @	527,600
Two Well Head Units	\$186,000 @	372,000
Two Cooling Tower Pairs	\$100,000 @	200,000
Complete Distribution System		2,223,000
Two Reverse Osmosis Packages	\$1,100,000 @	<u>2,200,000</u>
Sub-Total of System Costs		\$6,374,390
Contingency (20 percent)		<u>\$1,274,878</u>
Total Anticipated System Costs		\$7,649,268
Engineering Fee (15 percent)		<u>\$1,147,390</u>
TOTAL SYSTEM COSTS		<u><u>\$8,796,658</u></u>

The connection costs and heating system costs to the homeowner will be approximately:

Space and Water Heating System Costs	\$2,500
Connection Charges	<u>1,000</u>
TOTAL HOMEOWNER SYSTEM COST	<u><u>\$3,500</u></u>

This amount is similar to the cost of installing a warm-air furnace and duct-work, and therefore, it is considered equivalent in cost to a conventional system in successive analysis.

The annual operating and maintenance expenses for the operation of the geothermal district heating system would include the pumping and maintenance costs for the well and booster pumps described under the District Heating System. In addition, some administrative cost would be involved; the amount dependent largely on the method of billing the customers for operating expenses. At least two billing methods are apparent. One would be a flat monthly service charge for connection to the system at a rate sufficiently high to cover all annual operating and maintenance costs. The other method would be the metering of heat used by the individual customers and a billing based on energy consumption. The first is simpler and cheaper administratively; the second encourages conservation and a better potential utilization of the available energy. For the purposes of estimate, it will be assumed that the administrative organization must dedicate one full-time clerical person, the equivalent of a full-time maintenance person, a half-time customer relations person, and a one-quarter time portion of an administrator to oversee the normal operation of the system. These salaries together with some office supplies are assumed to cost \$60,000 per year. In addition a \$50,000 per year general maintenance requirement is assumed. These items are summarized below:

Well and Distribution System Pumping Expenses \$157,200 @	\$314,400
Administrative Expenses	60,000
General Maintenance Expenses	<u>50,000</u>
TOTAL DISTRICT HEATING ANNUAL EXPENSES	<u>\$424,400</u>

The annual operating costs of the reverse osmosis system is summarized in the Desalination section and appear to be around \$1.00/1000 gallons (3785 g) of product water. Customer charges as of January, 1982, are \$1.45/1000 gallons (3785 g) plus a monthly service charge based on meter size.

As of January, 1982, the most inexpensive conventional method of space and water heating in Dickinson is with natural gas. Using the heating loads of Appendix A and the projected 1982 gas rates of the servicing utility (Montana-Dakota Utilities) for each class of building, the annual total customer energy and maintenance cost replaced by the geothermal system is \$728,900 in 1982 dollars (See Appendix E).

The economic viability of the system can be summarized in response to five questions:

1. Does the geothermal heating system offer sufficient annual operational savings compared to natural gas space and water heating equipment to justify the system installations?

The first-year capital and operational costs for a system with two supply wells compared to natural gas systems are summarized below.

	<u>Geothermal System</u>	<u>Natural Gas Systems</u>
Initial Cost Difference (Two Supply Wells without R.O. Units)	\$5,484,696	-0-
Annual Operational Cost of a Geothermal System	424,400	-0-
Annual Residential System Cost	<u>233,700</u>	<u>\$772,400</u>
Total Annual Operating Costs	\$658,100	\$772,400
1st YEAR GEOTHERMAL SYSTEM SAVINGS	<u>\$114,300</u>	

A similar comparison for a single supply well and complete distribution system is shown below.

	<u>Geothermal System</u>	<u>Natural Gas Systems</u>
Initial Cost Difference (One Supply Well without R.O. Unit)	\$4,276,199	-0-
Annual Operational Cost of a Geothermal System	257,200	-0-
Annual Residential System Cost	<u>338,640</u>	<u>\$772,400</u>
Total Annual Operating Cost	\$595,840	\$772,400
1st YEAR GEOTHERMAL SYSTEM SAVINGS	<u>\$176,560</u>	

Based on projected increases in natural gas and electricity rates by Montana-Dakota Utilities (as of January, 1982) for the Dickinson area, the two well system would require four percent financing of the initial system cost to provide a system payback in 20 years. The single well system would require 11 percent financing of the initial capital cost to provide a payback in 20 years. Both systems would require higher annual charges with the geothermal system for the first eight-ten years compared to conventional natural gas systems to amortize the installation cost. Therefore, it does not appear that the geothermal system provides an economic advantage to the homeowner in the Dickinson addition if the system must be financed by conventional means and if no significant non-residential uses are found.

2. Are there possible industrial users for the excess thermal capacity of the system?

The key to improving the economics of the geothermal system is to find a major industrial user of low-grade thermal energy. With full development of the addition, a two well system possesses 7.02×10^{11} KJ/Yr of heat between 29°C and 71°C which must be dumped to the atmosphere. The space and water heating load represents a 15.6 percent utilization factor for the system capacity. The single supply well system retains 2.80×10^{11} KJ/Yr of excess heat and has a 32 percent system utilization factor.

If an industrial demand for about 9.5×10^{10} KJ/Yr could be found in or near the Dickinson addition, the geothermal energy could be provided at the same rate as natural gas upon completion of the one well system. This consumption, together with the space and water heating loads would permit financing of the system at eleven percent and a total annual consumer charge which would be equivalent to that for natural gas consumption. All future customer rates would then increase only with the increase in costs for electrical

pumping power, administration, and any major maintenance items; a projected three to four percent annual increase in rates. The two well system requires an additional 1.5×10^{11} KJ/Yr demand for the same condition to exist.

3. How will the effect of possible deregulation of natural gas and other energy escalation rates affect the annual potential savings?

Deregulation will affect gas rates in ways unique to a particular utility. Montana-Dakota Utilities expects their natural gas rates to approximately double between 1982 and 1990 under the effect of deregulation; an average eleven percent per year increase. If sufficient industrial use or other means of increasing the energy utilization level of the system can be found, the customer would experience a relatively fixed energy rate on the geothermal system as compared to the eleven percent annual increases for natural gas. If this extra utilization can not be accomplished to some significant level, the deregulation of natural gas alone will not likely provide sufficient incentive to justify the system.

4. How might the geothermal tax credits affect the system?

A North Dakota resident who is the first installer and owner of a geothermal system with inlet temperatures above 50°C is entitled to a 40 percent federal and 15 percent state income tax credit. If the single well system (\$4,276,199) is divided among 2,000 living units, the capital cost per living unit is \$2,138. When the installation cost of the space and water heating system (\$3,500) is added to the geothermal system, the unit system cost goes to \$5,638. If this cost could be reduced by application of the tax credits, the initial cost of the system would be around \$2,537 per living unit. Methods of financially structuring the geothermal system to entitle the lot owners to these credits are worth pursuing but were not within the scope of this study.

5. How does the cost of producing clean water from the reverse osmosis unit compare with other available water supply and treatment systems?

The operating and maintenance cost of the R.O. unit is approximately \$1.00/1000 gallons (3785 liters). The installed capital cost of the cooling towers and R.O. plant is approximately \$1,656,000 per 2271 Lpm (600 gpm) of product water capacity. If the initial capital cost is financed at 11 percent over 20 years, the debt service will be \$0.66/1000 gallons (3785 liters) for a total water cost of \$1.66/1000 gallons (3785 liters) of water, exclusive of distribution costs. This cost can be used as a guideline for comparing the geothermal/R.O. unit against end-of-treatment costs for other future water supplies.

SUMMARY

There do not seem to be any major technical roadblocks to the overall system concept. The major uncertainty is the actual supply temperature of water from wells in the Inyan Kara Formation at the Dickinson site. If it is indeed 71°C , the economic and energy analysis of this study is reasonable. If it is much less than this level, the ability to effectively heat domestic water is reduced or eliminated and water flow rates to each residence would need to be increased significantly with a resultant loss in total system space heating capacity. A second concern is the availability of pumping equipment to develop 4542 ℓpm (1200 gpm) with a 3785 meter (1000') head for well use. This well size is at the upper boundary of well technology for drilling contractors in this region.

The layout of the distribution system has been prepared in a preliminary form based on completion of the entire system at one time. Due to the planned staged development of the Dickinson additon, special design consideration needs to be given to the installation and economics of the distribution piping, as well as the rest of the system, for the proposed completion schedule of the addition. More attention also needs to be given to the details of the distribution system such as service access and layout with respect to other utilities. Although the water quality does not appear to provide any problems to the overall operation of either the heating or water treatment process, further analysis of the water quality at several points in the system should be performed to prevent scaling or corrosion problems due to the changes in water temperature throughout the system.

The economic feasibility of the system will be determined by two factors. The first is whether or not a large industrial user of low temperature heat can be found to increase the utilization level of the system. The second is

the method of financing the initial system cost. If residential and commercial space and water heating systems are the only system consumers, financing at rates well below conventional interest rates would be required. If an industrial consumer(s) can be connected to the systems, the concept shows promise at commercial and/or bond rate levels.

Dickinson has experienced periodic water shortages for several years. Due to its dependence on a surface reservoir in a semi-arid climate, the cost of water in the city will always be expensive with respect to other North Dakota communities. The projected cost of \$1.66/1000 gallons (3785 ¢) at the end of treatment may be competitive with future alternative water supplies.

REFERENCES

1. Preliminary Technical Assistance Report on a Geothermal Heating Utility for Lemmon, South Dakota; Dunham Associates, Inc., Consulting Engineers, 528 Kansas City Street, Rapid City, South Dakota 57701; Prepared for EG & G Idaho, Inc., Subcontract No. K-7651.
2. "Prospective Piping Materials for District Heating Networks," I. Olikar, Burns & Roe, Inc. Oradell, New Jersey.
3. "Discussion Memorandum of Alternative Operating Structures & Financing Strategies for a Geothermal District Heating System at Dickinson, North Dakota," February 11, 1982, Prepared for the North Dakota Energy Office by Eliot Allen & Associates, Inc., Salem Oregon, under contract to EG&G Idaho, Inc.
4. "A Primer on Economic Feasibility for Direct-Users," by William B. Eastlake, Idaho Office of Energy, Geothermal Energy, Page 29, Vol. 8, No. 10 and 11, October/November, 1980.
5. "Geothermal District Heating Analysis Guide," by Paul J. Lienau, May, 1981, Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, Oregon 97601.

APPENDICES

APPENDIX A

CALCULATION OF ENERGY AND WATER REQUIREMENT
FOR THE STATE BOARD OF HIGHER EDUCATION
ADDITION TO THE CITY OF DICKINSON, NORTH DAKOTA

A. ANNUAL SPACE HEATING REQUIREMENT

1. Single Family Residential

Number of units - 556

Design Heating Load - 47.5 MJ/hr (45,000 Btu/Hr)

Number of Design Load Hours - 1,500 Hrs/Year

$$\text{Annual Heating Load} = 556 \times 47.5 \text{ MJ} \times 1,500 \frac{\text{Hrs}}{\text{Yr}} = 39.6 \times 10^3 \text{ GJ/Yr.}$$

2. Multi-Family Living Units

Approximate Number of Units - 1,444

Design Heating Load - 21.1 MJ/Hr (20,000 Btu/Hr)

Number of Design Load Hours - 1,500 Hrs/Year

$$\text{Annual Heating Load} = 1444 \times 21.1 \text{ MJ} \times 1500 \frac{\text{Hrs}}{\text{Yr}} = 45.7 \times 10^3 \text{ GJ/Yr}$$

3. Commercial Buildings

Number of Units - 24

Design Heating Load - 84.4 MJ/Hr (80,000 Btu/Hr)

Number of Design Load Hours - 1,350 Hrs/Yr

$$\text{Annual Heating Load} = 24 \times 94.4 \text{ MJ} \times 1350 \frac{\text{Hrs}}{\text{Yr}} = 2.7 \times 10^3 \text{ GJ/Yr}$$

$$4. \text{ Total Annual Space Heating Load} = 88 \times 10^3 \text{ GJ/Yr}$$

B. ANNUAL DOMESTIC WATER HEATING REQUIREMENT

1. Assumptions

Total Population - 7,500 People

Daily Hot Water Consumption - 76 l/Person (20 Gallons/Person)

System (Storage and Distribution) Efficiency - 80%

Incoming Water Temperature - 10°C (50°F)

Delivery Water Temperature - 48.8°C (120°F)

2. Total Annual Water Heating Requirement (TAWHR)

$$\text{TAWHR} = (7,500 \times 76 \frac{\text{Liter}}{\text{Person-Day}} \times 1 \text{ Kg/l} \times 4.18 \frac{\text{KJ}}{\text{Kg-}^\circ\text{C}} \times (48.8-10)^\circ\text{C} \times$$

$$365 \text{ Days/Yr}) \div .80 = 42.2 \times 10^3 \text{ GJ/Yr}$$

C. ANNUAL WATER CONSUMPTION

1. Assumptions

Total Population - 7,500 people

Daily Water Consumption - 450 liter/person (150 Gallons/Person)

2. Annual Water Consumption (AWC)

$$AWC = 7500 \times 568 \frac{\text{Liter}}{\text{Person}} \times 365 \frac{\text{Days}}{\text{Year}} = 1.55 \times 10^9 \text{ Liter/Year}$$

APPENDIX B

CALCULATION OF FLOWS FOR INDIVIDUAL
RESIDENTIAL AND COMMERCIAL UNITS

A. SPACE HEATING FLOW REQUIREMENT FOR SINGLE FAMILY RESIDENTIAL UNITS

1. Assumptions

Low-Temperature Panel System Delivering - 47.5 MJ/Hr (45,000 Btu/Hr)

Supply Temperature to System - 71°C (160°F)

Exit Temperature from Panel - 29.4°C (85°F)

2. Water Flow Requirement (WFR)_{SF}

$$(WFR)_{SF} = \frac{47.5 \text{ MJ/Hr}}{250 \frac{\text{KJ-min}}{\text{Kg-}^{\circ}\text{C-Hr}} (71^{\circ}\text{C}-29.4^{\circ}\text{C})} = 4.54 \text{ lpm}$$

B. SPACE HEATING FLOW REQUIREMENT FOR MULTI-FAMILY LIVING UNITS

1. Assumptions

Low-Temperature Panel System Delivering - 21.1 MJ/Hr (20,000 Btu/Hr)

Supply Temperature to System - 71°C

Exit Temperature from Panel - 29.4°C

2. Water Flow Requirement (WFR)_{MF}

$$(WFR)_{MF} = \frac{21.1 \text{ MJ/Hr}}{250 \frac{\text{KJ-min}}{\text{Kg-}^{\circ}\text{C-Hr}} (71^{\circ}\text{C}-29.4^{\circ}\text{C})} = 2.03 \text{ lpm}$$

C. SPACE HEATING FLOW REQUIREMENT FOR COMMERCIAL BUILDINGS

1. Assumptions

Low-Temperature Panel System Delivering - 84.4 MJ/Hr (80,000 Btu/Hr)

Supply Temperature to System - 71°C

Exit Temperature from Panel - 29.4°C

2. Water Flow Requirement (WFR)_{CB}

$$(WFR)_{CB} = \frac{84.4 \text{ MJ/Hr}}{250 \frac{\text{KJ-min}}{\text{Kg-}^{\circ}\text{C-Hr}} (71^{\circ}\text{C}-29.4^{\circ}\text{C})} = 8.12 \text{ lpm}$$

D. WATER HEATING FLOW REQUIREMENT (ALL UNITS)

1. Assumptions

Water Heating Capacity - 15.8 MJ/Hr (15,000 Btu/Hr)

Supply Temperature to System - 71°C

Exit temperature from Tank Coil - 60°C

D. WATER HEATING FLOW REQUIREMENT (ALL UNITS) Continued

2. Water Flow Requirement $(WFR)_{WH}$

$$(WFR)_{WH} = \frac{15.8 \text{ MJ/Hr}}{250 \frac{\text{KJ-min}}{\text{Kg-}^{\circ}\text{C-Hr}} (71^{\circ}\text{C}-60.0^{\circ}\text{C})} = 5.75 \text{ lpm}$$

E. COMBINED SPACE HEATING AND WATER HEATING FLOW RATES

1. Single Family Units	10.2 lpm (2.7 gpm)
2. Multi-Family Units	7.5 lpm (2.0 gpm)
3. Commercial Buildings	13.6 lpm (3.6 gpm)

APPENDIX C

DISTRIBUTION SYSTEM

BILL OF MATERIALS AND APPROXIMATE COSTS

Pipe Size	Type	Length (Ft)	Cost/Foot	Total Costs
2"	Uninsulated Polybutylene	2,500	\$ 1.05	\$ 2,625
2"	Insulated Polybutylene	2,500	7.00	17,500
3"	Uninsulated Polybutylene	18,600	2.80	52,080
3"	Insulated Polybutylene	18,600	8.00	148,800
4"	Uninsulated Polybutylene	16,200	4.80	77,760
4"	Insulated Polybutylene	17,800	10.50	186,900
6"	Uninsulated Polybutylene	5,000	9.10	45,500
6"	Insulated Polybutylene	3,100	15.25	47,275
10"	Uninsulated Fiberglass	10,000	20.00	230,000
10"	Insulated Fiberglass	10,000	23.00	200,000
				<u>\$1,008,440</u>
Assorted T's, Caps, and Transitions				25,000
Stub-Ins, Connection Taps, and Access Man-Holes				500,000
Trenching Installation and Backfill Costs (53,000 Ft x \$3/Ft)				159,000
Total Materials and Labor				1,692,440
Contractors Margin (30%)				<u>507,732</u>
TOTAL DISTRIBUTION SYSTEM COST				<u><u>\$2,200,172</u></u>

APPENDIX D
EQUIPMENT QUOTATIONS AND LITERATURE

Process Heat Transfer Corporation

2100 Highway 35 • Sea Girt, N.J. 08750
Telephone (201) 449-3560

October 20, 1981

The University of North Dakota
Engineering Experiment Station
Box 8102 University Station
Grand Forks, North Dakota 58202

RECEIVED
UNIVERSITY OF NORTH DAKOTA
Grand Forks, N. D. 58202

ATTN: Don V. Mathsen PE

Re: Tower system Feasibility
Study

Dear Mr. Mathsen,

We are in receipt of your communication of Oct. 13, 1981, with Figure 1 System concept enclosed.

Without going into exact details as to the intricate workings of our new fan Jet Tower, we feel it will or might be the answer to your problem.

It's modular design allows you to add on as required and or as the expansion of the community demands.

Naturally, the capacity of the pumping system will have to be adjusted.

For the relatively small load (even at Case 3, 3,600 gpm) a spray pond or field erected hyperbolic tower would probably be too expensive.

Our towers, without accessories, pumps, controls, concrete storage pits, etc. would cost approx. as follows:

Case 1) 1200 gpm (2 modules)	\$20,000.00
Case 2) 2400 gpm (4 modules)	\$40,000.00
Case 3) 3600 gpm (6 modules)	\$60,000.00

Of course, we could put the whole system together, and design the same to allow for expansion, by you adding drawings, flow, electrical control system designs, pump requirements, pit details etc. as deemed necessary to complete the project.

For estimate purposes, please note:

System 1) 1200 gpm, complete, with pumping and control system, and all other auxiliaries. Assume....	\$75,000 to \$100,000
System 2) 2400 gpm, same as above. Assume.....	\$100,000 to \$125,000
System 3) 3600 gpm, same as above. Assume.....	\$125,000 to \$150,000

A future formal proposal (upon request) will separate the necessary hardware and detailed design costs.

We appreciate your interest in our products, and if you have any questions, please do not hesitate to contact us.

Very truly yours,

Karl Moellering, President
Process Heat Transfer, PHT

KM:rb

Shell Chemical Company

A Division of Shell Oil Company

One Shell Plaza
P.O. Box 2463
Houston, Texas 77001

January 14, 1982

RECEIVED

JAN 13 1982

Mr. Don Matheson
University of North Dakota
Engineering Station
Grand Forks, ND 58202

ENGINEERING STATION
University of North Dakota
Grand Forks, N. D. 58202

Dear Mr. Matheson:

I enjoyed the opportunity to talk with you and discuss your feasibility study on district hot water heating. Per our conversation, I have enclosed a literature package describing the use of DURAFLEXTM polybutylene in a variety of plumbing, heating, and industrial applications. Based on the operating conditions you described, we feel quite confident polybutylene could serve your needs.

Further to our discussion, you asked for pricing estimates which I would like to elaborate upon. Shell Chemical Company does not manufacture nor insulate pipe so the figures we have included are approximate costs based on recent projects. As a final comment, we would mention that polybutylene is generally sold by SDR (standard dimension ratios) for a given set of temperature/pressure operating conditions. Based on conditions you described of 160°F at 80 psi, we would suggest an SDR 13.5. Both insulated and uninsulated prices are listed since many times insulation is not required on return lines. We have some approximate pricing on SDR 13.5 as follows:

Nominal Diam	O.D. in	I.D. in	\$ / ft	
			Uninsulated	Insulated
1-1/2	1.9	1.28	.70	-
2	2.375	2.02	1.05	-
3	3.5	2.98	2.80	8.00
4	4.5	3.83	4.80	10.50
6	6.625	5.64	9.10	15.25

We trust this information will be useful in your study, and we would be willing to visit and discuss any particular details you might have at the appropriate time.

Very truly yours,

S. E. Pregun
S. E. Pregun
Staff Business Representative
Polybutylene Department

Enclosure

cc - Doug Greig, Qest

FILTRONICS, INCORPORATED

1157 North Grove Street • Anaheim, California 92806 • (714) 630-5040

January 22, 1982

Mr. Donald V. Mathsen
Engineering Experimental Station
University of North Dakota
Box 8103
Grand Fork, N.D. 58202

Dear Mr. Mathsen,

Thank you for your recent inquiry regarding our Electromedia I iron and manganese removal system. Enclosed is the literature that we discussed. Bulletin Number 2001 includes general descriptive information concerning the Electromedia process, also included are the following items:

- ° Quotation
- ° Filter Drawing D-022
- ° Reaction Vessel Drawing D-014
- ° Process and Instrumentation Drawing D-003
- ° Control and Chemical Room Drawing D-024

The quotation is for a filtration system designed to treat a flow of 1200 gallons per minute. A review of this quotation will provide you with many specifics concerning the equipment that is furnished as standard with our filter stations.

The vessel drawings provide important details to facility plant piping; and the process and instrumentation drawing identifies the inter-relationship of all plant components.

The control and chemical room drawing provides one arrangement of equipment that provides an economical and complete operating facility.

We are looking forward to working with you on solving your iron and manganese problems and hope that you will feel free to contact us if there is anything else that we can do to be of service to you.

Very truly yours,
FILTRONICS, INC.

Clarence A. Magnusen, P.E.

CAM :jd

FILTRONICS, INCORPORATED

1157 North Grove Street • Anaheim, California 92806 • (714) 630-5040

January 21, 1982

Engineering Experimental Station
University of North Dakota
Box 8103
Grand Fork, N.D. 50202

Attention: Mr. Donald V. Mathsen

Quotation #820121

Gentlemen:

We are pleased to offer our proposal covering the following filtration system:

APPLICATION: Pre Reverse Osmosis Treatment For
Iron and Manganese Removal - Electromedia I

The system is designed for a maximum flow of 1200 gpm at 60 psi pressure, having a maximum iron content of 0.2 ppm, manganese content of 0.03 ppm, hydrogen sulfide/dissolved sulfide content of 0.10 ppm and total organic carbon of 2.0 ppm in the raw water supply. The filtered water will be consistent with the requirements for feed water to reverse osmosis equipment for these elements/compounds.

One Filtronic Model FH-14, Electromedia I Automatic Filter
Station designed according to the following specifications:

FILTER VESSEL

The filter vessel shall be 84" diameter x 170" straight sideshell, ends fitted with torispherical and flanged heads. Tank shall be fabricated from carbon steel according to ASME code procedures for unfired filter vessels, stamped and shall have a working pressure of 60 psig and test pressure of 90 psig. Ports and connections shall be according to the drawing D-022 enclosed and as follows:

Inlet and outlet:	10" flanged
Access manholes:	Two each, 11" x 15" oval type in top
Access manway:	One each, 20" diameter round, bolted in one end
Drain:	4" victaulic
Air vent:	1 1/2" flanged
Supports:	Welded cradle type support bases

This Proposal is Subject to the General Terms of Sale on the Reverse Side.

Filter to be internally blasted clean to a shadow free No. 1 white metal surface and coated with Keysite 740 epoxy lining, 12 to 15 mil. holiday free dry film thickness. Exterior surface to be coated with one shop coat zinc chromate primer.

Filter internal equipment shall consist of upper and lower manifolds of SCH 80 CPVC-4 pipe with CPVC-4 distributor heads, piping and collector tubes. Couplings, support braces and hardware to be stainless steel or epoxy coated.

PIPES, VALVES AND METERS

Face piping and valve assembly will be provided to complete the system for normal filtration, backwash and purge operations. Piping shall be 10" SCH 40 steel pipe with 150# forged steel flanged connections. Fittings shall be 125# cast iron flanged. Pipe 2" and smaller shall be standard galvanized iron threaded with galvanized iron 150# fittings.

Five each wafer type butterfly valves with Buna-N seat, bronze disc and stainless steel stems shall be provided with double acting pneumatic actuators.

Air vent valve to be epoxy coated, cast iron body, stainless steel internals. Pressure gauges to be 0 to 100 psig.

Backflush flow control valve shall be a 10" Filtronics Model 4237-4R, 125# class, brass trim, set at 2000 gpm.

A 10" Filtronics Tube Meter shall be provided to be installed in the backflush inlet line to accurately measure backflush rate.

Effluent rate of flow control valve shall be one each, 10" Filtronics Model 4237-4R, 125# class, brass trim, set at 1200 gpm.

A 10" Filtronics Tube Meter shall be provided to be installed in the filter effluent line to accurately measure filter rate.

REACTION VESSELS

Two reaction vessels shall each be 54" diameter x 132' straight sideshell, ends fitted with torispherical heads. Tanks shall be fabricated from carbon steel according to ASME code procedures for unfired pressure vessels, and shall have a working pressure of 60 psig and test pressure of 90 psig.

Ports and connections provided in accordance with code procedures and located to suit customer's special requirements. Interior and exterior finishes same as for filter vessel. Each reaction vessel provided with air vent valve, epoxy coated with stainless steel internals.

MEDIA

One complete Electromedia I load, including support layers, shall be provided. Installation of concrete bases and media shall be by others.

AUTOMATION

Automatic controls for full, unattended operation shall be provided. Controls shall be housed in a NEMA 12 steel cabinet mounted on the filter. (Remote mounting available) System ON-OFF switch shall be Allen Bradley or equal.

Timers shall be adjustable reset type. Differential pressure switch shall be adjustable 0 to 70 psi. Operation will include filtration timer with differential pressure override and backflush timer with interlocking relays, status lights, and low air alarm circuitry.

CHEMICAL EQUIPMENT

One lot chemical pretreatment equipment shall be manually set and automatically operated with continuous standby reserve of chlorine and sulphur dioxide. Included is injection pump operate against a maximum pressure of 60 psig.

The pump shall be 3 HP, 3/60/230-460 including disconnect switch and magnetic starter, three-leg overload protection, heaters mounted in NEMA 1 enclosure with hand-off-automatic function and reset located in the cover. The pump will be electrically interlocked with the automatic controls. Also included are:

- One each, Direct Cylinder Mounted Gas Chlorinator with automatic switchover, diffuser, ejector and close coupled corporation cock.
- One each, Direct Cylinder Mounted Gas Sulphonator with automatic switchover, diffuser, ejector and close coupled corporation cock.
- One each, System analyzer and 30-day strip chart recorder for accurate adjustment of chemical dosage.
- One each, 1 HP, 1/60/115-230 compressor for instrument air including v-belt guard, motor, drive and air tank.

CUSTOMER TO FURNISH

Single phase power to terminal strips located on control enclosure.

THIS PROPOSAL DOES NOT INCLUDE

1. installation
2. exterior plumbing
3. exterior wiring
4. concrete or concrete design
5. any other item not specifically mentioned in this proposal.

THIS PROPOSAL DOES INCLUDE

1. Two days start-up supervision by factory representative.
2. Filtration system dimensional and electrical drawings.

FILTER MODEL - FH-14

TERMS

Net 15 days to approved credit accounts.
F.O.B. Anaheim, California.
Prices do not include any applicable taxes.
This proposal valid for (30) thirty days.

SHIPMENT

14 - 16 weeks after approval of drawings.

SHIPPING WEIGHT

38,900 lbs. approximately.

PRICE

----- \$118,402.00

Very truly yours,
FILTRONICS, INC.

Clarence A. Magnusen, P.E.

CAM:jd

FILTRONICS INC.

1157 North Grove Street
Anaheim, CA 92803
(714) 890-5040

**INDUSTRIAL
AND
MUNICIPAL
FILTRATION
SYSTEMS**

ELECTROMEDIA I

IRON AND MANGANESE REMOVAL SYSTEMS

- FLOW RANGES TO 2300 GALS PER MINUTE
- IRON CONCENTRATIONS TO 4 PPM*
- MANGANESE CONCENTRATIONS TO 1 PPM*
- AUTOMATIC OPERATION
- VERY LOW BACKWASH TO FILTRATION RATIO
- TURBIDITY REMOVAL
- HYDROGEN SULFIDE TASTE AND ODOR REMOVAL
- NO GREEN SAND
- NO POTASSIUM PERMANGANATE (KMnO_4)

The Filtronics' SYSTEM FOR IRON AND MANGANESE REMOVAL is a revolutionary development in the water treatment industry. A proprietary media and special chemical

pretreatment system combine to provide a simple, safe, compact filtration system requiring only weekly attendance by maintenance personnel.

* Systems for higher concentrations available.

ELECTROMEDIA I

IRON AND MANGANESE REMOVAL SYSTEMS

STANDARD EQUIPMENT

- Flow range 30 to 2300 gpm simplex systems.
- 60 psi pressure tank ASME code, stamped. Higher ratings available.
- Filter tanks are carbon steel, epoxy lined at all wetted surfaces.
- Standard interior fittings: cast iron, PVC, and stainless steel.
- Each tank fitted with 11" x 15" manholes, 6" x 8" handholes, or manways depending on filter size.
- Backwash flow controls, air release valves, and automatic filter control valves provided as standard.

AUTOMATION: Automatic filter controls include automatic reset timers for filtration, backwash and purge. Backwash is initiated by time or differential pressure override. Controls housed in a NEMA 4 enclosure.

WARRANTY: Filtronics warrants its filtration equipment to be free from defects in material and workmanship for a period of one year from date of shipment. Any Filtronics filtration equipment found to be defective within such period will be repaired or replaced, upon return to the factory.

The foregoing warranty is exclusive and in lieu of all other expressed or implied warranties whatsoever including but not limited to implied warranties of merchantability and fitness for a particular purpose.

THE SYSTEM AND HOW IT WORKS

Well water containing iron, manganese, and hydrogen sulfide in varying concentrations is chemically treated with chlorine at the first tank. This step oxidizes these elements to a processable form and provides a free chlorine residual to the water distribution system. The second step is to introduce a catalyst to accelerate the reactions and condition the water for the final filtration step.

The filtration step collects the iron and manganese essentially in hydroxide forms. The filter is cleaned by reversing the flow using processed water. The backwash to filtration ratio is usually less than 5%.

Your Local Representative is:

The chemical pretreatment is manually set and automatically operated with stand-by reserve to provide continuous uninterrupted treatment. The effluent is continually monitored with a special analyzer to permit the positive and simple adjustment of the system.

The filtration controls provide for a completely automatic operation of the filter with flexibility in simple adjustment of the various filter cycles.

A pilot testing program is employed to insure the proper operation of every system. The cost of this program is deductible from the purchase price.

APPENDIX E

CALCULATION OF THE SPACE AND WATER HEATING
COSTS FOR THE STATE BOARD OF HIGHER EDUCATION
ADDITION TO DICKINSON, ND, WITH NATURAL GAS (1982 DOLLARS)

The following calculations reflect those natural gas costs replaced by the geothermal heating system.

A. ANNUAL SPACE HEATING REQUIREMENT

1. Single Family Residences (556 Units)
Annual Heating Load = 39.6×10^3 GJ/Year
Natural Gas Required = 4.57×10^4 Mcf/Yr
(82% Conversion Efficiency)
Total Cost = 4.57×10^4 Mcf/Yr x \$4.48/Mcf $\approx$ \$205,000
2. Multi-Family Living Units (1,444 Units)
Annual Heating Load = 45.7×10^3 GJ/Year
Natural Gas Required = 5.28×10^4 Mcf/Yr
(82% Conversion Efficiency)
Total Cost = 5.28×10^4 Mcf/Yr x \$4.48/Mcf $\approx$ \$237,000
3. Commercial Buildings (24 Units)
Annual Heating Load = 2.7×10^3 GJ/Year
Natural Gas Required = 3,158 Mcf/Yr
(82% Conversion Efficiency)
Total Cost = 3,158 Mcf/Yr x \$4.08/Mcf $\approx$ \$12,900

B. ANNUAL DOMESTIC WATER HEATING REQUIREMENT

1. Single and Multi-Family Units (2000 Units - 7500 People)
Annual Heating Load = 42.2×10^3 GJ/Year
Natural Gas Required = 4.85×10^4 Mcf/Yr
(70% Conversion Efficiency and 85% of Total Load)
Total Cost = 4.85×10^4 Mcf/Yr x \$4.48/Mcf = \$217,500

C. TOTAL GAS COSTS REPLACED BY THE GEOTHERMAL SYSTEM: \$672,400

D. ANNUAL MAINTENANCE COSTS ON GAS AND WATER HEATER EQUIPMENT

\$50/Unit x 2,000 Living Units = \$100,000

E. TOTAL NATURAL GAS OPERATING COSTS = \$772,400

APPENDIX F
OUTLINE OF DISTRIBUTION SYSTEM

————— Supply (Hot Water)
 - - - - - Return (Cold Water)

Preliminary layout of distribution system.