TOWN OF SPRINGHILL GEOTHERMAL COMMITTEE

TOWN OF SPRINGHILL GEOTHERMAL DEMONSTRATION PROJECT

REPORT ON THE TEST DRILLING AND PUMPING TEST RESULTS

PROJECT NO. 4215

JACQUES, WHITFORD & ASSOCIATES LIMITED

CONSULTING ENGINEERS

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REPORT TO THE TOWN OF SPRINGHILL
GEOTHERMAL COMMITTEE

BY

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1046 BARRINGTON STREET
HALIFAX, NOVA SCOTIA

SEPTEMBER 17, 1987

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1.0 INTRODUCTION

A program of test drilling and mine water pump testing was carried out in August 1987 at the site of the abandoned Springhill coal mine workings in springhill, Nova Scotia. This Geothermal Demonstration project was carried out under the direction of the Town of Springhill Geothermal Committee, with technical assistance provided by Jacques Whitford and Associates Ltd. Precision thermal logging services were provided by Mr. J. Leslie.

1.1 Background

The Town of Springhill Nova Scotia plans to investigate the feasibility of utilizing the anomalously warm groundwater (up to 21°C) in abandoned coal mine workings underlying the Town as a source of low cost geothermal heat for industrial or institutional applications located over the workings. The development of a source of low cost thermal energy would improve the economic aspects of existing industries in the area and would attract new industry to this area which would in turn provide increased employment in the Town.

Interest in the utilization of geothermal heat has been on-going since November of 1984 when Mr. Ralph Ross, Supervisor of All Saints Hospital in Springhill, presented a brief to council on the possible uses of mine water for space heating. The Springhill Town Council approved funding to investigate this idea, and appointed a committee to oversee the project and to visit a site using similar technology in Wilkes Barre, Pennsylvania.

A conceptual engineering study funded by Energy Mines and Resources Canada was completed by J. Booth Engineering Ltd.

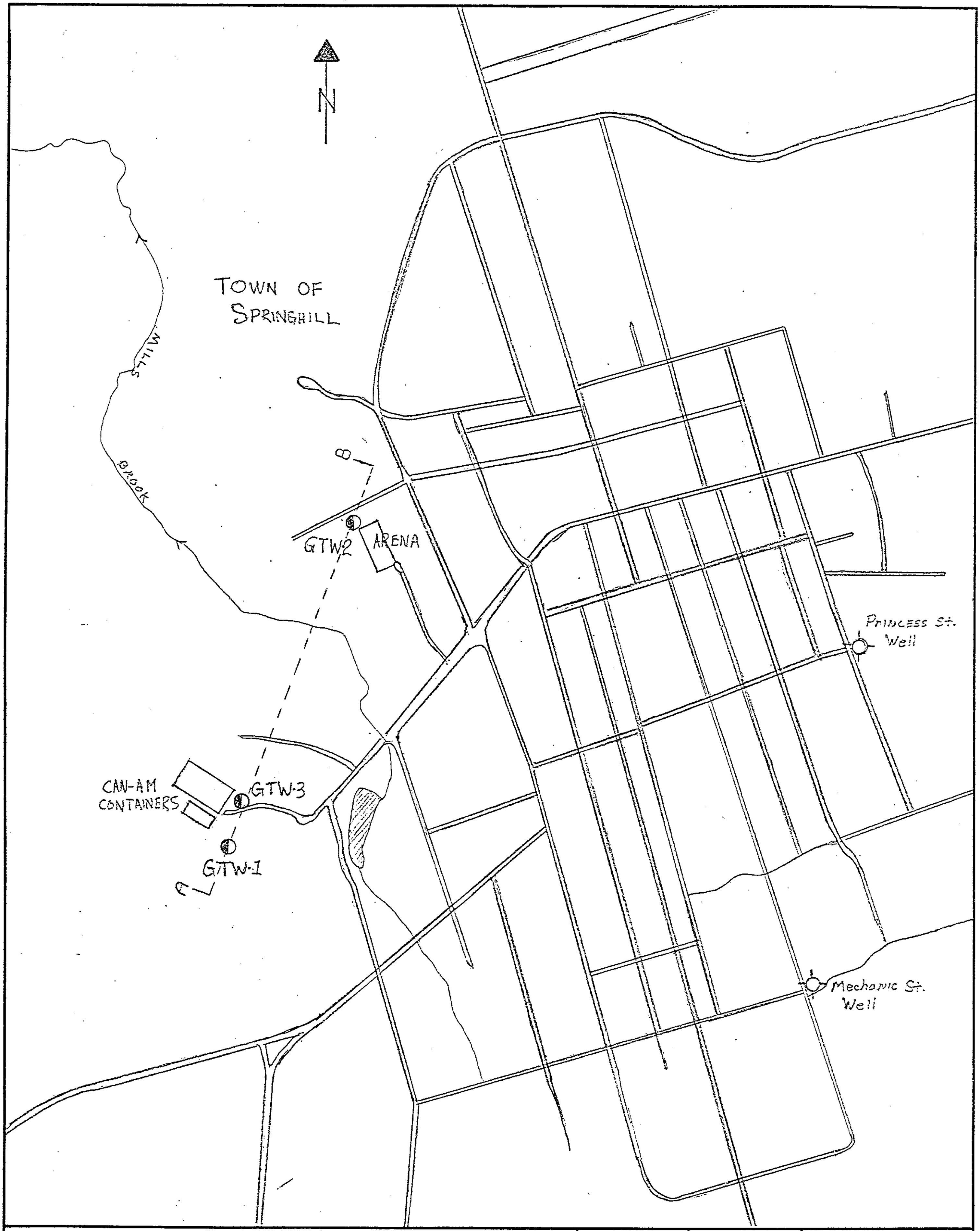

FIGURE 1. General Site Plan and Test Well Locations. Springhill Geothermal Demonstration.

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in 1986. This report concluded that the concept was technically sound, identified 24 facilities which could benefit from the project, and recommended that a test program be implemented to evaluate the geothermal resources underlying the Town for detailed design of the demonstration project. The Town Council has subsequently obtained funding from Energy Mines and Resources Canada to carry out a test drilling program and hydrogeological evaluation of two sites: one at the Industrial Park adjacent to the Can Am Containers Plant, and the other at the NSPC offices located west of the bowling alley (Figure 1).

1.2 Previous Studies of Mine Water Heat Pump Applications

A review of the available heat pump studies and reports indicates that to date there has been little investigation of the use of abandoned mine workings, and specifically coal mine workings, as a potential source of low grade geothermal energy. Two mine water heat pump systems in operation in the Wyoming Valley, Pennsylvania, were described by Schubert and McDaniel, 1982. These systems pump 5.6 to 5.7 L/s (75 to 80 igpm) at a temperature of 13 °C from shallow mine workings located 56 meters below ground surface. Both heating and cooling modes are used. These systems are operating well with no significant problems due to the elevated iron, sulfate and dissolved solids concentrations. The United States Dept. of the Environment has funded a geothermal demonstration project in the Wilkes-Barre area to assess heat pump applications for an industrial site, university buildings and a housing project (Schubert & McDaniel, 1982).

In Nova Scotia there has recently been interest by various groups in the utilization of the large groundwater reservoirs associated with the abandoned coal mines in the province, specifically in Springhill, which has the deepest coal mines in North America, in the Stellarton area of Pictou County and the extensive mines in Cape Breton, which underlie the second largest city in the province. A water supply well (71 m) constructed for Can Am Containers Ltd. in 1976 was reported to produce 4.54 L/s (60 igpm) with a water temperature in the order of 18 to 20°C. This well, which probably intersected coal seams or abandoned mine workings (38 m depth), were abandoned due to poor, (cloudy) water quality.

The feasibility of developing groundwater resources from the abandoned mine workings in Stellarton have been addressed by Meyboom (1961, Cross and Woodlock (1975), Novacorp, 1986 and CBCL (1987). It was concluded that this water is unsuitable for potable uses due to the poor chemical quality of the mine waters which typically exhibits elevated iron, manganese, TDS in the range of 2000 mg/L, sulphate, chloride and ammonia, but may have a number of industrial applications, including heating (CBCL,1987). Methane extraction studies by Novacorp in the early 1980's indicated that the mine water quality in the Foord, Allen and Stair pits ranged from a sodium bicarbonate to a calcium sulphate water increasing in hardness, sodium and chloride with depth. Mine water temperature ranged from 7.5° C in the shallow workings to 14.5° C for the deeper zones. (Nova Corp water quality monitoring, CBCL, 1987)

1.3 Study Objectives

The intent of this study is to demonstrate the use of geothermal heat from abandoned mine workings through the use of heat pump technology to produce low-cost heat for industrial and institutional consumers in the Springhill area. An assessment of the yield, thermal regime and geochemical conditions of the shallow mine reservoir is required to evaluate long term heat recovery potential and equipment design.

The study is organized into two phases: Phase 1 of the project will conduct an investigation of the Springhill geothermal resource sufficient to select a demonstration site(s), and provide baseline data on groundwater temperature, chemistry and hydrogeology for the optimum design of equipment materials and configuration, and development of accurate cost estimates by the design engineers.

Phase 2 will involve the design, construction and operation of a geothermal heat demonstration project at two locations in Springhill. A program of monitoring will be in operation throughout the Phase 2 demonstration project to obtain data on system performance and efficiency. This report presents the results of Phase 1 of the Geothermal Demonstration Project.

1.4 Project Rationale

The physical nature of groundwater makes it an excellent potential energy source in temperate climates. The specific heat capacity of water ($4.18\ J \bullet g^{-1} \bullet K^{-1}$) in general is higher than that of air (approx. $1.0\ J \bullet g^{-1} \bullet K^{-1}$), and in the case with groundwater flow systems, the heat retention capacity of the groundwater is augmented by that of the host aquifer, in this case coal-bearing sandstone and shale. In general, the seasonal variation in groundwater temperature is small, and is a function of depth and distance from the area of recharge. Furthermore, the average annual groundwater temperature is generally slightly higher than the mean annual air temperature of a given region, and as such, will be warmer than ambient in winter, and cooler than ambient in summer. In Nova Scotia, the average temperature of groundwater is around 7 degrees celsius, ranging from 3.8 to 10 degrees (NSDOE Records) which reflects the mean annual air temperature of 5.6 degrees celsius estimated for the Springhill area by Vaughan & Somers, (1980). Background groundwater temperatures in the Leamington area south of the study site is in the range of 8 to 10 °C for deep (150 m) test wells, (JWA, 1986). In the Springhill case, extensive deep mine workings provide an added bonus of 1300 metres of geothermal gradient and a large reservoir for heat storage.

A number of issues which could affect the performance of the geothermal system include:

- Long term safe yield of the mine reservoir
- Effects of shallow groundwater flow on the thermal regime, (e.g. aquifers above the workings) which could reduce the amount of heat available for recovery.
- Groundwater chemistry impacts on heat exchangers such as scaling in cooling mode, corrosion, iron precipitation, or explosion hazard (methane).
- Changes caused by temperature change or oxidation of the feed waters.
- Quality of mine waters for discharge to surface waters or re-injection into the mine workings (e.g. TDS, Fe, heavy metals, acid drainage)
- Seasonal transient groundwater temperature fluctuations, especially in the near surface areas.
- Bio-fouling of pump intakes, exchangers, and return well.

The pump testing program was designed to address the above, and to provide factual information regarding the temporal and spatial variation in groundwater temperatures in and around the mine workings, the volumes of groundwater flow in the strata overlying the mine voids, and the geochemistry of waters within the abandoned mines. The test drilling program was designed to obtain maximum information on temperature distribution, groundwater quality, and hydrogeology so that the mechanical equipment may be designed respecting possible water quality constraints, and the demonstration projects can be initiated using the test holes.

2.0 FIELD PROGRAM

2.1 TEST DRILLING

Three geothermal test wells (GTW) totalling 146 meters of drilling were constructed by R. White Well Drilling Ltd. on July 9, 10, and 14, 1987. The drilling sites were located near the Can Am Container plant and the community rink by Mr. John Calder of Nova Scotia Department of Mines and Energy, utilizing that agencies's mapping and resource drilling data pertinent to the old mine workings (Figure 1). Well drilling supervision and was provided by hydrogeologists from Jacques Whitford & Associates Ltd. (GTW 2 and GTW 3) and Mr. John Leslie of J. Leslie & Associates Ltd. (GTW 1).

Samples of rock cuttings were collected at 1.5 m intervals for interpretation at the JWA lab. Geologic logs were interpreted by JWA hydrogeologists with particular emphasis on the lithology and hydrogeology of the strata overlying the mine workings. Estimates of well yield were determined throughout the drilling by observation of air lift well discharge.

After completion of drilling, each test well was logged thermally and for dissolved oxygen by JWA personnel. Several profiles of temperature were taken by J. Leslie over the next few days after completion of drilling. Samples of groundwater were collected from both the overlying aquifer and from the coal zones after penetration (at GTW 1 and GTW 2). A water sample representative of stored water quality in the mine opening encountered in GTW 3 was collected with a double valve stainless steel bailer to characterize the geochemical regime prior to its disruption by pump testing. The results of these preliminary analysis (Table 1) were used to select key indicator parameters for monitoring during the pump test.

Geothermal Test Well 3 was reamed to 203 mm diameter to accommodate a 25 HP submersible pump. The well was cased to 8.22 meters into competent bedrock, and the remainder of the hole cleaned to the bottom of the mine opening. Full casing of the hole was not required due to the low yield and good structural integrity of the overlying formations.

The borehole logs are presented in Appendix 1, and include a summary of cumulative well yield determined from blow tests. Chemical analysis of bailed water samples are presented on Table 1.

2.2 Pump Testing Program

A seven day pump test was initiated on August 7, 1987 at a continuous discharge rate of 16.9 L/s (223 igpm). This rate was selected to simulate a major heat pump operation and to remove enough mine water to assess chemical changes. A 25 hp electric submersible pump was installed in the well to a depth of 42.2 m, approximately 1.0 m above the bottom of the workings. A 32 mm diameter PVC tube was attached to the pump column to a depth of 41.6 m to facilitate monitoring of the static water level in the workings during the test, and also allow thermal profiling of the water column after the test. The discharge was directed to a field about 75 meters north of the well, via a 100 mm fire hose. Discharge rate was monitored throughout the test with a series of flow meters, and controlled with a gate valve. Figure 2 illustrates the pump test set up.

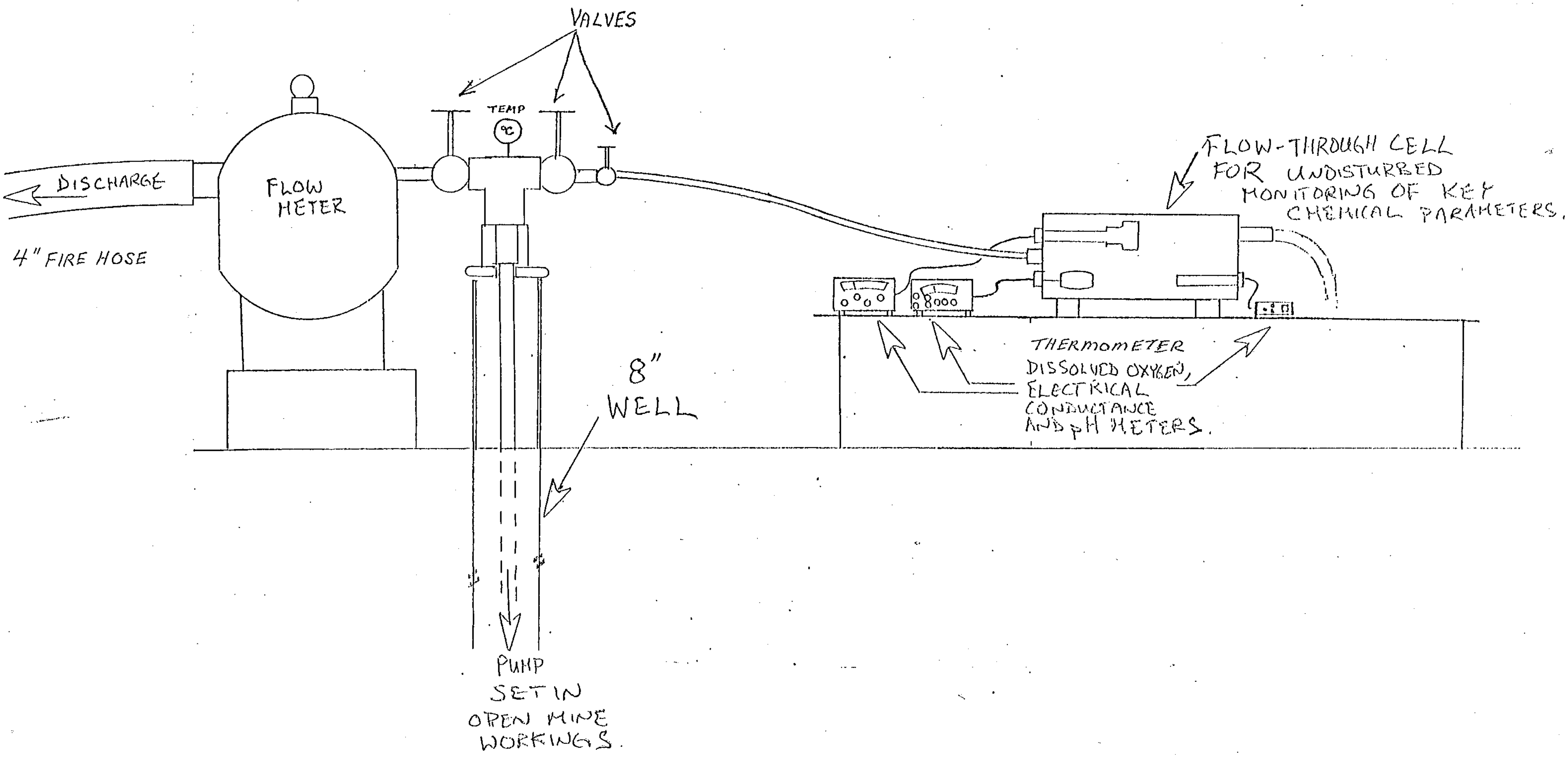

FIGURE 1. Schematic Illustration of Pump Test Set-up and Chemical Monitoring Apparatus for GTW - 3.

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Temperature of the discharge water was monitored throughout the test with a thermometer installed on the well head, hand held thermometers and the various instruments used to monitor temperature, conductance, and pH in a flow through cell (Figure 2). Close agreement was observed between the various techniques.

A flow through cell apparatus was installed on the discharge line to facilitate the collection of geochemical samples and to monitor sensitive parameters such as pH, dissolved oxygen, conductance and temperature without contact with the atmosphere. Three mine water samples were collected for complete general analysis. Sub-samples were filtered to 0.45 micron size and preserved with nitric acid for metal scans. In addition, 23 filtered and preserved samples taken at 6 hour intervals were analyzed for iron, sulfate and ammonia concentration. Appropriately preserved samples were collected at the beginning and termination of the test for analysis of hydrogen sulphide, methane gas, mercury and tritium. Samples were collected at 6 hour intervals throughout the test for analysis of key indicator parameters (sulphate, iron, ammonia) to assess chemical changes during pumping. All samples were submitted to the Environmental Chemistry Laboratory at the Victoria General Hospital, Halifax for analysis. Results are presented on Tables 1 and 2.

Table 1. Springhill Geothermal Demonstration Project. Chemical Analysis Results.

Well ID	GTW1	GTW1	GTW1	GTW2	GTW2	GTW2	GTW3	GTW3	GTW3	GTW3
Date	Jul 10/87	Jul 10/87	Jul 9/87	Jul 14/87	Jul 10/87	Jul 14/87	Jul 21/87	Aug 7/87	Aug 10/87	Aug 14/87
Depth	270'	112'	205'	165	146'	76'	142'	146'	146'	146'
Est Yield	30	30	30	30	100	120	400+	225	225	225
Sampled	bailed	bailed	airlift	bailed	airlift	bailed	bailed	1 h	72 h	168 h
Sodium	90.00	53.00	37.00	22.00	22.00	37.00	64.00	56.00	600.00	580.00
Potassium	10.50	14.50	10.50	14.00	14.00	13.00	18.30	14.00	26.00	27.00
Calcium	130.00	200.00	220.00	220.00	230.00	210.00	176.00	165.00	364.00	364.00
Magnesium	38.00	63.00	76.00	120.00	100.00	120.00	54.00	47.00	149.00	147.00
Hardness	481.00	739.00	862.00	1043.00	986.00	1018.00	662.00	606.00	1522.00	1514.00
Alkalinity	290.00	320.00		530.00		555.00	580.00	650.00	679.00	670.00
Sulphate	243.00	370.00	440.00	510.00	503.00	445.00	14.00	32.30	1540.00	1680.00
Chloride	47.00	67.00		45.00		46.00	58.00	55.00	480.00	450.00
Fluoride	0.40	0.20	<0.1	<0.1	0.20	0.20	0.30	0.20	0.30	0.20
Silica	10.00	11.00		4.30			21.00	22.00	16.00	16.00
O-Phosphorus	<0.01	<0.01		<0.01			<0.01	0.24	<0.01	<0.01
Nitrate	<0.05	<0.05		0.05		<0.05	<0.05	<0.05	<0.05	<0.05
Ammonia	0.17	0.28		0.16		0.10	1.60	1.30	1.70	1.70
Arsenic	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Iron	2.90	3.40	5.30	5.50	4.80	0.90	8.70	0.06	22.00	22.00
Manganese	0.53	0.82		1.10	2.00	0.73	1.10	0.81	1.10	1.10
Lead	0.006	0.014		<0.002	<0.002	<0.002	0.007	0.003	0.852	<0.002
Copper	<0.01	0.01		<0.01	0.02	<0.01	0.03	0.01	0.10	<0.01
Zinc	0.03	0.06		0.20	0.10	<0.01	0.07	0.07	0.10	0.12
Tot. Sol.	1117	1268	1453		1450	1333	993	781	3546	3734
S. Sol.	362	202			239	44	203	3	46	27
TDS	755	1066			1211	1290	790	778	3500	3707
Color	15	50		100	125	18	275	18	25	70
Turbidity	115	105		65	130	27	110	2	125	125
Conductance	1083	1360		1590	1460	1670	1207	1244	4350	4420
pH	7.50	7.40	7.50	7.00	7.40	7.00	7.10	7.00	6.80	6.80
Langlier Index	0.65	0.77		0.61		0.61	0.68	0.60	0.66	0.65
Diss. Oxygen								0.20		0.15
Temp (C)	12.00				9.30	13.80	13.00			
Aluminum				3.30				<0.05	<0.05	<0.05
Boron				0.04				0.07	0.19	0.19
Barium				0.03				0.26	0.05	0.04
Chromium				0.04				0.01	0.05	0.04
BOD				<2						
COD				<0.05						

All parameters in mg/L, except color (TCU), Turbidity (JTU), Conductance (mmhos/cm), pH

Table 2. Summary of Groundwater Monitoring Data For 7 Day Pumping Test.

Town of Springhill Geothermal Demonstration Project, August 7 to 14, 1987.

Date	Time hours	Drawdown (metres)	Temp. (C)	Conductance (mmhos/cm)	Diss. O2 (ppm)	Iron (mg/L)	Sulfate (mg/L)	Ammonia (mg/L)	pH
Aug. 7/87	0.1	0.01	14.2	820	0.75				7.07
	1	0.11	13.8	1244	0.40	0.1	32.3	1.3	6.94
	6	0.34	13.8	1000	0.20	4.1	59	1.4	6.87
Aug. 8/87	12	0.55	14.0	1290		7.7	122	1.5	7.03
	18	0.63	14.5	1690		10.4	323	1.7	7.41
	24	0.75	15.7	2290		18.7	790	1.8	6.82
	30	0.81	15.5	2350		22.5	880	1.9	6.98
Aug. 9/87	36	0.88	15.6	2400		23.8	920	1.8	6.74
	42	0.95	16.2	3250		19.8	1290	1.8	
	48	1.03	17.4	3610		15.0	1380	1.7	6.81
	54	1.07	17.2	3690		15.4	1540	1.7	6.73
Aug. 10/87	60	1.13	17.2	3700		15.0	1540	1.8	
	66	1.16	17.2	3750		14.7	1450	1.7	
	72	1.25	17.8	3890		22.0	1540	1.7	6.80
	78	1.27	17.7	3820		15.9	1600	1.8	
Aug. 11/87	84	1.31	17.7	3830		15.9	1580	1.8	
	91	1.37	17.5	3910		17.5	1540	1.7	
	96	1.4	17.9	3990		17.2	1500	1.7	
Aug. 12/87	114	1.52	17.9	4000		17.7	1450	1.8	
Aug. 12/87	120	1.56	18.0	3990		18.9	1540	1.9	
	126	1.61	17.9	3910		14.2	1580	1.8	
Aug 13/87	132	1.64	18.0	3880		14.0	1580	1.7	
	138	1.69	17.8	3950		17.4	1540	1.7	
	144	1.75	18.1	3990		16.0	1540	1.7	
	152	1.79	17.8	3910	0.24	16.9	1640	1.7	
Aug. 14/87	165	1.83	17.9	3790	0.35	19.4	1680	1.7	6.83
	168	1.84	18.0	4010	0.18	22.0	1680	1.7	6.84

3.0 DISCUSSION

3.1 Geologic Setting

The area of investigation is overlain by from 6.7 to 14.6 m of yellow brown silty gravel glacial till, increasing in thickness from GTW 1 northwards to GTW 2. Bedrock forms a topographical trough plunging towards the northwest. Bedrock encountered during the test drilling is described as predominantly grayish-green, carbonaceous and siderotic siltstone, shale, mudstone and minor fine-grained sandstone, which conforms to the description of the upper coal-bearing distal floodplain member of the lower fine facies of the Pennsylvanian-aged Cumberland group (Calder, 1980, Norwest, 1981). The fine grained materials tend to dominate in these areas, and no significant coarse sandstone units were encountered.

N.S. Dept. of Mines records indicate a mine slope dip of about 32 degrees to the northwest, which is consistent with the elevations of the observed coal encounters.

Figure 3 illustrates relationship between the three test wells, coal occurrences and the static water table. Several coal horizons were encountered in all holes. Major coal zones corresponding to the No. 1 and 2 slopes were identified by NSDME personnel. Abandoned water-filled mine workings were encountered in GTW 3 at 40.25 m depth, which were open to about 44 m depth.

Preliminary analysis of the test drilling results suggests that No. 2 slope was encountered in GTW 3 at 40.25 m depth, and possibly in GTW 2 at 50.6 m. Although no open mine workings were found in GTW 1, it is possible that the seam

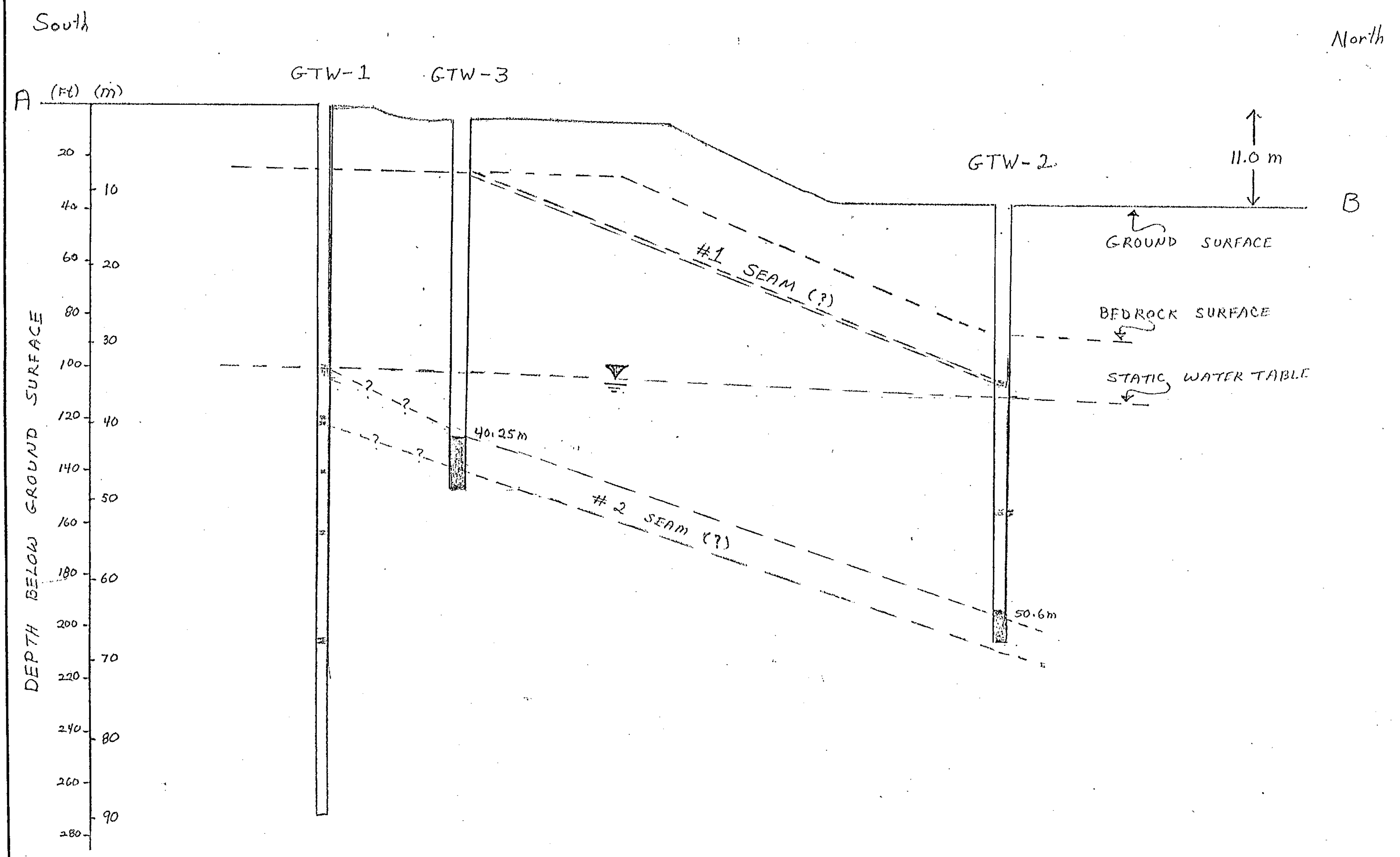

FIGURE 3. Conceptual Cross-section Of the Town of Springhill Geothermal Test Site.

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pinches out in this area (e.g. a small coal seam reported at 32 m depth in GTW 1,) or that a fault may be present. Two significant coal horizons were logged from 39.6 m to 53.3 m depth in GTW 1. The abandoned Can Am well, located 60 m southwest of GTW 3, may have encountered coal measures at 35.6 to 38 in depth; static water levels are reported at 30,.5 m, which is similar to GTW 1 and GTW 3.

In GTW 2 near the bowling alley, a small seam at 21.3 m may correlate with No. 1 seam (J. Calder, pers. com.) outcropping at the surface at GTW 3 where coal fragments were reported at the overburden-bedrock interface. The presence of wood fragments associated with the coal zone at the bottom of GTW 2 suggests that this well is likely immediately adjacent to workings. This is supported by the increase in well yield reported at this depth.

3.2 Groundwater Conditions

Hydrogeological logging of the test holes (Appendix 1) indicated very small groundwater inflows overlying the inferred mine workings at GTW 1 and GTW 3 at the Can Am Containers site, but substantial flows were observed at GTW 2 near the Bowling Alley. A maximum yield of 0.25 L/sec (2 to 3 igpm) was estimated above the coal zones at GTW 1 and GTW 3, and 7.6 L/s (100 igpm) was estimated by air lift blow testing at GTW 2 above the coal horizon. Total yield increased by about 1.5 to 2.3 L/s in the coal horizons in GTW 1 and GTW 2.

The combination of deep static water table (23.8 to 34.1 m below ground surface), direction of groundwater flow, and the increase in yield at the coal horizons at GTW 1 (2.3 L/sec (30 igpm) and GTW 2 (additional 1.5 L/sec (20 igpm) suggests that local groundwater flow is controlled by bedrock structure and the mine workings which appear to de-water the overlying beds at GTW 1 and 3. Groundwater flows towards the center of the northwesterly trending depression where extensive bedrock fracturing above the mine workings may provide good aquifer storage and more permeable conditions.

The mine waters are confined within the shallow workings. In GTW 3, static water level rose 8.22 m (27 ft) above the top of the mine. The consistent water levels across the site in the three wells (Figure 3) suggests hydraulic connection between the wells, likely due to the mine workings and consequent fracturing of the surrounding host rock. Estimated bailed well yields for the three test wells were 30 igpm (GTW 1), 120 igpm (GTW 2) and in excess of 400 igpm from the mine workings in GTW 3.

During the pump testing it was apparent that the three geothermal test wells were in hydraulic connection, recording total drawdowns of 1.86 m, 1.28 m and 1.36 m for GTW 3, 1 and 2 respectively after 7 days of continuous pumping at a rate of 17 L/sec.

3.3 Pump Test Results

During the test, static water level was monitored in the pumping well (GTW-3) and two observation wells (GTW-1 and GTW-2). At the end of the test, a total of 10,308 m^3 (2.27 x 10^6 imp. gal.) or the equivalent of 771 m of mine shaft 3.65 m square was removed from Number 2 seam. After 7 days of pumping, total drawdown in the shaft was 1.87 m, with 1.28 m and 1.36 m of drawdown recorded at GTW-1 and GTW-2 respectively (Figure 4).

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7 Day Pumping Test, Well GTW-3, August 7 to 14, 1987.

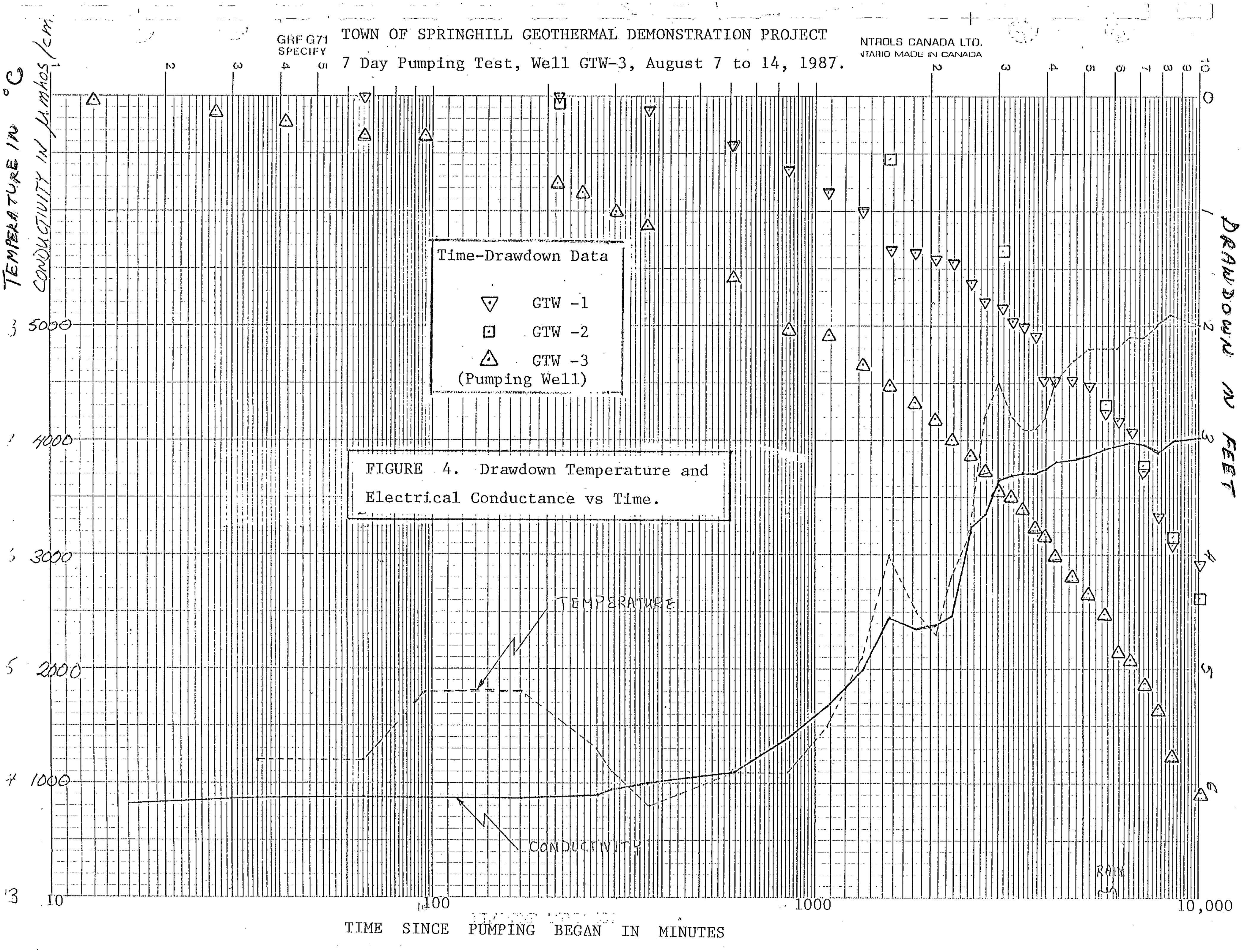


FIGURE 4. Drawdown Temperature and Electrical Conductance vs Time.

Figure 4 illustrates the drawdown behavior of the three wells during the 7 day test. After 220 minutes of pumping, the two observation wells began to respond, and conductivity values began to rise. The observed decrease in temperature at the time that the observation wells began to respond indicates movement of cooler groundwater towards the pumping well from distant areas. After 1000 minutes of pumping, a steady drawdown rate of 0.2 meters per day was observed in the production well, and 0.16 m/day in the two observation wells. Electrical conductance and temperature both rose steadily with increasing drawdown throughout the remainder of the test (Figure 4). The test clearly shows that the three wells are in hydraulic connection.

A decrease in the rate of drawdown between 1000 and 3000 minutes into the test, with associated decreases in temperature and conductance (1550-2100 min, and 3000-3600 min) suggests recharge from an outside source of cooler groundwater. Iron concentration increased dramatically over the same time period. Iron species are more soluble at lower temperatures. The delay in response of observation well GTW-2 until this time (1000 min) suggests that the source is the 100 igpm flow of groundwater encountered in the aquifer overlying the coal at GTW-2. This suggests hydraulic connection between the coal units and the aquifer identified north of the test site. Production wells located in this area will therefore need to be cased through the aquifer to the mine workings to prevent "thermal contamination" of the water.

During the test, 10 to 15 mm of rain from 93 to 101 hours into the test indicated only a negligible effect on drawdown, temperature and conductance (Figure 4). Although no decline was observed, a flattening of the rate of change was noted

(Figure 4). It is therefore possible that sustained periods of heavy rainfall may affect the thermal variation of the shallow system. During the Phase 2 work, careful monitoring of temperature during the spring and fall rain events should be implemented.

An accurate prediction of the long term sustainable yield of GTW 3 is not possible due to the large storage effect caused by many kilometers of mine workings. An estimate can be made, however, based on the rate of drawdown (0.17 m/day) over the final 4 days of the test. The well could be drawn down to the top of the shaft after 50 days of continuous pumping at 17 L/s, unless recharge boundaries are encountered. The data (Figure 4) infer an apparent system transmissivity of 180 m^2/day (12,000 igpd/ft. which suggests a 3 month continuous safe yield of 230 igpm) and a 20 year continuous yield of 18 L/s (175 igpm). This estimated safe yield is considered reasonable due to mine dewatering reports of 23 to 30 L/s. However it should be noted that this reported yield was for the entire mine, not just the shallow zones. The test does indicate that careful attention must be given to long term continuous flow rates in the shallow workings .

Drawdown should not be allowed to drop below the top of the mine workings. This would cause oxidation of the mine water and possible undesirable chemical quality change, such as iron precipitation, turbidity and explosion risk.

The recovery rate was very slow after termination of the pump test. After 4.5 hours of recovery measurements, the production well recovered 0.19 metres, with no observable recovery in the two observation wells. This reflects the slow drawdown response during the pumping test.

3.4 Water Temperature

Groundwater temperatures of up to 21°C (70°F) have been reported from exploration holes in the area (Can Am Containers Ltd.). It is suspected that much of this heat is due to deep geothermal gradients and possibly also exothermic reactions within the mine, which at 1310 meters (4300 feet) deep is one of the deepest coal mines in North America. The degree of input of heat from the coal burn areas to the shallower reaches of the mine by groundwater recharge is at present unknown, however the present work suggests that the majority of the warm water is from depth.

Another concern is the mixing of cooler groundwaters and rain recharge from the overlying bedrock formations with the warm mine waters, thus reducing the efficiency and C.O.P. of the heat pumps. The amount of yield of the test well above the mine openings will greatly affect the total cost of the demonstration well. Hydraulic response testing during the test drilling and the pumping test on GTW-3 suggests that the high yield encountered at GTW-2 will affect the performance of a geothermal well at that location, and indicates that the well must be cased the entire depth to the mine shaft,or packers can be used. At GTW-3 no casing or packers are needed for the demonstration.

Preliminary logging of the test wells with a YSI Model 33 SCT meter, a YSI Model 57 Dissolved Oxygen meter and a precision thermistor indicated consistent temperatures well above the provincial norm which ranges 3.8° to 10° celsius. Groundwater temperatures measured by JWA in the three wells prior to the pumping tests averaged:

GTW 1	11.5° C	(52.7° F)
GTW 2	9° C	(48.2° F)
GTW 3	13.8° C	(56.8° F)

A sample bailed by JWA from the bottom of the workings in GTW 3 recorded a temperature of 15.2°C or 59.9°F.

Thermal logging of the holes by J. Leslie prior to pumping and after the drilling are presented in Appendix 2. GTW 1 exhibited a slight decrease in temperature with depth on July 10, after drilling (Appendix 2) however, a profile of GTW 1 on July 21, 11 days after drilling by JWA, showed a slight temperature increase from 11.2°C at 35 m depth (1 m below water level) to 12°C at 52 m to the bottom of the hole. Logging of GTW 2 forty hours after drilling, indicated the lowest temperatures (9.3 °C) likely caused by the effects of the high flow rates (100 igpm) of shallow groundwater above the coal zone. This log suggests that this shallow groundwater has an average temperature of 9 °C. The profile for GTW 3, one hour after drilling indicated a consistent temperature of 13.35° C. Under pumping conditions over a period of seven days, the water temperature in this hole rose to 18° C.

Comparison of the JWA logging probe results with the high precision thermal logger used by J. Leslie shows a close correlation of about 3 percent.

As discussed in section 3.3, the shallow aquifer zones do affect the thermal variation of the shallow mine workings. Based on the pump test (Figure 4) this could be of concern at lower pumping rates which would require longer time to displace the cooler waters from the system, than at high pumping rates (225 igpm or more).

Based on the above, it is concluded that groundwater in the vicinity of the mine workings has a temperature in excess of regional means. Furthermore, it is possible that temperature could increase with depth and duration of pumping. For the purposes of this study, background groundwater temperature can be considered to be about 9.5°C (GTW 2 and other test wells in the Springhill area). The shallow mine workings exhibit temperatures in the order of 14°C at a depth of only 8.2 m below the water table, rising to at least 18° C under sustained pumping conditions.

3.5 Mine Water Chemistry

3.5.1 Test Well Water Quality

Chemically, the groundwater overlying the mine workings is similar to the moderately hard, alkaline, sodium to calcium bicarbonate water produced by the Town wells at Princess and Mechanic Streets to the east. These wells draw from shallow flow regimes in sandstone and shale units stratigraphically above the coal horizons.

Water quality data from blow test and bailed samples are presented on Table 1. Samples from GTW 1 and GTW 2 indicate a very hard calcium sulphate to calcium bicarbonate water associated with the coal zones. Calcium sulphate water with elevated sodium concentration (220 mg/L) was observed in a blow test sample from GTW 2 at the rink. A sample bailed from the top of the water table in this well showed a calcium bicarbonate water mixed with the sulphate waters, indicating the effect of the high yield of shallow groundwater on the chemistry of this well. Iron concentrations can be expected to be high, based on the oxidized blow test samples. The sample bailed from the workings after the completion of GTW-3 indicates a hard and alkaline (580 mg/L), calcium bicarbonate water elevated in iron (8.7 mg/L), manganese (1.1 mg/L), total solids (993 mg/L), Total Organic Carbon (105 mg/L), humic acids (33 mg/L) and ammonia (1.6 mg/L). The ph is near neutrality. Elevated suspended solids, colour and turbidity may be partially a result of the drilling process. Sulphate in this sample is low, but may indicate sulphate reduction to H_2S gas in this reducing environment. Dissolved oxygen levels were typically low, decreasing from 7 ppm at the water table, to less than 0.4 ppm in the mine.

3.5.2 Redox Conditions and Dissolved Gasses

Several profiles of dissolved oxygen were made on each well with the temperature logs. Immediately after completion of drilling, these logs showed a substantial decline with depth in concentration of dissolved oxygen, from near saturation at the water table to negligible concentration deeper in the hole, and rising again to supersaturated conditions at the bottom of the hole. This phenomenon is believed to be caused by air driven into the bedrock aquifer during drilling. Subsequent profiles taken 7 days later showed substantial decrease in D.O., which reached background levels of less than 0.05 mg/L after 11 days. Similar results were seen in GTW 3; however, no residual oxygen plume was left in the bottom of the well due to the presence of extensive voids (blow testing was carried out above the workings in the borehole).

During the Pump testing, dissolved oxygen concentration measured in the flow cell was in the range of 0.18 to 0.32 ppm. At the start of pumping, D.O. declined from 0.75 ppm to 0.20 ppm over the first 6 hours. It is expected that some oxygen uptake may have occurred between the well head and flow through cell. This very low concentration suggests that the mine waters are in a reducing geochemical environment as would be expected, due primarily to the uptake of oxygen during various redox reactions and organic (coal) decomposition. This condition is substantiated by the observed clear water quality upon release from the mine system, which quickly precipitates substantial quantities of iron as it contacts the air at the discharge pipe. Only minor H_2S was discerned during the test, and analysis indicated 0.10 mg/L or less of H_2S and 1.8 mg/L of ammonia in this water. Mine water pH levels ranged from 7.1 at the beginning of the test to a consistent average value of 6.8 throughout the test (Table 2). Ammonia rose from 1.3 mg/L at the start of the test, to a consistent value of 1.7 throughout the test.

At this time, the determination of the dissolve gasses in the mine water is not yet complete. Dissolved gasses observed in the mine water were not extremely high in quantity, however the presence certain gasses such as methane or hydrogen sulphide would provide the potential for a safety hazard. It is not likely that there is substantial dissolved H_2S. as determination of aqueous phase H_2S showed insignificant amounts. This is fortunate, as H_2S is very toxic as well as corrosive and an explosion hazard. The dissolved gasses are more likely to be methane, CH_4, also an explosive gas. The observed degassing rate and quantities did not suggest that this will be a major consideration, however it must be considered.

3.5.3 Dissolved Solids and Physical Characteristics

Electrical conductance is an indicator of TDS in groundwater.

Electrical conductance increased from 1000 microsiemens at the beginning of the test to 4420 microsiemens at the end of pumping (Figure 4). This observed increase in conductance is likely due to the dewatering of the low permeability zones above the mine workings. Electrical conductance values for the exploration boreholes ranged from 1029 to 1590 depending on depth. The higher conductivities later in the test reflect the higher TDS typical of coal mine waters. The TDS of the mine water is typically 3500 Mg/L under pumping conditions and about 1250 mg/L at static conditions.

Suspended solids and turbidity are moderate, at 27 to 47 mg/L and 125 JTU respectively (Table 1). This turbidity level should be considered in the design of the heat exchanger system. Color is typically high, ranging from 18 to 70 TCU over the 7 day period. The color is likely due to the elevated concentrations of iron and manganese in the water, and humic acids (33 mg/L) and TOC (105 mg/L). At the point of discharge, the effluent is very clear, but quickly shifts to a red-orange color upon exposure to the atmosphere.

3.5.4 Major Ion Chemistry

The major ion chemistry is shown in the Durov trilinear plot in Fig. 8, and a Piper Plot in Figure 9. Analysis results are presented on Table 1. Figure 8 plots the water samples in a two dimensional field based upon the relative predominance of the major ions. It can be seen that the local groundwaters are predominantly of a calcium-bicarbonate water type, (predominant cations and anions respectively). This sort of groundwater is indicative of fresh recharge water in a hydrogeological setting where calcium carbonate is the mineral of the greatest solubility encountered by the groundwater. The location of the study area, at the subcrop

SPRINGHILL GEOTHERMAL DEMO PROJECT

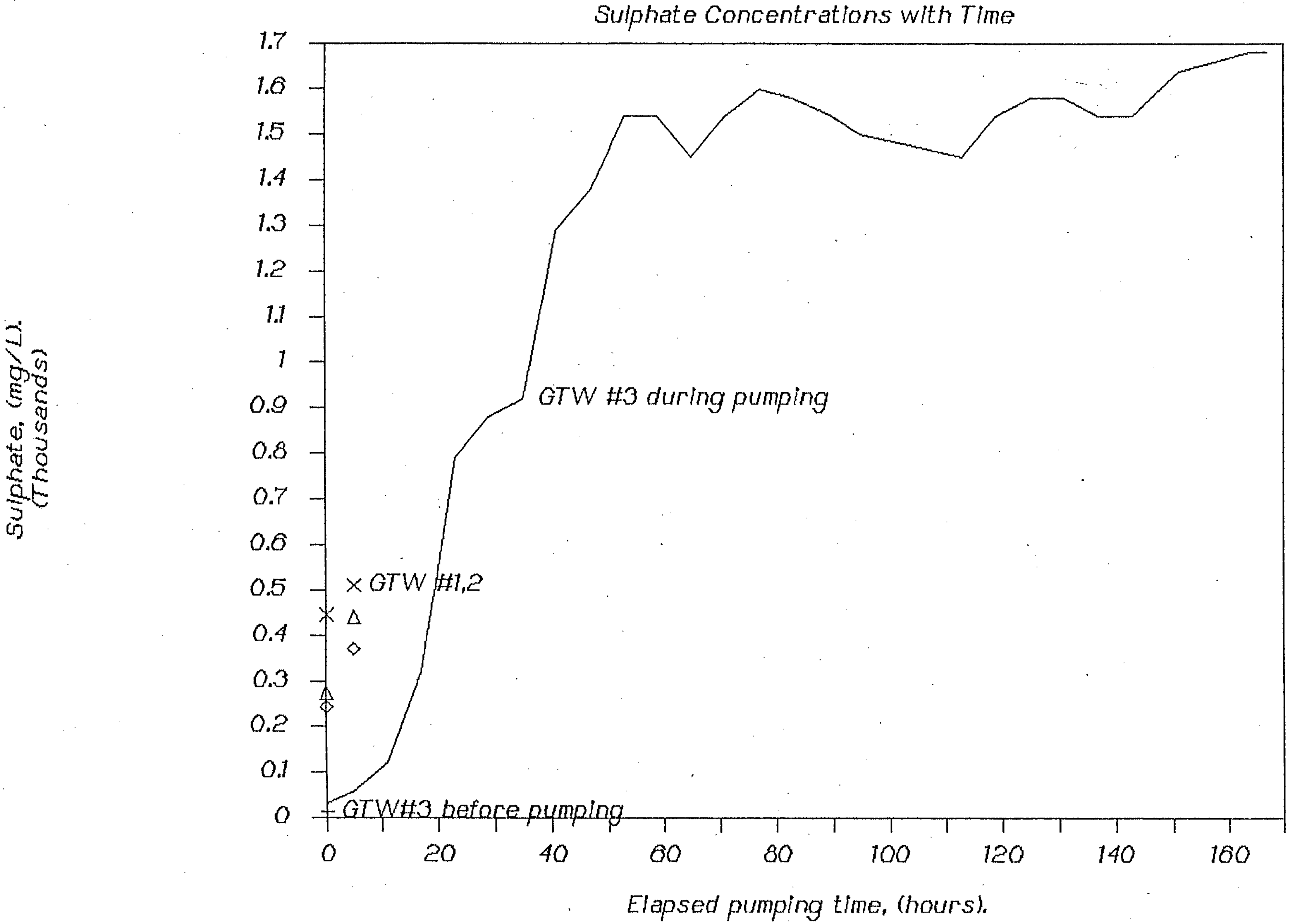


FIGURE 5.

SPRINGHILL GEOTHERMAL DEMO PROJECT

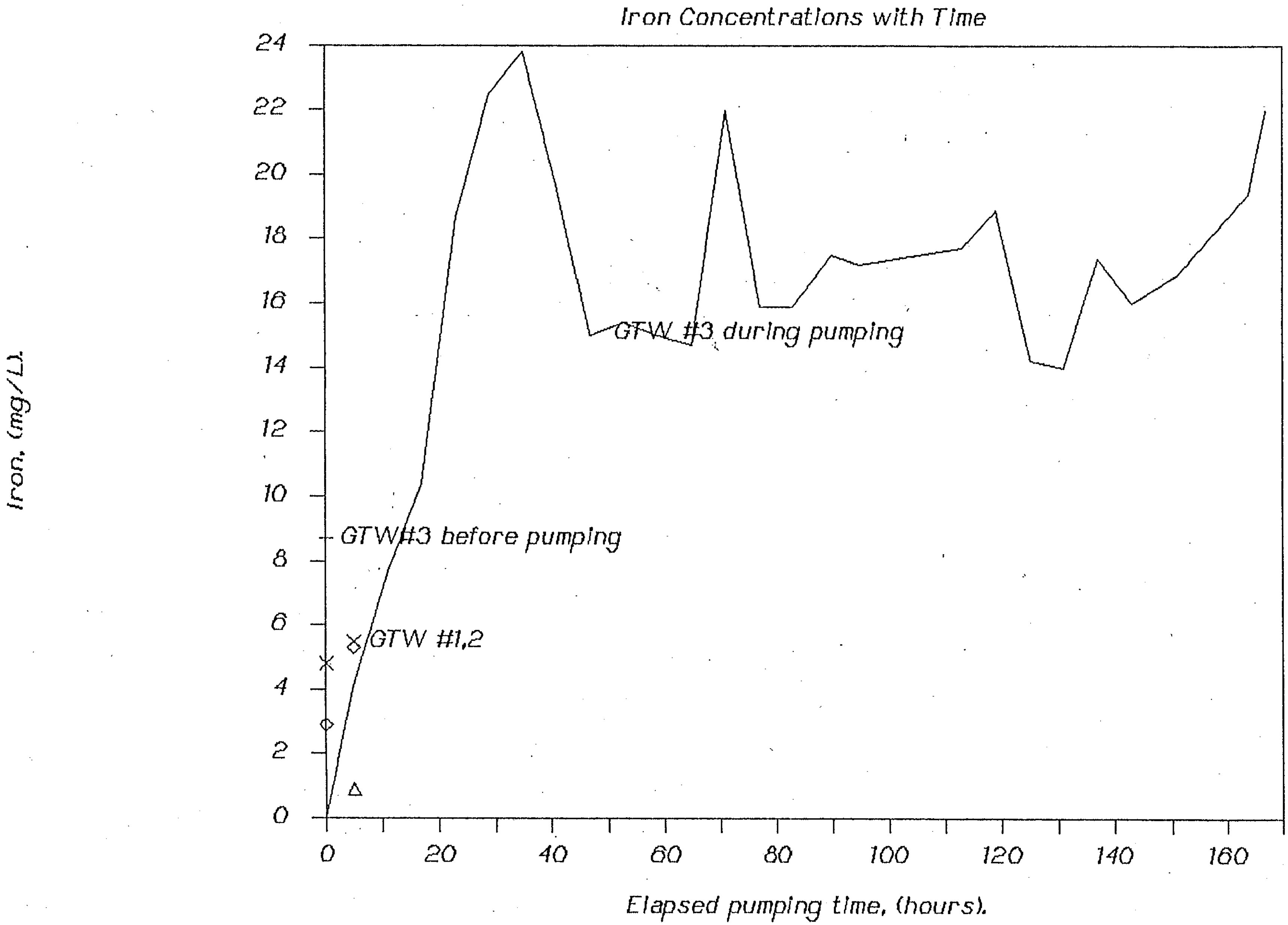


FIGURE 6.

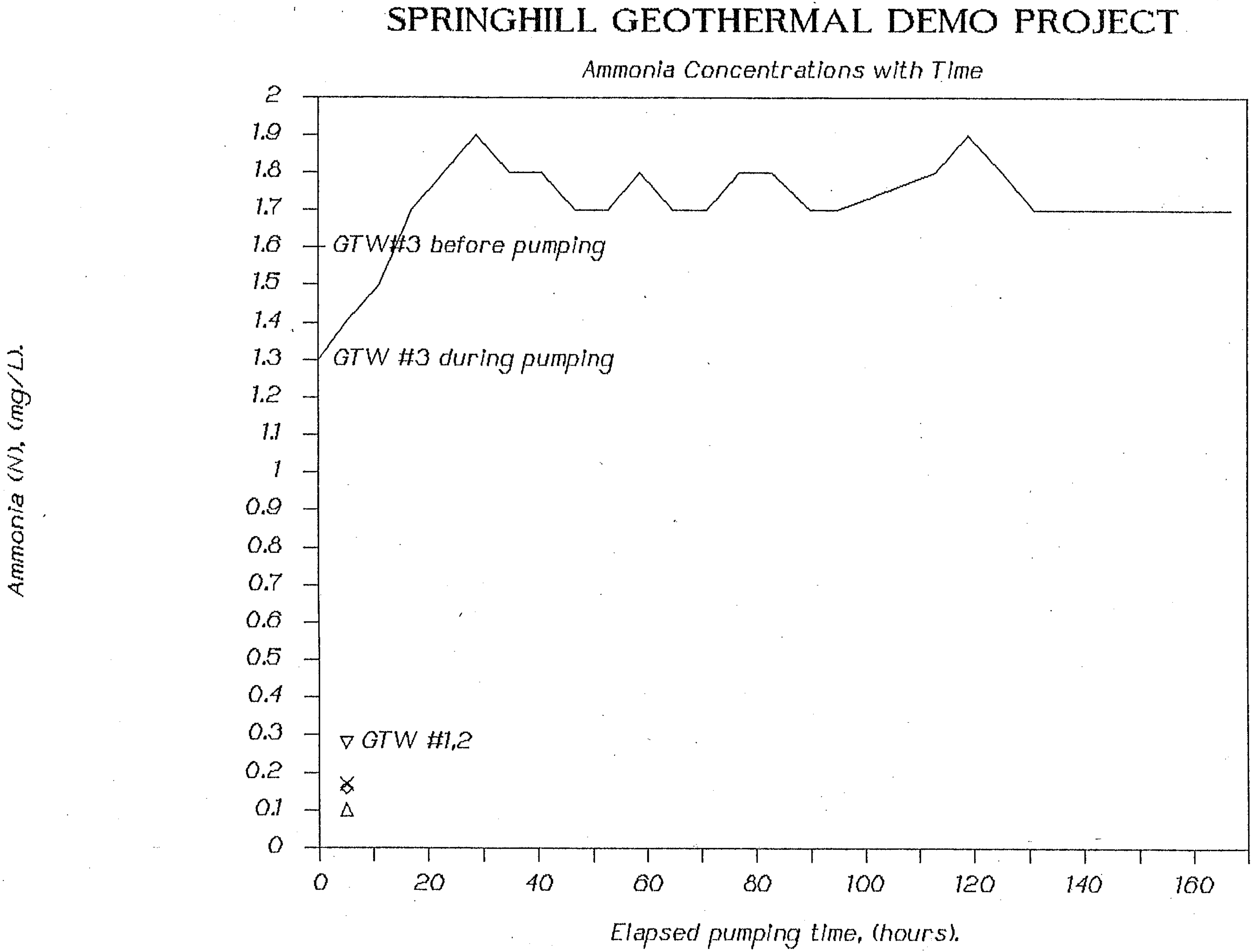

SPRINGHILL GEOTHERMAL DEMO PROJECT
Ammonia Concentrations with Time
Ammonia (N), (mg/L).
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
GTW#3 before pumping
GTW #3 during pumping
▽ GTW #1,2
×
◇
△
0
20
40
60
80
100
120
140
160
Elapsed pumping time, (hours).

FIGURE 7.

JACQUES, WHITFORD & ASSOC. LTD.

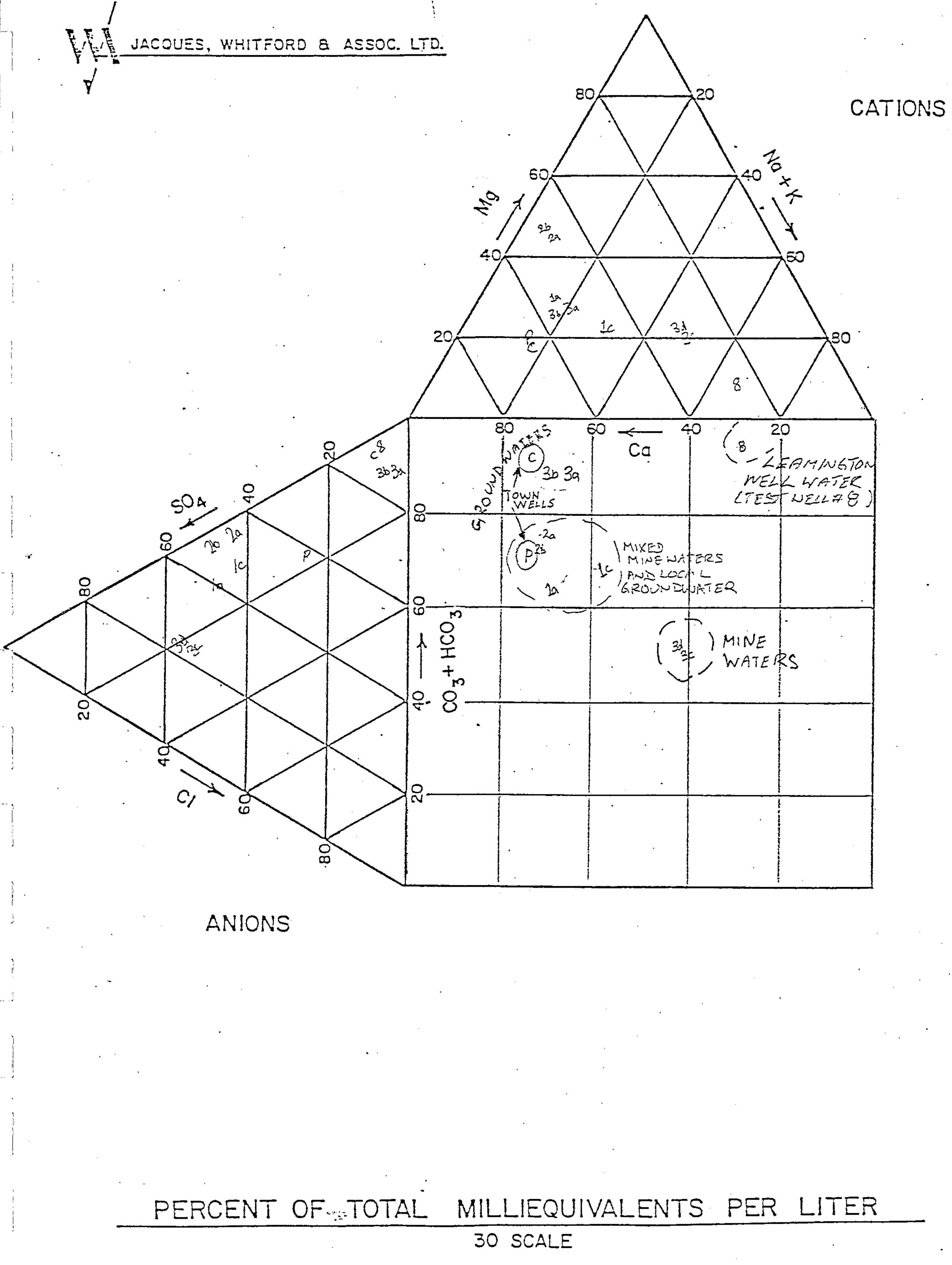


FIGURE 8. Durov Diagram of Major Ion Chemistry. Town of Springhill Geothermal Demonstration Project.

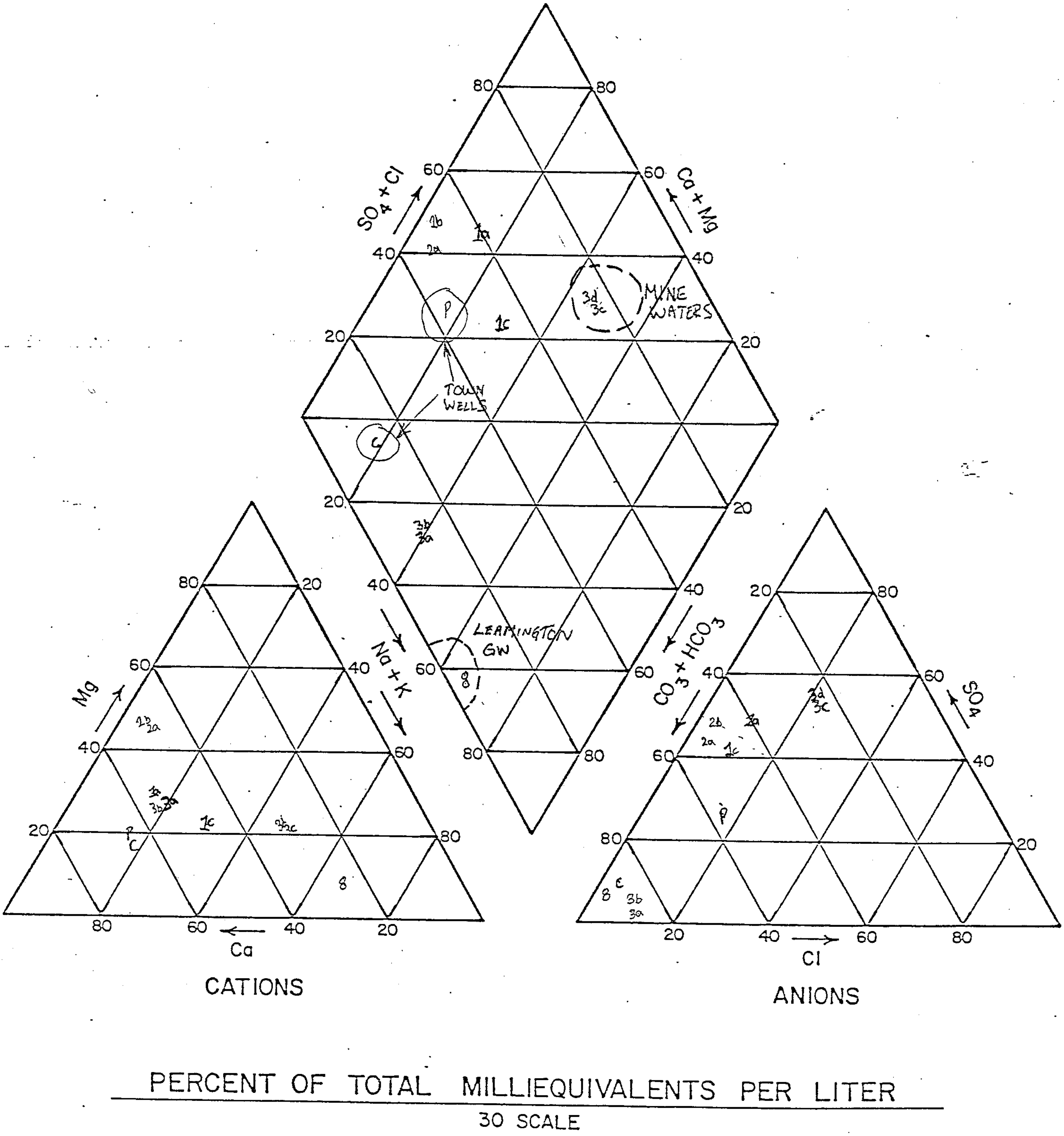


FIGURE 9. Piper Diagram of Major Ion Chemistry. Town of Springhill Geothermal Demonstration Project.

of the dipping strata overlain by sandy overburden, would tend to suggest that the area should be a recharge zone. As the groundwaters `age' and travel down the flow path there is a tendency for the calcium to be replaced by sodium by cation exchange as the water flows through clay-rich shale units, changing to a sodium bicarbonate type. This is illustrated on the durov diagram by the plot of the groundwater chemistry of test well #8, (JWA,1987) from the leamington district to the south of the study area.

The mine waters are significantly different in terms of their major ion chemistry. They are of a sodium sulphate chemical type, indicative of the dissolution of gypsum, and of cation exchange. Various other samples from geothermal test wells No.1 and 2, and from the Town of Springhill Princess street well, when plotted on the durov diagram fall approximately on a line in between the local recharging groundwaters and the mine waters indicating the possible mixing of the two water types (Figure 8). The mixing of warm mine water with local groundwater could have an influence on long term thermal regime of the shallow mine workings.

The distribution of temperature drawdown, sulfate, iron and ammonia with pumping time are presented on figures 4 to 7. These parameters were selected from the test well chemistries as indicator parameters most representative of mine water quality. A steady increase in temperature, conductivity (Figure 4), Sulfate (Figure 5), Iron (Figure 6) and to a lesser extent, Ammonia (Figure 7) was monitored throughout the test. Total iron and ammonia rose rapidly early in the test, peaking at 1.9 mg/L and 24 mg/L respectively 32 to 35 hours into the test. Maximum sulfate (1680 mg/L), conductivity (3700 mmhos/cm), and temperature occurred at about 50 to 55 hours. This suggests that after 50 hours of pumping the majority of the discharge water was derived from deep mine waters.

Concentrations of sodium and chloride rose from background values of 56 to 64 mg/L sodium and 55 mg/L chloride, to 600 mg/L sodium and 450 mg/L chloride at the end of the pumping test (Table 1). This reflects the increasing conductivity, temperature, iron and sulfate values and suggests a deeper water source. Sodium chloride waters have been reported from deep (152 m) test wells in the Leamington area of Springhill (JWA, 1986).

3.5.5 Trace Metal Chemistry

With the exception of iron (16 to 24 mg/L) and Manganese (1.1 mg/L), trace metal concentrations in the mine water are relatively low. Parameters above the analytical detection limits include: boron (0.02 to 0.19 mg/L), barium (0.03 to 0.26 mg/L), chromium (0.01 to 0.05 mg/l), lead (<0.002 to 0.85 mg/L), copper (<0.01 to 0.03 mg/L), and zinc (<0.01 to 0.20 mg/L). These are not likely to be in environmentally deleterious quantities. Lead concentration exceeded recommended drinking water limits in one sample. All other major metals were found to be below respective detection limits.

No mercury was found in samples field preserved with chromic acid. Significant quantities were not expected to be associated with the coals of the Springhill area, but mercury has been found to be associated with Carboniferous aged coals in the eastern part of north america, (principally in Pennsylvania coals).

3.5.6 Corrosion/Scaling Potential

The mine waters are not expected to be corrosive. The pH is near neutral, (6.8 to 7.4 range). There was little hydrogen sulphide found in the mine waters, (0.1 mg/L and less). The Langlier Calcite saturation Index is a measure of the degree of carbonate saturation of the groundwater and hence is commonly used to assess scale or corrosion tendency. The Springhill mine water averages + 0.65 at 20 °C, and would be in the order of +0.25 at groundwater temperatures of 5 to 7 °C at the discharge end of a heat pump system in heating mode, and +1.2 at 50 °C for a system in cooling mode. The thermodynamic equilibrium calculations using Wateq-F (Appendix 3) indicate that the mine waters are slightly oversaturated with respect to most carbonate and silicate species, and slightly undersaturated with respect to gypsum and anhydrite. The system is super-saturated with respect to most iron compounds.

This mine water has a low scale formation tendency, and should not pose any significant problems during heating mode. Only minor amounts of gypsum would be expected to come out of solution by decreasing the temperature to 6° C in a closed system. Most other minerals, including calcite, generally become more soluble at lower temperatures and should not cause increased scaling. In the cooling mode, where groundwater temperatures are increased to say 50 °C, there may be a tendency for precipitation of iron, carbonate, sulfate and silica compounds on the heat exchanger. If the system is to be used for cooling purposes, the use of Cupronickel in the exchanger design materials is recommended. This material tends to inhibit scale build-up due to its tendency to expand and contract during heat exchange.

3.5.7 Implications of Temperature Change and Aeration on Water Quality

To evaluate the effect of temperature change and oxidation/aeration on the chemistry of the mine water, a thermodynamic speciation model was utilized. Three runs were made (wateq F) for: the in-site mine water at 18°C and reducing conditions, the same water at 6°C under reducing conditions, and two runs simulating contact with the atmosphere at 6°C (heating mode) and 25°C (cooling mode).

The in-situ mine water is supersaturated with respect to iron species, slightly over-saturated with carbonate and silicate species, and slightly undersaturated with respect to sulfate species. These species are most likely to be involved in scale formation at the head exchanger.

In general, cooling the water to 6°C under closed system conditions (ie. no oxygen) should cause little scale problem. Gypsum solubility will decrease with lower temperature, and could cause minor scale. Heating the feed water on the other hand (ie. air conditioning mode) will tend to precipitate iron, carbonate and silicate at the exchanger.

Contact with the air must be avoided in all cases. At 18°C iron becomes supersaturated and precipites from solution. Calcite and dolomite solubility drops slightly, and gypsum remains the same. At 6°C, slightly less iron precipitation is expected and silicate may be deposited. At 25°C or higher, simulations indicate that all iron and carbonate minerals become more oversaturated, and are likely to precipitate.

The most important aspects of the chemical makeup of the mine waters, from the practical perspective of the operation of the system and the re-injection of the water will be associated with iron. Iron exists in the mine water in quantities analyzed at approximately 22 mg/L, total iron as Fe. A computer program used to determine chemical speciation and equilibrium predicts the iron species present to be predominantly $Fe^{2+}_{(aq)}$ (16.1 mg/L) and $FeSO_4{}^{0}_{(aq)}$ (15.7 mg/L). Calculations of potential iron precipitation under various thermodynamic conditions suggest that if exposed to the atmosphere, likely all of the sulphate-complexed iron will precipitate in the form of iron oxide, due to turbulence, pressure drop and temperature changes upon exposure to the atmosphere. As well, a substantial portion of the dissolved iron as Fe^{2+} may precipitate in the presence of oxygen. The amounts will depend on the temperature at which oxygen equilibrium is attained.

Under closed conditions, where the feed water is not allowed to contact the air, the precipitation of iron should be less of a problem. At higher temperatures, a larger iron precipitation problem will occur, due to reduced solubility of iron species. Therefore it is suggested that the design of the system include provision for the precipitation by the pumped waters, of approximately 40 mg/L of iron oxide, sulphate and carbonate scale.

The minimum expected iron scaling would be approximately 16 mg/L. The maximum iron scaling, if the water was used for air conditioning, heated to 25C and oxidized in a turbulent state, precipitating all Fe (III) iron as hematite would be approximately 40 mg/L. At the pumping rate used in the test, this corresponds to approximately 60 kg/day discharge to the environment. The iron scale will likely form mainly within the heat exchangers, and at constrictions etc. in the piping.

Calcium carbonate scaling should not be as great a problem. Although total calcium/magnesium hardness, (as $CaCO_3$) is approximately 1500 mg/L, calcium and magnesium species are not as substantially oversaturated as are those of iron. It is likely, however that some CaCO3 scaling will occur especially in the cooling mode.

The above considerations suggest that there could be significant problems with re-injection of the mine water to wells if the stream becomes oxidized prior to injection. Clogging of the aquifer or injection well will likely occur. Also, discharge of the effluent to surface water courses will result in discoloration and loading of up to 60 Kg per day or iron compounds.

4.0 CONCLUSIONS

1. The abandoned mine workings underlying the Town of Springhill are suitable for the development of low grade geothermal heat using conventional heat pump technology.

2. The shallow (40 m below ground surface) mine water is capable of at least 17 to 18° Celsius water temperatures under pumping conditions. Mine water temperatures during the test reached 18°C, which is twice the regional average groundwater temperature, and show indications of further increases.

3. The groundwater chemical regime associated with the mine workings will be predominantly a sodium-sulfate type of groundwater; reducing in nature, with dissolved oxygen and ammonia concentrations in the order of 0.1-0.2 ppm and 1.8 mg/L respectively; exhibit high hardness (1520 mg/L), Sulfate (1550 to 1650 mg/L), and total dissolved solids (3500 mg/L); a pH in the range of 6.8, and temperature in the range of 17.5 to 18 °C. There is a possibility of iron precipitation, and associated color in this water if it contacts the air, due to elevated concentrations of iron (16 to 24 mg/L) and manganese (1.1 mg/L typical), TOC (105 mg/L) and humic acid (33 mg/L). Suspended solids are in the range of 27 to 47 mg/L.

4. The key chemical concerns are the elevated iron, hardness, and sulfate which could precipitate at the heat exchanger or return well, and suspended solids (40 to 80 kg/day, predominantly iron) which could cause fouling of intakes if oxidation takes place.

5. The mine waters have a small scale forming tendency, based on laboratory analysis and computer simulations. Under closed conditions, the water should not cause significant problems when the heat pumps are in heating mode, but could deposit scale (iron, carbonate, sulfate, and silicate) under cooling mode operation which raises the temperature of the feed water.

6. Thermodynamic calculations indicate a potential for iron precipitation and clogging of re-injection wells or heat exchangers if the source water is allowed to become oxidized by exposure to the atmosphere. The water is supersaturated with respect to iron species, slightly oversaturated in carbonate and silicate, and slightly undersaturated with respect to gypsum and sulfur species.

7. The source of the high temperature water appears to be from depth in the mine, rather than from surface sources. This is supported by increasing conductance, iron, sulphate, salt and TDS and low dissolved oxygen with time of pumping. With the exception of a minor response in the No. 1 museum seam (0.12 m), during the test, no direct evidence was seen suggesting a direct connection with the burned waste dumps.

8. The shallow mine workings Penetrated by the three test wells are hydraulically interconnected. Drawdown response was observed in all wells and the mine shaft at the museum.

9. The high yield of groundwater (7.6 L/s) encountered over test well GTW-2 at the NSPC site is cooler (9.0°C) than the mine water, appears to be in hydraulic connection with the workings (1.34 m of response during pump

testing), and could reduce the overall thermal efficiency of a heat pump well in this area unless the well is cased into the workings.

10. A negligible change in temperature and chemistry were observed during a 5 hour rainfall event during the test. It is possible that rainfall events will influence the thermal regime of shallow (<100 m) mine workings, however the influence is expected to be small, and to decrease with depth.

11. Pumping test data suggest a recommended safe pumping rate 175 igpm continuous and 200-300 igpm short term, to prevent drawdown below the top of the mine workings. Regardless of the rate, continuous monitoring of drawdown must be implemented to prevent dewatering.

5.0 RECOMMENDATIONS

1. The heat pump system and exchanger methodology should be designed respecting the chemical characteristics of the mine water discussed herein.

2. It is recommended that a closed loop system be used, such that the mine water does not come in direct contact with the exchanger coils.

3. If the system is to be used for both heating and cooling purposes, the exchanger should be constructed of a cupronickel alloy that resists scale build-up due to its tendency to expand and contract with heating and cooling.

4. The water from the mine must be kept under pressure and isolated from the atmosphere prior to and during passage through the heat exchanger, to prevent iron precipitation.

4. The reject water should be re-introduced back into the mine workings at some distance down gradient from the source. Ideally, the mine water should flow through the heat exchanger under pressure and under ambient, non-oxidized conditions, directly to a subsurface return well where the water is re-injected back into the mine or another mine void below the water table such that oxidation does not occur. A significant likelihood exists of mineral precipitation, (calcium, sulfate, iron, silicate at injection wells under cooling mode operation if atmospheric conditions are encountered.

5. Once the demonstration heat pump system has been installed, and during the first year of operation, a

program of monitoring of such factors as temperature variation, hydraulic head fluctuation, water chemistry, power consumption and system performance should be implemented. This should include provision for temperature monitoring and collection of water samples for chemical analysis of key indicators (iron, sulfate, TOC, pH, conductivity, chloride, calcium).

6. Test wells in the vicinity of the NSPC office should be cased through the overlying aquifer to prevent thermal contamination of the source water by cooler aquifer water overlying the mine.

7. Drawdown should never be allowed to reach the top of the mine opening. The resultant oxidation of the water could adversely affect the heat pump system. Long term safe abstraction rates must be less than the yield of the mine. Pump test data suggest a continuous 20 year yield in the order 135 igpm, and a short term (2 month) yield of 230 igpm. Pumping equipment should include water level sensors and pump cut-out electrodes to prevent dewatering under high pumping rates.

8. The geothermal demonstration program should include a shallow monitoring well between the test site and the old waste dump to assess whether any recharge to the shallow mine workings originates from this source.

6.0 REFERENCES

Calder. J.H. (1980) Coal Exploration in the Springhill Coalfield. N.S. Dept. of Mines and Energy, Report 80-81, PP 41-50.

CBCL Limited (1987) Groundwater Development Potential of the Urbanized Sub-Regions of Pictou County, N.S. Report to the Municipality of the County of Pictou.

Cross, H. and Woodlock, T. (1975) Groundwater Potential of Pictou County, N.S. Preliminary report. Water Planning and Management Division, NSDOE. 15 p.

Jacques Whitford & Associates Limited (1986) Groundwater Resources Exploration, Phase 1. Town of Springhill, N.S. Report to the Town of Springhill Water Supply Steering Committee.

Meyboom, P. (1961) Prospects for a large industrial water supply in Two areas of Nova Scotia (Greenhill, Pictou Co. and Milford Hants Co.) GSC Topical Report No. 46. Can. Dept. Mines and Technical Surveys.

Novacorp Ltd (1986) Unpublished data files on the Stellarton Methane Recovery Project.

Norwest Resource Consultants Ltd. (1981) Geological Evaluation of the Springhill Project, For Novaco Ltd. Report No. 8115/6.

Schubert,J.P. and McDaniel, M.J. (1982) Using Mine Waters for Heating and Cooling. Argonne Nat. Laboratory Report 8204108.

Vaughan, J.G. and Somers, G.H. (1980) Regional Water Resources, Cumberland County, N.S. Water PLanning and Management Div., NSDOE. 80 p.

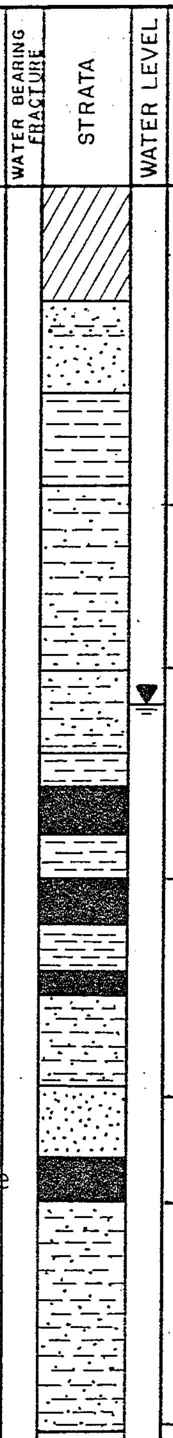
APPENDIX

TEST WELL

PROJECT No. 4215
DATE July 9, 1987
DRILLER R. White Well Drilling
ELEVATION 140 m (Approx.)
U.T.M. 20T-172552

WELL No. G1
DEPTH 82.3 m
CASING LENGTH 8.8 m
ESTIMATED YIELD 2.3 L/S
STATIC WATER LEVEL 34.1 m

DEPTH	LITHOLOGIC DESCRIPTION	CUMULATIVE WELL YIELD (BLOW TEST) L/S, DEPTH IN METRES
0		
5	Overburden	
10	Medium to fine light grey sandstone (some siltstone)	
15	Medium grey siltstone	
20	Medium grey siltstone and fine light to medium grey sandstone, (some dark grey sandstone) coal seen at 32 m	0.076 L/S
25		
30		0.23 - 0.30 L/S
35	Dark grey siltstone, some brownish grey siltstone and fine sandstone	
40	Grey siltstone - shale Coal	
45	Light grey siltstone and shale	0.53 - 0.61 L/S
50	Coal Dark grey shale, some fine light grey sandstone & white quartzite	
55	Coal or coal shale Medium grey siltstone and fine light grey fine and medium sandstone	
60	Light grey fine and medium sandstone	2.3 L/S
65	Dark grey shale, coal and some light grey siltstone	
70	Dark and medium grey siltstone with some light grey fine sandstone, becomes sandier with depth	
75		
80		



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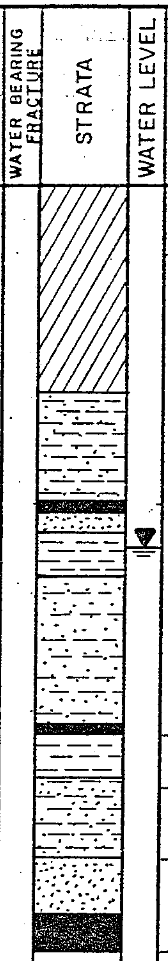
TEST WELL

PROJECT No. 4215
DATE July 10, 1987
DRILLER R. White Well Drilling
ELEVATION 20T - 169555
U.T.M.

WELL No. G2
DEPTH 50.6 m
CASING LENGTH 21.3 m
ESTIMATED YIELD 9.1 L/S
STATIC WATER LEVEL 23.8 m

(m) DEPTH	LITHOLOGIC DESCRIPTION	CUMULATIVE WELL YIELD (BLOW TEST) L/S, DEPTH IN METRES
5		
5	Overburden	
10		
15	Medium grey fine sandstone and siltstone	
20	Coal lense at 21.3 m Medium grey sandstone	
25	Soft grey shale	
30	Medium and dark grey sandstone and siltstone	
35	Coal or coal shale Grey and brown platy siltstone	0.15-0.23 L/S
40	Fine and medium grey sandstone, brown sandstone and grey siltstone	3.0-3.8 L/S
45	Grey and brown sandstone	7.6 L/S
50	Coal to 50.4 m, then into grey sandstone	9.1 L/S
		T = 11-12°C



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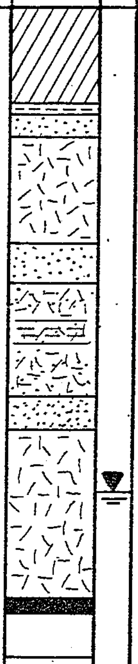
TEST WELL

PROJECT No. 4215
DATE July 21, 1987
DRILLER R. White Well Drilling
ELEVATION 137 m (Approx)
U.T.M. 20T-170552

WELL No. G3
DEPTH 43.3 m
CASING LENGTH 8.8 m
ESTIMATED YIELD 0.2 L/S
STATIC WATER LEVEL 32.0 m

DEPTH (m)	LITHOLOGIC DESCRIPTION	WATER BEARING FRACTURE	STRATA	WATER LEVEL	CUMULATIVE WELL YIELD (BLOW TEST) L/S, DEPTH IN METRES
0					
5	Overburden (coal shale at @ 4.6 to 6.1 m) Soft mudstone/shale				
10	Grey fine grainey sandstone Medium to dark grey siltstone				
15					
20	Grey fine to medium sandstone Hard red and grey mottled siltstone, some shale and sandstone				
25					
30	Fine medium grey sandstone Grey siltstone, minor sandstone and shale			▼	
35					
40	Coal Mine opening, coal and sandstone fragments(oxidized)				0.20 L/S @ 43 m T = 16°C
45					



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APPENDIX 2. TEST WELL THERMAL LOGS

(J. Leslie & Associates Ltd.)

TEMPERATURE LOG - SPRINGHILL MINE WATER PROJECT

Hole No.: 1 Total Depth: 82.1 m

Location: Can-Am Building Logged Depth: 82.1 m

Date: July 10, 1987, 15 hours after drilling.

Depth (m)	Temperature (C)	Lithology / Remarks
0.0	16.180	0 - 8.8 m: casing
5.0	14.185	
10.0	14.829	0 - 7.6 m: fill, overburden and weathered rock.
15.0	10.642	
20.0	10.765	
25.0	10.875	7.6 - 82.1 m: mainly siltstone with minor interbeds of mudstone. Coal (approx. 1 m) at 32.0 and 39.6 m. Coaly material at 45.7, 53.4 and 67.1 m.
30.0	11.070	
35.0	11.210	
40.0	11.351	
45.0	11.479	
50.0	11.593	
55.0	11.651	Water at 30.0 m.
60.0	11.708	
65.0	11.780	
70.0	11.694	
75.0	11.593	
80.0	11.522	
82.1	11.465	End of hole, end of log.

TEMPERATURE LOG - SPRINGHILL MINE WATER PROJECT

Hole No.: 1

Total Depth: 82.1 m

Location: Can-Am Building

Logged Depth: 82.1 m

Date: August 15, 1987, 24 hours after No. 3 hole pump test.

Depth (m)	Temperature (C)	Lithology / Remarks
0.0	-	0 - 8.8 m: casing
5.0	20.901	
10.0	19.358	0 - 7.6 m: fill, overburden and weathered rock.
15.0	18.854	
20.0	17.256	
25.0	16.727	7.6 - 82.1 m: mainly siltstone with minor interbeds of mudstone. Coal (approx. 1 m) at 32.0 and 39.6 m. Coaly material at 45.7, 53.4 and 67.1 m.
30.0	16.538	
35.0	11.031	
40.0	11.320	
45.0	11.439	
50.0	11.571	
55.0	11.641	Water between 30.0 and 35.0 m.
60.0	11.705	
65.0	11.752	
70.0	11.734	
75.0	11.648	
80.0	11.582	
82.1	11.487	End of hole, end of log.

TEMPERATURE LOG - SPRINGHILL MINE WATER PROJECT

Hole No.: 2

Total Depth: 50.0 m

Location: Rink

Logged Depth: 50.0 m

Date: July 12, 1987, 40 hours after drilling.

Depth (m)	Temperature (C)	Lithology / Remarks
0.0	23.456	0 - 21.0 m: casing.
2.5	20.575	
5.0	18.449	0 - 20.4 m: fill, overburden and weathered rock.
7.5	17.270	
10.0	15.970	20.4 - 48.5 m: mainly siltstone with minor mudstone. Coal fragments at 20.4 m.
12.5	15.084	
15.0	15.592	
17.5	14.037	48.5 - 50.0 m: coal.
20.0	12.953	
22.5	12.570	Water at 25.0 m.
25.0	8.877	
27.5	8.888	
30.0	8.921	
32.5	8.946	
35.0	8.961	
37.5	8.986	
40.0	8.999	
42.5	8.994	
45.0	9.006	
47.5	9.189	
50.0	9.296	End of hole, end of log.

TEMPERATURE LOG - SPRINGHILL MINE WATER PROJECT

Hole No.: 2 Total Depth: 50.0 m

Location: Rink Logged Depth: 50.0 m

Date: August 15, 1987, 24 hours after No. 3 hole pump test.

Depth (m)	Temperature (C)	Lithology / Remarks
0.0	17.958	0 - 21.0 m: casing.
2.5	17.042	
5.0	15.187	0 - 20.4 m: fill, overburden and weathered rock.
7.5	14.368	
10.0	13.346	20.4 - 48.5 m: mainly siltstone with minor mudstone. Coal fragments at 20.4 m.
12.5	13.280	
15.0	12.818	
17.5	12.558	48.5 - 50.0 m: coal.
20.0	12.376	
22.5	12.172	Water at 25.0 m.
25.0	9.017	
27.5	8.905	
30.0	8.933	
32.5	8.943	
35.0	8.953	
37.5	8.974	
40.0	8.986	
42.5	8.999	
45.0	9.029	
47.5	9.131	
50.0	9.369	End of hole, end of log.

TEMPERATURE LOG - SPRINGHILL MINE WATER PROJECT

Hole No.: 3 Total Depth: 44.2 m

Location: No. 2 Slope Logged Depth: 41.8 m

Date: July 21, 1987, 1 hour after drilling.

Depth (m)	Temperature (C)	Lithology / Remarks
0.0		0 - 8.3 m: casing.
2.5	22.462	
5.0	21.735	0 - 6.7 m: fill, overburden and
7.5	21.045	weathered rock. Coaly
10.0	20.112	at 6.7 m.
12.5	19.537	
15.0	18.964	6.7 - 40.9 m: mainly mudstone, minor
17.5	18.633	interbeds of siltstone
20.0	18.087	and fine grained
		sandstone.
22.5	17.676	40.9 - 44.2 m: mine workings.
25.0	17.462	
27.5	16.787	Water at 32.5 metres.
30.0	16.270	
32.5	13.360	
35.0	13.354	
37.5	13.354	
40.0	13.354	
41.8	13.345	End of log.

APPENDIX 3. Thermodynamic Chemical Data for In-Situ Mine Water (WateqF).

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                                  ----
                                  DATA
                                  ----

  I NREACT      DH      LOGKTO         I NSPEC      Z  DHA    GFW

  1 KFE +3      9.7000  -13.0380       1 CA         2  6.0   40.0800
  2 KFEH+2     20.1150  -15.2280       2 MG         2  6.5   24.3120
  3 KFEOH+     13.2180   -9.5000       3 NA         1  4.0   22.9898
  4 KFEOH3     30.3000  -31.0000       4 K          1  3.0   39.1020
  5 KFESO4     13.6100   -9.1180       5 CL        -1  3.0   35.4530
  6 KFECL      18.1520  -11.6000       6 SO4       -2  4.0   96.0616
  7 KFECL2       .0000  -10.9190       7 HCO3      -1  5.4   61.0173
  8 KFECL3       .0000  -11.9250       8 FE         2  6.0   55.8470
  9 KFESO       3.2300    2.2500       9 FE         3  9.0   55.8470
 10 SIDERITE   -6.1400  -10.5700      10 FEOH       2  5.0   72.8544
 11 MAGNESIT   -6.1690   -8.2400      11 FEOH       1  5.0   72.8549
 12 DOLOMITE   -9.4360  -17.0900      12 FE(OH)3   -1  5.0  106.8690
 13 CALCITE    -2.2970   -8.4800*     13 FEHPO4     1  5.4  151.8200
 14 KH3SIO4     8.9350   -9.9290*     14 H2S AQ     0   .0   34.0799
 15 KH2SIO4    29.7170  -21.6170*     15 FESO4      1  5.0  151.9086
 16 KHPO4      -3.5300   12.3460      16 FECL       2  5.0   91.3000
 17 KH2PO4     -4.5200   19.5530      17 ANAL H2S   0   .0   34.0799
 18 ANHYDRIT   -4.3000   -4.3840      18 CO3       -2  5.4   60.0094
 19 GYPSUM      -.0280   -4.6020*     19 MGOH       1  6.5   41.3194
 20 BRUCITE      .8500  -11.4100      20 MGF        1  4.5   43.3104
 21 CHRYSOTL   27.5850  -51.8000      21 MGCO3 AQ   0   .0   84.3214
 22 ARAGONIT   -2.5890   -8.3360*     22 MGHCO3     1  4.0   85.3293
 23 KMGF        4.6740    1.8200      23 MGSO4 AQ   0   .0  120.3736
 24 KCASO4      1.5000    2.3090      24 H4SIO4AQ   0   .0   96.1155
 25 KMGOH       2.0900    2.2100*     25 H3SIO4    -1  4.0   95.1075
 26 KH3BO3      3.2190   -9.2350*     26 H2SIO4    -2  5.4   94.0995
 27 KNH3       12.4770   -9.2440*     27 OH        -1  3.5   17.0074
 28 FORSTRIT    4.8700  -28.1100      28 FECL2      1  5.0  126.7530
 29 DIOPSIDE   21.1000  -36.2200      29 CAOH       1  6.0   57.0874
 30 CLENSTIT    6.6750  -16.8700      30 CAHCO3     1  6.0  101.0973
 31 KNAHPO       .0000     .2900      31 CACO3 AQ   0   .0  100.0890
 32 TREMOLIT   90.2150 -140.3000      32 CASO4 AQ   0   .0  136.1416
 33 KKHPO4       .0000     .2900      33 FECL3      0   .0  162.2060
 34 KMGHPO4     3.3000    2.8700      34 FESO4      0   .0  151.9086
 35 KCAHPO4     3.3000    2.7390      35 SIO2 TOT   0   .0   60.0848
 36 KH2CO3     -2.1770    6.3520*     36 H3BO3 AQ   0   .0   61.8331
 37 SEPIOLIT   26.5320  -40.1000      37 H2BO3     -1  2.5   60.8251
 38 TALC       45.0650  -62.2900      38 NH3 AQ     0   .0   17.0306
 39 HYDMAG    -25.5200  -37.8200      39 NH4        1  2.5   18.0386
 40 ADULAR     30.8200  -20.5700      40 MGPO4     -1  5.4  119.2834
 41 ALBITE     25.8960  -18.0000      41 MGH2PO4    1  5.4  121.2993
 42 ANORTH     17.5300  -19.3300      42 NACO3     -1  5.4   82.9992
 43 ANALCM     18.2060  -12.7000      43 NAHCO3     0   .0   83.9909
 44 KMICA      67.8600  -49.0900      44 NASO4     -1  5.4  119.0514
 45 PHLOG        .0000  -52.5300      45 PO4       -3  5.0   94.9714
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46 ILLITE      54.6840   -40.3100       46 KSO4       -1  5.4   135.1636
47 KAOLIN      49.1500   -36.9100       47 HPO4       -2  5.0    95.9794
48 HALLOY      44.6800   -32.8200       48 H2PO4      -1  5.4    96.9873
49 BEIDEL      60.3550   -45.2600       49 CAF+        1  5.0    59.0784
50 CHLOR       54.7600   -90.6100       50 NAHPO4     -1  5.4   118.9692
51 ALUNIT      29.8200   -85.3200       51 AL          3  9.0    26.9815
52 GIBCRS      14.4700   -32.7700       52 ALOH        2  5.4    43.9889
53 BOEHM       11.9050   -23.4100       53 AL(OH)2     1  5.4    60.9962
54 PYROPH        .0000   -42.4300       54 AL(OH)4    -1  4.5    95.0110
55 PHILIP        .0000   -19.8600       55 ALF         2  5.4    45.9799
56 ERION         .0000      .0000       56 ALF2        1  5.4    64.9783
57 CLINOP        .0000      .0000       57 ALF3        0   .0    83.9767
58 MORDEN        .0000      .0000       58 ALF4       -1  4.5   102.9751
59 NAHCOL       3.7200    -.5480        59 ALSO4       1  4.5   123.0431
60 TRONA      -18.0000    -.7950        60 AL(SO4)2   -1  4.5   219.1047
61 NATRON      15.7450   -1.3110        61 KHPO4      -1  5.4   135.0814
62 THRNAT      -2.8020     .1250        62 F          -1  3.5    18.9984
63 FLUOR        4.7100  -10.9600        63 HSO4       -1  4.5    97.0696
64 MONTCA      52.3730  -45.0000        64 H           1  9.0     1.0080
65 HALITE        .9180    1.5820        65 FEH2PO4     1  5.4   152.8340
66 THENAR       -.5720    -.1790        66 H2S CALC    0   .0    34.0799
67 MIRABI      18.9870   -1.1130        67 HS         -1  3.5    33.0720
68 MACKIT        .0000   -4.6310        68 S          -2  5.0    32.0640
69 KHCO3       -3.5610   10.3290*       69 SRHCO3      1  5.4   148.6373
70 KNACO3       8.9110    1.2680        70 PO2         0   .0    31.9988
71 KNAHCO3       .0000    -.2500        71 PCH4        0   .0    16.0430
72 KNASO4       1.1200     .7200        72 AH2O        0   .0    18.0153
73 KKSO4        2.2500     .8470*       73 MGHPO4      0   .0   120.2914
74 KMGCO3       2.7100    2.9800*       74 CAHPO4      0   .0   136.0594
75 KMGHCO3      1.0770    1.0660*       75 CAPO4      -1  5.4   135.0514
76 KMGSO4       4.6000    2.2380        76 CAH2PO4     1  5.4   137.0673
77 KCAOH        1.1900    1.4000        77 FE(OH)2     1  5.4    89.8616
78 KCAHCO3      4.1100    1.0950*       78 FE(OH)3     0   .0   106.8689
79 KCACO3       3.5560    3.2240*       79 FE(OH)4    -1  5.4   123.8762
80 KCAF+        4.1200     .9400        80 FE(OH)2     0   .0    89.8616
81 KALOH        1.4300    9.0300        81 LI          1  6.0     6.9390
82 KALOH2        .0000   18.7000        82 LIOH        0   .0    23.9464
83 KALOH4     -11.1600   33.0000        83 LISO4      -1  5.0   103.0005
84 KALF          .0000    7.0100        84 NH4CALC     1  2.5    18.0386
85 KALF2       20.0000   12.7500        85 NO3        -1  3.0    62.0049
86 KALF3        2.5000   17.0200        86 H2CO3       0   .0    62.0253
87 KALF4         .0000   19.7200        87 B TOT       0   .0    10.8100
88 KALSO4       2.1500    3.0200        88 SR          2  5.0    87.6200
89 KASO42       2.8400    4.9200        89 SROH        1  5.0   104.6274
90 KHSO4        4.9100    1.9870*       90 BA          2  5.0   137.3400
91 KH2SC      -65.4400   40.6440        91 BAOH        1  5.0   154.3474
92 KH2S         5.2990   -5.9420*       92 NH4SO4     -1  5.0   114.1002
93 KHS         12.1000  -12.9180        93 HCL         0   .0    36.4610
94 KOXY        34.1570  -20.7900        94 NACL        0   .0    58.4428
95 KCH4       -57.4350   30.7410        95 KCL         0   .0    74.5550
96 HYXAPT      17.2250  -59.3500        96 H2SO4       0   .0    98.0775
97 FLUAPT      19.6950  -66.7900        97 SRCO3       0   .0   147.6294
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 98 CHALC         4.6150    -3.5230        98 BR        -1  4.0    79.9090
 99 MAGADI         .0000   -14.3000        99 FEH2PO4    2  5.4   152.8340
100 SILGEL        5.5000    -2.7000       100 FEHPO4     0   .0   151.8200
101 SILGLAS       4.4400    -3.0170       101 MN         2  6.0    54.9400
102 QUARTZ        6.2200    -4.0050       102 MN         3  9.0    54.9400
103 KFEOH2         .0000   -18.7080       103 MNCL       1  5.0    90.3970
104 KFEOH3         .0000   -26.5380       104 MNCL2      0   .0   125.8540
105 KFEOH4         .0000   -34.6380       105 MNCL3     -1  5.0   151.3110
106 KFEOH2       28.5650   -20.5700       106 MNOH       1  5.0    71.8480
107 VIVIAN         .0000   -36.0000       107 MN(OH)3   -1  5.0   105.9640
108 MAGNET      -40.6600    -9.5650       108 MNF        1  5.0    73.9400
109 HEMATI      -30.8450    -4.0070       109 MNSO4      0   .0   151.0060
110 MAGHEM         .0000     6.3700       110 MN(NO3)2   0   .0   178.9560
111 GOETH        25.5550   -44.1970       111 MNHCO3     1  5.0   115.9590
112 GREENA         .0000   -63.1900       112 MNO4      -1  3.0   118.9400
113 FEOH3A         .0000     4.8850       113 MNO4      -2  5.0   118.9400
114 ANNITE       62.4800   -84.2400       114 SRSO4      0   .0   183.6800
115 PYRITE       11.3000   -18.4800       115 HMNO2     -1  5.0    87.9480
116 MONTBF         .0000   -34.9700
117 MONTAB         .0000   -29.7800
118 HUNTITE     -25.7600   -30.5100
119 GREGITE        .0000   -17.9700
120 FESPPT         .0000    -3.9150
121 KFEH2P         .0000     2.7000
122 KCAPO4        3.1000     6.4590
123 KCAH2P        3.4000     1.4080
124 KMGPO4        3.1000     6.5890
125 KMGH2P        3.4000     1.5130
126 KLIOH         4.8320      .2000
127 KLISO4         .0000      .6400
128 KNH4R      -187.0550   119.0770
129 LAUMON       39.6100   -30.9600
130 KSROH         1.1500      .8200
131 KBAOH         1.7500      .6400
132 KNH4SO         .0000     1.1100
133 KHCL           .0000   -30.0000
134 KNACL          .0000   -30.0000
135 KKCL           .0000   -30.0000
136 KH2SO4         .0000   -30.0000
137 KO2 SATD       .0000   -11.3850
138 KCO2        -5.0000    -1.4520
139 KFEHPO         .0000     3.6000
140 KFEHP+         .0000    -7.6130
141 ALOH3A       12.9900   -31.6100
142 PREHNT       10.3900   -11.5200
143 STRONT        -.4000    -9.2710#
144 CELEST         .2290    -6.5780#
145 BARITE        6.1410    -9.9780
146 WITHERIT      6.9500    -8.5850
147 STRENGIT     -2.0300   -26.4000
148 LEON         90.0700   -69.5700
149 KSRHCO3       6.0500     1.1800#
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150 NESQUE      -5.7890    -5.2110
151 ARTIN       -1.8420   -18.4000
152 K 02AQ      33.4570   -21.4950
153 KW          13.3410   -13.9920*
154 SEP PT        .0000   -37.2120
155 DIASP      -15.4050   -35.0600
156 WAIRKT      26.1400   -26.6200
157 KFEHP2        .0000    -7.5830
158 KMN 3+      25.7600   -25.5070
159 KMNCL+        .0000      .6070
160 KMNCL2        .0000      .0410
161 KMNCL3-       .0000     -.3050
162 KMNOH+        .0000     3.4490
163 KMN(OH)3      .0000     7.7820
164 KMNF+         .0000      .8500
165 KMNSO4       3.7000     1.7080
166 KMNNO3,2     -.3960      .0590
167 KMNHCO3+      .0000     1.7160
168 KMNO4-     176.6200  -127.9240
169 KMNO4--    150.0200  -116.4400
170 KSRCO3       5.2200     2.8100*
171 KHMNO2--      .0000   -34.4400
172 MANGANO    -24.0250    17.9380
173 PYROLUST   -29.1800    15.8610
174 BIRNSITE      .0000    18.0910
175 NUSTITE       .0000    17.5040
176 BIXBYITE   -15.2450     -.6110
177 HAUSMITE   -80.1400    61.5400
178 MNOH2        4.1000   -12.9120
179 MNOH3       20.0900   -35.6440
180 MANGANIT      .0000     -.2380
181 RHODOCHR    -2.0790   -10.5390
182 KSRSO4       1.6000     2.5500
183 MNCL2      -17.6220     8.7600
184 MNCL2,1W    -7.1750     5.5220
185 MNCL2,2W     1.7100     3.9740
186 MNCL2,4W    17.3800     2.7100
187 TEPHRITE   -40.0600    23.1220
188 RHODONIT   -21.8850     9.5220
189 MNS GRN     -5.7900     3.8000
190 MNSO4      -15.4800     2.6690
191 MN2SO4,3   -39.0600    -5.7110
192 MN3PO4,2     2.1200   -23.9270
193 MNHPO4        .0000   -12.9470

"*" DENOTES THAT AN ANALYTICAL EXPRESSION FOR KT HAS BEEN USED
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SUMMARY OF ANALYTICAL EXPRESSIONS OF THE FORM
  LOG K = A+B*T+C/T+D*T**2+E/T**2+F*LOG T


   I   NREACT        A            B           C           D            E              F

  13  CALCITE   -171.9055   -.077992998   2839.3191   .0000E+00   .000000E+00  7.1595001E+01
  14  KH3SIO4      6.3680   -.016346000  -3405.8999   .0000E+00   .000000E+00   .0000000E+00
  15  KH2SIO4     39.4780   -.065926999 -12355.0996   .0000E+00   .000000E+00   .0000000E+00
  19  GYPSUM      82.0904    .000000000  -3853.9360   .0000E+00   .000000E+00 -2.9811480E+01
  22  ARAGONIT  -171.9773   -.077992998   2903.2930   .0000E+00   .000000E+00  7.1595001E+01
  25  KMGOH         .6840    .005129500       .0000   .0000E+00   .000000E+00   .0000000E+00
  26  KH3BO3      28.6059    .012078000   1573.2100   .0000E+00   .000000E+00 -1.3225800E+01
  27  KNH3          .6322   -.001225000  -2835.7600   .0000E+00   .000000E+00   .0000000E+00
  36  KH2CO3     356.3094    .060919639 -21834.3691   .0000E+00  1.684915E+05 -1.2683390E+02
  69  KHCO3      107.8871    .032528490  -5151.7900   .0000E+00  5.637139E+05 -3.8925610E+01
  73  KKSO4        3.1060    .000000000   -673.6000   .0000E+00   .000000E+00   .0000000E+00
  74  KMGCO3        .9910    .006670000       .0000   .0000E+00   .000000E+00   .0000000E+00
  75  KMGHCO3      2.3190   -.011056000       .0000  2.2981E-05   .000000E+00   .0000000E+00
  78  KCAHCO3   1209.1200    .312940001 -34765.0508   .0000E+00   .000000E+00 -4.7878201E+02
  79  KCACO3   -1228.7321   -.299439996  35512.7500   .0000E+00   .000000E+00  4.8581799E+02
  90  KHSO4       -5.3505    .018341200    557.2461   .0000E+00   .000000E+00   .0000000E+00
  92  KH2S        11.1700   -.023860000  -3279.0000   .0000E+00   .000000E+00   .0000000E+00
 143  STRONT     155.0305    .000000000  -7239.5942   .0000E+00   .000000E+00 -5.6586380E+01
 144  CELEST      73.4150    .000000000  -3603.3411   .0000E+00   .000000E+00 -2.7443701E+01
 149  KSRHCO3     -3.2480    .014867000       .0000   .0000E+00   .000000E+00   .0000000E+00
 153  KW        -606.5220   -.097611003  31286.0000   .0000E+00 -2.170870E+06  2.1868434E+02
 170  KSRCO3      -1.0190    .012826000       .0000   .0000E+00   .000000E+00   .0000000E+00
1  Springhill Geothermal Test Well No. 3, T=18C, after 7 days



                           ----------------
                           INITIAL SOLUTION
                           ----------------



          TEMPERATURE =  18.00 DEGREES C     PH =  6.840
          ANALYTICAL EPMCAT =   57.098    ANALYTICAL EPMAN =   58.668



      ***** OXIDATION - REDUCTION *****



DISSOLVED OXYGEN =    .200 MG/L
EH MEASURED WITH CALOMEL = 99.0000 VOLTS          FLAG CORALK PECALC IDAVES
MEASURED EH OF ZOBELL SOLUTION = 99.0000 VOLTS      2    0      3      0
CORRECTED EH = 99.0000 VOLTS
PE COMPUTED FROM CORRECTED EH = 100.000
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               *** TOTAL CONCENTRATIONS OF INPUT SPECIES ***

                             TOTAL               LOG TOTAL             TOTAL
           SPECIES         MOLALITY              MOLALITY             MG/LITRE
           -------         --------              --------             --------

           CA        2    9.11794E-03            -2.0401            3.64000E+02
           MG        2    6.07043E-03            -2.2168            1.47000E+02
           NA        1    2.53289E-02            -1.5964            5.80000E+02
           K         1    6.93247E-04            -3.1591            2.70000E+01
           CL       -1    1.27433E-02            -1.8947            4.50000E+02
           SO4      -2    1.75583E-02            -1.7555            1.68000E+03
           HCO3     -1    1.10176E-02            -1.9579            6.69600E+02
           SIO2 TOT  0    2.67349E-04            -3.5729            1.60000E+01
           FE        2    3.95499E-04            -3.4029            2.20000E+01
           F        -1    1.05690E-05            -4.9760            2.00000E-01
           ANAL H2S  0    2.35676E-06            -5.6277            8.00000E-02
           CO3      -2    6.69212E-06            -5.1744            4.00000E-01
           NH4       1    9.46170E-05            -4.0240            1.70000E+00
           B TOT     0    1.75462E-05            -4.7558            1.90000E-01
           MN        2    2.01014E-05            -4.6968            1.10000E+00


                          *** CONVERGENCE ITERATIONS ***

       ITERATION  S1-ANALCO3   S2-SO4TOT    S3-FTOT     S4-PTOT    S5-CLTOT

           1      5.717E-04   1.038E-02   1.044E-06   .000E+00   3.050E-07
           2      2.291E-04   1.852E-03   4.414E-07   .000E+00   2.592E-08
           3     -8.650E-08  -2.349E-05   3.759E-10   .000E+00   5.259E-10
           4      1.806E-06   1.137E-05   3.457E-09   .000E+00  -6.206E-10

       Springhill Geothermal Test Well No. 3, T=18C, after 7 days


                          ****DESCRIPTION OF SOLUTION ****

                ANAL.     COMP.         PH          ACTIVITY H2O =   .9986
       EPMCAT    57.10     47.35       6.840        PCO2=  7.248505E-02
       EPMAN     58.67     48.94                    LOG PCO2 =  -1.1398
                                    TEMPERATURE     PO2 =  6.429608E-46
       EH = ******  PE =   3.244     18.00 DEG C    PCH4 =   .000000E+00
       PE CALC S =   -2.875                         CO2 TOT =  1.396890E-02
       PE CALC DOX= 13.944          IONIC STRENGTH  DENSITY =   1.0000
       PE SATO DOX=  3.244           7.172807E-02   TDS =     2959.3MG/L
       TOT ALK =  1.104E+01 MEQ                     CARB ALK =  1.103E+01 MEQ
       ELECT   = -1.500E+00 MEQ

       IN COMPUTING THE DISTRIBUTION OF SPECIES,
       PE =   3.244     EQUIVALENT EH =   .187VOLTS
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                    ----------------------
                    DISTRIBUTION OF SPECIES
                    ----------------------

 I  SPECIES          PPM        MOLALITY    ACTIVITY    LOG ACT    GAMMA

  1 CA         2  2.4520E+02  6.1420E-03  2.6551E-03   -2.576   4.3228E-01
  2 MG         2  1.0592E+02  4.3740E-03  1.9511E-03   -2.710   4.4607E-01
  3 NA         1  5.6301E+02  2.4587E-02  1.9768E-02   -1.704   8.0400E-01
  4 K          1  2.6160E+01  6.7168E-04  5.3059E-04   -3.275   7.8994E-01
 64 H          1  1.7271E-04  1.7202E-07  1.4454E-07   -6.840   8.4027E-01
  5 CL        -1  4.4999E+02  1.2743E-02  1.0066E-02   -1.997   7.8994E-01
  6 SO4       -2  1.2122E+03  1.2669E-02  5.2942E-03   -2.276   4.1789E-01
  7 HCO3      -1  6.2931E+02  1.0355E-02  8.3821E-03   -2.077   8.0951E-01
 18 CO3       -2  3.2443E-01  5.4278E-06  2.3308E-06   -5.632   4.2942E-01
 86 H2CO3      0  1.8283E+02  2.9593E-03  3.0133E-03   -2.521   1.0182E+00
 27 OH        -1  8.7435E-04  5.1615E-08  4.0671E-08   -7.391   7.8798E-01
 62 F         -1  1.7790E-01  9.4011E-06  7.4079E-06   -5.130   7.8798E-01
 19 MGOH       1  5.9930E-04  1.4562E-08  1.1942E-08   -7.923   8.2009E-01
 23 MGSO4 AQ   0  1.7484E+02  1.4583E-03  1.4826E-03   -2.829   1.0167E+00
 22 MGHCO3     1  1.9555E+01  2.3008E-04  1.8271E-04   -3.738   7.9410E-01
 21 MGCO3 AQ   0  3.2201E-01  3.8340E-06  3.8978E-06   -5.409   1.0167E+00
 20 MGF        1  4.2604E-02  9.8760E-07  7.8996E-07   -6.102   7.9988E-01
 29 CAOH       1  1.8023E-04  3.1696E-09  2.5846E-09   -8.588   8.1543E-01
 32 CASO4 AQ   0  3.5937E+02  2.6502E-03  2.6943E-03   -2.570   1.0167E+00
 30 CAHCO3     1  3.1190E+01  3.0974E-04  2.5074E-04   -3.601   8.0951E-01
 31 CACO3 AQ   0  9.9657E-01  9.9964E-06  9.2041E-06   -5.036   9.2074E-01
 49 CAF+       1  1.0590E-02  1.7996E-07  1.4493E-07   -6.839   8.0535E-01
 44 NASO4     -1  7.6880E+01  6.4834E-04  5.2483E-04   -3.280   8.0951E-01
 43 NAHCO3     0  7.6674E+00  9.1651E-05  9.3177E-05   -4.031   1.0167E+00
 42 NACO3     -1  6.0752E-02  7.3487E-07  5.9488E-07   -6.226   8.0951E-01
 94 NACL       0  1.1393E-29  1.9573E-34  1.9899E-34  -33.701   1.0167E+00
 46 KSO4      -1  2.8971E+00  2.1520E-05  1.7420E-05   -4.759   8.0951E-01
 95 KCL        0  3.9012E-31  5.2535E-36  5.3410E-36  -35.272   1.0167E+00
 63 HSO4      -1  7.4087E-03  7.6627E-08  6.1293E-08   -7.213   7.9988E-01
 24 H4SIO4AQ   0  2.5576E+01  2.6716E-04  2.7161E-04   -3.566   1.0167E+00
 25 H3SIO4    -1  1.8262E-02  1.9278E-07  1.5309E-07   -6.815   7.9410E-01
 26 H2SIO4    -2  2.0024E-07  2.1364E-12  9.1744E-13  -12.037   4.2942E-01
 14 H2S AQ     0  4.4051E-02  1.2977E-06  1.3193E-06   -5.880   1.0167E+00
 67 HS        -1  3.4886E-02  1.0590E-06  8.3450E-07   -6.079   7.8798E-01
 68 S         -2  3.2401E-08  1.0145E-12  4.2677E-13  -12.370   4.2066E-01
  8 FE         2  1.6056E+01  2.8864E-04  1.2762E-04   -3.894   4.4213E-01
  9 FE         3  3.6877E-09  6.6294E-14  1.3843E-14  -13.859   2.0882E-01
 10 FEOH       2  6.9909E-05  9.6200E-10  4.0468E-10   -9.393   4.2066E-01
 11 FEOH       1  1.4694E-02  2.0249E-07  1.6307E-07   -6.788   8.0535E-01
 12 FE(OH)3   -1  1.6267E-10  1.5282E-15  1.2307E-15  -14.910   8.0535E-01
 77 FE(OH)2    1  2.3153E-01  2.5868E-06  2.0940E-06   -5.679   8.0951E-01
 78 FE(OH)3    0  1.7797E-02  1.5719E-07  1.5998E-07   -6.770   1.0167E+00
 79 FE(OH)4   -1  1.7899E-03  1.4507E-08  1.1743E-08   -7.930   8.0951E-01
 80 FE(OH)2    0  4.5291E-07  5.0601E-12  5.1444E-12  -11.289   1.0167E+00
 15 FESO4      1  9.7727E-08  6.4599E-13  5.2016E-13  -12.284   8.0535E-01
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  16 FECL       2  5.8611E-10  6.4451E-15  2.7112E-15 -14.567  4.2066E-01
  28 FECL2      1  4.2896E-11  3.3977E-16  2.7363E-16 -15.563  8.0535E-01
  33 FECL3      0  4.3197E-14  2.6737E-19  2.7182E-19 -18.566  1.0167E+00
  34 FESO4      0  1.5695E+01  1.0366E-04  1.0539E-04  -3.977  1.0167E+00
 101 MN         2  8.0706E-01  1.4748E-05  6.5206E-06  -5.186  4.4213E-01
 102 MN         3  3.2810E-23  5.9957E-28  1.2520E-28 -27.902  2.0882E-01
 106 MNOH       1  6.6224E-05  9.2539E-10  7.4526E-10  -9.128  8.0535E-01
 107 MN(OH)3   -1  3.4738E-15  3.2914E-20  2.6507E-20 -19.577  8.0535E-01
 111 MNHCO3     1  4.0760E-01  3.5290E-06  2.8421E-06  -5.546  8.0535E-01
 109 MNSO4      0  2.2438E-01  1.4918E-06  1.5166E-06  -5.819  1.0167E+00
 103 MNCL       1  2.9689E-02  3.2974E-07  2.6555E-07  -6.576  8.0535E-01
 104 MNCL2      0  8.9587E-05  7.1466E-10  7.2656E-10  -9.139  1.0167E+00
 105 MNCL3     -1  6.5819E-07  4.0965E-12  3.2991E-12 -11.482  8.0535E-01
 108 MNF        1  3.1272E-05  4.2462E-10  3.4196E-10  -9.466  8.0535E-01
 115 HMNO2     -1  8.5038E-15  9.7076E-20  7.8179E-20 -19.107  8.0535E-01
  36 H3BO3 AQ   0  1.0818E+00  1.7565E-05  1.7857E-05  -4.748  1.0167E+00
  37 H2BO3     -1  4.9393E-03  8.1528E-08  6.3151E-08  -7.200  7.7459E-01
  38 NH3 AQ     0  2.7226E-03  1.6050E-07  1.6318E-07  -6.787  1.0167E+00
  39 NH4        1  1.5924E+00  8.8630E-05  6.8652E-05  -4.163  7.7459E-01
  92 NH4SO4    -1  6.6075E-01  5.8140E-06  4.6823E-06  -5.330  8.0535E-01


   MOLE RATIOS FROM          MOLE RATIOS FROM
 ANALYTICAL MOLALITY        COMPUTED MOLALITY        LOG ACTIVITY RATIOS
 --------------------      --------------------      --------------------

CL/CA   =  1.3976E+00     CL/CA   =  2.0747E+00     LOG CA/H2 =   11.1041
CL/MG   =  2.0992E+00     CL/MG   =  2.9134E+00     LOG MG/H2 =   10.9703
CL/NA   =  5.0311E-01     CL/NA   =  5.1829E-01     LOG NA/H1 =    5.1360
CL/K    =  1.8382E+01     CL/K    =  1.8972E+01     LOG K/H1  =    3.5648
CL/AL   =  1.2743E+28     CL/AL   =  1.2743E+28     LOG AL/H3 =   20.5200
CL/FE   =  3.2221E+01     CL/FE   =  4.4148E+01     LOG FE/H2 =    9.7859
CL/SO4  =  7.2577E-01     CL/SO4  =  1.0058E+00     LOG CA/MG =     .1338
CL/HCO3 =  1.1566E+00     CL/HCO3 =  1.2307E+00     LOG NA/K  =    1.5712
CA/MG   =  1.5020E+00     CA/MG   =  1.4042E+00
NA/K    =  3.6537E+01     NA/K    =  3.6605E+01

Springhill Geothermal Test Well No. 3, T=18C, after 7 days


     PHASE       IAP       KT       LOG IAP  LOG KT    IAP/KT  LOG IAP/KT


  18 ANHYDRIT 1.406E-05 4.918E-05   -4.852   -4.308  2.858E-01    -.544
  22 ARAGONIT 6.188E-09 5.072E-09   -8.208   -8.295  1.220E+00     .085
 151 ARTIN    2.707E-26 4.290E-19  -25.568  -18.368  6.309E-08   -7.200
  20 BRUCITE  3.227E-18 3.759E-12  -17.491  -11.425  8.587E-07   -6.066
  13 CALCITE  6.188E-09 3.600E-09   -8.208   -8.444  1.719E+00     .235
  98 CHALC    2.724E-04 2.487E-04   -3.565   -3.604  1.095E+00     .039
  21 CHRYSOTL                      -59.603  -52.288               -7.315
  30 CLENSTIT 8.802E-22 1.029E-17  -21.055  -16.988  8.555E-05   -4.068
 100 SILGEL   2.724E-04 1.596E-03   -3.565   -2.797  1.706E-01    -.768
  29 DIOPSIDE                      -41.977  -36.592               -5.385
  12 DOLOMITE 2.814E-17 1.192E-17  -16.551  -16.924  2.361E+00     .373
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113 FEOH3A   4.565E+06 7.674E+04    6.659    4.885  5.949E+01     1.774
120 FESPPT   7.368E-04 1.216E-04   -3.133   -3.915  6.058E+00      .782
 63 FLUOR    1.457E-13 9.057E-12  -12.837  -11.043  1.609E-02    -1.794
 28 FORSTRIT                      -38.546  -28.196              -10.350
111 GOETH                         -36.030  -44.647                8.617
112 GREENA                        -63.156  -63.190                 .034
119 GREGITE  7.112E-03 1.072E-18   -2.148  -17.970  6.637E+15    15.822
 19 GYPSUM   1.402E-05 2.480E-05   -4.853   -4.606  5.652E-01     -.248
 65 HALITE   1.990E-04 3.680E+01   -3.701    1.566  5.408E-06    -5.267
109 HEMATI   2.093E+13 3.440E-04   13.321   -3.463  6.083E+16    16.784
118 HUNTITE  5.820E-34 8.789E-31  -33.235  -30.056  6.622E-04    -3.179
 39 HYDMAG                        -50.862  -37.370              -13.492
 69 MACKIT   7.368E-04 2.339E-05   -3.133   -4.631  3.150E+01     1.498
 99 MAGADI   4.052E-22 5.012E-15  -21.392  -14.300  8.085E-08    -7.092
110 MAGHEM   2.093E+13 2.344E+06   13.321    6.370  8.927E+06     6.951
 11 MAGNESIT 4.548E-09 7.391E-09   -8.342   -8.131  6.153E-01     -.211
108 MAGNET   7.890E+09 1.417E-09    9.897   -8.849  5.568E+18    18.746
 67 MIRABI   2.041E-06 3.568E-02   -5.690   -1.448  5.719E-05    -4.243
 59 NAHCOL   1.657E-04 2.435E-01   -3.781    -.614  6.806E-04    -3.167
 61 NATRON   8.984E-10 2.580E-02   -9.047   -1.588  3.483E-08    -7.458
150 NESQUE   4.529E-09 7.781E-06   -8.344   -5.109  5.821E-04    -3.235
115 PYRITE   1.310E+04 2.093E-19    4.117  -18.679  6.258E+22    22.796
102 QUARTZ   2.724E-04 7.680E-05   -3.565   -4.115  3.546E+00      .550
 37 SEPIOLIT                      -45.678  -40.568               -5.110
 10 SIDERITE 2.975E-10 3.453E-11   -9.527  -10.462  8.614E+00      .935
101 SILGLAS  2.724E-04 8.031E-04   -3.565   -3.095  3.391E-01     -.470
 38 TALC                          -66.732  -63.084               -3.648
 66 THENAR   2.069E-06 6.778E-01   -5.684    -.169  3.052E-06    -5.515
 62 THRNAT   9.095E-10 1.494E+00   -9.041     .174  6.088E-10    -9.216
 32 TREMOLIT                     -150.686 -141.890               -8.796
 60 TRONA    1.505E-13 3.328E-01  -12.822    -.478  4.522E-13   -12.345
154 SEP PT                        -45.678  -37.212               -8.466
172 MANGANO  3.117E+08 2.298E+18    8.494   18.361  1.356E-10    -9.868
173 PYROLUST 5.020E+02 2.373E+16    2.701   16.375  2.116E-14   -13.675
174 BIRNSITE 5.020E+02 1.233E+18    2.701   18.091  4.071E-16   -15.390
175 NUSTITE  5.020E+02 3.192E+17    2.701   17.504  1.573E-15   -14.803
176 BIXBYITE 1.712E-15 4.546E-01  -14.767    -.342  3.765E-15   -14.424
177 HAUSMITE                       45.649   62.952              -17.303
178 MNOH2    1.079E-20 1.037E-13  -19.967  -12.984  1.040E-07    -6.983
179 MNOH3                         -50.075  -35.998              -14.076
180 MANGANIT 4.134E-08 5.781E-01   -7.384    -.238  7.152E-08    -7.146
181 RHODOCHR 1.520E-11 3.145E-11  -10.818  -10.502  4.832E-01     -.316
183 MNCL2    6.607E-10 1.178E+09   -9.180    9.071  5.617E-19   -18.251
184 MNCL2,1W 6.598E-10 4.451E+05   -9.181    5.648  1.482E-15   -14.829
185 MNCL2,2W 6.589E-10 8.788E+03   -9.181    3.944  7.498E-14   -13.125
186 MNCL2,4W 6.571E-10 2.534E+02   -9.182    2.404  2.594E-12   -11.586
187 TEPHRITE 2.645E+13 6.729E+23   13.423   23.828  3.932E-11   -10.405
188 RHODONIT 5.535E-01 8.085E+09    -.257    9.908  6.846E-11   -10.165
189 MN2 GRN  3.765E-05 7.981E+03   -4.424    3.902  4.717E-09    -8.326
190 MNSO4    3.452E-08 8.746E+02   -7.462    2.942  3.947E-11   -10.404
191 MN2SO4,3                      -62.633   -5.023              -57.611
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