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WATER USE POSSIBILITIES IN ABANDONED IRON MINES

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ABSTRACT

The Montreal and Cary Mines in northern Wisconsin produced over 64 million tons of iron ore during their 76 years of operation. When these mines closed, a network of shafts and tunnels remained, representing over 668 million cubic feet of underground space that is now filled with water. The purpose of this study has been to evaluate the thermal and mineral characteristics of these waters as: 1) a low-temperature geothermal heat source, 2) a public water supply and 3) a source of concentrated dissolved minerals.

Temperature profiles from each mine show different results. The Montreal No. 5 Shaft is 9 to 10° F hotter than the normal ground-water temperature of 47° F and is thoroughly well mixed. Water temperatures in the Cary Mine New Shaft are stratified, being 54° to 55° near the top of the shaft and relatively constant down to a depth of 2794 feet below ground surface. At this depth, the water temperature increases sharply 10°; at a depth of 3680 feet, a temperature of 74° F is reached.

If we assume an average water temperature of 55° F throughout the mines and if a 15° temperature drop through a heat exchange system is feasible, then 625 billion BTU's or 158 trillion calories are in storage and available for use. Assuming the mines can sustain a pumping rate of 700 gallons per minute (gpm), a yield of 126 million BTU's or 32 billion calories per day is available. This is equivalent to 900 gallons of home heating oil daily.

The chemical quality of water within the mines is questionable for drinking purposes, but does improve with depth. With standard treatment procedures, the mine waters could be used as a public water supply.

Based on mine pumpage records and the filling rates of the mines after abandonment, the mines can yield 700 to 1000 gpm perennially.

No water samples containing sufficient total dissolved solids to be considered a brine were collected. We conclude that brines reported in earlier investigations are either: 1) only in the deepest parts of the mines inaccessible to our sampling techniques, 2) diluted and mixed throughout the mines or 3) of a transient nature and no longer present.

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INTRODUCTION

Geology/Hydrology/Topography

The Montreal-Hurley area is in the Gogebic Range of north-northeastern Wisconsin (Figure 1). The area is covered by a thin layer of glacial drift ranging from 0 to 50-feet thick and composed of unsorted material from clay size to boulder erratics. The fine-grained fraction predominates, and wells in the glacial deposits usually produce only sufficient water for single family dwellings. These glacial deposits overly Precambrian formations, which dip steeply north.

Hothkiss (1919), Atwater (1935), Sims (1976), and LaBerge and Mudrey (1979) have published summaries of the Precambrian history and stratigraphy of the area.

Surface drainage is still developing over the area and many swamps and marshes exist, contributing organic material and a coffee color to most of the streams and shallow ground water. The presence of hydrogen sulfide has also been reported and, in combination with the color and organic material in surface water, presents expensive water treatment problems for public water systems.

The West Fork of the Montreal River and the main branch of the Montreal River drain the area south and east of Montreal and Hurley, carrying water north to Lake Superior. West of Montreal near the Town of Pence, surface drainage divides and flows west through Alder Creek to Bad River and through the Bad River Indian Reservation to Lake Superior.

The study area is approximately 1000 feet higher than Lake Superior, 1600 feet above mean sea level. Two resistant ridges trending southwest to northeast bound the area, with Montreal-Hurley lying in the intervening valley. The higher, more southern ridge is composed of the iron-bearing Ironwood Formation, and the more northerly ridge consists of resistant volcanic and intrusive rocks. The valley is underlain by the less resistant Tyler slates.

Oglebay, Norton & Company began operating the Montreal Mine in 1886. Production rose after an initial development period to a million tons annually. The Cary Mine also opened at this time and produced slightly less than half as much.

Although the Montreal and Cary Mines were owned and operated by different companies, the actual mine workings were connected at several locations down to a depth of 2870 feet below the surface. Based on production records, the Montreal Mine is about 2½ times larger than the Cary Mine. The mine workings extend over 4100 feet below ground surface and 3½ to 4 miles laterally. Skillings Mining Review (1966) lists the total production from the two mines as 64,089,344 tons. Olcott (1969) estimated about 668 million cubic feet of space underground, which is now filled with over 5 billion gallons of water.

The Montreal and Cary Mines closed in 1962 and 1964 respectively, due to competition from taconite ore processing and increased costs of mining at a depth below 4000 feet. With the closing of the mines, the economy of the area suffered radically and is still recovering. Tourism and lumbering are now the primary industries.

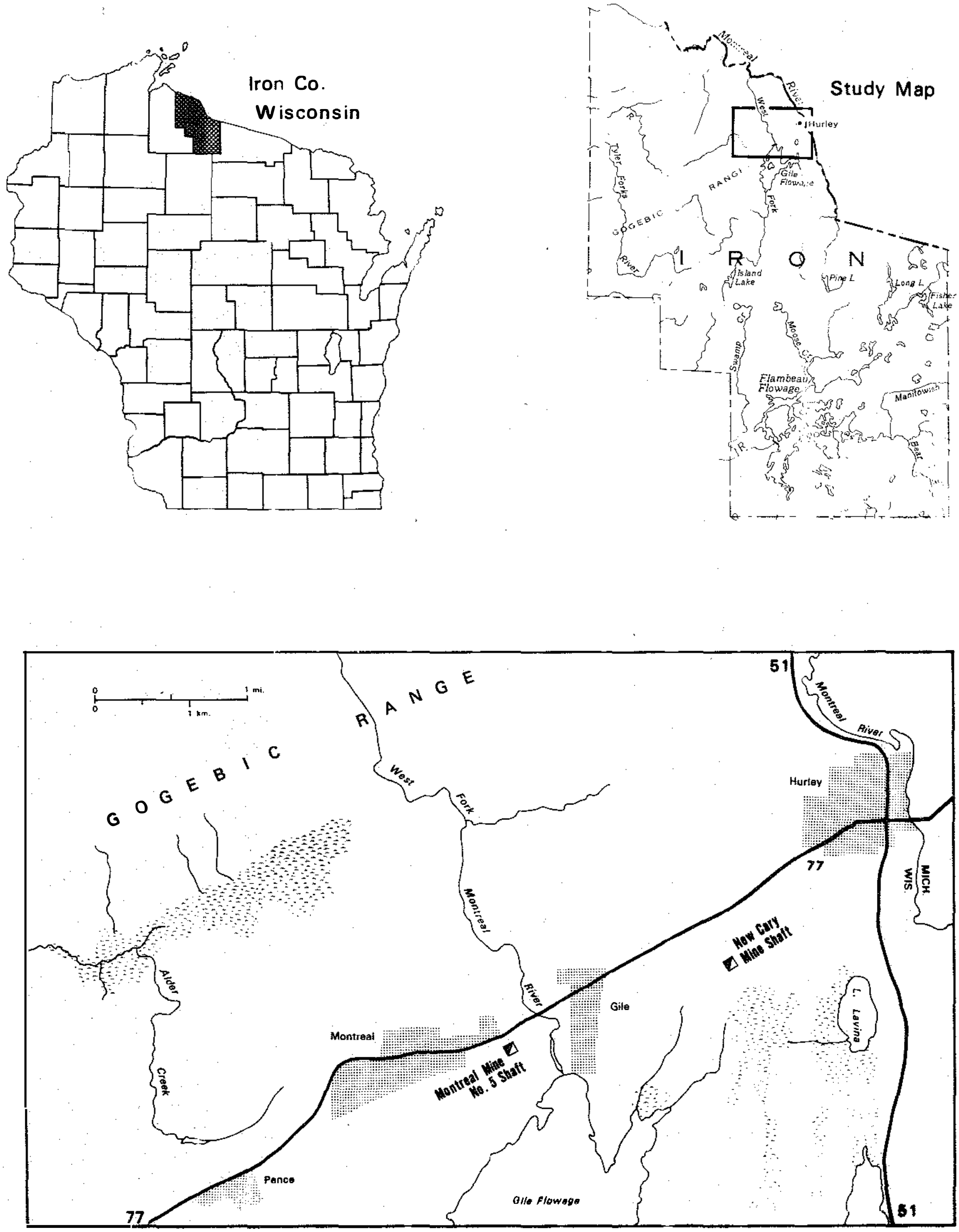

Figure 1: Location Map of Study Area

Previous Investigations

The Montreal No. 5 shaft has been maintained as a ground water sampling point since 1966 by the U.S. Geological Survey (U.S.G.S.) in cooperation with the Wisconsin Geological and Natural History Survey and the City of Montreal. The U.S.G.S. summarized their studies of the mines in an open-file report by Olcott (1969). The report concludes that the mines could yield about 1000 gpm of potable water with some treatment for excessive iron and manganese. Development of the mines as a water supply was not considered due to fear that pumping operations would aggrevate caving and roof collapse over mined out areas.

In 1978, the cities of Montreal and Hurley hired a private consulting company to evaluate possible water supplies in the area. The firm concluded that to use the water in the mine shafts, a treatment system as complex and expensive as a desalination plant would be required (Donohue & Associates, 1979).

Methods of Investigation

Previous investigators have collected water samples from the Montreal and Cary mine shafts by dropping a sampler into the surface water. While the mines were filling, the water was probably well-mixed, providing a representative sample. Later, the water level within the mines stablized and the water may have stratified, requiring a series of samples throughout its length for adequate characterization. Samples were taken at five depths within the Cary shaft and four depths within the Montreal No. 5 shaft to detect stratification. A messenger-tripped 1-liter bore-hole water sampler was used. The results of the analyses are shown in Table 1.

Temperature information was important for two reasons: first, slight changes in water temperatures would indicate flow into the shafts; second, temperature changes with depth would indicate the degree of stratification and also the presence of warmer water at depths useful as a heat source. A linear thermistor temperature probe accurate to 0.05° C was used to build a temperature profile of both shafts. These temperature profiles are shown in Figure 2.

The Mines as a Water Resource

The objective of this study has been to find a use for the mine waters. We must estimate the quantity of water available first, regardless of its chemical or thermal quality.

When the mines closed in the 1960's, the water level rose within the mines at rates as fast as a foot a day, although the level did decline in early 1967. In 1976, the water level reached the contact between the glacial deposits and the crystalline rock and began seeping out of the Montreal No. 5 shaft through the overlying, more permeable drift. This seepage was first noticed by the Montreal Mine engineer in April 1976, when water began flowing from the base of a spoil pile northeast of Montreal Shaft No. 5 and into the west fork of the Montreal River. It is difficult to estimate the amount of seepage that is occurring, but it is between 150 to 250 gallons per minute. This is the amount available at the surface without pumping.

Table 1

Chemical Analysis of Mine Waters
(concentrations in Mg/l unless otherwise noted)

	CARY SHAFT				MONTREAL SHAFT		
Depth of Water Sample (ft)	530	2,730	2,930	3,680	975	2,000	2,875
Conductance,	1,090	1,110	850	760	2,490	2,500	2,050
pH, units	6.6	6.6	6.4	6.4	6.6	6.4	7.0
Temperature, °C	13.0	12.2	13.5	23.0	14.0	13.5	13.0
Aluminum	.3	.3	.5	.5	.7	.7	.7
Antimony	.05	.05	.05	.03	.03	.05	.05
Barium	.3	.3	.3	.3	.1	.1	.1
Beryllium	.001	.001	.001	.001	.001	.001	.001
Bismuth	1.	1.	1.	1.	1.	1.	1.
Boron	.5	.5	.5	.5	1.	1.	1.
Cadmium	.01	.01	.01	.007	.001	.001	.001
Calcium	100	100	100	100	100	100	100
Chromium	.05	.05	.05	.05	.05	.05	.05
Cobalt	.5	.3	.3	.3	.01	.01	.01
Copper	.01	.01	.01	.01	.01	.01	.01
Gallium	.03	.03	.03	.03	.05	.05	.05
Germanium	.1	.1	.1	.1	.3	.3	.3
Iron	10	10	10	10	3.	1.	1.
Lead	.1	.03	.05	.05	.03	.05	.05
Lithium	.03	.03	.03	.03	.1	.1	.1
Magnesium	30	30	30	30	70	70	70
Manganese	1.	1.	1.	1.	1.	1.	1.
Molybdenum	.01	.03	.01	.03	.01	.01	.01
Nickel	.05	.05	.05	.05	.05	.05	.05
Potassium	7.	7.	7.	7.	30	10	10
Silica (S_1O_2)	10	10	10	10	30	30	30
Silver	.01	.01	.01	.01	.07	.05	.05
Sodium	50	50	50	50	100	100	100
Strontium	3.	3.	3.	3.	5.	5.	5.
Tin	1.	.7	.7	1.	1.	1.	1.
Titanium	.005	.005	.005	.005	.005	.005	.005
Vanadium	.01	.01	.01	.01	.01	.01	.01
Zinc	.1	.1	.1	.3	.01	.03	.03
Zirconium	.005	.005	.005	.005	.005	.005	.005
Tritium	232pCI/L ± 26				204pCI/L ± 23		

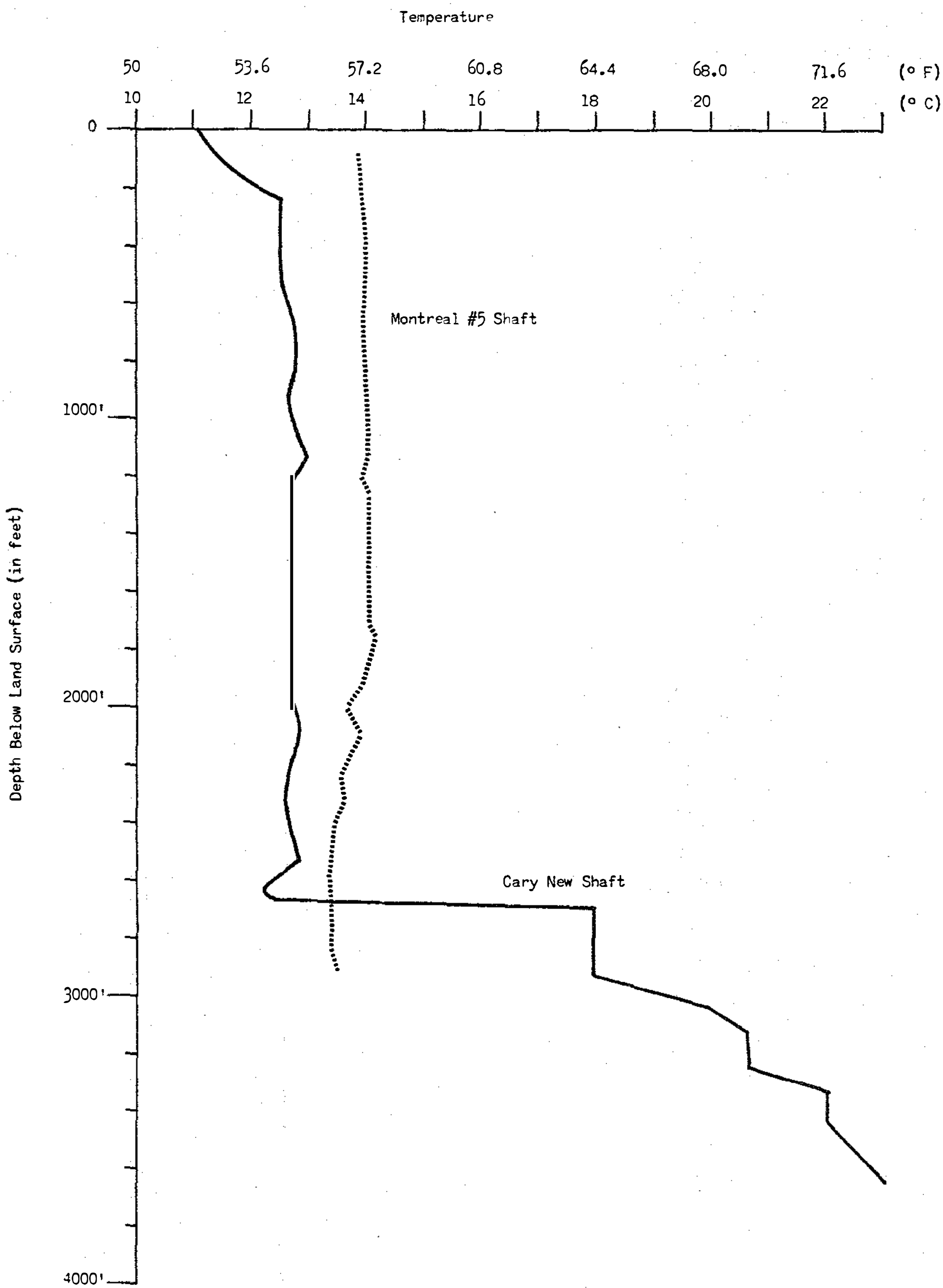

Figure 2: Temperature variation with depth for Cary Mine New Shaft and Montreal Mine Shaft No. 5

If we assume that the flow rate into the mines was relatively constant from 1962 to 1976, and that the mine workings held five billion gallons of water, then an average inflow rate of 700 gallons per minute is required to fill the space in the 14-year period. This estimate ignores many variables affecting the actual quantity of water flowing into the mines, but it demonstrates the minimum quantity of water that could be pumped on a continuing basis without excessive drawdowns.

The maximum amount of water available from the mines would be the quantity pumped by the mining companies to keep their operations dry. These figures are summarized in Table 2. Averaging the annual pumpage figures from 1934 to 1962, the average pumpage of the Montreal and Cary Mines was 1020 gallons per minute.

The Mines as a Geothermal Heat Source

Within the lowest levels of the mines, rock temperatures are about 75° F. If deeper ground-water flow systems were present, water warmer than 75° F could be flowing into the base of the mines; moreover, if higher heat flow were present, the water within the mines could be heated. Neither of these conditions exist, although marked differences in the thermal structure between the Montreal and Cary shafts were discovered.

The water in the Cary Mine Shaft remains a relatively constant 55° F down to the first side shaft level at 2588 feet, where it drops from 55° F to 54° F. At the next shaft level, 2794 feet below the collar, the temperature suddenly rises to 64° F within a distance of less than two feet. The temperature then remains constant down to the next side shaft at the 2992-foot depth where it gradually increases at the rate of 1° F per 100 feet until it reaches 74° F at 3680 feet (the temperature probe limit). The water in the Montreal Shaft has a relatively constant temperature throughout, from 55 to 57° F (Figure 2).

The Cary Mine Shaft cuts through competent crystalline rock. The first side shaft is 2588 feet below ground surface. The water within this main vertical shaft is stagnant and only circulates near the base through the connecting tunnels to the Montreal Mine. There is no evidence that water is seeping out of the Cary Mine New Shaft through the surficial units.

In contrast to the Cary Mine New Shaft, water in the Montreal No. 5 Shaft is unstratified and flowing actively, as indicated both by the seepage out of the shaft and the relatively constant temperature. A pump house in the shaft permitted the Montreal No. 5 Shaft to be probed only to a depth of 2900 feet. The Montreal No. 5 Shaft continues to at least 3868 feet below land surface.

Mine officials have stated that, during production, most of the seepage into the mines originated from the western workings of the shafts along contacts between surrounding rock and northeastward dipping dikes.* Olcott (1969) supports this and indicates that the dikes probably occur 3 to 4 miles southwest of the mines near Pence. Numerous openings to the surface also occur where old access and ventilation shafts and land areas allow surface runoff to enter the mines. The source of the water within the mines is thus a combination of surface water and ground water inflow from the west.

* A dike is a tabular-shaped body of igneous rock that cuts across the structure of adjacent rocks.

Table 2

Average Rates of Pumpage (G.P.M.) for the Montreal and Cary Mines, 1934 to 1962

Year	GPM	Year	GPM	Year	GPM	Year	GPM
1934	655	1942	1164	1950	1022	1958	1373
1935	808	1943	1019	1951	1430	1959	1212
1936	838	1944	949	1952	1449	1960	1248
1937	765	1945	1015	1953	1369	1961	1303
1938	985	1946	980	1954	1510	1962	1068
1939	1010	1947	996	1955	1492		
1940	909	1948	795	1956	1443		
1941	994	1949	765	1957	1272		

Yearly average from 1934 to 1962 = 1020 gpm.

Table 3

Comparison of Chemical Quality of Mine Waters with Maximum Acceptable Contaminant Levels for Municipal Water Supplies (Concentrations in Mg/L)

		Cary Shaft		Montreal Shaft	
	Maximum Contaminant Levels	Surface Sample	Deep Sample	Surface Sample	Deep Sample
Sample Depth (FT)		530	3680	975	2875
Barium	1.	.3	.3	.1	.1
Cadmium	0.010	.01	.007	.001	.001
Chromium	0.05	.05	.05	.05	.05
Lead	0.05	.1	.05	.03	.05
Iron	.3	10	10	3.	1.
Silver	0.05	.01	.01	.07	.05
Temperature ^{o}C		13.0	23.0	14.0	13.0
Specific Conductance		1090	760	2490	2050
pH		6.6	6.4	6.6	7.0

The only known outflow point is from the Montreal No. 5 Shaft, at an estimated rate of 150 to 200 gallons per minute. Montreal Shaft No. 3 may also be losing water by seepage, but there is no way of measuring or estimating the quantity.

To use the mine water as a low-grade geothermal heat source, the quantity of energy available can be estimated in two ways. The first assumes that only the energy stored now within the mines could be extracted. If the entire 5 billion gallons of 55° water passes through a 15° temperature drop heat exchange system, then over 625 billion BTU's or 158 trillion calories would be liberated. This is equivalent to 4.5 million gallons of heating oil. A second approach assumes that the mines can yield a continuous supply of water at the rate of 700 to 1000 gallons per minute. Using the 700 gpm rate and only a 10° temperature drop from 50° to 40°F, 126 million BTU's or about 32 billion calories would be available daily. This is equivalent to twenty-two 20-ton refrigeration units running continuously all day, or approximately 37,000 kilowatt hours of electricity daily.

Use of the mine waters as a low-temperature heat source is possible with a heat-pump system to concentrate the energy. Gass and Lehr (1977) have described the general applicability of ground-water heat pumps to heating and cooling, and Connelly (1979) has studied the adaptation of ground-water heat pumps to Wisconsin.

Currently, several other investigators are exploring low-grade thermal energy conversion using Joule-effect heat engines (Ginell, McNichols, and Cory, 1979). These use a temperature difference to directly create shaft power. The water might also be used for both heating and water supply. In addition, the chemical and thermal nature of these waters might prove ideal for fish farming.

The Mines as a Municipal Water Supply

Montreal and Hurley are presently purchasing their drinking water from the neighboring town of Ironwood, Michigan. City leaders have been searching actively for alternate reliable sources of good quality water. A private consulting company has considered several possible water sources but has eliminated the mines because of excessive development, water treatment, and transportation costs.

The vertical changes in water quality in the mines have never been considered. Most water samples have been collected near the surface, and the deeper water has been neglected. To more adequately characterize the water within the mines, a series of water samples was taken throughout the entire water column in the two deepest accessible shafts, the Montreal No. 5 Shaft and the Cary Mine New Shaft. The locations of the water samples were selected according to temperature changes discovered using the thermal probe. The results of these analyses are shown in Table 1. Table 3 lists those elements for which public drinking water standards have been set and the analysis of the mine waters for comparison. Iron and manganese exceed the limits in both shafts; lead also exceeds the maximum concentration in the Cary Mine New Shaft shale near the surface, but decreases in concentration in the deeper samples. Lead and boron concentrations in the Montreal Shaft equal the maximum allowable limit. The most significant result is the decrease in conductivity with depth in both mine shafts, indicating a decrease in total dissolved solids. This is the expected result if good quality ground water is seeping into the mines from the west, dissolving soluble minerals inside the mines and then flowing out through the Montreal No. 5 Shaft. This might also be expected if the contaminants result from surface runoff, road salt and other impurities.

In conversations with mine officials, we learned that most of the seepage into the mine comes from the west and that, at depths less than 2000 feet to 2500 feet, the water was of good quality and often was drunk by the miners. Below 2500 feet, seepage became saltier and less potable. Based on this study and all available records, it appears that if the mines were pumped, increased ground-water flow into the mines would be induced, thus improving the overall water quality and making the mines acceptable as a public water supply. If it is decided to use the mines, sources of surface water inflow should be located and eliminated to reduce the possibility of contamination.

The Montreal River water should also be considered for drinking. Presently, the local power company controls the river for electric power generation. If further investigations show that it is more economical to treat the river water than the mine water, an exchange agreement might be arranged. For example, Montreal and Hurley could withdraw river water for public supplies and replace it with water from the mines.

The Mine Water as a Source of Metal

As the mine workings were deepened below 3000 feet, saline water was encountered. Olcott (1969) reported brines with total dissolved solids 117,000 parts per million around the thirty-seventh level of the Cary Mine. The brine caused severe corrosion and electrical arching in mines to the east of the Montreal and Cary facilities, but was not a serious problem in the Montreal and Cary Mines. The presence of the great amount of total dissolved solids suggests the existance of minerals in economically recoverable amounts. Because water containing this large amount of dissolved solids is heavier than normal water, we tried to recover water samples from the deepest areas of the mines. For the Montreal Mine, Shaft No. 5 was the only accessible vertical shaft and was blocked at the 2900 foot level by a pump house. A sample collected just above this level did not contain any unusual quantities of dissolved solids. A sample was also collected from the Cary Mine New Shaft at the limit of our sampling equipment (3680 feet). The sample had the lowest conductivity of any sample retrieved, indicating a low concentration of dissolved solids. The absence of large amounts of dissolved solids in the water samples indicates that if the brines are still present, they are in the deepest part of the mines and are not mixing with the other mine water.

Summary, Conclusions and Recommendations

The Montreal and Cary Mines in northern Wisconsin are a vast underground reservoir of over 5 billion gallons of water. Their 3 to 4-mile length, 1-mile depth, and 0.5-mile width represent a collection area equivalent to a small watershed. From an examination of data on temperature and water quality and from discussions with mine officials, it appears that water is flowing into the mines from the west from both ground and surface sources. The water is heated in the deeper parts of the mine and flows out of the Montreal No. 5 Shaft. Chemical analyses of the mine waters indicates improvement in the water quality with depth. This shows that surface runoff containing road salt and other dissolved minerals flows into the mines through old shafts and caved areas. Simultaneously, ground water containing fewer dissolved minerals flows into the deeper parts of the mines, where they mix partially but still show a distinctive gradient.

Use of the mines as a public water supply will require treatment for excessive iron and manganese. Pumping of the mines would improve water quality by allowing more good quality ground water to flow into the mines. Induced caving and elimination of surface water inflow would be discussed at that time.

The mines could be used as a source of hot water by coupling a water supply system with a heat pump system or simply using the water as is. The quantity of extractable heat in storage is estimated at 625 billion BTU's, or the energy equivalent to 4.5 million gallons of home heating oil. If the source of heat were renewable at the same rate as the average inflow of water into the mines (700 gallons per minute), then approximately 126 million BTU's per day, or 31 billion calories per day, could be extractable across a 10° F temperature drop. This is equivalent to 900 gallons of heating oil.

No economically recoverable minerals were found.

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