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Geothermal energy from Con Mine for Heating the City of Yellowknife, NWT: A concept study

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On Behalf of
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Executive Summary

A preliminary study is conducted on the potential of Con Mine as a geothermal heat source for the City of Yellowknife. The objective of the study is to provide conceptual models of the resource and its potential energy value for the City of Yellowknife.

Yellowknife is one of the best Canadian Markets for low-enthalpy geothermal heat, as 70% of the energy used in the City is used for space heating homes and buildings (used at relatively low temperature). As most of the City's heat demand is supplied by burning fossil fuels, any level of geothermal development will proportionally reduce "Greenhouse Gas" emission of the City.

Con Mine has the potential to be used as a heat resource for the City of Yellowknife. The resource, if developed can reduce significantly the City's dependency on fossil fuel, make savings on energy costs, and reduce carbon emissions.

Deep levels of the mine (where the temperature exceeds 30°C) may be accessed for large-scale resource development. Smaller scale (demonstration) projects can be developed using the fluids in the Robertson shaft as an open loop or closed loop geothermal resource.

It is important to integrate the geothermal resource development strategy with the mine reclamation plan to minimize the development costs and maximize the system efficiency.

A demonstration project can be readily designed and built to provide experimental data for large-scale developments. The demonstration project can also provide an R&D facility to allow for fine-tuning of the design of larger-scale applications.

A comprehensive feasibility study is needed to qualify the resource and give details of all viable development options.

1.0 Introduction

In May 2007, the City of Yellowknife commissioned Mory Ghomshei, from the UBC Norman B. Keevil Institute of Mining, to conduct a preliminary study on the potential of Con Mine as a geothermal heat source for the City of Yellowknife. The objective of this study is to provide conceptual models of the resource and its potential energy value for the City of Yellowknife. This preliminary study discusses mainly the potential value of the resource and options to access the resource. The market value of the resource is also discussed for different scales of development. Example of cost and payback criteria is given for a conceptual 300 kW demonstration project.

The findings of this report remain at the conceptual level and provide only background information necessary to define and conduct a comprehensive feasibility study.

2.0 General background

The Con Mine is a decommissioned underground mine situated at the southern limits of the city of Yellowknife, and on the western edge of Yellowknife Bay on Great Slave Lake.

Con Mine produced over 5 million ounces of gold during its 65 years of operation. (1938 to 2003). According to the mine records, the total ore milled during this period is over 12 million tonnes.

The mine is managed by Miramar Con Ltd., which is committed to the development of site reclamation complying with:

1. The 2002 Mine Reclamation Policy Developed for NWT.
2. Guidelines for Remediation Planning for Mines in the Northwest Territories,1990
3. The MVLWB (Mackenzie Valley Land and Water Board) water License N1L2--0040

The reclamation process and implementation is under the direction of the Mackenzie Valley Land and Water Board (MVLWB). The process involves the public, interested stakeholders, and three levels of government (Federal, Territorial, and Municipal).

Miramar Con Ltd. works with the MVLWB and the Miramar Con Mine Closure & Reclamation Working Group that was formed in September 2003.

Reclamation activities so far conducted include:

- Mining operations stopped in September 2003

- Mine started to be flooded shortly after ceasing mining operations.
- Solvents and petroleum products removed before mine closed,
- larger equipment have been cleaned and abandoned
- DIAND (Department of Indian Affair and Northern Development) and Environment Canada inspected the site
- Risk assessment completed

Reclamation activities in progress include:

- Capping of shafts and raises
- Monitoring

3.0 Community background

Energy and Environment are two important items on the agenda of any community development planning today. For the City of Yellowknife, integration of these two items can play a major role in the economical and environmental sustainability of the community. Geothermal energy is potentially a unique element which can create synergy between different aspects of sustainable development in Yellowknife.

Some components of geothermal technology are off-the-shelf. Small-scale geothermal systems are routinely designed to match the technology to the project specifications. In large-scale developments, however, some degree of creativity and innovation is often required to respond to the specific needs of the community while using most efficiently its available resources. Some of the specifics to be considered in any large scale geothermal development for the City of Yellowknife include:

- *Yellowknife is a small compact community with a population of 20,000 people.*
- *Con Mine's shafts are as close as 1.5 km to the centre of the communities in downtown core, which has a high concentration of large office and apartment buildings. The mines inner workings extend below much of the community.*
- *Yellowknife is a growing community, supported by a large government base and a number of mines located in close proximity to the community. The City has plans to develop areas along the perimeter of the Con Mine sight in the next three to five years.*
- *85% of the community is serviced by utilities. Water is heated to 1.2°C at the main pumphouse for six months of the year. The water is then circulated throughout the municipal system in insulated pipes.*
- *95% of electricity is generated from two run of the river hydo systems owned by a Territorial crown utility. Power is distributed within the community through a City owned franchise agreement with Northland Utility an Atco company. The current capacity of*

the hydro system is 32MW with a 12MW expansion in the initial planning stage.

- *The community spends $114 million annually on energy of which 56% is consumed for space heating.*
- *Yellowknife produces 360,000 tonnes of GHG emissions annually, of which 77% is for space heating requirements.*
- *70% of energy consumed in Yellowknife is for space heating.*
- *Yellowknife does not have access to natural gas.*
- *Yellowknife has* 8256 heating degree-days (HDDs) with an average yearly temperature of -4.6°C.

For a thorough review of energy-related data for the City of Yellowknife see AD Williams (2006).

3.1 Con mine as a potential geothermal resource

Like any other underground mine, Con Mine is a geothermal resource (e.g. Ghomshei et al. 2005, 2003, 2002). Combination of three factors, however, makes the Con Mine a viable candidate for geothermal energy extraction (or heat mining). There factors are:

- Close proximity of the Mine to population (i.e. the City of Yellowknife)
- High heat demand of the City combined with high energy prices
- High rock temperatures (above 40°C) at the depth of the mine

Note that during the mine operation, deep working areas were kept around or below 34°C through air conditioning. Higher temperatures could, however, be observed in some areas of the mine away from ventilation (the author has measured 38°C in a secluded area of the mine at the 4500 level, in 1989). Now that the mine is not air conditioned, the temperature is expected to rise by natural temperature gradient (i.e. above 40 °C at 4500 level and possibly above 50°C at the deepest levels of the mine).

The Mine, can potentially provide the City of Yellowknife, with significant amounts of usable heat (for direct use applications and or use through heat pump technology).

The preset study provides background information on the resource quality (temperature) and quantity and its value in term of potential economic and environmental benefits to City of Yellowknife.

4.0 Resource evaluation

Like in any large-scale geothermal system, the Con Mine Geothermal Resource consists of 3 main components:

1- Heat

2- Water
3- Hydraulic conductivity

The heat component consists of:

- Heat residing in mine waters and mine rocks (static heat)
- Heat flux into the mine (from underlying and surrounding rocks)

The mine's present void space is estimated at 4 million cubic meters. The total void created during operation (including the backfilled) is however, estimated at above 10 million cubic meters. The total surface area of mine walls (estimated from the void space) is estimated to be above 10 million square meters. Note that the actual void space defines the Mine's water storage capacity, while the total created void can be linked to the overall hydraulic and thermal conductivity of the Mine.

4.1 Heat Reserve and Renewablity

Knowledge-base required for reserve estimation of the geothermal resource can be categorized in two super-sets of parameters (Ghomshei et al., 2002) related to:

1. Total heat available in the resource = H (BTU, kcal or kWh)
2. Energy conversion/transport systems and economy

The total heat (H) depends on:

1- average ground temperature (T_g °C),
2- specific heat of the soil/rock (C_g Cal g^{-1} °C^{-1}),
3- water content of the rock/soil or the saturated pore volume (pw %)
4- the specific heat of the water (C_w),
5- the volume of the sub-surface reservoir ($V = V_{ground} + V_{water}$),
6- specific density of the soil/rock (G_r),
7- the specific density of the pore water (G_w) and
8- the minimum temperature of the ground after heat extraction (T_m)

Combining these parameters, the total heat can be calculated by:

$$H = (V_g \bullet G_g \bullet C_g + V_w \bullet G_w \bullet C_w) \bullet (T_g - T_m)$$

In most cases these parameters are not known or at least are prone to variation related to ground inhomogeneity or climatic effects. The most controlled parameter in assessment of H is T_g (controlled by the resource) and T_m (controlled by the design). The ground tempeature ($T_{g},$) though relatively known (for different depths), does not necessarily remain constant in time (considering the progress of mine flooding and future geothermal production). The ground water temperature in Con Mine therefore changes with depth and time (depending on the rate of heat extraction from the Mine and design configuration of production/re-injection wells).

Assuming a wall thickness of 10 meters for the purposes of heat transfer through the mine walls and assuming an average temperature reduction of the Mine (for heat extraction) equivalent to 5 degrees Celsius, the total usable heat capacity of the rocks is conservatively estimated at 650,000 gigajoules (GJ). The usable heat content of the mine waters (in the flooded mine) is conservatively estimated at 350,000 GJ. The total static usable heat capacity of the mine is therefore estimated at about 1 million GJ.

Considering the continued heat flux into the mine (especially at depth where the rock temperature is above 40°C), if all the calculated heat capacity of the rock is extracted, the heat will be replenished by the natural gradient heat flux, which can be higher than $100mWm^{-2}$ in deeper levels of the mine (depending on the rate of heat mining). Heat flux modeling (including conductive and convective heat transfer) is needed to reliably assess the Mine's rate of heat recovery (after heat extraction). Assuming that the extracted heat is replenished in a year (taking into a account the heat flux through mine workings and all other hydrological conduits (e.g. inter-connected fractures and fault surfaces), the renewable portion of the heat can be as high as 10 to 20 MW. This value needs to be qualified through detailed geothermal modeling and testing of the resource.

For the purposes of our conceptual study, it can be estimated that the renewable portion of the mine's heat can be as much as 650,000 GJ per year which is equivalent to 20 MWt.(with a capacity factor of 75%). This means that the mine may have the potential to significantly contribute to the energy demand of the City of Yellowknife.

It should be cautioned that this type of lump-sum approach for energy reserve calculation is meant only to provide an order of magnitude evaluation of the resource. **A comprehensive geothermal modeling is needed (as part of a feasibility study) to provide a reliable assessment of both quantity and quality (i.e. temperature) of recoverable heat from the Mine. This model should include assessment of both conductive and convective heat fluxes into the mine.**

4.2 Mine waters and hydraulic conductivity

An assessment of the Mine flooding has been recently conducted and reported (DIAND, 2006). According to the findings of this report and more recent communication with the Mine Management (July 10007) mine's deeper levels (up to 4500' level) are already flooded.

Mine waters provide the main vehicle for transportation of heat to the surface, and the hydraulic conductivity provides the road for this vehicle. Mine flooding started in November 2003, with ceasing operations. A brief summary of the flooding of the Mine and water chemistry as given in DIAND (2006) is as follows:

> "The water level in the Robertson Shaft was determined to be about 1732m (5681 ft) below ground surface on June 18, 2004; the mine water collected from the top 3m of the water column in the Rob shaft on this day was saline

(computed TDS ~43,000 mg/L, Cl ~25,500 mg/L) and showed elevated concentrations of zinc (5,400µg/L); in contrast, arsenic concentrations were relatively low (150 µg/L As);
On June 20-22 2005, a second monitoring event was attempted in the Robertson Shaft (URS, 2005a); this time the auxiliary cage ceased at a depth of about 530m (1740 ft); the regulator and carriage were found to be dry upon ascent, suggesting that the water level in the shaft was at a depth >530m below ground surface; no water sample of the deep mine water was obtained."

Estimates of the time required for re-flooding the Mine are uncertain. Most reasonable estimates fall between 4 to 20 years. The mine, however, does not need to be fully re-flooded for being used as an open-loop geothermal resource. Deeper levels of the mine (which are already flooded) can be readily targeted for geothermal heat extraction.

According to the local mine management (Mr. Scott Stringer, personal communication, august, 2007), during the mine operation, the dewatering of the mine involved 300 GPM (up to 500 GPM) pumping. This means that the rate of water influx to the depth (in case of water extraction) can be as high as 20 to 30 liters per second. This value is very important for deep heat mining, as it can help calculating the sustainable rate of heat extraction (without re-injection).

It is recommended to target the deepest levels of the mine as it will enhance the system efficiency, considering the fact that the rock temperature rises with depth. The pumped waters should be re-injected to the mine, after heat extraction (to replenish the geothermal fluids and enhance the resource sustainability). Re-injection of chilled waters should be at a distance from the production well(s) to allow heat recovery. Note that re-injection is also necessary from an environmental point of view, considering the high salinity of the deep waters.

With re-injection, the amount of energy extraction from the mine would be controlled by the usable heat in the rocks (presently estimated in the order of 20 MW). Any production beyond the heat flux into the mine would lead to gradual heat exhaustion (i.e. cooling of the rocks, and degradation of the geothermal value of the mine). It should be noted that in case of monitoring heat exhaustion, the rate of heat extraction can be corrected to prevent damaging the resource sustainability.

5.0 Ideas on Resource Development

Any large-scale resource development should be based on accessing the mine waters (preferably at deeper levels). Present access to mine waters is limited to the Mine shafts. Mine Flooding monitoring requires that the surface caps of the three deep shafts (Robertson, Negus and C1) be fitted with a small access port (say 8" diameter hole) to allow for future monitoring and/or sampling. It is recommended that two additional holes (10" diameter) be fitted (in the capping of the remaining shafts) for geothermal use.

The Robertson Shaft can provide an excellent opportunity for a first stage (i.e. demonstration) project to provide heating to a close-by neighborhood (or a single large building) in the City. Geothermal access through the shaft should be designed prior to capping the shaft. Three 10” holes can be designed in the cap to provide access for water extraction, water re-injection and monitoring. Two lines of PVC pipes can be installed to appropriate depths for production and injection (Fig. 1). The design of the production and injection pipes need to be studied in detail to optimize the length, diameter and slotting configurations. No pipe needs to be installed in the monitoring hole.

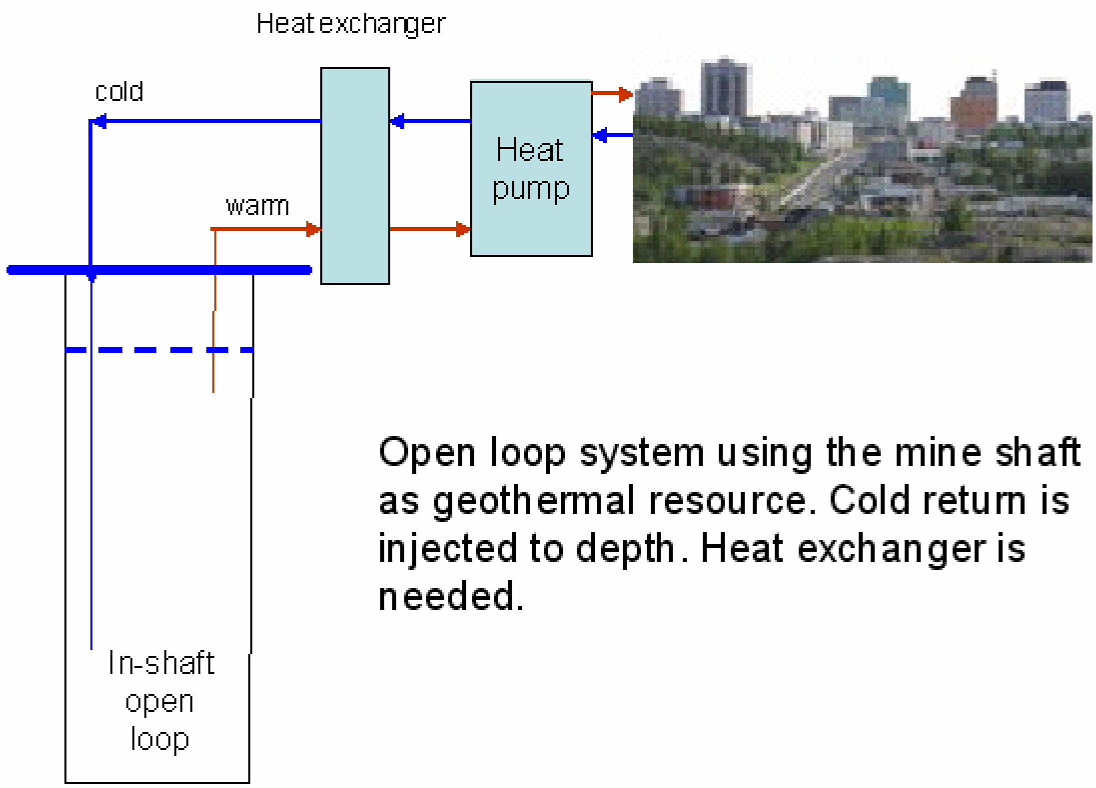

Fig. 1 Conceptual open loop geothermal development using the Roberson Shaft as the resource. Mine waters give their heat to a secondary fluid (in the heat exchanger) and will be fully returned to the deeper levels of the shaft.

An alternative development option (using the shaft) is installation of a permanent closed loop heat exchanger in the shaft prior to the capping (Fig. 2)

5.1 Conceptual design and scale

The scale and design of a geothermal heat extraction system depends on the City’s geothermal development strategy. Two options can be considered:

1- full-blown large scale resource development
2- Staged development (starting with a small- scale demonstration project)

The stages of development, if deemed feasible, would be to start with a demonstration project and then move to a full-scale resource development. Four stages can be considered in the development strategy as follows:

1. Demonstration project
2. Future City developments -
3. Downtown City core retrofit – largest concentration of energy use
4. Existing residential/commercial neighbourhood retrofits

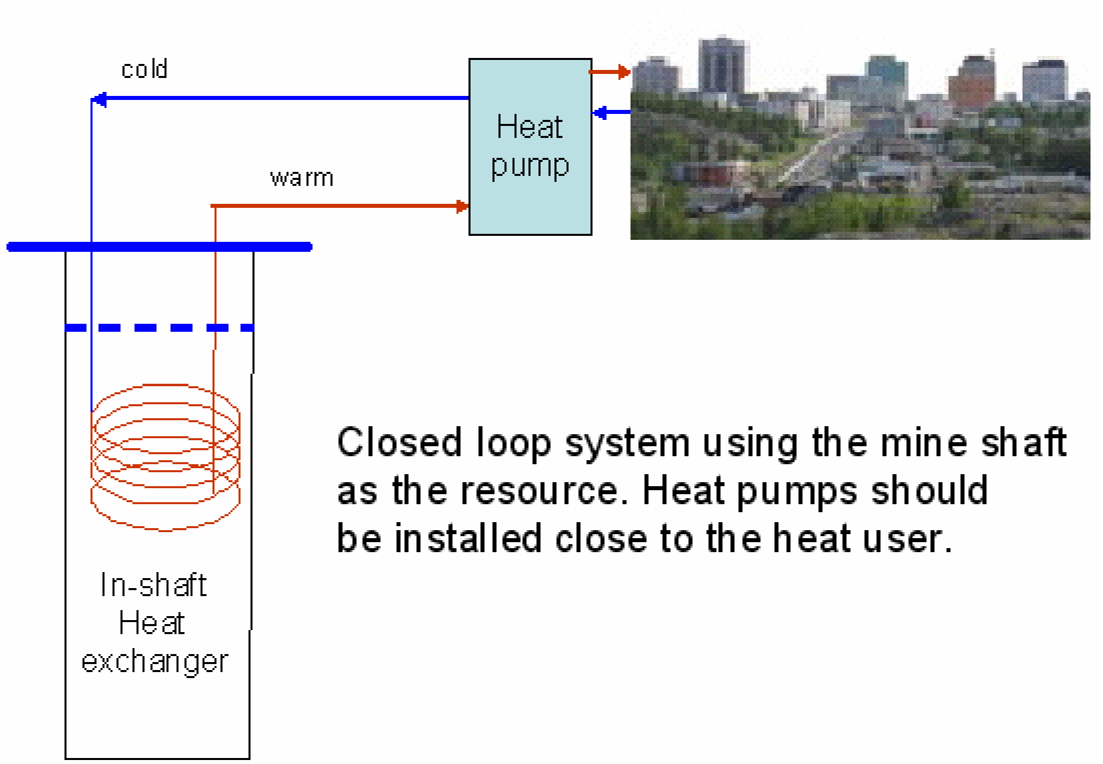

Fig. 2 – Closed loop geothermal development using the Robertson shaft as the resource. The heat exchanger (consisting of closed plastic tubing) is permanently installed in the shaft (below the water level).

This section provides a general overview on how to implement the above options.

While a small scale project can use the Robertson shaft the resource (Figs. 1 & 2), a large scale resource development (option 1) should target the deepest levels of the mine, through drilling several 6 to 8 inch holes to depths greater than 1000 m (3300 ft) (Fig. 3).

The location of these deep production wells should be based on the following factors:

- Shortest distance to the heat market (i.e. portion of the City which will use the Mine as an energy resource)
- Highest temperature gradient
- Presence of hydraulic conductivity (in the form of natural fracture systems and mine workings)

The re-injection well(s), for this option should target higher (therefore colder) levels of the mine. The re-injection wells can also target fault systems connected to deep mine workings.

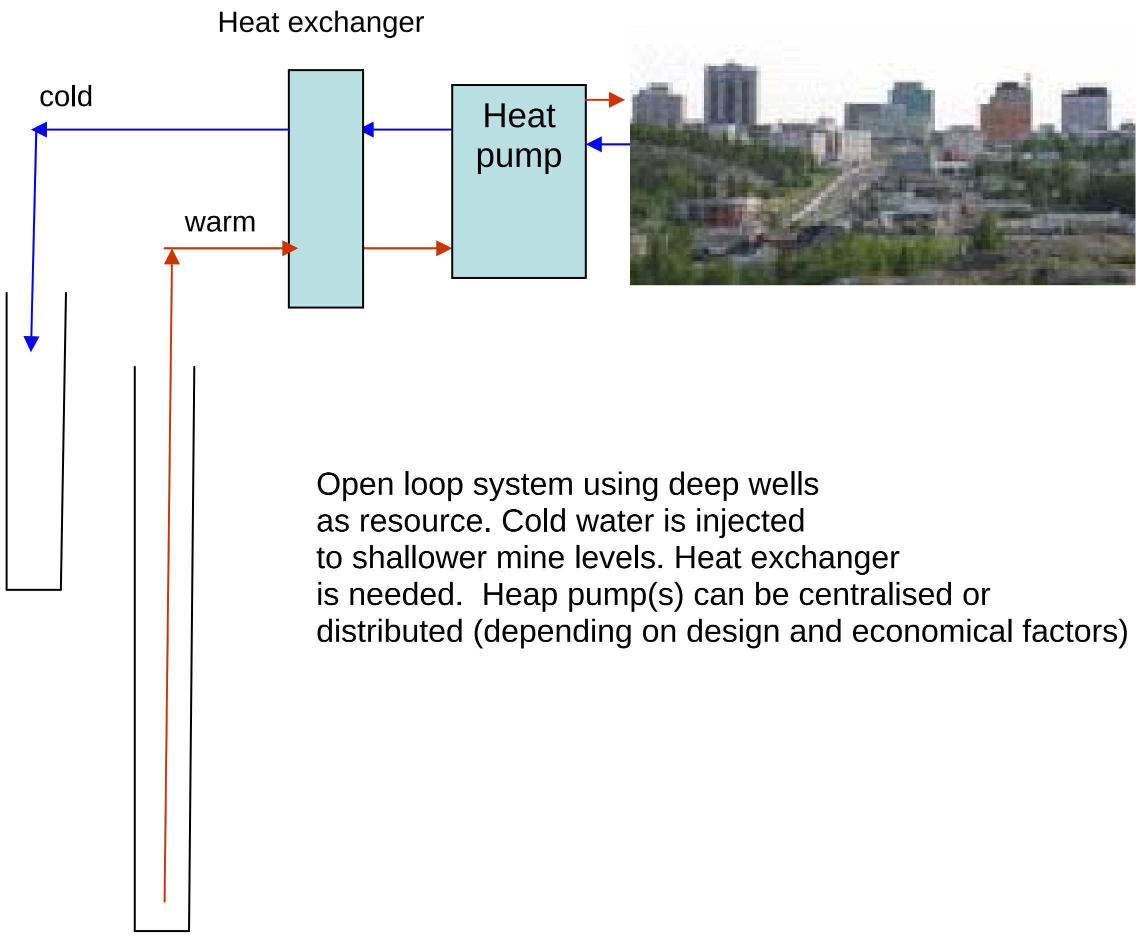

Fig. 3 – Geothermal resource development, using deep production wells (into the mine workings) and injection wells (into higher levels of the mine or permeable fault zones connected to the mine workings).

Heat exchanger(s) should be installed very close to the wellhead (to avoid heat loss). For a large-scale distributed system (where users are distributed over a large area), it may be more cost-effective to install a separate heat pump at each main centre. This will reduce the heat loss, as distribution of hot water (i.e. the output of a central heat pump) can lead to significantly more heat loss.

The capacity of a large-scale project depends on the maximum sustainable rate of heat extraction from the mine. This rate (here estimated to be as high as 20 MWt), should be qualified by detailed geothermal modeling and well testing (as part of a comprehensive feasibility study). The temperature of deep waters is estimated to be as high as 40 to 50°C. A temperature distribution modeling of the mine waters should, however, be carried out (as part of a feasibility study) to provide a three-dimensional picture of the temperature distribution in the entire mine area. This kind of modeling should use as input four sets of data:

1. Natural temperature gradient and heat flow data
2. Historic mine operational data, related to mine temperatures and cooling loads
3. Real-time temperature and water flow data (by monitoring the shafts and boreholes)
4. Water chemistry (to provide input to mixing models)

Deeper levels of the mine have been kept cool (below 34°C) during the operation. A conservative temperature of 35°C for deep mine levels may be a reliable starting point for early design purposes. The rate of the heating of the mine should be monitored to assess the equilibrium temperature (and modify the design accordingly). It is recommended that mine water temperature monitoring be considered as part of the feasibility study.

A staged development (option 2) can start with a relatively small-scale demonstration project for which the mine waters can be accessed from a shaft (most likely Robertson Shaft) and the chilled waters can be re-injected to another shaft (or even the same shaft as shown in Fig. 1). Alternatively a closed loop (polyethylene tubing) can be installed in the shaft (prior to capping) to provide an in-shaft heat exchanger (as shown in Fig. 2).

This kind of resource development can be used for an early demonstration project, with a limited capacity of a few hundred kW (depending on the quantity of extractable energy from the shaft).

The data from the demo project can be used to expand the project to medium scale (using additional resources such as a couple of deep wells). A medium-scale project with a maximum capacity of 2 MW can be expanded around the demonstration project and serve as a pilot for an eventual full-scale development (using the maximum sustainable rate of heat extraction supported by the resource).

Both new developments and retrofits can benefit from medium- and large-scale developments. The HVAC system in new developments can be designed to make maximum use of the geothermal system (e.g. using the system in reverse mode for summer cooling).

A medium-scale (Max 2 MWt) conceptual resource development model is shown in (Fig. 4) to provide and example for development options. The scale and design of development should however be based on reliable resource and market data (which will be provided by the feasibility study).

A feasibility study may prove that the mine can provide heat to a large section of the city of Yellowknife (considering the proximity of the mine to the City). Extra energy may also be shown to be available for heat-intensive operations (e.g. heating tap water, greenhouse growing, soil worming, snow melting etc).

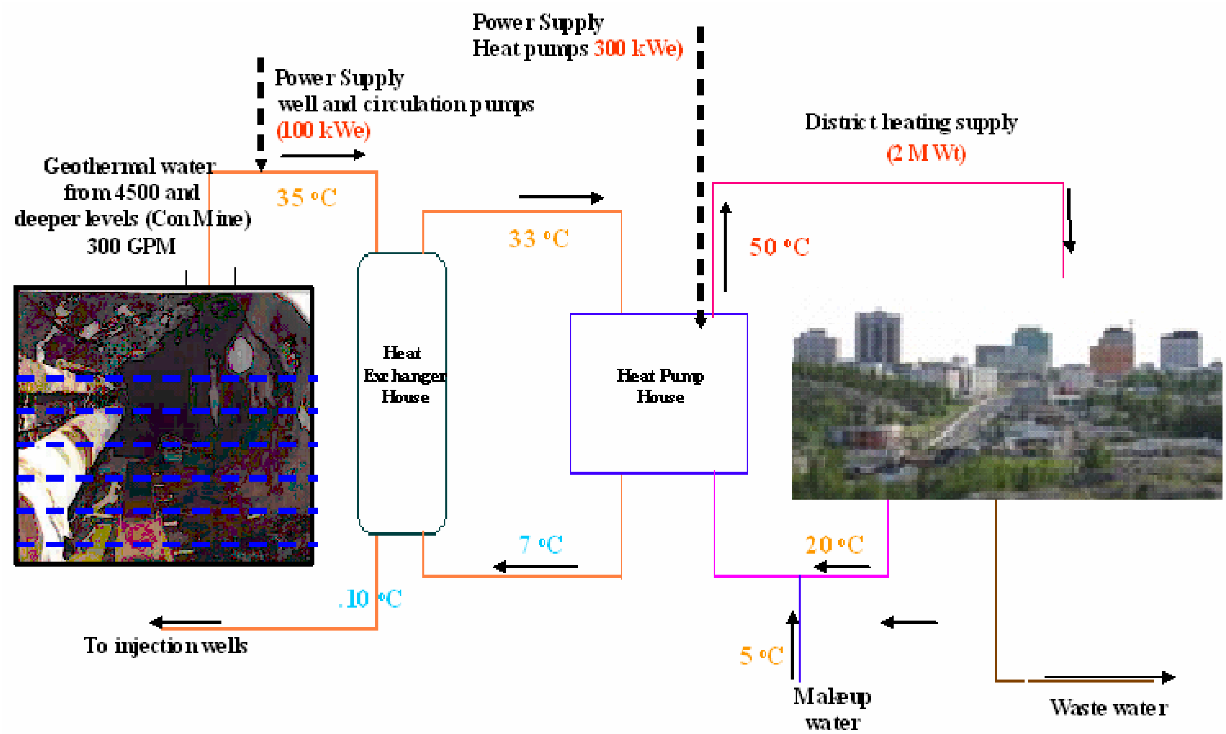

Fig. 4 – Conceptual development model for a 2 MWt system, using waters in deep mine workings as resource (assumed 35°C), the mine waters are totally returned to the mine (through injection well(s) to the shallower levels to replenish the mine fluids. A secondary fluid (clean surface water) will extract heat from the mine waters (in the heat exchanger) and communicates with the heat pump(s). Water demand is estimated at 300 GPM (which means re-injection is needed to avoid fluid depletion). Design parameters given here are conceptual and should be validated as part of a feasibility study.

5.2 conceptual example of a 300 kW demonstration project

A 300 kW demonstration project can be readily designed and developed while waiting for a comprehensive geothermal feasibility study to provide reliable information for large-scale development. The demonstration project can also provide R&D facility to allow fine-tuning the design of larger-scale developments.

The geothermal resource required for a 300 kWt geothermal facility is readily available in the waters stored (and flowing through) in the Robertson shaft. Assuming a pinch ΔT of 10°C (i.e the geothermal waters be chilled by about 10°C), the facility would require about 150 GPM (for an open loop, Fig. 1) of mine waters. To avoid any possible environmental contamination by the mine waters, high-quality stainless steel heat exchangers should be installed near the shaft (where the mine waters are brought to the surface). The mine waters will exchange heat with clean surface waters, before being returned to the deeper levels of the shaft. Assuming that water level being at 400 m, the power requirement for pumping would be about 25 kW. Another 5 kW of power would be required to bring the output of the heat exchanger to the target building(s) in town.

The power requirement for heat pump(s) (which would be installed in the building(s) where the heat is used) depends on the resource and supply temperatures. Assuming a modest resource temperature of 16 °C and a supply temperature of 45°C, the power requirement for the heat pump(s) is about 60 kWe (COP being equal to 5). The total power requirement is therefore estimated at 90 kW (i.e. less than one third of the generated thermal energy (i.e. 70% net efficiency).

Alternatively a closed loop (in shaft heat exchanger) can be used (as shown in Fig. 2). In this case the cost of stainless steel (or titanium) heat exchanger will be replaced by the cost of in-shaft plastic heat exchanger, the power required for pumping and circulation may be less than that of an open loop (leading to higher net efficiency). The size and design of the in-shaft heat exchanger would highly depend on the rate of heat extraction and convective heat flux into the higher levels of the shaft, where the closed loops are installed (this parameter needs to be evaluated by detailed hydro-geothermal modelling of the shaft).

It can be seen that for a small-scale (open loop) project the electricity demand is relatively high. For higher-scale projects, targeting higher-temperature mine waters (in the deep mine workings), the overall net system efficiency can significantly improve to 85% (i.e 15 kW electricity demand for each 100 MW heat production).

Cost estimates for a conceptual 300 kW open loop demonstration project using the shaft is presented in the Table 1.

Cost item	**Kind**	**Quantity / capacity**	**Price**
Pipes	8" insulated	2000 m	250,000
Heat exchanger	Plate SS		60,000
Pipeline construction		1000 m	100,000
Heat exchange room			50,000
Pumps and control			30,000
Heat pumps		300 kW	70,000
Hot water tank			20,000
Engineering			60,000
Subtotal			640,000
Contingency	20%		128,000
Total			**768,000**

Table 1 – capital costs for development of a conceptual 300 kW demonstration facility

Assuming a local energy price of $28 per GJ (for heat) and electricity price of 18 cents per kWh (ADWE, 2006), for a 300 kW GHP facility (working with a capacity factor of %75), the savings in energy costs will amount to:

Electricity costs for heat pumps $105,000/y
Heat cost saved $200,000/y

Net savings $95,000 per year

This translates into a payback period for the investment of less than 8 years. Note that this cost scenario best fits system development for geothermal heating of a residential apartment building (with heat demand of 300 kW) in the southern extension of the City (i.e. relatively close to the Robertson shaft, Fig. 5).

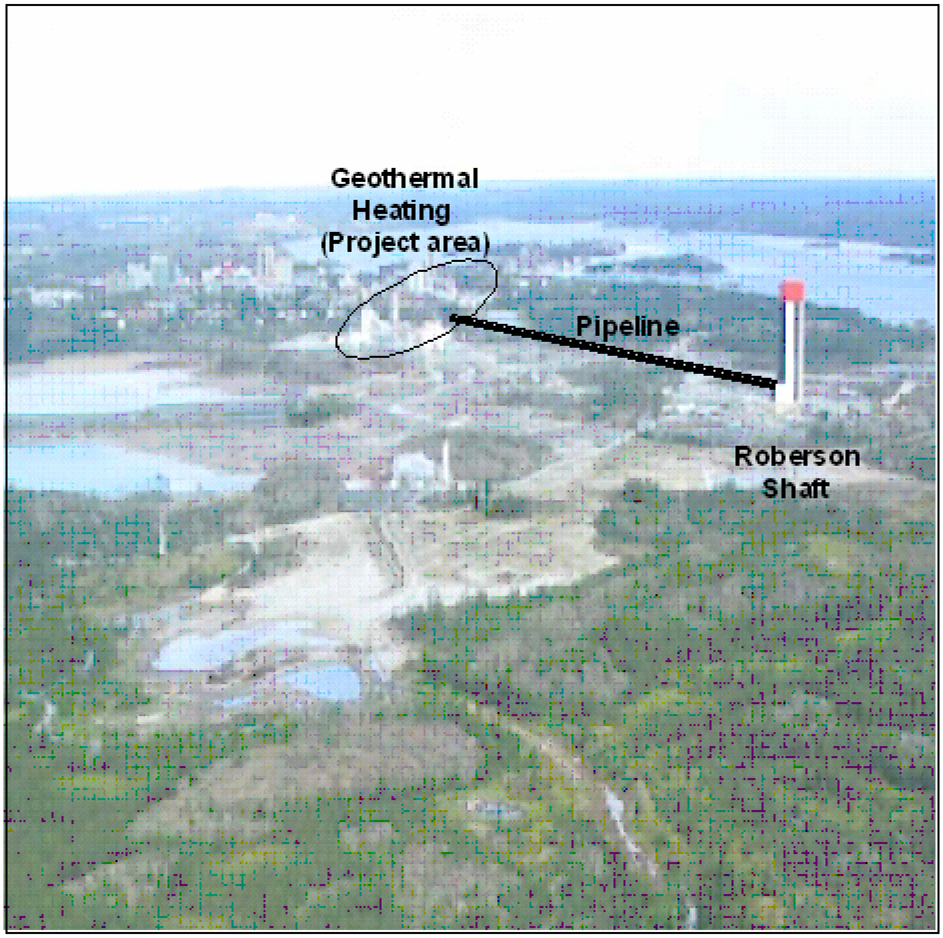

Fig. 5 – approximate target for demonstration geothermal heating project, using Robertson Shaft,

The payback period for larger scale projects (larger than 1 MW, Fig. 4) can be lower considering the lower infrastructure costs per unit of energy and also due to the fact that for high capacities deeper levels of the mine - therefore higher temperatures - can be targeted . It should be noted that for higher temperatures, the heat pump will work at a much higher COP (i.e lower electricity demand per unit of generated heat). Deep high-temperature fluids can also be used for direct use applications

5.3 Expansion to higher capacities

For high capacities deeper levels of the mine - therefore higher temperatures - can be targeted. It should be noted that for higher temperatures, the heat pump will work at a much higher COP (i.e lower electricity demand per unit of generated energy). Deep high-temperature fluids can also be used for direct use applications such as snow melting or heating of the City water.

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Estimates of resource temperatures and net system efficiencies for different scales of development are given in table 2, net efficiency being defined by:

$$NE = (SH-e)/RH$$

Where:

NE = Net System efficiency
SH = heat energy supplied to the user
e = electricity consumption by heat pumps and water pumps
RH = heat energy extraction from the resource

Scale	Depth	Temperature C	Net Efficiency %	Mine Viable Capacity (kW)
Small	500 m	15	65	300
Medium	1200	30	85	1000
Large	1700	40	90	2000

Table 2, estimated system efficiency for different scales of operation (using Con Mine waters as resource in a conceptual open loop geothermal heating system.

Higher resource temperature for larger capacities is because large-scale projects can absorb costs of deep drilling. The higher system efficiency is estimated from higher COP for higher temperatures and lower electricity for water pumps (per unit of energy extracted and transferred). Large-scale resource development, however, is strongly market dependent (i.e. a market should be secured before developing the resource).

6.0 Development components linked to the reclamation process

Considering that the geothermal value of the Con mine can potentially help with the sustainability of post-mining activities, it would make sense to tie, as much as possible, the geothermal development plans of the mine to the reclamation activities.

Two of the current reclamation activities (mine flooding and capping the shafts) can directly affect the extraction of geothermal energy from the mine waters.

a- Capping of the mine shaft

Mine shafts can potentially provide access to a portion of the geothermal resource. It is therefore important to modify the capping design to accommodate potential accessibility to the resource. Detailed resource assessment is necessary to fully understand the nature of resource accessibility through the shafts. Some of the modifications which may be recommended at this stage include:

- Geothermal access hole in the capping for extraction and re-injection of geothermal fluids.

- Geothermal pipes for production (from depth) and re-injection (to shallow levels) can be installed on the sides of the shaft prior to capping (note that installation of pipes though the holes would be a more challenging task).

- The monitoring holes in the cap should be able to allow probing for geothermal fluid quality (e.g. pH, T, Conductivity, turbidity, and sampling).

- In the case of in-shaft geothermal closed-loop design, the loop should be installed prior to capping.

b- Mine flooding

Mine flooding should be more systematically monitored to provide reliable information on mine's present and future hydrology. Note that reliable hydrological data are essential to the mine's geothermal resource evaluation and management.

7.0 Geothermal Market and viability of investment

Yellowknife is one of the best Canadian Markets for low-enthalpy geothermal heat, as 70% of the energy used in the City is used for space heating homes and buildings (used at relatively low temperature) (AD Williams, 2006). Considering the fact that most of the City's heat demand is supplied by burning fossil fuels, any level of geothermal development will proportionally reduce GHG emission of the City.

The total heating energy demand of Yellowknife is slightly less then (3.9 GJ) 4 million GJ per year. Assuming an average energy price of $28 per GJ (avg. oil price for 2006/07 = $0.80/l, the total heating market of the city in 2004 was 68 million dollars. Assuming that Con mine can provide about 20% of the Cities heat demand, the market value of the Mine's geothermal resource can exceed 13 million dollars per year. This high market value can justify deep drilling into the highest-temperature sections of the resource.

Considering that geothermal will mostly replace diesel fuel, the total GHG reduction for the city can exceed 40,000 tonnes per year (i.e. 2 tonnes of reduction for each Yellowknifer). The market value of the saved GHG (at $12 to $15/tonne) can exceed half a million dollars per year.

In order to reduce the cost of geothermal infrastructure (i.e. drill holes, pipe, lines and energy distribution system), it is recommended that only a section of the south end of the City (i.e. the areas which are closer to deep mine workings) be targeted for geothermal heating from Con Mine. If it is deemed feasible to drill into the mine, it would be possible to access it from anywhere in the city that is in close proximity to a mine drift.

A distributed resource development may therefore be preferred over a centralized system. Mine workings extend below much of the City. Separate geothermal systems for different high-density new developments or retrofits can be developed to minimize requirements for distribution.

Considering the present heating cost of the City, and assuming a payback period of 5 years for the investment, up to 10 million dollars may be afforded to be invested for each 2MW geothermal resource development and infrastructure. The real investment per MW for high-capacity developments (more that 5 MW) can be significantly less than the defined threshold.

Existing international statistics on the capital cost of geothermal systems for district heating is less than $2500 per kW. This means that development of a 10 MW geothermal district heating capacity for the City of Yellowknife can be as low as 25 millions.

8.0 Concluding remarks

Con Mine has the potential to be used as a geothermal resource for the City of Yellowknife
The resource, if confirmed and developed can reduce significantly the City’s dependency on fossil fuel, make savings on energy costs, and reduce GHG emissions.

Deep levels of the mine (where the temperature exceeds 35 °C) may be accessed for large-scale resource development. Smaller scale (demonstration) projects can be developed using the fluids in the Robertson shaft (as an open loop or closed loop geothermal resource)

It is important to integrate the geothermal resource development strategy with the mine reclamation plan to minimize the development costs and maximize the system efficiency.

A comprehensive feasibility study is needed to qualify the resource and give details of development options.

Respectfully Submitted

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Reference Documents:

A. D. WILLIAMS ENGINEERING INC. June 1, 2006. Yellowknife Interim Community Energy Plan, Action Area Studies, ACTION AREA 8: RENEWABLE ENERGY IN YELLOWKNIFE FOR HOMES AND BUILDINGS Prepared For CITY OF YELLOWKNIFE, Prepared By, ADWE FILE NO. 11592.00

Miramar Con Mine Ltd.'s Final Closure & Reclamation Plan. Mackenzie valley land and water board. Staff report, Miramar Con Mine Ltd., Yellowknife. Application: N1L2-0040. Prepared on April 2, 2007 Meeting Date: April 26, 2007

DIAND's report on the underground flooding at Con Mine, and their comments on Sections 7 – 8.

URS Engineering Risk Assessment and Risk Management Plan. Final report prepared by Miramar Con Mine Ltd. (2005), for MVLWB (file: NIL2-004)

Papers referenced:

Ghomshei, M.M. K, MacLeod, T.L. Sadlier-Brown, J.A. Meech, R.A. Dakin. (2005). Canadian Geothermal Energy Posing for Takeoff. Proceedings of World Geothermal Congress, Turkey, April. 2005, p. 10

Ghomshei, M. and J.A. Meech, 2003. "Useable Heat from Mine Waters: Coproduction of Energy and Minerals from "Mother Earth" Intelligence in a Materials World: Nanotechnology for the 21st Century, Eds.: J.A. Meech, Y. Kawazoe, V.J. Kumar, J. Maguire, H.P. Wang, CRC Press, pp. 5.

Ghomshei, M.M., J. A. Meech, D.W. Fraser, and R.A. Dakin, 2002. "Geothermal Heat Pump Options: Fuzzy Arithmetic for a Bright Decision", In: Intelligence in a Materials World. Eds. J.A. Meech, M.M. Veiga, Y. Kawazoe, S.R. LeClair, CRC Press, New York, 609-614.

Internet data resources:

http://www.conmine.ca/s/Reclamation.asp

http://www.conmine.ca/i/pdf/ConCR-List%20of%20SupportingDocs.pdf