Using hydrogeologic data for geoexchange potential mapping, City of Whitehorse, Yukon

H. Scott Schillereff
EBA Engineering Consultants Limited, Kelowna, British Columbia, Canada

ABSTRACT
Hydrogeologic, geologic, thermal and land-use information was compiled for 121 control points within a 220 km^2 developable portion of the City of Whitehorse, Yukon. A weighted semi-quantitative scoring system was developed to evaluate potential for open loop groundwater and other geoexchange applications. Contoured scores were mapped at city scale showing good (green), fair (yellow) and poor (red) geoexchange potential. Much of Whitehorse has good to fair geoexchange potential. Such maps are useful for municipal planning and managing thermal resources, showing suitable types of ground heat exchangers over large areas. Further work on ground temperature and groundwater chemistry is on-going.

RÉSUMÉ
L'information hydrogéologique, géologique, thermique et de l'emploi de terre etaient compilés pour 121 points dans une région d'exploitation de 220 km^2 en Whitehorse, Yukon. Une méthode de pointe était développée pour l'évaluation du potentiel de la nappe phréatique. Le potentiel geothermique de Whitehorse était produit sur une carte des points de contours. La plupart de Whitehorse a potentiel bon ou passable. Ces cartes sont utiles pour la planification de l'urbanisme et l'exploitation des ressources thermiques à travers des grandes régions. On a les projects en cours qui analyse la température du sol et la chimie de la nappe phréatique.

1 INTRODUCTION

The City of Whitehorse, Yukon (City) is currently working on an Integrated Community Sustainability Plan which focuses on sustainable municipal infrastructure. The City is interested in identifying opportunities for applying geoexchange and other renewable energy technnologies within the city limits.

EBA Engineering Consultants Ltd. was retained to assess the geoexchange potential over the entire City area, and to present findings in a City-hosted sustainability charrette. Three broad classes of coupling with earth heat were considered: open loop groundwater systems, closed loop vertical borehole systems, and sanitary sewer heat recovery. This paper focuses on the method and process to compile the groundwater-based open loop geoexchange potential map for the City.

Figure 1 shows a location plan for the City of Whitehorse, including the City boundary and the study area for this project (developable area within the City).

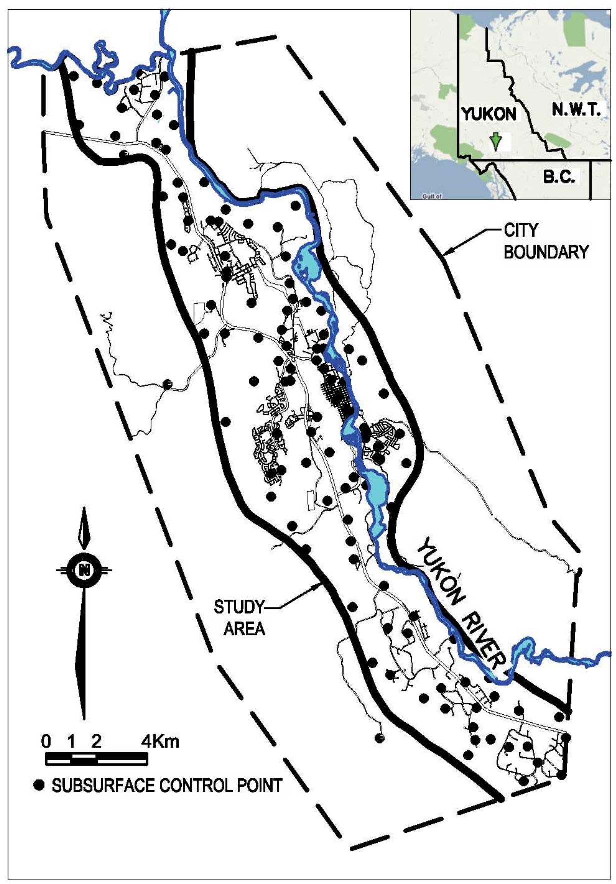


Figure 1. Site location plan for City of Whitehorse study.

2 GEOEXCHANGE AND MAPPING OBJECTIVES

2.1 Geoexchange

Geoexchange is the technological process of coupling to low-grade heat from earth sources (*soil, rock, groundwater, surface water, ocean, waste heat*) and transforming it using heat pump technology to higher-grade heat for building conditioning, domestic hot water or process purposes. Figure 2 shows the three main components of a geoexchange system – an earth energy source (coupled using a ground heat exchanger), a heat pump or heat exchanger, and a distribution system to a load (e.g., a building).

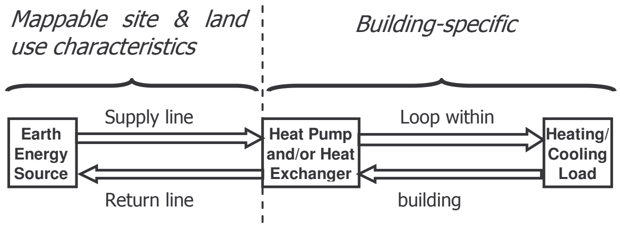


Figure 2. Components of a geoexchange system, and portion included in geoexchange potential mapping.

Ground heat exchangers fall into two broad categories: **Closed loop** systems which rely on conductive heat transfer between the earth and a network of subsurface piping through which a thermal exchange fluid is circulated in a closed circuit. Examples of closed-loop ground heat exchangers include vertical closed-loop borehole arrays or horizontal trench systems; and **Open loop** systems which rely on heat exchange with water (groundwater, surface water or ocean water) pumped from one source and disposed of in a different location (forming a discontinuous or "open" loop).

2.2 Mapping Objectives

Figure 2 also shows that the mappable site and land use characteristics relate to the earth or ground side of the system. Aspects of heat pump or heat exchanger, and in-building distribution are building-specific, and were not pertinent to areal mapping.

For groundwater open loop geoexchange systems, key design parameters are groundwater quantity (to meet diversified peak demand of the building load), adequate separation of supply well and disposal point (to avoid thermal breakthrough), water quality (to plan for potential fouling or corrosion of screens and heat exchangers) and deep ground temperature (for heat pump design).

In this work, groundwater quantity and supply-disposal separation were considered. Groundwater quality was considered site specific, and deep ground temperature data around the City were too sparse for areal mapping. Ground temperature data are being collected, as described in Section 5.3.

3 SOURCE DATA AND SCORING METHOD

3.1 Source Data

A spreadsheet database was developed for 121 control points of known subsurface conditions throughout the study area (developable areas of the City as determined from the Official Community Plan). Table 1 shows the database parameters and source information, as used for the entire study.

For the open loop groundwater assessment, three specific parameters were used to develop the geoexchange potential score: depth to groundwater (affects pumping effort and controls available unsaturated zone thickness for reinjection), transmissivity (controls well yield and affects groundwater quantity) and lot size (controls available space for adequate separation of supply and disposal point).

Parameter	Source Data/ Estimation Method
UTM Coordinates	borehole logs/ locations provided in existing City & consultant reports
Lot Size	City Official Community Plan (OCP)
Depth to Bedrock	Borehole/well logs provided in existing City & consultant reports
Dominant Overburden Type	Borehole/well logs/ surficial geological mapping/ in-house data
Bedrock Type	Borehole/well logs, bedrock geological mapping
Depth to Groundwater	Borehole/well logs/ consultant reports
Thermal Conductivity	Measured (one point) or inferred (Hellstrom 1991, Kavanaugh and Rafferty, 1997)
Hydraulic Conductivity	Calculated from transmissivity and aquifer thickness
Transmis-sivity	Calculated based on depth to groundwater and dominant overburden type (or aquifer properties where known)
Ease of Drilling	Inferred from material type and local drilling experience

Table 1. Database parameters and data sources.

Other parameters have some effect on open loop potential, but much less than these three governing factors. For example, unlike closed loop vertical borehole arrays (for commercial scale systems), where ease of drilling can greatly affect the capital cost of a ground heat exchanger, drilling ease is less important where only a few wells are involved.

3.2 Scoring Method

For each of the three governing parameters, a parameter score was assigned with one corresponding to the lowest value and 10 corresponding to the highest value. For simplicity, no weighting was applied.

Database Parameter	Data Range	Units	Parameter score (1 -10)
Depth to Groundwater	0.15 – 75	m	1 = 75 10 = 0.15
Transmissivity	0.01 – 5,820	m^2/day	1 = 0.01 10 = 5820
Lot Size	300 – 10,000	m^2	1 = 300 10 = 10000

Table 2. Whitehorse parameter values and score ranges

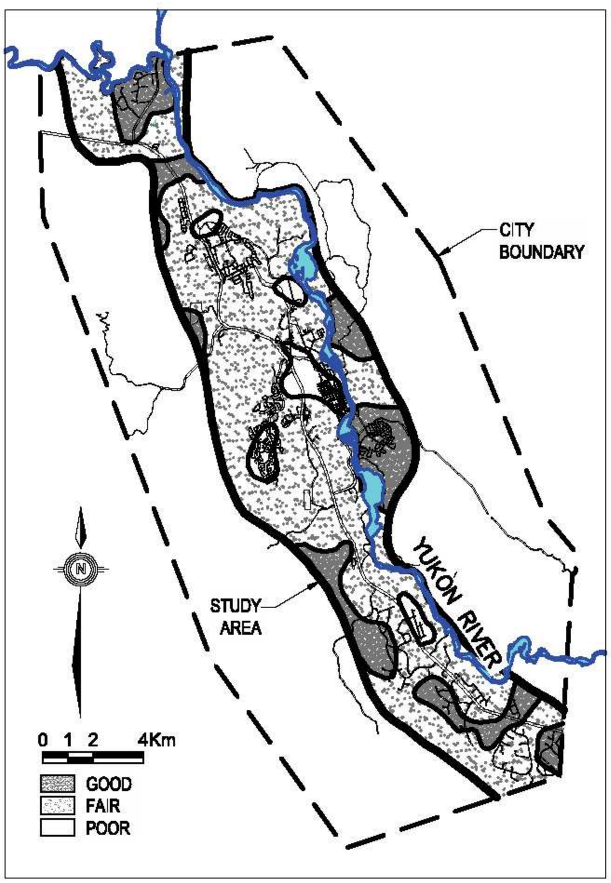
A composite score for each control point was calculated by first multiplying the parameter scores together, then taking the logarithm of the product. As an example from Table 2, for depth to groundwater of 0.15 m, transmissivity of 5,820 m^2/d and lot size of 300 m^2, the parameters scores would be 10, 10 and 1, respectively. The composite score is log(10x10x1) = 2.0. With three parameters, the potential composite scores could range from 0 (log of 1) to 3 (log of 1,000).

4 OPEN LOOP GEOEXCHANGE POTENTIAL MAP

For mapping purposes, threshold values for composite scores were developed by calculating equivalent scores for sets of parameter values judged to constitute the good and poor threshold conditions. Values assigned for the good threshold condition were transmissivity >1000 m^2/day, depth to groundwater <20 m, lot size >5,000m^2, giving a composite score of 1.9. Values for poor threshold condition were transmissivity <100 m^2/day, depth to groundwater >60 m, lot size <1,000 m^2, giving a composite score of 1.1. Scores between 1.1 and 1.9 were assigned as a fair condition.

These final scores and qualitative categories were mapped by assigning green for "good", yellow for "fair" and red for "poor" conditions. Using these "stop light" colours can immediately and intuitively convey the qualitative geoexchange potential to a wide range of audiences.

Figure 3 shows the open loop groundwater geoexchange potential map for Whitehorse compiled for this study (note: due to black and white production constraints here, good is shown as dark stipple, fair as light stipple and poor as no stipple).



5 DISCUSSION

5.1 Uncertainty and Utility

Based on the variety and range of quality of the source Information and since some parameters were calculated or estimated, there is a varying degree of uncertainty in the results. Inherently, where there is denser, known subsurface control, the uncertainty of the resulting composite score is considered to be lower than in less well-constrained areas. This scoring method is tied to localized conditions (actual parameter ranges are scaled to 1-10 parameter scores). These parameter ranges may be quite different in other settings, but the general method would still apply. It is important to note that this method is intended to reveal a relative comparison of expected geoexchange potential over large areas (km scale). It is not intended to represent pre-design characterization of specific sites or to predict the performance of geoexchange systems. The applicability of geoexchange for a given project depends on site conditions as well a building characteristics (heating or cooling loads), project HVAC system and geoexchange system objectives (energy savings, greenhouse gas reduction, etc.). In this light, we consider the uncertainty in the Whitehorse findings to be tolerable.

This method could be refined by weighting individual parameters, if there was a sound basis to show that certain parameters were more significant for geoexchange potential than others, and if there was a suitably robust subsurface database to support a weighting approach. This effort was not within the scope of this assignment with the City of Whitehorse.

Conversely, this areal mapping approach could potentially be applied to areas with geologic mapping (bedrock and surficial) and only rudimentary knowledge of subsurface hydrogeology (e.g., sparse water well information) to give a first-order approximation of geoexchange potential. In such cases, suitable limiting statements would be essential to convey the higher uncertainty in the results.

5.2 Geoexchange Potential in Whitehorse

Figure 3 shows there is fair to good open loop geoexchange potential throughout study area. We and the City considered this favourable. Five localized areas were ranked as poor areas, for a variety of causes (either low transmissivity, excessive depth to groundwater, a small lot size, or a combination of these factors).

There was a high level of interest in these results by City officials and media. After the presentation at the charrette, there were several newspaper articles, a radio and local television interviews, and a feature article on CBC national web site. These results were also presented to the City Council of Whitehorse. During discussions with the City, several neighborhoods (both residential and industrial) were identified as possible candidates for district energy systems. With this level of interest, the City also applied for and has received funding for assessing the feasibility of geoexchange and waste heat recovery for the planned new Whistle Bend neighbourhood community at Porter Creek Bench. The City is currently pursuing this initiative.

Finally, this geoexchange resource mapping project has won an internal EBA Engineering award for innovation, and an Award of Merit in the Consulting Engineers of BC Engineering Excellence Awards competition in March, 2008.

5.3 On-Going Work

The City is currently engaged in a project to profile temperatures in ten existing water wells (from 50 to 300 m deep) around the City. These profiles will show the depth and range of near-surface temperature variability (down to about 10-15 m), a neutral zone of limited variability, and the geothermal gradient in deeper portions of the wells. From this, the magnitude and areal variations in deep ground temperature can be determined, which will be useful for evaluating the benefits of different types of ground heat exchangers in Whitehorse.

In addition, groundwater samples are to be collected from these profile wells for analysis of inorganic water chemistry and environmental isotopes (oxygen-18 and deuterium). These analyses will be used to assess the differing hydrochemistry and provenance around the City.

6 CONCLUSIONS

A method was developed for mapping the areal geoexchange potential for open loop groundwater applications for the City of Whitehorse (~200 km^2). The governing parameters selected were transmissivity, depth to groundwater and lot size. Composite scores for 121 control points around the City were developed by multiplying individual parameter scores together and taking the logarithm of the product.

Threshold composite scores were developed for good, fair and poor conditions in Whitehorse, based on the local ranges of the three governing parameters. Composite scores were contoured and depicted in simple good-fair-poor zones on a city-scale map. This presentation intuitively and effectively conveys the results to a wide audience. The City of Whitehorse is pursuing supplementary studies to assess deep ground temperature and groundwater chemistry around the City area, and is pursuing a detailed feasibility study for geoexchange in a planned neighbourhood development.

This method could be applied to other settings, with varying amounts of subsurface control. Uncertainty of the results is directly related to the density and quality of the available subsurface information and data.

This approach can be a valuable tool for assessing large areas and assisting local governments in planning and managing renewable energy resources.

ACKNOWLEDGEMENTS

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