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Deep Geothermal Heating Potential for the Communities of the Western Canadian Sedimentary Basin

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Abstract: We summarize the feasibility of using geothermal energy from the Western Canada Sedimentary Basin (WCSB) to support communities with populations >3000 people, including those in northeastern British Columbia, southwestern part of Northwest Territories (NWT), southern Saskatchewan, and southeastern Manitoba, along with previously studied communities in Alberta. The geothermal energy potential of the WCSB is largely determined by the basin's geometry; the sediments start at 0 m thickness adjacent to the Canadian shield in the east and thicken to >6 km to the west, and over 3 km in the Williston sub-basin to the south. Direct heat use is most promising in the western and southern parts of the WCSB where sediment thickness exceeds 2–3 km. Geothermal potential is also dependent on the local geothermal gradient. Aquifers suitable for heating systems occur in western-northwestern Alberta, northeastern British Columbia, and southwestern Saskatchewan. Electrical power production is limited to the deepest parts of the WCSB, where aquifers >120 °C and fluid production rates >80 kg/s occur (southwestern Northwest Territories, northwestern Alberta, northeastern British Columbia, and southeastern Saskatchewan. For the western regions with the thickest sediments, the foreland basin east of the Rocky Mountains, estimates indicate that geothermal power up to 2 $MW_{el.}$ (electrical), and up to 10 times higher for heating in $MW_{th.}$ (thermal), are possible.

Keywords: heat flow; deep geothermal heat; foreland basin; WCSB; energy transfer

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1. Introduction

Direct heating with geothermal energy could provide an important energy resource in cold climate regions, such as the Canadian prairie provinces where heating accounts for 80% of the total energy demand. Sedimentary basins, such as the Western Canadian Sedimentary basin (WCSB), hold significant heat that could be used to support communities overlying the basin. Direct use geothermal energy is commonly used for district heating systems [1–4]. Typically, district heating systems require temperatures >60 °C and fluid production rates >30 kg/s, using two or more geothermal wells with at least one production well and one injection well [5].

District heating systems could significantly reduce CO_2 emissions by replacing gas and oil combustion with renewable energy resources [6–11]. The WCSB contains large geothermal energy reserves, with temperatures reaching over 160 °C. About half of the basin area is >2 km deep, with measured temperatures >60 °C [11–16].

Previous studies of the WCSB examined both direct heating energy, in GJ per year, and potential electrical power generation (MW electrical), but for only the province of Alberta [17]. We expand on this previous work by examining geothermal potential for all communities with populations >3000 people that overly the WCSB, adding geothermal energy calculations for northeastern British Columbia, Saskatchewan, southern Manitoba, and southwestern NWT (see location of the study area in Figure 1 and location of the municipalities in Figure 2). Maps specific to these new assessment areas are presented in Appendices A and B, while combined maps for the entire WCSB are presented here. Calculated geothermal potential for specific communities are in tables in Appendix C. These tables include geothermal energy available assuming an average energy use of 130 GJ/year, enthalpy, calculated formation temperature, and the drill depth required for calculated temperatures.

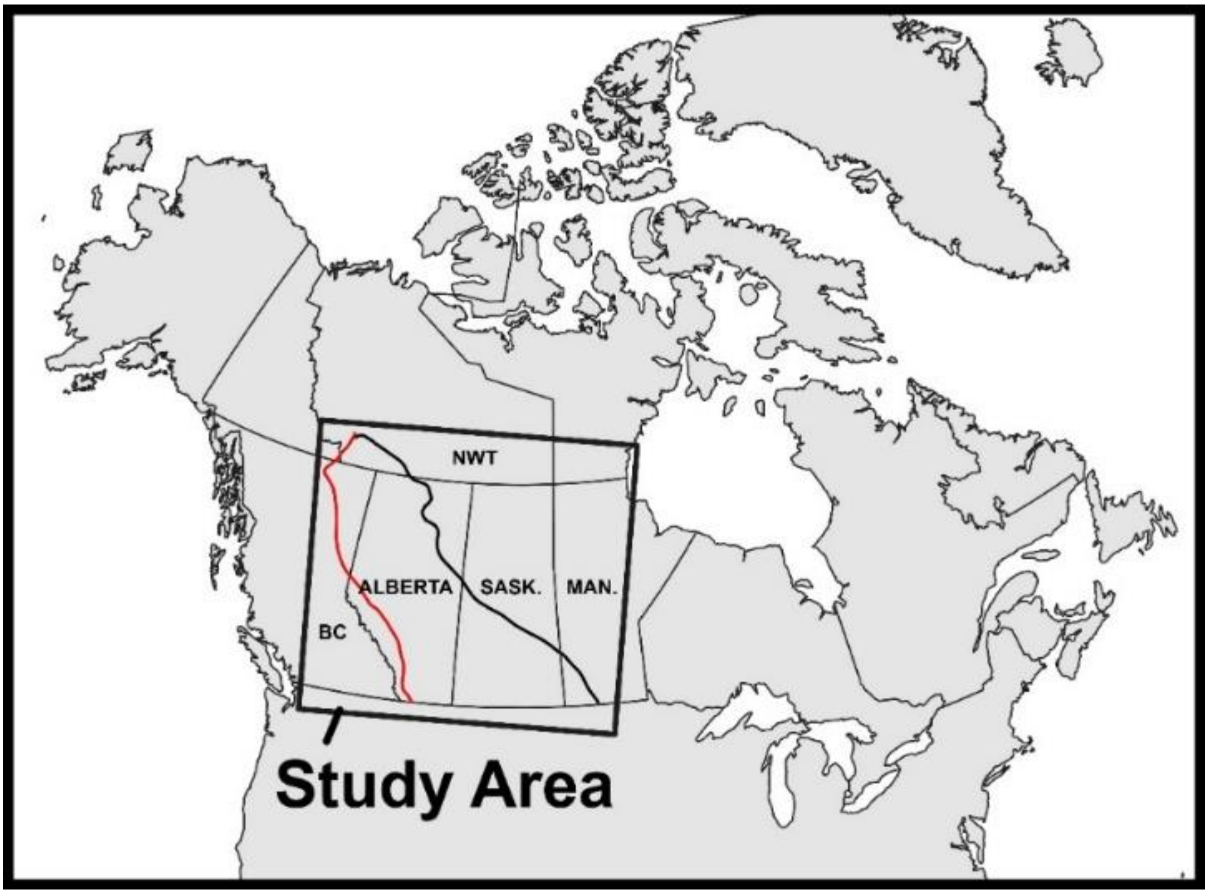

Figure 1. Map of Canada showing the study area (rectangle). Provinces and territories that are considered in the study are indicated along with the outline of the Western Canada Sedimentary Basin (WCSB). BC = British Columbia, NWT = Northwest Territories, Sask. = Saskatchewan, Man. = Manitoba. The red line depicts the western margin of the WCSB which is defined by the deformation front of the Canadian Rocky Mountains. The black line shows the eastern edge of our study defined by 1 km sedimentary thickness.

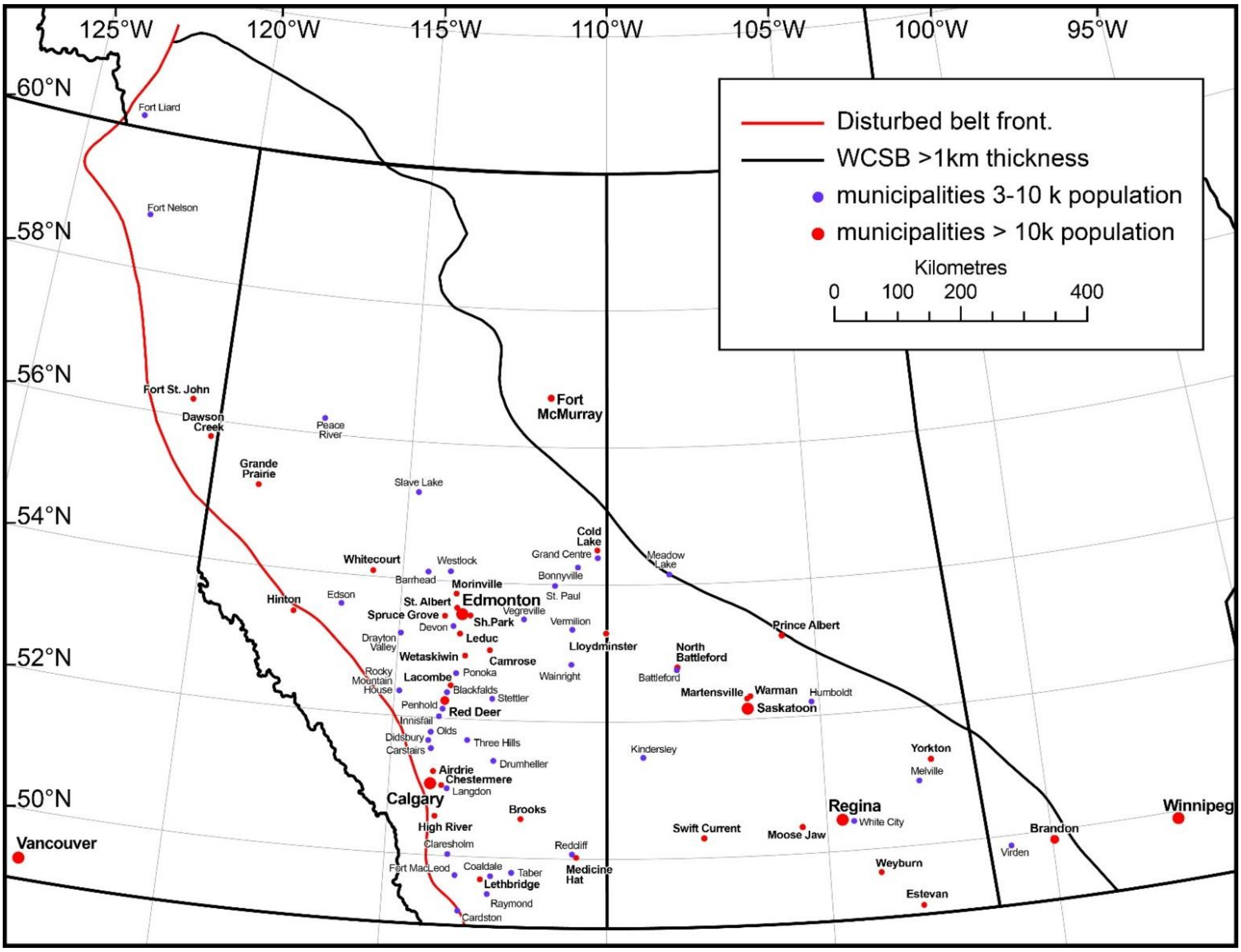

Figure 2. Location map of the Western Canadian Sedimentary Basin (WCSB) with provincial boundaries and locations of municipalities with populations >3 k. The red line depicts the western margin of the WCSB defined by the deformation front of the Canadian Rocky Mountains.

2. Background

Geothermal production of electrical power, through the Organic Rankin (ORC) or Kalina cycle (KC), needs to be in the vicinity of an existing power grid to be economical. Such infrastructure is available in some remote areas as already shown by wind-based power production in Alberta. However, the low ~10% efficiency of ORC and KC power plants is a limiting factor, making only high enthalpy regions of interest for electrical potential, such as the deepest parts of the WCSB in Alberta and southern Saskatchewan [11]. However, "The Alberta Climate Leadership Plan" goal of replacing 5000 megawatts of coal-generated electricity with power coming from renewable sources by the year 2030 is daunting. Electrical power from geothermal sources would require thousands of geothermal doublet well installations, while two well systems with 1–2 MW potential is feasible in only limited areas (see Tables in Appendix C). The cost of geothermal wells to produce sufficient electricity would be upwards of $50 billion dollars for 1000 systems [7]. District heating (DH) may therefore be the most feasible use of geothermal resources in cold climate regions such as the Canadian prairie provinces. This also comes with challenges though.

Transmitting hot fluids over large distances comes with significant energy loss, which means that to be useful, DH projects must be as close to a community as possible [18,19]. Modelling by Kapil et al. [19] indicates that there is an ~1% heat loss for every km of insulated pipe distance. However, the Kapil et al. [19] model did not consider the cost for pump operation to determine the economically feasible distance of heat transmission. Later work shows that distance needs to be even smaller for DH systems. Economic constraints mean that high enthalpy, high temperature (120–250 °C) [20], steam can be transported 3–5 km, water with temperatures 90–175 °C some 30 km, and waters with lower grade heat [21], ~15 km [18].

3. Structural Setting of the WCSB

The WCSB underly 1,400,000 km^2 of Western Canada, (southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia (BC) and the southwest corner of the Northwest Territories (NWT)). A massive wedge of sedimentary rock extends from the Rocky Mountains (Canadian Cordillera) in the west, to the Canadian Shield in the east. This wedge is about 6 km thick at the deepest part of the basin bordering the Cordillera but thins to zero m at its eastern margins in Manitoba, northeastern Saskatchewan, and southwestern NWT (see Figure 3 below). A geological cross-section perpendicular to the basin's strike shows the general configuration of the Pre-Cambrian basement and overlying sedimentary formations. We show in Figure 3 that a 2 km drilling depth will reach 60–70 °C fluids according to [22], while a 3 km depth will reach some 90–100 °C.

A generalized stratigraphic column of the WCSB is also shown in Figure 3. Table 1 lists the Geological Period from Cretaceous down to Cambrian and the formations that are known to have significant permeability [15]. The tops of these formations and groups, their thickness maps and cross- sections, are readily available from the Alberta Geological Survey (AGS) online: <https://ags.aer.ca/reports/atlas-western-canada-sedimentary-basin>. The geological information is not repeated here as we focus on the thermal conditions of most the most prospective sedimentary groups.

Table 1. Potential geothermal target formations in the WCSB (modified from [15]).

Period	Group	Formation	Lithology
Cretaceous	Mannville		sandstone
Cretaceous	Mannville	Cadomin	sandst./congl.
Mississippian	Rundle		carbonates
Mississippian	-	Charles	carbonates
Mississippian	-	Banff	limestone
Devonian	Wabamun	Wabamun	dolomite
Devonian	Winterburn	Nisku	carbonates
Devonian	Woodbend	Grosmont	dolomite
Devonian	Woodbend	Leduc	dolomite
Devonian	Woodbend	Cooking Lake	carbonates
Devonian	Beaverhill	Slave Point	carbonates
Devonian	Beaverhill	Swan Hills	carbonates
Devonian	Elk Point	Pine Point	dolostone
Devonian	-	Granite Wash	sandstone
Cambrian	Lynx	Deadwood Fm.	sandstone
Cambrian	-	Basal Sandstone	sandstone

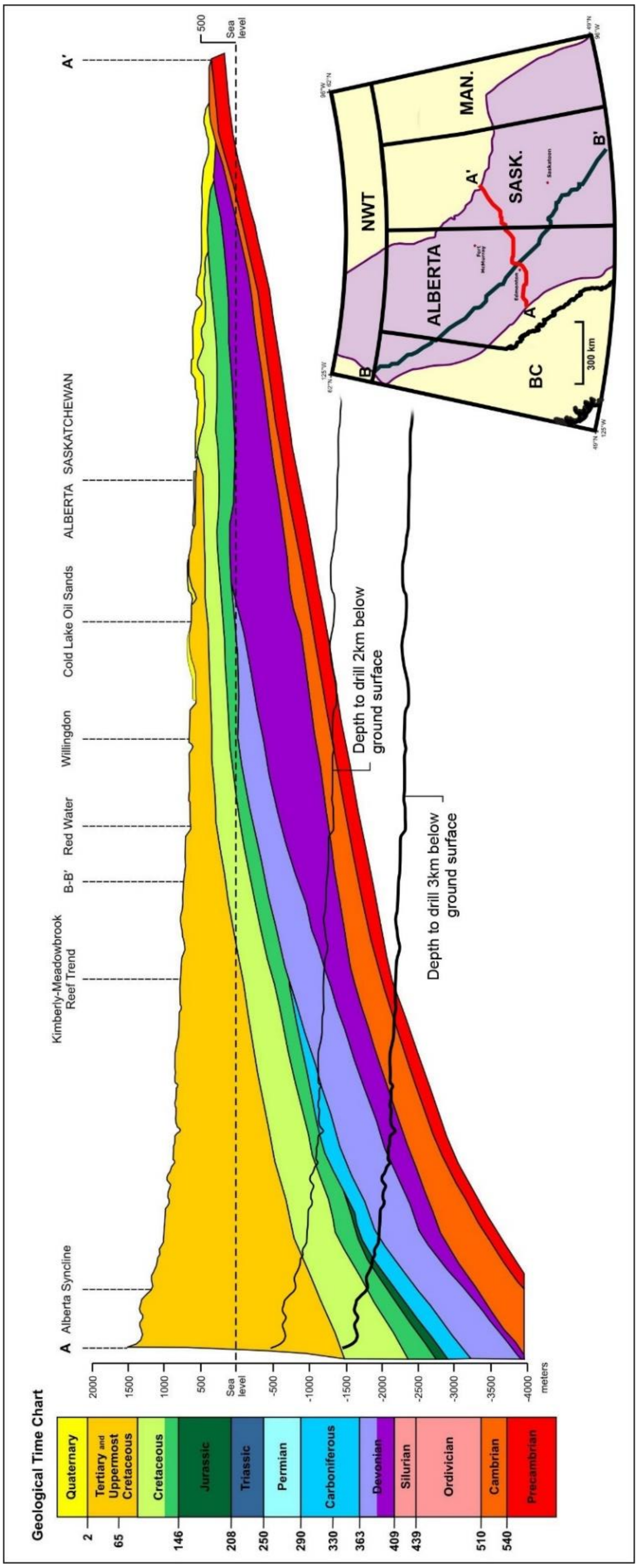

Figure 3. Geological cross-section through the Western Canadian Sedimentary Basin. The main geological formations are shown. Depth to drill to 2 km 60–70 °C below the surface and 3 km 90–100 °C is indicated.

4. Geothermal Gradient and Maximum Temperatures—WCSB

The heat flow Q map of the study area [10,23] is plotted in Figure 4. Locations of municipalities studied here, those with populations > 3000 people, are shown on a map of average geothermal gradient (Grad T(z), where T—temperature, z—depth) of the WCSB in Figure 5. The map of Grad T(z) is based on industrial temperature logs, corrected bottom hole temperature data, drill stem test temperature records, and shut-in wells temperature data from tens of thousands of boreholes drilled for oil and gas [9,16,23,24].

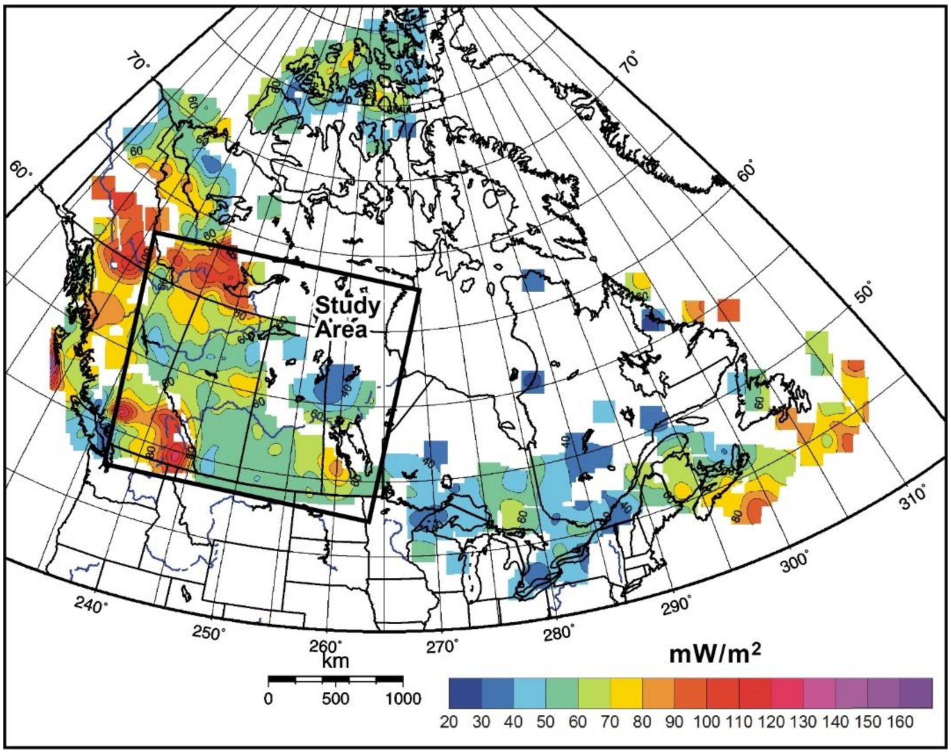

Figure 4. Study area against the map of heat flow Q of Canada (modified from [10]).

Most of the municipalities are in the southern part of the WCSB, where thermal gradients are low (20 °C/km) to moderate (30–45 °C/km) in southern Alberta. The central western part of basin is >2.5 km deep and has elevated GradT(z) of >35 °C/km. In southeastern Saskatchewan, the basin has an elevated Grad T(z) of 40 °C/km. The northwestern part of the basin has just a few communities, like Fort Nelson and Fort Liard, which occur in areas of elevated GradT(z) (40–50 °C/km). Geothermal gradients of 35–50 °C/km for large parts of the WCSB are high compared to other sedimentary basins worldwide [25].

The Precambrian basement which underlies the WCSB has radiogenic heat generation two times higher than in outcrops of the correlative Canadian Shield [23–26]. Radiogenic heat production (A) [$\mu W/m^3$] in the Precambrian basement underlying the WCSB shows large variability but averages 2.1–2.4 $\mu W/m^3$. This explains the higher heat flow of the WCSB as compared to the Canadian Shield to the east.

The temperature distribution in sediments of the WCSB is determined from ground surface temperature records [27], the WCSB heat flow Q map [16,23], and the WCSB thermal conductivity k map [23]. Some 40–50% of Q is from radiogenic heat in the crust and 50–60% comes from deeper sources in continental settings [28–30]. The review of Epelbaum et al. [31] suggests mantle heat flow is in the order of 15–84% of total. Heat flow determinations in Canada are based on single heat flow determinations in wells and group of wells from industrial temperature records. Some areas thus lack data (Figure 4) due to its remoteness and/or lack of drilling [10]. While the North America heat flow map extrapolates over large areas of Canada with no data [32], these regions are shown in white here.

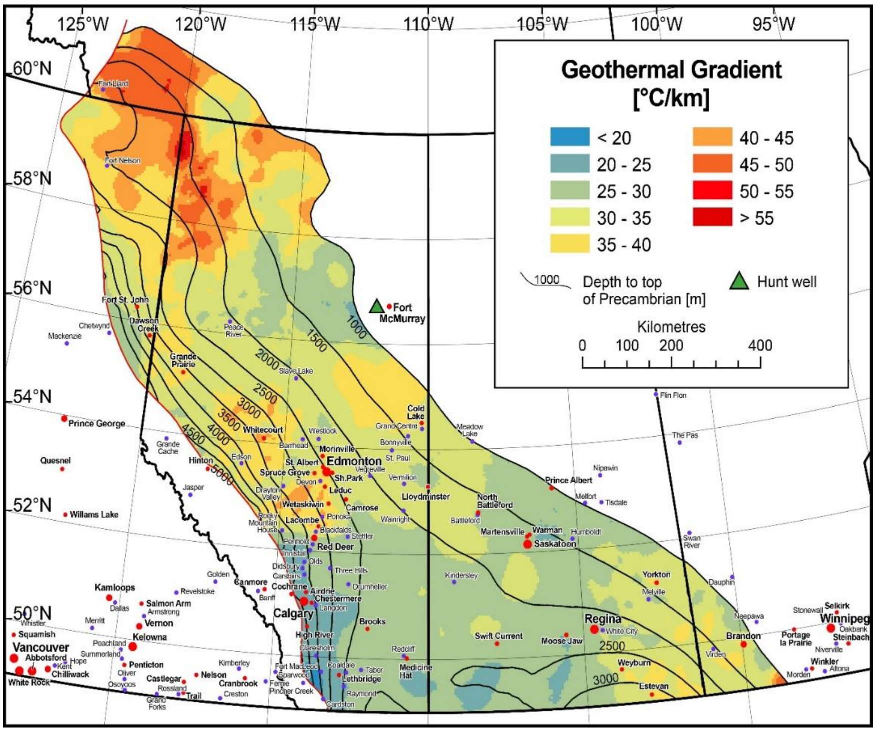

Figure 5. The communities' studies here shown against the map of average geothermal gradient for the WCSB with sediment thickness >1000 m. The red line is the western boundary of the WCSB marked by the Rocky Mountains disturbed belt modified from [16]. The Hunt well near Fort McMurray is the site of first heat flow determined below the WCSB, in an interval of the 0.5–2.4 km in Precambrian granites [33].

The only high precision deep (>1 km) heat flow results in the WCSB are from the deep (2.3 km) Hunt well near Fort McMurray (Figure 5), that shows surface heat flow of Q = 57 mWm^{-2} [33], significantly higher than Q in the Canadian Shield to the east (44 ± 7 mWm^{-2}, [25]). This result is interpreted as being related to the high average A of 2.9 µWm^{-3} in the upper granitic crust of the well [33]. The rest of heat flow data for the WCSB come from thousands of single depth bottom hole and drill stem test temperatures and effective thermal conductivity estimates based on net rock data and measured rock conductivities of typical lithologies [10,12,16,23].

Since geothermal gradient is defined by Equation (1):

$$\mathrm{GradT}(z) = Q/k \tag{1}$$

Thermal conductivity k will control Grad T(z) at constant heat flow Q. Thermal conductivity of the sedimentary fill (k_{sed}) of the WCSB was studied for sedimentary rocks and a map of k_{sed} pattern was constructed [23]. Thermal conductivity of sediments $k_{sed.}$ of Cenozoic, Mesozoic, and upper to lower Paleozoic rocks varies in relationship with the overall composition from low k of shales (1.2 W/m K) to high k of carbonates (3 W/m K), quartzite sediments (4–6 W/m K), and salt (7 W/m K). The variability in the thickness of lithostratigraphic units, changes in sedimentary facies, and the presence or absence of sedimentary units, results in variability of net k with depth. Calculated $k_{sed.}$ shows a trend of increasing eastward towards the shield. Some very low k zones, like in the northwestern Alberta-BC part of the basin ($k_{sed.}$ = 1.4–1.6 W/m K), can explain some of the highest GradT observed in the WCSB (Figure 5). Very high integrated $k_{sed.}$ (2.6–2.8 W/m K) in the eastern shallow parts of the WCSB are close to the k of underlying Precambrian basement, explaining the low temperatures at depth in those areas [22]. The areas with the lowest net k are prospective for high temperature geothermal systems, as the rate of temperature increase with depth are the highest for constant heat flow (Equation (1)). The highest heat flow-lowest $k_{sed.}$ areas have the highest temperatures and thermal heat storage. In general, the westward increasing thickness of the WCSB, and decreasing net $k_{sed.}$ increases available thermal energy.

Below the WCSB, the average k of basement rocks [26] is significantly higher. The highest average conductivity is that of igneous rocks (3.4 W/m K N = 56) and then metamorphic rocks (3.2 W/m K, N = 146). At the observed average heat flow of the Alberta basin (70 m W/m^2) this would cause changes in the geothermal gradient below the Pre-Cambrian surface of 28 °C/km to 19 °C/km, respectively.

5. Geothermal Energy Calculation

We calculated geothermal energy for each of the municipalities in our study area. An outflow fluid temperature of 60 °C was assumed for geothermal heating systems based on the upper limit of the Paris DH system [2,4]. For electrical production we assumed 50–60 °C for an ORC electrical power plant system according to Tester et al. [5]. The range of the feasible net geothermal heat and geothermal electrical power production was calculated using parameters from Table 2 and temperatures derived from maps in Figures 6 and 7a–d. In previous geothermal assessments the specific heat capacity (C_w) of low salinity waters was used (4200 J/kg/K in [11]. Here we adjusted C_w to lower values (3150 J/(kg K)—3993 J/(kg K)), [34] that more accurately reflect the brines which occur in the most perspective geological formations we examined [6,35–42]. To calculate these C_w values we used the MIT charts [34]. Feasible flow rates used were based on various published pumping test results for the WCSB, as well as in analogous basins in the USA and Germany, as summarized by Majorowicz and Grasby [11].

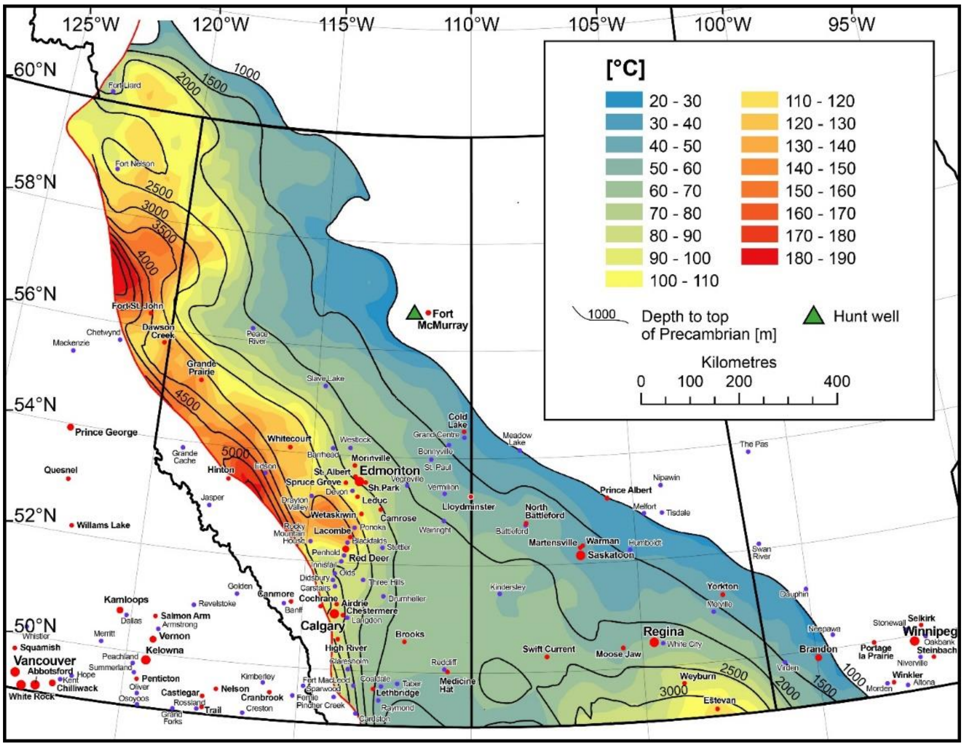

Figure 6. WCSB municipalities >3k population plotted against the calculated temperature [°C] pattern at the base of the Phanerozoic = top of Precambrian basement. Red line depicts western reach of the WCSB which is at the Rocky Mountains deformation front.

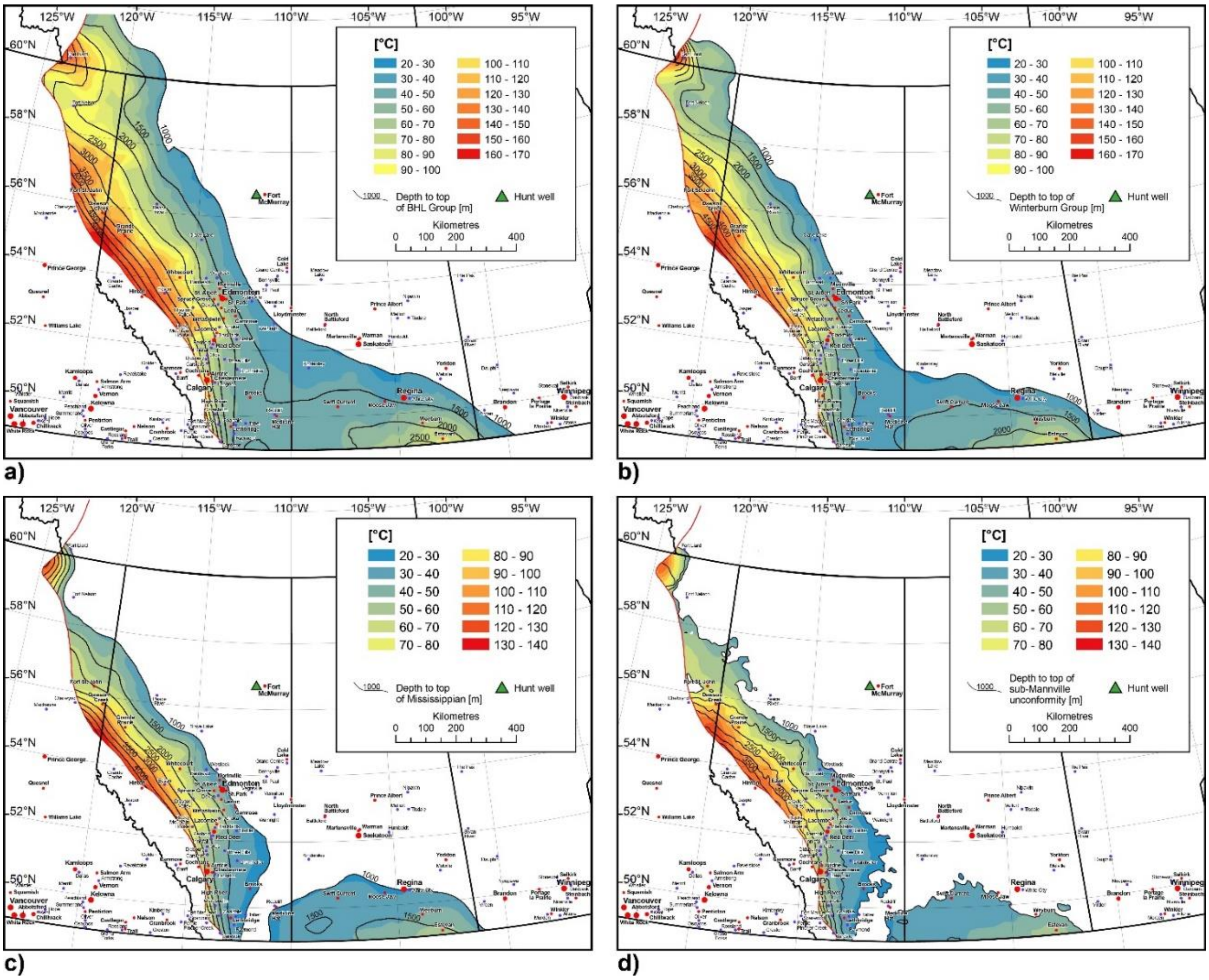

Figure 7. WCSB municipalities with >3 k population plotted against the maps of temperature at various geological surfaces [15]; (**a**) The base of Upper Devonian Beaverhill Lake Group; (**b**) The top of the Upper Devonian Winterburn Group; (**c**) The top of Mississippian formations; (**d**) at the sub-Mannville unconformity. Note: The red line depicts western margin of the undeformed WCSB.

Table 2. Assumed parameters.

Parameter	Range	Unit
Production temperature of geothermal fluid	70–160	°C
Backflow temperature	50–60	°C
Specific heat capacity	3150–3993	J/kg °C
Flow rate	30–80	kg/s
Conversion MWthermal to MWelectrical factor [1]	8–12	%

[1] common for the Organic Rankin cycle power plants [5].

6. WCSB Prospects—Summary

The map of communities vs. highest available temperatures at the base of the Phanerozoic of the WCSB, above the Precambrian basement, is shown in Figure 6. Similar maps are also shown for the Middle Cambrian and Upper Cambrian, Devonian Granite Wash Formation (Figure 6), base of Beaverhill Lake Group (Figure 7a), top of the Upper Devonian Winterburn Group (Figure 7b), top of Mississippian formations (Figure 7c), and at the sub-Mannville unconformity (Figure 7d).

For most of the study area, the highest temperature zones are found in the deep foreland basin adjacent to the Rocky Mountains in western Alberta [15,39,40] and in the Williston sub-basin of southern Saskatchewan. The calculated geothermal energy is shown in Table A3 (Appendix C). Results in Table A2 (Appendix C) show that temperatures >80 °C can be found in the Upper Devonian Beaverhill Lake Group [15,41]. Other potential formations with geothermal feasibility include the Woodbend Group's Grossmond karstic dolomites, Cooking Lake dolomites, the Beaverhill Lake's Group Swan Hill Formation, Slave Lake Formation, and the Elk Point's Group Pine Point Formation [15]. The Winterburn Group, and Wabamun and Nisku formations geothermal prospects for heating and electrical power are shown in Table A5. The Wabamun group's partly porous dolomites [15], and Winterburn group's Nisku Formation sandstones and limestones [15] have sufficient temperatures (Figure 7) to form geothermal energy prospects west of Edson and to the northwest towards Grande Cache (Table A3). The Mississippian Rundle Group's dolostones and limestones, Charles Formation dolostones and limestones, and Banff Formation limestones [15] are all in the >80 °C temperature zone in the deepest western part of the WCSB in Alberta (Figure 7c). The calculated energy, power and enthalpy gains for these units are shown in Table A4 (Appendix C). Low to mid-enthalpy potential for geothermal hot saline fluids also exists for the Cretaceous Mannville Group sediments and Cadomin Formation sandstone & conglomerates, as found by Lam and Jones, [37], in the deepest parts of the WCSB in the Edson-Hinton area. The sub-Manville unconformity temperature distribution in Figure 7d shows temperatures >70 °C that are useable for geothermal heating for the towns of Drayton Valley, Edson, and Rocky Mountain House (Table A5 (Appendix C)).

7. Discussion of Results

A summary of results is presented in Tables A1–A5 in Appendix C. Results show that there are many municipalities that could potentially exploit deep geothermal heat reserves, and fewer cases for electrical production (Fort Liard NWT: Hinton Alberta, Estevan Saskatchewan). However, there are many regions of the WCSB with good electrical potential, but without nearby populated areas, which would increase transmission costs.

Analysis of geothermal feasibility for municipalities show that geothermal heat is available from several geological formations (Tables A4 and A5 and Figures 6 and 7c,d). In parts of the deep basin in western Alberta, the Granite Wash, Middle Cambrian basal sandstone, Winnipegoisis, and Deadwood formations [15,39–42] reach temperatures of 140–170 °C close to the municipalities of Hinton, Edson, Grand Prairie, Rocky Mountain House, and Whitecourt (Table A3). Temperatures >90 °C (Figure 7a) are also found for the BeaverHill Lake Group (Table A2). Temperatures sufficient or direct heating prospects occur in the Devonian Winterburn/Wabamun groups (Figure 7b; Table A3). Temperatures >70 °C are found in western Alberta in the Rundle Group's Charles Formation dolostones and limestones, as well as Banff Formation limestones) (Table A4).

In Table A5 we summarize energy calculations for the formations above the sub-Manville unconformity. The potential for geothermal hot saline fluids exists for the Mannville and Cadomin sandstones and conglomerates. As we move from deep formations above the Precambrian surface up towards shallower formations, like the Mississippian and/or Mannville prospects for direct heating, many municipalities' drop off the list (Tables A4 and A5) due to too low local temperatures for DH systems (<70 °C) or that the municipality lies outside of the formation sub-crop boundaries in the eastern and northeastern parts of the WCSB (see Tables A3 and A4).

Depending on the temperature of deep aquifers T (°C) and production rates (kg/s) (Tables A1–A5) there is a whole range of possibilities to use geothermal energy for direct heating. The calculated number of households feasible to be heated by a direct deep-aquifer sourced geothermal energy is in 100 s to 1000 s for Alberta, BC, and NWT, as well as deep parts of the Williston Basin sub-basin in southern Saskatchewan.

The calculated enthalpy gains for all the communities overlying the WCSB are given in Appendix C Tables A1–A5 and they are ranked 1–5 as listed below [43]:

1. Very low enthalpy gain <80 kJ/kg—aquifer,
2. Low to Medium enthalpy (80–200) kJ/kg—Geothermal heat prospects with uplift by heat pumps
3. Medium enthalpy prospects (200–320) kJ/kg—Prospects for direct deep aquifer source based geothermal heating.
4. High enthalpy (320–520 kJ/kg)—Very good direct heat prospects, marginal EGS geothermal electrical power prospects.
5. Very high enthalpy (>520 kJ/kg)—Electrical power and direct heating prospects.

High to very high enthalpy ranking (4–5) was calculated for the deepest portions of the WCSB (Appendix C Tables A1–A3). The highest ranked prospect area (rank 5) occurs in the northern and western parts of the WCSB, in the Hinton area west of Edson, Alberta, and in Fort Liard NWT. High enthalpy (4) is found in central-western Alberta (municipalities of Grand Prairie, Whitecourt, Wetaskiwin, Lacombe, Red Deer, Blackfalds, Panoka, Rocky Mountain House, Penhold, Devon, and Drayton Valley), north eastern BC (Dawson Creek, Fort St. John, and Fort Nelson) and southeastern Saskatchewan (Estevan area). Medium enthalpy (Ranked 3) geothermal heating is most common in the 2–3 km deep parts of the basin in Alberta and southern Saskatchewan. In the shallow parts of the basin (see Tables A4 and A5, lifting of fluid temperature would be needed before direct heating applications could be considered (lifting fluid temperature by heat exchanger from 40 to 50 °C to at least 70 °C, and or heat pumps would be required).

8. Conclusions

The economics of two well systems—producer and reinjection—will depend on drilling cost (increasing exponentially with depth), efficiency of the geothermal power plants (usually very low 10+/−3%), or of heat exchangers (~90%) for geothermal heating. The electrical power required for pumps for moving fluids through a two-well system (producer and injector wells) and moving fluids through surface piping and the geothermal plant, has been assessed to vary between 0.1 and 0.7 MW electrical [11]. In the WCSB the required drilling depth to get >70 °C resources is on average 2 km, and this increases to >3.7 km for electric power at >120 °C (Figure 8).

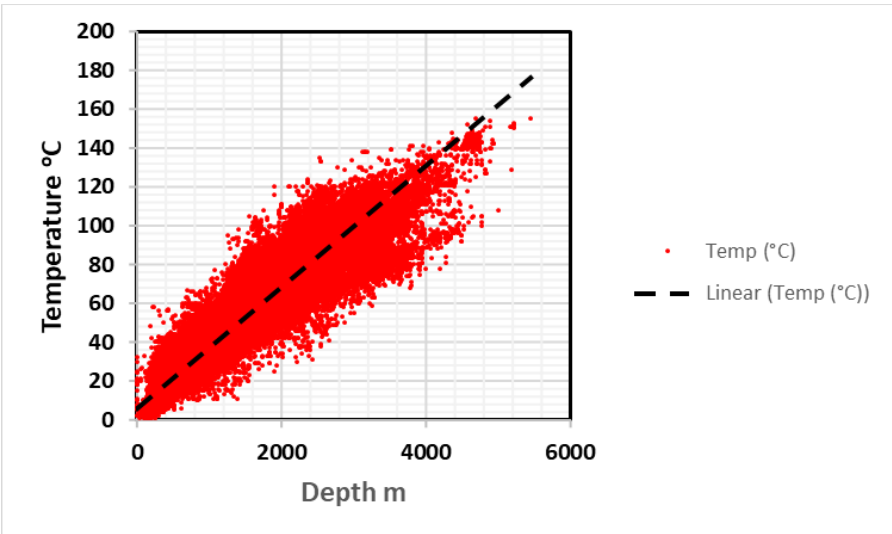

Figure 8. WCSB temperature records from (APP) Annual Pool Pressure test temperature data from shut-in wells. Linear approximation is: T (°C) = 0.031z + 5.58. Correlation coefficient is R = 0.96.

The costs of drilling geothermal wells can be calculated from the equation given by Lukawski et al. [44], with a correlation coefficient of 0.92:

$$\text{Geothermal well cost} = 1.72 \times 10^{-7} \times (z)^2 + 2.3 \times 10^{-3} \times z - 0.62 \quad (2)$$

where cost is in ($) and z(m) is depth of well. The geothermal wells drilling cost is higher than these of oil and gas [43].

In Tables A1–A5 in Appendix C we gave depths to be drilled to prospective geothermal formations. There are few communities with good prospects at depths less than 2 km. Drilling a well to 2–3 km (see depth to drill against geological cross section WCSB in Figure 2) would be expensive, $4.7 to 8 m per borehole, and two wells are needed for a doublet geothermal system. Geothermal electrical power production by low efficiency (some 10% +/− 3%) geothermal power plants requires >120 °C and preferably >150 °C. Such projects would require 4–5 km drilling depth costing $11–15 m, respectively. This means usually that the drilling cost per one MW electrical would be some $15 m for the best cases we show in Tables A1–A3. This high drilling cost limits prospects for economic geothermal electrical power to best case scenarios under current drilling technology. Such high cost per $MW_{electrical}$ would not be competitive with wind that has a typical cost of $3–5 million per megawatt (MW) of electricity-producing capacity. However, geothermal provides baseload power supply that may make the higher cost for reliable generation more attractive.

Municipalities with potentiall for heat energy production, heating >1 k households, are highlighted in Appendix C Tables A1–A5. These are recommended to be explored first. Large areas of the WCSB are outside the prospects for deep heat for direct heating. These are in many cases areas with temperatures that are still suitable for low enthalpy geothermal heat use. They are temperature <60 °C and shallower depths for drilling (<2 km). Lower enthalpy geothermal sites would be still good for geothermal heating using non-direct techniques, including heat pumps for the lowest enthalpy shallow basin locations. Heat pumps require external energy like electrical power which would require connection with other renewables. Geothermal heating greenhouses could be an opportunity to be explored next.

We showed that direct heating by geothermal energy is most promising for deeper parts of the WCSB in the central and western parts of Alberta, northeastern British Columbia, southern Saskatchewan, and southwestern NWT, where >70 °C aquifers with the prospect of >30 kg/s production rates are feasible. Power production is possible near only a limited number of communities, including the Hinton-Edson—Grand Prairie area in Alberta, Fort Liard in southwestern NWT, and Weyburn-Estevan in southern Saskatchewan. Electrical power from geothermal is between single decimals of MW electrical and up to 3 MW electrical (see our calculations in Table A1) assuming a maximum flow rates of 80 kg/s. However, horizontal wells in target horizons promise to increase potential production rates that could make power production more viable in areas of suitable temperatures as in the ongoing DEEP project [45–48].

The above calculations of heat and electrical power that is feasible to produce from geothermal sources are first order estimates due to uncertainty in production rates. There are several approaches we used to assess reasonable production rates. We took the most probable range of required flow rates (30–80 Kg/s) based on real pumping test data [11,35], estimates based on hydraulic head and permeability data [37,38,42], as well as examination of thousands of pumping and reinjecting tests through the WCSB [35]. Fluid production rates required to achieve different levels of energy production were calculated by others, [49,50]. To produce $1MW_{electric}$ the flow rate should be from 30 to 60 kg/s for the northwestern British Columbia part of the WCSB, according to Palmer-Wilson et al. [50]. It makes good sense if the geothermal two-well systems are to be engineered by EGS, to enhance permeability and flow [5].

Further research is recommended that focuses on the geothermal potential of specific municipalities based on more in-depth analyses of local geothermal and geologic conditions.

In particular, aquifer parameters require further study given their heterogeneous nature, making it difficult to predict local hydrogeological properties.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Saskatchewan SE Manitoba municipalities >3 k population against maps of geothermal energy prospects for communities >3 k.

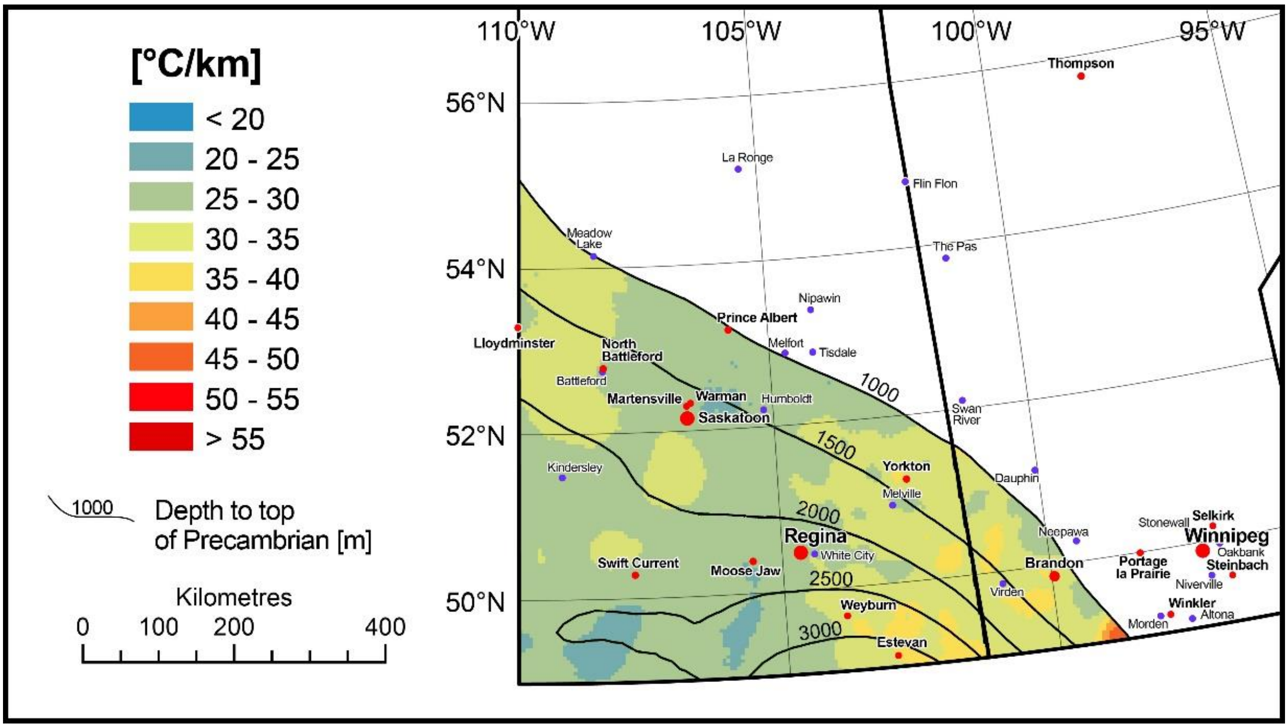

Figure A1. Geothermal gradient—Saskatchewan–Manitoba WCSB.

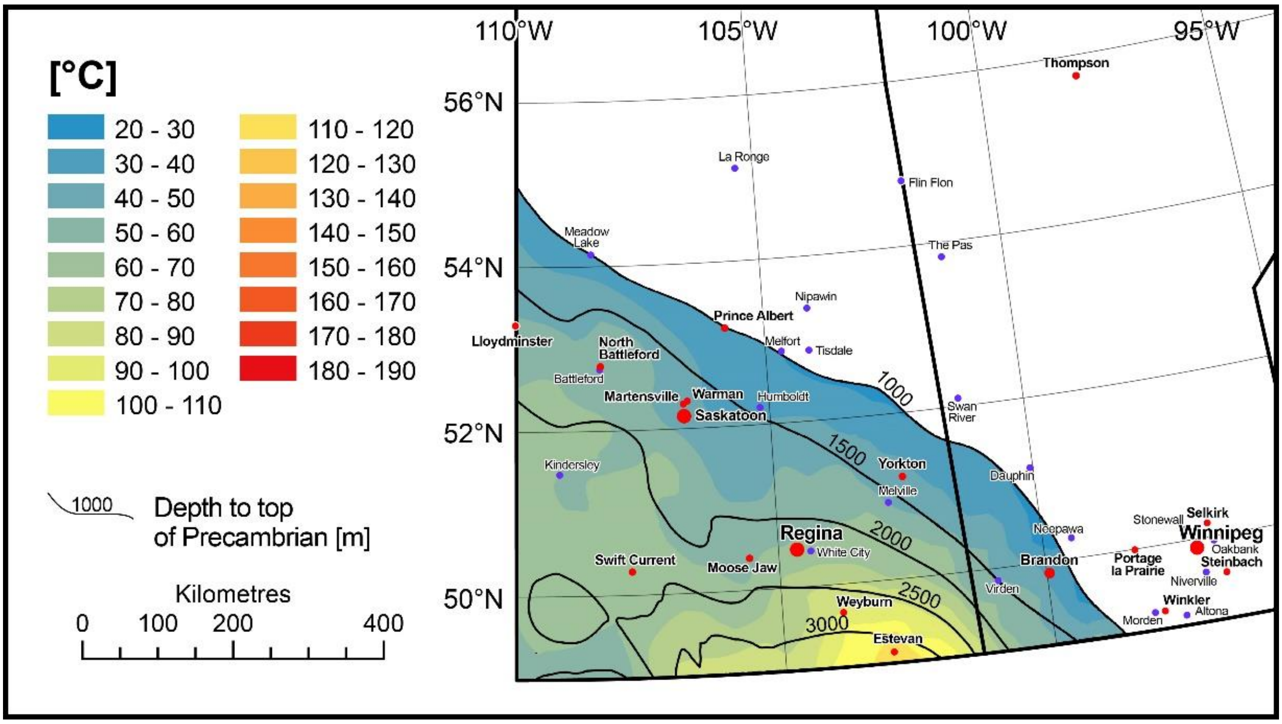

Figure A2. Temperatures top of Precambrian—Saskatchewan–Manitoba WCSB.

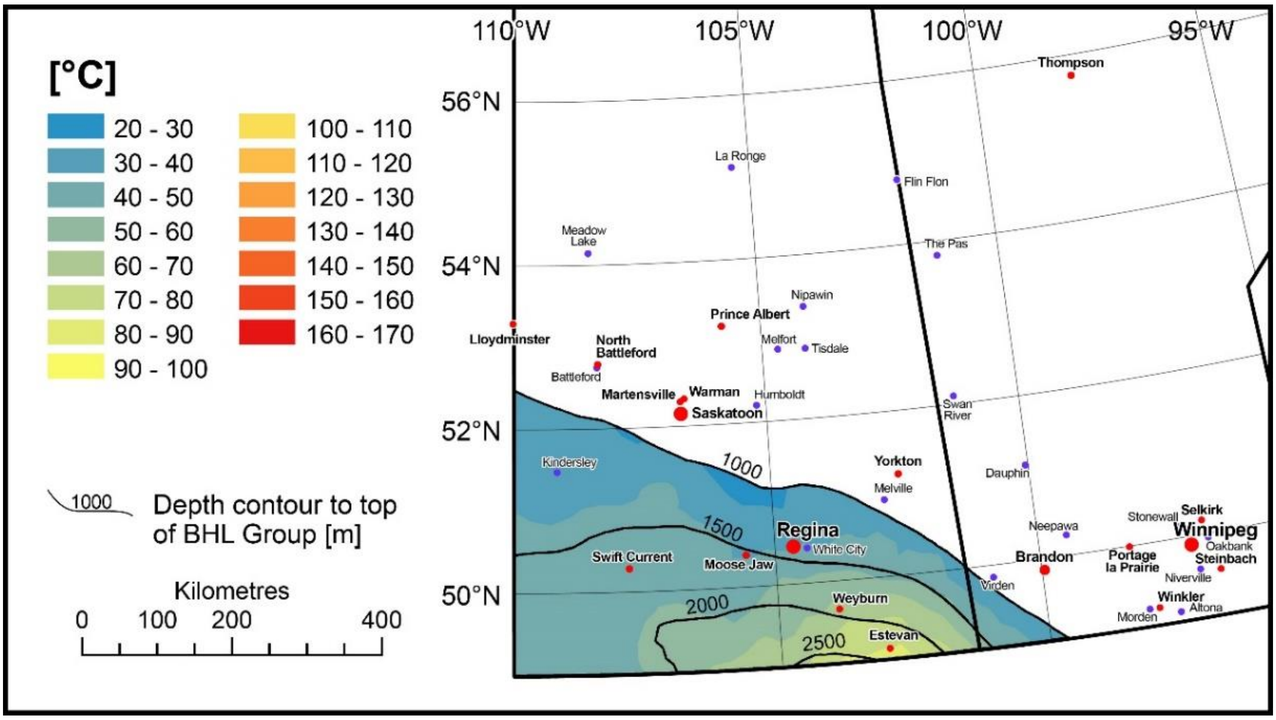

Figure A3. Temperatures top of BHL Group—Saskatchewan–Manitoba WCSB.

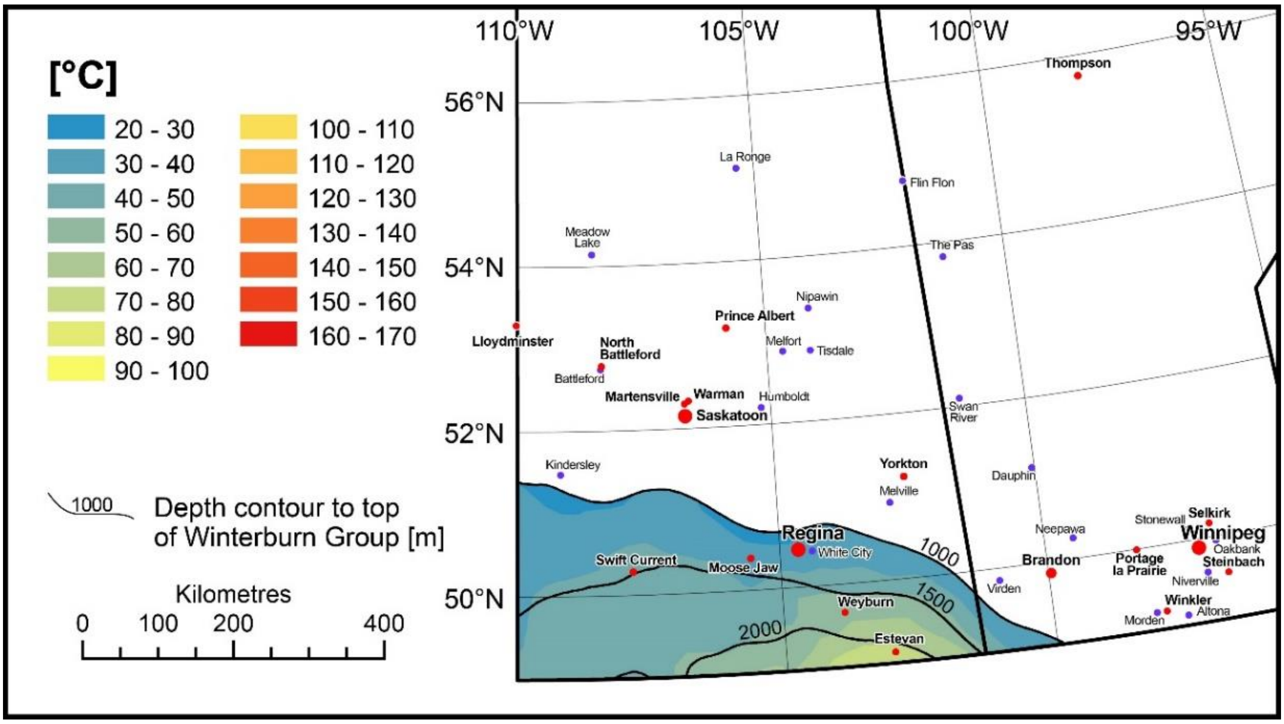

Figure A4. Temperatures top of Winterburn Group—Saskatchewan–Manitoba WCSB.

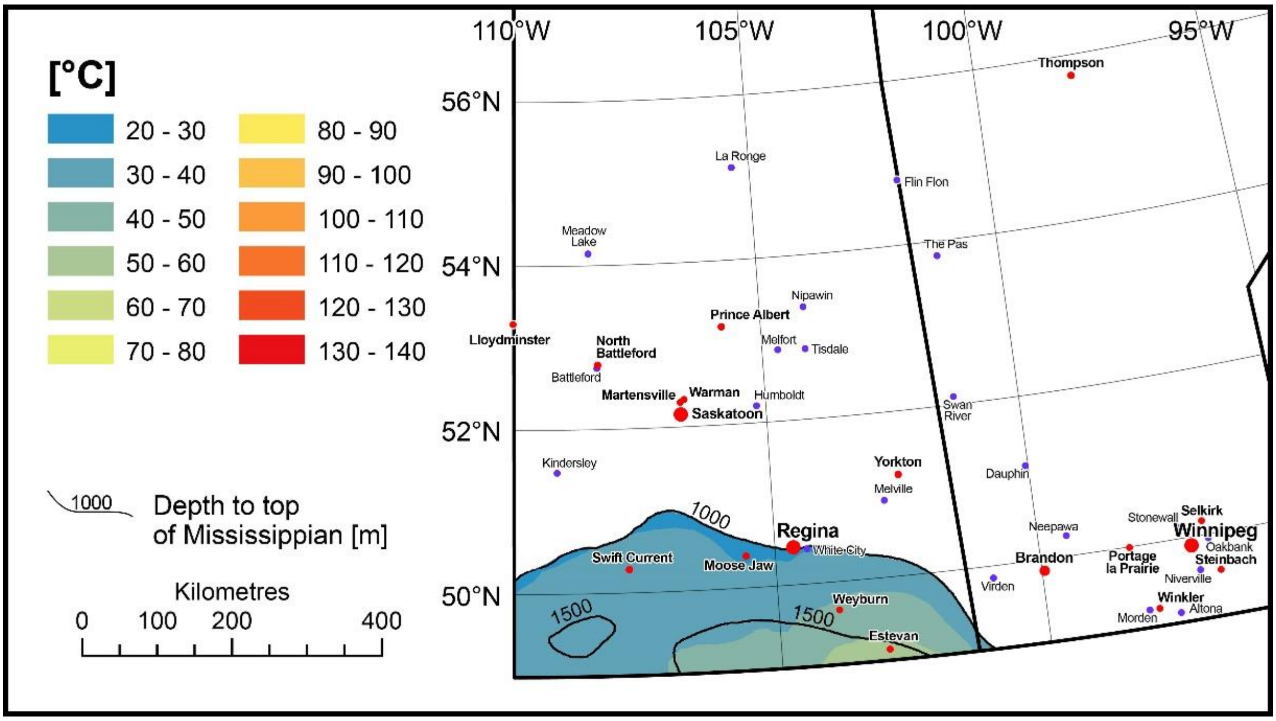

Figure A5. Temperatures top of Mississippian—Saskatchewan–Manitoba WCSB.

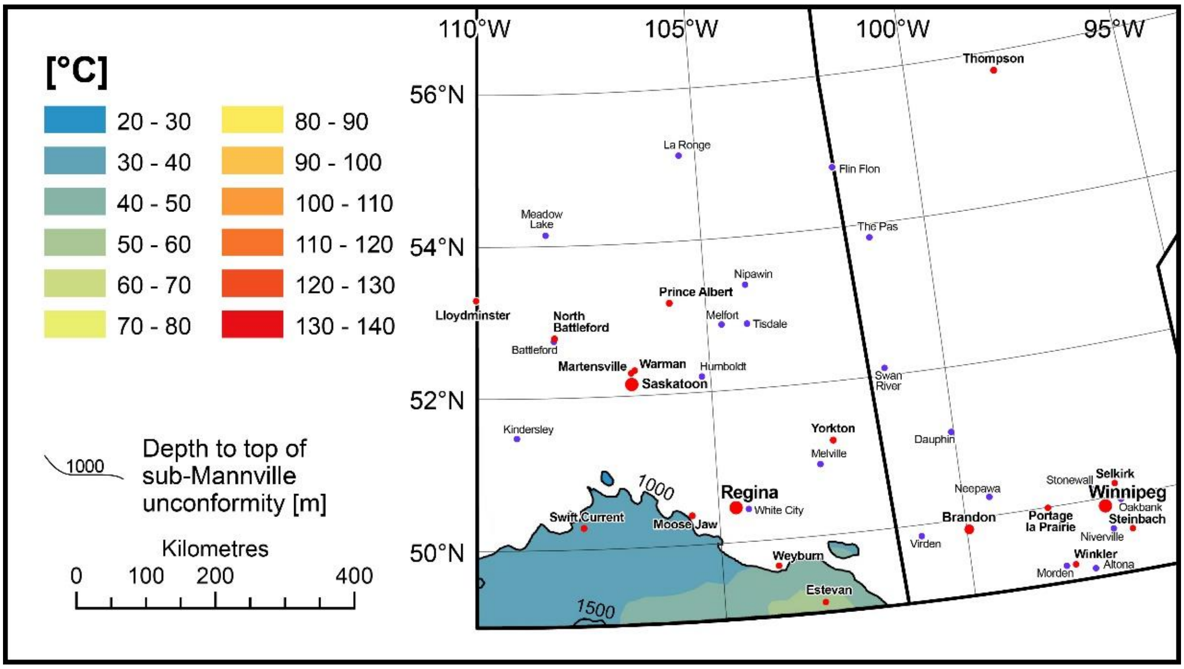

Figure A6. Temperatures top of sub-Mannville unconformity—Saskatchewan–Manitoba WCSB.

Appendix B

NE British Columbia S. NWT geothermal prospects for communities >3 k.

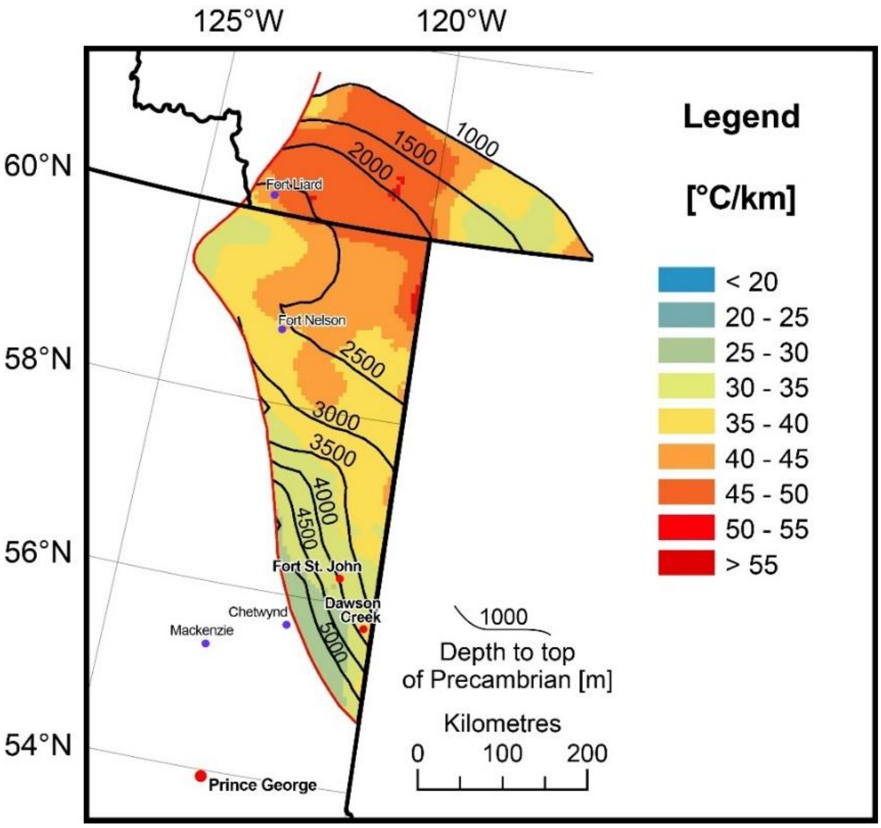

Figure A7. Geothermal gradient—NE British Columbia S. NWT WCSB.

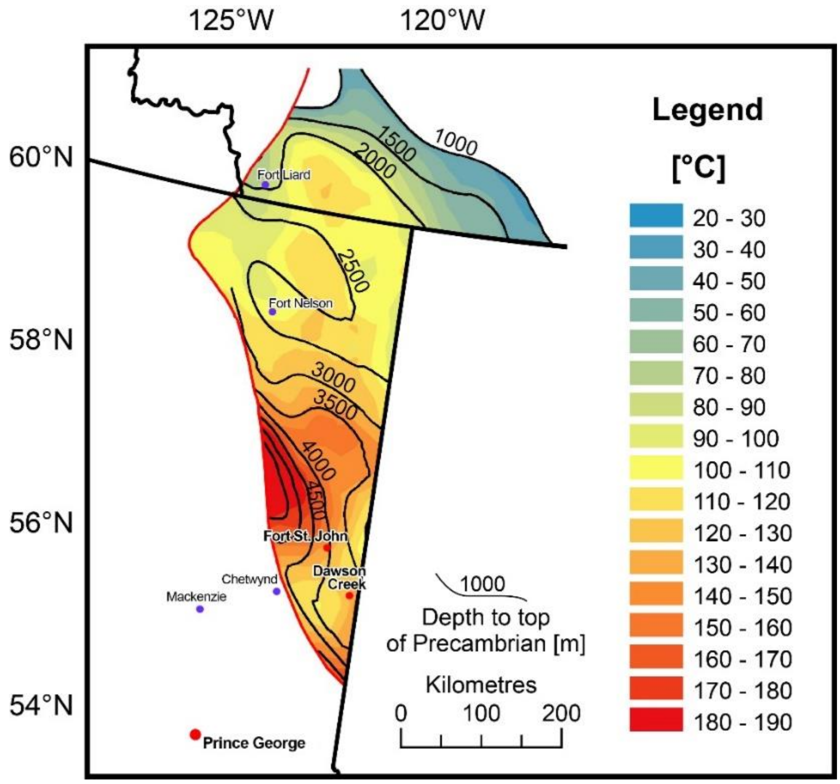

Figure A8. Temperatures top of Precambrian—NE British Columbia S. NWT WCSB.

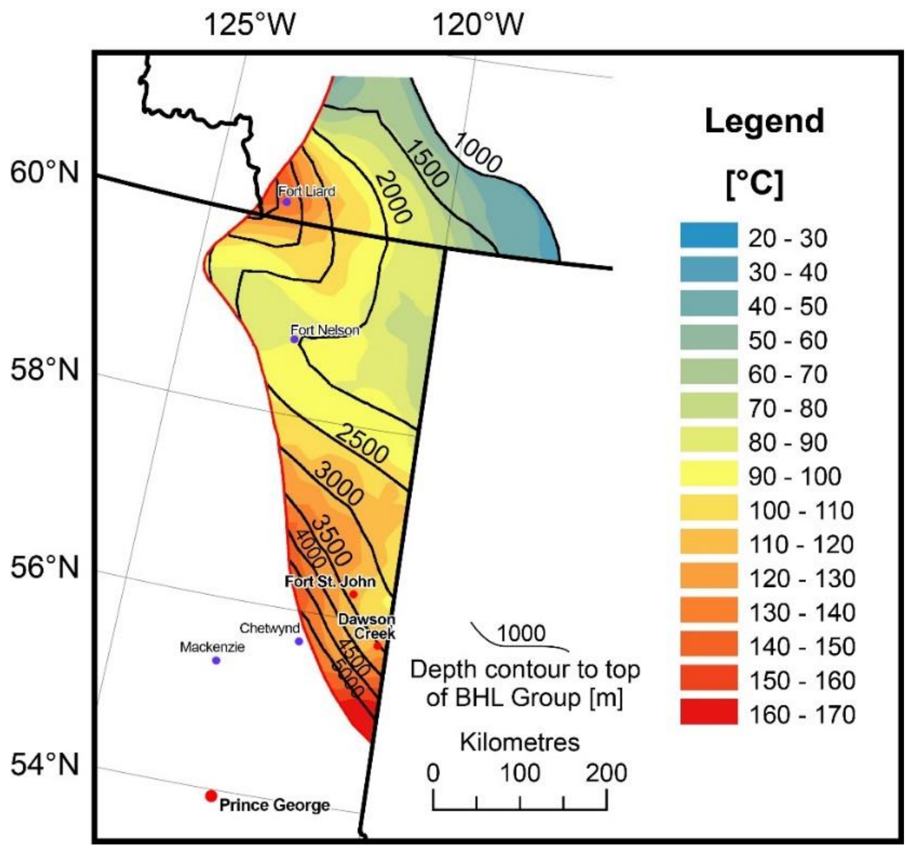

Figure A9. Temperatures top of BHL Group—NE British Columbia S. NWT WCSB.

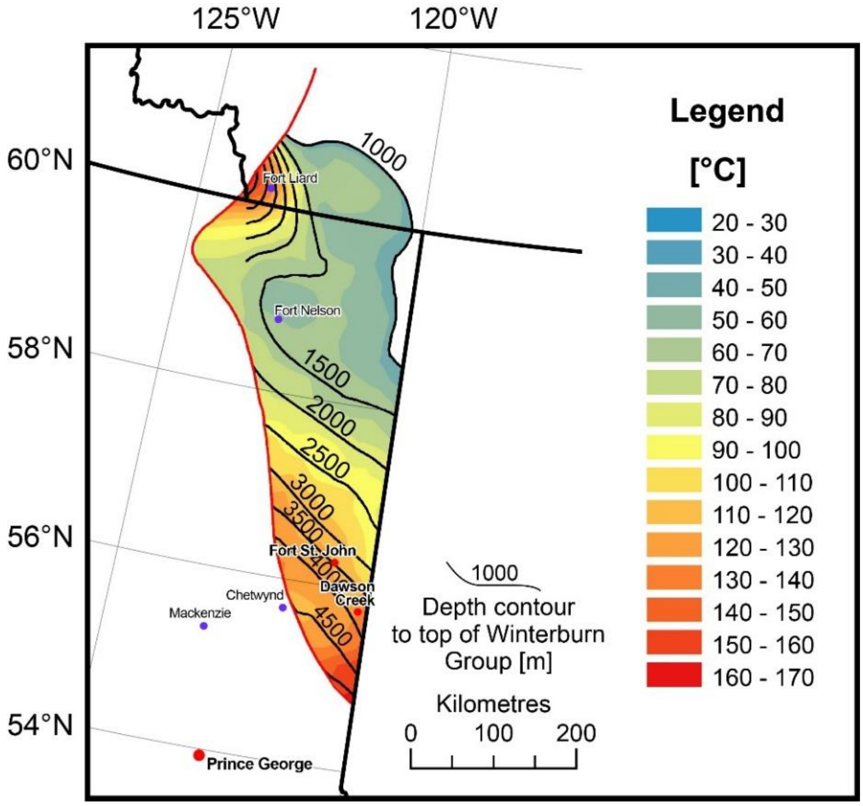

Figure A10. Temperatures top Winterburn Group—NE British Columbia S. NWT WCSB.

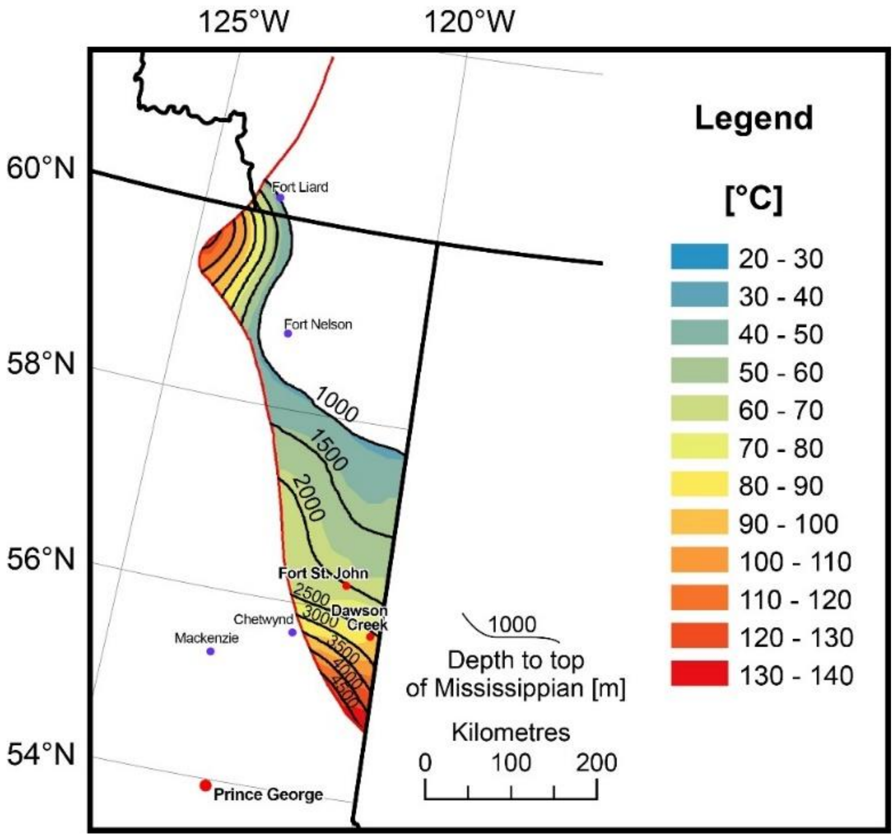

Figure A11. Temperatures top of Mississippian—NE British Columbia S. NWT WCSB.

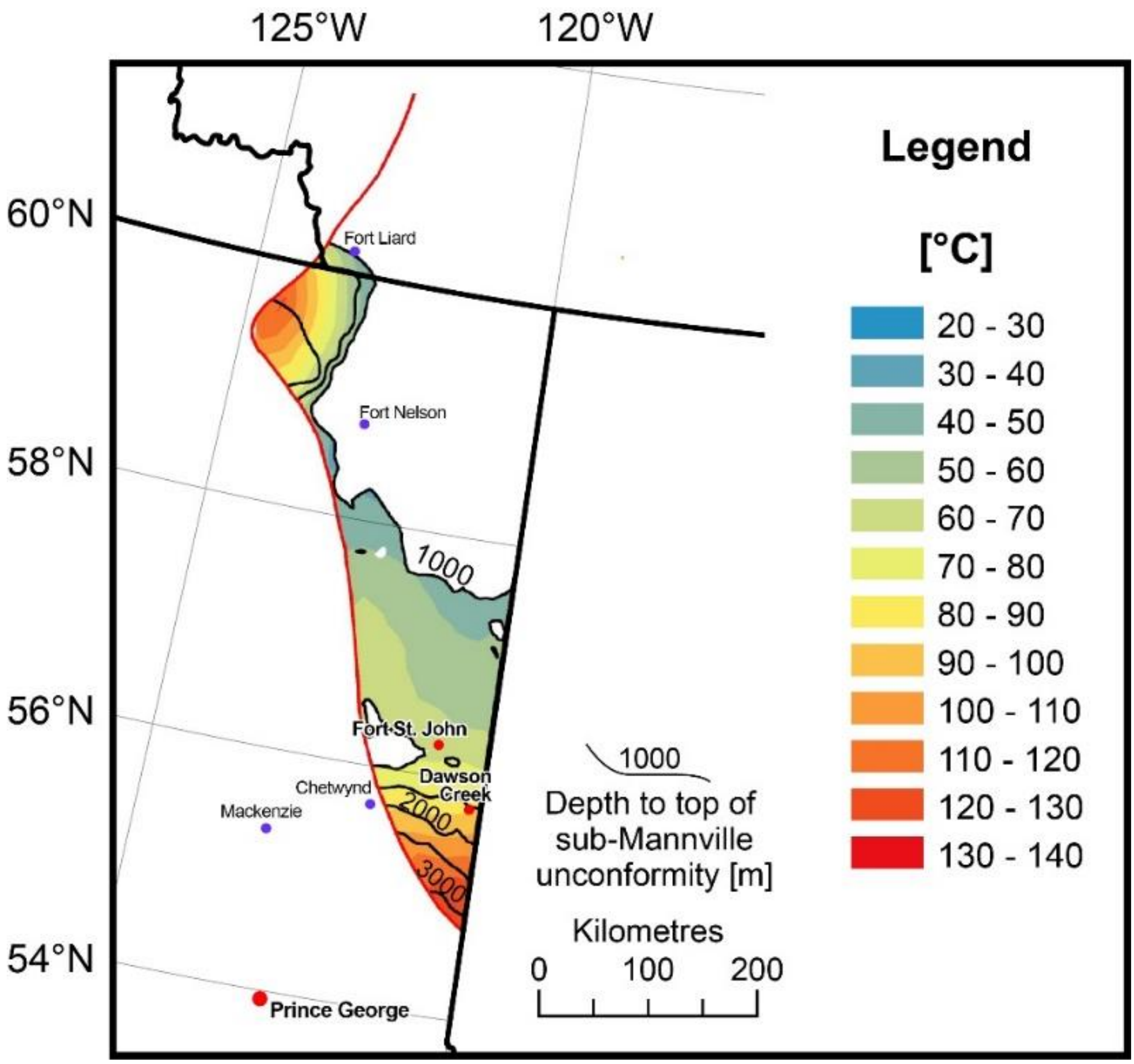

Figure A12. Temperatures top of sub-Mannville Unconformity—NE British Columbia S. NWT WCSB.

Appendix C

Tables of results.

The results of calculations for all >3k population cities and towns in the WCSB are shown in Tables A1–A5. These Tables show geothermal energy for a range of flow rates (well production rate), specific heat capacity of geothermal brine, the number of direct geothermal heated households feasible for small communities of >3 k to <10 k population at average energy use of 130 GJ/Year at 0.7 yearly uses, enthalpy, and calculated formation temperature and depth required to drill to prospective geological formations at these calculated temperatures.

The best opportunities for geothermal heat use are highlighted in yellow and geothermal power most prospects are highlighted in red.

Table A1. WCSB >3 k populations centers geothermal prospects summary—Deepest basin above the crystalline basement—Energy, Enthalpy, Power, Number of direct geothermal heated Energy, Enthalpy, Power, No. of direct deep geothermal energy heated households feasible.

City Location	Province	Temperature T	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthalpy Gain	Formation Group	Depth
			at C = 3993 at 30 kg/s	at C = 3150 at 30 kg/s	at C = 3993 at 80 kg/s	at C = 3150 at 80 kg/s	Minimum number @ 130 GJ/Year	Maximum number @ 130 GJ/Year	at C = 3993 at 30 kg/s	at C = 3150 at 80 kg/s	at C = 3993		
Name	Name	°C	GJ Year	GJ Year	GJ Year	GJ Year			MW el.	MW el.	kJ/kg		km
Airdrie	AB	90	66,110	52,153	176,293	139,074	401	1356	0.5	0.8	280	M. Cambrian Basal Sands.	3.7
Banff	AB	?	–	–	–	–	–	–	–	–	–	Disturbed belt	?
Barrhead	AB	83.2	51,125	40,331	136,333	107,550	310	1049	0.4	0.6	252	M. Cambrian Basal Sands.	2.6
Battleford	Sask.	51	–	–	–	–	–	–	–	–	124	M. Cambrian Basal Sands.	1.7
Beaumont	AB	90	66,110	52,153	176,293	139,074	401	1356	0.5	0.8	280	M. Cambrian Basal Sands.	2.6
Blackfalds	AB	120.25	132,770	104,740	354,054	279,306	806	2723	0.8	1.5	400	M. Cambrian Basal Sands.	3.25
Bonnyville	AB	49	–	–	–	–	–	–	–	–	116	M. Cambrian Basal Sands.	1.4
Brooks	AB	70	22,037	17,384	58,764	46,358	134	452	0.2	0.3	200	M. Cambrian Basal Sands.	2.4
Calgary	AB	100	88,146	69,537	235,057	185,432	535	1808	0.6	1.0	319	M. Cambrian Basal Sands.	3.8
Camrose	AB	80	44,073	34,768	117,528	92,716	267	904	0.4	0.5	240	M. Cambrian Basal Sands.	2.4
Canmore	AB	40	–	–	–	–	–	–	–	–	80	RM Def. f.	–
Cardston	AB	70	22,037	17,384	58,764	46,358	134	452	0.2	0.3	200	Disturbed belt fm	3.5
Carstairs	AB	90	66,110	52,153	176,293	139,074	401	1356	0.5	0.8	280	M. Cambrian Basal Sands.	3.6
Chestermere	AB	90	66,110	52,153	176,293	139,074	401	1356	0.5	0.8	280	M. Cambrian Basal Sands.	3.7
Claresholm	AB	75.6	34,377	27,119	91,672	72,318	209	705	0.3	0.4	222	M. Cambrian Basal Sands.	3.6
Coaldale	AB	62.5	5509	4346	14,691	11,589	33	113	0.1	0.1	170	M. Cambrian Basal Sands.	2.5
Cochrane	AB	100	88,146	69,537	235,057	185,432	535	1808	0.6	1.0	319	M. Cambrian Basal Sands.	4.1
Cold Lake	AB	42	–	–	–	–	–	–	–	–	88	M. Cambrian Basal Sands.	1.2
Cold Lake	AB	40	–	–	–	–	–	–	–	–	80	M. Cambrian Basal Sands.	1.2
Dawson Creek	NE BC	*137*	*168,580*	*132,989*	*449,546*	*354,638*	*1023*	*3458*	1.0	1.9	*465*	M. Cambrian Basal Sands.	*3.9*
Devon	AB	99.9	87,926	69,363	234,469	184,968	534	1804	0.6	1.0	319	M. Cambrian Basal Sands.	2.7
Didsbury	AB	92.5	71,619	56,499	190,984	150,663	435	1469	0.5	0.8	289	M. Cambrian Basal Sands.	3.7
Drayton Valley	AB	119	130,016	102,567	346,709	273,512	789	2667	0.8	1.5	395	M. Cambrian Basal Sands.	3.4

Table A1. *Cont.*

City Location	Province	Temperature T	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthalpy Gain	Formation Group	Depth
Name	**Name**	**°C**	**at C = 3993 at 30 kg/s GJ Year**	**at C = 3150 at 30 kg/s GJ Year**	**at C = 3993 at 80 kg/s GJ Year**	**at C = 3150 at 80 kg/s GJ Year**	**Minimum number @ 130 GJ/Year**	**Maximum number @ 130 GJ/Year**	**at C = 3993 at 30 kg/s MW el.**	**at C = 3150 at 80 kg/s MW el.**	**at C = 3993 kJ/kg**		**km**
Drumheller	AB	72.9	28,427	22,426	75,806	59,802	173	583	0.3	0.3	211	M. Cambrian Basal Sands.	2.7
E. Lloydminster	Sask.	51	–	–	–	–	–	–	–	–	124	M. Cambrian Basal Sands.	1.7
Edmonton	AB	90	66,110	52,153	176,293	139,074	401	1356	0.5	0.8	280	M. Cambrian Basal Sands.	2.5
Edson	AB	147	191,718	151,243	511,248	403,314	1163	3933	1.2	2.2	507	M. Cambrian Basal Sands.	4.2
Estevan	Sask.	115	121,642	95,961	324,378	255,896	738	2495	0.8	1.4	380	U. Cambrian Deadwood	3.2
Fort Liard	NWT	170	242,402	191,226	646,406	509,937	1471	4972	1.4	2.8	599	M. Cambrian Basal Sands.	4.25
Fort Nelson	NE BC	104	96,961	76,491	258,562	203,975	588	1989	0.6	1.1	335	M. Cambrian Basal Sands.	2.6
Fort Sask.	AB	90	66,110	52,153	176,293	139,074	401	1356	0.5	0.8	280	M. Cambrian Basal Sands.	2.4
Fort St. John	NE BC	128	149,849	118,213	399,596	315,234	909	3074	0.9	1.7	431	M. Cambrian Basal Sands.	4
Grand Centre	AB	40.5	–	–	–	–	–	–	–	–	82	M. Cambrian Basal Sands.	1.35
Grande Cache	AB	?	–	–	–	–	–	–	–	–	–	Disturbed belt fm	?
Grande Prairie	AB	140	176,293	139,074	470,113	370,863	1070	3616	1.1	2.0	479	Granite Wash	3.7
High River	AB	100	88,146	69,537	235,057	185,432	535	1808	0.6	1.0	319	M. Cambrian Basal Sands.	4
Hinton	AB	170	242,402	191,226	646,406	509,937	1471	4972	1.4	2.8	599	M. Cambrian Basal Sands.	5.6
Humboldt	Sask.	35	–	–	–	–	–	–	–	–	60	M. Cambrian Basal Sands.	1.4
Innisfail	AB	87.5	60,601	47,807	161,602	127,484	368	1243	0.4	0.7	270	M. Cambrian Basal Sands.	3.5
Jasper	AB	?	–	–	–	–	–	–	–	–	–	Disturbed belt	?
Kindersley	Sask.	59	–	–	–	–	–	–	–	–	157	M. Cambrian Basal Sands.	2.2
Lacombe	AB	120	132,219	104,305	352,585	278,148	802	2712	0.8	2.0	399	M. Cambrian Basal Sands.	3.2
Langdon	AB	80.5	45,175	35,638	120,467	95,034	274	927	0.4	0.5	242	M. Cambrian Basal Sands.	3.5
Leduc	AB	110	110,183	86,921	293,821	231,790	669	2260	0.7	2.0	359	M. Cambrian Basal Sands.	2.7
Lethbridge	AB	70	22,037	17,384	58,764	46,358	134	452	0.2	0.3	200	M. Cambrian Basal Sands.	2.7
Lloydminster	AB	50	–	–	–	–	–	–	–	–	120	M. Cambrian Basal Sands.	1.7

Table A1. *Cont.*

City Location	Province	Temperature T	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthalpy Gain	Formation Group	Depth
			at C = 3993 at 30 kg/s	at C = 3150 at 30 kg/s	at C = 3993 at 80 kg/s	at C = 3150 at 80 kg/s	Minimum number @ 130 GJ/Year	Maximum number @ 130 GJ/Year	at C = 3993 at 30 kg/s	at C = 3150 at 80 kg/s	at C = 3993		
Name	Name	°C	GJ Year	GJ Year	GJ Year	GJ Year			MW el.	MW el.	kJ/kg		km
Malville	Sask.	48	–	–	–	–	–	–	–	–	112	M. Cambrian Basal Sands.	1.6
Martensville	Sask.	45	–	–	–	–	–	–	–	–	98	M. Cambrian Basal Sands.	1.65
Meadow Lake	Sask.	35	–	–	–	–	–	–	–	–	60	M. Cambrian Basal Sands.	1
Medicine Hat	AB	60	–	–	–	–	–	–	0.1	–	160	M. Cambrian Basal Sands.	2.2
Melford	Sask.	30	–	–	–	–	–	–	–	–	40	M. Cambrian Basal Sands.	1
Moose Jaw	Sask.	55	–	–	–	–	–	–	0.1	–	140	M. Cambrian Basal Sands.	2.2
Morinville	AB	100	88,146	69,537	235,057	185,432	535	1808	0.6	1.0	319	M. Cambrian Basal Sands.	2.4
North Battleford	Sask.	50	–	–	–	–	–	–	–	–	118	M. Cambrian Basal Sands.	1.65
Olds	AB	90	66,110	52,153	176,293	139,074	401	1356	0.5	0.8	280	M. Cambrian Basal Sands.	3.6
Peace River	AB	67.2	15,866	12,517	42,310	33,378	96	325	0.2	0.2	188	Devonian Granite Wash	2.1
Penhold	AB	95.2	77,569	61,192	206,850	163,180	471	1591	0.5	0.9	300	M. Cambrian Basal Sands.	3.4
Pincher Creek	AB	89.3	64,567	50,936	172,179	135,829	392	1324	0.5	0.7	277	Disturbed belt fm	4.7
Ponoka	AB	123	138,830	109,521	370,214	292,055	842	2848	0.9	1.6	411	M. Cambrian Basal Sands.	3
Prince Albert	Sask.	30	–	–	–	–	–	–	–	–	40	M. Cambrian Basal Sands.	1
Raymond	AB	57.5	–	–	–	–	–	–	–	–	150	M. Cambrian Basal Sands.	2.5
Red Deer	AB	115	121,201	95,613	323,203	254,969	735	2486	0.8	1.4	379	M. Cambrian Basal Sands.	3.3
Redcliff	AB	60.5	1102	869	2938	2318	7	23	0.1	0.0	162	M. Cambrian Basal Sands.	2.2
Regina	Sask.	61	1983	1565	5289	4172	12	41	0.1	0.0	163	U. Cambrian Deadwood	2.1
Rocky Mountain House	AB	144	185,107	146,027	493,619	389,407	1123	3797	1.1	2.1	495	M. Cambrian Basal Sands.	4.8
Saskatoon	Sask.	48	–	–	–	–	–	–	–	–	110	M. Cambrian Basal Sands.	1.7
Slave Lake	AB	73.5	29,749	23,469	79,332	62,583	181	610	0.3	0.3	214	M. Cambrian Basal Sands.	2.1
Spruce Grove	AB	90	66,110	52,153	176,293	139,074	401	1356	0.5	0.8	280	M. Cambrian Basal Sands.	2.6

Table A1. *Cont.*

City Location	Province	Temperature T	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthalpy Gain	Formation Group	Depth
			at C = 3993 at 30 kg/s	at C = 3150 at 30 kg/s	at C = 3993 at 80 kg/s	at C = 3150 at 80 kg/s	Minimum number @ 130 GJ/Year	Maximum number @ 130 GJ/Year	at C = 3993 at 30 kg/s	at C = 3150 at 80 kg/s	at C = 3993		
Name	Name	°C	GJ Year	GJ Year	GJ Year	GJ Year			MW el.	MW el.	kJ/kg		km
St. Albert	AB	90	66,110	52,153	176,293	139,074	401	1356	0.5	0.8	280	M. Cambrian Basal Sands.	2.5
St. Paul	AB	55.25	–	–	–	–	–	–	–	–	141	M. Cambrian Basal Sands.	1.7
Stettler	AB	78.3	40,327	31,813	107,538	84,835	245	827	0.3	0.5	233	M. Cambrian Basal Sands.	2.7
Stony Plain	AB	90	66,110	52,153	176,293	139,074	401	1356	0.5	0.8	280	M. Cambrian Basal Sands.	2.6
Swift Current	Sask.	65	10,578	8344	28,207	22,252	64	217	0.2	0.1	179	M. Cambrian Basal Sands.	2.4
Taber	AB	59.4	–	–	–	–	–	–	–	–	157	M. Cambrian Basal Sands.	2.2
Three Hills	AB	80.6	45,395	35,811	121,054	95,497	275	931	0.4	0.5	242	M. Cambrian Basal Sands.	3.1
Varman	Sask.	43	–	–	–	–	–	–	–	–	93	M. Cambrian Basal Sands.	1.6
Vegreville	AB	64	8815	6954	23,506	18,543	53	181	0.2	0.1	176	M. Cambrian Basal Sands.	2
Vermilion	AB	55.8	–	–	–	–	–	–	–	–	143	M. Cambrian Basal Sands.	1.8
Virden	Man.	56	–	–	–	–	–	–	–	–	144	M. Cambrian Basal Sands.	1.6
Wainwleft	AB	64	8815	6954	23,506	18,543	53	181	0.2	0.1	176	M. Cambrian Basal Sands.	2
Westlock	AB	73.6	29,970	23,643	79,919	63,047	182	615	0.3	0.3	214	M. Cambrian Basal Sands.	2.3
Wetaskiwin	AB	110	110,183	86,921	293,821	231,790	669	2260	0.7	1.3	359	M. Cambrian Basal Sands.	2.7
Weyburn	Sask.	92	70,076	55,282	186,870	147,418	425	1437	0.5	0.8	287	U. Cambrian Deadwood	2.7
White City	Sask.	65	9916	7823	26,444	20,861	60	203	0.2	0.1	178	U. Cambrian Deadwood	2.15
Whitecourt	AB	140	176,293	139,074	470,113	370,863	1070	3616	1.1	2.0	479	M. Cambrian Basal Sands.	3.3
Yorkton	Sask.	46	–	–	–	–	–	–	–	–	102	M. Cambrian Basal Sands.	1.3

Table A2. WCSB >3 k populations centers geothermal prospects summary—Upper Devonian Beaverhill Lake Group—Energy, Enthalpy, Power, Number of direct deep geothermal energy heated households feasible.

City Location	Province	Temperature T	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthalpy Gain	Formation Group	Depth
			at C = 3993 at 30 kg/s	at C = 3150 at 30 kg/s	at C = 3993 at 80 kg/s	at C = 3150 at 80 g/s	Minimum number @ 130 GJ/Year	Maximum number @ 130 GJ/Year	at C = 3993 at 30 kg/s	at C = 3150 at 80 kg/s	at C = 3993		
Name	Name	°C	GJ Year	GJ Year	GJ Year	GJ Year			MW el.	MW el.	kJ/kg		km
Airdrie	AB	80	44,073.14	34,768.44	117,528.4	92,715.84	267.4495	904.0643	0.35937	0.504	239.58	/Leduc	1.9
Banff	AB	?	–	–	–	–	–	–	–	–		Disturbed belt	?
Barrhead	AB	59.2	–	–	–	–	–	–	–	–	156.5256	U. Devonian Beaverhill L.	1.85
Battleford	Sask.	–	–	–	–	–	–	–	–	–	–	–	–
Beaumont	AB	60	–	–	–	–	–	–	–	–	159.72	Beaverhill l. Group	1.7
Blackfalds	AB	85	55,091.42	43,460.55	146,910.5	115,894.8	334.3119	1130.08	–	0.63	259.545	U. Devonian Beaverhill L.	2.5
Bonnyville	AB	–	–	–	–	–	–	–	–	–	–	Shallow basin	
Brooks	AB	50	–	–	–	–	–	–	–	–	119.79	Beaverhill l. Group	1.7
Calgary	AB	80	44,073.14	34,768.44	117,528.4	92,715.84	267.4495	904.0643	0.35937	0.504	239.58	/Leduc	3.4
Camrose	AB	60	–	–	–	–	–	–	0.11979	–	159.72	Beaverhill l. Group	1.6
Canmore	AB	–	–	–	–	–	–	–	–	–	–	Disturbed belt	–
Cardston	AB	66	13,221.94	10,430.53	35,258.51	27,814.75	80.23486	271.2193	–	–	183.678	U. Devonian Beaverhill L.	3.3
Carstairs	AB	75.6	34,377.05	27,119.38	91,672.12	72,318.36	208.6106	705.1702	–	–	222.0108	Leduc F.	3.15
Chestermere	AB	75	33,054.85	26,076.33	88,146.27	69,536.88	200.5872	678.0483	–	–	219.615	/Leduc	3
Claresholm	AB	70.35	22,807.85	17,992.67	60,820.93	47,980.45	138.4051	467.8533	–	–	201.0476	U. Devonian Beaverhill L.	3.35
Coaldale	AB	47.5	–	–	–	–	–	–	–	–	109.8075	U. Devonian Beaverhill L.	1.9
Cochrane	AB	–	–	–	–	–	–	–	–	–	–	Disturbed belt	–
Cold Lake	AB	–	–	–	–	–	–	–	–	–	–	Shallow basin	–
Cold Lake	AB	–	–	–	–	–	–	–	–	–	–	Shallow basin	–
Dawson Creek	NE BC	126	145,441.4	114,735.9	387,843.6	30,5962.3	882.5835	2983.412	0.910404	1.6632	423.258	U. Devonian Beaverhill L.	3.6
Devon	AB	72.2	26,884.61	21,208.75	71,692.3	56,556.66	163.1442	551.4793	–	–	208.4346	Cooking Lk F.	1.9
Didsbury	AB	78.75	41,318.57	32,595.41	110,182.8	86,921.1	250.7339	847.5603	–	–	234.5888	Leduc F.	3.15
Drayton Valley	AB	86.8	59,058	46,589.71	157,488	124,239.2	358.3824	1211.446	–	0.67536	266.7324	U. Devonian Beaverhill L.	2.8
Drumheller	AB	51.3	–	–	–	–	–	–	–	–	124.9809	Leduc F.	1.9
E.Lloydminster	Sask.	–	–	–	–	–	–	–	–	–	–	–	–
Edmonton	AB	70	22,036.57	17,384.22	58,764.18	46,357.92	133.7248	452.0322	–	–	199.65	Beaverhill l. Group	1.7
Edson	AB	126	145,441.4	114,735.9	387,843.6	30,5962.3	882.5835	2983.412	0.910404	1.6632	423.258	Beaverhill l. Group	3.6
Estevan	Sask.	82.8	50,243.38	39,636.02	133,982.3	105,696.1	304.8925	1030.633	0.392911	0.57456	250.7604	U. Devonian Beaverhill L.	2.3
Fort Liard	NWT	136	167,477.9	132,120.1	446,607.8	352,320.2	1016.308	3435.445	1.030194	1.9152	463.188	U. Devonian Beaverhill L.	3.4

Table A2. *Cont.*

City Location	Province	Temperature T	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthalpy Gain	Formation Group	Depth
Name	**Name**	**°C**	**at C = 3993 at 30 kg/s** **GJ Year**	**at C = 3150 at 30 kg/s** **GJ Year**	**at C = 3993 at 80 kg/s** **GJ Year**	**at C = 3150 at 80 g/s** **GJ Year**	**Minimum number @ 130 GJ/Year**	**Maximum number @ 130 GJ/Year**	**at C = 3993 at 30 kg/s** **MW el.**	**at C = 3150 at 80 kg/s** **MW el.**	**at C = 3993** **kJ/kg**		**km**
Fort Nelson	NE BC	84	52,887.76	41,722.13	141,034	111,259	320.9394	1084.877	_	0.6048	255.552	U. Devonian Beaverhill L.	2.1
Fort Sask.	AB	60	_	_	_	_	_	_	_	_	159.72	Beaverhill l. Group	1.6
Fort St. John	NE BC	112	114,590.2	90,397.94	305,573.7	241,061.2	695.3688	2350.567	0.742698	1.3104	367.356	U. Devonian Beaverhill L.	3.5
Grand Centre	AB		_	_	_	_	_	_	_	_		Shallow basin	_
Grande Cache	AB		_	_	_	_	_	_	_	_		Disturbed belt	_
Grande Prairie	AB	90	66,109.71	52,152.66	176,292.5	139,073.8	401.1743	1356.097	0.47916	0.756	279.51	/Leduc	3.5
High River	AB	80	44,073.14	34,768.44	117,528.4	92,715.84	267.4495	904.0643	0.35937	0.504	239.58	Beaverhill l. Group	3.5
Hinton	AB	160	220,365.7	173,842.2	587,641.8	463,579.2	1337.248	4520.322	1.31769	2.52	559.02	/Leduc	3.4–5.4
Humboldt	Sask.	_	_	_	_	_	_	_	_	_	_	_	_
Innisfail	AB	68.75	19,282	15,211.19	51,418.66	40,563.18	117.0092	395.5282	_	_	194.6588	U. Devonian Beaverhill L.	2.75
Jasper	AB	_	_	_	_	_	_	_	_	_	_	Disturbed belt	
Kindersley	Sask.	32.4	_	_	_	_	_	_	_	_	49.5132	U. Devonian Beaverhill L.	1.2
Lacombe	AB	130	154,256	121,689.5	411,349.3	324,505.4	936.0734	3164.225	0.95832	1.764	439.23	Beaverhill l. Group	2.3
Langdon	AB	69.6	21,155.11	16,688.85	56,413.62	44,503.6	128.3758	433.9509	_	_	198.0528	Leduc F.	2.9
Leduc	AB	80	44,073.14	34,768.44	117,528.4	92,715.84	267.4495	904.0643	_	0.504	239.58	Beaverhill l. Group	1.9
Lethbridge	AB	60	_	_	_	_	_	_	_	_	159.72	Beaverhill l. Group	2.3
Lloydminster	AB	_	_	_	_	_	_	_	_	_	_	Shallow basin	_
Malville	Sask.	_	_	_	_	_	_	_	_	_	_	Shallow basin	_
Martensville	Sask.	_	_	_	_	_	_	_	_	_	_	Shallow basin	_
Meadow Lake	Sask.	_	_	_	_	_	_	_	_	_	_	Shallow basin	_
Medicine Hat	AB	50	_	_	_	_	_	_	_	_	119.79	Beaverhill l. Group	1.6
Melford	Sask.	_	_	_	_	_	_	_	_	_	_	_	_
Moose Jaw	Sask.	37.5	_	_	_	_	_	_	_	_	69.8775	U. Devonian Beaverhill L.	1.5
Morinville	AB	70	22,036.57	17,384.22	58,764.18	46,357.92	133.7248	452.0322	_	_	199.65	/Cooking Lk F.	1.6
North Battleford	Sask.	_	_	_	_	_	_	_	_	_	_	Shallow basin	_
Olds	AB	76.25	35,809.42	28,249.36	95,491.8	75,331.62	217.3028	734.5523	_	_	224.6063	Leduc F.	3.05
Peace River	AB	67.2	15,866.33	12,516.64	42,310.21	33,377.7	96.28183	325.4632	_	_	188.4696	Leduc F.	2.1
Penhold	AB	70.2	22,477.3	17,731.9	59,939.47	47,285.08	136.3993	461.0728	_	_	200.4486	U. Devonian Beaverhill L.	2.6
Pincher Creek	AB	_	_	_	_	_	_	_	_	_		Disturbed belt	_
Ponoka	AB	88	61,702.39	48,675.82	164,539.7	129,802.2	374.4294	1265.69	_	0.7056	271.524	U. Devonian Beaverhill L.	2.2

Table A2. *Cont.*

City Location	Province	Temperature T	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthalpy Gain	Formation Group	Depth
Name	**Name**	**°C**	**at C = 3993 at 30 kg/s GJ Year**	**at C = 3150 at 30 kg/s GJ Year**	**at C = 3993 at 80 kg/s GJ Year**	**at C = 3150 at 80 g/s GJ Year**	**Minimum number @ 130 GJ/Year**	**Maximum number @ 130 GJ/Year**	**at C = 3993 at 30 kg/s MW el.**	**at C = 3150 at 80 kg/s MW el.**	**at C = 3993 kJ/kg**		**km**
Prince Albert	Sask.	–	–	–	–	–	–	–	–	–	–	Shallow basin	–
Raymond	AB								–		111.804	U. Devonian Beaverhill L.	2
Red Deer	AB	90	66,109.71	52,152.66	176,292.5	139,073.8	401.1743	1356.097	–	0.756	279.51	/Leduc F. to SE	2.6
Redcliff	AB	45.375	–	–	–	–	–	–	–	–	101.3224	U. Devonian Beaverhill L.	1.65
Regina	Sask.	42	–	–	–	–	–	–	–	–	87.846	U. Devonian Beaverhill L.	1.4
Rocky Mountain House	AB	108.5	106,877.4	84,313.47	285,006.3	224,835.9	648.5651	2192.356	0.700772	1.2222	353.3805	U. Devonian Beaverhill L.	3.5
Saskatoon	Sask.	–	–	–	–	–	–	–	–	–	–	Shallow basin	–
Slave Lake	AB	54.4	–	–	–	–	–	–	–	–	137.3592	U. Devonian Beaverhill L.	1.6
Spruce Grove	AB	70	22,036.57	17,384.22	58,764.18	46,357.92	133.7248	452.0322	–	–	199.65	Beaverhill l. Group	1.9
St. Albert	AB	60	–	–	–	–	–	–	–	–	159.72	/Cooking Lk F.	1.7
St. Paul	AB		–	–	–	–	–	–	–	–	−79.86	Shallow basin	–
Stettler	AB	55.5	–	–	–	–	–	–	–	–	141.7515	Leduc F.	1.85
Stony Plain	AB	70	22,036.57	17,384.22	58,764.18	46,357.92	133.7248	452.0322	–	–	199.65	Beaverhill l. Group	2
Swift Current	Sask.	45.9	–	–	–	–	–	–	–	–	103.4187	U. Devonian Beaverhill L.	1.7
Taber	AB	45.9	–	–	–	–	–	–	–	–	103.4187	U. Devonian Beaverhill L.	1.7
Three Hills	AB	59.8	–	–	–	–	–	–	–	–	158.9214	U. Devonian Beaverhill L.	2.3
Varman	Sask.	–	–	–	–	–	–	–	–	–	–	Shallow basin	–
Vegreville	AB	35.2	–	–	–	–	–	–	–	–	60.6936	U. Devonian Beaverhill L.	1.1
Vermilion	AB		–	–	–	–	–	–	–	–	–	Shallow basin	–
Virden Man.	Man.	–	–	–	–	–	–	–	–	–	–	Shallow basin	–
Wainwright	AB	33.6	–	–	–	–	–	–	–	–	54.3048	U. Devonian Beaverhill L.	1.05
Westlock	AB	51.2	–	–	–	–	–	–	–	–	124.5816	U. Devonian Beaverhill L.	1.6
Wetaskiwin	AB	80	44,073.14	34,768.44	117,528.4	92,715.84	267.4495	904.0643	–	–	239.58	Beaverhill l. Group	2
Weyburn	Sask.	66.3	13,883.04	10,952.06	37,021.43	29,205.49	84.2466	284.7803	–	–	184.8759	U. Devonian Beaverhill L.	1.95
White City	Sask.	42	–	–	–	–	–	–	–	–	87.846	U. Devonian Beaverhill L.	1.4
Whitecourt	AB	110	110,182.8	86,921.1	293,820.9	231,789.6	668.6238	2260.161	0.71874	1.26	359.37	Swan H. - Slave Pt	2.7
Yorkton	Sask.	–	–	–	–	–	–	–	–	–	–	Shallow basin	–

Table A3. WCSB >3 k populations centers geothermal prospects summary—Winterburn/Wabamun Groups—Energy, Enthalpy, Power, Number of direct deep geothermal energy heated households feasible.

City Location	Province	Temperature T	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthalpy Gain	Formation Group	Depth
			at C = 3993	at C = 3150	at C = 3993	at C = 3150	Minimum	Maximum	at C = 3993	at C = 3150	at C = 3993	top of Winterburn Group	
			at 30 kg/s	at 30 kg/s	at 80 kg/s	at 80 kg/s	number @ 130	number @ 130	at 30 kg/s	at 80 kg/s			
Name	Name	°C	GJ Year	GJ Year	GJ Year	GJ Year	GJ/Year	GJ/Year	MW el.	MW el.	kJ/kg		km
Airdrie	AB	70	22,036.57	17,384.22	58,764.18	46,357.92	133.7248	452.0322	0.23958	0.252	199.65	/Dolomite Nisku	2.9
Banff	AB	–	–	–	–	–	–	–	–	–	–	Disturbed belt	–
Barrhead	AB	44.8	–	–	–	–	–	–	–	–	99.0264	Wabamum dolomite	1.4
Battleford	Sask.	–	–	–	–	–	–	–	–	–	–	Shallow basin	–
Beaumont	AB	50	–	–	–	–	–	–	–	–	119.79	Wabamum dolomite	1.3
Blackfalds	AB	73.1	28,867.9	22,773.33	76,981.08	60,728.88	175.1794	592.1621	0.276715	0.33012	212.0283	Dolomite Nisku	2.15
Bonnyville	AB	–	–	–	–	–	–	–	–	–	–	Shallow basin	–
Brooks	AB	40	–	–	–	–	–	–	–	–	79.86	Winterburn/ Wabamun	1.4
Calgary	AB	70	22,036.57	17,384.22	58,764.18	46,357.92	133.7248	452.0322	0.23958	0.252	199.65	/Dolomite Nisku	3
Camrose	AB	50	–	–	–	–	–	–	–	–	119.79	/Dolomite Nisku	1.3
Canmore	AB	–	–	–	–	–	–	–	–	–	–	Shallow basin	–
Cardston	AB	60	–	–	–	–	–	–	–	–	159.72	top of Winterburn Group	3
Carstairs	AB	68.4	18,510.72	14,602.74	49,361.91	38,940.65	112.3288	379.707	0.220414	0.21168	193.2612	Dolimite Nisku	2.85
Chestermere	AB	70	22,036.57	17,384.22	58,764.18	46,357.92	133.7248	452.0322	0.23958	0.252	199.65	/Dolomite Nisku	2.8
Claresholm	AB	60.9	1983.291	1564.58	5288.776	4172.213	12.03523	40.6829	0.130571	0.02268	163.3137	top of Winterburn Group	2.9
Coaldale	AB	–	–	–	–	–	–	–	–	–	79.86	top of Winterburn Group	1.6
Cochrane	AB	–	–	–	–	–	–	–	–	–	–	Shallow basin	–
Cold Lake	AB											Shallow basin	–
Cold Lake	AB	–	–	–	–	–	–	–	–	–	–	Shallow basin	–
Dawson Creek	NE BC	131.25	157,010.5	123,862.6	418,694.8	330,300.2	952.789	3220.729	0.973294	1.7955	444.2213	top of Winterburn Group	3.75
Devon	AB	57									147.741	Wabamum dolomite	1.5
Didsbury	AB	70	22,036.57	17,384.22	58,764.18	46,357.92	133.7248	452.0322	0.23958	0.252	199.65	Dolomite Nisku	2.8
Drayton Valley	AB	72	26,443.88	20,861.06	70,517.02	55,629.5	160.4697	542.4386	0.263538	0.3024	207.636	Wabamum dolomite	2.4
Drumheller	AB	45.9	–	–	–	–	–	–	–	–	103.4187	Dolomite Nisku	1.7
E.Lloydminster	Sask.	0	–	–	–	–	–	–	–	–	–	Shallow basin	–
Edmonton	AB	50	–	–	–	–	–	–	–	–	119.79	/Dolomite Nisku	1.2
Edson	AB	112	114,590.2	90,397.94	305,573.7	241,061.2	695.3688	2350.567	0.742698	1.3104	367.356	top of Winterburn Group	3.2
Estevan	Sask.	77.4	38,343.63	30,248.54	102,249.7	80,662.78	232.6811	786.536	0.328225	0.43848	229.1982	top of Winterburn Group	2.15
Fort Liard	NWT	132	158,663.3	125,166.4	423,102.1	333,777	962.8183	3254.632	0.982278	1.8144	447.216	top of Winterburn Group	3.3

Table A3. *Cont.*

City Location	Province	Temperature T	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthalpy Gain	Formation Group	Depth
			at C = 3993	at C = 3150	at C = 3993	at C = 3150	Minimum	Maximum	at C = 3993	at C = 3150	at C = 3993	top of Winterburn Group	
			at 30 kg/s	at 30 kg/s	at 80 kg/s	at 80 kg/s	number @ 130 GJ/Year	number @ 130 GJ/Year	at 30 kg/s	at 80 kg/s			
Name	Name	°C	GJ Year	GJ Year	GJ Year	GJ Year			MW el.	MW el.	kJ/kg		km
Fort Nelson	NE BC	56	–	–	–	–	–	–	0.071874	–	143.748	top of Winterburn Group	1.4
Fort Sask.	AB	40	–	–	–	–	–	–	–	–	79.86	/Dolomite Nisku	1.1
Fort St. John	NE BC	112	114,590.2	90,397.94	305,573.7	241,061.2	695.3688	2350.567	0.742698	1.3104	367.356	top of Winterburn Group	3.5
Grand Centre	AB	–	–	–	–	–	–	–	–	–	–	Shallow basin	–
Grande Cache	AB	–	–	–	–	–	–	–	–	–	–	Disturbed belt	–
Grande Prairie	AB	130	154,256	121,689.5	411,349.3	324,505.4	936.0734	3164.225	0.95832	1.764	439.23	/Limestone Nisku	3.4
High River	AB	80	44,073.14	34,768.44	117,528.4	92,715.84	267.4495	904.0643	0.35937	0.504	239.58	Winterburn/ Wabamun	3.3
Hinton	AB	150	198,329.1	156,458	528,877.6	417,221.3	1203.523	4068.29	1.1979	2.268	519.09	/Dolomite Nisku	3.7−5.2
Humboldt	Sask.	0	–	–	–	–	–	–	–	–	–	Shallow basin	–
Innisfail	AB	–	–	–	–	–	–	–	–	–	–	Shallow basin	–
Jasper	AB	–										Disturbed belt	–
Kindersley	Sask.	–	–	–	–	–	–	–	–	–	–	Shallow basin	–
Lacombe	AB	80	44,073.14	34,768.44	117,528.4	92,715.84	267.4495	904.0643	0.35937	0.504	239.58	/Dolomite Nisku	2
Langdon	AB	62.4	5288.776	4172.213	14,103.4	11,125.9	32.09394	108.4877	0.14854	0.06048	169.3032	Dolomite Nisku	2.6
Leduc	AB	60	–	–	–	–	–	–	0.11979	–	159.72	Wabamum dolomite	1.5
Lethbridge	AB	50	–	–	–	–	–	–	–	–	119.79	Winterburn/ Wabamun	1.9
Lloydminster	AB	–	–	–	–	–	–	–	–	–	–	Shallow basin	–
Martensville	Sask.	–	–	–	–	–	–	–	–	–	–	Shallow basin	–
Meadow Lake	Sask.	–	–	–	–	–	–	–	–	–	–	Shallow basin	–
Medicine Hat	Sask.	40	–	–	–	–	–	–	–	–	–	Winterburn/ Wabamun	1.3
Melford	AB	–	–	–	–	–	–	–	–	–	–	Shallow basin	–
Melville	Sask.	–	–	–	–	–	–	–	–	–	–	Shallow basin	–
Moose Jaw	Sask.	32.5	–	–	–	–	–	–	–	–	49.9125	top of Winterburn Group	1.3
Morinville	AB	50	–	–	–	–	–	–	–	–	119.79	Wabamum dolomite	1.2
North Battleford	Sask.	–	–	–	–	–	–	–	–	–	–	Shallow basin	–
Olds	AB	67.5	16,527.43	13,038.17	44,073.14	34,768.44	100.2936	339.0241	0.209633	0.189	189.6675	Dolomite Nisku	2.7
Peace River	AB	56									143.748	top of Winterburn Group	1.75
Penhold	AB	62.1	4627.679	3650.686	12,340.48	9735.163	28.0822	94.92676	0.144946	0.05292	168.1053	top of Winterburn Group	2.3
Pincher Creek	AB	–	–	–	–	–	–	–	–	–	–	Disturbed belt	–
Ponoka	AB	72	26,443.88	20,861.06	70,517.02	55,629.5	160.4697	542.4386	0.263538	0.3024	207.636	Winterburn/ Dolomite Nisku	1.8

Table A3. *Cont.*

City Location	Province	Temperature T	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthalpy Gain	Formation Group	Depth
			at C = 3993	at C = 3150	at C = 3993	at C = 3150	Minimum	Maximum	at C = 3993	at C = 3150	at C = 3993	top of Winterburn Group	
			at 30 kg/s	at 30 kg/s	at 80 kg/s	at 80 kg/s	number @ 130 GJ/Year	number @ 130 GJ/Year	at 30 kg/s	at 80 kg/s			
Name	Name	°C	GJ Year	GJ Year	GJ Year	GJ Year			MW el.	MW el.	kJ/kg		km
Prince Albert	Sask.	_	_	_	_	_	_	_	_	_	_	Shallow basin	_
Raymond	AB	42	_	_	_	_	_	_	_	_	_	top of Winterburn Group	1.75
Red Deer	AB	70	22,036.57	17,384.22	58,764.18	46,357.92	133.7248	452.0322	0.23958	0.252	199.65	/Dolomite Nisku	2.2
Redcliff	AB	34.375									57.39938	top of Winterburn Group	1.25
Regina	Sask.	39	_	_	_	_	_	_	_	_	75.867	top of Winterburn Group	1.3
Rocky Mountain House	AB	93	72,720.68	57,367.93	193,921.8	152,981.1	441.2917	1491.706	0.515097	0.8316	291.489	Wabamum dolomite	3.1
Saskatoon	Sask.	0	_	_	_	_	_	_	_	_	_	Shallow basin	_
Slave Lake	AB	37.4	_	_	_	_	_	_	_	_	69.4782	Dolomite Nisku	1.1
Spruce Grove	AB	60	_	_	_	_	_	_	0.11979	_	159.72	Wabamum dolomite	1.6
St. Albert	AB	50	_	_	_	_	_	_	_	_	119.79	Wabamum dolomite	1.3
St. Paul	AB	_	_	_	_	_	_	_	_	_	_	Shallow basin	_
Stettler	AB	43.5	_								93.8355	top of Winterburn Group	1.5
Stony Plain	AB	60	_	_	_	_	_	_	0.11979	_	159.72	Wabamum dolomite	1.5
Swift Current	Sask.	40.5	_	_	_	_	_	_	_	_	81.8565	top of Winterburn Group	1.5
Taber	AB	37.8	_	_	_	_	_	_	_	_	71.0754	top of Winterburn Group	1.4
Three Hills	AB	50.7	_	_	_	_	_	_	_	_	122.5851	Dolimite Nisku	1.95
Vegreville	AB	_	_	_	_	_	_	_	_	_	_	Shallow basin	_
Vermilion	AB	0	_	_	_	_	_	_	_	_	_	Shallow basin	_
Virden Man.	Man.	0	_	_	_	_	_	_	_	_	_	Shallow basin	_
Wainwright	AB	0	_	_	_	_	_	_	_	_	_	Shallow basin	_
Warman	Sask.	0	_	_	_	_	_	_	_	_	_	Shallow basin	_
Westlock	AB	38.4	_	_	_	_	_	_	_	_	73.4712	Wabamum dolomite	1.2
Wetaskiwin	AB	60	_	_	_	_	_	_	0.11979	_	159.72	/Dolomite Nisku	1.6
Weyburn	Sask.	57.8	_	_	_	_	_	_	0.093436	_	150.9354	top of Winterburn Group	1.7
White City	Sask.	39	_	_	_	_	_	_	_	_	75.867	top of Winterburn Group	1.3
Whitecourt	AB	90	66,109.71	52,152.66	176,292.5	139,073.8	401.1743	1356.097	0.47916	0.756	279.51	Winterburn/Wabamum	2.3
Yorkton	Sask.	_	_	_	_	_	_	_	_	_	_	Shallow basin	_

Table A4. WCSB >3 k populations centers geothermal prospects summary—Mississippian Groups—-Energy, Enthalpy, Power, Number of direct deep geothermal energy heated households feasible.

City Location	Province	Temperature T	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthalpy Gain	Formation Group	Depth
			at C = 3993	at C = 3150	at C = 3993	at C = 3150	Minimum	Maximum	at C = 3993	at C = 3150	at C = 3993	top of Winterburn Group	
			at 30 kg/s	at 30 kg/s	at 80 kg/s	at 80 kg/s	number @ 130 GJ/Year	number @ 130 GJ/Year	at 30 kg/s	at 80 kg/s			
Name	Name	°C	GJ Year	GJ Year	GJ Year	GJ Year			MW el.	MW el.	kJ/kg		km
Airdrie	AB	60	_	_	_	_	_	_	0.11979		159.72	/Rundle dolstone	2.3
Banff	AB	_	_	_	_	_	_	_	_	_	_	Disturbed belt	_
Barrhead	AB	35.2	_	_	_	_	_	_			60.6936	Mississippian	1.1
Battleford	Sask.	_	_	_	_	_	_	_	_	_	_	shallow basin	_
Beaumont	AB	40	_	_	_	_	_	_	_	_	79.86	Mississippian	1.2
Blackfalds	AB	59.5	_	_	_	_	_	_	0.113801	−0.0126	157.7235	Banff l.	1.75
Bonnyville	AB	_	_	_	_	_	_	_	_	_	_	shallow basin	_
Brooks	AB	30	_	_	_	_	_	_	_	_	39.93	/Rundle/Banff carbonates	1.1
Calgary	AB	60	_	_	_	_	_	_	0.11979	_	159.72	/Rundle/Charles carbonates	2.4
Camrose	AB	40	_	_	_	_	_	_	_	_	79.86	Mississippian	1.1
Canmore	AB	_	_	_	_	_	_	_	_	_	_	Disturbed belt	_
Cardston	AB	50	_	_	_	_	_	_			119.79	Banf/Rundle l.	2.5
Carstairs	AB	55.2	_	_	_	_	_	_	0.062291		140.5536	Banf l./Rundle d.	2.3
Chestermere	AB	50	_	_	_	_	_	_	_	_	119.79	/Rundle dolstone	2.1
Claresholm	AB	50.4	_	_	_	_	_	_			121.3872	Banf/Rundle l.	2.4
Coaldale	AB	30	_	_	_	_	_	_	_	_	39.93	Rundle l.	1.25
Cochrane	AB	_	_	_	_	_	_	_	_	_	_	Disturbed belt	_
Cold Lake	AB	_	_	_	_	_	_	_	_	_	_	shallow basin	_
Cold Lake	AB	_	_	_	_	_	_	_	_	_	_	shallow basin	_
Dawson Creek	NE BC	91	68,313.36	53,891.08	18,2169	143,709.6	414.5468	1401.3	0.491139	0.7812	283.503	Mississippian	2.6
Devon	AB	51.3	_	_	_	_	_	_	_	_	124.9809	Mississippian	1.35
Didsbury	AB	57.5	_	_	_	_	_	_	0.089842	_	149.7375	Banff l.	2.3
Drayton Valley	AB	60	_	_	_	_	_	_	0.11979		159.72	Banff l.	2
Drumheller	AB	37.8	_	_	_	_	_	_			71.0754	Mississippian	1.4
E.Lloydminster	Sask.	_	_	_	_	_	_	_	_	_	_	shallow basin	_
Edmonton	AB	40	_	_	_	_	_	_	_	_	79.86	Mississippian	1.2
Edson	AB	96.25	79,882.56	63,017.8	213,020.2	168,047.5	484.7523	1638.617	0.554029	0.9135	304.4663	Rundle l.	2.75
Estevan	Sask.	57.6	−5288.78	_	_	_	_	_	_	_	150.1368	Mississippian	1.6
Fort Liard NWT	NWT	40	_	_	_	_	_	_	_	_	_	Mississippian	1
Fort Nelson	NE BC	_	_	_	_	_	_	_	_	_	_	shallow basin	_
Fort Sask.	AB	40	_	_	_	_	_	_	_	_	79.86	Mississippian	1.1
Fort St. John	NE BC	64	8814.627	6953.688	23,505.67	18,543.17	53.48991	180.8129	0.167706	0.1008	175.692	Mississippian	2
Grand Centre	AB	_	_	_	_	_	_	_	_	_	_	shallow basin	_
Grande Cache	AB	_	_	_	_	_	_	_				Disturbed belt	_
Grande Prairie	AB	90	66,109.71	52,152.66	176,292.5	139,073.8	401.1743	1356.097	0.47916	0.756	279.51	/Rundle/Banff carbonates	1.9
High River	AB	60	_	_	_	_	_	_	0.11979	_	159.72	/Rundle/Banff carbonates	2.4

Table A4. *Cont.*

City Location	Province	Temperature T	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthalpy Gain	Formation Group	Depth
			at C = 3993	at C = 3150	at C = 3993	at C = 3150	Minimum	Maximum	at C = 3993	at C = 3150	at C = 3993	top of Winterburn Group	
			at 30 kg/s	at 30 kg/s	at 80 kg/s	at 80 kg/s	number	number	at 30 kg/s	at 80 kg/s			
Name	Name	°C	GJ Year	GJ Year	GJ Year	GJ Year	@ 130 GJ/Year	@ 130 GJ/Year	MW el.	MW el.	kJ/kg		km
Hinton	AB	135	165,274.3	130,381.7	440,731.4	347,684.4	1002.936	3390.241	1.018215	1.89	459.195	/Turney Valley/Elkton	3−4.5
Humboldt	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Innisfail	AB	50									119.79	Banff l.	2
Jasper	AB	–	–	–	–	–	–	–	–	–	–	Disturbed belt	–
Kindersley	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Lacombe	AB	70	22,036.57	17,384.22	58,764.18	46,357.92	133.7248	452.0322	0.23958	0.252	199.65	Mississippian	1.7
Langdon	AB	46	–	–	–	–	–	–	–	–	103.818	Rundle d.	2
Leduc	AB	55	–	–	–	–	–	–	–	–	139.755	Mississippian	1.3
Lethbridge	AB	35	–	–	–	–	–	–	–	–	59.895	Runde limestone	1.4
Lloydminster	AB	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Martensville	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Meadow Lake	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Medicine Hat	Sask.	30	–	–	–	–	–	–	–	–	39.93	/Rundle/Banff carbonates	–
Melford	AB	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Melville	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Moose Jaw	Sask.	30	−66,109.7	–	–	–	–	–	–	–	39.93	Mississippian	1.2
Morinville	AB	40	–	–	–	–	–	–	–	–	79.86	Mississippian	1.1
North Battleford	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Olds	AB	57.5	–	–	–	–	–	–	0.089842	–	149.7375	Mississippian	2.3
Peace River	AB	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Penhold	AB	50.4	–	–	–	–	–	–	–	–	121.3872	Banf l.	1.8
Pincher Creek	AB	–	–	–	–	–	–	–	–	–	–	Disturbed belt	–
Ponoka	AB	64	8814.627	6953.688	23,505.67	18,543.17	53.48991	180.8129	0.167706	0.1008	175.692	Mississippian	1.6
Prince Albert	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Raymond	AB	31.2	–	–	–	–	–	–	–	–	44.7216	Rundle l.	1.3
Red Deer	AB	60	–	–	–	–	–	–	0.11979	–	159.72	/Banff limestone	1.8
Redcliff	AB	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Regina	Sask.	30	−66109.7	–	–	–	–	–	–	–	39.93	Mississippian	1
Rocky Mountain House	AB	81	46,276.79	36,506.86	123,404.8	97,351.63	280.822	949.2676	0.371349	0.5292	243.573	Rundle l/Banff l.	2.7
Saskatoon	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Slave Lake	AB	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Spruce Grove	AB	45	–	–	–	–	–	–	–	–	99.825	Mississippian	1.3
St. Albert	AB	45	–	–	–	–	–	–	–	–	99.825	Mississippian	1.2
St. Paul	AB	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Stettler	AB	37.7	–	–	–	–	–	–	–	–	70.6761	Mississippian	1.3
Stony Plain	AB	50	–	–	–	–	–	–	–	–	119.79	Mississippian	1.4
Swift Current	Sask.	31.05	−63,795.9	–	–	–	–	–	–	–	44.12265	Mississippian	1.15

Table A4. *Cont.*

City Location	Province	Temperature T	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthalpy Gain	Formation Group	Depth
			at C = 3993	at C = 3150	at C = 3993	at C = 3150	Minimum	Maximum	at C = 3993	at C = 3150	at C = 3993	top of Winterburn Group	
			at 30 kg/s	at 30 kg/s	at 80 kg/s	at 80 kg/s	number	number	at 30 kg/s	at 80 kg/s			
Name	Name	°C	GJ Year	GJ Year	GJ Year	GJ Year	@ 130 GJ/Year	@ 130 GJ/Year	MW el.	MW el.	kJ/kg		km
Taber	AB	27	–	–	–	–	–	–	–	–	27.951	Rundle l.	1
Three Hills+M8A6:M41	AB	41.6	–	–	–	–	–	–			86.2488	Rundle d.	1.6
Vegreville	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Vermilion	AB	–	–	–	–	–	–	–				shallow basin	–
Virden Man.	Man.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Wainwright	AB	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Warman	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Westlock	AB	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Wetaskiwin	AB	60	–	–	–	–	–	–	0.11979	–	159.72	Mississippian	1.4
Weyburn	Sask.	44.2	−34,817.8	–	–	–	–	–	–	–	96.6306	Mississippian	1.3
White City	Sask.	30	−66,109.7	–	–	–	–	–	–	–	39.93	Mississippian	1
Whitecourt	AB	70	22,036.57	17,384.22	58,764.18	46,357.92	133.7248	452.0322	0.23958	0.252	199.65	/Banff limestone	1.8
Yorkton	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–

Table A5. WCSB >3 k populations centers geothermal prospects summary—Lower Cretaceous—Energy, Enthalpy, Power, Number of direct deep geothermal energy heated households feasible.

City Location	Province	Temperature T	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthalpy Gain	Formation Group	Depth
			at C = 3993 at 30 kg/s	at C = 3150 at 30 kg/s	at C = 3993 at 80 kg/s	at C = 3150 at 80 kg/s	Minimum number	Maximum number	at C = 3993 at 30 kg/s	at C = 3150 at 80 kg/s	at C = 3993	Lower Cretaceous	
Name	Name	°C	GJ Year	GJ Year	GJ Year	GJ Year	@ 130 GJ/Year	@ 130 GJ/Year	MW el.	MW el.	kJ/kg		km
Airdrie	AB	45	–	–	–	–	–	–	–	–	99.825	Lower Mannville Group	2.3
Banff	AB	–	–	–	–	–	–	–	–	–	–	Disturbed belt	
Barrhead	AB	38.4	–	–	–	–	–	–	–	–	73.4712	Lower Mannville Group	1.2
Battleford	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Beaumont	AB	30	–	–	–	–	–	–	–	–	39.93	Lower Mannville Group	1.2
Blackfalds	AB	63	6610.971	5215.266	17,629.25	13,907.38	40.11743	135.6097	0.155727	0.0756	171.699	Lower Mannville Group	1.75
Bonnyville	AB	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Brooks	AB	20	–	–	–	–	–	–	–	–	0	Lower Mannville Group	1.1

Table A5. *Cont.*

City Location	Province	Temperature T	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthalpy Gain	Formation Group	Depth
Name	**Name**	**°C**	**at C = 3993 at 30 kg/s GJ Year**	**at C = 3150 at 30 kg/s GJ Year**	**at C = 3993 at 80 kg/s GJ Year**	**at C = 3150 at 80 kg/s GJ Year**	**Minimum number @ 130 GJ/Year**	**Maximum number @ 130 GJ/Year**	**at C = 3993 at 30 kg/s MW el.**	**at C = 3150 at 80 kg/s MW el.**	**at C = 3993 kJ/kg**	**Lower Cretaceous**	**km**
Calgary	AB	50	–	–	–	–	–	–	–	–	119.79	Lower Mannville Group	2.4
Camrose	AB	30	–	–	–	–	–	–	–	–	39.93	Lower Mannville Group	1.1
Canmore	AB	–	–	–	–	–	–	–	–	–	–	Disturbed belt	–
Cardston	AB	–	–	–	–	–	–	–	–	–	–	Disturbed belt	–
Carstairs	AB	–	–	–	–	–	–	–	–	–	149.7375	Lower Mannville Group	2.3
Chestermere	AB	40	–	–	–	–	–	–	–	–	79.86	Lower Mannville Group	2.1
Claresholm	AB	–	–	–	–	–	–	–	–	–	121.3872	Lower Mannville Group	2.4
Coaldale	AB	32.5	–	–	–	–	–	–	–	–	49.9125	Lower Mannville Group	1.3
Cochrane	AB	–	–	–	–	–	–	–	–	–	–	Disturbed belt	–
Cold Lake	AB	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Cold Lake	AB	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Dawson Creek	NE BC	56	–	–	–	–	–	–	–	–	143.748	Lower Mannville Group	1.6
Devon	AB	51.8	–	–	–	–	–	–	–	–	126.9774	Lower Mannville Group	1.4
Didsbury	AB	57.5							0.089842		149.7375	Lower Mannville Group	2.3
Drayton Valley	AB	68.25	18,180.17	14,341.98	48,480.45	38,245.28	110.3229	372.9265	0.218617	0.2079	192.6623	Lower Mannville Group	1.95
Drumheller	AB	37.8	–	–	–	–	–	–	–	–	71.0754	Lower Mannville Group	1.4
E.Lloydminster	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Edmonton	AB	35	–	–	–	–	–	–	–	–	59.895	Lower Mannville Group	1.2
Edson	AB	91	68,313.36	53,891.08	182,169	143,709.6	414.5468	1401.3	0.491139	0.7812	283.503	Lower Mannville Group	2.6
Estevan	Sask.	46.8	–	–	–	–	–	–	–	–	107.0124	shallow basin	1.3
Fort Liard NWT	NWT	40	–	–	–	–	–	–	–	–	–	shallow basin	1
Fort Nelson	NE BC	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Fort Sask.	AB	30	–	–	–	–	–	–	–	–	39.93	Lower Mannville Group	1.1
Fort St. John	NE BC	43.2	–	–	–	–	–	–	–	–	92.6376	Lower Mannville Group	1.35
Grand Centre	AB	–	–	–	–	–	–	–	–	–	–	shallow	–
Grande Cache	AB	–	–	–	–	–	–	–	–	–	–	Disturbed belt	–
Grande Prairie	AB	70	22,036.57	17,384.22	58,764.18	46,357.92	133.7248	452.0322	0.23958	0.252	199.65	Lower Mannville/Cadominium	1.9

Table A5. *Cont.*

City Location	Province	Temperature T	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthalpy Gain	Formation Group	Depth
			at C = 3993 at 30 kg/s	at C = 3150 at 30 kg/s	at C = 3993 at 80 kg/s	at C = 3150 at 80 kg/s	Minimum number	Maximum number	at C = 3993 at 30 kg/s	at C = 3150 at 80 kg/s	at C = 3993	Lower Cretaceous	
Name	Name	°C	GJ Year	GJ Year	GJ Year	GJ Year	@ 130 GJ/Year	@ 130 GJ/Year	MW el.	MW el.	kJ/kg		km
High River	AB	50	–	–	–	–	–	–	–	–	119.79	Lower Mannville Group	2.4
Hinton	AB	120	132,219.4	104,305.3	352,585.1	278,147.5	802.3486	2712.193	0.83853	1.512	399.3	Lower Mannville/Cadominium	4
Humboldt	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Innisfail	AB	50	–	–	–	–	–	–	–	–	119.79	Lower Mannville Group	2
Jasper	AB		–	–	–	–	–	–	–	–		Disturbed belt	–
Kindersley	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Lacombe	AB	60	–	–	–	–	–	–	–	–	159.72	Lower Mannville Group	1.7
Langdon	AB	43.7									94.6341	Lower Mannville Group	1.9
Leduc	AB	45	–	–	–	–	–	–	–	–	99.825	Lower Mannville Group	1.3
Lethbridge	AB	30	–	–	–	–	–	–	–	–	39.93	Lower Mannville/Cadominium	1.4
Lloydminster	AB	–	–	–	–	–	–	–	–	–	–	shallow basin	0
Malville	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Martensville	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Meadow Lake	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Medicine Hat	AB	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Melford	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Moose Jaw	Sask.	25	–	–	–	–	–	–	–	–	19.965	shallow basin	1
Morinville	AB	30	–	–	–	–	–	–	–	–	39.93	Lower Mannville Group	1.1
North Battleford	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Olds	AB	57.5	–	–	–	–	–	–	–	–	149.7375	Lower Mannville Group	2.3
Peace River	AB	–	–	–	–	–	–	–	–	–	–	shallow basin	
Penhold	AB	–	–	–	–	–	–	–	–	–	140.1543	Lower Mannville Group	1.9
Pincher Creek	AB	–	–	–	–	–	–	–	–	–	–	Disturbed belt	–
Ponoka	AB	65.6	12,340.48	9735.163	32,907.94	25,960.44	74.88587	253.138	0.186872	0.14112	182.0808	Lower Mannville Group	1.6
Prince Albert	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Raymond	AB	–	–	–	–	–	–	–	–	–	49.5132	Lower Mannville Group	1.35
Red Deer	AB	50	–	–	–	–	–	–	–	–	119.79	Lower Mannville Group	1.8

Table A5. *Cont.*

City Location	Province	Temperature T	Energy 1	Energy 2	Energy 3	Energy 4	Households	Households	Power	Power	Enthalpy Gain	Formation Group	Depth
			at C = 3993 at 30 kg/s	at C = 3150 at 30 kg/s	at C = 3993 at 80 kg/s	at C = 3150 at 80 kg/s	Minimum number	Maximum number	at C = 3993 at 30 kg/s	at C = 3150 at 80 kg/s	at C = 3993	Lower Cretaceous	
Name	Name	°C	GJ Year	GJ Year	GJ Year	GJ Year	@ 130 GJ/Year	@ 130 GJ/Year	MW el.	MW el.	kJ/kg		km
Redcliff	AB		–	–	–	–	–	–	–	–	–	shallow basin	–
Regina	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Rocky Mountain House	AB	78	39,665.82	31,291.6	105,775.5	83,444.26	240.7046	813.6579	0.335412	0.4536	231.594	Lower Mannville Group	2.6
Saskatoon	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Slave Lake	AB	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Spruce Grove	AB	40	–	–	–	–	–	–	–	–	79.86	Lower Mannville Group	1.3
St. Albert	AB	40	–	–	–	–	–	–	–	–	79.86	Lower Mannville Group	1.2
St. Paul	AB	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Stettler	AB	40.6	–	–	–	–	–	–	–	–	82.2558	Lower Mannville Group	1.4
Stony Plain	AB	40	–	–	–	–	–	–	–	–	79.86	Lower Mannville Group	1.4
Swift Current	Sask.	27	–	–	–	–	–	–	–	–	27.951	shallow basin	1
Taber	AB	–	–	–	–	–	–	–	–	–	–	shallow	–
Three Hills	AB	–	–	–	–	–	–	–	–	–	96.6306	Lower Mannville Group	1.7
Varman	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Vegreville	AB	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Vermilion	Man.	–	–	–	–	–	–	–	–	–	–	shallow	–
Virden Man.	AB	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Wainwright	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Westlock	AB	32	–	–	–	–	–	–	–	–	47.916	Lower Mannville Group	1
Wetaskiwin	AB	50	–	–	–	–	–	–	–	–	119.79	Lower Mannville Group	1.4
Weyburn	Sask.	30.6	–	–	–	–	–	–	–	–	42.3258	shallow basin	0.9
White City	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–
Whitecourt	AB	65	11,018.28	8692.11	29,382.09	23,178.96	66.86238	226.0161	0.179685	0.126	179.685	Lower Mannville Group	1.8
Yorkton	Sask.	–	–	–	–	–	–	–	–	–	–	shallow basin	–

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