ASSESSMENT OF THE POTENTIAL GEOTHERMAL RESOURCE OF BRITISH COLUMBIA

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GEOB 270 Final Project
The University of British Columbia
Monday, December 5th, 2016

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ABSTRACT
We quantify the geothermal energy potential of British Columbia via a Multi-Criterion Evaluation employing geological, environmental, and socio-economic factors. 3 scenarios are considered, which differ in their prioritization of: a) geological factors, b) socio-economic factors, and c) a combined balance of the two. It is found that an integration of all of the factors chosen for this study produces a map that shows four main sites of highest feasibility. These sites are located in central and southern B.C. Our results show that most of northern B.C is considered least favourable for the development of geothermal power production sites. Our primary sources of uncertainty are in the scoring systems that we use for various layers. In these systems, we assume definitive scores which may not be a true representation of the relevant physical situations. For instance, upon considering the hot spring distribution, we assumed a linear dependence of geothermal power generation feasibility with distance away from the hot spring. Based upon analysis results, we recommend the development of geothermal power generation plants in South East B.C., East-Central B.C., South-West interior B.C., and West-Central B.C.

I INTRODUCTION: DESCRIPTION OF PROJECT, STUDY AREA, AND DATA

Geothermal power generation, with its relatively high capacity factor of ~90%, is one of the few renewable energy sources capable of providing baseload power; an imperative to balance the intermittency of increasing abundance of wind and solar energy in the coming decades. Furthermore, not only does geothermal power production occur via an underground heat exchanger such that its surficial land use is minimal, its emissions of carbon dioxide are extremely low, and its levelized unit electricity cost is 5.09 cents/kWh, one of the lowest amongst all energy technologies (Hatch Energy 2008).

While Canada's theoretically attainable geothermal reserves could produce one million times Canada's current electrical consumption (Grasby et. al. 2012), there are unfortunately zero sources of geothermal electricity generation in Canada at present, owing to the high costs and risks typically associated with geothermal exploration. Furthermore, examination of a map of theoretical geothermal energy at 5km depth reveals significant gaps in heat flow measurements throughout substantial portions of B.C (Appendix F, Figure i). In an effort to alleviate such risk, we therefore seek through this study to quantify the geothermal potential of British Columbia, with the aim of investigating the most favourable areas in British Columbia for geothermal power production. We define *geothermal potential* as the relative feasibility that a particular area will be able to sustain geothermal power generation. Furthermore, for our purposes, it is a relative measure of a complex nexus of physical/geological, economic, social, and environmental factors, rather than an absolute, physical measure such as an estimate of theoretical power extraction.
In this study, we focus upon hydrothermal reservoirs: the most ubiquitous and economically feasible geothermal reservoirs (Barbier 2002), in which intrusions of magma into continental crust initiate convective circulation of groundwater. We specify several criteria that need to be met in order for an area to be classified as a potential site:

1. Bedrock geology
2. Fault density
3. Proximity to hot springs
4. Proximity to transmission lines
5. Proximity to metropolitan areas
6. Location in relation to Aboriginal reserves
7. Location in relation to National and Provincial parks

These multidisciplinary criteria encompass factors such as geology (bedrock geology, fault density and permeability, proximity to hot springs), and social, economic, and environmental considerations (proximity to transmission lines, population density and distance to population centres). For further elaboration upon the rationale for inclusion of each layer, and the relative importance of each layer in the overall weighting scheme, see appendix G.

II METHODOLOGY

We conduct a multi-criteria evaluation (MCE), in which the layers previously described are processed, reclassified, and assigned scores, then overlaid together with respective levels of influence to produce a final weighted map containing the combined information from all layers. This process is described at a general level below; for further details see the methodological flowchart of Appendix D.

Firstly, raw data for each layer is obtained from various sources, particularly DataBC, The University of British Columbia's Department of Geography G-drive, and The BC Ministry of Energy, Mines, and Petroleum Resources (see Appendix A for further details). Data from all layers is then transformed to the *NAD_1983_CSRS_BC_Environmental_Albers* projected coordinate system, and the Albers projection (an equal-area, conic projection) is employed. The Albers projection is one of three standard projections employed in BC (Resources Inventory Committee 1997), and preserves area while distorting shape and distance. We deem this to be an acceptable trade-off; while the areas of geothermal potential in our final map are important to preserve in order to allow for comparison between different favourable areas, this map is not being used for navigation, nor is the preservation of shape particularly important.

Data is then filtered for each layer in order to reduce the data volume. This is particularly important for the bedrock geology layer: while the file contains hundreds of different polygons representing rock types and sub-types, we processed the layer such that only rock types were classified in a raster layer. The rock types were then assigned a score from 1 to 5 where a higher score would represent a greater favourability for geothermal generation. For some layers, data is also inspected and cleaned. This was necessary for the hot springs layer, due to the necessity of assigning a quantitative temperature value to qualitative descriptors such as 'HOT' and 'COLD'.

At this point, analytical tools were applied to selected layers. For the power-line layer, a multiple-ring buffers was applied in order to reflect the fact that energy transmission costs increase substantially with the required transmission distance (Kimball 2010). For the fault layer, the line density tool was applied in order to attain a measure for the number of faults per unit area of 5500 m^2. This area is sufficiently small such that local variations in fault density should be apparent. For the national parks, provincial parks, and native reserve layers, a nominal scale was used; a value was assigned within the boundaries of the parks and reserves, and an alternative value was assigned for all non-park or reserve locations.

Having determined spatially extensive property maps for each layer, we clip each layer to the BC basemap, then convert the vector polygons to raster format (the latter of which is essential for the final step of integrating all layers). Each layer is then re-classified into 5 groups, and assigned a score on a scale of 1-5. It should be noted that this is an ordinal scale, seeing as the boundary between each score number is arbitrarily determined.

Finally, we apply the ‘Weighted Overlay’ tool, an implementation of a weighted linear combination (WLC). As input for this tool, each layer is assigned a weight (Appendix B) based upon a subjective judgement of which layers are most relevant in terms of geothermal potential. It is conceivable that different entities have different priorities with respect to emphasis upon physical, social, economic, or environmental factors (eg. provincial energy planners vs. utility executives vs. environmental activists, etc.). For each layer, all scoring raster cells are multiplied by this weighting factor, then summed over all layers, creating a final, composite, weighted map incorporating the scores from all layers under consideration. Different weighting schemes are then experimented with, providing three favourability maps corresponding to the following three ‘prioritization scenarios’ (Appendix F, Figures xii-ix):

a) Scenario 1: Prioritization of geological factors (fault density, bedrock geology, hot springs)
b) *Scenario 2:* Prioritization of socio-economic factors (transmission lines, proximity to metropolitan centres)
c) Scenario 3: Balanced prioritization (compromise between Scenarios 1 and 2)

III RESULTS AND DISCUSSION

The resulting three maps are composite raster layers showing the most suitable areas for geothermal energy extraction for all of British-Columbia. The study is useful for a regional analysis of geothermal potential, but would require further refinement and the consideration of other local factors such as topography in order to investigate at a larger scale (see Limitations, Errors, Uncertainty, and Improvement below for more details.) To maintain optimum accuracy of the model, the maps have not undergone post-processing such as smoothing, or conversion to polygon vectors, although this does come at the cost of map aesthetics. While this may make for a less presentable map, loss of accuracy in the result is deemed to be more important. The resolution of one cell is approximately 30 km^2, which is larger than the required footprint of geothermal energy production plant. And while the study is more significant at a regional level, it is still valid to retain the best level of detail obtained from the model.

In scenario 1 (Appendix F, Figure xii), which prioritizes the geologic factors of fault density, hot springs, and bedrock geology over socio-economic factors, there are four main regions of highest favourability. These four sites, in approximate decreasing order of areal extent, are located in Central-Western BC (East of Smithers), South-Eastern BC (~100km West of the Alberta border), South-Western BC (around the Northern border of the Lower Mainland), and Eastern BC (~150km West of the Alberta border, North of Prince George). These most favourable areas do not, for the most part, coincide with National/Provincial Parks nor with First Nations Reserves, such that construction of geothermal infrastructure at these sites is at least permissible, if not necessarily economical. Each of these areas is also surrounded by an annulus of moderate favourability. In addition to this, the majority of Vancouver Island is also moderately favourable. Slightly favourable regions are concentrated towards the West Coast, forming a broad swath of ~50-100km along the coast, in addition to regions in central and Eastern BC. Finally, regions of least favourability are concentrated in North-Eastern BC.

In scenario 2 (Appendix F, Figure xiii), we consider social and economic factors that could either support or inhibit the development of geothermal power production sites. The main factors considered here are locations of transmission lines and high population density metropolitan areas. Our results show that nearly all of northern BC and a portion of Western BC fall in the least favourable zone, while the rest of BC ranges from slightly to most favourable, with the most favourable areas being most concentrated in the central and southern portions of the province. In contrast to the map corresponding to scenario 1, the regions of highest favourability are very strongly constrained by the spatial distribution of power lines (Appendix F, Figure vii); a fact even more apparent upon comparison with the map displaying proximity to power lines (Appendix F, Figure viii).

Scenario 3 (Appendix F, Figure ix) weights both socio-economic and the geologic layer, in an attempt to balance these considerations. As a result, the distribution of favourability zones fall somewhere in between the zones observed in scenarios 1 and 2, though much closer to scenario 1. The high weighting of power lines in scenario 2 partially carries over to scenario 3; most of the moderate and high favourability regions are proximal to the powerline distribution layer (Appendix F, Figure vii). However, the higher weighting of geologic features, which exhibit significant variation on a local scale (Appendix F, Figure ii) results in a favourability map that has somewhat less cohesive favourability zones (ie. zones of high and moderate favourability are not as homogeneous as in scenario 2). Also notable is the fact that the most favourable zones coincide with zones of highest fault density (Appendix F, Figure iv). Therefore, zones of higher fault density, of appropriate geology, and proximal to power lines are typically the regions considered most favourable for geothermal development (see the Victoria region, South-East B.C., and regions of Central B.C.) Meanwhile, zones proximal to metropolitan centres (Appendix F, Figure) do not strongly coincide with the zones of highest favourability in scenarios 1 and 3. Similar to scenario 2, there is a large, mostly low favourability zone in North-Western B.C.

Significantly, the four areas of highest potential most noticeable in scenarios 1 and 3 are also high in scenario 2. This comparison provides another level of focus for the identification of potential areas where geothermal energy generation could be more successful. The ideal areas of focus would be the ones that consistently maintain a high favourability, even when criteria are changed to suit different positions, as is to be expected given the political reality of a continually changing regulatory environment. In the case of this evaluation, the four regions near Terrace, Prince George, Cranbrook, and Kamloops are the most interesting, constantly ranking high on the three selected scenarios. In each area we find appropriate rock type, high enough fault density, a presence of hot springs, a close proximity to power transmission lines, and a reasonable distance to urban areas where power can be consumed.

Our investigation of feasible geothermal power production sites involves combining several layers in ArcGIS to account for geological, environmental, social, and economic factors affecting feasibility. Our results show a wide range of results, which are highly dependent upon the factors taken into account. An observation common to all scenarios is that the majority of southern BC and parts of eastern, central, and southern BC are of either most or moderately favourable, forming a three-sided ‘ring’, with a notable low favourability zone on the remaining side (consisting of the region spanning the few 100s of kilometres north of Vancouver Island) and inside this ring. In addition, for all scenarios, it is fortunate that national/provincial parks and Aboriginal reserves (Appendix F, xi) do not typically overlap with zones of highest favourability; however, they do constrain prospects for construction of geothermal power facilities in a limited extent of the moderately favourable zones. Meanwhile, most of northern BC can be categorized as low favourability for power production, consisting mostly (scenario 1) and almost entirely (scenarios 2 and 3) of only somewhat favourable and least favourable zones. This can be explained by low population densities and large distances from transmission lines (Appendix F, Figure x).

When geologic factors are considered most important, as in scenario 1, zones of high favourability shift away from the highly-populated Lower Mainland and interior regions, and towards the more geologically favourable central and northern regions of the province. In scenario 2, which emphasizes economic criteria, the most favourable regions are strongly correlated with power line distribution. This makes sense, given the farther away from existing transmission lines the plant is built, the more transmission line infrastructure must be built. For scenario 3, there is as expected compromise between scenarios 1 and 2, given its balanced weighting between geological and socio-economic factors. This is illustrated by the fact that while geologic features pull the areas of greatest feasibility towards the East, West, South-East, and South-West regions of BC, the general power line distribution is also evident. Therefore, the analysis shows that a geothermal power plant would be best located, overall, in one of these regions.

IV LIMITATIONS, ERROR, UNCERTAINTY, AND IMPROVEMENTS

Due to limitations in access of data, some information that would allow for a better assessment was not included in our analysis, and shall now be elaborated upon.

In terms of geological factors, the most significant limitation of the analysis is lack of consideration of temperature gradient, which determines the amount of power that can be physically extracted by a given geothermal power plant. Temperature gradient describes the rate of change of temperature with depth, and can be converted to heat flow via Fourier's law of heat conduction. A larger temperature gradient indicates the presence of hotter source rock, and hence a more favourable locale for geothermal power production. While typical crustal temperature gradients range from 20-30°C km^{-1}, temperature gradients of 100°C km^{-1} and greater are typical for regions considered as viable for geothermal power production. Unfortunately, an accessible source of temperature gradient data was not found to be available. Incorporating heat flow and temperature gradient information into our map would be a vital next step. This information is extremely important in determining sites suitable for geothermal power development, with the potential to change our final favourability maps substantially.

Regarding hot springs, it is worth noting that to generate an expression of the hot springs on our map, we arbitrarily created, via a multiple-ringed buffer, a 'region of influence' of approximately 60 km diameter over each hot spring. However, given that they were provided as points in our input data set, While the density values are reflective of the respective temperatures, their footprint is not quantified but implies that the source of heat at depth is much larger than its manifestation at the surface. Additionally, the file obtained from the Department of Energy and Mining website did not have a set coordinate system. Trial and error with different coordinate systems and projections produced a satisfactory result with known locations of certain hotsprings. Because we processed the data in such a way that an arbitrary footprint was created, the small uncertainty in the exact location of the data point in negligible for the purpose of this study.

Another geological factor relates to our use of fault density. While our calculated fault density is a proxy for the ease with which hydrothermal fluids can flow from depth to the surface, spatially extensive, quantitative measurements of hydraulic permeability (and therefore fluid flow velocity) would determine whether the thermal energy stored in hydrothermal fluids at depth can actually reach the surface and be usefully extracted to produce energy. Furthermore, topography which was not considered as part of this analysis, as well as borehole data from nearby mine sites which could provide temperature at depth.

Regarding environmental factors, additions can be made to our environmental analysis of BC. For example, one could more widely consider environmental and ecosystem impact, such as by accounting for densely forested areas and habitation areas of wild animals (especially those near extinction). Another significant environmental factor is access to water, and therefore proximity to bodies of water such as rivers and lakes: a necessity, since water is the medium for heat transfer. Therefore proximity to water should be a factor when looking at a larger scale map. For the scope of this study, water was not considered because it is relatively ubiquitous throughout British-Columbia at the scale of this study.

Economically, an aspect lacking from our study is the consideration of data from the neighbouring province of Alberta and the territory of Yukon. This could present a gap in our analysis if, for instance, Alberta possessed some transmission lines close to its Western border, that could used by BC. A more comprehensive study would therefore extend certain layers to include power infrastructure and Alberta and Yukon.

V CONCLUSIONS: RECOMMENDATIONS AND FURTHER RESEARCH

Having summed the contributions from geologic, environmental, and socio-economic factors, our Multi-Criterion Evaluation quantitatively determines the geothermal potential of BC, over a variety of scenarios in which the weighing of these factors is varied. It is found that, irrespective of scenario, the majority of southern BC and parts of eastern, central, and southern BC are either of *high favorability* or *moderate favourability*. Meanwhile, the vast majority of northern BC, in addition to a smaller zone -from the west coast over the few 100s of kilometres north of Vancouver Island, to central BC- can be categorized as only *somewhat favourable* and *least favourable zones*. We therefore recommend the commencement, at minimum, of systematic drilling and geophysical surveying in the high favourability regions: this occurrence of high favourability is largely concentrated in four regions, each approximately ~100km in extent, which are proximate to the cities of Terrace, Prince George, Cranbrook, and Kamloops.

The three scenarios, in conjunction with the maps of individual layers provided within this report, offer a way to qualitatively interpolate to alternate scenarios not run in our model; for instance, an engineering manager tasked with identifying sites of greatest potential power production, but for whom social factors such as the labour pool available to work at the production facility (which is proportional to the distance to urban centres) is still a matter of consideration. While error is inevitably incurred due to the necessity of making arbitrary estimations of the value of each factor used in the study, we have sought to provide a starting point for those interested in what the province of BC can offer with respect to its potential for geothermal energy extraction. Different projects have different factors that influence their feasibility. For example, a project that would propose an enhanced geothermal system (EGS) for energy production would be less reliant upon a high density of natural fault systems because EGS systems use hydraulic fracturing to increase the permeability of the the rock. Furthermore, because of the risks and consequences associated with EGS and hydraulic fracturing, proximity to urban areas is not as necessary as for the hydrothermal resources examined in this study (Grasby et. al., 2012). Seeing as proximity to urban areas imposes a limitation on potential geothermal sites, future study of geothermal potential with respect to enhanced rather than hydrothermal systems would substantially increase the area of favourable sites, and thus warrants further study.

VI APPENDICES

A) Classification of layers with corresponding data type, source, and weights

Data name	Raw Data type	Data Source	Weighting Fractions (Scenario 1: Geology)*	Weighting Fractions (Scenario 2: Socio-economics)**	Weighting Fractions (Scenario 3: Balanced)***
Bedrock geology	Vector	BC Ministry of Energy, Mines, and Petroleum Resources	0.2	0.1	0.15
Faults	Vector (lines)	BC Ministry of Energy, Mines, and Petroleum Resources	0.4	0.15	0.3
Hot springs	Vector (points)	BC Ministry of Energy, Mines, and Petroleum Resources	0.15	0.05	0.1
Transmission lines	Vector (lines)	UBC Department of Geography: G-drive	0.15	0.45	0.3
Metropolitan areas	Vector (polygons)	BC Government data (DataBC catalogue website)	0.1	0.25	0.15
National and Provincial Parks	Vector (polygons)	BC Government data (DataBC catalogue website)	N/A	N/A	N/A
Aboriginal Reserves	Vector (polygons)	BC Government data (DataBC catalogue website)	N/A	N/A	N/A

*Scenario 1: Geological factors are prioritized, including fault density, bedrock geology, and hot springs. This is a more theoretical scenario, assuming that long transmission distances and long distances from population centres are not an insurmountable obstacle to implementation of geothermal power.

**Scenario 2: Socio-economic factors are prioritized, including transmission lines and proximity to metropolitan centres. This is a heavily practical scenario, assuming that the feasibility of power distribution is far more determinative of geothermal potential than geological constraints.

***Scenario 3: Both geological and socio-economic factors are considered; this is an intermediate scenario between Scenarios 1 and 2, assuming fault density and proximity to transmission lines to be the most important factors affecting geothermal potential, with bedrock geology, hot springs, and proximity to metropolitan areas being of secondary importance.

B) Weighting Score Tables

i) Bedrock Geology

Score	Rock Type	Qualitative Description
1	Ultramafic	Least Favourable: Least likely indicator of high heat flow
1	Unknown	
2	Volcanic	
2	Metamorphic	
3	Sedimentary	
4	Volcanic & Sedimentary	
5	Subvolcanic Intrusive	Most Favourable: Most likely indicator of high heat flow

ii) Fault Density

5 Categories based on Natural Breaks where 1 is least dense, and 5 is the most dense.

Score	Fault Density	Qualitative Description
1	(Determined by natural breaks)	Least Favourable: Lowest density of faults per unit area
2	‘’	
3	‘’	
4	‘’	
5	‘’	Most Favourable: Highest density of faults per unit area

iii) Hot Springs

In the TEMP field, most entries had a ˚C value but a few (8 values) had a qualitative entry (Hot or Warm). Using Field Calculator, the values of *Hot* where changed to 80˚C and *Warm* to 30˚C. 109 entries have no temperature data associated. The value was set to zero, so that they are plotted, but are not incorporated into the weighted overlay.

Score	Hotsprings	Qualitative Description
1	<20 ˚C	Least Favourable: Cold
2	20-40 ˚C	Cool
3	40-60 ˚C	Warm
4	60-80 ˚C	Very Warm
5	> 80 ˚C	Most Favourable: Hot

iv) Transmission Lines

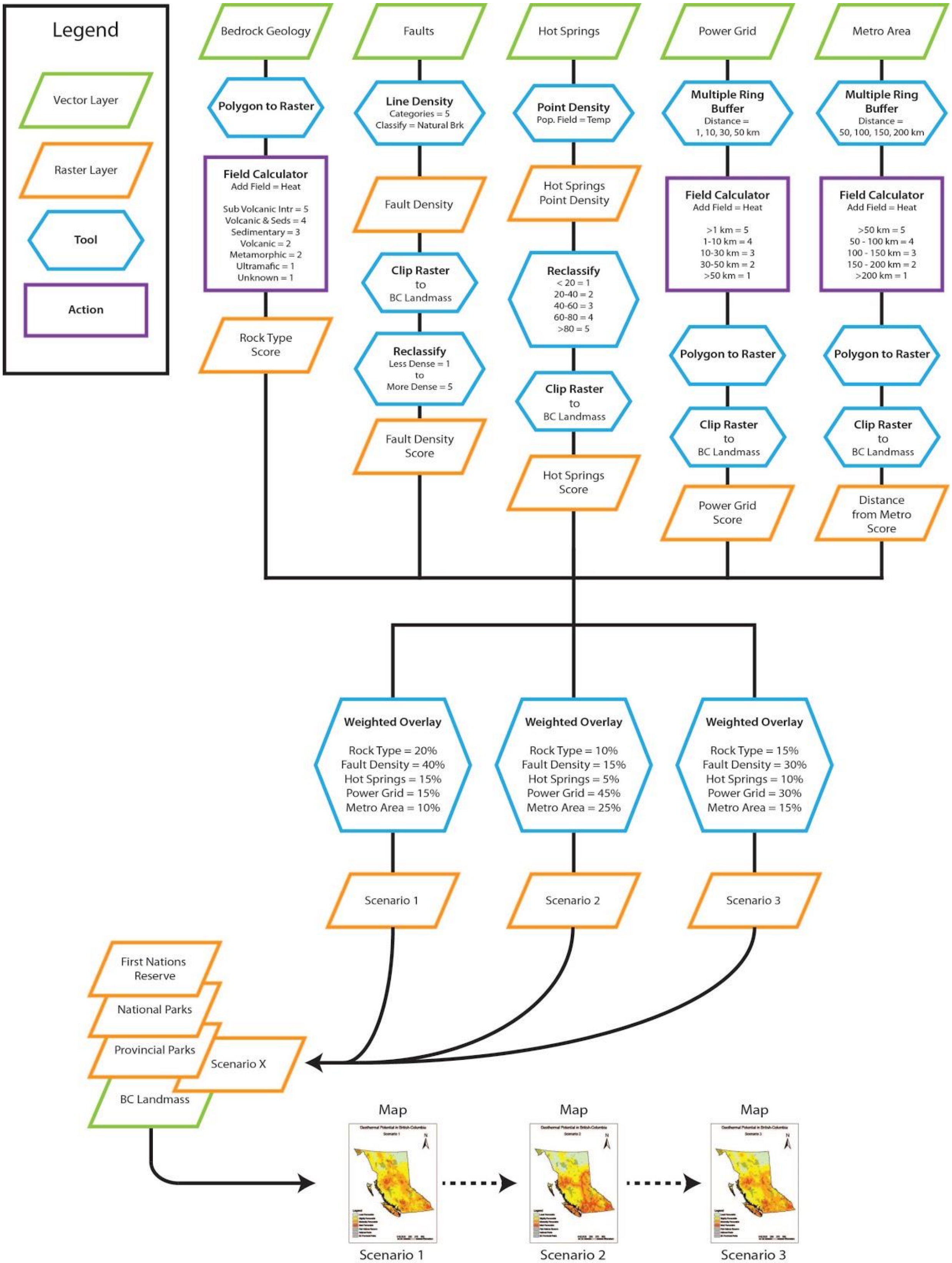
Data files for the transmission lines were found in the UBC Geography G: Drive as vector lines for transmission lines. Each segment of the complete transmission line was grouped and merged to form one layer with the complete network.

Score	Distance from Transmission Lines	Qualitative Description
1	>50 km	Least Favourable: Lowest proximity to transmission lines
2	30-50 km	
3	10-30 km	
4	1-10 km	
5	< 1 km	Most Favourable: Highest proximity to transmission lines

v) Proximity to Metropolitan Centres

Score	Distance to Metropolitan Centres	Qualitative Description
1	>200 km	Least Favourable: Low proximity to metropolitan centres
2	150-200 km	
3	100-150 km	
4	50-100 km	
5	<50 km	Most Favourable: High proximity to metropolitan centres

D) Methodology Flowchart



E) References

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Yousefi, H., Noorollahi, Y., Ehara, S., Itoi, R., Yousefi, A., Fujimitsu, Y., et al. *Developing the geothermal resources map of Iran*. Geothermics. 39. 2010. 140-151. <http://www.sciencedirect.com/science/article/pii/S0375650509000698>. Web. Accessed November 25th, 2016.

F) Maps

i) Estimated Theoretical Geothermal Energy at 6.5km Depth in Canada

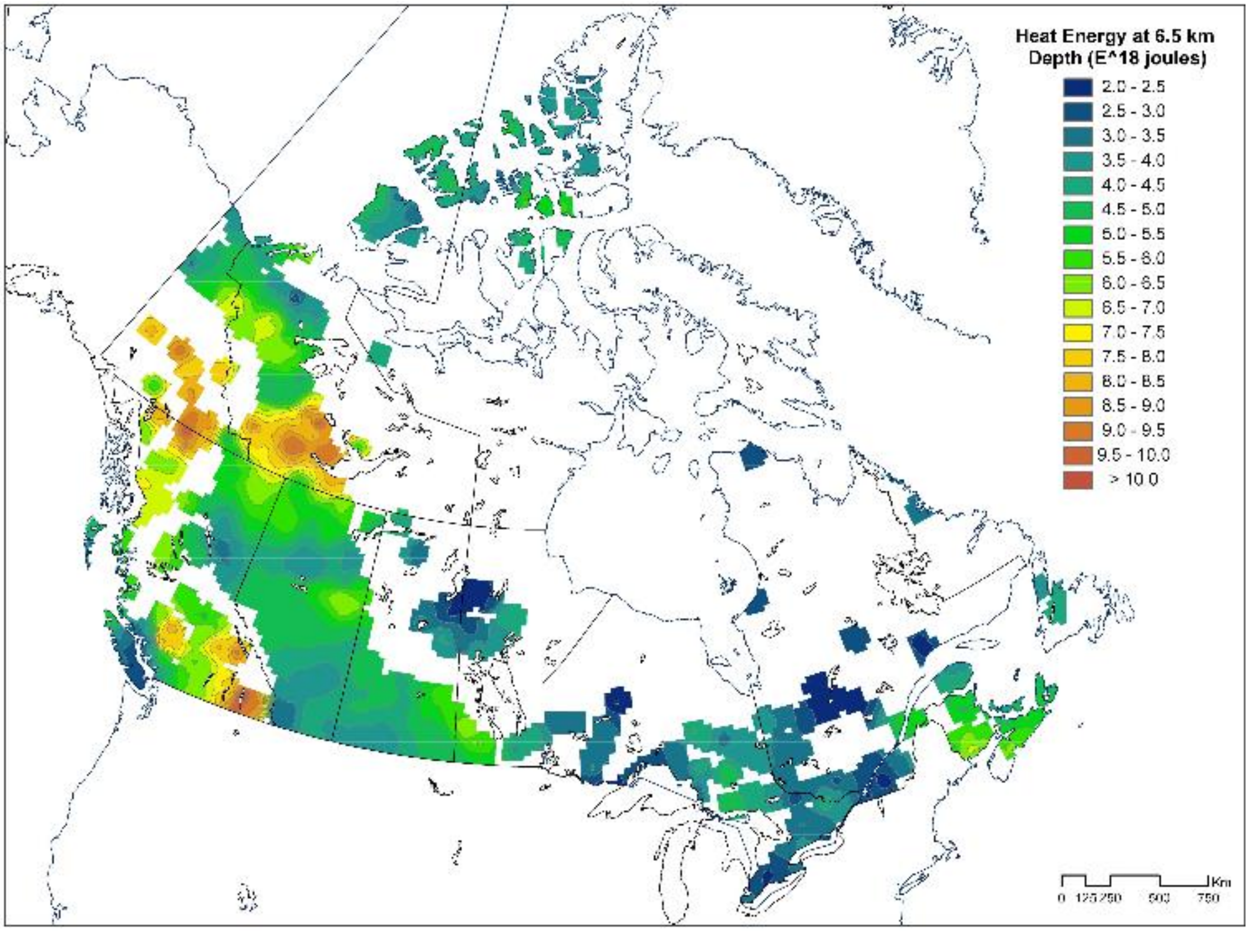
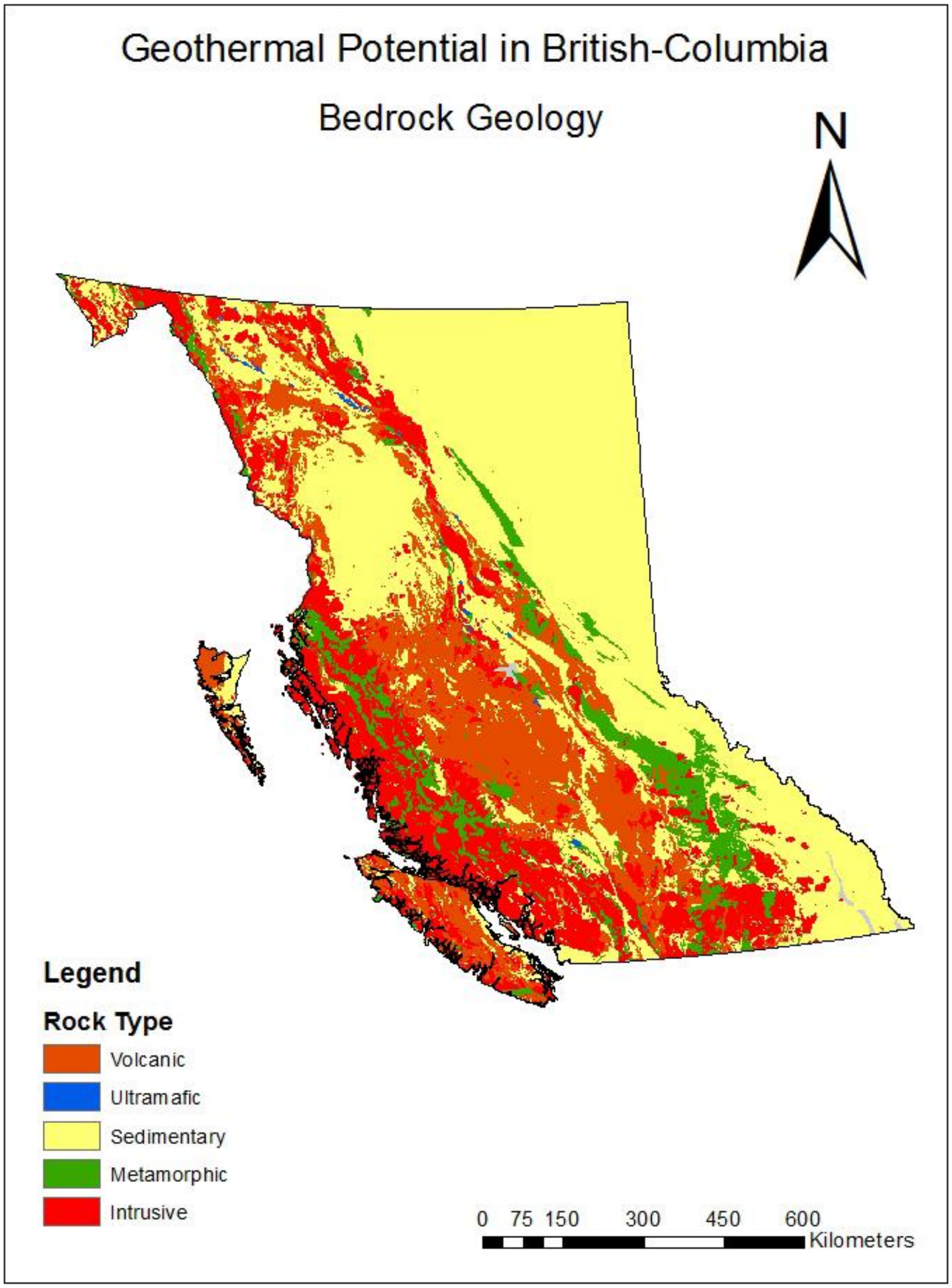
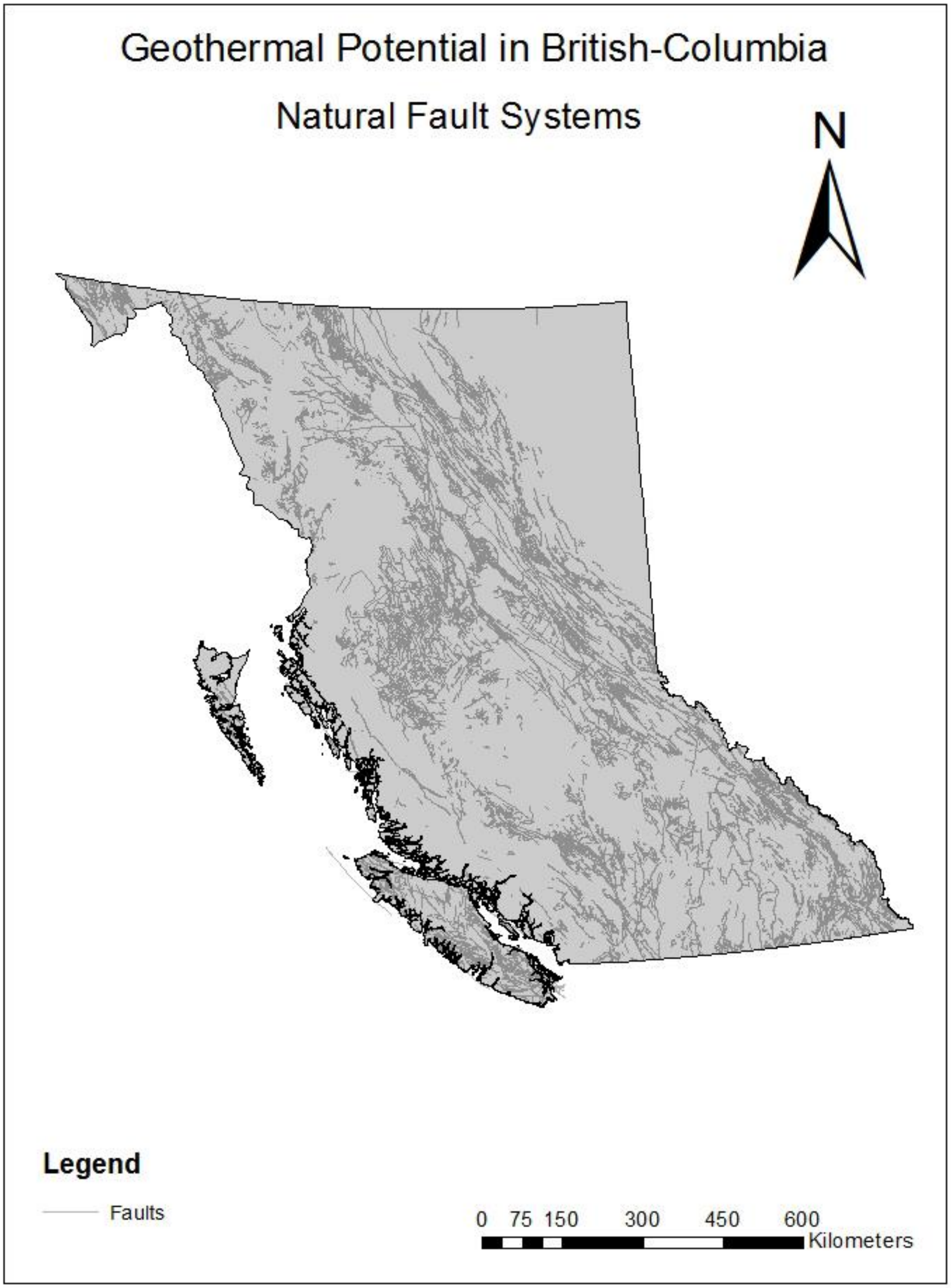


Figure 1 from Grasby et. al. (2012): Map showing the estimated in-place geothermal energy at depths of 6-7km across Canada. Note that this energy is similar to that found in shallower and deeper bands.

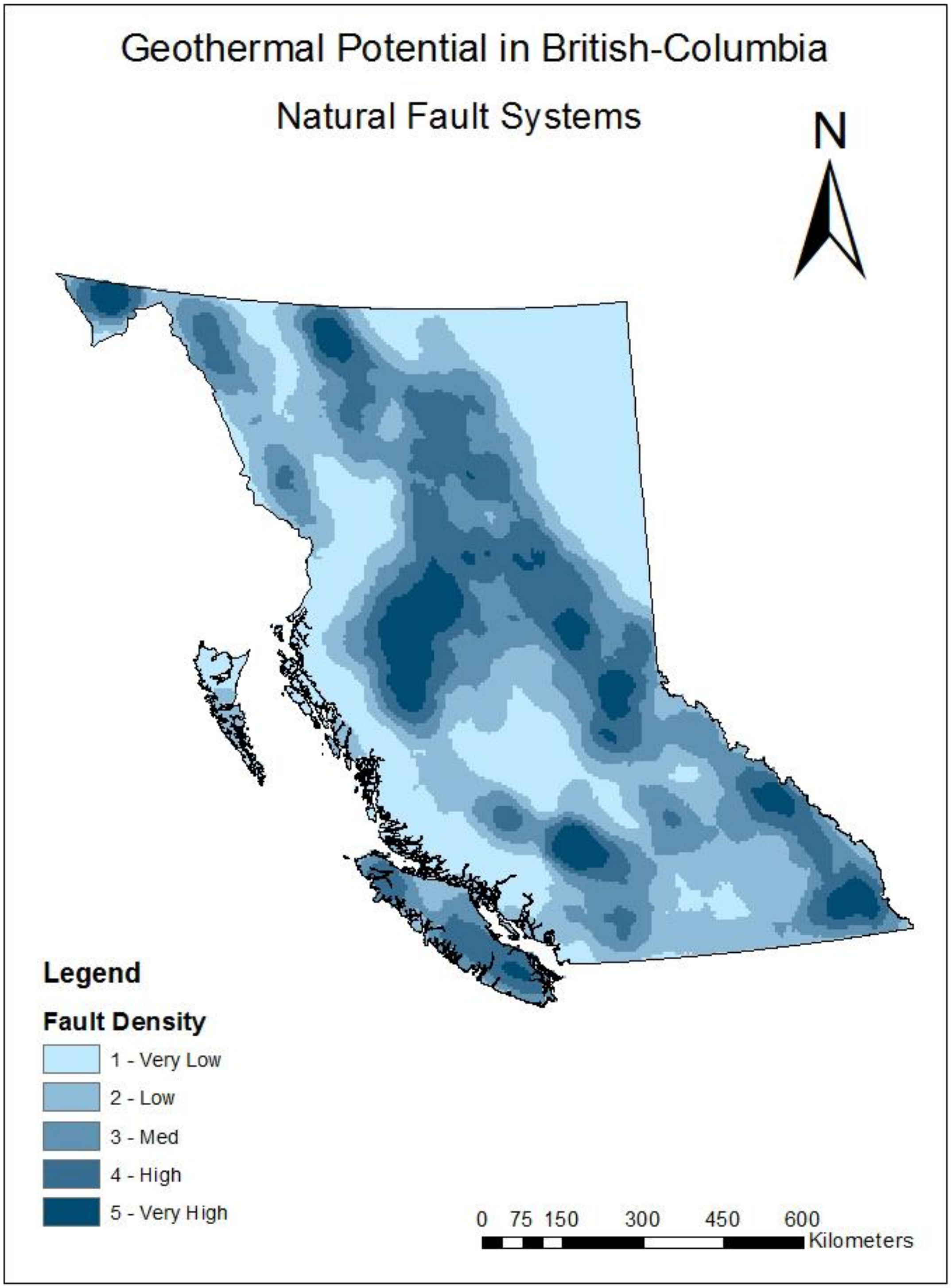
ii) Bedrock geology



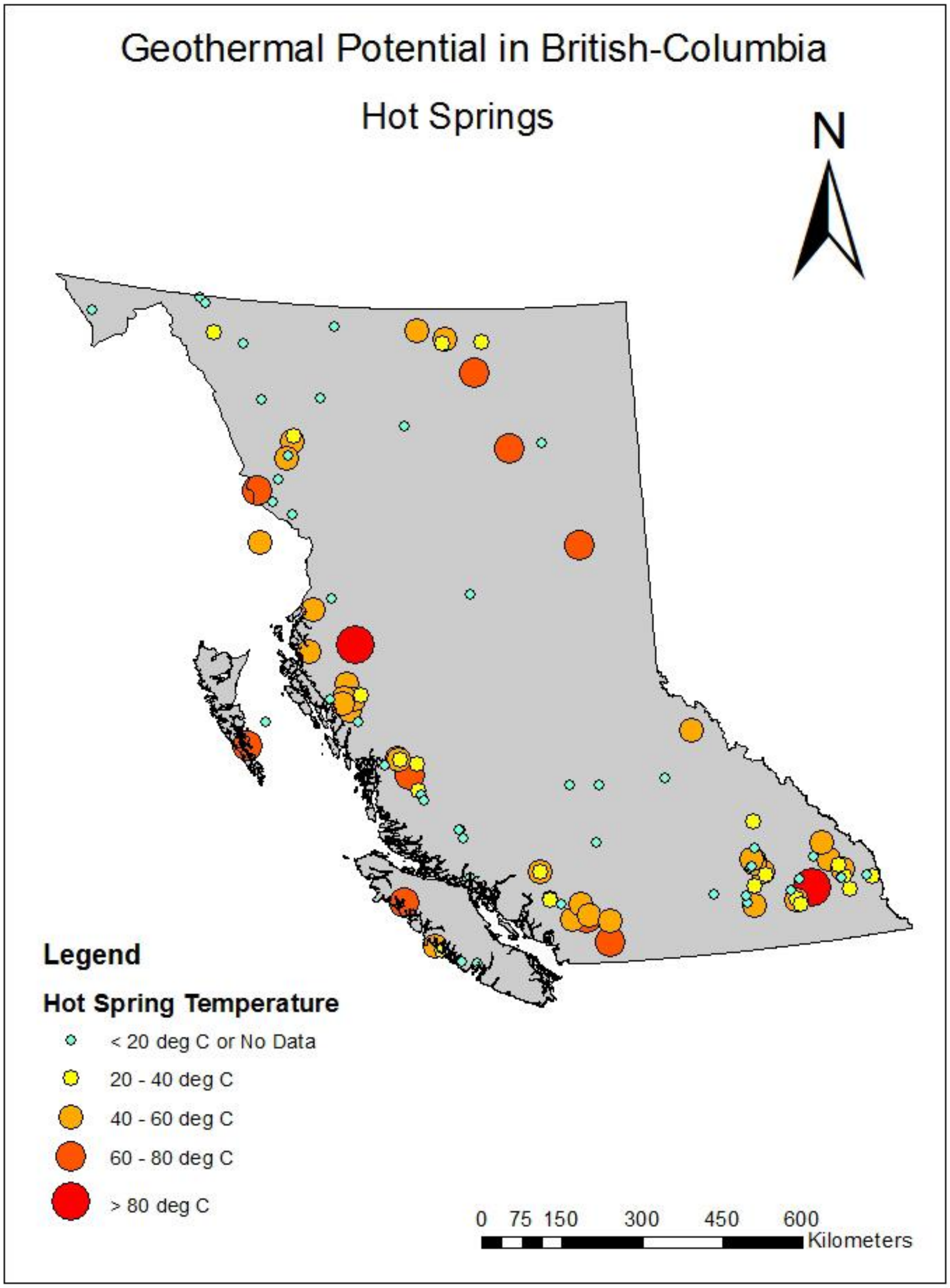
iii) Natural fault systems



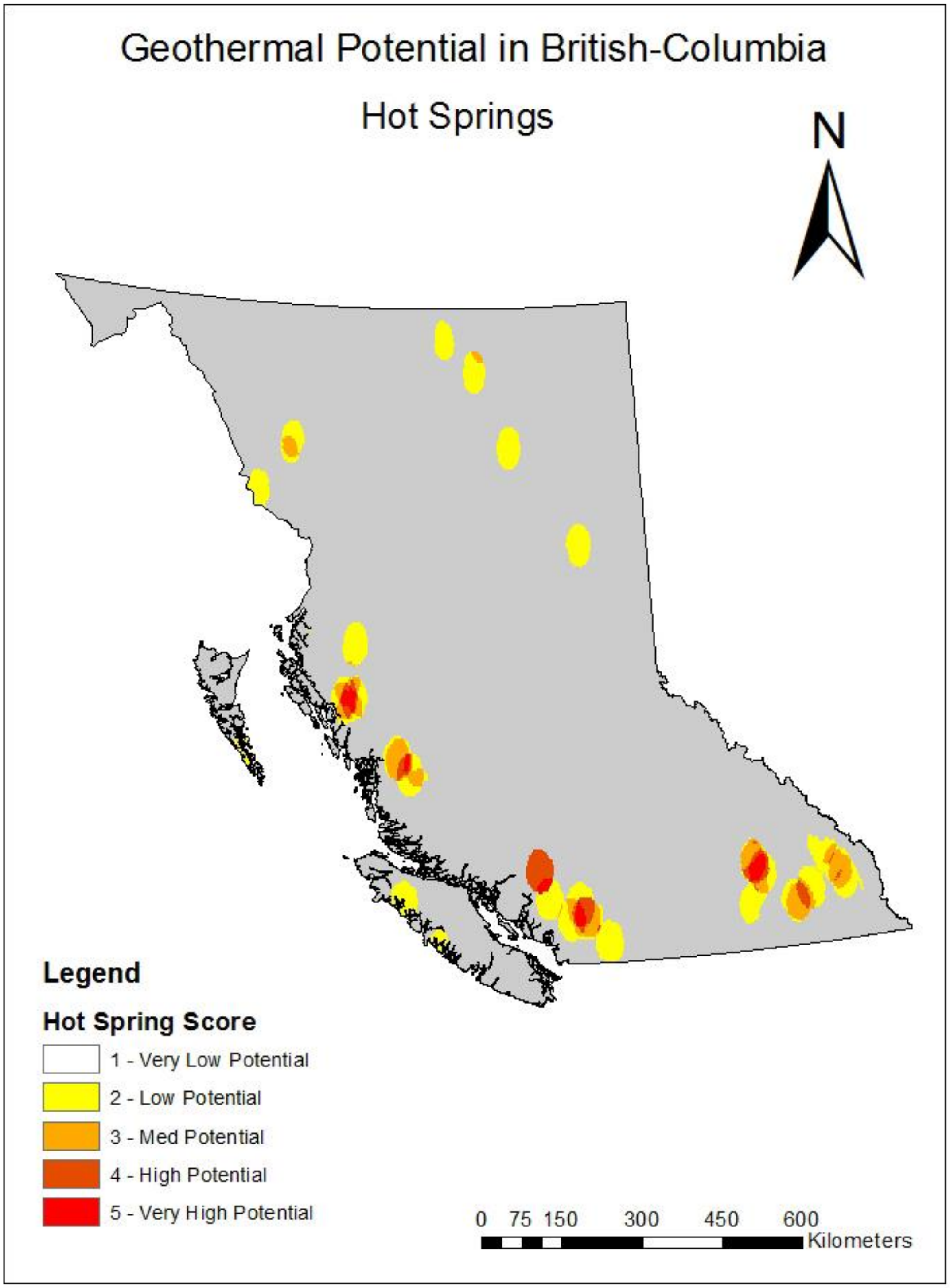
iv) Line Density of Natural Fault Systems



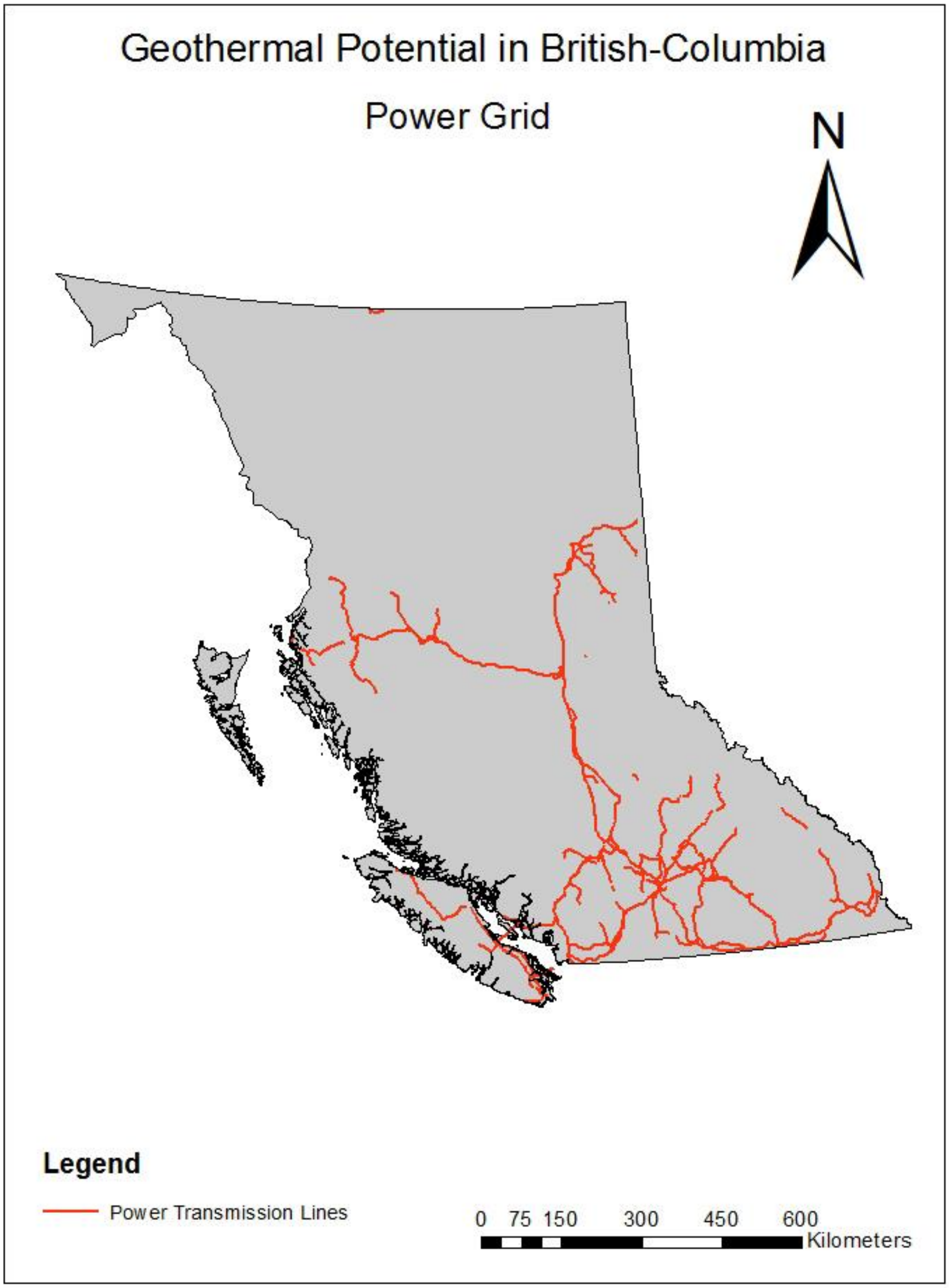
v) Location and Temperature of Hot Springs



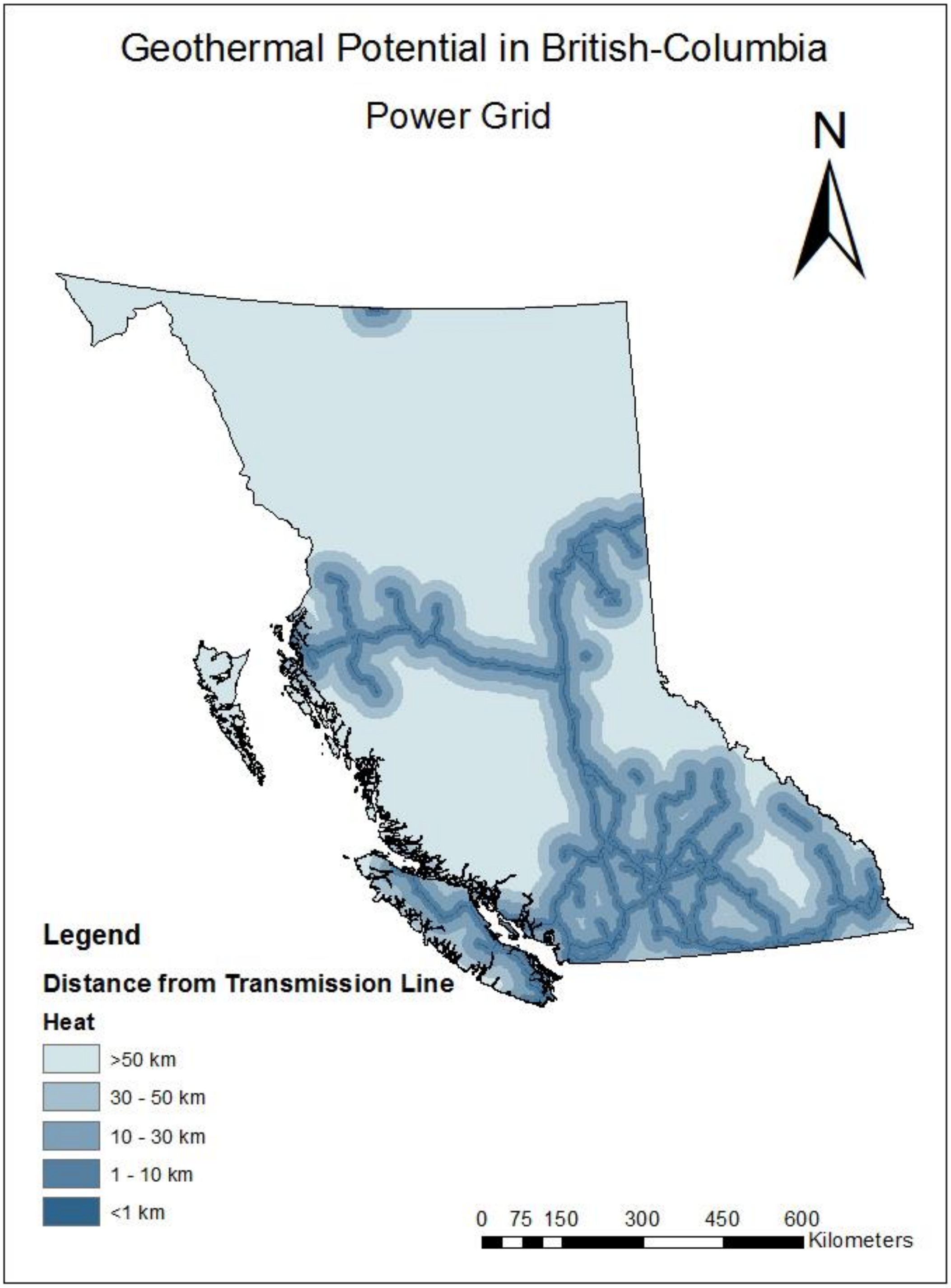
vi) Temperature-Dependent Point Density of Hot Springs



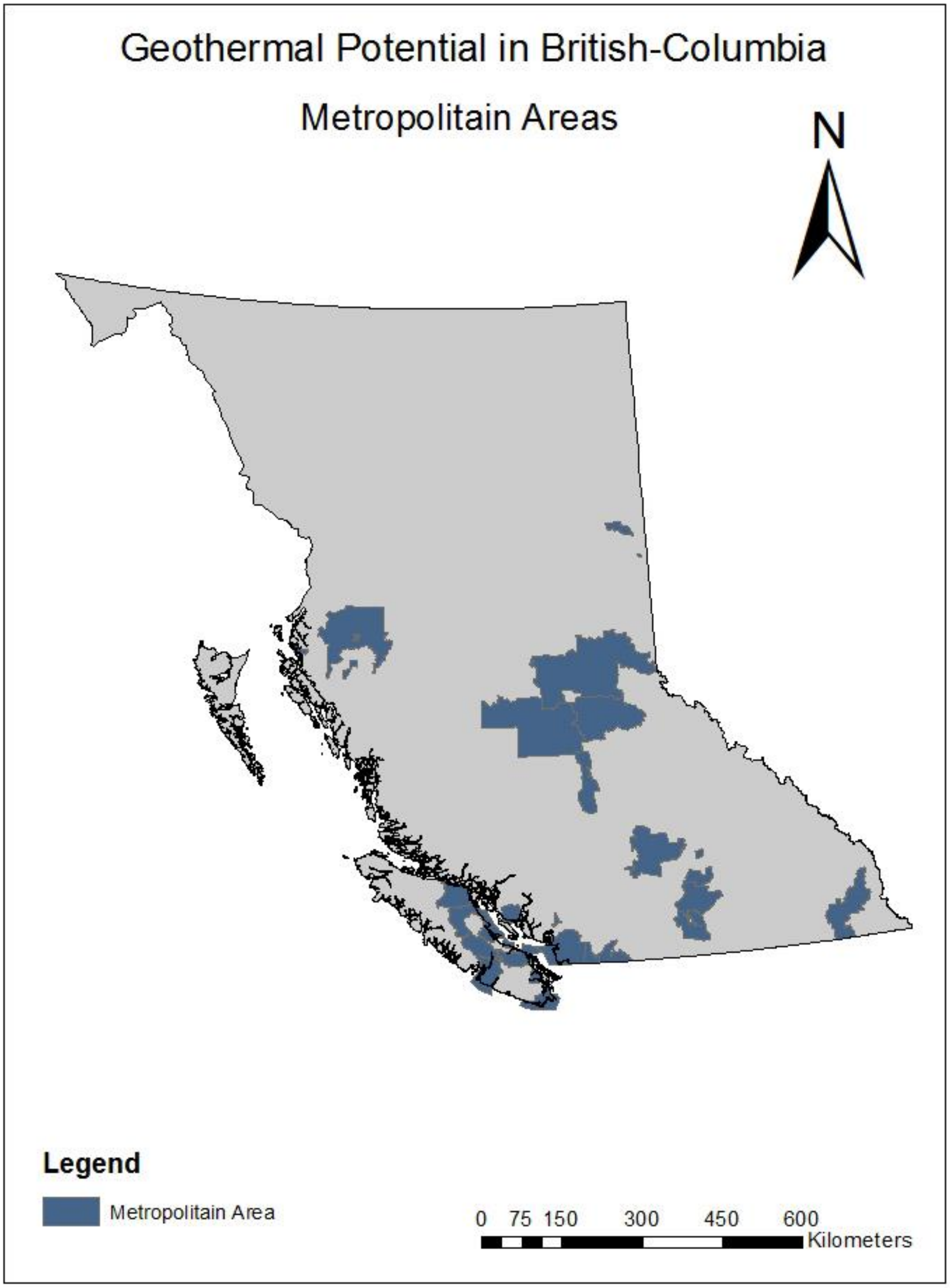
vii) Power Grid: Transmission Lines



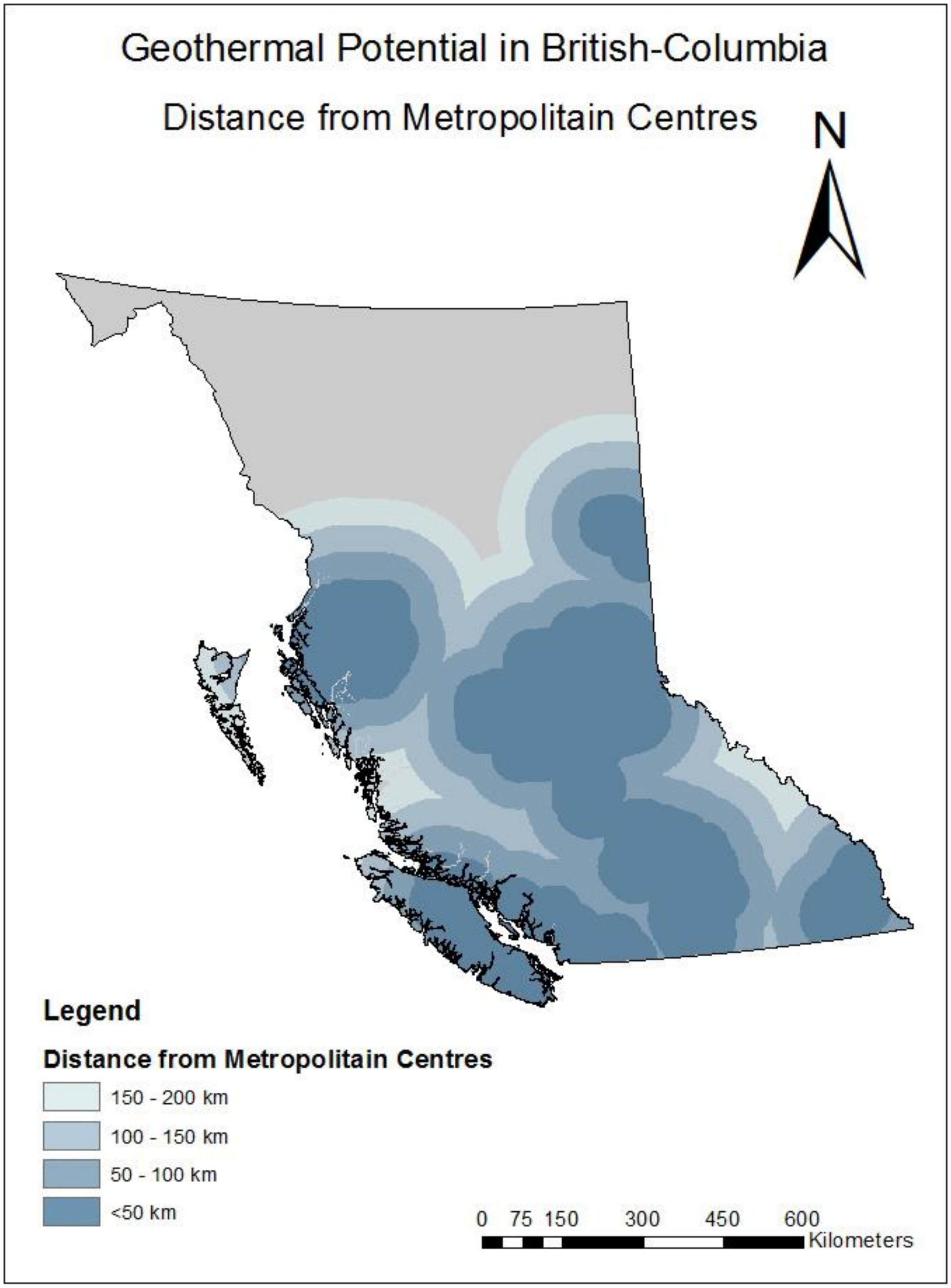
viii) Power Grid: Proximity from Transmission Lines



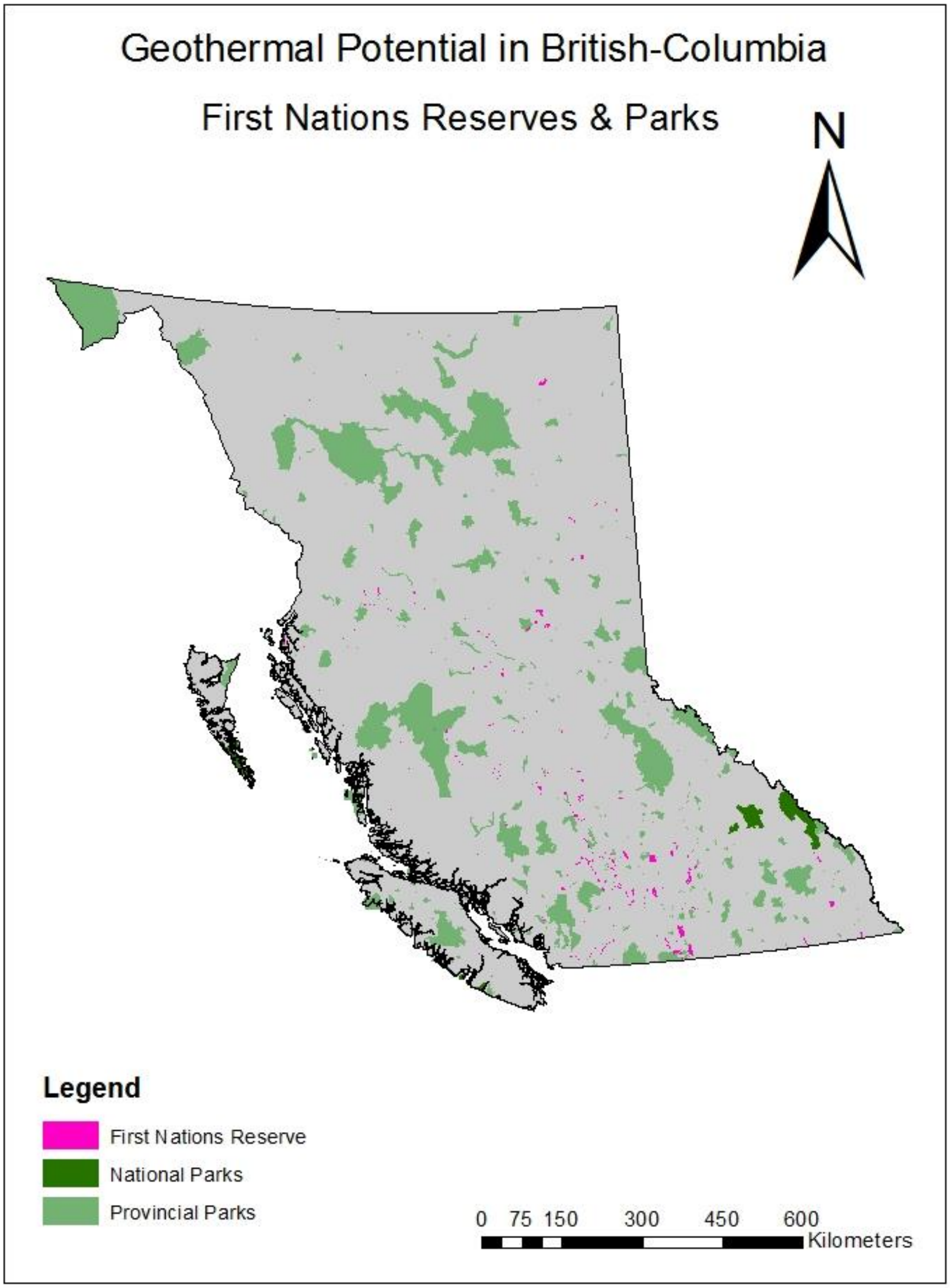
ix) Metropolitan Centres (Census tracts with populations of >50,000)



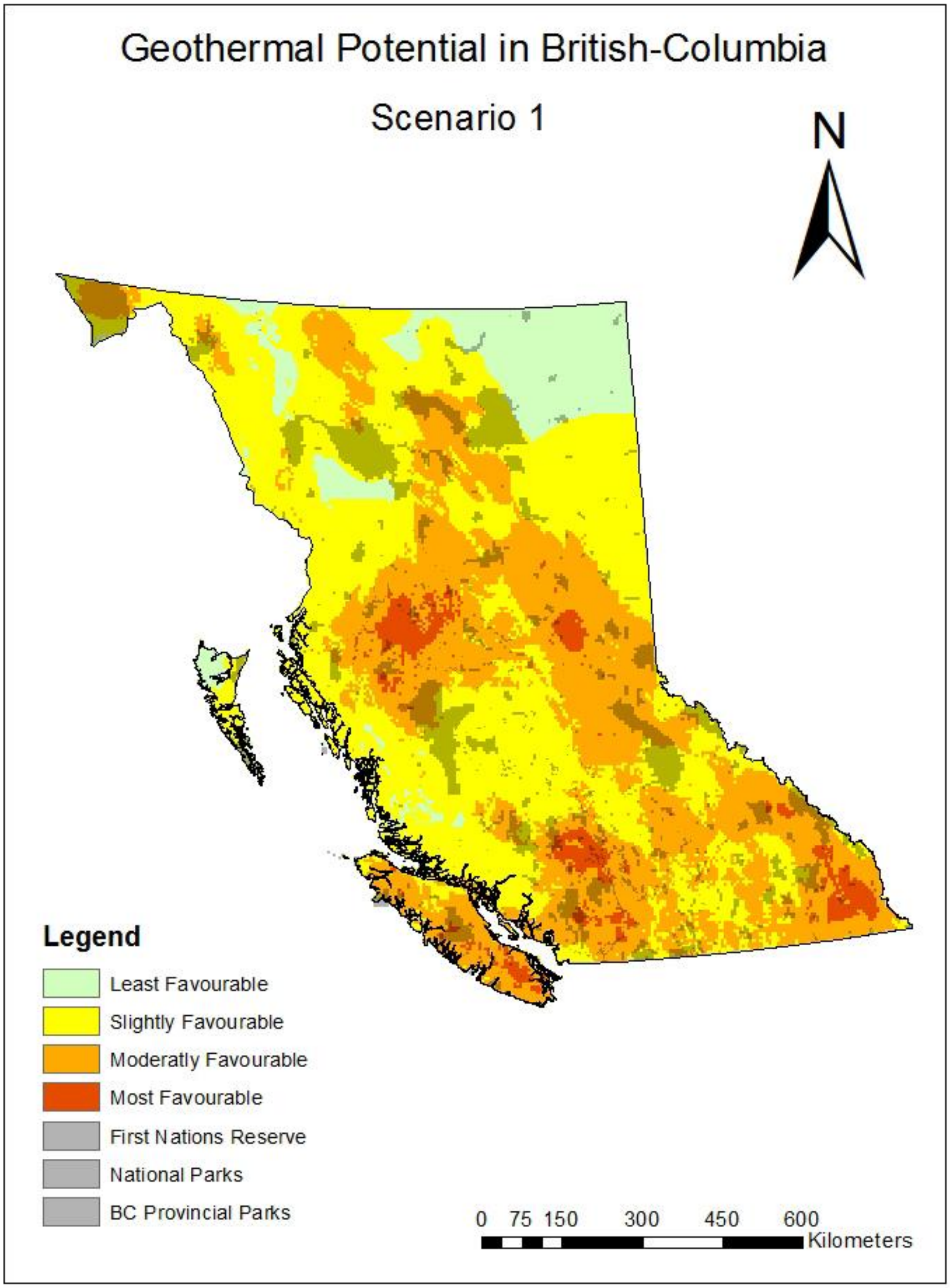
x) Proximity to Metropolitan Centres



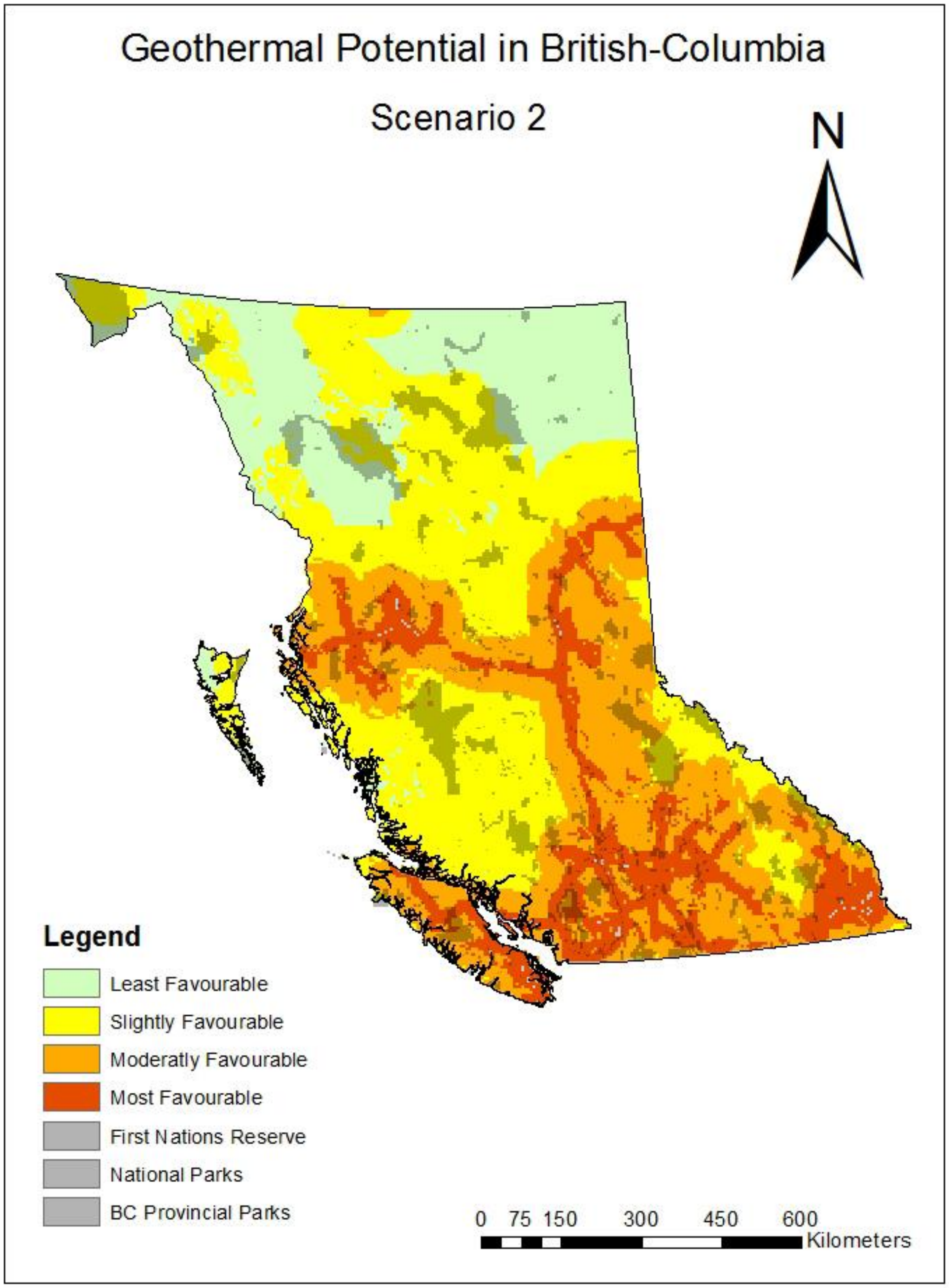
xi) First Nations Reserves and Provincial and National Parks



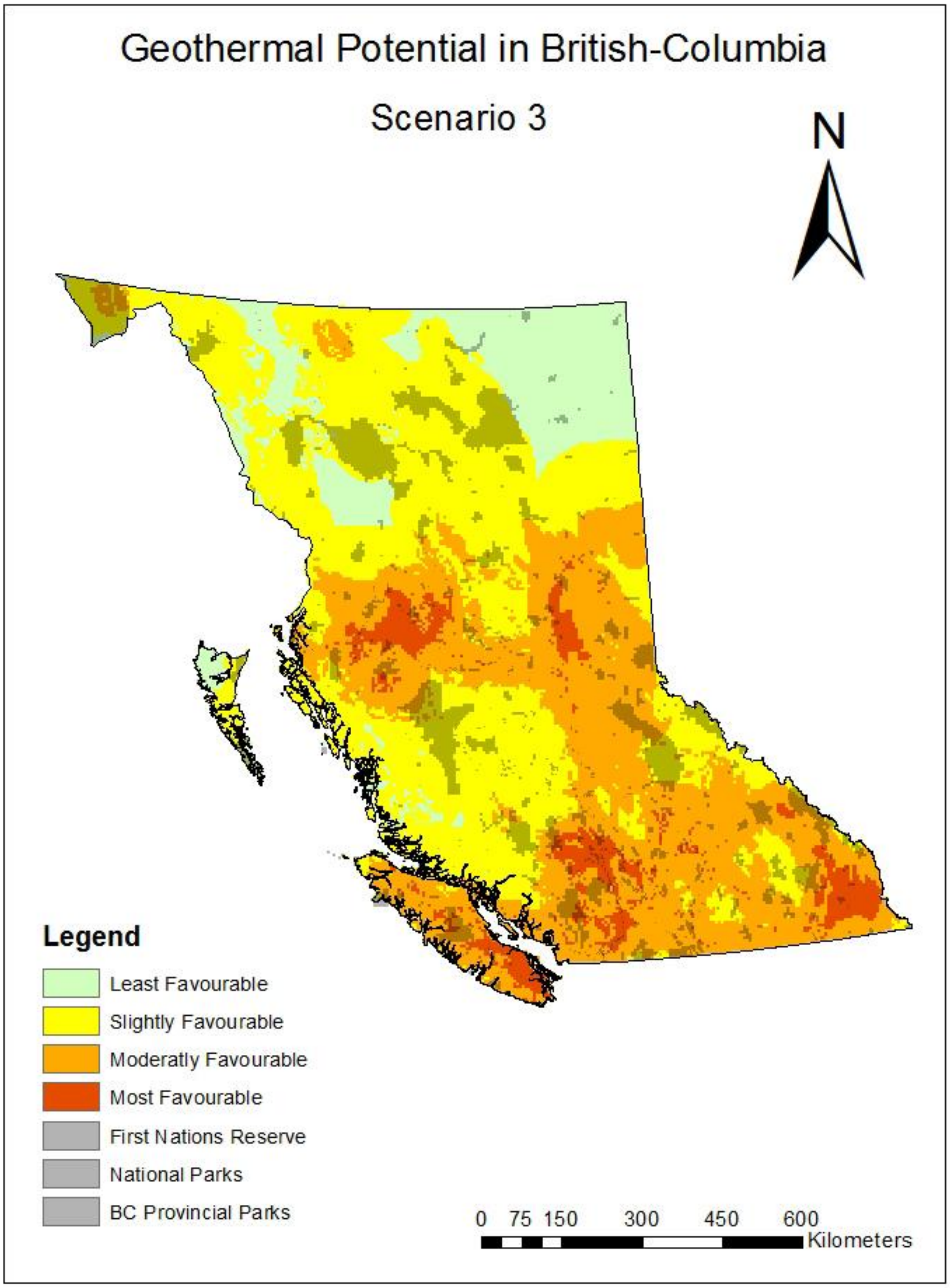
xii) Weighted Overlay: Scenario 1 (Geologic Prioritization)



xiii) Weighted Overlay: Scenario 2 (Prioritization of Socio-economic Factors)



xiv) Weighted Overlay: Scenario 3 (Balanced Prioritization)



G) Description of Criterion and Rationale for Weighting Scheme (ordered from greatest to least weight accorded in Scenario 3):

1) **Bedrock geology** may influence of geothermal potential; in particular, younger plutonic rocks may still retain heat in the shallow crust. Igneous intrusive bodies such are great heat conductors but require a dense network of fractures in order to allow groundwater to circulate through and absorb heat. Sedimentary basins are also of interest due to their high level of porosity and permeability and are less dependent of fault networks. Additionally, sedimentary rocks have a greater abundance of naturally occurring radioactive elements which generate heat. Volcanic rock hold a certain significance because they are located near volcanic edifices, however their extrusive nature do not imply a source of heat. Metamorphic rocks are hard and difficult to drill with usually less fracturing, and are less desireable for this purpose. In general, most rock regardless of their type become hotter with depth, hence the type of rock is less trivial than faults. (Erdlac, 2008)

2) **Geologic faults** are natural complex networks of fractures in rock caused by physical stresses such as tectonic plate movement, isostatic rebound, and volcanic activity. This system of interconnected fractures provides conduits for fluid flow, and consequently the hydraulic permeability necessary to circulate fluids of sufficiently high temperature for economic energy extraction (Coolbaugh et. al. 2005). Faulting is necessary for the circulation of fluids at depth and is important to geothermal energy extraction. Dense natural fault systems are ideal, however some methods such as hydraulic fracturing are available to increase the fault density. (Géraud, 2010)

3) **Hot springs** are natural sites at which geothermally heated groundwater rises from an aquifer to the surface. They have led to the identification of a myriad of geothermal resources internationally (Iceland in particular), with warmer hot springs typically being indicative of greater heat flow at relatively shallow depth within the crust. It has been shown that the distribution of thermal springs is largely controlled by faults, as well as by nearby volcanic systems. However, since they are limited in spatial extent, they are only given an intermediate weight in our analysis.

4) **Transmission lines** provide the infrastructure necessary to transport remotely produced geothermal energy to electricity-consuming population centres. However, given that transmission construction in BC costs ~$1 million per km of line (Kimball 2010), large transmission distances render even the most otherwise promising geothermal prospects infeasible. In addition, areas near both metropolitan areas and transmission lines are most favourable because they will have lower costs associated with distributing power to consumers, as close proximity to transmission lines vastly reduces costs associated with building new power lines from production sites to consumers. For example, the cost of the 344 kilometer Northwest Transmission Line built near Terrace, BC is projected to cost around $740 million due to British-Columbia's rugged terrain (BC Hydro, 2014), incurring an average cost of $2 million per kilometer of transmission line. Furthermore, power production is more efficient if the distance which power has to be transported is small, as larger distances engender higher loss rates. In light of the aforementioned considerations, the importance of this factor with respect to economic feasibility leads us to allocate a high weight to this factor.

5) **Proximity to metropolitan centres** (defined as areas with >50,000 people per Census Tract) describes the utility of building power infrastructure with respect to their potential to deliver power to urban centres, at which electricity consumption can be expected to be

significant. This layer is considered because power infrastructure proximate to urban centres minimizes transmission line losses incurred from large transmission distances and accounts for improved access to power generation sites.

6) **Aboriginal reserves, provincial parks, and national park** impose environmental and societal conditions upon our analysis with the goal of preserving these regions for posterity. Areas located within provincial parks, national parks, or First Nations reserve are deemed inappropriate for hydrothermal power generation.