UNIVERSITY OF CALGARY

Establishing a recharge area for Big Hill Springs, Alberta, Canada

by

Soren Poschmann

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Abstract

A recharge area for Big Hill Springs, Alberta, Canada was estimated using a combination of methods. A two year monitoring program of flow, temperature and electrical conductivity suggested a local recharge area. Stable isotope and tritium dating techniques dated the water between less than 5 to 10 years old. Electrical resistivity imaging results illustrated a layer of gravel or sand and gravel with a fluctuating surface located northwest of the springs. Topographic evidence and the glacial history of the area suggested that the layer of gravel or sand and gravel was deposited prior to the latest Wisconsian glaciation in a fluvial setting. These fluvial sediments provide an area of higher hydraulic conductivity from which the springs are sourced. The springs are issuing from the contact between the fluvial sediments and the bedrock. Based on the location of the fluvial sediments, topographic evidence and ground truthing, a recharge area of approximately 31 km^2 was estimated for Big Hill Springs.

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Introduction

Big Hill Springs is an anomaly due to its consistently high, year-round flow rate. The flow rate cannot be easily explained by typical seasonal runoff or by precipitation alone (Caron, 2004). The source itself appears to be issuing from horizontal or vertical fractures in the bedrock. However, the high flow rate cannot be due to bedrock flow alone as the flow rate of Big Hill Springs is much higher than other springs issuing out of the same bedrock (Borneuf, 1983). Previous work concluded that an area of enhanced recharge would effectively explain the phenomenon of the high flow rate of the springs. The purpose of this study was to attempt to determine the watershed of Big Hill Springs based on the hypothesis that they are fed through an area of enhanced recharge.

Site Location and Climate

Big Hill Springs is located 37 km northwest of Calgary, Alberta, Canada within a Provincial Park by the same name. Figures 1 and 2 provide the location of the springs at two different scales with respect to northwest Calgary and to Cochrane. Figures 3 and 4 show the elevation of the area in both a topographic and digital elevation model respectively. The springs flow into Big Hill Creek southeast of the source location. Big Hill Creek then flows south along the length of a glacial meltwater channel and drains into the Bow River. Cochrane Lake is indicated in Figure 3 and is the only non-ephemeral ponded water located in the area. The other mapped areas of standing water are seasonal and are present after the spring melt but before the ground completely unthaws. Climate in the area is typical to that of Southern Alberta. Environment Canada reports the annual precipitation at the Calgary airport is 412.6 mm/year and the annual average temperature is 4.1 ºC. The calculated average potential evapotranspiration of the area is 494 mm/year (Hydrogeological Consultants, 2002).

Geology

The geology of the area contains a layer of glacial sediments consisting of till, sand and gravel unconformably overlying the Paskapoo Formation. Figure 5 provides a generalized geologic cross section of the area. The Paskapoo Formation consists of interbedded sandstone with smaller silt and clay layers. It is a fluvial system that was deposited in the Tertiary (Hydrogeological Consultants, 2002). Figure 6 shows the extent of the Paskapoo Formation in the study area, and Figure 7 illustrates the various members of the formation within the municipal district (Rockyview No. 44) that the study site is located. The Dalehurst member, which underlies the Big Hill Springs area, has a maximum thickness of 800 m within the MD. It is composed mostly of shale and siltstone with sandstone, bentonite, and coal seams. The Paskapoo Formation is a known aquifer, and 7 041 of 11 578 water wells on record in the MD are defined as being completed below the top of the bedrock. Figure 8 showss the apparent yields for wells drilled into the Dalehurst member. Apparent yields average between 10 to 75 m^3/day with 20% of the values being more than 100 m^3/day. (Hydrogeological Consultants, 2002).

The surficial sediments overlying the Paskapoo Formation are separated into a lower and upper unit. The lower unit consists of preglacial fluvial sediments. The upper unit includes the more typical glacial till and meltwater deposits. The surficial sediments are, on average, less than 50 m thick, but up to 100 m of sediment can be seen in bedrock valleys. The surficial sediments can also act as an aquifer. In wells completed around Big Hill Springs, apparent yields can exceed 100 m^3/day. (Hydrogeological Consultants, 2002). Figure 9 shows the apparent yields for wells completed in the surficial sediments within the MD and Figure 10 illustrates the thickness of the sand and gravel deposits.

In the area where Big Hill Springs is located, there is a significant layer of surficial sediments. Water well records from the area only describe the upper few feet of the well as ‘gravels’ and no distinction is made between the two surficial units. Dr. Erick Burns constructed a diagram illustrating the depth to the bedrock based on water well records, found as Figure 11. It is again seen that there is a substantial thickness of surficial sediments around Big Hill Springs and continuing northwest from the source.

Previous Work

Previous studies attempted to differentiate between a local and a regional recharge system in the area. Caron (2004) completed a geochemical analysis of the springs, as well as a discharge, temperature and EC monitoring program. Isotopes were also analyzed and dated. Caron (2004) concluded that the geochemistry of the springs suggested a clean (low TDS), local source. The average temperature of the springs was measured to be 5.9 °C, which is higher than the annual average air temperature of 4.1 °C. Caron (2004) concluded that this was also indicative of a local recharge area. However, the constant flow rate and isotopic signature did not show any seasonal variations, consistent with a regional system. Grieef (2006) tritium dated the spring water at an age of less than 5 to 10 years old. This was not compared to the ages obtained by Caron (2004) through isotopic techniques.

In addition to the geochemical and monitoring program, Caron (2004) analyzed a recharge area estimated by Komex International Ltd. (1998). This estimate is found as Figure 12. The 26 km^2 area was constructed by following topographic high points around Big Hill Springs. When multiplied by the annual average precipitation, a slightly higher flow rate was calculated than what is observed at the springs. Assuming the flow is dominantly controlled by topography and precipitation, it was calculated that the recharge rate was 20%. In order to obtain a more reasonable recharge rate of 4-5% a recharge area of 105 km^2 was needed. The 20% recharge rate was deemed unreasonable due to the aridity and strong evapotranspiration of the region. Caron (2004) concluded that the recharge of the springs may not be controlled by topography alone and there may be a zone of enhanced recharge within the watershed.

Hypothesis

This study builds on the conclusions of Caron (2004); Big Hill Springs is being fed through an area of enhanced recharge. A number of methods were used to test this hypothesis. A two year flow, temperature and electrical conductivity (EC) monitoring program was used to consistently monitor any changes in these variables over time. Four electrical resistivity imaging (ERI) lines were used to resolve the subsurface. Groundwater dating results that had been completed in two previous studies were also analyzed. Based on these results, the final hypothesis was produced: Big Hill Springs are fed through an area of enhanced recharge underlain by a preglacial channel. Through topographic evidence, ground truthing and the consultation of Dr. Len Hills of the University of Calgary, the preglacial channel was constructed. Finally, using the location of the channel, again along with topography, ground truthing and locations of non-ephemeral surface water, the watershed for Big Hill Springs was constructed.

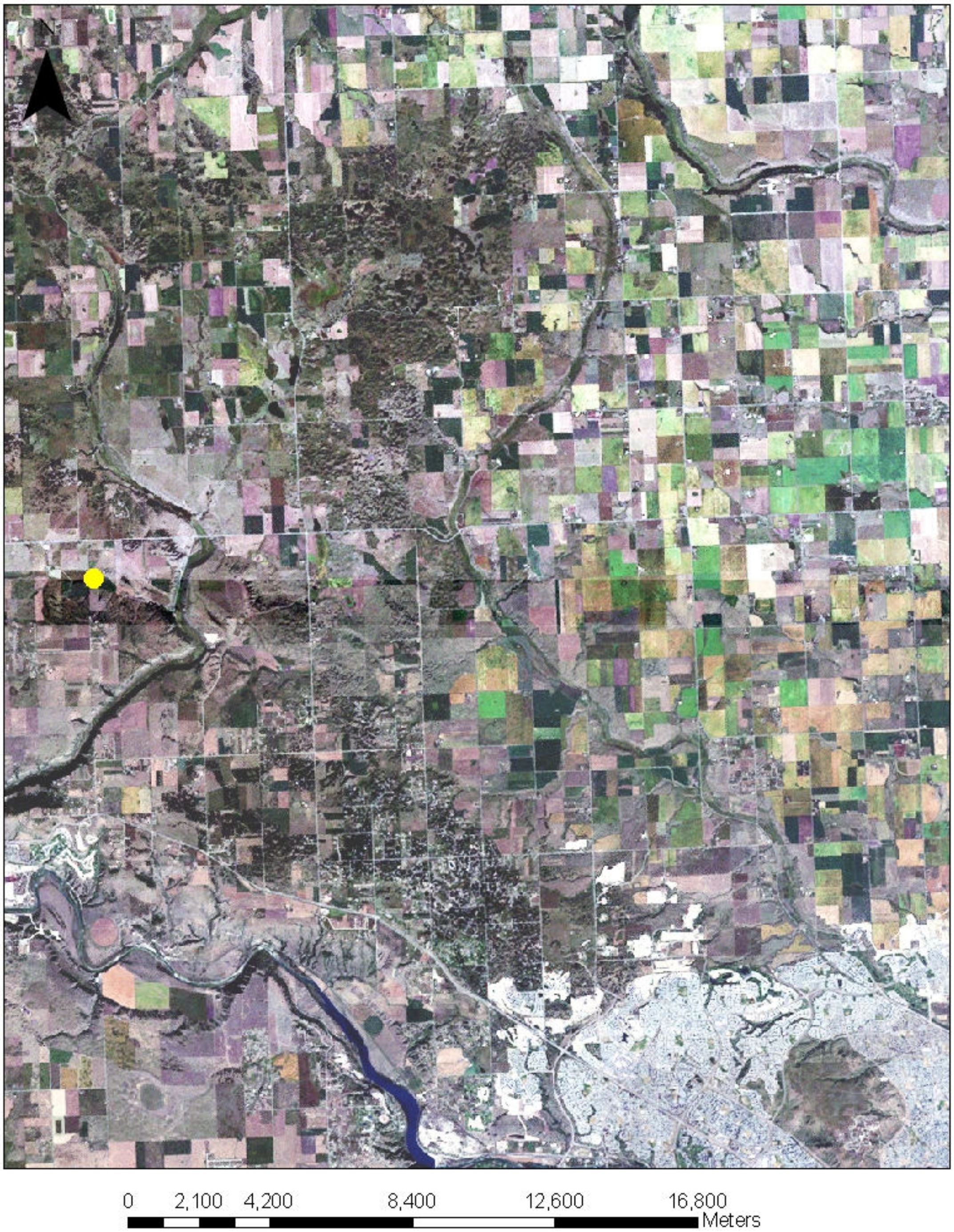


Figure 1: Location of the source of Big Hill Springs (yellow dot) with respect to NW Calgary in the bottom right of the map

Figure 2: Location of the source of Big Hill Springs (yellow dot) with respect to Cochrane in the SW corner of the map

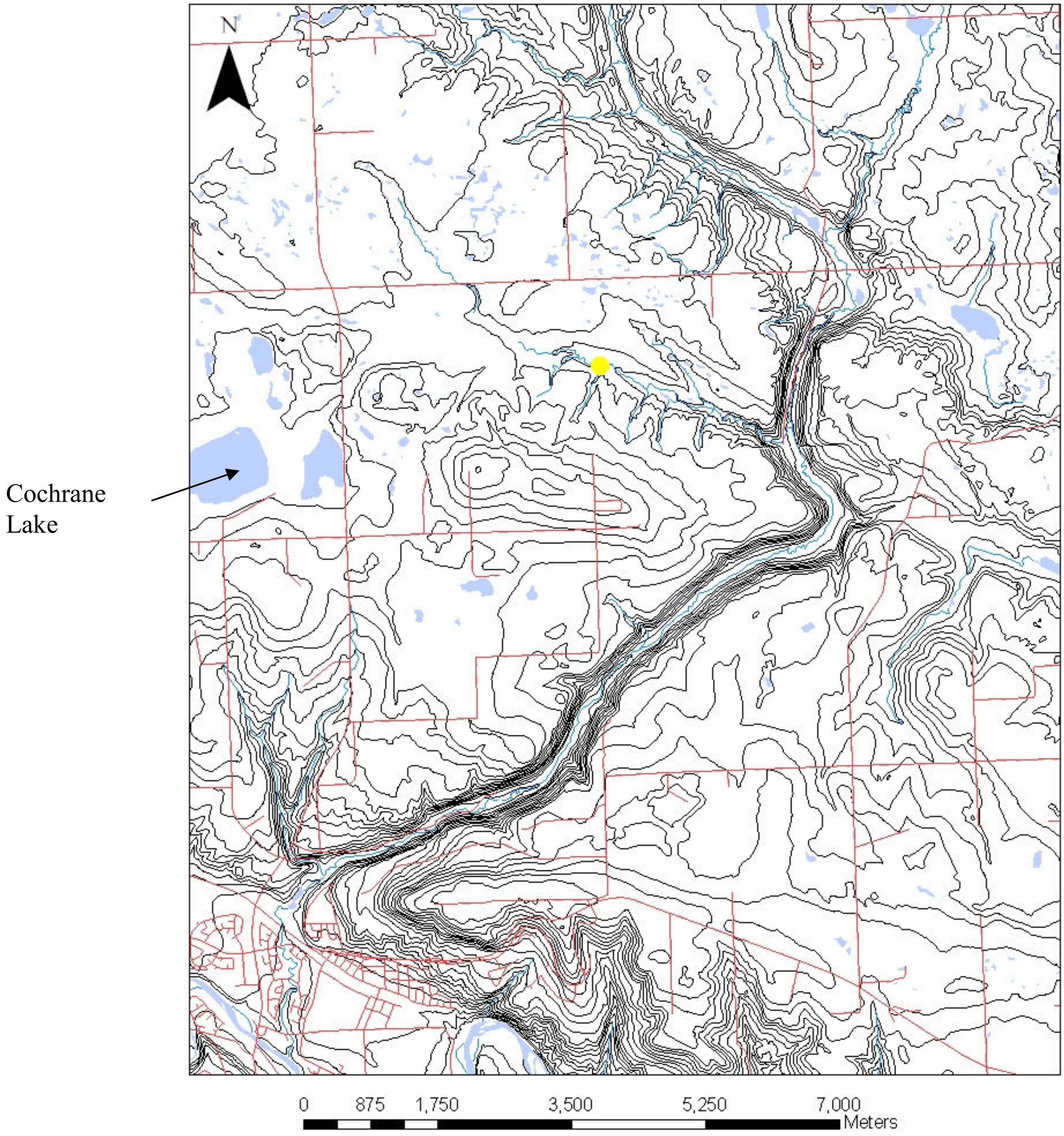


Figure 3: Topographic map of the Big Hill Springs area. The source is indicated by the yellow dot.

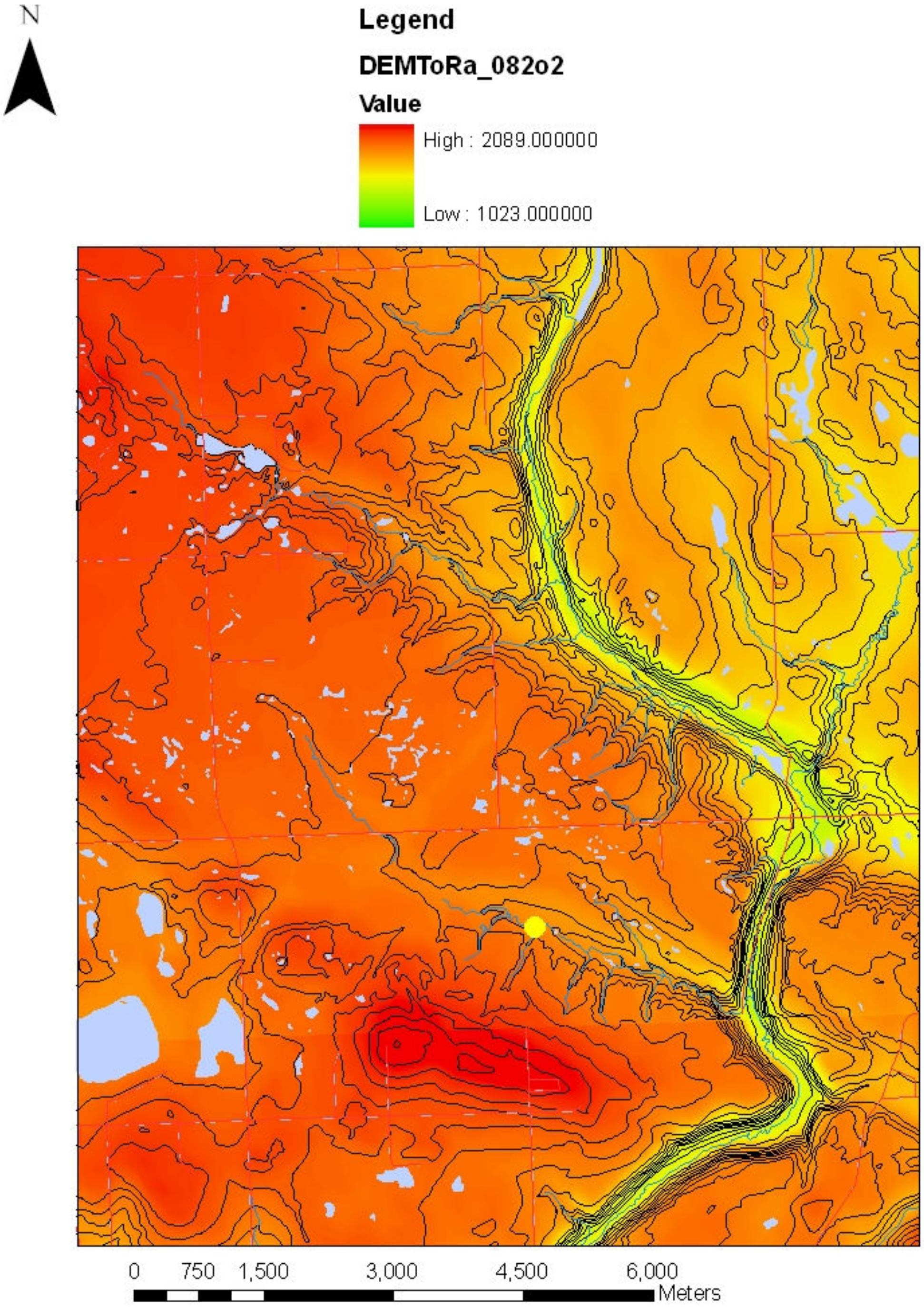


Figure 4: Digital elevation model (DEM) of the Big Hill Springs area. Contour interval is 10 m and DEM values are in meters. The source is indicated by the yellow dot.

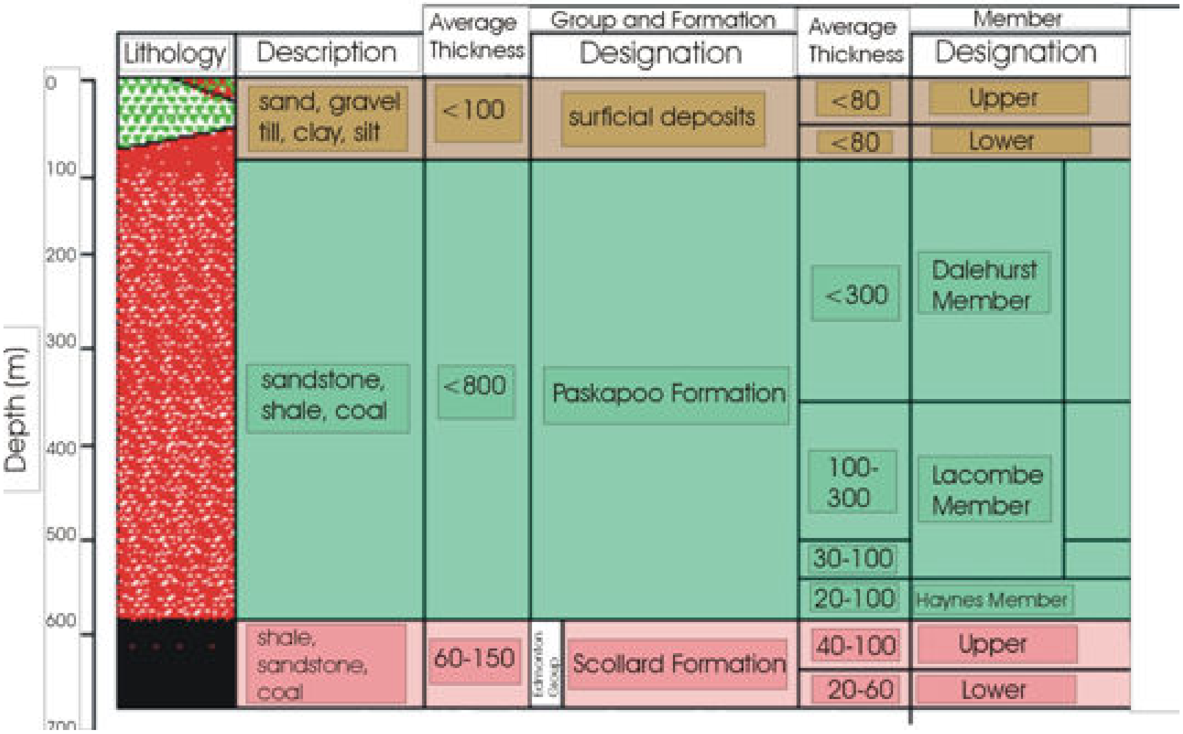


Figure 5: Simplified geological cross section of the MD of Rockyview No. 44 (modified from Hydrogeological Consultants 2002)

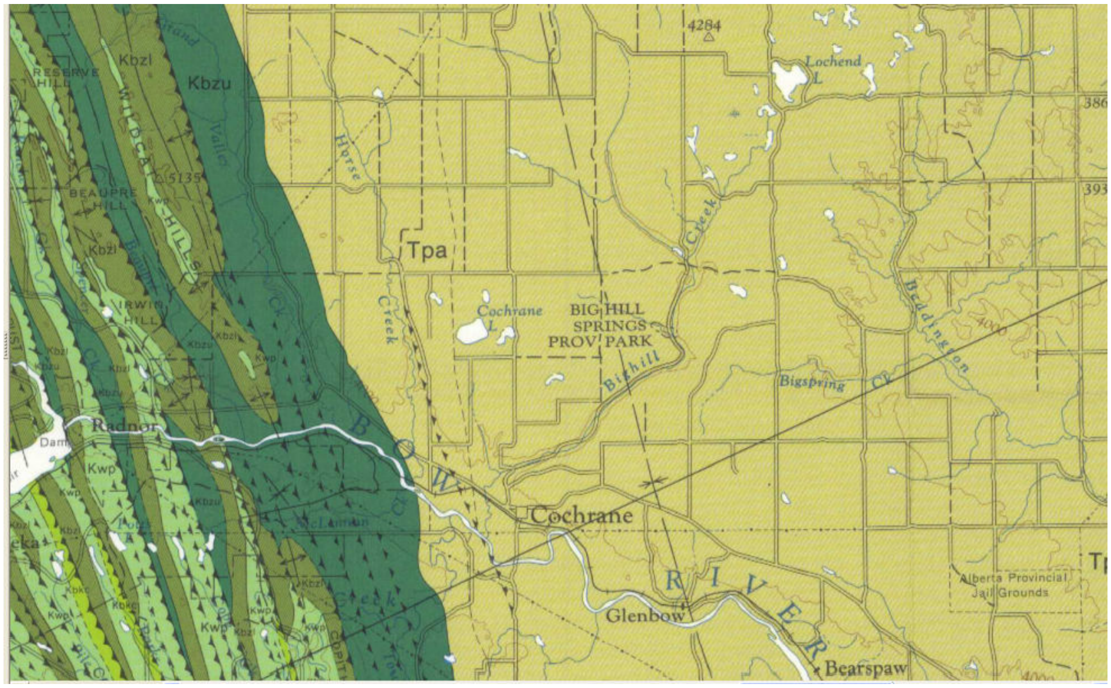


Figure 6: Geological Map of Big Hill Springs area. Tpa = Paskapoo Formation (modified from GSC map 1457A)

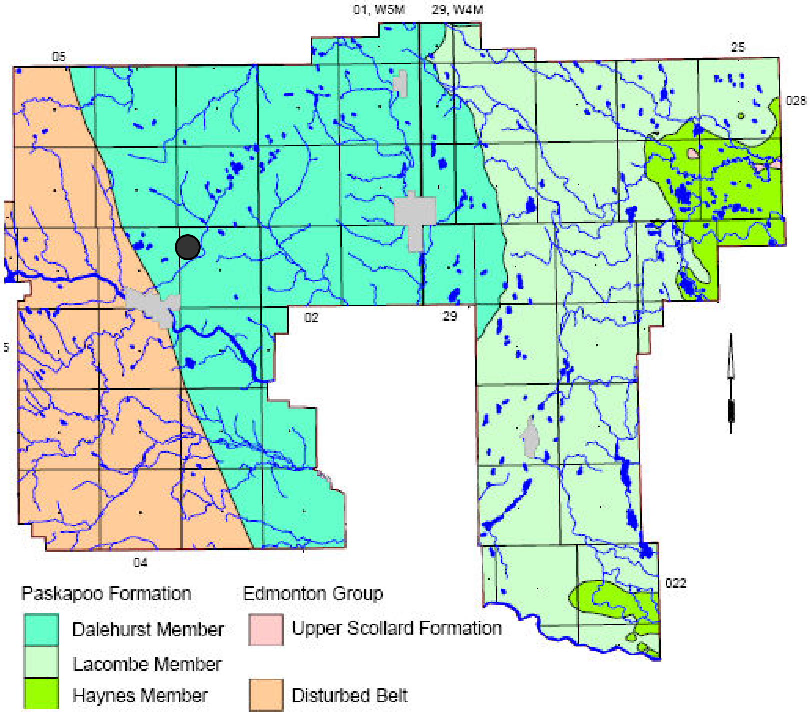


Figure 7: Geological map of the MD of Rockyview No. 44. The approximate location of Big Hill Springs is indicated by the black dot (modified from Hydrogeological Consultants 2002).

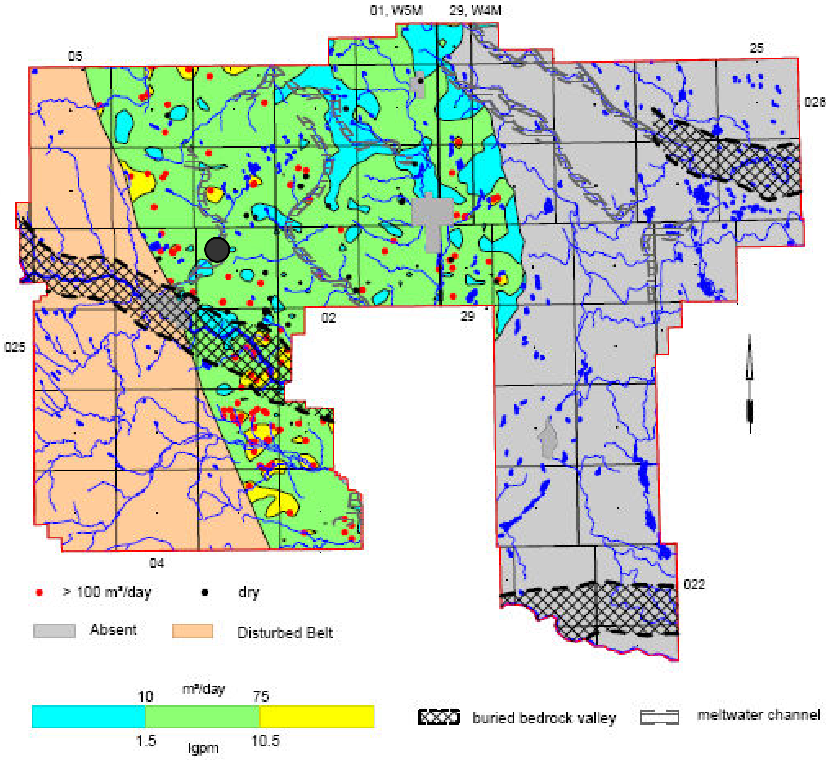
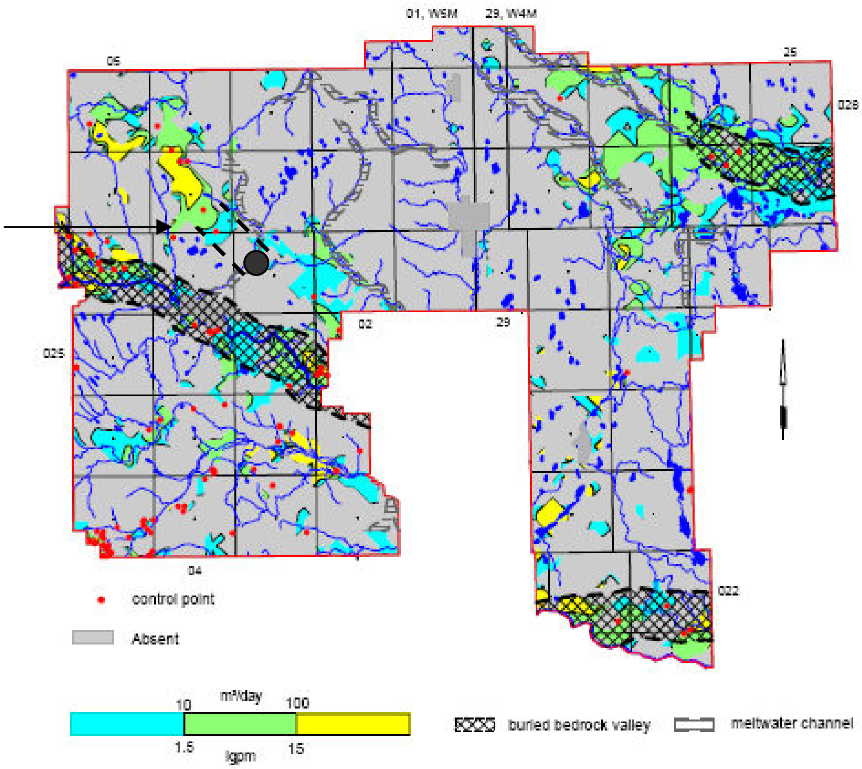
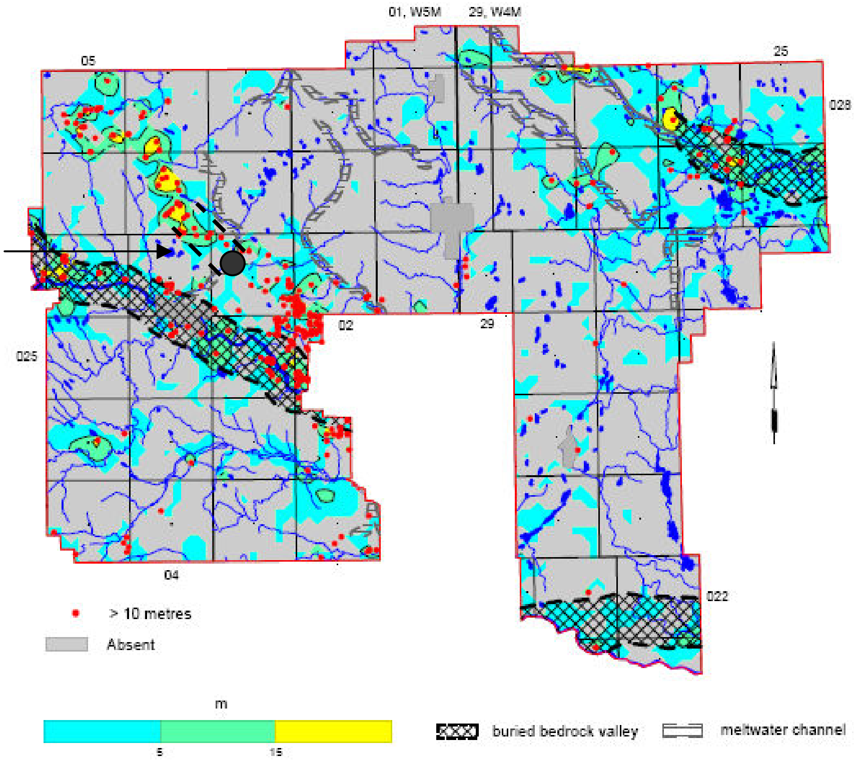


Figure 8: Apparent yield for water wells completed through the Dalehurst member. Approximate location of Big Hill Springs is indicated by the black dot (modified from Hydrogeological Consultants 2002).



Approximate location of preglacial channel

Figure 9: Apparent yield for water wells completed in the surficial sediments. Approximate location of Big Hill Springs is indicated by the black dot (modified from Hydrogeological Consultants 2002).



Approximate location of preglacial channel

Figure 10: Thickness of sand and gravel deposits. Approximate location of Big Hill Springs is indicated by the black dot (modified from Hydrogeological Consultants 2002).

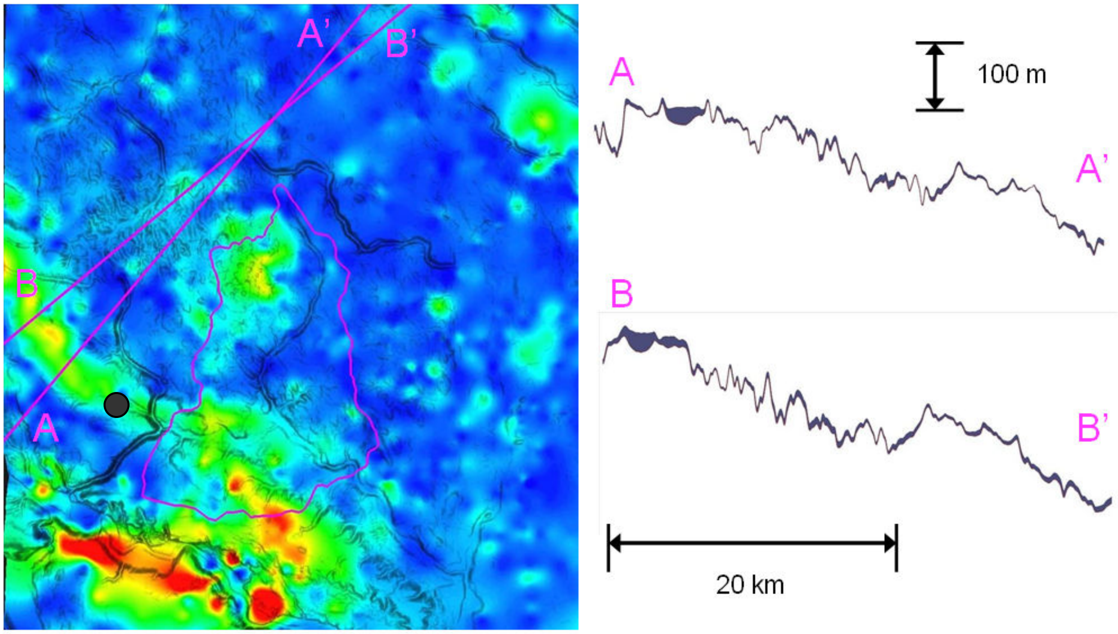


Figure 11: Depth to bedrock model based on water well records. The scale ranges from blue (shallowest) to red (deepest). The approximate location of Big Hill Springs is indicated by the black dot. Thanks to Dr. Erick Burns for use of this image.

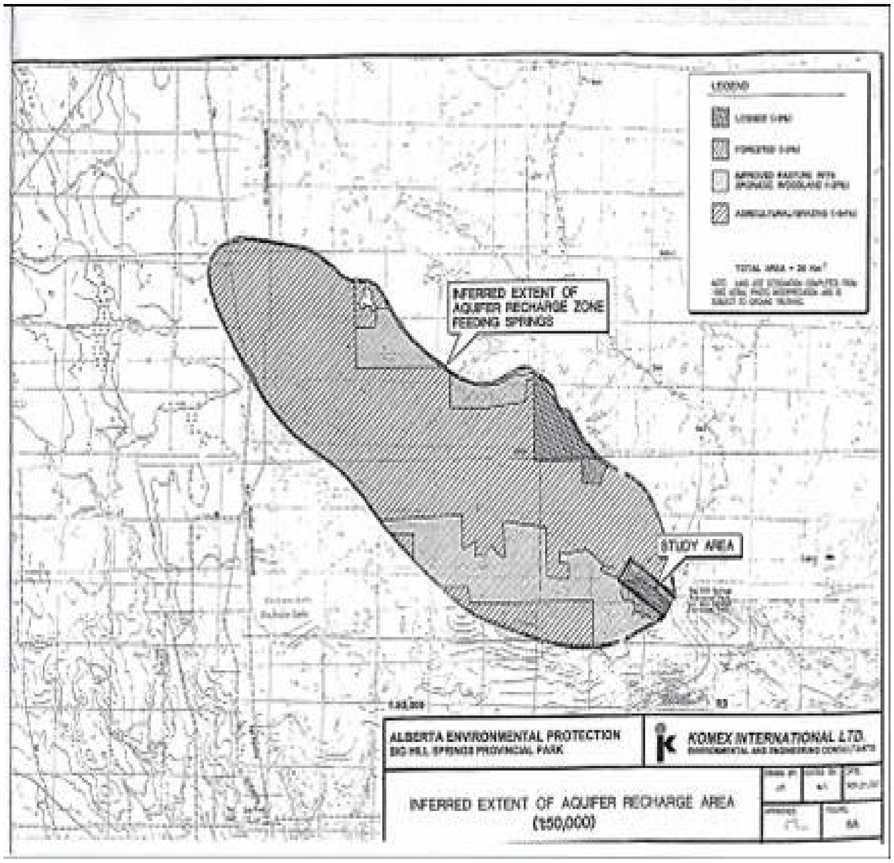


Figure 12: Komex International recharge estimate for Big Hill Springs (modified from Komex International Ltd. 1998)

Methods

The discharge, temperature and electrical conductivity (EC) of Big Hill Springs were monitored intermittently between October 2003 and November 2005. Between October 2003 and February 2004 measurements were taken every week as part of Caron's 2004 study. Measurements were taken approximately every few months after February 2004 with a higher sampling frequency in the summer and spring months. All measurements were taken at the source of the springs.

Flow, Temperature and Electrical Conductivity

Flow measurements were taken by dividing the channel into a number of widths and sampling at each width interval (Caron, 2004). Flow velocity (q) was measured using Global Water's "Global Flow Probe". The depth of the channel was also measured wherever the flow measurement was recorded. Using an average depth from one reading to the next, the area (A) of the section of the channel being measured could be calculated. From this, the final discharge (Q) measurements were calculated in m^3/s using Q=qA. Temperature and EC measurements were taken using Barnant's "Thermocouple Thermometer Type T" and VWR Scientific's "EC Meter Model 2052". EC was corrected for temperature to 25 ºC by Equation 1.

$$EC_{t=25^{\circ}C} = \frac{EC_t}{1+0.0187(t-25^{\circ}C)} \qquad (1)$$

(Hayashi, 2004)

Where:

t = measured temperature of the water
EC_t = EC measured at temperature t

Groundwater Dating

Stable isotope ($\delta^{18}O$) sampling was completed by Caron (2004) at the source of the springs. Analysis was done at the University of Calgary Isotope Laboratory by dual inlet mass spectrometry with the Micromass SIRA II (Caron, 2004). The groundwater age was calculated using Equation 2. All values were estimated by Caron (2004).

$$T_o = \frac{\sqrt{\frac{1}{f^2} - 1}}{2\pi} \qquad (2)$$

(Mayer, 2004)

Where:
T_o = age of groundwater
f = B/A
B = groundwater measurement error / natural variation = 0.5 ‰
A = precipitation measurement error / natural variation = 20 ‰
(Caron, 2004)

Samples to be analyzed for tritium were collected by Grieef (2006) and sent for analysis to the University of Waterloo Environmental Isotope Laboratory. There, the sample was enriched fifteen times by electrolysis and then counted by liquid scintillation. The detection limit for this type of analysis is 0.6 ± 0.8 tritium units (TU) (Grieef, 2006).

Electrical Resistivity Imaging

Four electrical resistivity lines (ERI) were run over what was initially thought to be a small meltwater channel. The location for the lines is found as Figure 13. A gravel pit is located to the immediate northeast of lines 1 through 3 and is indicated in Figure 13. A 200 V Wenner array was used. Each line spanned 213 m and used 3 m electrode spacing over 72 electrodes. The last 6 electrodes of lines 1 through 3 were overlapped in order to provide a consistent image of the subsurface. The lines were surveyed using a total station and the final sections were corrected for topography. Lines were inverted using Res2DInv.

Channel and Watershed Mapping

The preglacial channel was mapped using a number of different methods. Topographic evidence was used to locate areas that appeared to be topographically low before the latest Wisconsian glaciation. Ground truthing of the area confirmed or rejected inferences made based on topography alone. Most ground truthing involved looking for standing or flowing water that was mapped on the topographic maps, but were only ephemeral streams or ponds. Consultation with Dr. Len Hills of the University of Calgary also advanced understanding of the glacial history of the area. Knowing where the preglacial channel, and thus the area of enhanced recharge, was located, the watershed for Big Hill Springs was constructed. The watershed location was also based on topography as well as locations of ephemeral ponded water.

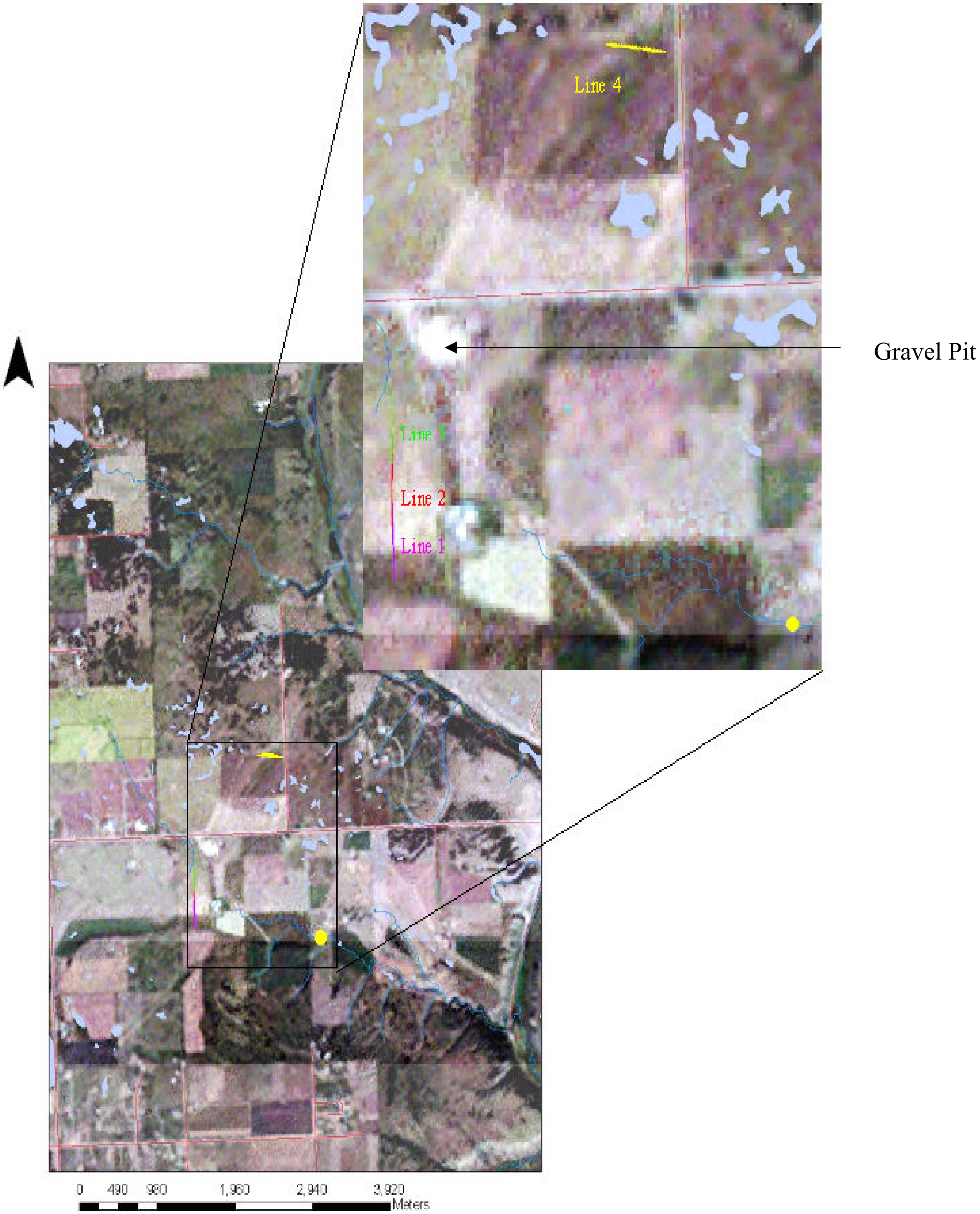


Figure 13: Location of ERI lines with respect to the source of Big Hill Springs (yellow dot)

Results and Discussion

Flow

The total discharge measurements for each day of sampling were plotted versus time and can be found as Figure 14. The raw data is located in Table 1. The average discharge is about 0.1 m^3/s. The sampling frequency decreased significantly after Caron's 2004 work. The data appears to fluctuate, especially when the sampling frequency decreased. The fluctuating flow data would suggest a more local source of the water, as the flow would vary with the seasons. In comparison, a regional recharge source would show less fluctuation in the flow over time. There is also a slight seasonal lag, as the highest discharge is observed in the summer months, slightly after the high spring runoff. With such sporadic sampling it is difficult to make any definite inferences on the fluctuations of the flow over time. The data presented does seem to fluctuate slightly, however when and how much remains unclear.

Temperature

The plot of temperature variations with time is located as Figure 15. The raw data can be found in Table 2. The average overall temperature was 5.7 ºC with a standard deviation of 0.59 ºC. The average temperature of the springs in the winter months was 5.7 °C and 5.3 °C in the summer months. Therefore, the overall average temperature is skewed towards the winter months, where most of the sampling took place. The temperature does not fluctuate very much, as is seen from the standard deviation. The maximum measured temperature was 7.0 ºC to a minimum of 4.8 ºC. The measured average temperature of the springs in both winter and summer is higher than the annual average temperature of 4.1 ºC.

Typically, the average groundwater temperature is approximately equal to the average annual temperature of an area. Since the Big Hill Springs water is higher than average, this would suggest a more local recharge area. This is due to the fact that the water is not in the ground long enough to become equilibrated with the average ground temperature. There is also evidence of a slight seasonal lag in the temperature. The higher temperatures occur in the late fall and early winter, whereas the coldest temperatures appear in the late spring. This seasonal lag in both temperature and flow measurements again indicates a more local source. However, as with the flow measurements, the sporadic sampling makes definitive conclusions difficult.

Electrical Conductivity

Figure 16 gives the plot of electrical conductivity versus time. Table 2 provides the raw data used. The average EC was 544.1 μS/cm with a standard deviation of 28.2 μS/cm. Like the temperature measurements, the EC does not fluctuate much with time.

EC can be related to sum of the anions or cations of a system. The relationship is:

$$\frac{EC(\mu S/cm)}{100} \cong \Sigma_{anions} \cong \Sigma_{cations} \qquad (3)$$

(Appelo and Postma, 2005, pp. 19)

This relationship only holds for samples less than 1500 μS/cm, so it is valid for use in this study, as the maximum measured EC was 581 μS/cm. Since EC can be used as an estimate of the sum of the anions or cations in a water sample, it can also be used as a comparative tool for the total dissolved solids (TDS) in the water. Local sources for water have a lower TDS than more regional sources due to the short resonance time of the water. The shorter the resident time of the groundwater, the less time it has to dissolve ions and raise its TDS (Appelo and Postma, 2005, pp. 54-55). The lower the EC of a water, the lower its anions or cations, and therefore, the lower its TDS. Due to this, an estimate can be made on the extent of the recharge area based on the EC of the water and EC can be used comparatively to other springs to differentiate recharge areas.

When compared to springs issuing out of bedrock, Big Hill Springs has a much lower TDS. Obed Spring, located in west-central Alberta, and Rockyford Spring, in the southern plains, both issue from the Paskapoo Formation. Obed Spring has a temperature corrected EC of 630.3 μS/cm and Rockyford Springs has a calculated EC of 5185.9 μS/cm. It is noted that some flow in Obed Spring could come from drift water contributions, explaining the lower TDS. Also, irrigation waters infiltrating Rockyford Spring could contribute salts to the water and account for the high TDS (Borneuf, 1983). However, when compared to these two springs issuing from the Paskapoo, Big Hill

Springs does have a lower EC. Therefore, this would suggest that Big Hill Springs has a smaller recharge area, shorter residence time and flow through bedrock does not contribute to the recharge as much as in other bedrock springs. .

Big Hill Springs can also be compared to other springs located to the east in the West Nose Creek watershed. The measurements taken at springs in the watershed are located in Figure 17. All the springs have a lower EC than Big Hill Springs. The measured EC value for Big Hill Springs in Figure 17 is significantly higher than what was averaged over the two year monitoring period. For accuracy, the two year average value of 544 μS/cm is going to be used as the EC of Big Hill Springs because of the higher number of measurements. Since the other springs in the West Nose Creek watershed have higher EC, it can be inferred that Big Hill Springs has a smaller recharge area.

Groundwater Dating

The $\delta^{18}O$ dating completed by Caron (2004) yielded a groundwater age of 6.36 years old using Equation 2. Tritium analysis by Grieef (2006) yielded tritium levels of 12.0 TU, which corresponds to a groundwater age between less than 5 to 10 years old. Detectable tritium in groundwater indicates that the water has been recharged by recent direct infiltration of precipitation (Clark and Fritz, 1997, pp. 184-185). Compared to tritium levels in wells completed in Paskapoo Formation bedrock (Grieef, 2006), Big Hill Springs has more tritium and therefore a younger age. Tritium levels found in springs in the West Nose Creek watershed are found as Figure 17. A majority of the levels are lower than those of Big Hill Springs, which also indicates older groundwater since tritium levels between 0.8 and 4 TU correspond to a mixture of submodern and recently recharged water (Clark and Fritz, 1997, pp. 184-185). Therefore, the water of Big Hill Springs is young compared to the ages of groundwater issuing from springs in the same area.

Electrical Resistivity Imaging

The results for the four ERI lines completed at the locations given in Figure 13 are provided as Figures 18 to 21. The lines are labeled in Figure 13 and these same labels are used to describe the lines in the results. The upper, less resistive layers are interpreted as being composed of soil or glacial tills. The middle, highly resistive layers include gravels or a mixture of sand and gravel. These layers would be analogous to the upper and lower units of the surficial sediments described by Hydrogeological Consultants Ltd. (2002). In the area of the images only a thin veneer of soil covers the gravel or sand and gravel. Underlying these two layers is the lower resistance bedrock. The main layer of interest is the middle, higher resistive layer. The layer of sediments is intermittent, as they seem to have a break in continuity visible in line 2. They also fluctuate in depth from approximately 5 m depth to the surface. This is most evident in the gravel pit, shown in Figure 13, and also in line 4, where the gravels appear to intersect the surface. This line was run over a depression in the ground where the landowner has reported trouble retaining water. The presence of gravel or sand and gravel at the near surface could explain this problem, as the gravels would cause the water to preferentially flow through the area of highest conductivity. The fluctuating, semi-continuous gravel or sand and gravel can be explained by the presence of a preglacial channel that deposited this layer of fluvial sediments before the latest glaciation.

Glacial History

Based on the findings of the flow, temperature and EC monitoring, as well as the groundwater dating and ERI lines, it was hypothesized that Big Hill Springs is being fed through the layer of gravel or sand and gravel seen in the ERI sections. This would provide a local source of recharge that was indicated by the flow, temperature, EC and dating results. The springs are issuing from the contact between the fluvial sediments and the bedrock.

Mapping of the layer of fluvial sediments was based on the premise that a preglacial channel cut through the area and then backfilled in the channel with fluvial sediments. The channel appears to be a braided river that may have meandered through the valley it cut around Big Hill Springs. The course of this channel can be projected to the east where it joins with another tributary and continues into the West Nose Creek watershed. When the latest Wisconsian glaciation moved in, the Cordilleran ice sheet from the west reached the Big Hill Springs area first. Eventually the Cordilleran sheet retreated, and the Laurentide ice sheet advanced in from the east. These glaciations deposited a layer of till over the gravels that were already deposited by the preglacial channel. The meltwater channel that runs through where Big Hill Springs joins with Big Hill Creek was caused by glacial runoff. This meltwater channel crosscuts the preglacial channel and begins in a moraine complex to the north. The channel is estimated as preglacial in origin due to the till backfill within the channel that is apparent by hummocky terrain and the cross cutting relationship with the late glacial coulee. The fact that the coulee does not have a layer of till within it and begins in a moraine complex to the north suggests that the coulee is postglacial in origin and thus postdates the preglacial channel (Hills, 2007).

The preglacial channel deposited a layer of gravel or sand and gravel commonly grouped together in the formation entitled Saskatchewan Gravels. Initially termed 'South Saskatchewan Gravels', they referred to pebble conglomerates, incoherent gravels and silty beds (Stalker, 1968). Generally, sands and gravels of western origin that predated sediments of the latest glaciation were included in the description. Eventually the term South was dropped from the name, and the Saskatchewan Gravels became included as part of the Empress formation. The major identifying criteria for Saskatchewan Gravels are rounded, quartzite pebbles with a lack of stones from the Canadian Shield (Stalker, 1968). The gravels located in the Big Hill Springs area are included in the classification for Saskatchewan gravels, as these criteria are met. In a 500 rock count of the sediments found in the gravel pit, all were rounded to well-rounded. They were all quartzite with some conglomerates and sandstones. No Shield sediments were found in the sample. The maximum size of the sediments was approximately 20 cm, with a minimum of millimeter size sand particles. The average grain size was 2 to 3 cm in diameter. Separate sand and gravel layers are present in the pit walls. This is also indicative of a fluvial setting, with different sediments being deposited as the channel meandered due to fluctuating flow rates of the preglacial river.

The channel location is found as Figure 22. Note that the springs are sourcing near the contact of the terminus of the channel with bedrock. This could also be a possible explanation for why the springs are sourcing where they are. The dashed lines indicate boundaries that are not as certain. The questionable boundary to the north is present due to the gravel or sands and gravel visible in ERI line 4. It is most likely an absolute maximum northern boundary of the channel. The channel could have meandered anywhere between the extents of the boundaries and deposited sediments, especially if it was a braided system. The few tributaries were included with the channel based on topography and ground truthing of the area.

Watershed

Based on the known presence of the layer of gravel or sand and gravel deposited in the preglacial drainage system, a watershed for Big Hill Springs was constructed which is found as Figure 23. The watershed was constructed based not only on the channel location, but also using topography and boundaries with other watersheds. The north boundary of the watershed was based on the presence of seasonal runoff streams draining north into Big Hill Creek. Since those streams are seasonal, the boundary could be drawn closer to them as the groundwater divide will exist close to those streams. The western most boundary is based on drainage patterns flowing west into the Horse Creek watershed. Again, most of those tributaries are ephemeral. The southern boundary is based on topography, as there is a fairly large ridge just south of the source of Big Hill Springs. Within the watershed, there is very little documented ponding of water at the surface, especially compared to areas east of Big Hill Springs. This indicates that water rapidly infiltrates and does not get blocked at the surface by an impermeable layer.

With a watershed now defined, an estimate on the amount of recharge accounted for by precipitation can be calculated. The area of the watershed is approximately 31.23 km^2, and the average discharge at the source is 0.1 m^3/s. Dividing the discharge by the area gives an approximate average recharge of 3.2 x 10^{-3} m/s, or 101 mm/yr. Dividing this flux rate by the average annual precipitation (412.6 mm/yr), a percent recharge by precipitation was calculated to be approximately 25 %. This high recharge rate is only possible for an area of enhanced recharge. Also, this rate is close to the one calculated from the recharge area estimated by Komex International Ltd. (1998) so the watershed area calculated through topography alone was close to the one constructed through the presence of an area of enhanced recharge.

A back of the envelope calculation can be made to find an approximate discharge that is to be expected at the source of the springs. Dividing the distance from the approximate middle of the water shed to the source (3820 m) by the average groundwater age (7 years) yields a velocity of 1.7 x 10^{-5} m/s. Multiplying this by 0.3, a reasonable porosity value for sand and gravel yields a flux of 5.1 x 10^{-6} m/s. The approximate thickness of the preglacial channel is 20 m, and the average width of the channel is 1300 m. However, it is estimated that only approximately 10 m of the channel is saturated. Multiplying the saturated thickness with the width of the channel gives the area of the channel. Multiplying this area with the flux gives an approximate discharge rate of 0.07 m^3/s. This is very close to the same order of magnitude as the average measured discharge of the springs (0.1 m^3/s). Therefore, the hypothesis that the springs are being recharged through the preglacial channel seems reasonable.

The dashed lines indicate areas in question. It is not apparent how far the watershed continues past the source of the springs. It is also still unsure whether or not Cochrane Lake and surrounding areas are included within the watershed. Cochrane Lake has no surface input or output, and topographically could drain into the Big Hill Springs watershed. However, it could also just as easily drain to the south or west into Horse Creek. The few smaller ridges to the north of Cochrane Lake may impede any sort of drainage from Cochrane Lake into the Big Hill Springs watershed. The tributaries of the preglacial channel could potentially provide drainage of Cochrane Lake into the Big Hill Springs watershed. The elevation of Cochrane Lake is 1290 m, whereas the elevation of the source of Big Hill Springs is 1270 m. This was approximated through both the digital elevation model along with a GPS reading at the sites. Based on elevation alone, Cochrane Lake could theoretically drain to Big Hill Springs, but no definitive conclusions can be made from this data.

Although the presence of the fluvial sediments is a good indication of what is causing the high flow rate in the springs, there is nothing disproving there is no flow between the fluvial sediments and the underlying Paskapoo sandstone. The Paskapoo Formation is a known aquifer, and does hold water in its permeable layers. Although the hydraulic conductivity of the fluvial sediments would be much higher than the sandstone, there could be some flow between.

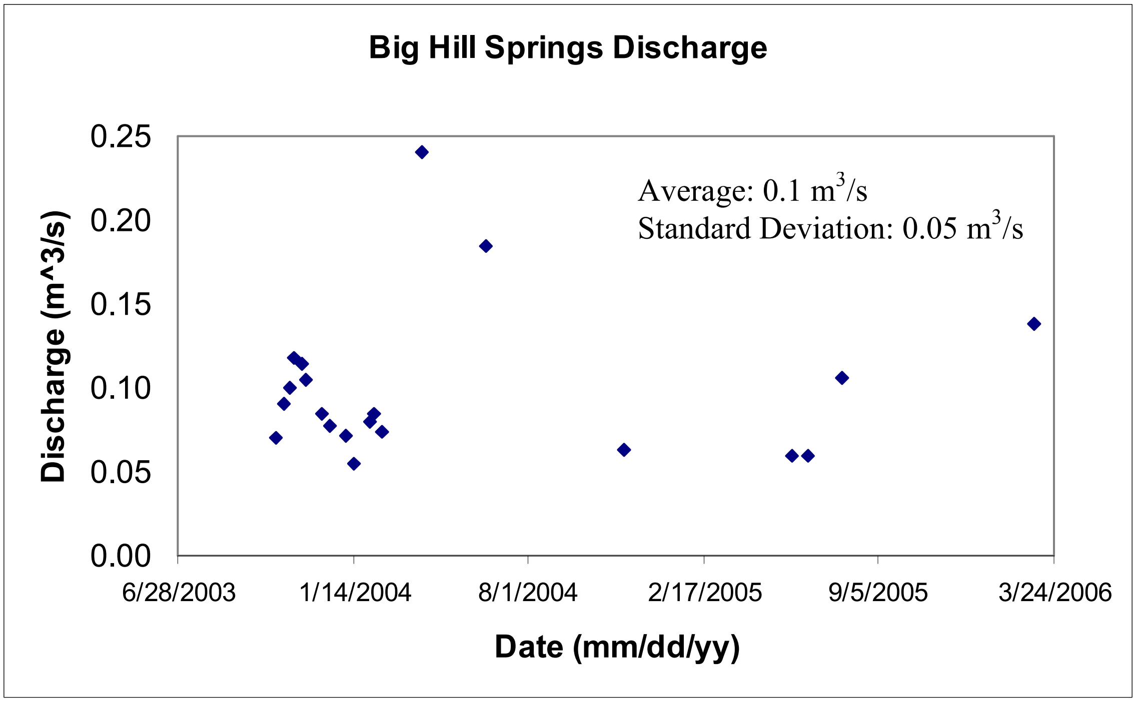


Figure 14: Discharge versus time measured at the source of Big Hill Springs

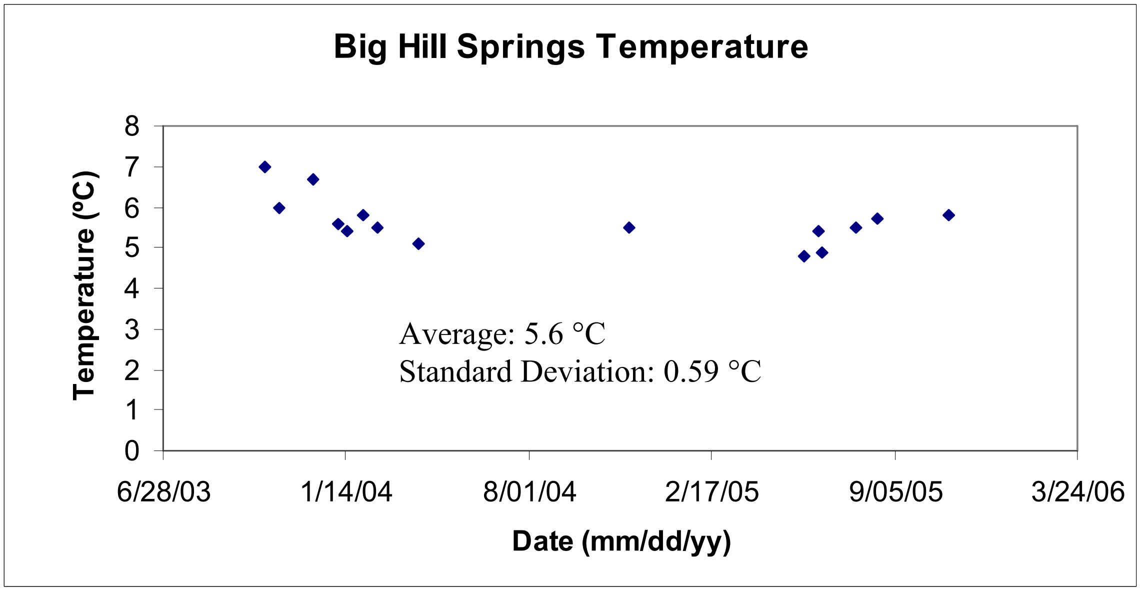


Figure 15: Temperature versus time measured at the source of Big Hill Springs

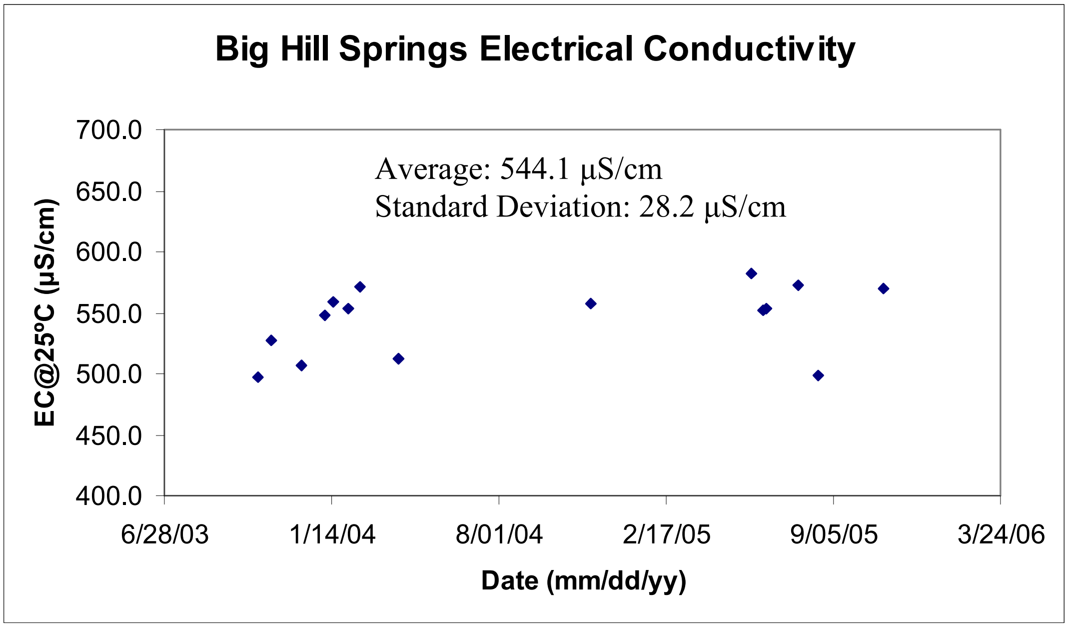


Figure 16: Electrical conductivity versus time measured at the source of Big Hill Springs

Date (dd/mm/yy)	Discharge (m^3/s)
10/17/2003	0.07
10/26/2003	0.09
11/2/2003	0.10
11/8/2003	0.12
11/16/2003	0.11
11/22/2003	0.11
12/9/2003	0.08
12/18/2003	0.08
1/5/2004	0.07
1/16/2004	0.05
2/2/2004	0.08
2/7/2004	0.09
2/17/2004	0.07
4/2/2004	0.24
6/13/2004	0.18
11/18/2004	0.06
5/30/2005	0.06
6/17/2005	0.06
7/25/2005	0.11
3/1/2006	0.14

Table 1: Data used for discharge analysis

Date	Time	EC (µS/cm)	T (ºC)	EC @ 25ºC (µS/cm)
10/17/03	-	330	7	497.4
11/02/03	-	340	6	527.4
12/09/03	-	333	6.7	506.2
1/05/04	-	349	5.6	547.7
1/16/04	-	354	5.4	558.8
2/02/04	-	355	5.8	553.9
2/17/04	-	363	5.5	571.3
4/02/04	14:50	322	5.1	512.8
11/18/04	12:00	354	5.5	557.2
5/30/05	-	362	4.8	581.8
6/13/05	15:50	350	5.4	552.5
6/17/05	10:30	345	4.9	552.8
7/25/05	12:20	364	5.5	572.9
8/18/05	16:00	319	5.7	499.1
11/04/05	13:20	365	5.8	569.5

Table 2: Data used for temperature and EC analysis

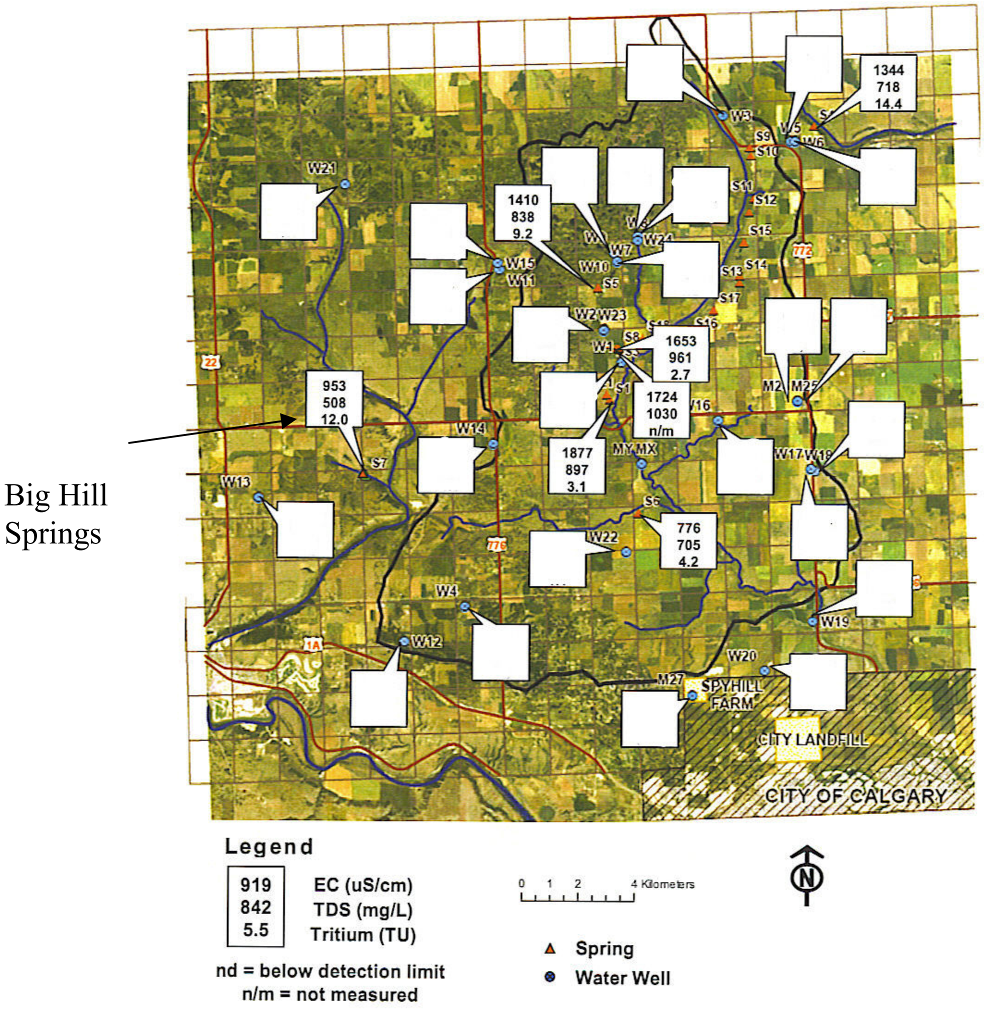


Figure 17: EC, TDS and tritium measurements in the West Nose Creek watershed. Well information has been erased for clarity. Only spring measurements remain. Big Hill Springs is indicated (modified from Grieef, 2006)

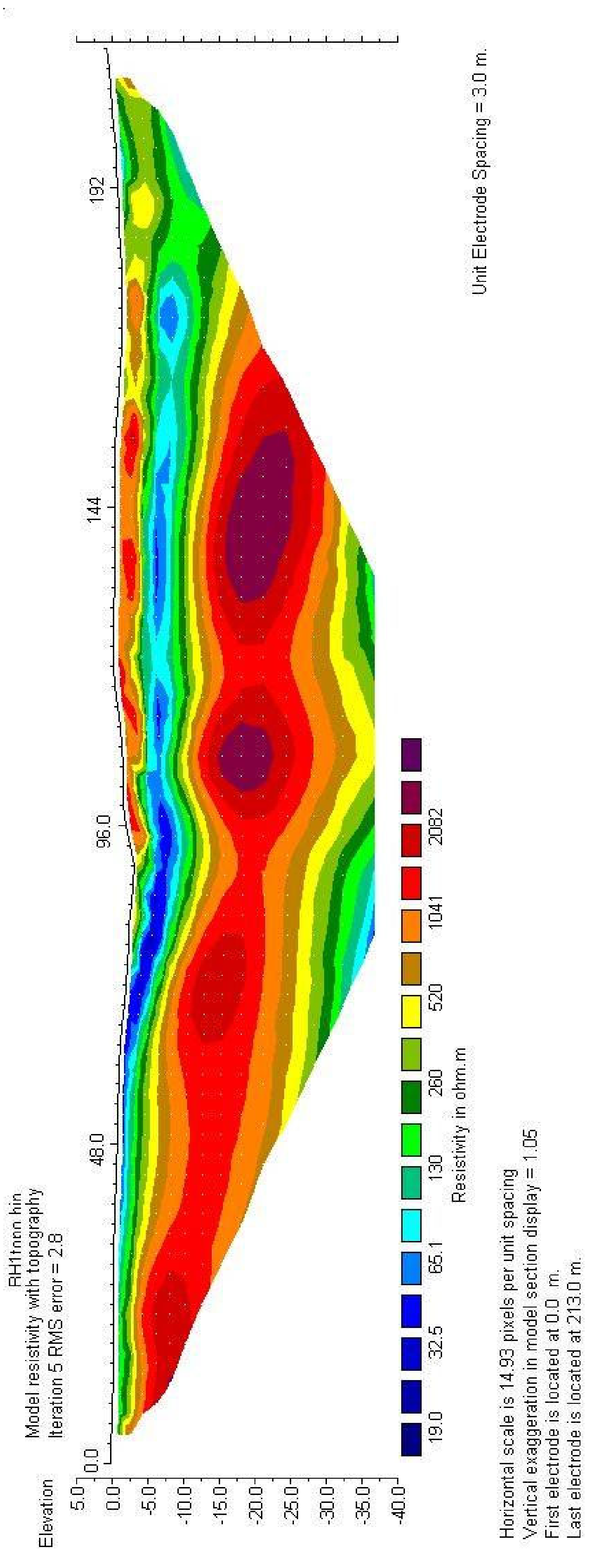


Figure 18: ERI Line 1

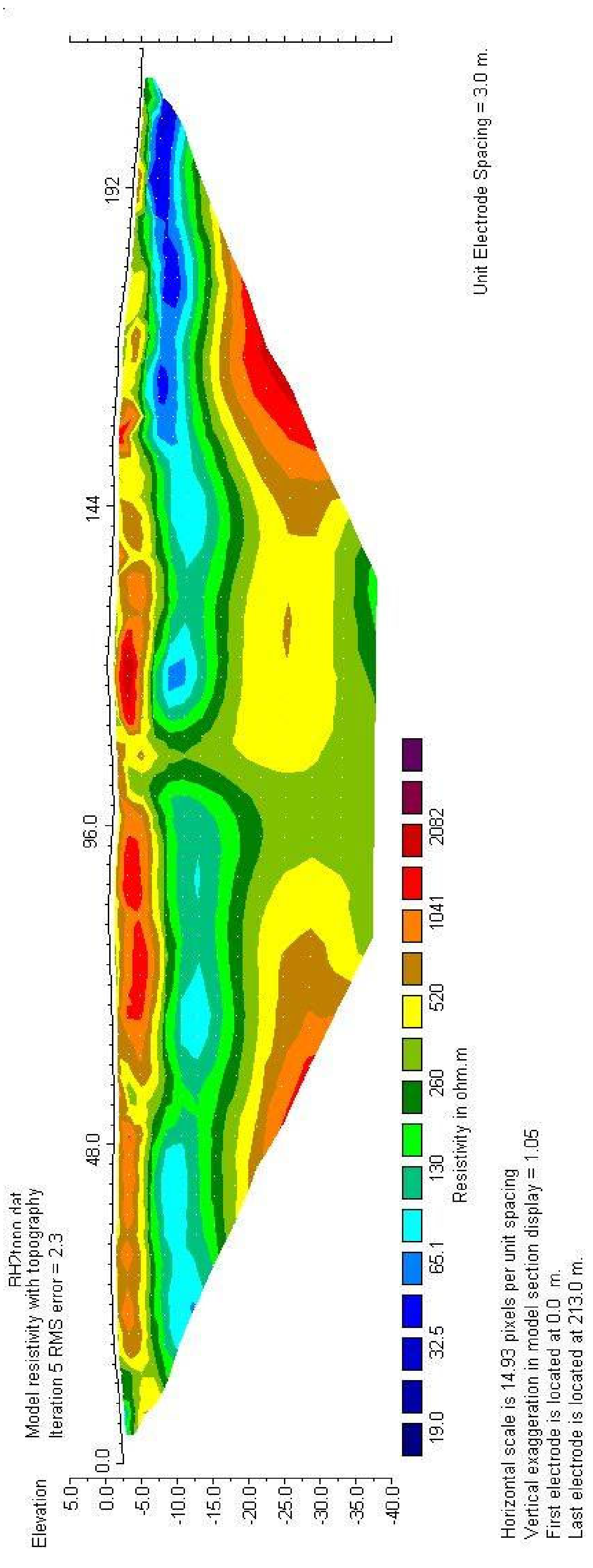


Figure 19: ERI Line 2

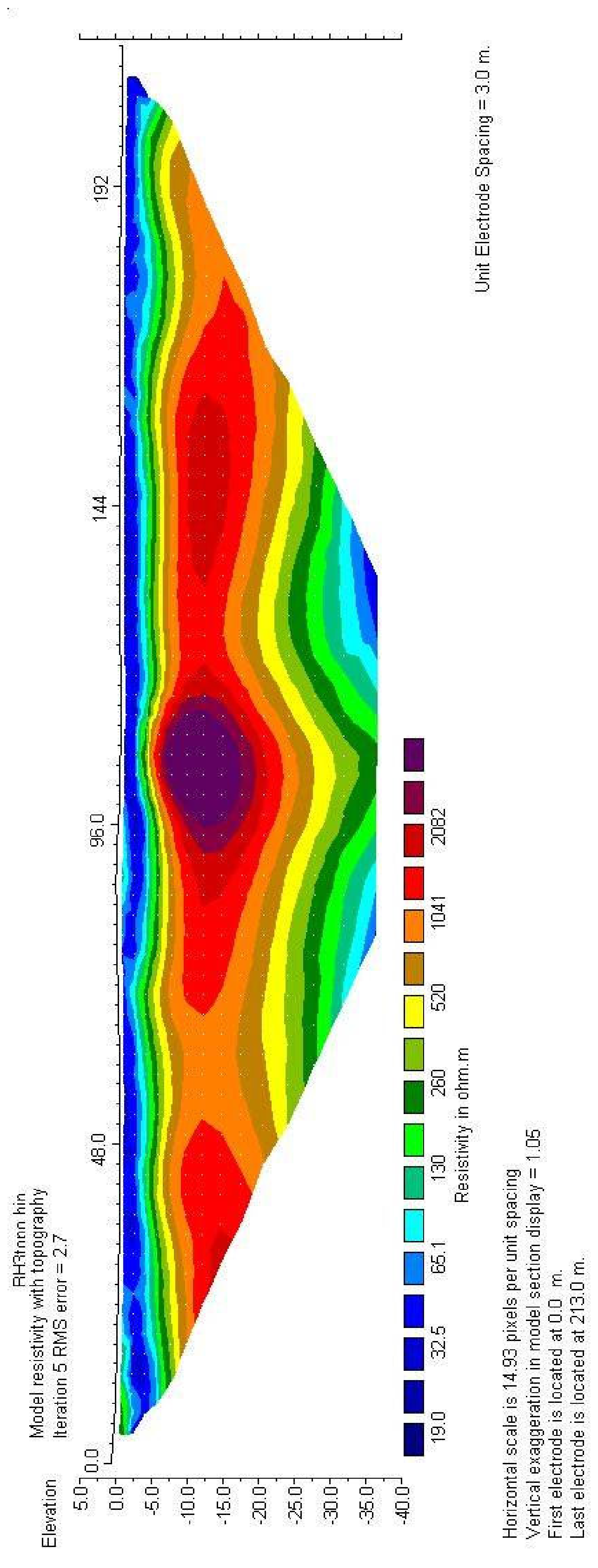


Figure 20: ERI Line 3

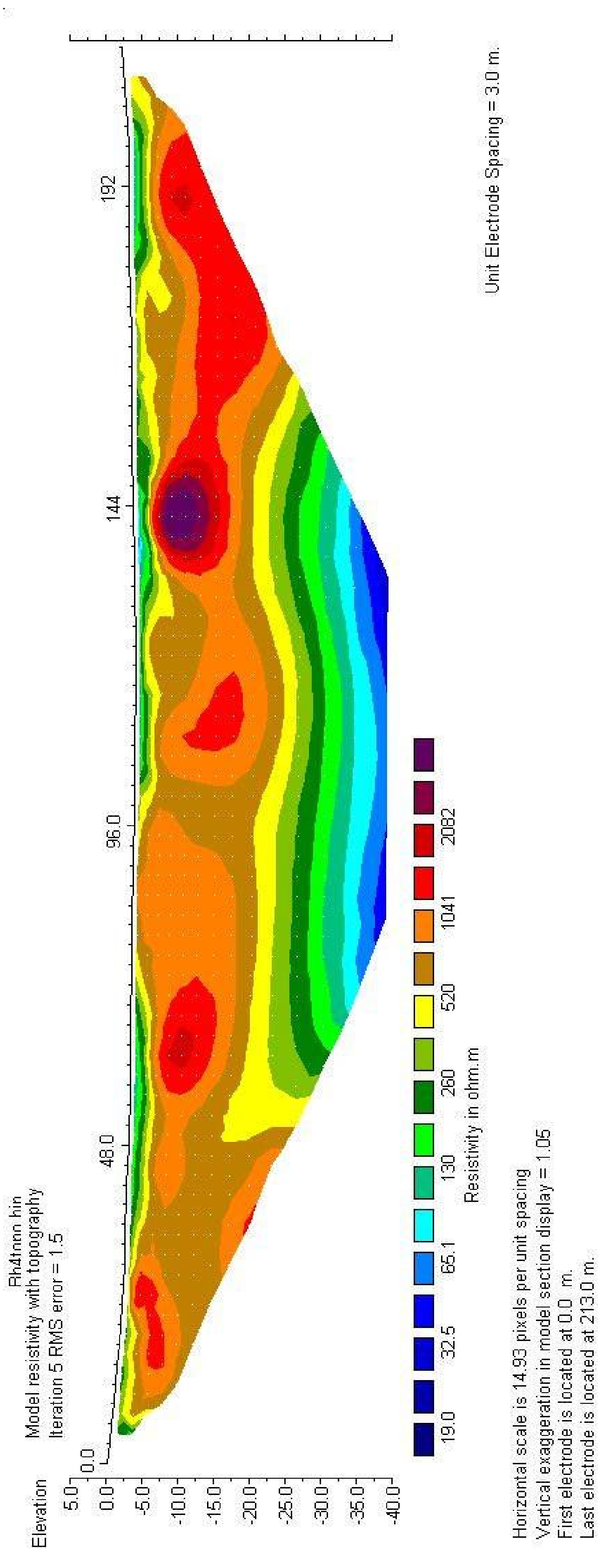


Figure 21: ERI Line 4

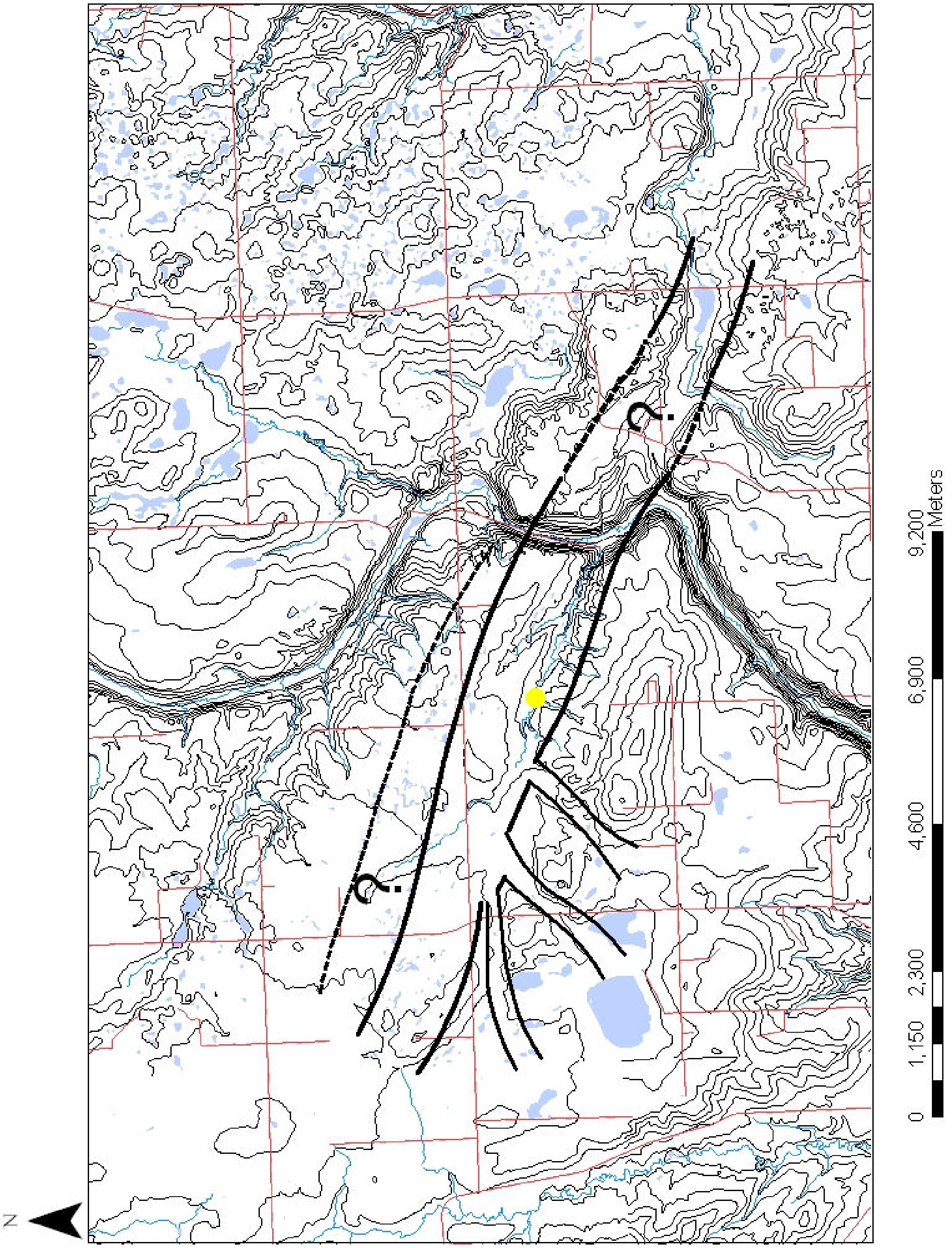


Figure 22: Location of preglacial channel. Dashed lines indicate boundaries that are not as certain. The source of Big Hill Springs is indicated with a yellow dot.

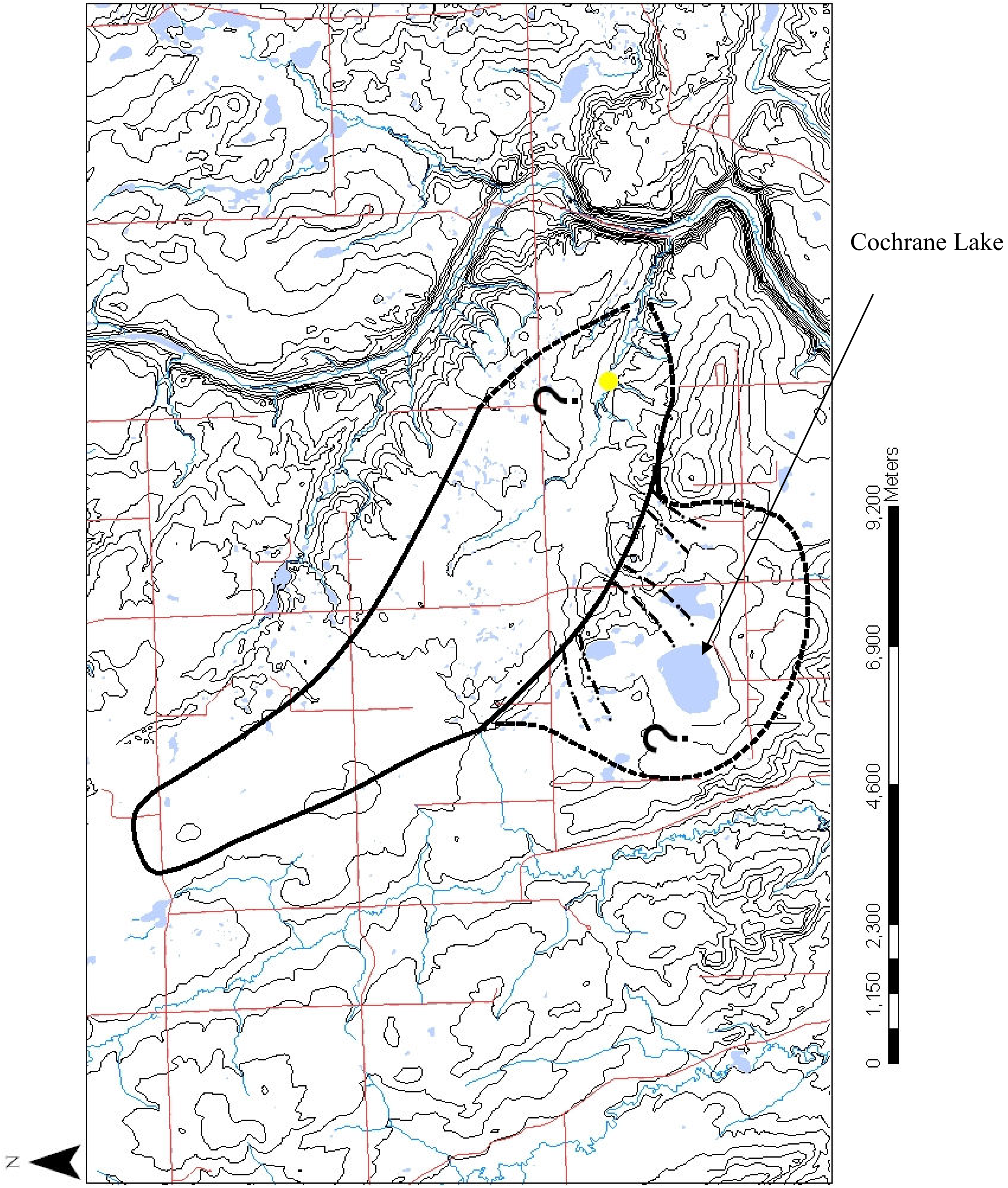


Figure 23: Watershed for Big Hill Springs. Areas in question are indicated by dashed lines. The source is indicated by a yellow dot. The dot-dashed lines are the locations of the tributaries of the preglacial channel.

Conclusions

Building on conclusions arrived at by Caron (2004), a watershed for Big Hill Springs, Alberta, Canada was constructed based on the premise that a zone of enhanced recharge existed in the area. This was tested through analysis of a two year monitoring program of the flow, temperature, and electrical conductivity of the springs. Along with analysis of two groundwater dating techniques, four electrical resistivity lines were run. The flow monitoring program indicates fluctuating volumetric discharge rates with a potential seasonal lag present. The temperature proved to be consistently higher than the annual average temperature, again with a potential seasonal lag. The EC was also quite consistent and it was seen that Big Hill Springs has a lower EC than spring water flowing from bedrock and springs located in the West Nose Creek watershed. The fluctuating flow, higher than yearly average temperature, and low EC are all indicative of a local recharge area. Stable isotope dating by Caron (2004) dated the groundwater at 6.36 years old, and tritium dating by Grieef (2006) placed the waters between less than 5 and 10 years old. Again, when compared to waters from bedrock and other springs, Big Hill Springs proves to be fairly young. ERI lines resolved a layer of gravel or sand and gravel underlying a thinner layer of organic matter and/or till. The depth to gravel or sand and gravel varies from a depth of about 5 m up to the surface and from Figures 10 and 11, the buried channel sands and gravels seem continuous to the northwest.

This layer of gravel or sand and gravel is acting as an area of enhanced recharge, based on evidence pointing to a local recharge area with young groundwater. The sediments were deposited in a fluvial setting by a preglacial channel. The springs are issuing from the contact of the channel with bedrock. Based on the locations of these higher conductivity sediments, along with topography and the locations of other watersheds, the watershed for Big Hill Springs was constructed.

Future Work

Future work should include the installation of a continuous flow and temperature monitoring system. Consistent EC measurements would also be an asset. From these, deductions can be made on whether or not the inferences made on the EC and the flow are true.

A qualitative study could be undertaken to try to prove if there is, in fact, flow between the Paskapoo and the overlying fluvial sediments. A variation of a column test could possibly be used to determine any amount of flow between the two types of material. If there is flow between, some sort of quantitative estimate would be very useful.

More ERI lines can be used to attempt to determine the extent of the fluvial sediments. Specifically, around the source would be helpful to prove if the springs do issue at the terminus of the channel, and if there is a layer of gravel or sand and gravel past the source of the springs. Lines can also be run in the Cochrane Lake area to attempt to determine if there is a layer of hydraulically conductive material that would allow water to flow towards Big Hill Springs. Specifically, running a few lines over the mapped tributaries of the preglacial channel would be useful in determining if that area could drain the lake. ERI surveys at the northwestern most extent of the watershed would also be helpful in examining if the fluvial sediments feed the springs for the entire extent of the watershed. This would also aid in further mapping the preglacial channel.

Finally, a more in depth study of Cochrane Lake would be useful in determining its effect on the Big Hill Springs watershed, if any. An attempt at a water balance of the lake could determine what watershed it is a part of. If it does turn out to be a part of the Big Hill Springs watershed, a geochemical analysis can be undertaken to find any sort of similarity to the geochemistry found at Big Hill Springs. EC can also be used as a quick comparison to the water at Big Hill Springs.

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