EUB/AGS Geo-Note 2002-06

Baseline Discharge and Geochemistry of the Wiau Channel Springs, 1999 - 2001, Athabasca Oil Sands (In Situ) Area, Alberta

Alberta Energy and Utilities Board

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Baseline Discharge and Geochemistry of the Wiau Channel Springs, 1999-2001, Athabasca Oil Sands (In Situ) Area, Alberta

Sheila Stewart

Alberta Geological Survey

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The standard laboratory water-analyses were performed by Norwest Labs. The stable isotopes values for $\delta^{18}O$, $\delta^{2}H$, $\delta^{34}S$ and $\delta^{13}C$ were determined by the Isotope Science Laboratory at the University of Calgary, headed by Steve Taylor. The stable isotope values of $d^{11}B$ were determined by Dr. M. Wieser at the University of Calgary. The $^{87}Sr/^{86}Sr$ values were determined by the Isotope Laboratory at the University of Saskatchewan headed by Dr. Chris Holmden. The neutron atomic adsorption analyses for chloride, bromide and iodide were performed by Dr. John Duke at the SLOWPOKE Nuclear Reactor Facility at the University of Alberta.

Calibration of the flowmeter was conducted by Barb L. Near of Environment Canada's National Calibration Service, National Water Research Institute, Canada Centre for Inland Waters. Rick Pickering of Alberta Environment, Edmonton, provided alternate flowmeters.

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Abstract

The Alberta Geological Survey mapped a number of springs issuing from the bank of the Athabasca River at the presumed outcrop of the Wiau Channel Aquifer. Groundwater from the springs was sampled and analysed in the laboratory to confirm that they are discharging from this aquifer. A weir was installed on one of the major springs to determine base flow from the springs and to document discharge rates.

Field determinations of pH, oxidation-reduction potential (ORP), temperature, conductivity, dissolved oxygen (DO) and total alkalinity were made. Samples were analysed in the laboratory for major, minor and trace elements, extractable silica and silicon, and the determination of $\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C$, $\delta^{34}S_{SO4}$, $\delta^{34}S_{S}$, $\delta^{11}B$ and $^{87}Sr/^{86}Sr$.

This report provides a site description, field methodology, field measurements and laboratory analysis results. Our preliminary interpretation is that the springs are indeed discharging from the Wiau Channel Aquifer.

1 Introduction

The purpose of this investigation was to determine the water chemistry and flow volume of a number of springs along the Athabasca River that are believed to be discharging from the buried Wiau Channel Aquifer (Stein et al., 1993). Slumping at the site obscures all outcrop and prevents direct confirmation of the geology at surface. The water chemistry of these springs compares to that of wells completed in the aquifer, indicating a strong likelihood of hydraulic connection between the springs and the aquifer. Observations of flow volume, or discharge, of the springs were made because they provide information necessary for regional groundwater-flow modeling.

1.1 Previous Work

An extensive network of fluvial valleys was incised into the top of the bedrock in Alberta before glaciation and during episodes of glacial melting and retreat. The bedrock surface in Winefred Lake area (map sheet NTS 73M) was recently mapped by Andriashek et al. (2001). The bedrock topography in NTS 73M is dominated by a very large, east-west trending buried valley called the Wiau Channel (Gold et al., 1983).

The Wiau Channel is considered to be one of the largest, if not the largest, buried bedrock channel in the Plains region of North America (L. Andriashek, pers. comm.) and is filled with as much as 300 m of glacial and non-glacial sediment deposited during the Tertiary and Quaternary Periods (Stein et al, 1993). The Channel (Figure 1) has been mapped from the Alberta/Saskatchewan Border to its intersection with the Athabasca River, an estimated length of 200 km along the thalwag of the channel. At it's eastern edge along the provincial border, the Wiau Channel lowland is between 25 and 30 km wide. In the vicinity of the Athabasca river the channel narrows to 15 to 20 km in width.

The Empress Formation forms a basal aquifer system above the floor of the Channel. It is divided into 3 units. Unit 1, the basal sand, ranges from 30 m to more than 60 m thick. Unit I makes up most of the formation thickness within the Channel. Unit 2 is made up of silt and clay and the topmost Unit 3 consists of sand (Stein et al, 1993).

In December 1999, Alberta Geological Survey (AGS) staff observed several springs along the Athabasca River in the area of Township 78, Range 17, Sections 5 and 8. It was suspected at the time that the water from these springs was being sourced from the buried Wiau Channel based on relative elevations and preliminary bedrock topography mapping. Figure 2 shows a detailed location map of the discharge basin with postings of the individual springs and compares bedrock top elevation to modern land surface elevation. The elevation of the bedrock top (Colorado Group shale) within the vicinity of the Athabasca River is between 430 and 440 metres above sea level (masl) and the elevation of the top of the Empress Unit 1 is between 470 and 490 masl (Stein et al., 1993). The surveyed elevation of the source of the largest spring, Spring 2, is 466 masl, and others are estimated at 490 masl. Therefore there is a fairly high level of certainty that the springs along the River are the result of discharge from the aquifer within the Wiau Channel. An important objective of this project was to confirm this interpretation using geochemical methods and to collect spring-flow data that may be used to quantify the groundwater resource potential of the Wiau Channel in the future.

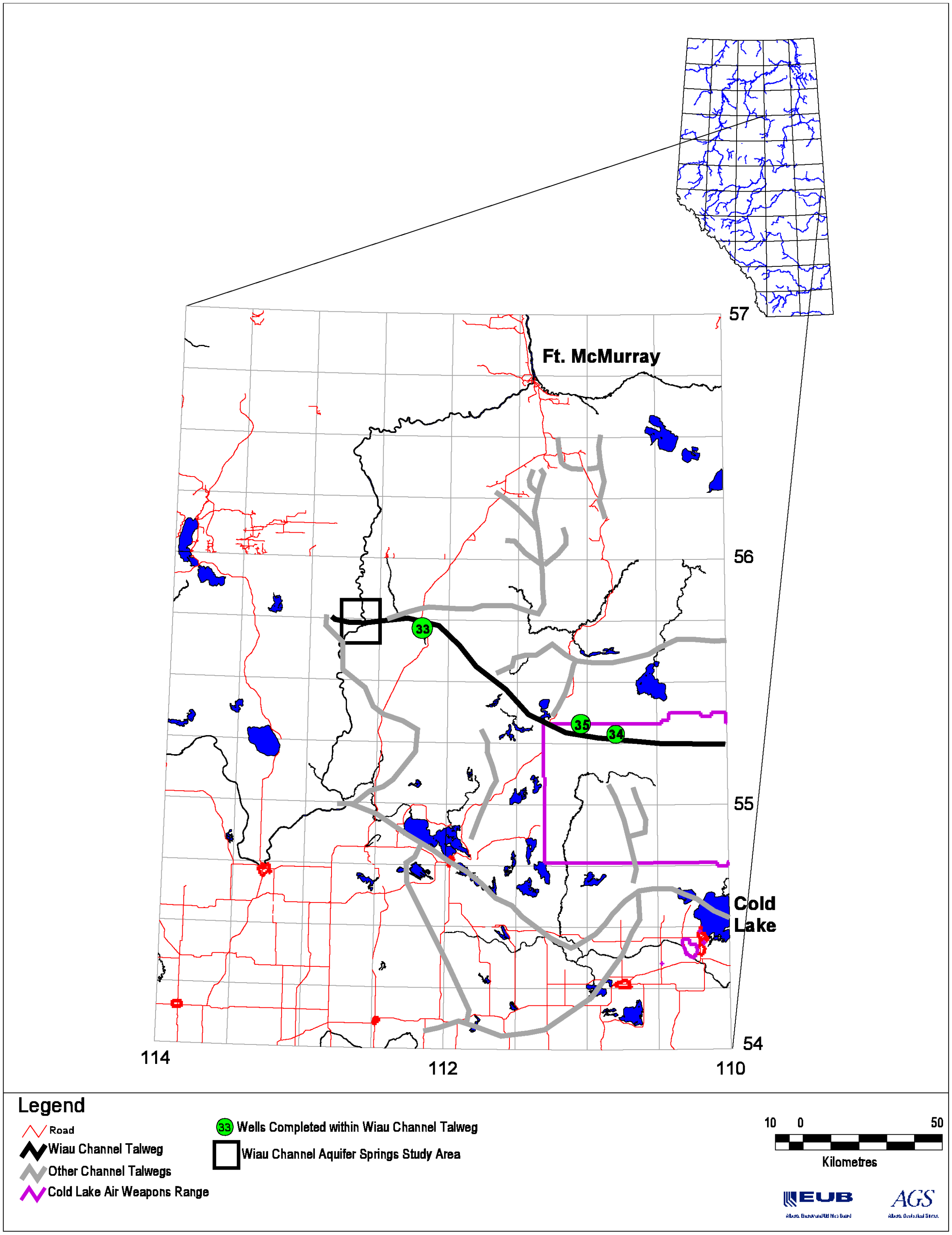


Figure 1. Study area.

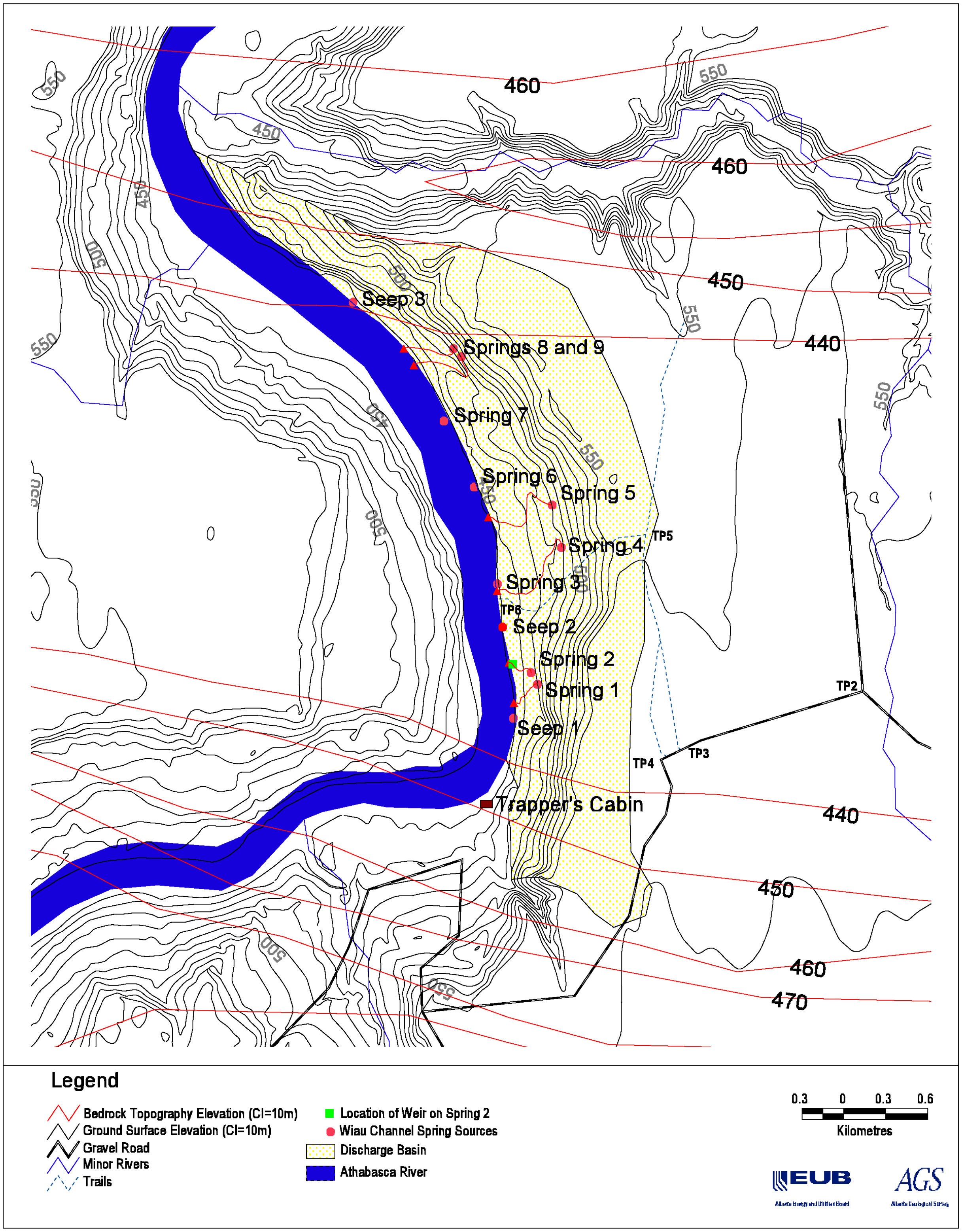


Figure 2. Locations of the Wiau Channel Springs and comparison of top of bedrock elevation with modern land surface elevation.

2 Methods

2.1 Flow Measurements

Two methods of measurement were used in order to determine the flow volumes of the various springs. The first method, deemed the most reliable, involved the construction of a weir and “Still Well” on one of the higher volume springs, Spring 2. The site was selected and the weir was constructed based on ASTM Standard Method D 5242-92 (ASTM, 1992). A construction schematic is shown in Figure 3. All weirs work by restricting the stream channel to a known and consistent size. The height of the water (head) behind the weir determines the rate at which the water flows through the opening. The head is determined by attaching a stream gauge to a piece of angle iron and driving it into the bed of the channel in the still waters behind the weir plate. The “0” on the stream gauge is at exactly the same height as the apex of the V-notch.

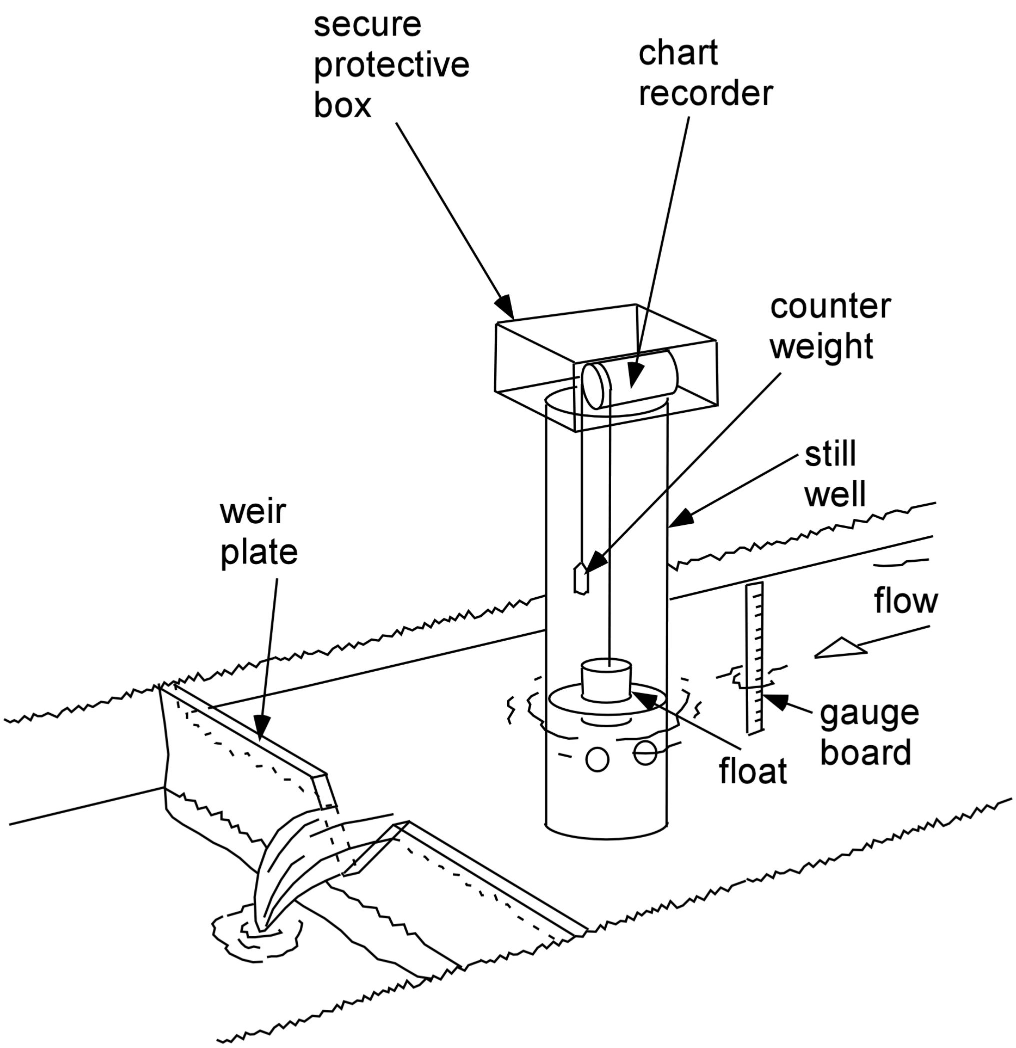


Figure 3. Weir and Still Well setup (not to scale).

In this study, a 90° V-notch weir was used based on the flow volume of the spring, which was estimated to be less than the upper limit of 70 l/s for this type of weir (Brassington, 1998). The head of the water behind the weir is mathematically converted to flow volume based on the following equation (Brassington, 1998):

$$Q=1.342h^{2.48} \quad (1)$$

Where

Q is discharge (m^3/s)

h is the height of the backwater above weir crest (m)

A Still Well with a Stevens Type F Model 68, 32-day chart recorder was then constructed in the pool behind the weir at a standard distance so as not to disturb the flow over the weir. The chart recorder is a constant and relatively simple method of recording continuous head measurements. The Still Well is a vertical pipe set into the stream bed behind the weir with a hole to allow flow so as to maintain the same water level within the well as that of the pond behind the weir. The cart recorder float within the Still Well is protected against ripples on the surface of the pond as well as weather and flotsam. It also serves as a stable support or stand for the chart recorder. Measurements were not recorded when the Still Well was frozen.

The second method of measuring flow volumes involved the use of a Price 1210 AA type in-stream flowmeter on a wading rod (Figure 4). This method was employed so that other springs in the discharge basin could also be accurately measured. The spring with the weir (Spring 2) was used as a calibration point to ensure the accuracy of the flowmeter.

Figure 4. Flowmeter and wading rod.

Two different flowmeters of the same type were used for this study. Both were calibrated by Environment Canada's National Calibration Service at the National Water Research Institute, Canada

Centre for Inland Waters. All flowmeter measurements were taken by the same individual to ensure consistency (except for those taken in August of 2001 as discussed in Section 4.2.1.). A stage discharge relationship (Figure 5), which is a plot of the theoretical flow over the weir versus the flow measured by the flowmeters, shows that they performed acceptably well.

Not all the springs could be measured on a monthly basis because of access difficulty during high water. Springs 1, 2, 3 and 4 were easily accessed due to their fortuitous location along a somewhat straight stretch in the river. Data for these springs were obtained on a monthly basis. Springs 5 to 9 however, are located farther north along the most difficult portion of the river to access, and were visited only when the river was either frozen or very low. The scarcity of data from these springs is a reflection of this fact. Flowmeter measurements were not taken from December 2000 to February 2001 because severe icing conditions would have adversely affected the flowmeter.

2.2 Chemical Analysis

Water samples from the springs were collected by AGS staff and analysed in the laboratory for major, minor and trace elements, extractable silica and silicon, and for the determination of $\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C$, $\delta^{34}S_{SO4}$, $\delta^{34}S_{S}$, $\delta^{11}B$ and $^{87}Sr/^{86}Sr$ using protocols described in detail by Lemay (2002a).

It is important to note that two methods of sampling for $\delta^{34}S_{SO4}$ and $\delta^{34}S_{S}$ were used for Spring 2 only. Initial results from a synchronous sampling program showed similar results for $\delta^{34}S_{SO4}$ and $\delta^{34}S_{S.}$ This seemed to indicate that sulphide may be oxidizing to sulphate in which case analysis for either may provide similar results. Initially, one-litre samples of water were taken from the spring, cadmium acetate was added and cadmium sulphide precipitated. This was then sent for analysis for $\delta^{34}S_{S.}$ In order to obtain a $\delta^{34}S_{SO4}$ value, another sample, this time in a 125ml bottle was taken from Spring 2 and a few drops of dilute HCl and Barium Chloride was added, and then sent to be analysed. This method, it was thought, allowed for the potential for oxidation. Therefore, Spring 2 was re-sampled with a modified procedure, and the only $\delta^{34}S_{S}$ and $\delta^{34}S_{SO4}$ sample from Spring 8 was also obtained using the following modified procedure. Cadmium acetate was added, the CdS precipitate filtered off after one day, and $BaCl_2$ was added to the filtrate to precipitate $BaSO_4$. The CdS precipitate was dried in an oven for a few hours and stored in a plastic vile, which was then sent for analysis for $\delta^{34}S_{S}$. The water sample containing the $BaSO_4$ was also sent for analysis to determine $\delta^{34}S_{SO4.}$ Results of the analysis are discussed later in sections 4.2.2.2, and 5.3.2.4.

Field parameters including pH, temperature, electrical conductivity, oxidation-reduction potential (ORP) and dissolved oxygen (DO), were taken using standard methods described in the instruction manuals of the digital meters. Alkalinity was measured in the field with a Hach digital titration kit.

All efforts were made to deliver the samples to an analytical laboratory within the specified holding times recommended by the receiving laboratory.

Water samples from three water wells completed within the Empress I sands and gravels were also analysed for the same constituents using protocols compiled by AGS and described in detail by Lemay (2002b). In addition, surface water near the source of Spring 2 was sampled for the same constituents following similar protocols (Lemay, 2002a).

3 Occurrence and distribution

The Wiau Channel Springs are located along the Athabasca River in Tp. 78 Rg 17 W4M, north of the

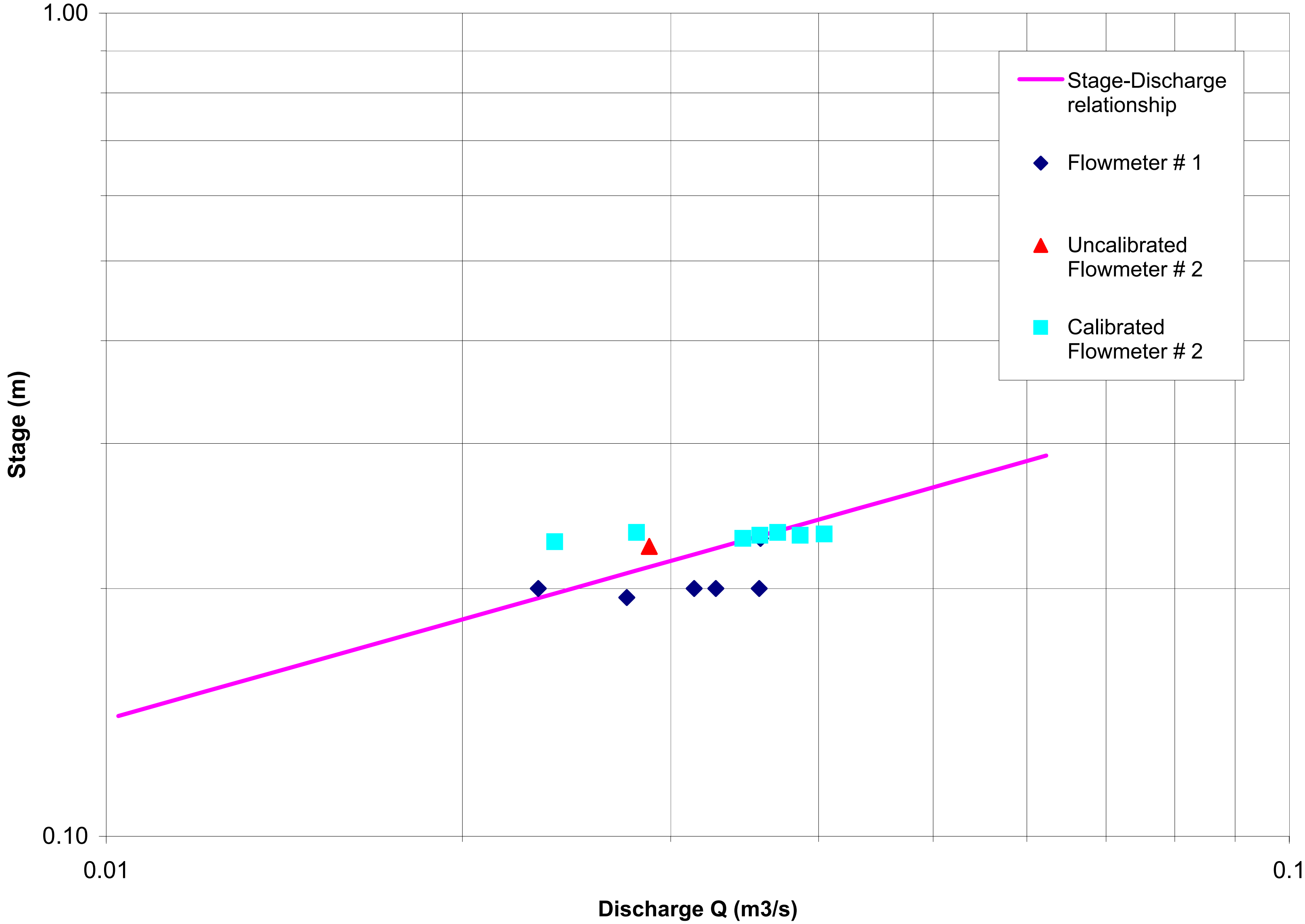


Figure 5. Stage/discharge relationship of flowmeter measurements.

town of Wandering River and directly West of the House River Campground off Highway 63 (Figure 1). All of the springs in this study lie along the east bank of a bend in the river that is thought to be where the Athabasca River cuts into the outcrop of the Wiau Channel Aquifer (Figure 2). Detailed location data measured by hand-held GPS devices are included in Table 1. A total of 9 distinct springs and three seeps were mapped, as shown in Figure 2.

3.1 Access

Road access to within a few kilometres of the river is possible at any time of the year by vehicle. The remaining distance can be covered either on foot or by all terrain vehicle (ATV) along cutlines and trails. Key turning points on the cutlines and trails are designated by the label "TP" on Figure 2. During normal river levels (river flow volume ~500 to 700 m^3/s), Springs 1, 2, 3 and 4 are easily accessible by ATV. When the river flow volume exceeds 800 to 1000 m^3/s, it is necessary to walk above the high water level to these four springs. The discharge points of Springs 5 to 9 may only be accessed by ATV when the river volume is less than 300 m^3/s. Otherwise, foot access is required. The river level information may be accessed at the Alberta Environment Hydrology Branch web site (see references). UTM co-ordinates for the various turning points and spring locations are in Table 1.

Table 1. Turning point and spring locations.

Turning points	Easting	Northing	Elevation(masl)	Description
TP1	424239	6177814	619 (est.)	Turnoff Highway 63 to get to springs
TP2	402179	6177241	570 (est.)	Park truck, ATV staging area
TP3	400908	6176863	565 (est.)	Intersection of East/West road and North/South ATV trail
TP4	400787	6176825	565 (est.)	Intersection of East/West road and roughed up cutline entrance
TP5	400683	6178346	558 (est.)	"Y" junction in ATV trail
TP6	399655	6177903	450 (est.)	Intersection of ATV trail and Athabasca River
Spring 1	399928	6177301	470 (est.)	Spring 1 source
	399763	6177169	450 (est.)	Confluence of Spring 1 discharge and river
Spring 2	399884	6177381	466.6	Spring 2 source
	399728	6177451	446.4	Confluence of Spring 2 discharge and river
Spring 3	399649	6178002	450 (est.)	Spring 3 source
Spring 4	400096	6178257	490 (est.)	Spring 4 source
	399645	6177951	445 (est.)	Confluence of Spring 4 discharge and river
Spring 5	400030	6178553	490 (est.)	Spring 5 source
	399583	6178466	445 (est.)	Confluence of Spring 5 discharge and river
Spring 6	399485	6178678	445 (est.)	Spring 6 source
Spring 7	399274	6179138	445 (est.)	Spring 7 source
Spring 8	399396	6179587	490 (est.)	Spring 8 source
	399065	6179528	445 (est.)	Confluence of Spring 8 discharge and river
Spring 9	399340	6179645	490 (est.)	Spring 9 source
	398993	6179645	445 (est.)	Confluence of Spring 9 discharge and river

*Note: All co-ordinates UTM Zone 12, Nad 83; (est.)=estimated from map

4 Description of Springs

Northeastern Alberta is vegetated with boreal forest consisting of large stands of poplar, spruce, pine, alder and willow, with undergrowth of mosses and other common species of woodland perennials. The bank of the Athabasca River near the springs is no different with the exception of ferns, which grow quite extensively beneath the thick poplar canopy. The river valley bank descends fairly steeply from the flats above. It is generally very stable with the exception of the outcrops where the spring-discharge meadows occur. Here, the slope has failed in a number of places producing segments of steeper slopes above the generally flat discharge meadows. The discharge meadows may be a series of terraced wetlands, or a single, level meadow depending on the stability of the slope they are situated on. The discharge meadows may be as large as 150 m in diameter. All of the larger springs occur in similar settings, typically between 20 to 25 vertical metres above the Athabasca River and anywhere from 200 to 300 m inland from the river edge. Springs 1, 2, 4, 5, 8, and 9 discharge from this type of setting, and they generally are characterized by numerous small discharge points within the meadow which coalesce to form a single discharge channel. A flowmeter was used to measure spring discharge within these channels.

The remaining springs, Springs 3, 6 and 7, occur in a different kind of physical setting. Each of these springs are within metres, both vertically and laterally, of the river level. The sources of these three springs are right on the flood plain of the Athabasca River and the discharge at each is from a single point with a generally low flow volume. The discharge point-source areas may be measured in square metres as opposed to the tens or hundreds of square metres for the discharge meadow of the larger springs.

Phreatophytes such as willows, rushes, sedges and grasses grow extensively in and around the discharge points of all the springs, and iron in the sediment is common.

In February 2002, Springs 1 to 4 were observed to be flowing when the air temperature was –25° C. Because of the consistency in water temperature, there is plant growth within the deepest parts of the spring channels even during the depths of winter (Figure 6), and growth within close proximity to the channels began much earlier in the spring than anywhere else.

Figure 6. Plant growth in the channel of Spring 2 in February, 1999.

4.1 Spring 1

4.1.1 Discharge

Spring 1 is the southernmost spring and is the second largest in terms of average flow volume. The discharge meadow is estimated to be 150 m long by 50 m wide.

Spring discharge was measured almost monthly with a flowmeter between August 2000 and November 2001. Discharge volumes ranged between 18 l/s in August of 2001, to as much as 39 l/s in May of 2001 with an average of about 27 l/s (Table 2). A total of twelve measurements were made between August 2000 and November 2001.

4.1.2 Chemistry

No chemical analysis were performed on Spring 1. Based on similarities in the discharge environment and field parameters between Spring 1 and Spring 2 (described below) it is expected that the water type is very similar to that of Spring 2. Furthermore, the source of Spring 2 is within 90 m of the source of Spring 1 and at about the same elevation. Field conductivity was measured at 564 µS, which is twice that of the Athabasca River, and pH was neutral at 7.55. The temperature of the spring at the source was 5.4 °C in September 2001. Field parameters are documented in Table 3. Some iron oxide deposition was noticed in the sediment at the source.

4.2 Spring 2

4.2.1 Discharge

Spring 2 had the largest flow volume of all the springs, with an average measured discharge volume in 2000-2001 of about 32 l/s. The weir and chart-recorder equipped Still Well discussed above were constructed on this spring. Measurements taken with the chart recorder show large fluctuations due to storms. At one point in July 2001, the chart-recorder measured flood stage river-levels on the Athabasca River that reached upwards to only a few centimetres from the base of the chart recorder box.

A hydrograph of the spring 2 hydrograph data versus precipitation at the May Lookout Station and an on-site rain gauge (Figure 7) shows various hydrological occurrences such as storm events and local evapotranspiration cycles. It also shows a base-level increase of about 10 l/s from the summer and fall of 2000 to the summer and fall of 2001. This may be the result of a one-year time lag in the pressure pulse generated from higher precipitation in 2000 in the recharge area. Longer-term measurements and more precipitation data would be needed to determine if this time lag actually exists with any certainty.

In-stream flowmeter measurements generally agree with the expected performance of the weir for Spring 2 as indicated previously (Figure 5). However, discrepancies of as much as 10 l/s (almost 30%) did occur in August 2000 and August 2001, which was attributed to inexperienced use of the in-stream flowmeter. On the first occasion, the flow was overestimated using the flowmeter and on the second it was underestimated. It is important to note, however that the mean annual flow volumes using the flowmeter and the weir were within 1% of each other, being 32.4 l/s and 32.1 l/s respectively.

One observation of note was that in June 2001, 6-foot stands of a plant subjectively evaluated based on photographs as marsh ragwort (Matt Besko, Regional Endangered Species Specialist, Alberta Fish and

Table 2. Monthly stream flow readings of selected spring-fed streams, Wiau Channel Springs locality.

Date	Spring 1 Volume (l/s)	Measurement Method	Spring 2 Volume (l/s)	Measurement Method	Spring 3 Volume (l/s)	Measurement Method	Spring 4 Volume (l/s)	Measurement Method	Spring 5 Volume (l/s)	Measurement Method	Spring 6 Volume (l/s)	Measurement Method
16-Aug-00	n/m		24.8	Weir	n/m		n/m		n/m		n/m	
17-Aug-00	24.2	Flow Meter	24.8	Weir	9.3	Flow Meter	14.6	Flow Meter	n/m		n/m	
14-Sep-00	36.2	Flow Meter	24.8	Weir	9.4	Flow Meter	10.0	Flow Meter	n/m		n/m	
12-Oct-00	30.8	Flow Meter	24.8	Weir	7.8	Flow Meter	11.2	Flow Meter	n/m		n/m	
15-Nov-00	21.4	Flow Meter	23.2	Weir	3.0	Flow Meter	12.2	Flow Meter	n/m		n/m	
18-Feb-01	n/m		30.0	Weir	n/m		n/m		n/m		n/m	
20-Mar-01	n/m		33.2	Weir	n/m		5.7	Estimated	6.1	Estimated	0.1	Estimated
25-Apr-01	26.6	Flow Meter	35.0	Weir	2.0	Flow Meter	12.2	Flow Meter	n/m		n/m	
25-Apr-01			35.0	Weir			4.7	Estimated	n/m		n/m	
25-May-01	39.2	Flow Meter	35.8	Weir	3.5	Flow Meter	6.2	Flow Meter	n/m		n/m	
25-Jun-01	29.3	Flow Meter	36.5	Weir	7.4	Flow Meter	7.4	Flow Meter	n/m		n/m	
26-Jul-01	27.3	Flow Meter	36.2	Weir	1.1	Estimated	8.7	Flow Meter	n/m		n/m	
28-Aug-01	17.9	Flow Meter	34.3	Weir	2.8	Flow Meter	8.8	Flow Meter	n/m		n/m	
29-Aug-01	n/m				n/m		n/m		n/m		2.3	1L bottle
08-Sep-01	n/m		35.8	Weir	n/m		n/m		n/m		n/m	
27-Sep-01	27.1	Flow Meter	36.5	Weir	8.7	Flow Meter	8.6	Flow Meter	n/m		n/m	
28-Sep-01	n/m				n/m		n/m		n/m		n/m	
26-Oct-01	22.8	Flow Meter	36.5	Weir	4.4	Flow Meter	7.0	Flow Meter	1.7	Estimated	n/m	
27-Nov-01	26.3	Flow Meter	35.0	Weir	5.3	Flow Meter	4.8	Flow Meter	n/m		n/m	
27-Nov-01	n/m		35.0	Weir	n/m		n/m		n/m		n/m	
Mean (l/s)	**27.4**		**32.1**		**5.4**		**8.7**		**3.9**		**1.2**	
Mean (m^3/d)	**2369.7**		**2769.6**		**466.3**		**752.9**		**337.0**		**100.7**	
n/m = not measured.												

Table 2 (continued). Monthly stream flow readings of selected spring-fed streams, Wiau Channel Springs locality .

Date	Spring 7 Volume (l/s)	Measurement Method	Spring 8 Volume (l/s)	Measurement Method	Spring 9 Volume (l/s)	Measurement Method	Seeps Volume (l/s)	Measurement Method	Sum of Arithmetic Mean
16-Aug-00	n/m		n/m		n/m		n/m		
17-Aug-00	n/m		n/m		n/m		n/m		
14-Sep-00	n/m		n/m		n/m		n/m		
12-Oct-00	n/m		n/m		n/m		n/m		
15-Nov-00	n/m		n/m		n/m		n/m		
18-Feb-01	n/m		n/m		n/m		n/m		
20-Mar-01	0.8	Estimated	0.8	Estimated	7.6	Estimated	0.3	Estimated	
25-Apr-01	n/m		n/m		n/m		n/m		
25-Apr-01	n/m		n/m		n/m		n/m		
25-May-01	n/m		4.4	Flow Meter	6.3	Flow Meter	n/m		
25-Jun-01	n/m		n/m		n/m		n/m		
26-Jul-01	n/m		n/m		n/m		n/m		
28-Aug-01	n/m		n/m		n/m		n/m		
29-Aug-01	n/m		3.6	Flow Meter	4.4	Flow Meter	n/m		
08-Sep-01	n/m		n/m		n/m		n/m		
27-Sep-01	n/m		3.1	Flow Meter	n/m		n/m		
28-Sep-01	n/m		n/m		n/m		n/m		
26-Oct-01	n/m		3.3	Flow Meter	5.5	Flow Meter	n/m		
27-Nov-01	n/m		3.6	Flow Meter	6.5	Flow Meter	n/m		
27-Nov-01	n/m		n/m		n/m		n/m		
Mean (l/s)	**0.8**		**3.1**		**6.1**		**0.3**		**88.9 L/s**
Mean (m^3/d)	**64.8**		**269.0**		**525.4**		**25.9**		**7681.2 m^3/d**
n/m = not mea									

Table 3. Results of chemical analysis.

Key	Sample Date	Name	Field Temp	Field pH	Field Cond (uS/cm)	Eh (mV)	Field DO (mg/L)	Field P-Alk (mg/L)	Field T-Alk (mg/L)
33	May 24, 2001	AGS WR 99-1-230	6.0	7.72	492.00	47.00	0.10	<2	406
34	July 25, 2000	AEC N. Primrose Comp. Station Production Well	8.6	7.99	593.00	7.40	0.00	<2	480
35	April 24, 2001	RAX WS1 Kirby	7.6	7.90	689.00	22.40	2.35	<2	564
101	September 26, 2001	Spring2(clear)	8.6	7.60	600.00	147.40	3.8		384.00
102	September 26, 2001	Spring2(iron)	6.1	7.35	578.00	147.90	3.22		344.00
103	September 26, 2001	Spring8	5.8	7.19	551.00	152.20	0.1		350.00
104	September 27, 2001	Spring1	5.4	7.55	564.00	74.60	0.25		350.00
105	September 27, 2001	Spring4	5.3	7.68	416.00	234.70	3.45		276.00
106	September 27, 2001	Spring3	5.1	7.50	465.00	51.90	0.33		334.00
107	September 27, 2001	Spring5	5.5	7.65	525.00	271.50	2.3		392.00
108	September 14, 2000	Spring2(iron)	7.6	7.97	627.00	71.40	6.35		400.00
130	July 11, 2000	Spring2	6.0	7.33	600.00				
131	July 11, 2000	Spring3	5.0	7.05	460.00				
132	July 11, 2000	Spring4	6.0	6.20	525.00				
133	October 12, 2000	Spring5	5.5	8.16	496.00				
134	October 13, 2000	Spring2	5.0	7.46	600.00	-31.00			
135	October 12, 2000	Athabasca R	7.2	8.60	225.00				
136	September 26, 2001	Athabasca R	11.5	8.53	268.00	376.50	13.20		132
137	September 14, 2000	Surface Drainage	7.4	6.30	50.00	240.60	1.14		30.00

Table 3 (continued). Results of chemical analysis.

Key	Laboratory P-Alkalinity (mg/L $CaCO_3$)	Laboratory Total Alkalinity (mg/L $CaCO_3$)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	Cl (mg/L)	Cl by NAA (ug/ml)	Br by NAA (ug/ml)	Br/Cl (ug/ml)	I by NAA (ug/ml)
33	<5	295.0	64.8	18.7	98.9	5.4	482.00	<6	<0.5	0.44	0.01	0.02	<0.01
34	<5	425.0	25.2	8.56	171	3.2	518.00	<6	35.10	44.00	0.29	0.01	0.18
35	<5	495.0	7.4	3.47	215	2	603.00	<6	16.50	15.80	0.08	0.01	0.06
101	6	388	64.3	20.4	113.0	4.6	460	7	3.50	3.23	0.03	0.01	0.03
102	<5	362	81.2	24.5	97.9	4.6	442	<6	3.90	2.77	0.02	0.01	0.02
103	21	383	63.0	19.7	101.0	4.5	416	25	2.50	1.67	0.01	0.01	0.01
104													
105													
106													
107													
108	<5	386	74.2	22.9	113.0	4.8	471	<6	3.00	2.99	0.05	0.02	0.01
130													
131													
132													
133													
134													
135													
136													
137	<5	40	16.9	3.3	1.6	0.8	49	<6	1.40	0.58	<0.04		<0.013

Table 3 (continued). Results of chemical analysis.

Key	SO_4 (mg/L)	Hardness (mg/L $CaCO_3$)	TDS (mg/L)	Charge Balance Error (%)	As (mg/L)	B (mg/L)	Cd (mg/L)	Cr (mg/L)	Co (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Li (mg/L)	Mn (mg/L)	Hg (mg/L)	Mo (mg/L)
33	38.1	239	463	2.9	0.020	0.360	<0.0005	<0.0008	0.0011	0.002	0.051	<0.002	0.064	0.099	<0.0001	0.009
34	10.6	98.3	509	-1.1	0.020	0.333	<0.0005	<0.0008	0.0007	0.003	0.205	<0.002	0.032	0.044	<0.0001	0.014
35	3.8	32.7	544	-1.8	0.010	0.438	<0.0005	<0.0008	0.0024	0.003	0.133	<0.002	0.018	0.013	<0.0001	0.038
101	91.4	244	530	1.9	<0.01	0.361	<0.0005	<0.0008	0.0014	<0.001	0.005	<0.002	0.056	0.105	<0.0001	0.007
102	138.0	303	567	1.0	<0.01	0.321	<0.0005	<0.0008	0.0010	<0.001	0.006	<0.002	0.057	0.159	<0.0001	0.007
103	66.4	239	487	5.7	<0.01	0.384	<0.0005	<0.0008	0.0014	<0.001	0.013	<0.002	0.056	0.144	<0.0001	0.008
104																
105																
106																
107																
108	119.0	280	568	1.6	<0.01	0.329	<0.0005	<0.0008	0.0013	<0.001	0.158	<0.002	0.057	0.053	<0.0001	0.006
130																
131																
132																
133																
134																
135																
136																
137	4.9	55.70	53.00	14.1	<0.01	0.017	<0.0005	<0.0008	0.0007	<0.001	1.390	<0.002	0.004	<0.001	<0.0001	<0.001

Table 3 (continued). Results of chemical analysis.

Key	Ni (mg/L)	P (mg/L)	Se (mg/L)	Si (mg/L)	Extractable Si (mg/L)	SiO_2 (mg/L)	Extractable Silica (mg/L)	Ag (mg/L)	Sr (mg/L)	S (mg/L)	Tl (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)	Al (mg/L)	Sb (mg/L)
33	<0.001	0.170	<0.004	11.600	18.300		39.100	<0.001	0.497	12.700	<0.004	<0.004	<0.001	0.0007	<0.08	<0.005
34	<0.001	0.650	<0.004	7.630	17.700		38.000	<0.001	0.306	3.540	<0.004	<0.004	0.002	0.0017	0.036	<0.005
35	0.002	2.030	<0.004	7.670	35.700		76.500	<0.001	0.105	1.270	<0.004	0.001	<0.001	0.0041	0.021	<0.005
101	0.002	0.220	0.015	9.010	8.340		17.8	<0.001	0.58	30.5	<0.004	<0.0004				
102	0.002	0.080	0.009	9.740	8.890		19.0	<0.001	0.64	45.9	<0.004	<0.0004				
103	0.002	0.200	0.006	9.810	8.990		19.2	<0.001	0.54	22.1	<0.004	<0.0004				
104																
105																
106																
107																
108	<0.001	0.200	0.006	8.170	7.740	8.170	16.600	<0.001	0.637	39.500	<0.004		0.003	<0.0006	0.018	<0.005
130																
131																
132																
133																
134																
135																
136																
137	<0.001	0.090	0.013	5.900	5.700		12.200	<0.001	0.078	1.650	<0.004	<0.0004	<0.001	0.0012	0.042	<0.005

Table 3 (continued). Results of chemical analysis.

Key	Ba (mg/L)	Be (mg/L)	Bi (mg/L)	Acetic acid (mg/L)	Butyric acid (mg/L)	Formic acid (mg/L)	Propionic acid (mg/L)
33	0.0966	<0.0005	<0.007				
34	0.156	<0.0005	<0.007				
35	0.136	<0.0005	<0.007	<0.2	<0.3	<0.1	164
101							
102							
103							
104							
105							
106							
107							
108	0.0243	<0.0005	<0.007	<0.2	1410	<0.1	174
130							
131							
132							
133							
134							
135							
136							
137	0.0172	<0.0005	<0.007	<0.2	1340	<0.1	17.9

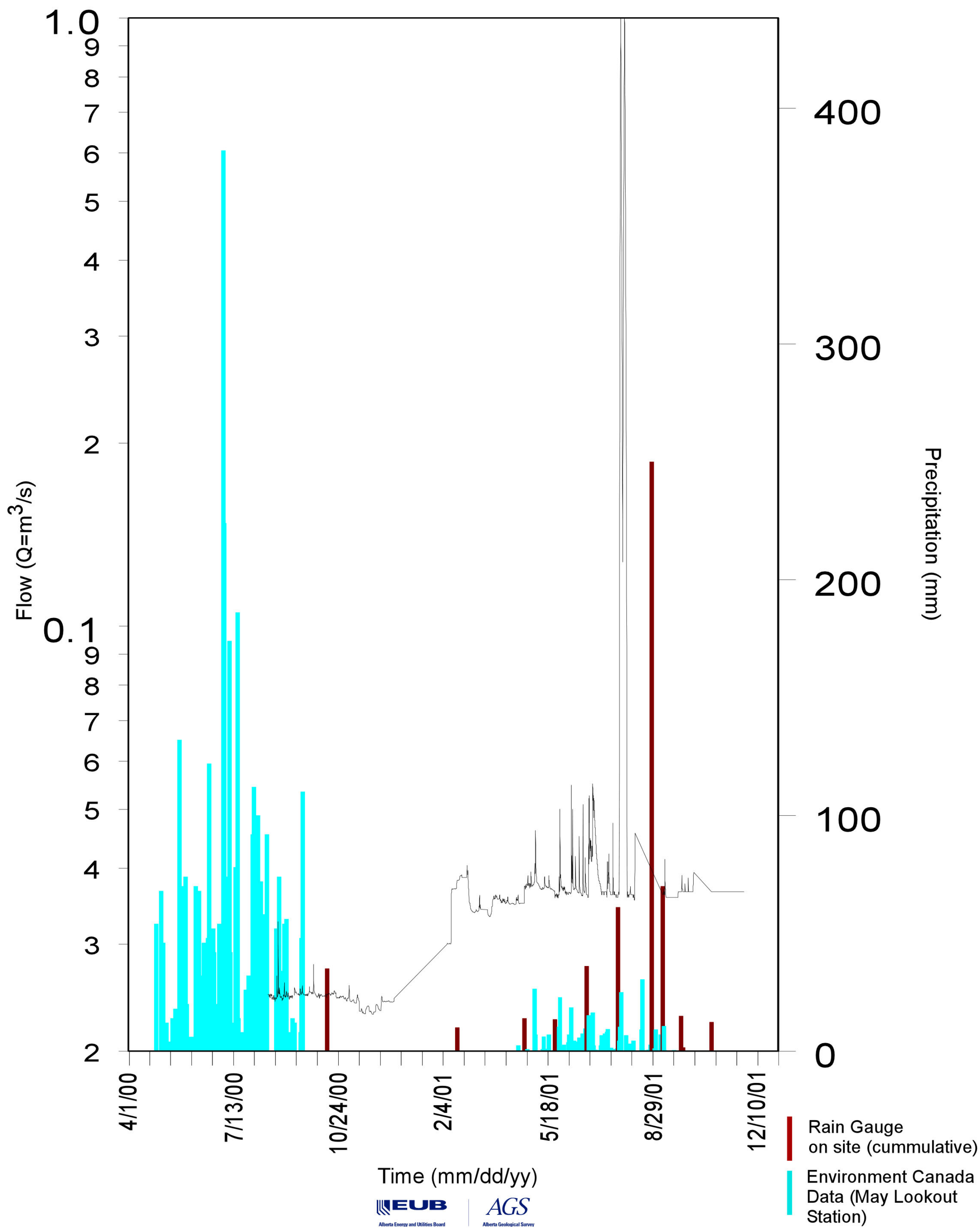


Figure 7. Stream-level hydrograph from Still Well and monthly precipitation, Wiau Channel Spring 2, 2000 and 2001.

Wildlife, pers. comm.) flourished in the discharge meadow of Spring 2 (Figure 8). Evapotranspiration associated with these stands may have contributed to the large daily fluctuations noticed in the chart of the stillwell for this month (Figure 9).

Figure 8. Spring 2 discharge meadow showing extensive growth of marsh ragwort (see text).

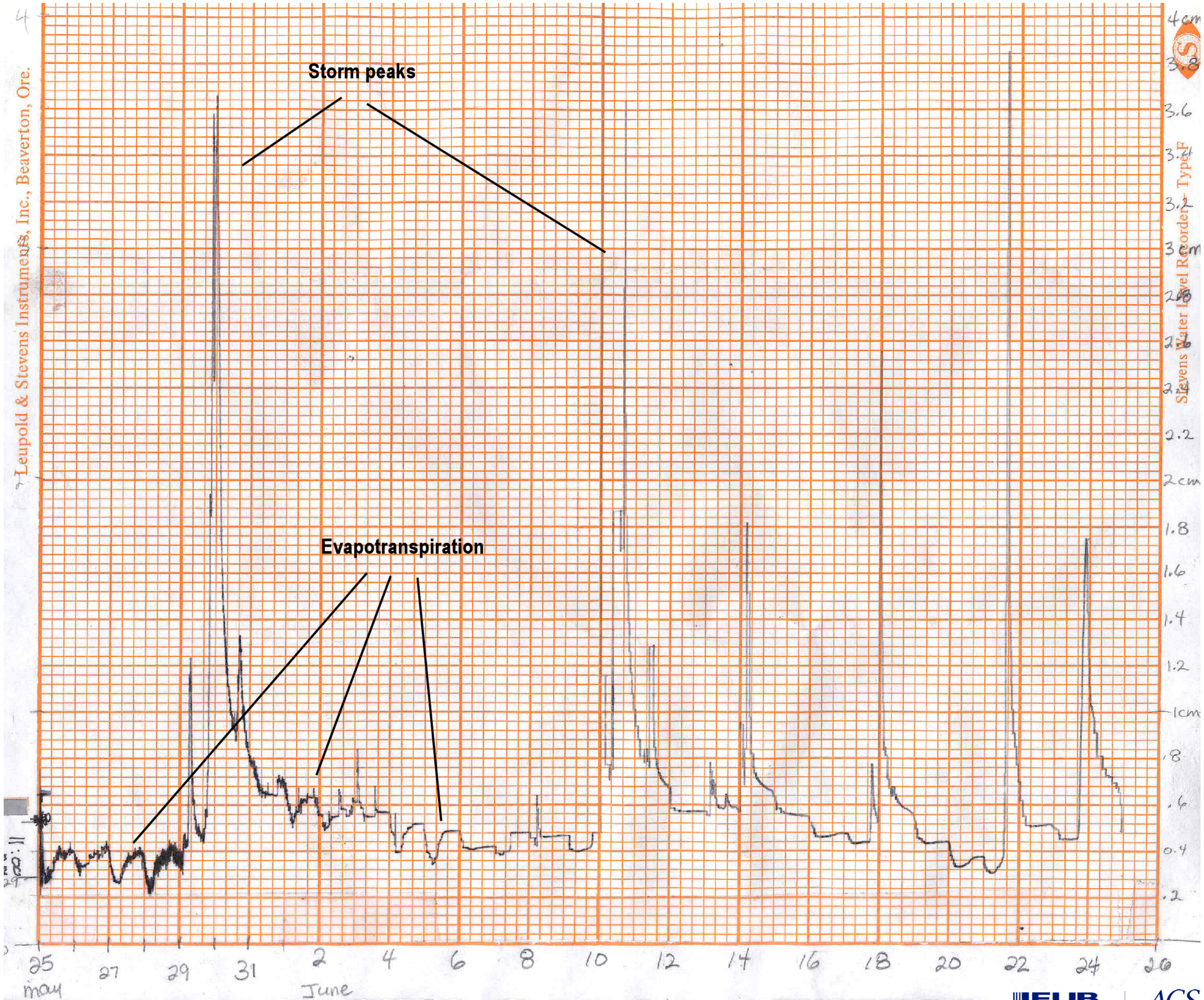
4.2.2 Chemistry

Spring 2 was sampled several times for field parameters and stable isotopes, twice for major, minor and trace elements and once for organic acids. The results of these analyses are in Tables 3 and 4.

4.2.2.1 Field Parameters

Samples were taken from two different point sources at the spring on four separate occasions. One of the discharge streams from one of the point sources shows visible iron oxide precipitation on the rocks and sediments in the stream and is referred to as the “iron” stream. The stream originating from the other discharge point shows no evidence of iron oxide precipitation and is referred to as the “clear” stream. For each of these point sources, an average temperature of 6.7 °C, an average pH of 7.5 and an average electrical conductivity of 601uS/cm were observed.

One anomalous reading occurred with regards to Eh at Spring 2. An ORP reading of –250 was obtained which, based on temperature, equates to Eh –31mV. Field notes indicate that the meter may not have been properly calibrated, and so the reading is suspect. There were no other significant differences in the field parameters based on the source of the sample. These and other field parameters are in Table 3.



EUB Alberta Energy and Utilities Board
AGS Alberta Geological Survey

Figure 9. June chart from Still Well in Spring 2 showing evapotranspiration and storm events.

Table 4. Isotope data for springs of the Wiau Channel Aquifer.

Key	Sample Date	Name	$\delta^{87}Sr/\delta^{86}Sr$	$\delta^{18}O_{H2O}$	$\delta^{2}H_{H2O}$	$\delta^{34}S_{sulfide}$	$\delta^{34}S_{SO4}$	$\delta^{13}C_{Dic}$	$\delta^{11}B$
33	May 24, 2001	AGS WR 99-1-230	0.708788	-18.3	-144		6.7	-14.0	24
34	July 25, 2000	AEC N. Primrose Comp. Station Production Well	0.708726	-17.6	-142		40.8	-18.4	25
35	April 24, 2001	RAX WS1 Kirby	0.708774	-17.1	-140		15.9	-19.1	
101	September 26, 2001	Spring2(clear)*	0.708655	-18.8	-137	-2.9	1.0	-14.4	
102	September 26, 2001	Spring2(iron)*	0.708695	-18.8	-144	-8.3	-0.7	-14.5	
103	September 26, 2001	Spring8*	0.708706	-18.7	-141	-2.6	3.2	-14.3	
104		Spring1							
105		Spring4							
106		Spring3							
107		Spring5							
108	September 14, 2000	Spring2(iron)		-18.2	-145			-12.8	25
109	November 15, 2000	Spring2(clear)		-18.5	-150				
110	June 25, 2001	Spring2(iron)(A)		-18.8	-142	11.3	-6.8	-14.2	
111	June 25, 2001	Spring2(clear)(B)				12.7	-6.4		
137	September 14, 2000	Surface Drainage		-16.4	-130	-10.7	-0.9		
		* Denotes modified sampling procedure for $\delta^{34}S$							

4.2.2.2 Stable Isotopes

Samples were taken for stable isotopes on four separate occasions (Table 4) and from two different point sources on the spring. Multiple sampling events were conducted because variability in stable isotope ratios at springs can sometimes indicate seasonality and strong hydraulic connectivity with nearby surface water. Results were generally constant for the ratios of $^{87}Sr/^{86}Sr$, $\delta^{18}O$, and $\delta^{14}C$, although the clear stream showed a more depleted $\delta^{2}H$ value on one occasion, and a more enriched value on another. There is also a difference in results of $\delta^{34}S_{SO4}$ and $\delta^{34}S_{S}$ from June 2001 to September 2001. This is attributed to different methods of sampling (see previous Section 2.2 Methods, and Lemay, 2002a). The results showed a difference between the two methods, but samples were taken over different seasons which may also influence the results. More work is required to determine the best sampling method to use.

Only one sample of Spring 2 water was taken for $\delta^{11}B$.

4.2.2.3 Major, Minor, and Trace Analysis

Samples were taken at Spring 2 on two separate occasions, once in September 2000, and again in September 2001 (Table 3). The samples that were taken in September 2001 were taken from two different point sources to serve as a basis of comparison between the iron stream and the clear stream. Surprisingly, the dissolved iron content of each was very close, within 0.001 mg/L of each other. However, there were slight differences in other constituents. For example, the iron stream of Spring 2 had slightly higher calcium, sulphate and sulphur, but lower sodium and bicarbonate than the clear stream. All other concentrations of dissolved species were comparable.

The samples taken from the iron stream in September 2000 show similar results as those taken one year later, except the sodium and bicarbonate contents are similar to that of the clear spring sampled in the next year. The iron content is also slightly, but not significantly, higher in September 2000 than September 2001. There does not seem to be any obvious pattern of similarities or differences between the sources or the time of sampling.

4.3 Spring 3

4.3.1 Discharge

This spring lies north of the access trail to the river (near TP6 on Figure 2). Its source is within metres of the river and the associated discharge meadow is estimated at 10 m x 10 m. This locality may be flooded during high river levels. Spring 3 averaged 5.4 l/s in flow volume, which makes it one of the smaller of the springs. Flow was measured monthly.

4.3.2 Chemistry

No samples were taken for chemical analysis. This spring has considerable iron deposition on the sediment and rocks within the stream. The discharge water from Spring 3 had a field-measured electrical conductivity value twice that of the river, but somewhat less than the springs which emanate from higher up the riverbank. This may be due to mixing with fresher river water as a result of bank storage during higher river levels. The temperature and pH are similar to the other springs (Table 3).

4.4 Spring 4

4.4.1 Discharge

The setting of this spring is much the same as Springs 1 and 2. It is located about 450 m up the slope of the river valley and at about 490 masl. The flow volume averages about 8.7 l/s from measurements conducted on a monthly basis. The spring is located north of the access trail.

4.4.2 Chemistry

No iron staining was observed on the rocks and sediment of the stream discharging at Spring 4. In this manner it was similar to the clear type water of Spring 2. Field parameters at the source were taken on two different occasions, and also indicate a strong similarity with Spring 2. Conductivity ranged between 416 and 525 µS/cm, and pH ranged from 6.2 to 7.68 (somewhat more acidic). No other chemical analyses were conducted on this spring.

4.5 Spring 5

4.5.1 Discharge

The setting for Spring 5 is similar to Springs 1, 2, and 4. The discharge meadow is estimated at 100 m x 80 m. Numerous discharge points occur around the south and southeast portion of the meadow, but drainage of the entire meadow occurs at the northwest corner. The discharge meadow is about 450 m up the slope of the river valley from the river, at an elevation of about 490 masl.

The average flow volume was slightly less than 4 l/s. This average is based on only two measurements because access to the stream was available only when the Athabasca River was low. It was measured once before the spring flood in March 2001, and again in October 2001 when the river was close to base level.

4.5.2 Chemistry

No samples were taken for analysis, but field parameters were measured on two occasions. The temperature was 5.5 °C on both occasions, the pH varied between 7.65 and 8.16, which is similar to the other springs. The conductivity is also comparable with the other springs and varied between 496 and 525 µS/cm. Although there is no visible iron staining on the sediment and rocks within the main discharge stream, significant iron deposition is visible in the muddy sediment around the point sources.

4.6 Spring 6

4.6.1 Discharge

This spring's discharge point is at least 20 metres from the riverbed. Flow is very low such that it could not be measured with the in-stream flowmeter. However, it was estimated on one occasion at 0.1 l/s (~1 igpm) and measured at 2.3 l/s on another occasion by timing how long it took to fill a bottle of known volume.

4.6.2 Chemistry

No field parameters or samples were taken. There was no visible iron staining on the rocks and sediment within the stream.

4.7 Spring 7

4.7.1 Discharge

The source of spring 7 is within metres of the river and it also has a very low estimated flow. It was estimated on one occasion, in March 2001 at 0.8 l/s.

4.7.2 Chemistry

No samples were taken or field parameters measured. Iron staining was noticed on the rocks in and around the stream flow.

4.8 Spring 8

4.8.1 Discharge

The source of Spring 8 is very similar to the sources of Springs 1,2,4 and 5. It is about 200 m from the river at a vertical elevation of about 490 masl. This is about 30 m higher in elevation than Spring 2. The discharge meadow is about 100 m across. It forms a large horseshoe shape with numerous discharge mounds converging into one stream on the southern portion of the meadow.

The flow volume of Spring 8 averages about 3 l/s and was measured 5 times with the in-stream flowmeter, and estimated once. The sources have considerable brown and black bacterial growth, as well as algal growth year round (Figure 10).

4.8.2 Chemistry

Spring 8 was sampled for field parameters, stable isotopes, major, minor and trace analysis. The results of these analyses are in Tables 3 and 4.

4.8.2.1 Field Parameters

Field parameters were measured once in September 2001 and the results are generally similar to Spring 2. Temperature was measured at 5.8°C, pH was 7.19 and electrical conductivity was 551µS/cm. Field parameters are in Table 3.

4.8.2.2 Stable Isotopes

Samples taken for stable isotopes (Table 4) show similar results as those taken from Spring 2. Analysis of $\delta^{34}S_{sulfide}$ and $\delta^{34}S_{SO4}$ in particular show similarities to the clear stream of Spring 2 sampled on the same date. No samples were taken for $\delta^{11}B$.

4.8.2.3 Major, Minor and Trace Analysis

Analysis of the water from Spring 8 is similar to Spring 2 with a few exceptions. The total dissolved solids (TDS) is slightly lower at 487 mg/L while CO_3 is three times that of the highest result obtained for Spring 2. SO_4 and S are slightly lower than Spring 2. It is important to note that the charge balance error is rather high at 5.7%.

Figure 10. Out of season plant growth at Spring 2 (top) and bacterial growth at Spring 8 (bottom).

4.9 Spring 9

4.9.1 Discharge

The source of Spring 9 is 80 m northwest of Spring 8 at an estimated elevation of 490 masl. Flow was high enough to take flowmeter measurements on five different occasions and was estimated once. The average flow was slightly more than 6 l/s.

4.9.2 Chemistry

No field parameters were measured, or samples taken for analysis because of the similarity in setting and close proximity to Spring 8.

4.10 Seeps

4.10.1 Discharge

Seeps were observed in a few different locations along the stretch of the Athabasca River encompassing the above springs. They were observed south of Spring 1, between the access trail (near TP6 on Figure 2) and Spring 2, and north of Spring 9. In all cases they were estimated to flow at less than 1 l/minute and therefore were not measured with the flowmeter. Because of their low flow volume, the seeps were frozen during the winter months.

4.10.2 Chemistry

The seeps were not sampled for chemistry. In the winter they were completely frozen but still showed evidence of iron staining in the ice, although none was evident in the summer during flow.

5 Discussion

5.1 Flow Volumes

Flow volumes for Spring 2 were calculated using a weir, in-stream flowmeter and Still Well as described above. All other spring flow volumes were either measured using an in-stream flowmeter or estimated. Table 2 shows the data by spring and measurement method as well as the simple arithmetic mean of each spring. The total mean volume of all the springs is also presented.

Spring 2 had the highest mean flow volume at 32 l/s followed by Spring 1 at 27 l/s. The remaining springs are an order or two in magnitude less in flow volume. Springs 5 to 9 have significantly less data due to poor access. The sum of the mean of all the observed springs is 89 l/s, or almost 7700 m^3/d. It is important to note that arithmetic mean of three of the springs was calculated on only one or two values, but because these are lower volume springs, they will have less of an impact on the total discharge volume. Three of the springs which would have the largest impact on the total discharge volume: Springs 1,2, and 4, were measured regularly. Significantly more work is necessary to more accurately determine total flow volumes, but the calculated mean volume described above is a significant initial step in determining discharge from the Wiau Channel aquifer basal sands and gravels.

5.2 Field Parameters

Field parameters included temperature, pH, electrical conductivity, ORP, DO and alkalinity. Only temperature, pH and electrical conductivity are discussed in detail in this report. Temperature, pH, conductivity, ORP, DO, and alkalinity are tabulated in Table 3.

5.2.1 Temperature

One of the most important indicators used in this study to differentiate surface run-off from spring discharge is the water temperature. Spring temperatures were recorded on a number of occasions and found to be in the range of 5 to 6 °C, which is similar to the calculated mean multi-annual ground surface temperature of 5 to 6 °C for the area (Bachu, 1999), but slightly warmer than mean average annual air temperature of 3.2 °C for the Edmonton area to the south (Rozanski, 1993). The multi-annual ground surface temperature value incorporates temperatures at the ground surface below the insulating effect of snow cover. Therefore the multi-annual ground surface temperature is warmer than the mean average annual air temperature, and is probably more representative of shallow groundwater.

The temperature of the springs at source remained fairly stable throughout the year. The springs remained unfrozen during the winter months. The relatively uniform temperature of the springs enables both plant and bacterial growth throughout the year. Plant growth was observed in the channel of a number of the springs in February 1999, bacterial and algal growth in March 2001 and pre-seasonal plant growth in April 2001 (Figure 10). The springs are very easily observed in the winter as their discharge contrasts with the snow-covered landscape and frozen Athabasca River. In contrast, temperature variations were observed in the Athabasca River near the site, reflecting the impact of seasonal changes in air temperature (Table 3) .

For comparison, the measured temperature of nearby wells completed in the Wiau Channel Aquifer ranges from 6°C to 8.6°C (Table 3, sample keys 33, 34, and 35; also shown on Figure 1).

5.2.2 pH

The pH of all the samples except one are relatively neutral (between 7 and 8) given that neutrality at 5 ºC is 7.37 (Fetter, 1994). Athabasca River water tends to have a higher pH (>8) than most of the springs. One measurement of Spring 5 was also higher than pH 8 but a second measurement of the same spring one year later was more in range with the rest of the springs.

The pH of surface runoff (slough drainage) is slightly more acidic at 6.3, possibly due to the presence of decaying organics. The dark 'tea-coloured' water of the surface drainage is a strong indication of tannic and/or humic acid that may produce a more acidic pH. Analyses were conducted to test for the presence of organic acids. Butyric and propionic acid concentrations are actually lower in the surface drainage water than that of Spring 2. However, alkalinity of Spring 2 is an order of magnitude higher than the surface runoff sample. It is postulated that the bicarbonate in the spring water may be able to buffer the acids in the spring water much more efficiently than the surface drainage water (Lemay, pers. comm.).

The pH of the groundwater from wells completed within the Wiau Channel Aquifer compares with the range of pH measured for the springs.

5.2.3 Electrical Conductivity

Electrical conductivity values for the springs varied from 416 µS/cm to 627 µS/cm with a mean of 539 µS/cm. The mean conductivity for the Athabasca River was less than half that of the springs, 246.5 µS/cm. The conductivity of the surface runoff was an order of magnitude lower than the springs. The electrical conductivity of groundwater in wells completed in the Wiau Channel Aquifer is similar to that of the springs.

5.3 Chemistry

The springs were sampled and analysed using protocols compiled by AGS and described by Lemay (2002a). Springs 2 and 8 were sampled in September 2001 for major, minor and trace elements, anions, and for the determination of isotopes of $\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C_{DIC}$, $\delta^{34}S_{SO4}$, $\delta^{34}S_{sulphide}$, $^{87}Sr/^{86}Sr$, and ^{11}B.

5.3.1 Major Ions

A Piper plot of the major anions and cations was constructed and is shown Figure 11. The Piper plot also shows groundwater from wells completed at various points along the Wiau Channel Aquifer (see Figure 1). Figure 11 shows that the spring water is comparable to well number 33 completed 26 kilometres up-channel from the springs. The water from the springs and well number 33 is of the Na-Ca-HCO_3 type. The fact that these samples contain more Ca+ relative to wells 34 and 35 possibly indicates more mixing with shallow groundwater near the springs. More information on chemistry, lithology and completions of the wells mentioned in this report are in Andriashek and Jean (2002), and Lemay and Jean (2002).

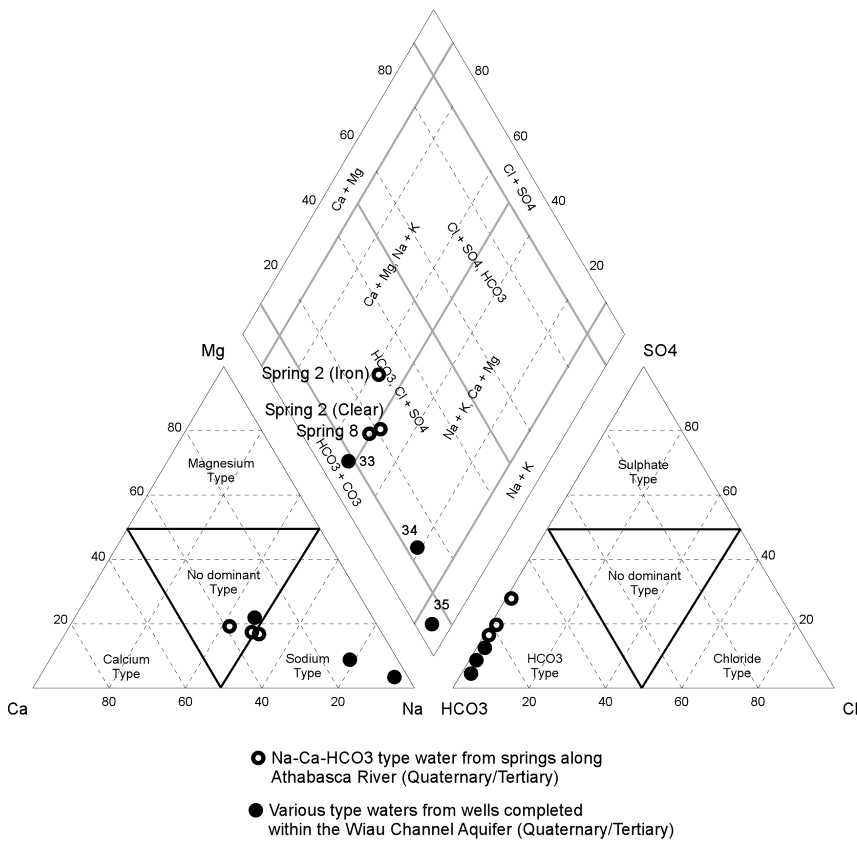


Figure 11. Wiau Aquifer Spring and well water chemistry.

5.3.2 Isotopes

5.3.2.1 $\delta^{18}O_{H2O}$ and $\delta^{2}H_{H20}$

The isotope geochemistry of springs suggests that the spring water is a mix of groundwater from the Wiau Channel Aquifer (the major component), local recharge, or direct precipitation. The isotopic signature of the first two components may be affected by bioactivity and water-rock interaction, complicating the isotopic signature. Precipitation may be affected by seasonality or anthropogenic effects. Baseline isotopic data for precipitation, groundwater in the Wiau Channel Aquifer, and drift aquifers are available in the general region. However, none of these data are from sample locations in close proximity to the spring discharge meadows. Given this fact, the following interpretations should be regarded as preliminary.

As reported above, Springs 2 and 8 were sampled for the determination of $\delta^{18}O$ and $\delta^{2}H$ on different occasions (Table 4). A plot of $\delta^{18}O$ versus $\delta^{2}H$ (Figure 12) compares the Global Meteoric Waterline (Rozanski, 1993), the Edmonton Meteoric Waterline (best fit of multi-annual data provided by IAEA, 2001), an Alberta Formation water trend line (Hitchon and Friedman, 1969), water from the Wiau Channel Springs, water from water wells completed in the Wiau Channel Aquifer, and local surface drainage from a wetland on the flats above and slightly to the east of Spring 2. A more thorough discussion regarding stable isotopes of water from wells completed in the Wiau Channel Aquifer is available in Lemay (2002b).

Given the potential for mixing, the scatter within the plot on Figure 12 is not unexpected. Nearby surface water shows isotopic enrichment probably due to evaporative effects. Water wells completed within the Wiau Channel Aquifer plot below the Edmonton Meteoric Water Line (EMWL). Based on preliminary interpretations of the isotope data, Lemay (2002b) proposes that climatic differences between paleo-recharge and modern conditions could explain the isotopic shift below the EMWL. (The shift below the EMWL could indicate higher humidity levels during recharge, while a shift above the EMWL would indicate drier conditions.) The formation water line (FWL) proposed by Hitchon and Friedman represents data analysed from various waters within the Alberta Basin. Data from the wells falls slightly below and parallel to this line, while the springs are scattered both above and below it.

5.3.2.2 $\delta^{13}C$ in Dissolved Inorganic Carbon

Analysis for $\delta^{13}C_{DIC}$ in the springs revealed consistency in results except for one analysis that was slightly less enriched in $\delta^{13}C$ (Table 4). The values range from –12.8 to –14.5‰ which may suggest that the $\delta^{13}C$ values are a result of mixing between dissolved inorganic carbon derived from carbonate dissolution, and dissolved soil CO_2 (Clark and Fritz, 1997). The spring values compare well with water well number 33, which is completed in the Wiau Channel Aquifer to the east of the springs and has a value of -14‰. A plot of $\delta^{13}C_{DIC}$ versus HCO_3 is shown in Figure 13. The plot shows that the springs are relatively similar to well number 33 but not wells 34 and 35 with respect to these parameters, which are more depleted with respect to $\delta^{13}C_{DIC.}$

5.3.2.3 ^{87}Sr / ^{86}Sr

Analysis of all spring samples for $^{87}Sr/^{86}Sr$ gave results between 0.708655 and 0.708706, well within the range expected for Tertiary/Quaternary aquifers. Typical Tertiary/Quaternary waters range from about 0.7074 to 0.709, and Cretaceous waters are as low as 0.7067 (Clark and Fritz, 1997). Modern seawater is 0.70924 (Clark and Fritz, 1997). The $^{87}Sr/^{86}Sr$ results of wells completed in the Wiau Channel Aquifer

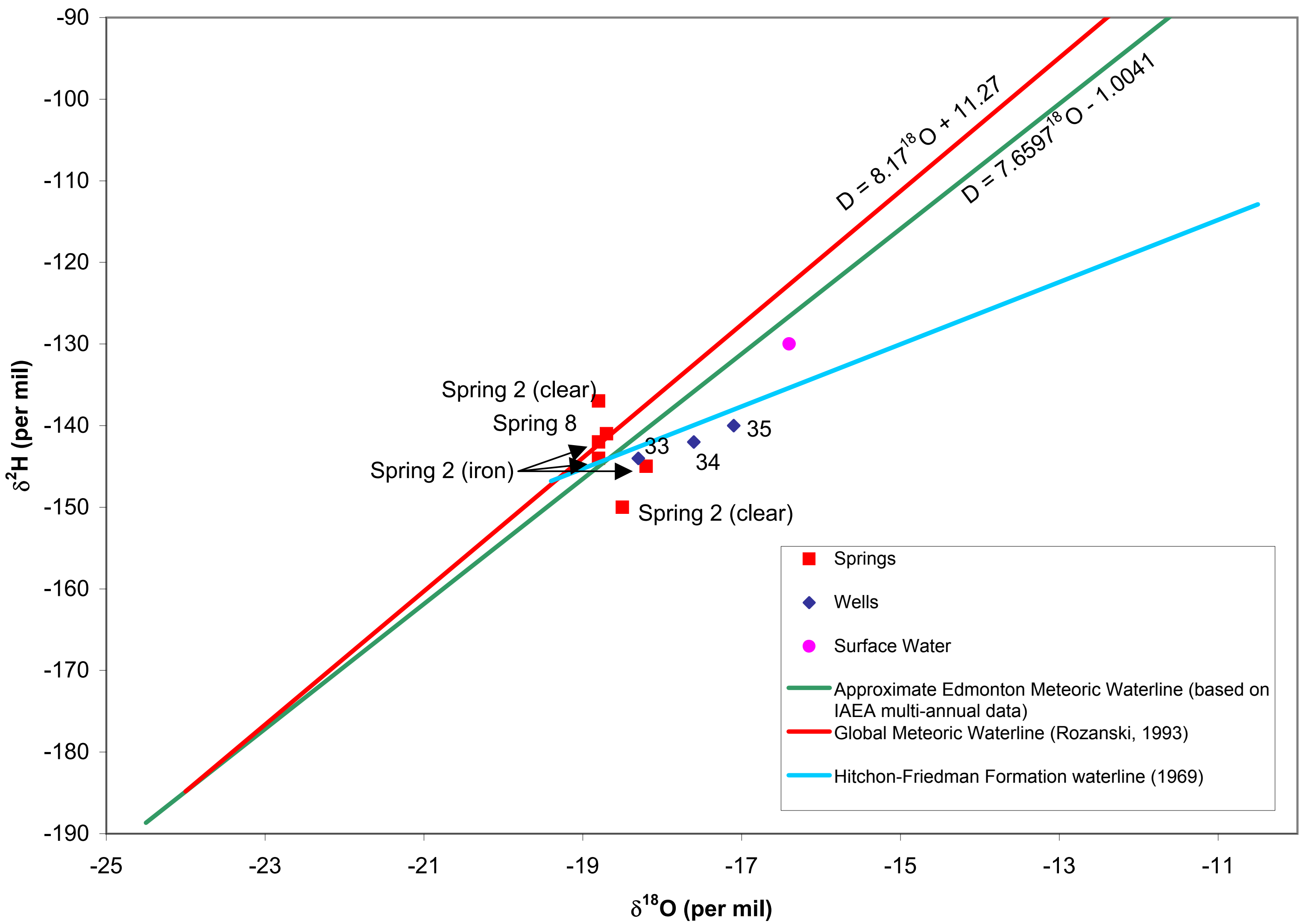


Figure 12. $\delta^{18}O$ **versus** $\delta^{2}H$.

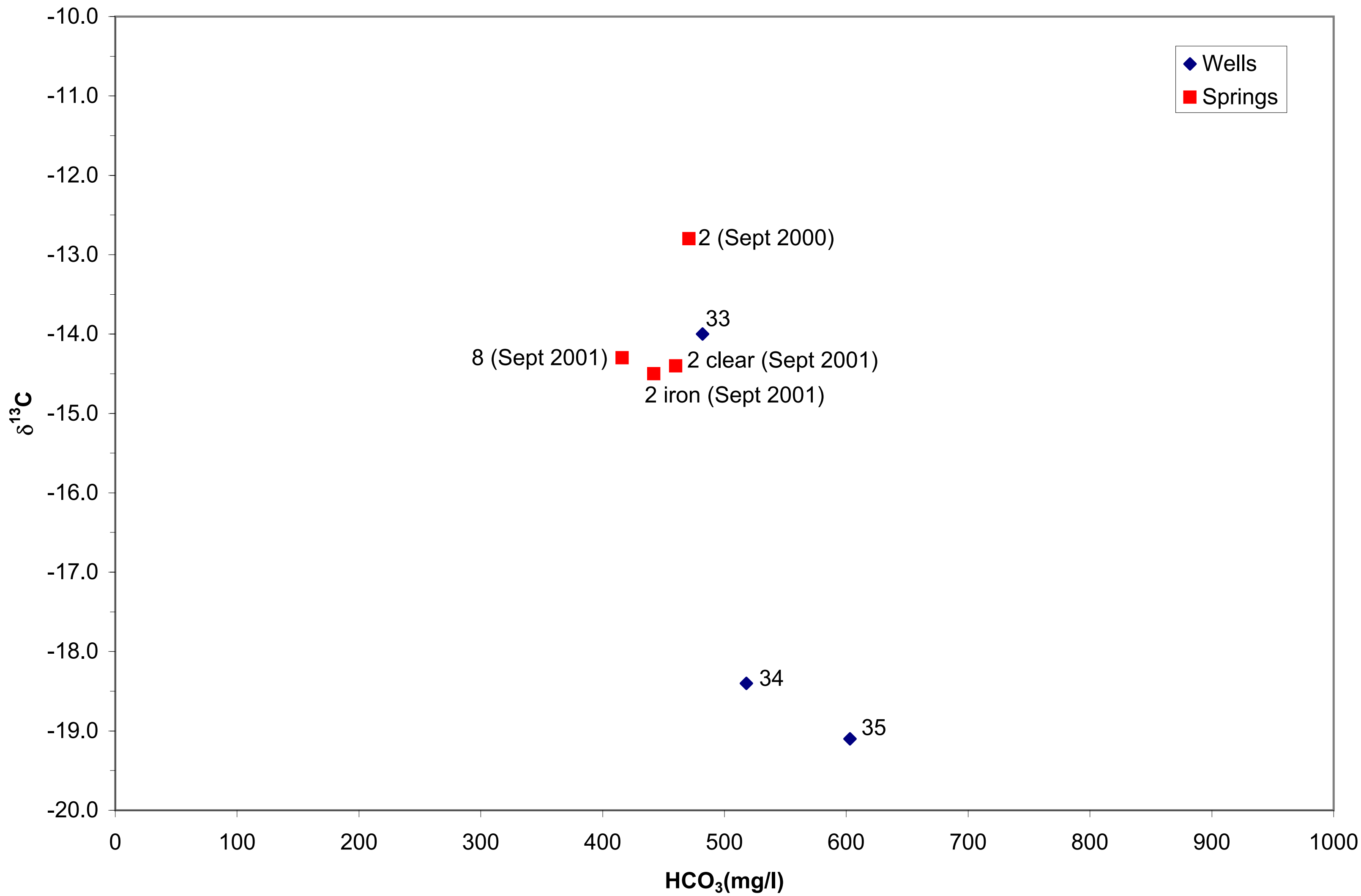


Figure 13. $\delta^{13}C$ **versus** HCO_3.

and the springs are plotted against Sr concentrations in Figure14. There is a definite trend suggesting an increase in Sr along the flow path of the Wiau Channel Aquifer from east to west towards the springs. Lemay (2002b) indicates that the source of Sr is likely to be carbonate dissolution. The springs cluster on the graph close to well number 33. The similarity in $^{87}Sr/^{86}Sr$ ratios with wells in the Wiau Channel Aquifer and placement of the spring-water values properly on the increasing westward total Sr trend is more strong evidence that the major contribution of the spring water is from the Wiau Channel Aquifer.

5.3.2.4 $\delta^{34}S_{SO4}$ and $\delta^{34}S_S$

Sources of sulphur in ground water include atmospheric sulphur, dissolution of sulphate minerals like gypsum and oxidation of sulphide minerals such as pyrite. According to Fetter (1994), oxidation of reduced sulphur species results in enrichment of $\delta^{32}S$ and thus depletion of $\delta^{34}S$. This may be the case as shown by a plot of $\delta^{34}S_{SO4}$ versus SO_4 (Figure15), which indicates depletion of $\delta^{34}S_{SO4}$ with increasing SO_4 for the springs and for wells Number 33 and 35. The surface water sample shows slightly negative $\delta^{34}S_{SO4}$ and very low SO_4 which may indicate a reducing environment. Wells number 34 and 35 show enriched and very enriched $\delta^{34}S_{SO4}$ values respectively, which generally would indicate dissolution of gypsum or possibly bacterial sulphur cycling (Clark and Fritz, 1997). Significantly more work needs to be done to further define the possible sources of sulphur contributing to the $\delta^{34}S_{SO4}$ and $\delta^{34}S_S$ and the processes affecting those values.

When $\delta^{34}S_{SO4}$ is plotted against $\delta^{34}S_S$ (Figure 16) there is a clear shift in the sulphur-isotope geochemistry of Spring 2, between June 2001 and September 2001. The shift almost looks like seasonal variation. However, the samples taken in September of 2001 were sampled with slightly differently methodology than the samples taken in June of 2001 (previously described in Methods, Section 2.2). This may or may not be the reason for the dramatic shift between the two sets. It would be preferable to resample using the latter described method (Section 2.2) during different times of the year in order to determine the source of the shift.

5.3.2.5 $\delta^{11}B$

Only one result of $\delta^{11}B$ was captured for the springs, and one each for wells number 33 and 34. A plot of $\delta^{11}B$ versus 1/Boron is in Figure 17. The strong similarities in boron isotope-values and concentrations between Spring 2 and well Numbers 33 and 34 suggest a common source of groundwater. Well number 33, however is also very close with a value of 24 ‰. Vengosh and Hendry (2001) reported $\delta^{11}B$ ratios in sea water as 39‰. Vengosh and Hendry (2001) reported $\delta^{11}B$ ratios in glacial till in Saskatchewan to be between 17 and 28.4 ‰, and $\delta^{11}B$ ratios in Cretaceous bedrock to range from 25.6 to 39.3 ‰. The fact that the observed $\delta^{11}B$ ratios fall at the upper end of reported till values and the lower end of reported Cretaceous bedrock values means that no interpretation is readily made regarding Cretaceous bedrock discharge contribution to the springs.

6 Conclusions

The following conclusions may be drawn from the previous information:

- Chemical and isotopic analysis support the conclusion that the springs in this study are sourced from the water in the Wiau Channel Aquifer, especially when compared with groundwater from wells completed in that aquifer. They also show distinct geochemical differences from surface water.

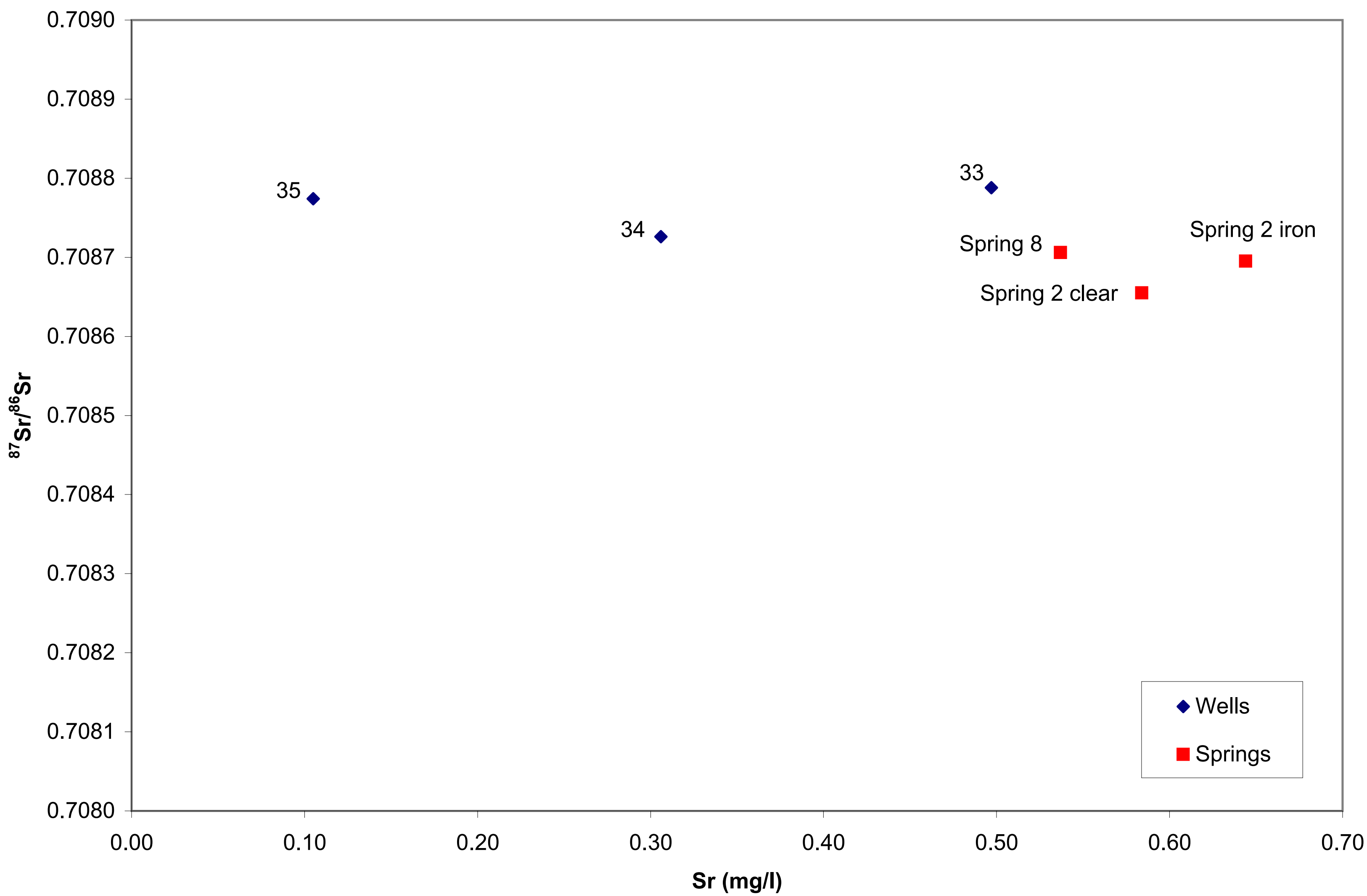


Figure 14. $^{87}Sr/^{86}Sr$ **versus Sr.**

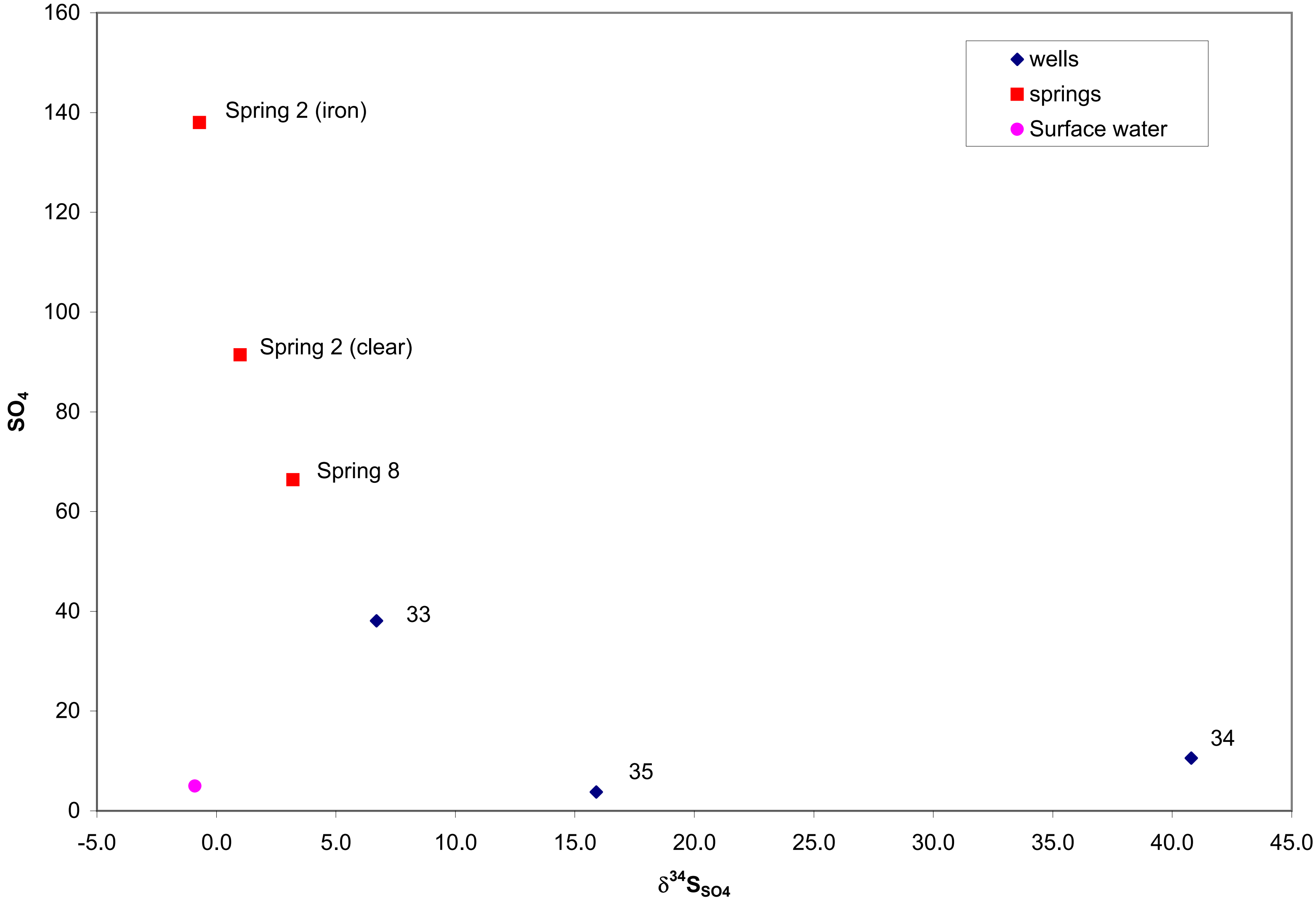


Figure 15. SO_4 versus $\delta^{34}S_{SO4}$.

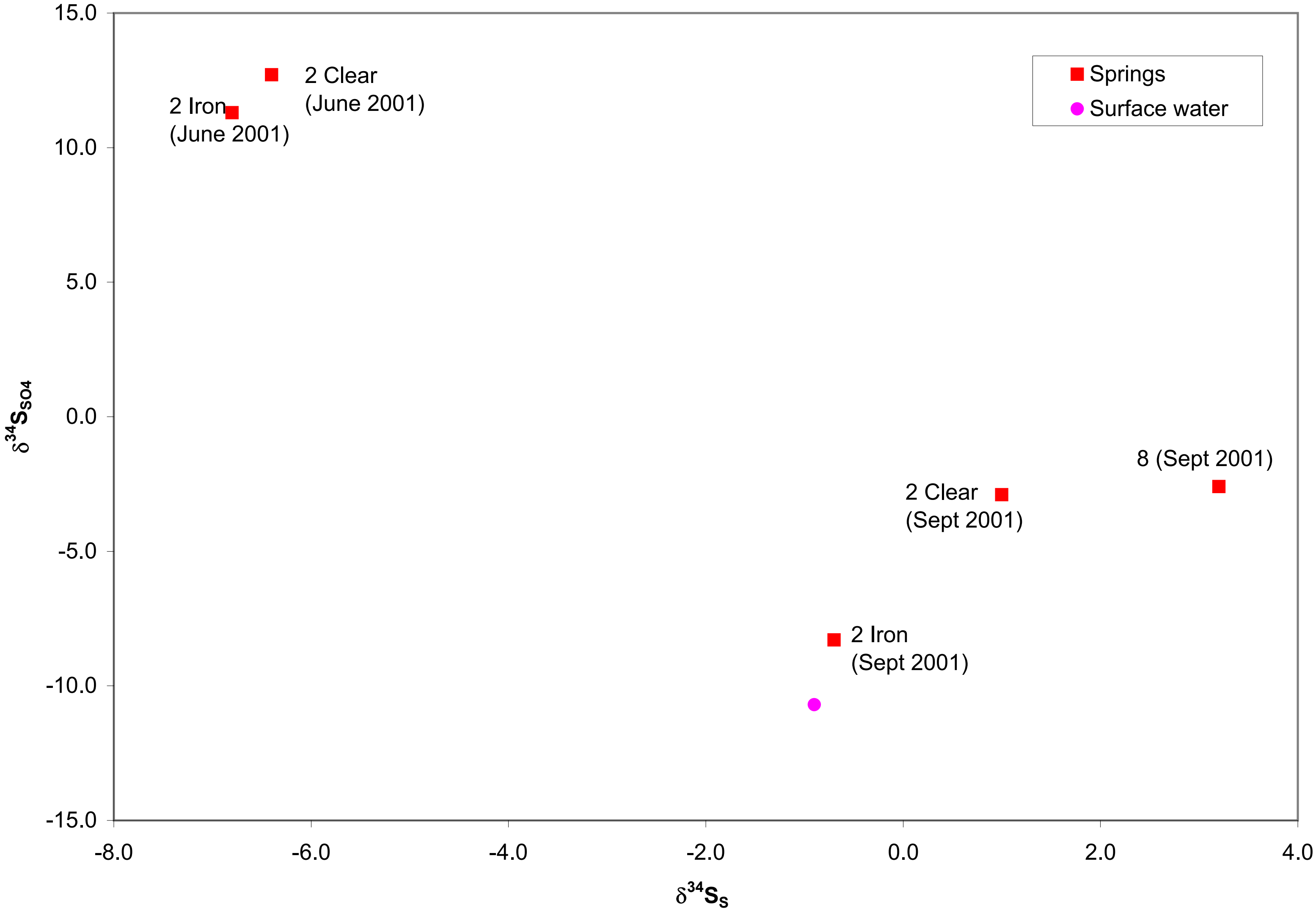


Figure 16. $\delta^{34}S_S$ **versus** $\delta^{34}S_{SO4}$.

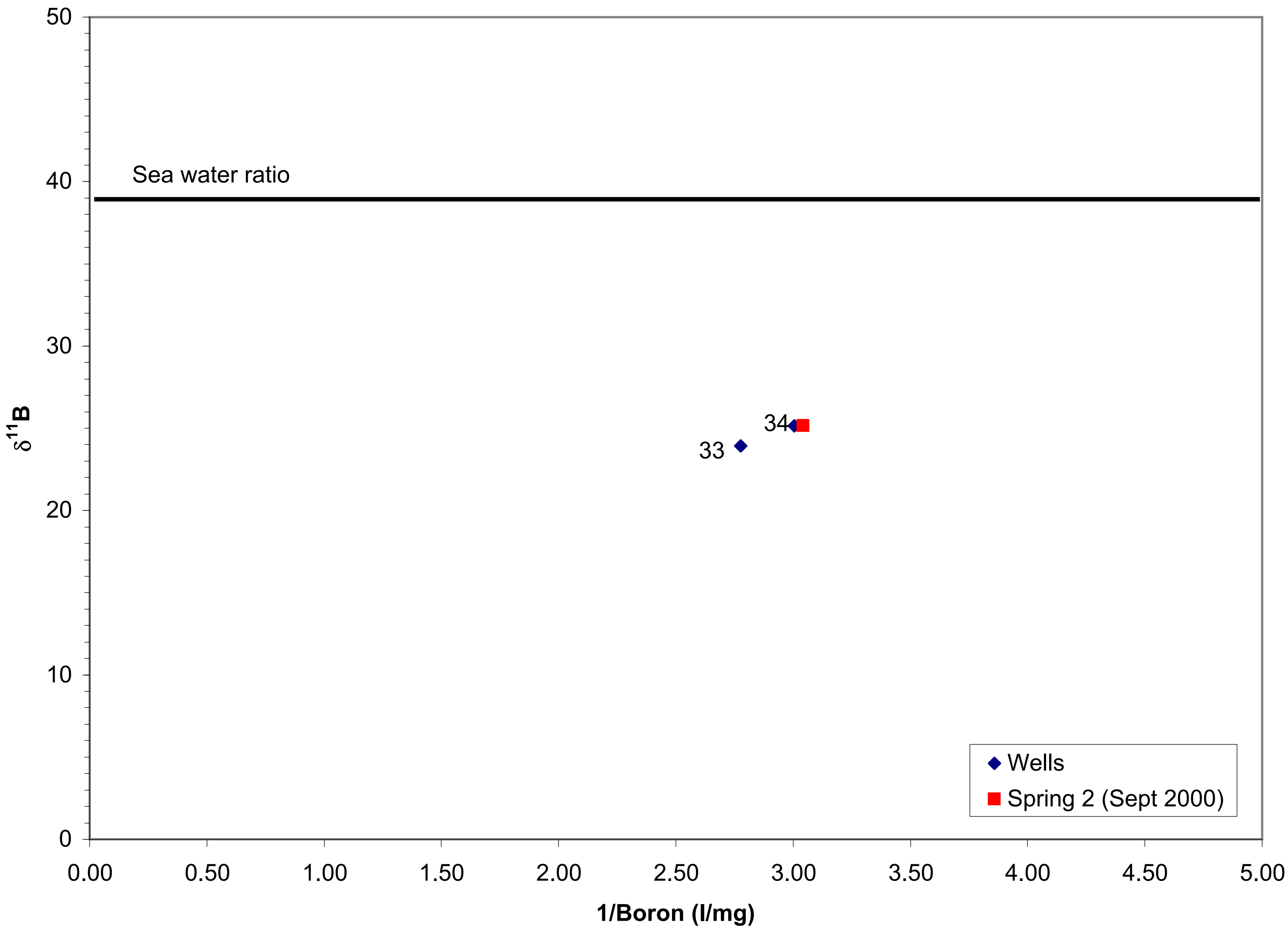


Figure 17. $\delta^{11}B$ versus Boron concentration.

- The total mean flow volume from all observed seeps and springs was calculated at about 7700 m3/d over the one year period. Since there may be unobserved springs and seeps obscured by vegetation or discharging along the river bottom, this number should be used as a lower estimate.

- Flow volumes from monthly monitoring compared with precipitation indicate a possible one year time lag in the pressure pulse induced from recharge.

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