Mountain Ash Limited Partnership

Summit Gravel Pit

Review of hydrogeology, geochemistry, fish and aquatics, and climate change

Prepared by:

Dr. Jon Fennell, M.Sc., Ph.D., P.Geol.
Hydrogeologist and Geochemist
Water Security | Climate Resiliency

On behalf of:

Friends of Big Hill Springs Provincial Park
and
Bighill Creek Preservation Society

For:

Rocky View County Council
Re: Bylaw C-8051-2020

January 2021

Water flows over lumpy deposits of tufa at Big Hill Springs Provincial Park

Table of Contents **Page**

List of figures in text

List of tables in text

List of Tables

Appendices

Executive Summary

Mountain Ash Limited Partnership (MALP) is applying to develop an open pit gravel mine in the headwaters area of Big Hill Springs Provincial Park. This is one of many aggregate developments likely to come forward in the future given the land ownership in this area. The sand and gravel is being extracted from a buried channel system that is already being mined by Hillstone Aggregates 800 m to the west.

Big Hill Springs Provincial Park, and the spring complex that feeds water down into the fish-bearing Bighill Creek, is located roughly 800 m southeast of the MALP property. This creek is currently listed on the Fisheries and Oceans Canada "Aquatic species at risk map" possibly having bull trout (i.e. a protected species). Big Hill Springs Provincial Park (the Park) was established back in 1957 and is a cherished and unique ecological enclave located in a prairie farmland setting that receives over 250,000 visitors each year. It is so poplar that upgrades are currently underway to ensure that Park's visitors continue to enjoy its redeeming qualities.

The flow of water from the springs originates from groundwater that discharges from a buried sand and gravel-filled channel system and the underlying fractured Paskapoo Formation bedrock. The MALP site is located on top of the south-west section of the aquifer that supplies the springs. The almost constant temperature and quality of the groundwater that sustains these springs year-round is responsible for the development of unique fish habitat in Bighill Creek. Therefore any impacts to that water threaten the aquatic ecology in the local area. Similarly, local residents rely on the local groundwater for their daily consumptive needs. This will be placed at risk if subsurface development activities lead to contamination of their water wells.

MALP's proposal to the Rocky View County Council is to mine the sand and gravel from beneath their property to within 1 metre of the water table. This will remove the vast majority of the filter that protects this important aquifer system in the headwater area of the Big Hill Springs complex. In doing so this places the remaining aquifer and groundwater discharging at the springs at risk of contamination during open pit operations and post-reclamation.

The proposal submitted by MALP is lacking in critical detail and is conceptual at best. The potential issues regarding impacts to Big Hill Springs and Bighill Creek have not been sufficiently explored or communicated. This includes no evaluation of how removal of a substantial part of this aquifer might affect the local aquatic environment (and terrestrial wildlife habitat).

Despite MALP's contention that the "above water table" gravel mining operations will not adversely affect local groundwater conditions, evidence from elsewhere indicates the opposite. Studies have found increased water table elevations and notable changes to groundwater quality due to the reduced filtration from overlying sediments. It is noteworthy that the pre-mining groundwater quality reported by MALP indicates the presence of contaminants like **arsenic, cadmium, chromium, and selenium** at concentrations above those listed for the protection of freshwater aquatic life.

Mining of the sand and gravel will expose the aquifer to atmospheric oxygen and enhanced weathering processes. This will also increase flushing of the remaining sand and gravel deposits with infiltrating waters. The removal of this essential filter will increase the risk of mobilizing fine particles, harmful trace elements like the ones already noted, and other contaminants like spilled fuels or process chemicals, into the local groundwater. Once mobilized, these contaminants will be difficult to recover before they reach fish-bearing waters and may eventually result in provincial and/or federal violations under the *Environmental Protection and Enhancement Act,* the *Fisheries Act,* or the *Species at Risk Act*.

Unfortunately, MALP has not addressed any of these critical environmental issues in their 2020 Master Site Development Plan or Hydrogeological Assessment Report (SLR 2020). As a result, the Rocky View County Council does not have enough information to make an informed decision regarding this application (including any potential future liability that could result from its approval).

There are plenty of other less environmentally-sensitive sand and gravel deposits throughout Rocky View County. Because of this, the responsible and sustainable response to MALP's application is to protect Big Hill Springs Provincial Park and the Bighill Creek system by establishing a suitable development buffer around these features.

A setback distance of at least 1.6 kilometers is therefore recommended. Also, to further protect groundwater quality in this important headwater area sand and gravel extraction within 800 m of this setback should be restricted to at least 4 metres above the water table to ensure suitable filtration of recharging water.

Proper consideration of future climate change effects should also be addressed to protect against extreme events that may result in unintended damaging releases from the site into the area's groundwater. This important issue has also been overlooked by MALP.

Implementing these recommended land use planning steps will protect local groundwater quality that feeds the sensitive aquatic system in the area, and ensure the protection of local water wells, while still allowing prudent gravel development to occur.

Introduction

Mountain Ash Limited Partnership (MALP) has put forward a plan to develop a sand and gravel (aggregate) open pit mine near the headwaters areas of Big Hill Springs Provincial Park. The plan is to strip overburden materials and stockpile them for later use during reclamation, followed by excavation, crushing, and screening of the aggregate for transport to market. Excavation of the pit is proposed to be kept to within 1 metre of the historical high-water mark of the local water table. Despite this, there are significant environmental concerns regarding this development and how appropriately the site conditions and the operational disturbance have been assessed. The main concerns with this proposed development relate to the following:

1. Proximity to the Big Hills Springs Park (and the potential for impacts to the unique system of springs and Bighill Creek, which is fed by these springs).
2. Risk of potentially irreparable adverse impacts to groundwater quality (and associated effects to nearby receptors).
3. Potential risks for protected fish and fish habitat (including aquatic species that support fish populations known to be present in Bighill Creek).
4. Questionable success of any mitigation (including post-reclamation timeframes) that might be necessary.
5. Risks associated with climate change (and the impact to safe mine operations and reclamation efforts).
6. Cumulative effects (from other similar developments extracting gravel near the Big Hill Springs headwater area and along Bighill Creek).

The Friends of Big Hill Springs Provincial Park (FBHSPP), a local landowner group, and the Bighill Creek Preservation Society (BCPS), a local watershed group mandated to develop a watershed plan for the Bighill Creek basin, are concerned for the future of the springs should this, or any other similar development, be approved by the Rocky View County Council. Both groups would like to see a protective buffer established around this unique and popular prairie setting. To assess the appropriateness of such an initiative, the group retained Dr. Jon Fennell to review and comment on the MALP's 2020 Master Site Development Plan and associated Hydrogeological Assessment Report (SLR 2020). Dr. Fennell is a Senior Hydrogeologist, Geochemist, and Water resource Specialist with over 30 years experience in environmental and contaminated sites investigations, risk analysis, and climate change assessment. He is a registered member-in-good-standing with the Association of Professional Engineers and Geoscientists of Alberta (APEGA), among other similar agencies in Western Canada. Further information regarding Dr. Fennell's credentials is provided in Appendix 1.

The remainder of this report summarizes the critical environmental issues that the RVC Council need to consider regarding this and any other similar developments near the Big Hill Springs Provincial Park and Bighill Creek system.

Key Findings

1. Proximity to the Big Hill Springs Provincial Park

The proposed MALP gravel pit is located in the west half of Section 31, Township 26, Range 3 West of the 5th Meridian and consists of 131 hectares (or 323 acres) of land designated as Ranch & Farm District under Rocky View County's Land Use Bylaw C-4841-97. The aggregate deposit that MALP is intending to mine is part of a large, buried sand and gravel deposit that extends towards the northwest for up to 10 km or so. This large accumulation of granular material, which ranges in thickness anywhere from less than 10 m up to almost 30 m, was formed during the last glaciation of the area and was deposited in a former valley eroded into the underlying bedrock of the pre-glacial landscape. Given the hydraulic properties of the sand and gravel aquifer it classifies as a Domestic Use Aquifer[1].

Overlying the sand and gravel deposit is anywhere from 3-6 m of glacial till consisting of clay and silt, with some sand and rocks, followed by about 30-60 cm of topsoil. Underneath the sand and gravel deposit is bedrock of the Paskapoo Formation comprising layers of sandstone, siltstone, and shale/mudstone sequences. These bedrock deposits have been subjected to fracturing and faulting as a result of deformation during formation of the Rocky Mountain foothills area and offloading of thick glacial ice between 10,000-15,000 years ago[2].

The footprint of the MALP property is located approximately 800 m from the boundary of Big Hill Springs Provincial Park, a very popular recreation spot for locals, Calgarians, and tourists visiting the area. It is a unique ecological enclave surrounded by farmlands that has considerable recreational and environmental value. The land area that is intended to be mined comprises gently rolling terrain with drainage towards the south and east across the property. The southern half of the proposed development has an abrupt change in elevation from 1292 metres above sea level (masl) to 1272 masl due to the presence of a large drainage-way leading down to the Big Hill Springs complex. Within this drainage-way is a small intermittent tributary stream located approximately 300 m to southeast of the property boundary that also leads down to the springs. This tributary is documented by SLR Consulting (Canada) Ltd. as being fed only by surface

[1] Alberta Government 2019

[2] Moran 1986

drainage (SLR 2020); however, it is very likely that groundwater in the local sand and gravel deposits, as well as the upper bedrock, discharge to this tributary stream at some point further downslope from its origin.

Big Hill Springs is a spring complex fed by the very same groundwater residing in the sand and gravel deposit that MALP intends to mine for aggregate resource. Investigative work done by SLR during the period of 2014 to 2019 found the water table to be located at a depth of up to 30 metres below surface on the upland portion of the site , and a depth of around 12 metres at the southern end where the land surface drops down into the drainage-way. The springs flow year-round at rates ranging from 0.4 to 0.1 cubic metres per second and eventually discharge into Bighill Creek – a fish-bearing water body indicated as having protected bull trout, which is a threatened species under the Species at Risk Act (SARA). The water from Bighill Creek eventually discharges into the Bow River at the Town of Cochrane. The relatively stable (and cool) temperature of the spring water (around 6°C), and its high quality (low mineralization and turbidity), has led to development of local habitat that supports various vegetation, wildlife, and aquatic species. As such, the Big Hill Springs, the established Park area, and the associated ecology are an important aspect of Bighill Creek's ability to sustain ecological viability.

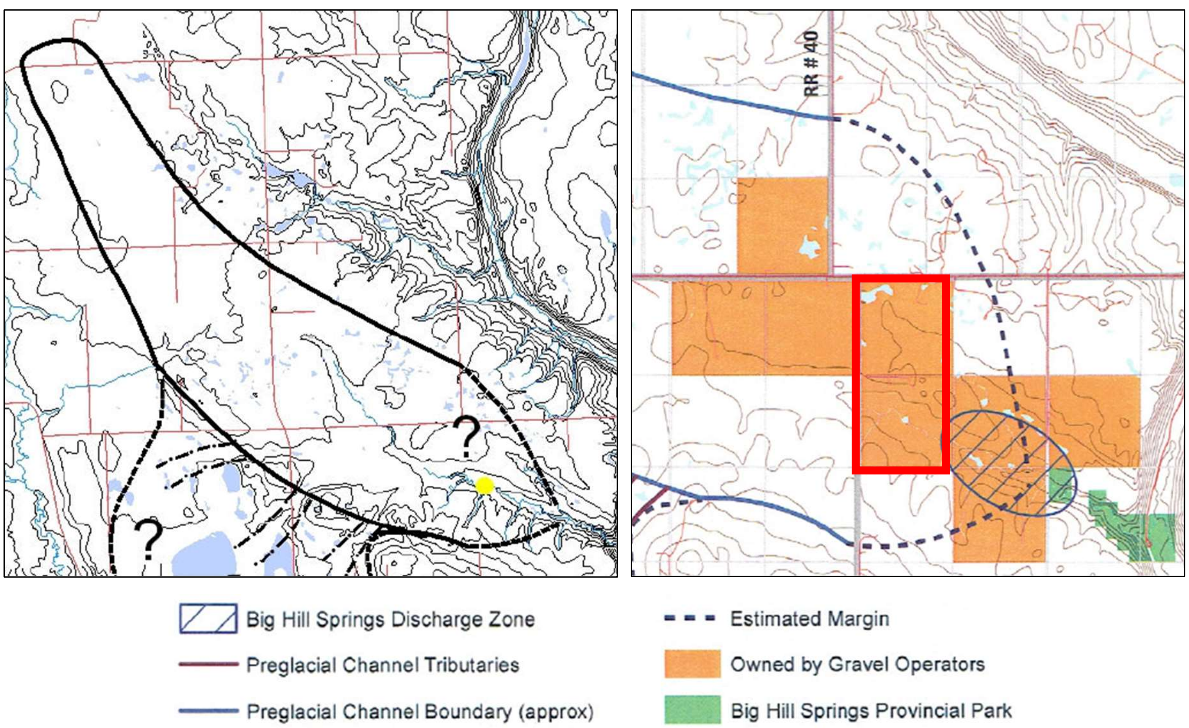


Figure 1. Mapped preglacial channel for Big Hill Springs (left)[3], where dot-dashed lines indicate extent of buried tributaries, and extent of lands owned by gravel operators near Big Hill Springs Provincial Park (right)[4] *Note: MALP property outlined in red.*

[3] Excerpt from Figure 22 of Poschmann S. (2007)

[4] Excerpt from a figure provided by Bighill Creek Preservation Society

The MALP development is not the only pressure facing the headwater area of Big Hill Springs complex. In addition to the MALP proposal there are a number of other land parcels that are currently owned by gravel operators, the locations of which are shown in Figure 1. It is clear from a review of this map that there are numerous locations where gravel could be mined, if approved, included areas right up against the Park limits and the spring complex itself. It is also clear that the MALP property itself (outlined in red) impinges on the identified discharge zone for the springs.

It is MALP's opinion that development of their sand and gravel pit will not adversely affect the quality and quantity of water reporting to the Big Hill Springs complex as they only intend to mine down to within 1 metre of the historical high-water level for the local water table. Although the final pit depth is yet to be established, MALP assumes that the operation will be a dry pit configuration, and no dewatering of the gravel will be required, thus no drawdown impact to the groundwater underneath. In fact SLR goes on to say in their technical report that the development will actually increase the recharge of water to the sand and gravel left in place, which they consider to be a "positive" effect. However, there are some significant considerations that contradict that position. These will be explained in the paragraphs and sections that follow.

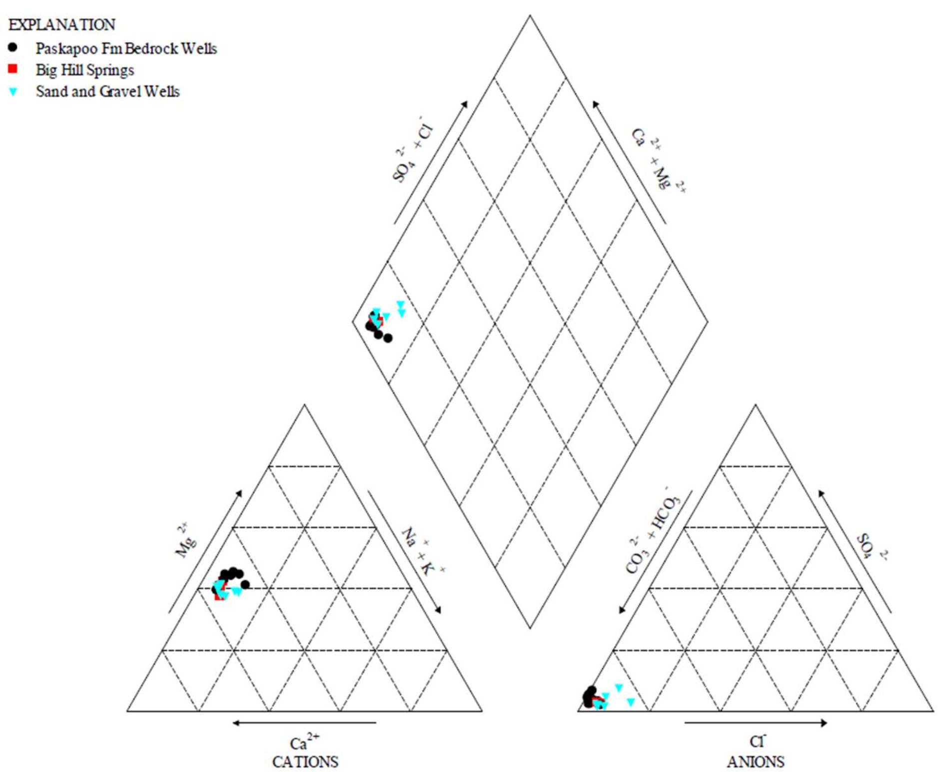


Figure 2. Piper plot showing similarity of water chemistry from various sampling locations (i.e. the sand and gravel monitoring wells established on the MALP property, nearby domestic water wells completed in the bedrock, and Big Hill Springs)[5]

[5] Figure 1 from SLR's Hydrogeological Assessment Report (2020), pdf page 19 of 335.

Results of SLR's hydrogeological assessment clearly indicate that the groundwater in the sand and gravel deposits and fractured upper bedrock, and the water discharging at the Big Hill Springs complex, are chemically the same. This is demonstrated by the similarity of major ion compositions in the Piper plot prepared by SLR (Figure 2).

Given this evidence of this hydraulic connectivity, any changes to groundwater quality or quantity within the excavated footprint of MALP's gravel pits will eventually manifest themselves at the Big Hill Springs complex and eventually Bighill Creek. Based on the calculated groundwater flow direction to the southeast and a velocity of about 300 m/year, using data from SLR (2020), the estimated travel time for groundwater to move from MALP's property to the springs is 2-3 years. This is considered a rather short timeframe for groundwater flow and places the springs at considerable risk of adverse impacts from any contaminants that might originate from pit operations or reclaimed areas. Figure 3 shows the locations of monitoring wells (MW-series) and local water wells (WW-series) used in the SLR's 2020 site assessment.

Figure 3. Location of monitoring wells and local water wells (used in the 2020 SLR Hydrogeological Assessment) and mapped water table elevations and contours[6]. *(Note: blue arrow indicates direction of flow)*

2. Risk of impact to groundwater quality

Results of the SLR (2020) investigation indicate that natural groundwater is already affected to some degree by certain metals and trace elements at concentrations above Guidelines for Canadian Drinking Water (GCDWQ)[7]. These, include:

---

[6] Drawing No.4 from SLR's Hydrogeological Assessment Report (2020), pdf page 43 of 335.

[7] Health Canada (2020)

- Aluminum
- Arsenic
- Barium
- Cadmium
- Chromium
- Iron
- Lead
- Mercury

It is also stated in the SLR (2020) report that the reason for detections of metals and trace elements above GCDWQ is turbidity from their wells, which ranges from below detection levels (<0.1 NTU) up to >4000 NTU (see Tables section in this report). This is a common occurrence when turbid water samples are analyzed for Total Metals, and usually results from the preservation of unfiltered water samples with laboratory-grade nitric acid. When assessing water sample collected by SLR with low turbidity values (<10 NTU), the exceedances of GCDWQ values become restricted to a lesser number of elements:

- Aluminum
- Barium
- Iron
- Lead
- Manganese

It is important to note that the groundwater beneath the area does not just support drinking water supplies. It also sustains the flow of water at Big Hill Springs, which also provides significant discharge to the fish-bearing Bighill Creek to the east. When guidelines for the protection of freshwater aquatic life, or FWAL[8], are applied to the groundwater monitoring results the following elements exhibit concentrations above long-term chronic guidelines:

- Aluminum
- Arsenic
- Cadmium
- Chromium
- Copper
- Iron
- Lead
- Selenium
- Zinc

Review of water quality at the Big Hill Springs complex itself, as reported by SLR (2020) and summarized in the Tables section of this document, does not indicate concentrations of many parameters exceeding the FWAL guidelines. Only the occasional aluminum, chromium, and selenium exceedances are noted. Similarly, results from water samples collected from Bighill Creek near the location where Big Hill Springs discharges into it, also provided in the Tables section of this report, indicate the following elements occasionally approaching or exceeding FWAL guidelines[9]:

- Aluminum
- Cadmium
- Chromium
- Iron
- Selenium

[8] Alberta Government (2018). Environmental Quality Guidelines for Alberta Surface Waters.

[9] Fouli Y. (2020)

It is therefore clear that naturally-elevated concentrations of various metals and trace elements are already present in the groundwater and surface water of the study area, and that the aquatic habitat and fish within the Big Hill Springs and Bighill Creek system are already exposed to them. The question that remains unanswered by MALP is:

> *"How will the excavation of sand and gravel at their proposed pit, exposure of the remaining sand and gravel to oxygen in the atmosphere, and enhanced recharge through a relatively thin layer of remaining sand and gravel above the water table affect the mobility of contaminants (i.e. metals, trace elements, nutrients, turbidity and any other constituents associated with their operation) into the groundwater used by local residents, and discharge that supports the Big Hill Springs, and eventually flow in Bighill Creek?"*

It is a well-known fact that when buried sediments are excavated and exposed to the atmosphere the local geochemical conditions change. The increased chance of mineral oxidation combined, with the usual wetting and drying cycles from recharge and rainfall events, work to enhance weathering and leaching reactions and ultimately the release of various constituents into the local groundwater. Table 1 provides an example of how the water quality beneath "above water table" gravel pits can change[10].

Table 1. Example of difference in natural groundwater and groundwater measured 2.5 m below above watertable gravel extractions areas *(Source: Hatva 1994)*

Parameter		Rainwater n = 12			Natural groundwater areas n = 43-60			Gravel extraction areas n = 76-240		
		Md	min	max	Md	min	max	Md	min	max
Temperature	°C				4.7	1.1	6.8	5.6	0.0	8.8
Acidity	pH	4.5	4.1	6.3	6.4	5.6	7.3	5.9	5.4	7.3
Conductivity	mS m^{-1}	4.0	2.0	9.0	6.0	3.0	9.0	7.0	4.0	19.0
Carbonic acid	mg l^{-1}				11.0	2.0	44.0	24.0	2.0	62.0
Bicarbonate	mg l^{-1}				25.0	15.0	38.0	20.0	8.0	45.0
Chloride	mg l^{-1}	1.0	1.0	3.5	2.0	1.0	7.0	3.0	2.0	37.0
Sulphate	mg l^{-1}	2.0	0.5	3.0	4.0	4.0	12.0	10.0	5.0	16.0
$KMnO_4$-consumption	mg l^{-1}				3.0	0.0	9.0	2.0	0.0	51.0
Hardness	°dH				1.0	0.5	1.5	1.0	0.5	3.0
Nitrate	mg l^{-1}	2.1	1.4	6.7	0.4	0.0	4.0	1.9	0.0	11.5

Note: n = number of samples; Md = median values

What is most striking about the change in median values from natural groundwater areas to gravel extraction areas is the slight increase in temperature (4.7 to 5.6°C) and reduction in pH (6.4 to 5.9), the 2 times increase in carbonic acid (11 to 24 mg/L), and 2.5 times increase in sulphate (4 to 10 mg/L). It is the carbonic acid that is of most significance given its importance in mineral weathering and other surface-related reactions involving minerals with trace elements adsorbed to their surfaces (e.g. clays). The increase in nitrate (0.4 to

[10] Hatva T. (1994)

1.9 mg/L) is evident and associated with the reduced protection to the underlying groundwater from removal of the protective soil cover. Removal of this material effectively reduces the attenuating, or filtering, capacity of the remaining material below before the infiltrating water reaches the underlying water table.

Once released into the local groundwater environment, geochemical conditions will dictate the mobility and toxicity characteristics of contaminants released. Chromium, for example, tends to be more mobile and toxic under oxygenated conditions, and exists in the hexavalent form as chromate ions (CrO_4^{2-}). Similarly, selenium exists as selenate (SeO_4^{2-}) and selenite (SeO_3^{2-}) species, with selenite being the more toxic and mobile form. Figure 4 provides Eh-pH diagrams showing the various stability fields for chromium and selenium species in water. The red dots indicate the type of Eh and pH conditions that would be expected in well-oxygenated recharge water moving through a relatively thin layer of residual sand and gravel beneath a gravel pit (like MALP's).

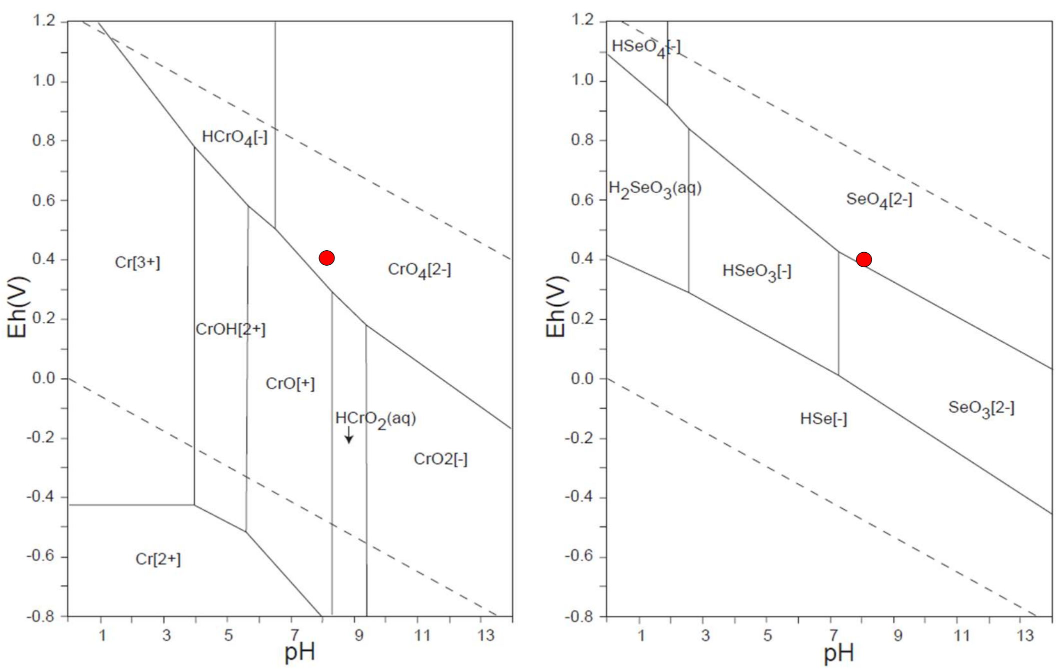


Figure 4. Eh-pH diagrams for chromium (left) and selenium (right)[11]. *(Note: red dots represent conditions expected in well-oxygenated groundwater delivered by recharge through a thin remaining layers of gravel)*

The potential for mobilization of fine particulate matter and/or colloids[12] into the groundwater as a result of MALP's mining operations also exists. Removal of the protective cover of glacial till, followed by a significant reduction in the thickness of the sand and gravel deposit, will leave a small amount of material

---

[11] Atlas of Eh-pH diagrams

[12] Colloids are very low diameter particles (1 nanometer, or 10^{-6} mm to 1 micrometer, or 0.001 mm) which are responsible for the turbidity or the color of water. In fast moving groundwater systems such particles can remain suspended and move considerable distances due to the physical lifting effect of the water and associated charge characteristics (positive, negative, or neutral).

above the water table. This residual sand and gravel will be exposed to increased infiltration and weathering of minerals by infiltrating runoff. The enhanced recharge of water will increase the ability to flush fine particulate matter into the underlying groundwater and eventually into the fractures of the upper bedrock. The local water table will also have a high probability of increasing above the normal range of variability. An example of the increase in groundwater levels below natural versus developed areas is provided in Figure 5.

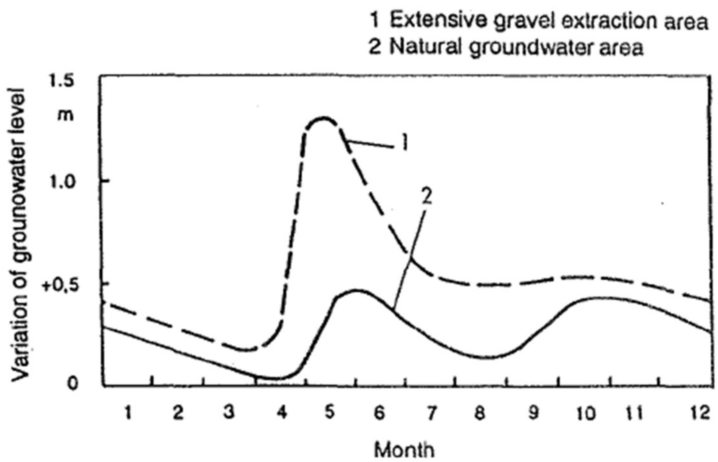


Figure 5. Example of expected increase to water table due to above water table gravel extraction operations *(Source: Hatva 1994)*

Turbidity issues have been documented at gravel pits, with measurable effects being noted as far as 1.8 km downgradient of those operating areas[13]. The following quote is taken from Mead (1995), indicating the significant distance that turbidity plumes can travel through permeable sand and gravel deposits:

> *"This DEQ study found a turbidity plume that extended more than a mile to the north (downgradient) of the gravel operation. The average turbidity of the water being discharged from the washing operation into the pond at the site was 2,737 nephelometric turbidity units (NTUs). Nearly all wells sampled within the first 6,000 feet of the turbidity plume were measured at 5 NTU or more. Many wells within the first 3,000 feet of the plume had turbidity levels of 10 NTU or more. Nearly all wells outside the plume had turbidities of 2 NTU or less."*

The most consistent position of most regarding turbidity movement within the subsurface is that the fine particles will be strained out in the pores of the granular material. However, this may not apply to the very small particles, or colloids, that can still make their way through the soil grains and continue on. For reference, Alberta's FWAL turbidity guideline for long-term exposure (>24hr) in clear running waters is

[13] Mead R.D. (1995)

2 NTUs above background levels. Based on data provided by SLR (2020), and included in the Table section of this report, the background turbidity in the groundwater beneath the MALP property is generally less than 1 NTU. Therefore the risk of increasing local turbidity values in the groundwater exists.

Another concern that has not been addressed, at all, is the potential for leaching of inorganic or organic constituents from the previously disturbed soil materials placed back over the excavated areas once mining and reclamation activities are complete. The fact that the till is clay-rich and will likely have some metals and trace elements that could be leached by infiltrating precipitation of naturally lower pH presents an additional risk. For reference, the average pH of precipitation in the Calgary area is around 6, with a minimum of around 4.9[14]. The reason for the pH values below neutral (pH 7) is the equilibration of the atmospheric moisture with carbon dioxide (CO_2) and the formation of carbonic acid (H_2CO_3). Other constituents like oxides of sulphur and nitrogen gases released from things like sour gas plants and agricultural lands development can also serve to reduce the pH through the development of sulphuric acid (H_2SO_4) and nitric acid (HNO_3). Such pH values are considered mildly acidic and therefore can enhance minerals weathering reactions.

The risk associated with the release of harmful metals and trace elements, as well as other things such as nutrients, turbidity and other site-specific contaminants (e.g. fuel spills), into the local groundwater is twofold:

i) these constituents can eventually impact local water wells, and
ii) they can eventual discharge at Big Hill Springs resulting in increased loading of nutrients and harmful constituents to Bighill Creek, thus compromising sensitive fish habitat.

3. Potential issues for fish and aquatic habitat

The presence of naturally-elevated concentrations of trace elements in the local groundwater is a clear indication that the geochemical conditions in the area are conducive the mobilization. With the exposure of the open gravel pit areas to atmospheric oxygen and increased recharge, there is increased risk to mobilize even more of these harmful trace elements into the groundwater and eventually Big Hill Springs, either in dissolved form or associated with colloidal material in a process known as "facilitated transport". As noted earlier, the groundwater that feeds the Big Hill Springs complex eventually discharges to Bighill Creek, adding up as much as 20 to 50% of its flow[15] and regulating its water temperature.

MALP's application documents fail to explore the topic of fish and fish habitat and therefore this aspect has not been considered as a "valued component" in the assessment process. A search of Fisheries and

[14] Alberta precipitation quality monitoring program website

[15] Fouli Y. (2020); BRBC (2020)

Ocean Canada website, showing the location of stream protect under the Species at Risk Act, identified bull trout, which is a protected species (Figure 6).

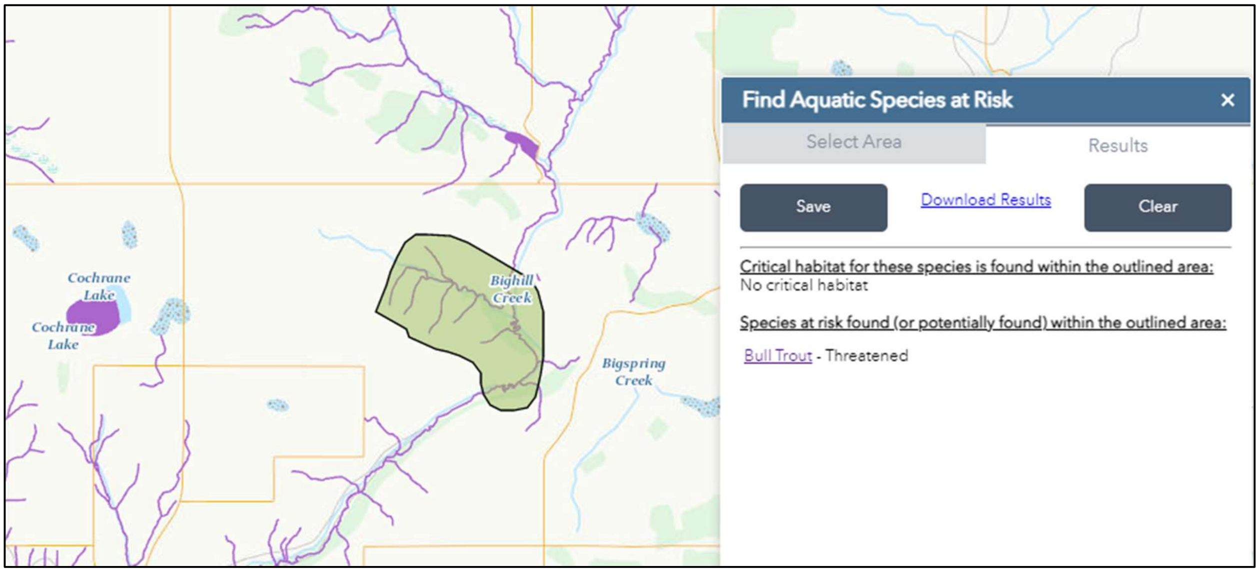


Figure 6. Excerpt from the Fisheries and Oceans Canada Aquatic species at risk map *(Note: area shown in green indicates the Big Hill Springs headwaters and the confluence with Bighill Creek)*[16]

A report prepared for the BCPS by Trout Unlimited Canada (TUC)[17] identified a number of fish species in Bighill Creek, in particular long nose dace, brook trout, brown trout, longnose/mountain/white sucker, mountain whitefish, and rainbow trout. As noted earlier, the *SARA*-protected bull trout species is also identified. At the location where discharge from Big Hill Springs enters Bighill Creek there is a significant lowering of stream water temperatures and the development of unique habitat for cooler water fish species. As noted by TUC:

> *"The highest density of Brook Trout within reach 4 occurred at the confluence of Bighill Creek and Bighill Springs Creek, likely due to the thermal preference of Brook Trout for the cold water from Bighill Springs. The water temperature in Bighill Springs Creek was dramatically colder than all other sites and only supported Brook Trout."*

Additionally, results from a 2019 biomonitoring program[18] using environmental DNA metabarcoding identified that the highest species richness is noted in this reach of Bighill Creek, underscoring the importance contributions of water from Big Hill Springs in providing unique aquatic habitat[19].

---

[16] Fisheries and Oceans Canada

[17] TUC (2018)
[18] Hajibabaei Lab 2019

[19] Fish habitat means water frequented by fish and any other areas on which fish depend directly or indirectly to carry out their life processes, including spawning grounds and nursery, rearing, food supply, and migration areas.

Because fish frequent Bighill Creek, the greatest risk posed by MALP's (or any other) pit development in the headwaters areas of the Bighill Creek system is the altering of groundwater quality and eventual impact to aquatic receptors from discharge of contaminants released into groundwater reporting to that water course. This has particular relevance with respect to metals and trace elements that SLR has shown to be already present at elevated concentrations in the groundwater beneath MALP's property. Spills of fuels, lubricants, and other chemicals used during the gravel mining process is also a concern.

In Alberta, the *Water Act, Environmental Protection and Enhancement Act, Wildlife Act,* and their associated regulations are the main legislative instruments that provincial regulators rely upon when reviewing development applications such as this. This review process is meant to determine:

i) if the application is sufficient and complete,

ii) whether the potential impacts to wetlands, water bodies, fish and fish habitat (as well as wildlife) are adequately described,

iii) whether proposed avoidance and mitigations are appropriate, and

iv) whether the project should be approved, modified, or rejected.

Federally, the *Fisheries Act* and *Species at Risk Act* are the main legislation that address fish-related issues (as well as vegetation and wildlife) associated with development activities. In particular, under the *Fisheries Act* no one is to create a situation where there will be harmful alteration, disruption or destruction (HADD) of fish habitat. Equally, the release of deleterious substance is forbidden. The relevant excerpts form the Act are as follows:

Section 35:

Harmful alteration, disruption or destruction of fish habitat

35 (1) No person shall carry on any work, undertaking or activity that results in the harmful alteration, disruption or destruction of fish habitat.

Section 36:

Deposit of deleterious substance prohibited

(3) Subject to subsection (4), no person shall deposit or permit the deposit of a deleterious substance of any type in water frequented by fish or in any place under any conditions where the deleterious substance or any other deleterious substance that results from the deposit of the deleterious substance may enter any such water.

It is clear that MALP has failed to adequately address the potential impacts to Bighill Creek and the groundwater feeding Big Hill Springs that eventually discharges into it, and therefore the potential impacts to fish and fish habitat.

The main challenge facing the RVC Council in assessing MALP's pit application, and any other similar applications close to the Big Hill Springs complex and/or Bighill Creek itself, is the potential adverse impacts to fish or fish habitat including the aquatic species that support those fish. Allowing the development of gravel pits too close to the headwaters of Big Hill Springs, or other critical areas along Bighill Creek itself, where the release of dangerous and deleterious substances like **arsenic, cadmium, chromium, selenium**, etc. can occur may trigger a contravention of provincial and/or federal Acts. This application has yet to be reviewed by Alberta Environment and Parks (AEP) and/or the Department of Fisheries and Oceans (DFO), and therefore it is premature to approve any such application where the risk to fish and fish habitat has not been properly considered or assessed.

4. Success of any mitigation

The preceding evidence and examples of how "above water table" sand and gravel pits can alter groundwater conditions (both physically and chemically) demonstrates that it is likely that contaminants and particulate matter will be released into the local groundwater from MALP's development, should it proceed. The risk of this occurring has obviously not been assessed by MALP with appropriate calculations or geochemical modelling. Therefore it would be left up after-the-fact monitoring to detect these contaminants and signal the need for responsive actions. However, once detected these contaminants are already on the move and will require mitigation before they reach and negatively impact a nearby receptor like a water well or spring. Again, MALP has provided no evidence that they have considered this aspect, including what they would propose do in the event of such an occurrence. A more proactive stance would be appropriate considering the risks posed.

A typical approach to a contaminant release is establishing a groundwater recovery well, or wells, to intercept impacted groundwater before it can reach a receptor. Pumping effectively creates a capture zone where contaminants are pulled in and recovered to the surface where they can be dealt with accordingly. In MALP's location a recovery system operating this close to the Big Hill Springs complex would capture of groundwater that would otherwise report to (feed) those springs, and possibly local water wells. And, if the recovery wells needed to be installed in the bedrock, because of low groundwater levels below the remaining sand and gravel deposits, this could pull contaminants and particulate matter down into the fracture networks and become even more of a challenge.

If groundwater recovery is not viable, then establishing some other form of mitigation would be required. The difficulty with any type of engineered system is the ability to successfully commission that system and ensure it is functioning properly so as not to negatively affect local groundwater users or downgradient locations reliant on that same groundwater. Therefore, the best approach to ensure protection is to eliminate the risk of contamination altogether.

Establishing a suitable buffer zone both vertically and laterally within this gravel deposit would allow groundwater quality impacts to be remediated through natural processes before reaching the water table and affecting local receptors. With respect to a development setback, a distance of at least 1.6 km from nearby domestic use water wells and important water features like Big Hill Springs and Bighill Creek is justified given the findings of Mead (1995), unless substantiated otherwise through a rigorous scientific review process. This would mean no gravel pit development in this setback area. Additionally, to provide added protection outside of the development setback, recommendations provided by Hatva (1994) indicate that maintenance of a vertical buffer of at least 4 metres of sand and gravel above the water table would allow for the natural filtration and remediation of any contaminants that may be released by peripheral operations. The recommended distance to extend this pit development constraint is an additional 800 meters. In order to stay 4 meters above the water table, or even 1 metre for that matter, will require a firm understanding of the historical high-water level for the location so as not to extend the gravel pit too deep. This critical determination has not been clearly defined by MALP for the area beneath their property.

5. Climate change considerations

There is concern that the impacts of climate change have not been addressed, at all, in MALP's development application. Figure 7 shows the anticipated change in temperature and precipitation conditions for the Calgary region based on output from 24 separate GCMs (General Circulation Models) provided by the Pacific Climate Impact Consortium through the Climate Atlas of Canada website[20].

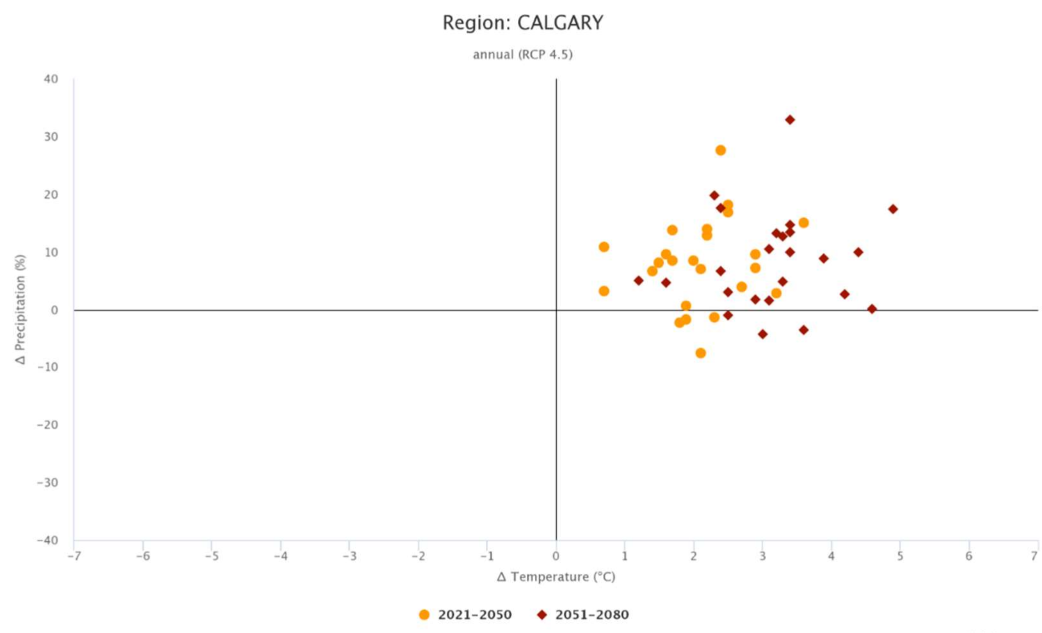


Figure 7. Anticipated change to temperature and precipitation in the Calgary region over this century (RCP 4.5 scenario)

[20] Climate Atlas of Canada

In the majority of model cases the expectation is for an increase in precipitation anywhere from less than 5% up to as much as 35% in the coming decades. Also, a doubling of the number of days with heavy precipitation (20 mm) from 2 to 4 days is projected by the end of the century, with the extreme model cases showing up to 11 days in the latter part of this century. Convective storm activity is also expected to increase due to warmer temperatures as the ability of the atmosphere to hold water increases. Convective storms can deliver large amounts of precipitation over a short period of time and overwhelm holding pond systems if not properly designed with this in mind. Kuo et al. (2015) indicate that an overall shift in the intensity, duration and frequency, or IDF, of precipitation events in general, is expected:

> *"Future IDF curves show a wide range of increased intensities especially for storms of short durations (≤1-h). Conversely, future* ***IDF curves are expected to shift upward*** *because of increased air temperature and precipitable water which are projected to be about 2.9°C and 29% in average by 2071–2100, respectively."*

This anticipated change to hydroclimatic conditions is related to a shifting of the mean towards more extreme conditions, an increase the degree of variability, and a change in symmetry relating to the major climate drivers - temperature and precipitation. This is illustrated in Figure 8 (on the following page). What is obvious is that as the world continues to warm, and climate conditions shift towards a new regime, the probability of extreme events, commonly described by the 10th and 90th percentiles, will adjust as a result. Therefore, gravel pit developments with operations extending out multiple decades and leaving behind landscapes in the form of reclaimed depressional areas need to consider how projected climate change will affect their design, longevity and ultimate success in reaching stated goals and regulatory requirements.

It is my professional experience that there is a general lack of consideration for climate change in most development applications and how this might affect risk to nearby receptors. MALP's application is no different. If approved, each open pit will form a local catchment for snow melt and rainwater, thus focussing recharge into the subsurface despite all efforts to mange water out of the working areas. Ponds will need to be properly sized considering the likelihood of more extreme events, compared to current conditions, so they do not overtop and/or fail. All indications, thus far, are that normal return periods for extreme events will shorten in duration, so a 1:25-year event may become a 1:10-year event, and a 1:100 may become a 1:50, so on.

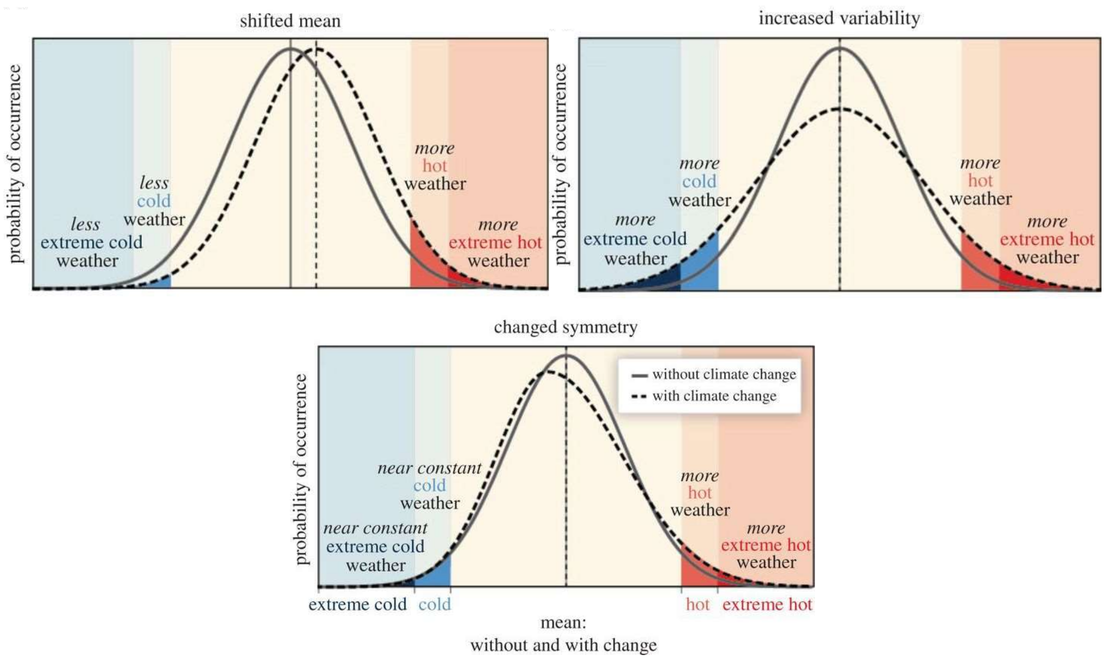


Figure 8. Example of how climate can change with a shift in mean, variability, and symmetry conditions[21]

It is also unclear what effect the altered landscape will have on the local watertable under future climate conditions. For the reasons outlined in this document, the focussing of recharge caused by the excavation and removal of large amounts of sand and gravel from the MALP property will:

i) threaten groundwater quality due to exposure of the aquifer,
ii) reduce the thickness of the remaining sand and gravel, and the associated filtration and contaminant attenuation capacity,
iii) increase the elevation of the water table due to enhanced recharge,
iv) increase the risk of contaminant migration into the groundwater within the remaining sand and gravel and fractured bedrock, and
v) increase the risk of adverse impact to systems receiving groundwater discharge from the pit areas.

Post-development, the reclamation landscape will continue to focus this recharge, but now over a broader area through disturbed till and topsoil on top of a reduce thickness of filtering material above the fractured bedrock. This may further exacerbate the delivery of soluble and particulate contaminants present in those reclamation materials, such as metals and trace elements and nutrients (nitrogen, organic carbon), into the

[21] Ummenhofer and Meehl 2017

underlying groundwater supplying local wells and the Big Hill Springs complex. Restoration of agricultural development and/or grazing will increase the risk of further contamination into the future as well.

A much higher water table due to enhanced recharge from capture of annual precipitation or large convective storms could also lead to water ponding on the surface leading to enhanced runoff, erosion risk, and increased sedimentation of downgradient areas like the Big Hill Springs and Bighill Creek. These are all considerations that MALP has failed to adequately assess, and therefore leads to an extreme risk of unintended consequences.

5. Cumulative effects

There is currently one operating gravel pit (Hillstone Aggregates) located about 850 m due west of the MALP property along Highway 567. That operation is extracting gravel from the same buried channel deposit that MALP intends to exploit. A number of other gravel mining developments have been proposed, or are under consideration, at the downstream end of this buried sand and gravel deposit and in headwater area for Big Hill Springs. This raises concerns regarding the cumulative effect that multiple pits would have on the water balance and water quality in this sand and gravel aquifer and the resulting impacts to connected aquatic features. In response to this concern, a legal challenge was presented to the Court of Queen's Bench in 2019 (Docket 1701 12053), and on September 16 of that same year the decision was made by Justice J.T. Eamon to set aside the RVC Council's decision to approve a Natural Resource Industrial (NRI) District within the west half of Section 31. This is exactly where the MALP property resides. The County is presently appealing this court ruling, but it is understood that the lands still remain designated as Ranch & Farm (R&F) District.

The concern for cumulative development effects on the Big Hills Springs complex, and local water well owner, is the reason why the original court challenge to the RVC Land Use Bylaw was launched back in 2019. It is evident that a considerable amount of aggregate development would occur in the headwater area, and other parts of the extended sand and gravel deposit (see Figure 1, right image) should a change be made from R&F to an NRI District. It is also evident that the risk of adverse impacts from the MALP development will add to any impacts propagating from other nearby sand and gravel pits. As such, the effects of all developments regarding increased recharge and constituent mobilization into the groundwater sustaining Big Hill Springs and local users is a grave concern considering its value to the local environment.

This fact is the reason for the recommended 1.6 kilometer development setback (at a minimum, unless determined otherwise) and maintenance of a vertical 4 metre buffer above the water table for any other gravel pit developments within 800 metres of that development setback. The sole purpose of this strategy is to maintain the quality of the groundwater sustaining the springs and supporting aquatic habitat reliant on the delivery of good quality water of stable temperature. Such a development buffer will also protect the quality of groundwater for nearby households and farms reliant on water wells for their everyday needs.

Given that there are plenty of gravel resources in other locations in the County and away from this sensitive headwater, establishing such a development buffer would:

i) preserve the quality of a well-loved provincial park and prairie spring complex,
ii) ensure that regulatory violations do not occur down the road, and
iii) not adversely affect the potential for the County to realize aggregate levies.

To achieve sustainability (i.e. the balancing of economic and environmental consideration for societal benefit) it is important to make room for, and preserve, natural landscape features when considering the impacts of resource development projects. This can be achieved through prudent land use planning and decision-making.

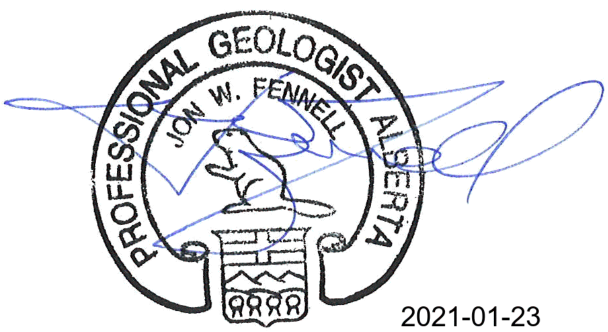
Closure

It is clear that Big Hill Springs is a unique feature in Rocky View County that serves the recreational needs of residents and visitors and provides a quiet respite for many to connect with nature or relax with family and friends. It is also frequented by wildlife. The area is located between Parkland and Foothills natural regions and contains a large complex of springs feeding a tributary creek and series of small waterfalls that flow year-round over rocky terraces (and unique tufa deposits) covered with a lush growth of shrubs and grasses. The area is also the site of an historic fish hatchery. In fact, the area is so special, and regionally unique that the government established this as a provincial park in 1957, which received over 250,000 visitors each year.

The spring complex at the headwaters of Big Hill Springs Provincial Park is sustained by groundwater that discharges from a large, buried sand and gravel aquifer deposited thousands of years ago. These sand and gravel deposits are gaining increased attention, and pressure, to be developed as aggregate by various companies. Despite the fact there are multiple other locations in Rocky View County and the immediate region where sand and gravel aggregate can be extracted, or is already being exploited, MALP (and others) are interested in establishing pits in close proximity to Big Hill Springs Provincial Park and the headwaters of the Big Hill Springs complex.

There are definite future ramifications for this type of development when considering local groundwater users and surface water bodies that receive, and rely on, the groundwater discharging from this sand and gravel aquifer. The risks of future impacts to the local groundwater are only increased due to the cumulative pressures from multiple aggregate operations that want to establish themselves in the same area. Not only is there an issue regarding changes to groundwater quality, but there is also legal liability associated with future impacts to aquatic habitat and fish in Bighill Creek, which could trigger a series of violations related to provincial and federal Acts. Establishing a development setback of at least 1.6 kilometers, and the requirement to maintain an adequate vertical buffer of undisturbed sand and gravel above the water table of at least 4 metres for any other development within 800 metres of this development setback, would manage the risks posed to the Big Hill Springs complex and the Bighill Creek system. And, in doing this will also avoid the potential for future interventions on development applications and manage the risk of regulatory violations.

Respectfully submitted by,



2021-01-23

Jon Fennell, M.Sc., Ph.D., P.Geol.
Hydrogeologist & Geochemist

References

Alberta Government (2018). Environmental Quality Guidelines for Alberta Surface Waters. Water Policy Branch, Alberta Environment and Parks, March 28, 2018, ISBN (PDF) 978-1-4601-3873-1, 58 pp. https://open.alberta.ca/publications/9781460138731

Alberta Government (2019). Alberta Tier 1 Soil and Groundwater Remediation Guidelines. AEP, Land Policy, 2019, No. 1, ISBN 978-1-4601-2695-0, https://open.alberta.ca/dataset/842becf6-dc0c-4cc7-8b29-e3f383133ddc/resource/a5cd84a6-5675-4e5b-94b8-0a36887c588b/download/albertatier1guidelines-jan10-2019.pdf

Atlas of Eh-pH diagrams: Intercomparison of thermodynamic databases, Geological Survey of Japan Open File Report No.419; https://www.nrc.gov/docs/ML1808/ML18089A638.pdf, 287 pp.

Fouli Y. (2020). Bighill Creek Water and Sediment Quality Baseline Study Phase II: 2019-2020. Prepared by Dr. Ymène Fouli for the Bighill Creek Preservation Society, http://bighillcreek.ca/wp/wp-content/uploads/2020/10/20200914_PhaseII_Report1-1.pdf, 59 pp.

Bow River Basin Council, BRBC (2020). Preserving Our Lifeline, Vol. 20, Issue 4 (www.brbc.ca)

Hajibabaei Lab (2019) Preliminary DNA Data: Bighill Creek (Bow River) AB. Centre for Biodiversity Genomics, University of Guelph, WWF Canada & Environment and Climate Change Canada, 18 pp. http://bighillcreek.ca/wp/wp-content/uploads/2020/08/STREAM_Report_RP11_Tobin_Dec19-11.pdf

Hatva T. (1994). Future Groundwater Resources at Risk. Proceedings of the Helsinki Conference, June 1994, IAHS Publ. no. 222. 8 pp. http://ccob.ca/wp-content/uploads/2012/05/finnish-study-effect-of-gravel-extraction-on-groundwater.pdf

Health Canada (2020). Guidelines for Canadian Drinking Water Quality – Summary Table. Prepared in collaboration with the Federal-Provincial-Territorial Committee on Drinking Water of the Federal-Provincial-Territorial Committee on Health of the Environment, September 2020, 28 pp. https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/water-quality/guidelines-canadian-drinking-water-quality-summary-table.html

Kuo C.-C. and Gan T.Y. (2015) Potential impacts of climate change on intensity duration frequency curves of central Alberta. Climate Change, 130, pp. 115-129, DOI 10.1007/s100584-1347-9, https://www.researchgate.net/publication/273450354_Potential_impact_of_climate_change_on_intensity_duration_ frequency_curves_of_central_Alberta

Mead R.D. (1995). The Direct and Cumulative Effects of Gravel Mining on Groundwater within Thurston County, Washington. Ground Water Management Program, Environmental Health Division, Thurston County Public Health and Social Services Department, Appendix A of Technical Memorandum #33 (August 2018), 65 pp. https://www.thurstoncountywa.gov/planning/planningdocuments/3%20-%20Tech%20Memo%2033%20-%20Hydrogeologic%20review%20of%20Mineral%20Extraction%20Code%2008152018.pdf

Morin S.R. (1986). Surficial geology of the Calgary urban area - Bulletin No. 53. Terrain Sciences Department, Alberta Research Council, Edmonton AB, 57 pp. https://www.ags.aer.ca/publications/BUL_053.html

MALP Limited Partnership, MALP (2020). Master Site Development Plan – the Summit Pit (Draft for Circulation Purposes). March 2020, 64 pp.

Poschmann S. (2007). Estimating a recharge area for Big Hill Springs, Alberta Canada. B.Sc. thesis , Dept. of Geology & Geophysics, University of Calgary, 41 pp, http://www.countynewsonline.ca/wp-content/uploads/2018/03/BCPS-recharge-area-for-Big-Hill-Springs.pdf

SLR Global Environmental Solutions, SLR (2020). MALP Limited Partnership Aggregate Operation – NW and SW 31-26-03 W5M, Rocky View County, Alberta: Hydrogeological Assessment Report. SLR Project No. 212.06650.00003, January 2020, 335 pp.

Trout Unlimited Canada, TUC (2018). Electrofishing Investigations in Bighill Creek, June 2918: Trout Unlimited Canada Technical Report. Prepared for Bighill Creek Preservation Society, 19 pp. http://bighillcreek.ca/wp/wp-content/uploads/2018/10/BCPS_Bighill-Creek-Fish-Inventory-Report2018.pdf

Ummenhofer C.C. and Meehl G.A (2017). Extreme weather and climate events with ecological relevance: a review. Philosophical Transactions of the Royal Society B, published 08 May 2017, https://royalsocietypublishing.org/doi/10.1098/rstb.2016.0135

Websites

Alberta precipitation quality monitoring program, accessed January 4, 2021, https://open.canada.ca/data/en/dataset/ed1d9a68-fce1-4dbc-8158-67d38019aef8

Climate Atlas of Canada, accessed January 15, 2021, www.climateatlas.ca

Fisheries and Oceans Canada: Species at risk map, accessed January 19, 2021, https://www.dfo-mpo.gc.ca/species-especes/sara-lep/map-carte/index-eng.html

TABLES

Table 1. Groundwater quality in and around MALP property (SLR 2020)

Parameters	Units	FWAL criteria	Sand & Gravel monitoring wells			Bedrock wells				Big Hill Springs		
			MW14-101	MW14-103	MW19-110	WW1	WW2	WW3	WW4			
			20-Nov-14	04-Aug-15	10-Jul-19	Median	Median	Median	Median	30-Oct-14	04-Aug-15	10-Jul-19
General quality indicators												
pH	S.U.	6.5-9.0	7.9	8.0	7.8	8.1	8.0	8.0	8.0	8.2	8.2	8.1
TDS	mg/L		337	333	290	314	317	340	330	342	334	210
Hardness (calc)	mg/L		328	316	278	310	281	333	333	336	317	200
Turbidity	NTU		9.6	8	<0.10	0.3	0.8	0.23	0.60	0.8	1.07	5.1
Major ions												
Calcium	mg/L		76	73	62	69	59	71	75	74	72	48
Magnesium	mg/L		34	33	30	33	33	38	35	37	33	20
Sodium	mg/L		6	8	6	7	13	8	7	8	8	5
Potassium	mg/L		5	4	3	3	2	3	3	3	3	5
Bicarbonate	mg/L		382	375	330	363	363	385	365	376	371	240
Chloride	mg/L	120	11	9	8	4	2	8	11	10	10	8
Sulphate	mg/L	429 or greater	9	11	8	7	16	11	7	9	8	5
Nitrate-N	mg/L	3.0	1.2	1.8	1.9	1.7	0.7	1.9	3.2	2.8	3.0	1.4
Nitrite-N	mg/L		--	--	--	--	--	--	--	--	--	--
Total metals & trace elements												
Aluminum	mg/L	0.05	0.16	0.11	10.0	0.009	0.006	0.006	0.004	0.018	0.014	0.30
Arsenic	mg/L	0.0050	0.0004	0.0003	0.0084	0.0001	0.0002	0.0001	0.0002	0.0002	0.0006	0.0006
Barium	mg/L		0.424	0.332	2.20	0.283	0.128	0.223	0.225	0.304	0.313	0.210
Boron	mg/L	1.5	--	--	--	0.022	0.028	--	0.023	0.024	<0.020	<0.020
Cadmium	mg/L	0.000340	0.000016	<0.000005	0.004200	0.000013	0.000024	0.000032	0.000024	0.000032	0.000008	0.000034
Chromium	mg/L	0.001 *(assume 6+)*	--	0.002	0.019	--	--	--	0.001	--	--	0.001
Copper	mg/L	0.040	--	0.0013	0.032	0.022	0.002	0.065	0.006	--	0.0010	0.0013
Iron	mg/L	0.300	0.28	0.22	10.0	0.015	0.029	--	0.018	0.03	0.02	0.25
Lead	mg/L	0.007	0.000	--	0.019	0.001	0.001	0.003	0.001	--	--	--
Mercury	mg/L	0.000005	--	--	0.000002	--	--	--		--	--	0.000003

Parameters	Units	FWAL criteria	Sand & Gravel monitoring wells			Bedrock wells				Big Hill Springs		
			MW14-101	MW14-103	MW19-110	WW1	WW2	WW3	WW4			
			20-Nov-14	04-Aug-15	10-Jul-19	Median	Median	Median	Median	30-Oct-14	04-Aug-15	10-Jul-19
Manganese	mg/L		0.020	0.010	7.300	--	0.004	0.001	0.004	0.0019	0.0012	<0.0040
Molybdenum	mg/L	0.073	0.001	0.001	0.002	0.001	0.002	0.001	0.001	0.0014	0.0009	0.0004
Nickel	mg/L	0.120	--	0.001	0.065	--	0.001	0.002	0.001	--	<0.00050	0.0009
Selenium	mg/L	0.002	--	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001
Thallium	mg/L	0.0008	--	--	0.0002	--	--	--		--	--	--
Uranium	mg/L	0.015	0.002	0.002	0.006	0.001	0.001	0.002	0.001	0.0020	0.0019	0.0013
Zinc	mg/L	0.030	--	--	0.140	--	0.035	0.205	0.041	--	--	--
Microbiological												
Total coliforms	MPN/100		-	<1	180	<1	<1	<1	6	-	2420	>2400
E.coli	MPN/100		-	<1	63	<1	<1	<1	<1	-	1733	1600

Notes:

1. Parameters highlighted in red indicate concentrations above published FWAL criteria (AB government 2018)
2. Average hardness of 250 mg/L (as $CaCO_3$) used for determining metals and trace element guidelines, as required.
3. FWAL = freshwater aquatic life

Table 2. Bighill Creek water quality: 2019-2020 (Fouli 2020)

Sampling Location	Units	FWAL criteria	SITE 1 - upstream of Big Hill Springs at Hwy 567			SITE 2 – near confluence of Big Hill Springs and Bighill Creek		
			Median	Min	Max	Median	Min	Max
General quality indicators								
pH		6.5-9.0	8.1	7.8	8.3	8.1	8.0	8.5
TDS	mg/L	--	310	180	490	330	210	370
Hardness (as $CaCO_3$)	mg/L	--	280	160	430	280	180	340
Selected ions								
Sodium	mg/L	--	20	11	31	15	11	17
Chloride	mg/L	120	9.8	7.8	23	9.0	5.7	15.0
Sulphate	mg/L	429 or greater	13	7	28	13	10	14
Nutrients								
Nitrate (as N)	mg/L	3.0	0.077	0.027	.033	3.3	0.84	9.2
Total Phosphorus	mg/L	--	<0.10	<0.10	<0.10	0.10	<0.10	0.120
Total metals & trace elements								
Aluminum	mg/L	0.050	0.055	0.031	0.440	0.053	0.017	0.160
Arsenic	mg/L	0.0050	0.0010	0.0007	0.0013	0.0009	0.0002	0.0011
Barium	mg/L	--	0.165	0.120	0.260	0.200	0.130	0.280
Boron	mg/L	1.5	0.018	<0.02	0.026	0.010	<0.020	0.023
Cadmium	ug/L	0.034	0.010	<0.010	0.039	0.026	0.010	0.037
Chromium	mg/L	0.0010 *(assume 6+)*	0.0005	<0.0010	0.0013	0.0005	0.0005	0.0012
Copper	mg/L	0.040	0.0005	0.0004	0.0015	0.0007	0.0003	0.0009
Iron	mg/L	0.0300	0.410	0.240	0.830	0.240	0.170	0.580
Lead	mg/L	0.0070	0.0001	<0.0001	0.0004	0.0001	<0.002	0.0002
Manganese	mg/L	--	0.026	0.014	0.220	0.015	0.011	0.047
Molybdenum	mg/L	0.0730	0.0010	0.0003	0.0012	0.001	0.000	0.001
Nickel	mg/L	0.110	0.0008	0.0006	0.0012	0.0006	<0.0003	0.0011
Potassium	mg/L	--	5.0	3.8	7.1	4.1	3.5	6.0
Selenium	mg/L	0.0020	0.0005	0.0004	0.0013	0.0008	0.0005	0.0015

Sampling Location	Units	FWAL criteria	SITE 1 - upstream of BHS at Hwy 567			SITE 2 - confluence of BHS and Bighill Creek		
			Median	Min	Max	Median	Min	Max
Silicon	mg/L	--	4.9	2.2	8.4	4.4	3.1	7.3
Strontium	mg/L	--	0.555	0.320	0.820	0.500	0.360	0.560
Sulphur	mg/L	--	4.7	3.0	7.8	2.9	2.7	5.0
Titanium	mg/L	--	0.003	0.002	0.013	0.001	0.001	0.005
Uranium	mg/L	0.0150	0.003	0.002	0.003	0.002	0.001	0.003
Vanadium	mg/L	--	0.001	<0.001	0.002	0.002	0.002	0.002
Zinc	mg/L	0.030	0.003	0.002	0.005	0.004	0.004	0.004

Notes:

1. Parameters highlighted in red indicate concentrations above published FWAL criteria (AB government 2018)
2. Average hardness of 250 mg/L (as $CaCO_3$) used for determining metals and trace element guidelines, as required.
3. BHS = Big Hill Springs; FWAL = freshwater aquatic life

APPENDICES

Jon Fennell. M.Sc., Ph.D., P.Geol.

PROFESSIONAL PROFILE

Dr. Jon Fennell has been a practicing consultant in the natural resource sector for over 30 years offering support in the environmental sciences and resource management. His experience includes contaminated sites assessment, development of local and regional-scale groundwater systems, mine dewatering strategies, water supply and disposal, groundwater-surface water interaction assessment, implementation of monitoring and management systems, climate analysis and adaptation strategies, and environmental forensics including applications of:

i) remote sensing
ii) downhole, earth-based and airborne geophysical methods
iii) geochemical assessment & modelling
iv) stable and radiogenic isotopes to support source water tracing, chemical fingerprinting, and age-dating

The bulk of Jon's experience is associated with various oil & gas and mineral resource development projects in Canada and abroad. Over the last 13 years Jon has worked closely the Alberta Government through various initiatives to support the Water for Life Strategy, Land Use Framework, and Cumulative Effects Management System in the province. A primary area of focus is on developing strategies to ensure water security and communicating the importance of water knowledge as it applies to sustainable development activities.

PROJECT EXPERIENCE

International support

United Nations – Joint Caribbean Climate Change Partnership

Technical lead for the development of UNFCCC-sanctioned National Adaptation Plans for the countries of Belize and Guyana, with the goal of addressing multi-sector impacts from future climate change. Responsibilities included review of existing policies and studies supporting climate change adaptation, assessment of current adaptation plans for major economic, social, and environmental sectors, Incorporation of IPCC model results under various RCP scenarios, delivery of facilitated in-country workshops for various ministries, provision of recommendations to address gaps identified in current plans, liaison with government officials and UNDP organizers, completion of risk assessment and options analysis to identify high-value actions, preparation of capacity-building plan and 10-yr strategic plan, and risk and vulnerability assessment (including spatial aspects under various climate change scenarios – SRES and RCP).

Mexican Soda and Water Company – Monterrey Mexico

Lead for a groundwater evaluation project to supplement beverage making operations a large manufacturing plant in the city of Monterrey. Responsibilities included review of background geological, hydrogeological and geochemical information across a large study area centered on the Monterrey Metropolitan Area; assessment of structural fabric of study area including presence of major folds, faults, and other features (e.g. karst), amalgamation of background data with result from Quantum Geoelectrophysics reconnaissance program to identify prospective drilling targets, completion of a 4C report (compare, contrast, correlate, confirm) and selection of prime drilling target for testing and evaluation.

Dept. of Environment & Resource Management – Coal Seam Gas Development, Queensland Australia

Lead for a hydrogeochemical assessment and water fingerprinting exercise in Great Artesian Basin aquifers of the Surat and Bowen basins to support Coal Seam Gas development and cumulative effects analysis. Responsibilities included a comprehensive data and information inventory to facilitate source water fingerprinting and collation of large public-domain data sets to provide a first-of-its-kind database of water quality information, review of major ions, metals and trace elements, stable and radiogenic isotopes and dissolved gases to identify recharge phenomenon, cross-formational flow characteristics and distinct water types, and statistical analysis to assess data groupings and spatial trends.

Additionally, lead for an aquifer vulnerability assessment to assess groundwater and groundwater-dependent ecosystem risks from Coal Seam Gas development in southeast Queensland. Responsibilities included development of a multi-criteria weighting and ranking system linked with GIS to display areas of highest risk to drawdown including areas users and groundwater dependent ecosystems, and facilitation of industry and government workshops to present and vet results.

Origin Energy – Coal Seam Gas Development, Queensland Australia

Groundwater lead for a large-scale coal seam gas project (up to 10,000 wells) located in the headwaters of the Murray-Darling Basin and recharge area for the Great Artesian Basin. Responsibilities included, development of a regional-scale groundwater monitoring system using vulnerability and risk mapping, design of a hydrogeological model covering a 173 000 km^2 area (using FEFLOW) to assess cumulative effects from coal seam gas development, completion of supporting Technical Report (including risk mapping, injection feasibility, model development) and Environmental Impact Statement chapter, and liaison with the Queensland Department of Environment and Natural Resources to address needs for the required Environmental Impact Assessment.

Texas Petroleum Company – Hydrocarbon Development, Columbia South America

Completion of an onsite environmental assessment of oilfield operations in support of the transfer of the Teca Nare, Cocorná, Velásques Oil Fields and the Velásquez-Galan Pipeline. Responsibilities included phase 1 site assessment of field operations, verification of site conditions at all well sites including soil and vegetation conditions prior to property transfer, assessment of baseline surface water and groundwater chemical conditions, as wells as environmental quality assessment to determine contamination from oilfield operations, and provision of summary report including recommendations.

Texas Petroleum Company – Hydrocarbon Development, Ecuador South America

Completion of a baseline groundwater and surface water study in a remote and environmentally sensitive area of the Amazon basin (headwaters area) to support a helicopter-assisted drilling program for oil and gas exploration. Responsibilities included field reconnaissance to establish the suitability of proposed drilling targets, assessment of the suitability of local surface water and groundwater sources for drilling fluid provision (quality and quantity), review of baseline soil quality, site hydrogeology, and geochemical conditions, and development of recommendations for pit construction and site preparation.

Canadian International Development Agency – Municipal works, Ecuador South America

Completion of a baseline soil and groundwater study (physical and chemical) around the City of Catamayo to determine the feasibility of siting an engineered wastewater impoundment for the treatment of municipal sewage treatment (project funded by CIDA). Responsibilities included general site reconnaissance, collection of soil and groundwater samples for baseline geochemical quality assessment, review of hydrogeological conditions and processes relating to baseline conditions, and submission of recommendations on the suitability of the proposed location and possible approaches to rectify existing limitations.

Government of Yemen – National water supply, Yemen

Hydrogeological and geochemical support for a regional-scale study of water supply potential in the country. Responsibilities included hydrogeological and hydrogeochemical facies mapping, geochemical assessment and flow path evolution modelling, groundwater flow field assessment and modelling, sustainable yield evaluation, and groundwater age dating.

Blackbird Mine – Acid Rock Drainage assessment, Idaho USA

Completion of a hydrogeological baseline study and associated stable isotope investigation ($\delta^{34}S$, $\delta^{18}O$, and $\delta^{2}H$) to determine the source of acid mine drainage near active underground workings. Responsibilities included review of existing geochemical data and related mineral equilibria conditions (i.e. baseline and impacted), and assessment of geochemical reactions leading to ARD conditions, including biogeochemical aspects.

Government support

Alberta Environment, Oil Sands Science and Monitoring Division

Preparation of oil sands tailings pond seepage review report. Responsibilities included review of background information pertaining to oil sands produced water (OSPW) seepage research and natural bedrock groundwater discharge studies, review of industry-submitted EPEA compliance reports to assess current "state of affairs" regarding monitoring and OSPW detections, assessment of seepage management systems, review of geological pathways for OSPW migration, and development of seepage risk profiles for all active tailings ponds.

Alberta Environment and Parks (AEP)

Provision of external expert review for the Implementation Directive for the Surface Water Body Aggregate Policy (SWBAP). Responsibilities included review of relevant Government of Alberta documents relating to aggregate mining in or near surface water bodies and/or floodplain environments, use of information from relevant policies in other jurisdictions as well as studies and research (aquatic, terrestrial, river morphology, climate risk) regarding impacts of aggregate mining in floodplain areas, identification of gaps regarding goals and objectives of the approval and management process, ,review of risk assessment approach to approving aggregate mines near surface water bodies, and provision of recommendations for monitoring, evaluating and reporting, and interaction with AEP project team members and presentation of results.

Also, participation on expert hydrogeology panel to development a template for groundwater management frameworks (GMFs) in Alberta. Responsibilities included assessment of background on Alberta groundwater resources and documents highlighting existing GMFs inside and outside of Canada, review of sustainability goals and challenges with groundwater management (quantity and quality), review of prevailing concepts to groundwater management (i.e. surface water capture, risk and vulnerability assessment), identification of data needs and required infrastructure to support cumulative effects management, identification of proposed indicators using DPSIR approach, and participation in external panel and internal AEP team of hydrogeological experts to define aspects of a standardized GMF template.

Alberta Environmental Monitoring Evaluation and Reporting Agency (AEMERA)

Assessment of Alberta's groundwater observation well network, including redundancy and gap analysis. Responsibilities included groundwater risk mapping, development of a numerical scoring scheme to prioritize monitoring wells, statistical and spatial analysis of provincial water chemistries using information from the Alberta water well information database, and development of monitoring strategy including analytes and frequency to address key development activities (e.g. hydraulic fracturing, waste disposal, large-scale groundwater extractions).

Alberta Environment (AENV)

Various projects include:

- Assistance with scoping, conceptual design and development of approach to Groundwater Management framework template
- Expert review for Implementation Directive for the Surface Water Body Aggregate Policy
- Review and comment on Groundwater Monitoring Directive (2012 draft)
- Technical assistance with development of a guidance framework to respond to the implications of thermal mobilization of constituents at in-situ bitumen recovery projects including facilitation of team workshops to communicate the physical and chemical aspects of thermal mobilization and the risks posed by in-situ operations, development of a risk-based, phased, approach to assessing thermal mobilization to address source-pathway-receptor aspects, development of a draft guidance document and interaction with the AEP communications team, and support for industry and CAPP consultation meetings to review the draft guidance document.
- Completion of vulnerability and risk mapping for the Lower Athabasca Regional Planning area and development of groundwater management framework for the mineable and thermal in situ areas.
- Completion of an inventory of existing quality and quantity issues, water supply conditions and related environmental policy.
- Participation in technical and policy-related work sessions involving various stakeholder representatives.
- Assessment of potential cumulative effects from thermal in-situ bitumen recovery operations and related activities (i.e. water withdrawal for steam generation; fluid waste injection)
- Facilitation of technical and policy-related work sessions to engage stakeholders (operators, AENV and ERCB) directly affected by changes to provincial water management.

Alberta Environment and Sustainable Resource Development (ESRD)

Various projects include:

- Development of a multi-attribute point-scoring system and ArcGIS tool to assist with optimal siting of provincial monitoring wells to address concerns regarding hydraulic fracturing (HF). Responsibilities included identification of key risks to groundwater resource from HF activities, conceptualization and construction of a subsurface risk assessment, and identification of surface access opportunities in an ArcGIS platform to identify prime locations for monitoring in active and future development areas.

- Northern Athabasca Oil Sands Region groundwater monitoring program. Responsibilities included development of sampling methodology, data evaluation process and program logistics, communication to technical team comprising oil sands operators, ERCB and AEP representatives, development of an on-line visualization tool, and client liaison.
- Review of LARP management plan, supporting Groundwater Management Frameworks and supporting guidance documents re: Thermal Mobilization of Trace Elements during In Situ Developments and Groundwater Monitoring Directive.
- Preparation of summary document for Scientific Advisory Committee of the Oil sands GW working group, and Alberta Environment.

Alberta Land Use Secretariat (LUS)

Assistance with development of land planning scenarios in NE Alberta to guide future development in the Lower Athabasca Regional Plan area pursuant to the goals of the Alberta Land-use Framework. Responsibilities included presentations to the Land Use Secretariat, Regional Planning Team and Regional Advisory Council, development and assessment of modelled results from a cumulative effects simulator, completion of groundwater modelling over a 93 000 km^2 area (using MODFLOW), and development of an approach to deal with groundwater resources in the LARP area.

Alberta Utilities Commission (AUC)

Provision of expert review support for a wind power application in the Provost AB area. Responsibilities included review of project concept and environmental implications, assessment of completeness regarding baseline hydrogeological assessment, assessment of impact analysis and proposed mitigation, identification of gaps and provision supplemental information requests.

BC Ministry of Energy, Mines and Petroleum Resources

Provision of expert review support for hydraulic fracturing review process. Responsibilities included preparation of background information pertaining to water quality risks and source-pathway-receptor aspects of hydraulic fracturing operations, provision of recommendation regarding geochemical fingerprinting (ion ratios, isotopes, NORMs), risk assessment and mapping techniques, and monitoring, and appearance at in-camera session to discuss water quality aspects with academic panel members including recommendations.

Agency support

Alberta Innovates (AI)

Provision of hydrogeological support services for the following University of Alberta research studies:

- Resolving human versus Industrial Influences on the water quality of the Lower Athabasca River (data synthesis; geophysical and geochemical assessment; isotope geochemistry source water fingerprinting, GW-SW interaction – identification and flux)
- Review of Arsenic in Alberta's groundwater (collation of multiple open source and private data bases, GIS platform design; correlation/cluster/factor analysis to determine source/cause/reasons(s), both physical and geochemical, for elevated concentrations, development of a risk mapping tool to identify existing and potential future high-risk areas and aquifer intervals)
- Predicting Alberta's Water Future (complete estimates of groundwater recharge to Alberta's 2200 sub-basins; determining groundwater use projection by major sector to 2050; assessing baseflow contributions and groundwater stress area based analytic model outputs; project changes to provincial

water supplies based on population growth, energy extraction, food production, land use, and climate variability/change; coordinate results with climate change model outputs and SWAT model outputs to generate preliminary Water Risk map for the province.

Alberta Water Research Institute (AWRI)

Preparation of a report assessing Alberta's inventory of water and its associated dynamics (natural and human-induced). Responsibilities included the development of a partnership model including participants from Universities and Institutes in Beijing, Switzerland, Edmonton, Calgary and Lethbridge, completion of a complete inventory of surface water, groundwater and fossil water (glaciers and deep groundwater) to identify current and future risks to water supplies in the province, and assessment of climate variability and change implications to provincial groundwater water resources

Canada's Oil Sands Innovation Alliance (COSIA)

Completion of a tailing pond seepage risk assessment and preparation of a peer-review journal manuscript to place suspected oil sands impacts into perspective. Responsibilities included review of individual tailings ponds established at the various operating oil sands mines in the Athabasca Oil Sands region, application of source-pathway-receptor model in relation to calculated groundwater flow velocities, stand-off distances from receptors, and natural attenuation properties to assess risk associated with each structure, and preparation of manuscript to place into context natural discharge of low-quality groundwater from bedrock formation versus oil sands seepage.

Other projects include:

- Completion of regional geochemical assessments in NE Alberta (35,000 km^2 area) supporting the Regional Water Management Initiative. Responsibilities included, collation of regional geological, hydrogeological, and geochemical data using public domain and industry information, assessment and interpretation of hydrogeological setting and of conceptual models, assessment of traditional and isotope geochemistry to determine source water chemistry to define flow path phenomena areas of aquifer interactions, statistical analysis of data to determine groupings and associations (PCA analysis), and documentation and presentation of results at various public venues.
- Completion of a water disposal assessment in NE Alberta (153,000 km^2 area) supporting the Regional Water Management Initiative. Responsibilities included collation of regional geological, hydrogeological, and water production data using public domain and industry information, development of a multi-criteria analysis approach to assessing Injection Potential and Theoretical Injection Rates based on a system of weighted and ranked physical and chemical attributes, and development of an ArcGIS platform to identify high-value disposal formations in relation to existing and planned in situ developments and pipelines
- Completion of oil sands industry study assessing the risks and benefits of landfills, salt caverns and disposal wells in liquid waste management. Responsibilities included participation in industry workshops. assessment of liquid waste management options, documentation and presentation of the results to industry members.

Cumulative Environmental Management Association (CEMA)

Assessment of baseline hydrological and hydrogeological conditions and development of a regional-scale groundwater quality monitoring network (18 000 km^2 study area) located in the Athabasca Oil Sands Region of northeast Alberta. Responsibilities included refinement of conceptual hydrogeological model, groundwater-surface water interaction assessment, assessment of quality conditions and trends (including statistical analysis), knowledge and data gap analysis, pathway identification and vulnerability assessment for sensitive receptors, field reconnaissance and well selection, isotope interpretation ($\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C$, Carbon-14), groundwater hydrograph analysis, report preparation and presentation, and liaison with government and industry representatives.

Other projects include:

- Preparation of a groundwater monitoring and management plan in support of the State of the Muskeg River Watershed report. Responsibilities included assessment of baseline groundwater quantity and quality conditions in the study area, identification of development stresses and potential short and long-term impacts, identification of proposed physical, chemical and state indicators for monitoring, and interaction in multidisciplinary team.
- Overview of historical, current, and planned groundwater initiatives in the Regional Municipality of Wood Buffalo. Responsibilities included interviews with relevant industry, government, academia, aboriginal, and non-governmental organization groups, identifying and accessing relevant studies, reports, and investigations relating to groundwater and groundwater-surface water interaction, and development of a useable database with relevant descriptors of content and results.

Lakeland Industry and Community Association (LICA)

Assessment of the current health of two large watersheds (covering over 8500 km^2) in response to changing climatic conditions, changing land use practices, and increased pressure on water resources (surface water and groundwater) by agricultural and industrial users. Responsibilities included the assessment of historical Landsat imagery, review of stream and groundwater hydrograph data, assessment of effects of climate phenomena on basin hydrology, development of a hydrogeological framework from over 11,500 water well records, and review of temporal quality data from lakes and water wells.

Petroleum Technology Alliance of Canada (PTAC)

Completion of studies and industry workshops assessing environmental net benefit of saline water use versus non-saline water use in unconventional oil and gas development and the role of collaboration in unconventional oil and gas development.

Municipal and Watershed Stewardship Groups

Butte Action Committee

Preparation for, and participation in, AEP-led Surface Water Body Aggregate Policy 2017 stakeholder review workshops. Responsibilities included consultation with stakeholder group, provision of support for Leduc workshop, review of AEP materials in advance of Airdrie workshop (AEP policies, guides, codes, risk assessment framework), review of other Canadian and International policies and guides to aggregate mining near water bodies, review of impact studies related to aggregate mine development near surface water bodies (erosion, pit capture, infrastructure risk, fisheries and riparian area impacts), assessment of climate change implications for streamflow timing and magnitude, as well as intensity, duration, and frequency of storms and related runoff, on 1:100 levels, and documentation of questions to AEP for clarification and response to AEP questions re: climate change implications.

Red Deer River Watershed Alliance (RDRWA)

Assistance with development of an Integrated Watershed Management Plan to address future development in the basin. Responsibilities included assessment of aquifer types and groundwater inventory, water use patterns, effects of land use and climate variability/change on basin storage, assessment of water quality conditions, risk and vulnerability analysis, development of beneficial management practices, and development of a conceptual monitoring system to achieve plan goals and objectives.

South McDougall Flats Protection Society, Sundre AB

Review of proposed re-zoning for aggregate mine development in historic floodplain of Little Red Deer River in Sundre, AB. Responsibilities included review of proposed gravel pit re-zoning area, air photo assessment and delineation of paleo-floodplain. preparation and presentation of workshop materials at public forums re: pros and cons of gravel mining (including policy framework review), and support for Town Council hearing.

Town of Okotoks, AB

Assistance with review of development applications and support for ensuring water security through conjunctive use strategies. Responsibilities included expert review of development applications assessing cumulative drawdown effects and provision of recommendations to manage effects, engagement with Town official on development of a sustainable water management strategy, and provision of support for AENV and Environmental Appeal Board process.

Also, completion of a pre-feasibility study to assess aquifer storage and recovery (ASR) and managed aquifer recharge (MAR) as a solution to water supply challenges. Responsibilities included review of regulatory setting and constraints for ASR and MAR (Canada and international jurisdictions), review of ASR and MAR projects world-wide, assessment of local geological and hydrogeological conditions and identification of potential areas to facilitate ASR and MAR success, modelling to determine optimal placement of MAR system to enhance baseflow conditions, groundwater-surface water interaction assessment, and preparation and presentation of pre-feasibility summary to Town Council and Mayor.

Town of High River, AB

Lead for the development of a Water Sustainability Plan predicated on risk identification and alternative storage and management options for a large alluvial aquifer system. Responsibilities included concept and program design, execution of vulnerability mapping approach to assess risk to High River from groundwater impacts (e.g. underground storage tanks), development of conceptual hydrogeological framework, review of groundwater–surface water interaction and climate variability effects, assistance with groundwater model development, and liaison with town officials, MD Foothills official and other project stakeholders.

Tsuut'ina First Nation

Completion of flood analysis for the Redwood Meadow development on the Elbow River floodplain. Responsibilities included review of river hydrology, flood frequency, and related changes in river morphology, assistance with hydrological modelling to address groundwater flooding potential to existing and panned development areas, calculation of damage estimates associated with 5-, 20-,100-, 200- and 500-year return periods, and liaison with First Nations representatives, Government of AB, and Canadian Environmental Assessment Agency.

Industry support

Alberta Energy Company (AEC)

Preparation of an Environmental Operations Manual for all aspects of petroleum exploration and development in Alberta. Contents of the manual included environmental procedures for seismic cutline provision and reclamation, siting and construction of drilling leases and processing facilities, siting and construction of pipeline right of ways, spill response and cleanup, and site reclamation.

Amoco Canada

Various projects include:

- Numerous gas plant and batter investigations, including the completion of geophysical surveys (EM38, EM31, and EM61), and the design, installation, testing and sampling of groundwater monitoring networks.
- Completion of environmental site assessments and landfill delineation programs for gas plant divestitures. Responsibilities included installation, testing and sampling of groundwater monitoring wells, completion of soil sampling programs, and assessment of the results to determine the liability cost associated with property transfer.
- Completion of a stable isotope study using $\delta^{34}S$, $\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C$ to determine the source of anomalous groundwater sulphate concentrations (natural vs. anthropogenic), and review of fresh groundwater usage for steam injection. Responsibilities included assessment of historical monitoring well and lake level readings to evaluate local effects resulting from groundwater withdrawal.
- Sounding Lake area monitoring program to determine effects from nearby drilling activity. Responsibilities included interviews with well-owners, assessment of the water delivery system, short-term aquifer testing, sample collection using ultra-clean sampling methods, evaluation of the data, and communication of results to client and owner.

Apache Canada

Completion of watershed analysis and intake siting in support of a Water Act Application on Smoky Lake. Responsibilities included assessment of Smoke Lake watershed and water supply potential, water supply modelling to determine availability and reliability of lake water, review of historical flow data and determination of suitable IFN at outlet (i.e. Q80), review of terrestrial, fisheries and water quality data to support water diversion strategy, development of proposed monitoring and response plan, and liaison with AEP and AER representatives.

Bellatrix Exploration Ltd.

Completion of a Water Sourcing study for Rocky Mountain asset. Responsibilities included review of existing and potential water sourcing options, development MCA and of GIS tool to assess and map high-value water opportunities, and completion of a corporate water security plan.

BP Canada

Resident well sampling program to determine effects from nearby drilling programs and existing gas wells. Responsibilities included well-owner interviews, assessment of the well conditions and water delivery system, sample collection using ultra-clean sampling methods, and communication of results.

Canadian Occidental

Completion of a stable isotope studies to determine the source of sulphate impact from two large sour gas processing facilities (Balzac and Okotoks). Responsibilities included drilling, installation, and testing of monitoring wells, development of a conceptual site model , review of site-wide geochemistry (soil and groundwater), and application of $\delta^{34}S$, $\delta^{18}O$, $\delta^{2}H$, and $\delta^{13}C$ isotopes to resolve natural versus anthropogenic influences.

Devon Canada

Various projects include:

- Development of a thermal mobilization risk model to support development efforts in the Jackfish and Pike oil sands developments. Responsibilities included review and evaluation of existing geochemical data including metals and trace elements, development of conceptual site model using existing geological picks for various identified formations, design of Spatial MCA approach to map risk of thermal mobilization from artificial ground heating, and preparation of summary document and presentation at various public venues.
- Completion of detailed studies to define baseline hydrogeological and hydrological conditions in support of a CBM project in the Crowsnest Region of the eastern Rocky Mountains. Responsibilities included, completion of detailed field reconnaissance program, establishment of a spring and water well monitoring network, investigation of surface water/groundwater interactions, development of a conceptual hydrogeological framework in a mountainous area using geological and geochemical data, groundwater age dating of regional confined aquifers using radioactive isotopes (i.e. Tritium and Chlorine-36), and public and regulatory liaison.
- Hydrogeological support for D51 disposal application. Responsibilities included refinement of conceptual model and identification of hydrodynamic conditions supporting disposal water entrapment by stagnation zone using geochemical and isotope evidence.

Enerplus

Completion of a Water Security Plan for the Western Canadian assets. Responsibilities included review of asset operations and water management process, assessment of basin water risk conditions and current mitigations in place, source water and disposal opportunity assessment, and development of multi-criteria assessment (MCA) process to rank water risk profile of each asset and provide recommendations for mitigation.

Graymont Western US Inc.

Preliminary development of a mine dewatering and water management strategy for a large limestone quarry located in the eastern from ranges of the Rocky Mountains. Responsibilities included assessment of baseline hydrogeological and hydrogeochemical conditions in a mountain environment, source water fingerprinting and groundwater age-dating, fracture and lineament analysis using structural geology and geophysical analysis (GPR, borehole tele-viewer), groundwater-surface water interaction assessment (i.e., Bow River), conceptualization of dewatering strategy utilizing oriented and horizontal well technology, and issues identification and risk analysis.

Hammerhead Resources

Completion of watershed analysis, flood assessment and intake siting in support of a Water Act Application on the Smoky River. Responsibilities included assessment of Smoky River watershed and water supply potential, review of historical flow data and assessment of Q80 and Q95, flood assessment to determine 1:10 and 1:25 year event levels, review of fisheries and bank stability assessment in support of intake siting, development of proposed monitoring and response plan, and liaison with AEP and AER representatives.

Husky Oil Operations Ltd.

Completion of a water security plan for the Ansell asset, west-central Alberta. Responsibilities included review of project water profile and future requirements for hydraulic fracturing, facilitation of risk review workshop, and review of water source opportunities and development of MCA opportunity ranking process.

Also, completion of a Water Security Plan for a 200,000 barrel per day thermal in situ oil sands operation. Responsibilities included, review of water supply and disposal needs for the duration of the planned project, risk and opportunity analysis using multi-criteria analysis to ensure viability of supply and disposal strategies, and identification of strategies to ensure project viability and project sustainability.

Imperial Oil

Various projects include:

- Completion of field and bench-scale tests to determine facilitated mobility of metals, trace elements, and dissolved organics resulting from artificial ground heating around thermal in situ wells. Responsibilities included drilling, installation, testing, and sampling (soil and water) from 22 deep (up to 90 m) monitoring wells at a newly established thermal in situ pad to determine baseline geochemistry and groundwater flow directions, tracer experiment to determine groundwater flow velocities in a deep (>80 m) confined aquifer, collection of sediment samples (under anoxic conditions) for bench-scale heating experiments to determine metals mobility and related kinetics, review of stable isotopes in groundwater and dissolved gases to determine effects of heating from in-situ thermal wells on local geochemical conditions (inorganic and organic constituents), reaction path modelling to determine processes influencing changes metals concentrations and biological activity resulting from subsurface heating, determination of activation energies for metals release, and the role of biogeochemical reactions in facilitating metals release, transport and fate modelling to determine the long-term risk of thermal mobilization of metals (and other related constituents) to the surrounding environment, and documentation of result and liaison with client and regulatory agencies.
- Design and implementation of dewatering program for large process water ponds. Responsibilities included review of site geological conditions, installation of dewatering wells, acquisition and interpretation of aquifer test data, design of dewatering system using appropriate theoretical calculations and analytical modelling solution, and development of dewatering plan and associated performance monitoring
- Completion of a regional groundwater investigation and development of a regional-scale ground water monitoring network (per EPO 95-07 requirements) in a multi-layer inter-till aquifer system in east-central Alberta. Responsibilities included assessment and interpretation of Quaternary stratigraphy, interpretation of seismic line data and geophysical borehole log analysis, regional groundwater flow mapping, geochemical facies mapping, assessment of regional arsenic concentrations, trends, and potential connection to thermal in situ development activities, groundwater age-dating and stable isotope analysis ($\delta^{18}O$, $\delta^{2}H$, $\delta^{34}S$, $\delta^{11}B$ and $\delta^{13}C$: dissolved constituents and gases), preparation of investigation report to address EPO questions (i.e. source and cause of groundwater quality issues), and liaison with regulators during investigation and EPO closure process.
- Completion of an environmental liability assessment to determine the cost of decommissioning, abandoning and restoring the area currently occupied by the Norman Wells field. Responsibilities included completion of a Phase 1 audit of production facilities and supporting infrastructure (i.e. wellheads, pipelines, satellites, batteries and former refinery), design and implementation of a late Fall field program to sample a statistically sufficient number of locations to generate realistic liability costing for field shutdown and closure, generation of a summary report, and assistance with design of liability costing model and summary reporting.

- Completion of numerous isotope studies using to determine groundwater flow rates in regional confined aquifers and the source of anomalous groundwater quality conditions and dissolved gas concentrations near a large heavy oil recovery operation using assessment of $\delta^{18}O$, $\delta^{2}H$, $\delta^{34}S$, $\delta^{11}B$ and $\delta^{13}C$ and Tritium and Carbon-14 for groundwater age-dating.
- Tritium age dating of groundwater in Norman Wells, NWT to determine vertical groundwater flow characteristics in discontinuous permafrost environment
- Development and implementation of a site characterization program at a former refinery and battery (circa 1930s) located approximately 160 km south of the Arctic Circle. Responsibilities included the design and installation of a monitoring network in discontinuous permafrost, and assistance in development of assessment programs to generate Tier II criteria in support of a human health and ecological risk assessment.
- Support for re-licensing of supply wells for oilfield injection using Alberta Environment "Water Conservation and Allocation Guideline for Oilfield Injection" and "Groundwater Evaluation Guideline." Responsibilities included, completion of field-verified surveys, review of site geological conditions, acquisition and interpretation of aquifer test data, assessment of groundwater/surface water interaction, and determination of long-term sustainable yield using analytical solutions
- Hydrogeological lead for a large oil sands mine EIA (Kearl Oil Sands Mine Project). Responsibilities include evaluation and interpretation of water well information and chemical data, defining Quaternary stratigraphy, temporal water level assessment to determine potential impact to regional groundwater quality and quantity arising from mine development and dewatering, and support at Joint Panel hearing.
- Cold Lake area monitoring program (Arsenic Investigation – 30 private residents). Responsibilities included interviews with well-owners, assessment of the water delivery system, sample collection using ultra-clean sampling methods, review of the data, and communication of results to client, well owner and Alberta Environment
- Completion of an environmental liability assessment and costing exercise in support of the sale of the Judy Creek field to PenGrowth Corp. to statistically sample a sufficient number of facilities to generate realistic liability cost for property transfer. Responsibilities included completion of Phase 1 audits of production facilities and supporting infrastructure (i.e. wellheads, pipelines, satellites, and batteries), design and implementation of winter field program to sample facilities to generate realistic liability cost for property transfer
- Conceptual model design for dewatering scheme in support of mine development. Responsibilities included assessment of geological conditions, boundary assessment, parameter selection and optimization, and assessment of model results
- Completion of a groundwater modelling study to determine the sustainable yield of a major deep freshwater aquifer in the Cold Lake area. Responsibilities included the provision of hydrogeological support for model conceptualization and design, input parameter selection, and evaluation and communication of results
- Development and implementation of a regional groundwater quality monitoring network covering an area of 1,200 km^2. Responsibilities included, regular interaction with environmental regulatory agencies and the local landowners, installation, testing and sampling of deep (up to 230 m) monitoring wells to assess potential impact to confined aquifers due to production well casing failures, design, implementation and interpretation of aquifer tests in support of groundwater remediation programs, and development of cost effective approaches towards restoring water quality conditions in deep aquifers influenced by heavy hydrocarbons and associated production fluids.

- Preparation of an AB environment approved Incident Response Plan to deal with groundwater quality issues identified during routine monitoring activities at a large heavy oil recovery scheme. Responsibilities included design of a cost-effective sampling schedule including rationalization of a 200 well monitoring network to provide a meaningful network of approx. 100 wells, and development of statistical limits for response and mitigation actions.

Japan Canada Oil Sands (JACOS)

Execution of hydrogeological section of an expansion EIA for the Hangingstone Thermal In Situ Oil Sands project. Responsibilities included development of baseline hydrogeology, EIA sections, and SIR responses, liaison with project team and governing agencies, and stakeholder consultation with First Nations and 3PC.

Also, completion of a water supply project in support of a heavy oil recovery scheme using Alberta Environment "Water Conservation and Allocation Guideline for Oilfield Injection" and "Groundwater Evaluation Guideline." Responsibilities included assessment of geophysical logs and EM survey results, design and implementation of field programs, step rate test and constant rate test data acquisition and analysis, well screen selection and well design, well efficiency assessment, and use of pertinent analytical equations to predict effect of long-term pumping.

Mobil Oil Canada

Completion of a stable isotope study to determine the source of sulphate impact from a large sour gas processing facility. Responsibilities included, drilling and installation of monitoring wells, development of a conceptual site model , review of site-wide geochemistry (soil and groundwater), and application of $\delta^{34}S$, $\delta^{18}O$, $\delta^{2}H$, and $\delta^{13}C$ isotopes to resolve natural versus anthropogenic influences.

Nexen ULC

Development of a water strategy to service the Aurora LNG project/Dilly Creek asset. Responsibilities included assessment of development trajectory with respect to water use, identification of feasible water supply source to accommodate up to 6.5 million m^3 per year of water, conceptualization of water storage strategy to reduce pressure on local water sources and minimize physical footprint of development, development of a water conveyance strategy utilizing existing rights of way, including Class 5 cost estimation, and liaison with Fort Nelson first Nations to facilitate development of baseline hydrology monitoring program and facilitation of a Section 10 water licence (following successful EAB appeal of previous licence).

Also, the design and completion of bench-scale testing to determine the mobilization of metals and trace elements under applied heating. Responsibilities included conceptual design of experimental process in collaboration with AGAT lab representatives, assessment of frozen core samples and selection of appropriate intervals for physical (grain size, mineralogy via XRD) and chemical testing (total metals, leachable metals), assessment of results from sequential batch heating experiments extending from 5-100°C for metals species released to solution, geochemical modelling of kinetic experiment results to determine activation energies of metals release, completion of attenuation experiments to determine potential for mobilized metals to re-associated with sediments under cooled conditions, and preparation of suitable documentation to present to the client and AER.

Pembina Pipeline Corporation

Provision of expert legal support to review source and cause of industrial chemical contamination at an operating gas plant. Responsibilities included review of existing site investigations, procedures, and documentation, assessment of efficacy of investigations and protocols (field and laboratory), development of conceptual model to explain presence and movement of sulfolane in bedrock deposits, and review of risk assessment findings and provision of recommendations to close data and information gaps.

Petro-Canada

Various projects include:

- Completion of detailed regional and local baseline studies, and cumulative impact assessment, to establish regional and local hydrogeological and geochemical characteristics in support of a 30,000 bbl/d heavy oil recovery expansion (MacKay River Project). Responsibilities included defining Quaternary stratigraphy, temporal water level assessment to determine potential impact to regional groundwater quality and quantity arising from bitumen recovery operations, development of a numerical groundwater model to assess long-term effects of water withdrawal and waste disposal to support project activities, and completion of climate change assessment formed part of the assessment for project design.
- Conceptualization and design of field program to assess water supply and water disposal for two major heavy oil projects (>30,000 bbl/d). Responsibilities included selection of drilling locations based on geophysical reconnaissance, implementation of field programs, step rate test and constant rate test data acquisition and analysis, well efficiency assessment, well screen selection and well design, and use of pertinent analytical equations.
- Review of fresh groundwater use for a water flood project. Responsibilities included interpretation of historical monitoring well data to determine the effects of the groundwater withdrawal from the local aquifer.
- Assessment of long-term effects of industrial water supply wells used for a water flood scheme. Responsibilities included a review groundwater chemistry and well hydraulic data to determination sustainable production rates.
- Completion of an environmental operations audit and subsequent industrial landfill delineation to determine the source area of possible groundwater contamination. Responsibilities included completion of a comprehensive intrusive landfill delineation and soil sampling program to determine the extent and volume of landfill contamination.
- Completion of an industrial landfill delineation project to determine possible sources of groundwater contamination. Responsibilities included completion of a magnetometer survey, follow-up excavation and soil sampling near a decommissioned landfill to determine the presence, extent and volume of residual landfill material.

Procor

Review of operational history of a salt cavern storage facility including an assessment of groundwater quality near the large brine storage ponds and the potential for impact to the Regina Aquifer.

Shell Canada

Various projects include:

- Completion of watershed analysis and intake siting in support of a Water Act Application on Iosegun Lake. Responsibilities included assessment of Iosegun Lake watershed and water supply potential, water supply modelling to determine availability and reliability of supply, review of historical flow data and determination of suitable IFN at outlet (i.e. Q80), review of terrestrial, fisheries and water quality data to support water diversion strategy, development of proposed monitoring and response plan, and liaison with AEP and AER representatives.

- Hydrogeological support for Jackpine Mine Expansion EIA
- Development of Groundwater Management Plan and annual monitoring support at Shell's Muskeg River Mine. Responsibilities included review of site-wide groundwater monitoring network for applicability to EPEA Approval requirements (including gap analysis, routine monitoring and reporting per EPEA requirements, selection of indicator suites to facilitate routine monitoring, evaluation, and reporting, identification of locations with water quality concerns, development of approach to statically assessing and responding to data excursions and trends, and preparation of the GMP for consideration and acceptance by AEP.
- Support for Carmon Creek EIA and assessment of brackish water supply potential in support of heavy oil operations in the Peace River area. Responsibilities included assessment of baseline hydrogeological conditions and potential impacts from project development, preparation of climate change assessment for project development, support for SIR submissions and EIA team interactions, feasibility assessment of potential for deep formations to produce sustained supplies and conceptual well-field development, and liaison with regulatory agencies
- Development of a regional-scale ground water monitoring network in a multi-layer aquifer system in the Peace River region of Alberta. Responsibilities included assessment of Quaternary stratigraphy, interpretation of seismic line data, geophysical borehole log analysis, and geochemical facies mapping and solution chemistry analysis.
- Assistance with the development and construction of an induced infiltration groundwater supply system for the Shell Caroline Gas Plant industrial water supply project. Responsibilities included drilling and installation of large diameter water production wells, borehole geophysical logging and interpretation. sand quantification testing and analyses to determine sediment production volumes prior to pipeline construction, and liaison with client and local landowners.

Suncor Energy

Various projects include:

- Lead subsurface specialist for a multi-criteria decision analysis and life-cycle value analysis in support of a regional brine management strategy in the Athabasca Oil Sands area. Responsibilities included development of a holistic weighting and ranking approach to address triple-bottom-line assessment of treatment and disposal options for liquid and solid waste streams originating from oil sands mining and in situ assets located across a 30 000 km^2 area, facilitation of, and participation in, workshops to assess viable options for treatment and disposal including Class 4 costing, and development of a constraints mapping approach (vulnerability, risks and opportunities) using ArcGIS to assist in management and disposal options for liquid and solids waste streams.
- Development of an Athabasca River reconnaissance program to identify and sample natural groundwater-surface water interaction zones discharging waters from the Cretaceous and Devonian formations. Responsibilities included planning/execution and interpretation of a marine-based geophysical program using EM31 imaging and bathymetric readings, development of pore water sampling program including geochemical assessment of waters and source fingerprinting (major ion, trace element, dissolved organics, and stable and radiogenic isotopes), interpretation of results and presentation at various venues (government, industry.
- D51 disposal monitoring at the Firebag Thermal In Situ Project
- Thermal mobilization assessments (Firebag, Lewis, Meadow Creek)
- Development of brine water management strategy including options analysis and Class 4 costing

- Preparation of an oil sands mining closure strategy outlining goals, objectives, tasks, timelines, and consulting and research agencies to execute in support of Life of Mine Closure and Reclamation process
- Assistance with Fort Hills Operational Plan regarding preservation of McClelland Lake and wetland complex; review of physical hydrogeology and geochemical setting; assessment of numerical model design and output; review of cut-of wall design and mitigation system; review of adaptive management processes
- Review of Devonian – McMurray interactions at the North Steepbank mine expansion and assistance with investigation program design (including geochemical assessment)
- Completion of geophysical and porewater surveys on the Athabasca and Steepbank Rivers to determine contributions of natural discharge versus industry inputs
- Review of existing water supply for Steepbank and Millennium mine operations and development of contingency supply options. Responsibilities included review of past water resource evaluations, development of geophysical investigation program and interpretation of results, assessment of contingency water supply (groundwater and operations water), client consultation and liaison with Alberta Environment, and implementation of horizontal well technology to provide a secure supply of water for continued operations
- Groundwater age-dating and source area identification in support of active tailings pond seepage investigations. Responsibilities included conceptual site model design, review of traditional geochemistry to determine end-point water types, and application of Tritium, $\delta^{18}O$, $\delta^{2}H$, $\delta^{34}S$, $\delta^{11}B$ to resolve geochemical setting and potential areas of seepage
- Preparation of an AB Environment approved Groundwater Management Plan at a large oil sands mining operation. Activities included, the design of a cost-effective sampling schedule including rationalization of over 300 wells to establish a meaningful monitoring network of 150 wells, development of statistically established trigger values for response and mitigation, and lliaison with Government of Alberta during review and approval.

Syncrude Canada

Participation on expert hydrogeology panel to review Devonian investigation program for Aurora mine and assess mitigation strategies to control high risk areas (Les Gray - UBC, Carl Mendoza, - UofA, Ken Baxter - Golder, Jon Fennell - WP). Responsibilities included review of existing baseline data for active mining site, identification of high-risk areas to consider for future investigation and monitoring, participation in group workshop settings to communicate findings and accumulate input for recommendations refinement, and participation in internal panel meetings to discuss concepts and develop final recommendations.

Teck Resources Limited

Evaluation of stream response to groundwater interception in support of fisheries habitat offsetting at Line Creek Mine, BC. Responsibilities included baseline reconnaissance of Line Creek alluvial system and GW-SW water interactions with Line Creek, assessment of area springs, shallow groundwater, and creeks to determine geochemical quality and flow conditions (using drive point well technology and data logger systems), completion of ground penetrating radar survey to map thickness and morphology of alluvial deposits, water quality fingerprinting using major ion, trace elements (in particular selenium) and stable isotopes to determine interaction of groundwater environment with Line Creek, and assessment of selenium mobilization conditions related to active mine workings and development of a conceptual (passive) mitigation strategy to offset impacts to fisheries habitat.

Total E&P

Support for Joslyn North Mine EIA submission and development of a mine dewatering strategy for. Responsibilities included development of baseline hydrogeology, EIA sections and SIR responses , liaison with project team and governing agencies, joint Panel hearing support.

Also, selection and phasing of depressurization wells and associated monitoring wells, review of deep well injection potential, including geochemical compatibilities of waters, development of a performance monitoring system, selection of pipeline route, and preparation of a design-based memorandum with related costs (Class 3) of implementation and long-term operation.

Various Gas Plants, Batteries and Refineries (Alberta, British Columbia, Saskatchewan)

Completion of piezometer network design at numerous operating facilities to assess the potential impact to local groundwater quality resulting from industrial activities and extent of contaminant migration from known source areas (Imperial Oil, Shell, Mobil, Canadian Occidental); and, provision of hydrogeological services in support of a gas plant decommissioning (ongoing). Responsibilities include, well installation, testing and sampling, involvement in a site-specific risk assessment (ecological and human health), development of sampling protocols, and assessment of cost-effective remediation techniques to address various contaminant situations in both soil and groundwater.

Various Oil and Gas Facilities (Alberta, Saskatchewan)

Completion of environmental operations audits and development of waste management plans for numerous operating oil and gas facilities (Amoco, Petro-Canada, Shell). Responsibilities included review of historical operations files (spill reports, waste handling procedures, EUB and AENV records), completion of site inspections and interviews, and historical air photo analysis and interpretation.

EDUCATION

Ph.D. (Geochemistry) – University of Calgary, 2008

M.Sc. (Physical Hydrogeology and Isotope Geochemistry) – University of Calgary, 1994

B.Sc. (Geology: hard rock, sedimentology, mineralogy, structural, geochemical) – University of Saskatchewan, Saskatoon, 1985

REGISTRATIONS & AFFILIATIONS

APEGA (P.Geol. – Alberta)

EGBC (P.Geo. – British Columbia)

APEGS (P.Geo. P.Eng. – Saskatchewan)

NAPEG (P.Geol. – Northwest Territories and Nunavut)

National Ground Water Association (NGWA)

International Association of Hydrogeologists

Canadian Water Resources Association (CWRA)

Sustainable Energy Development Program (Univ. of Calgary) – External Advisory Board – 2017 to present

Bow River Basin Council (Calgary), Board of Directors (2008-2013), Chair of Monitoring and Modelling committee (2008 to 2012), Member of Legislation and Policy Committee (2006-2011), Member of Integrated Watershed Management Group (2007 to 2010)

SPECIFIC TECHNICAL EXPERTISE

- ICP-MS, GC-MS, Ion chromatography (LC-MS, HPLC, IC)
- SEM, XRD (bulk and clays), XRF, EDS and Synchrotron Light (XANES, and EXAFS)
- Isotope ratio mass spectrometry (IRMS)
- Solid-phase extraction, Alumina fraction, and sequential soil extraction
- Toxicity identification evaluation for metals and organics
- Selection of appropriate inorganic or organic analytical techniques based on Standard Methods for Water and Wastewater
- Statistical analysis (e.g. population testing, trend analysis, control charting, PCA, HCA, spatial analysis)
- Multi-criteria decision analysis (MCDA)
- Vulnerability and risk mapping
- Risk assessment (human and ecological)
- Climate tele-connections assessment, climate model analysis and impact identification, development of adaptation strategies

PUBLICATIONS

Fennell J. and Aciszewski T (2019). Current knowledge of seepage from oil sands tailings ponds and its environmental influence in northeastern Alberta. Science of the Total Environment, 686, p. 968-985.

Birks S.J., **Fennell J.W.**, Gibson J.J., Yi. Y., Moncur M.C., and Brewster M. 2019. Using regional datasets of isotope geochemistry to resolve complex groundwater flow and formation connectivity in northeastern Alberta, Canada. Applied Geochemistry, 101 (2019), p. 140-159.

Hatala R., **Fennell J.,** and Gurba G. 2018. Advances in the realm of Hydrogeophysics: The emerging role of Quantum Geoelectrophysics in Aquifer Exploration. Can. Soc. of Expl. Geoph., RECORDER October Focus - Hydrogeophysics: the Past, Present, and Future. Vo. 43, No. 6, p. 32-36.

Birks S.J., Moncur M.C., Gibson J.J., Yi Y., **Fennell J.**, and Taylor E.B. 2018. Origin and hydrogeological setting of saline groundwater discharges to the Athabasca River: Characterization of the hyporheic zone. Applied Geochem., 98, p. 172-190.

Fennell J., 2018. Predictions, perceptions and the precautionary principle: responding to climate change in a realm of uncertainty. Canadian Water Resources Association, Water News, Fall/Winter 2018. Vo. 37, No. 2, p. 6-9.

Fennell J., 2018. Water, Peace, and Global Security: Canada's Place in the World We Want (Sandford and Smakhtin, eds.), Groundwater and Canada's Future – Moving data and information to knowledge and security. Prepared for the United Nations University, Institute for Environment, Water and Health, 17 pp.

Fennell J. 2018. Poison Well: Chasing arsenic in Alberta's groundwater. Water Canada, January/February 2018, p. 20-21.

Fennell J. 2017. Let's make a deal: Canada's vital role in the Columbia River Treaty. Water Canada, September/October 2017. p. 42-43.
Faramarzi M., K. Abbaspour, V. Adamowicz, W. Lu, **J. Fennell**, A. Zehnder and G. Goss 2017. Uncertainty based assessment of dynamic freshwater scarcity in semi-arid watershed of Alberta, Canada. *Journal of Hydrology: Regional Studies*, 9, p. 48-68.

Fennell J. 2015. Disposal in the unconventional oil and gas sector: Challenges and solutions. American Assoc. of Petroleum Geologists, *Environmental Geosciences*, Vol. 22, No. 04, December 2015, p. 127-138.

Fennell J. and O. Keilbasinki 2014. Water, food, and our climate: Is California a harbinger of things to come? *WaterCanada*, July/August 2015, p. 24-25.

Fennell J. and O. Keilbasinki 2014. Water without Borders: What is Canada's role in water security? *WaterCanada*, November/December 2014, p. 50-51.

Gibson J.J., **J. Fennell**, S.J. Birks, Y. Yi, M. Moncur, B. Hansen and S. Jasechko 2013. Evidence of discharging saline formation water to the Athabasca River in the northern Athabasca oil sands region. *Canadian Journal of Earth Sciences*, 50, p. 1244 - 1257.

M.S. Ross, A.S. Santos Pereira, **J. Fennell**, M. Davies, J. Johnson, L. Sliva, and J.W. Martin 2012. Quantitative and Qualitative Analysis of Naphthenic Acids in Natural Waters Surrounding the Canadian Oil Sands Industry. *Environmental Science and Technology*, 46, p. 12796 – 12805.

Fennell J. 2011. Total Water Management – a new and necessary paradigm. Environmental Science and Engineering Magazine, May/June edition.

Fennell J., Klebek M. and Forrest F. 2011. An approach to managing cumulative effects to groundwater resources in the Alberta Oil Sands. World Heavy Oil Congress proceedings, March 2011.

Fennell J. 2010. Protecting water supplies in CSG development. *Water Engineering Australia*, Vo. 4, No. 6, September 2010.

Fennell J. 2008. Effects of Aquifer Heating on Groundwater Chemistry with a Review of Arsenic and its Mobility. Ph.D. thesis, Department of Geoscience, University of Calgary.

Fennell J. Zawadzki A. and Cadman C. 2006. Influence of natural vs. anthropogenic stresses on water resource sustainability: a case study. *Water Science and Technology*. Volume 53, No. 10, p 21-27.

William L.B., M.E. Wieser, **J. Fennell**, I. Hutcheon, and R.L. Hervig 2001. Application of boron isotopes to the understanding of fluid-rock interactions in a hydrothermally stimulated oil reservoir in the Alberta Basin, Canada. *Geofluids*, Vol. 1, p. 229-240.

Kellett R., **J. Fennell**, A. Glatiotis, W. MacLeod, and C. Watson 1999. An Integrated Approach to Site Investigations in Permafrost Regions: Geophysics, Soils, Groundwater, and Geographical Information Systems. ARCSACC Conference, Edmonton '99.

Gilson E.W., R. Kellett, **J. Fennell**, P. Bauman, and C. Sikstrom 1998. High Resolution Reflection Seismic and Resistivity Imaging of Deep Regional Aquifers for Stratigraphic Mapping. CSEG Conference.

Fennell J. and Bentley L. 1997. Distribution of Sulphate and Organic Carbon in a Prairie Till Setting: Natural versus Industrial Sources. *Water Resources Research*, Vol. 34, No. 7, p. 1781-1794.

Fennell J. and Sevigny J. 1997. Effects of Acid Conditions on Element Distribution Beneath a Sulphur Base Pad (Acid Mobilization Study). Publication submitted to the Canadian Association of Petroleum Producers (CAPP).

Fennell J. 1994. Source and Distribution of Sulphate and Associated Organics at a Sour Gas Plant in Southern Alberta. M.Sc. thesis, Department of Geology and Geophysics, University of Calgary.
Hayes B., J. Christopher, L. Rosenthal, G. Los, B. McKercher, D. Minken, Y. Tremblay, and

J. Fennell 1994. *Atlas of the Western Canadian Sedimentary Basin – Chapter 19: Cretaceous Manville Group*. Canadian Society of Petroleum Geologists and Alberta Research Council, ISBN 0-920230-53-9.

PRESENTATIONS & LECTURES

COSIA Oil Sands Innovation Summit, June 2019 Calgary AB: Fact or fiction – the truth regarding tailings pond seepage in Canada's oil sands (response to a Free Trade Agreement Challenge)

CWRA Alberta Branch conference, April 2019 Red Deer: Flooding, climate change, and the need for a precautionary approach.

University of Calgary, Sustainable Energy Development Program. February 2019, Decision support processes and tools in sustainable energy development projects.

Mine Water Solutions, June 2018. Total Water Management: Canada's contribution to sustainable mine development.

Canadian Water Resources Association, April 2018, Red Deer, AB. Arsenic and Alberta's Groundwater: the where and why.

Southern Alberta Institute of Technology (water Initiative), February 2018, Calgary AB. Risky business: understanding Alberta water security

Canadian Society of Unconventional Resources (CSUR), January 2018, Calgary AB. Managing through nature's extremes: ensuring water security for successful UCOG operations.

SEAWA, Nov 2017, Medicine Hat AB. Hydrology of riparian areas: the need for protection and preservation.

CWRA National Conference, June 2017, Lethbridge AB. Climate change, the Columbia River Treaty, and considerations for a successful re-negotiation.

Thermal mobilizations and the regulatory response, May 2017, Calgary AB. CHOA forum.

National Ground Water Association, March 2017, Denver CO. Advances in the realm of hydrogeophysics: the role of Quantum Geoelectrophysics in groundwater exploration

Haskayne School of Business IRIS series, Feb 2017. Following the molecules: the importance of water to Canada's future.

BRBC-CEAC, Feb 2017, Cochrane AB, GW-SW interaction and the implication for development in riparian lands.

Watertech, April 2017, Banff AB. Arsenic in Alberta's Groundwater: the where and why; Isotopes and Geochemistry:

National Ground Water Association, Hydrogeophysics for deep groundwater exploration, March 2017, Denver CO. Advances in the realm of Hydrogeophysics: the role of Quantum Geoelectrophysics in Groundwater Exploration

Haskayne School of Business CPC IRIS seminar series, February 2017, Calgary AB. Following the molecules: the importance of water in Canada's future.

Bow River Basin Council/Cochrane Environmental Action Committee Collaborating for Healthy Riparian Lands Engagement Workshop, February 2017, Cochrane AB. Groundwater-Surface water interaction and the implications of human development in riparian lands.

Watertech, April 2016, Banff AB. Predicting Alberta's Groundwater Future & An Integrated Approach to Resolving Complex Hydrogeological Settings.

Canadian Water Resources Association (CWRA), April 2016, Edmonton AB. Natural discharge and its role in Athabasca River water quality.

Canada's Oil Sands Innovation Alliance (COSIA) Water Forum, March 2016, Calgary AB. Natural discharge and its role in Athabasca River water quality.

Canadian Association of Petroleum Geologists (CSPG), March 2016, Calgary AB. Climate, water availability, and the success of Western Canada's Energy Development & Natural discharge and its role in Athabasca River water quality.

Underground Injection Control (GWPC), February 2016, Denver CO. Disposal in the unconventional oil and gas sector: challenges and solutions.

AGAT Environmental Series, Jan/Feb 2016. Calgary and Edmonton, AB. Climate, water availability and the success of Western Canada's energy industry.

International Water Conference, November 2015, Orlando FL. Disposal in the unconventional oil and gas sector: challenges and solutions.

Chemistry Industry Association of Canada, October 2015, Edmonton AB. Water Sustainability: and its importance to successful industry.

EnviroAnalysis, July 2015, Banff AB. Thermal mobilization and Arsenic: implication for the oil sands.

WaterTech, April 2015, Kananaskis AB. Smart Monitoring to address challenges of Unconventional Gas development and an approach to mapping risk related to thermal mobilization of constituents.

Canadian Water Resources Association, April 2015, Red Deer AB. Water, Energy and Canada's Future (keynote address)

Underground Injection Council, February 2015, Austin TX. Monitoring to address challenges of Unconventional Gas development (invited speaker)

National Ground Water Association, Groundwater monitoring for Shale Gas developments workshop, November 2014, Pittsburgh PA. Smart monitoring to address the challenges of Unconventional Gas Development (invited speaker)

Canadian Water Resources Association, June 2014, Hamilton ON. Water disposal in the Oil Sands: challenges and solutions and What is Water Security and Why is it Important.

Water Management in Mining, May 2014, Vancouver BC. Total Water Management: a necessary paradigm for sustainable mining.

CSPG GeoConvention May 2014, Calgary AB. Water disposal in the Oil Sands: challenges and solutions; Placing the risk of thermal mobilization into perspective; What is Water Security and Why is it Important?

WaterTech, April 2014, Banff AB. Water disposal in the Oil Sands: challenges and solutions and Placing the risk of thermal mobilization into perspective.

Canada's Oil Sand Innovation Alliance (COSIA), March 2014, Edmonton AB. Water disposal in the Oil Sands: challenges and solutions and Placing the risk of thermal mobilization into perspective.

International Assoc. of Hydrogeologists, GeoMontreal 2013, October 2013, Montreal QC. The role of subsurface heating in trace element mobility.

Oil Sands Heavy Oil Technology 2013, July 2013, Calgary AB. The role of subsurface heating in trace element mobility.

Watertech, April 2013, Banff AB. The role of subsurface heating in trace element mobility.

International Assoc. of Hydrogeologists World Congress 2012, September 2012, Niagara ON. Session Chair for Hydrogeological Issues in the Oil Sands and presenter: i) Oil Sands overview – economic and environmental setting; ii) Framing groundwater vulnerability in the oil sands: an approach to identify and discern; and iii) Climate: a driving force affecting water security in the oil sands

Water in Mining 2012, June 2012, Santiago Chile. Total Water Management: a necessary paradigm for sustainability.

BCWWA 2012 Annual Conference, April 2012, Penticton BC. The role of inventory, dynamics, and risk analysis in water management: a case study.

WaterTech, April 2012, Banff AB. Plenary Session. Bringing context to the oil sands debate: understanding the role of nature and its environmental effects.

BCWWA Hydraulic Fracturing Workshop, Fort St. John BC, March 2012. Keynote address: Striking a Balance – water resource management versus economic development (keynote address).

CONRAD 2012, March 2011, Edmonton AB. Bringing context to the oil sands debate: understanding the role of nature and its environmental effects.

Alberta Irrigation Projects Assoc., November 2011, Lethbridge AB. Managing what we have: a review of Alberta's water sources, volumes and trends (invited speaker).

Alberta Innovates Technology Talks, November 2011, Calgary AB. Dynamics of Alberta's Water Supply: a review of supplies, trends and risks.

Red Deer River Watershed Alliance Annual General Meeting, October 2011, Red Deer AB. Water in the Red Deer: volumes, patterns, trends and threats.

Land and Water Summit, October 2011, Calgary AB. Total Water Management: a necessary paradigm for water security.

CEMA Groundwater Working Group, June 2011, Fort McMurray AB. Groundwater in the oil sands: facts, concepts and management processes.

CWRA Alberta / Alberta Low Impact Development Annual Conference, April 2011, Red Deer AB. A Review of Alberta's Water Supply and trends.

WaterTech, April 2011, Banff AB. Managing what we have: a review of Alberta's water supply.

World Heavy Oil Congress 2011, March 2011, Edmonton, AB. An approach to managing cumulative effects to groundwater resources in the Alberta Oil Sands.

Engineers Australia, August 2010, Brisbane Qld. CSG development in Australia: an approach to assessing cumulative effects on groundwater (invited speaker).

Joint IAH/AIG meeting, July 2010, Melbourne Vic. Assessing the effects of coal seam gas development on water resources of the Great Artesian Basin (invited speaker).

18th Queensland Water Symposium, June 2010, Brisbane Qld. A cumulative effects approach to assessing effects from coal seam gas development on groundwater resources (invited speaker).

WaterTech, April 2010, Lake Louise AB. Regional Groundwater Monitoring Network Implementation: Northern Athabasca Oil Sands Region.

University of Calgary, December 2009, Calgary AB. What's happening to our water? A review of issues and dynamics.

CSPG Gussow Conference, October 2009, Canmore AB. Water sustainability in the Alberta Oil Sands: managing what we have (invited speaker).

Bow River Basin Council, Legislation and Policy Committee Groundwater Licensing Workshop, March 2009, Calgary AB. Groundwater: the hidden resource

BlueWater Sustainability Initiative, January 2009, Sarnia ON. Planning approaches and forensic tools for large-scale regional monitoring initiatives.

CWRA Technical luncheon session, October 2008, Calgary, AB. Water sustainability in a growing Alberta.

Bow River Basin Council, September 2008, Calgary AB. Basin Monitoring and Management Approaches.

IAH/CGS GeoEdmonton08, Edmonton AB. Coordinator and Chair of Groundwater Development Session.

North American Lake Management Society (NALMS) 2008, Lake Louise AB, Coordinator and Chair of Climate Change Effects to Lakes, Reservoirs and Watersheds section.

EcoNomics™ Luncheon, May 2008, Calgary AB. Water Sustainability in the Hydrocarbon Industry.

WaterTech, April 2008, Lake Louise AB. Effects of climate and land cover changes on basin water balances.

CWRA Annual Conference, April 2008, Calgary AB. Role of climate change and land cover on water supply sustainability.

Bow River Basin Council, March 2007, Calgary AB. Forest Hydrology and the effects of Climate Change.

ALMS/CWRA, October 2006, Lethbridge AB. Reservoir Maintenance Workshop. Climate tele-connections and their effects on basin water supplies

Bow River Basin Council, June 2006, Calgary AB. Groundwater sustainability: the invisible resource (Climate change and basin sustainability)

Engineering Institute of Canada, May 2006, Ottawa ON. CCC2006 Land use and climate change effects at the basin scale.

International Water Association, Watershed and River Basin Management Specialists Group Conference, Calgary, AB, 2005. Basin Water Management Strategies.

Burgess Shale Geoscience Foundation, August 2004 and 2005, Field BC. Water in a Changing Climate: understanding and adapting.

C-CAIRNS, October 2005, Victoria BC, Climate and Fisheries Impacts, Uncertainty and Responses of Ecosystems and Communities, Effects of Climate and the PDO on Hydrology of a Major Alberta Watershed.

North American Lake Management Society, November 2004, Victoria BC. Climate Change and Effects on Water Resources.

Canadian Institute Conference, June 2004, Calgary AB. Water Management Strategies for the Oil and Gas Industry: The challenge and approach

Canadian Society of Petroleum Geologists, Gussow Conference, March 2004, Canmore AB. Understanding the Effects of Natural and Anthropogenic Forcings on Basin Water Resources.

Alberta Environment and EUB, April 2003, Elk Point AB. Climate and Land Use Change Effects on Basin Water Resources in the Lakeland Region - East-central Alberta.

Joint CGS/IAH Conference, June 2001, Calgary AB. A Multidisciplinary Approach to Resolving Complex Hydrogeologic Systems.

Aquatic Toxicity Workshop, October 1996, Calgary AB. Use of site characterization and contaminant situation ranking to focus a risk assessment evaluation at a decommissioned sour gas plant and associated landfill.

Joint GAC/MAC Conference, April 1995, Waterloo ON. Use of geochemical modelling and stable isotopes to determine the source of groundwater quality impacts near a sour gas processing facility.

Joint GAC/MAC Conference, Edmonton AB, 1994. Assessment of depression-focused recharge as a mechanism for variable groundwater and soil chemistry.

GasRep Conference, Calgary AB, 1994. Use of stable isotopes to determine the source of water quality impacts near a sour gas processing facility.