Characterizing Dissolved Methane in Groundwater in the Peace Region, Northeastern British Columbia, Using a Regional, Dedicated, Groundwater Monitoring Well Network

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Introduction

Methane in groundwater in areas of oil and gas development is a complex issue and the subject of much controversy. Although methane is naturally ubiquitous in groundwater, there have been isolated documented instances of unintentional release into the subsurface from oil and gas development activities, leading to anthropogenic impacts on groundwater. Previous research to investigate the prevalence of anthropogenic sources of methane in groundwater has proved inconclusive due to two key limitations: 1) scientifically designed and purpose-built monitoring wells have not been used to collect data; and 2) natural 'background' dissolved methane concentrations have not been adequately characterized from which anthropogenic impacts, or lack thereof, can be assessed. Consequently, much conjecture has ensued with deterioration of public confidence and backlash against increasing development. Through this project, this issue will be addressed in the Peace region of northeastern British Columbia (BC) through review of existing data and installation of 30 purpose-built and scientifically designed groundwater monitoring wells, to generate a comprehensive scientifically defensible groundwater dataset. Through this project, groundwater dissolved methane and geochemistry conditions within the Peace region of northeastern BC will be comprehensively and conclusively characterized, along with details of subsurface geological and aquifer conditions. The results will be used to inform appropriate groundwater monitoring strategies in light of continued oil and gas development for the region. As a legacy, the project will provide a scientifically designed and extensive regional groundwater monitoring network available for future scientific research and ongoing monitoring of groundwater quality in the Peace region.

The progress made in the first year of this project is described herein. This includes refinement and finalization of the scientific plan, identification of potential areas at which to assess baseline conditions, a desk study to review existing groundwater data, scoping and drilling of the first monitoring wells (including geological characterization and sampling), and various public engagement activities.

Background

Methane may be present in groundwater in areas of oil and gas resource development due to both natural and anthropogenic factors. Dissolved methane is known to be naturally ubiquitous (e.g., commonly up to 5 mg/L) in groundwater systems (Darling and Gooddy, 2006), present within an ambient or background range. Such background methane can be microbial and/or thermogenic (Brantley et al., 2014), and concentrations are primarily controlled by methane source and prevailing redox conditions of a given groundwater system (Humez et al., 2016a, b). Other natural factors have also been suggested to affect both groundwa-

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ter methane concentrations and the presence of shallow gas-phase methane in areas of hydrocarbon resource development, and occurrences in excess of the typical background range have been documented. For example, soil gas survey methods to identify surface methane seeps and their origins have been employed as a method to explore for gas resources (e.g., von der Dick et al., 2002; von der Dick and Bosman, 2011), suggesting geological and resource-related factors affect the distribution of subsurface methane in sedimentary basins. Dissolved methane in domestic water wells has been associated with specific geological features such as coal beds in West Virginia (Harkness et al., 2017), natural fault systems in east Texas (Nicot et al., 2017) and undeveloped shale bed gas resources in Ontario (Hamilton et al., 2015). Finally, topography has also been identified as a potential factor influencing natural distribution of dissolved methane concentrations in northeastern Pennsylvania (Molofsky et al., 2013).

In regions of oil and gas development, anthropogenically derived occurrences of elevated subsurface methane have also been documented as occurrences of 'gas migration'. Gas migration, with respect to upstream oil and gas resource development (as defined in *Drilling and Production Regulation, Section 41* [Province of British Columbia, 2017]), refers to the development of pathways within a cemented wellbore permitting the buoyant flow of natural gas (primarily composed of methane) vertically upward toward or directly into the shallow subsurface via inadequately sealed wellbores (i.e., leaky wells; e.g., Dusseault and Jackson, 2014; Ingraffea et al., 2014). Available data indicate observed and documented cases of gas migration originate from approximately 0.73% of oil and gas wells in Alberta (Bachu, 2017). Gas migration, as "the flow of gas outside the surface casing of a well" (BC Oil and Gas Commission, 2017), may be identified by the observation of bubbles in standing water around a wellhead (Briskin, 2015; BC Oil and Gas Commission, 2017) or may manifest as an unobserved subsurface occurrence. A concern with observed or unobserved gas migration is the potential for elevated levels of dissolved methane in surrounding groundwater. It has been shown that if gas migration is occurring in the subsurface, an extensive and dispersed plume of dissolved hydrocarbons in groundwater can be generated (Cahill et al., 2017).

Consequently, anthropogenically derived methane sources and their management are topics of interest to academics, regulators, industry and the general public (Kelly et al., 1985; Van Stempvoort et al., 2005; Darling and Gooddy, 2006; Canadian Association of Petroleum Producers, 2012; Vidic et al., 2013; Council of Canadian Academies, 2014; Vengosh et al., 2014; BC Oil and Gas Commission, 2017). Although methane itself is nontoxic, colourless and odorless, and there are no federal or provincial regulatory standards for drinking water or for the protection of aquatic life, several key questions regarding the consequences of fugitive methane in groundwater remain. For example, it has been shown that anthropogenic methane may change groundwater chemistry when microbially metabolized, potentially reducing groundwater quality (Cahill et al., 2017), and there is continuing research to understand these processes (Cahill et al., 2019). Additionally, elevated dissolved concentrations of methane in groundwater, above the solubility limit, can indicate a potential fire or explosion hazard due to exsolution and accumulation of gas phase methane in confined spaces or infrastructure. In response to this concern, which has been historically associated with coal mining, dissolved methane in water at concentrations >10 mg/L has been specified as a warning level to indicate potential for accumulation of free gas (Eltschlager et al., 2001). And finally, due to buoyancy forces, subsurface anthropogenic methane may find a path to the ground surface and emit to the atmosphere, contributing to greenhouse gas emissions.

Regulations and engineering standards for well drilling, cementing, testing and maintenance (e.g., BC Oil and Gas Commission, 2017; Province of British Columbia, 2017) are in place to minimize the potential for the development of gas migration, leading to the reduction of both the likelihood of occurrence and the degree or extent of associated dissolved methane in groundwater, should pathways develop. However, key scientific questions and controversy remain regarding the origins of groundwater methane across regions of oil and gas development, as well as the prevalence of unobserved gas migration and its effects on groundwater. For example, a strong and pervasive association of elevated levels of dissolved methane in groundwater with energy well locations have been suggested by some researchers utilizing available groundwater data from domestic wells (e.g., Osborn et al. [2011a] and Jackson et al. [2013] for northeastern Pennsylvania; Sherwood et al. [2016] for Colorado). A subsequent study for the same northeastern Pennsylvania area using an enhanced domestic well dataset, however, found no statistical association between elevated levels of dissolved methane and energy wells (Siegel et al., 2015).

Controversy related to the above noted research is due, in part, to two key factors:

1) lack of a scientifically designed groundwater monitoring network and reliance on data from domestic wells; and
2) lack of characterization of background levels of groundwater methane to provide a basis to distinguish anthropogenic impacts.

With respect to key factor (1), the limitations of using data from domestic wells to investigate environmental impacts in areas of oil and gas development are well known (e.g., Gorody, 2012; Jackson and Heagle, 2016), and include location biases; confidentiality issues limiting documentation of results; lack of well and system maintenance; uncontrolled sample collection points (e.g., posttreatment from faucets or taps); unknown potential contamination sources; uncertainty in well information (geology and well construction); and well ownership and property access constraints. Thus, although domestic wells can provide for inexpensive and large datasets, such wells are not located and designed with scientific integrity in mind, and reliance on data solely from domestic wells limits the conclusions that can be made. With respect to key factor (2), as described herein, dissolved methane may be naturally ubiquitous at low levels or naturally elevated due to geological, topographic and/or other factors. Consequently, adequate characterization of natural background levels of dissolved methane is required to support the identification of anthropogenic impacts.

No regional-scale studies to date have fully addressed the two key factors noted above, leading to continued scientific debate regarding groundwater methane origins in areas of oil and gas development (Jackson et al., 2011; Osborn et al., 2011b; Saba and Orzechowski, 2011). To address this controversy, ongoing research must be supported with a scientifically designed groundwater monitoring well network, which includes both purpose-built monitoring wells and appropriately selected domestic wells, and must include characterization of natural background methane concentrations. Such an approach will provide the benefits of a large sample population and regional coverage (i.e., through selected domestic wells) with a means to verify and augment domestic well data (i.e., with purpose-built monitoring wells). From such an endeavour, a robust, scientifically defensible groundwater dataset can be compiled upon which science-based regulatory policy can be developed and appropriate and effective long-term groundwater monitoring strategies determined. To date no such research initiative has been initiated in Canada or elsewhere.

Such a study is being undertaken in the Peace region of northeastern BC by The University of British Columbia (UBC) in collaboration with Simon Fraser University, University of Calgary, BC Oil and Gas Commission (BCOGC) and BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development. It will involve the design and installation of a scientific groundwater monitoring well network for the region. It will be placed in and amongst ongoing resource development and more than 150 domestic water wells from which baseline samples have recently been taken. Approximately 30 purpose-built groundwater monitoring wells will be installed to verify and augment the existing groundwater data, leading to establishment of a reliable and detailed scientific groundwater database. The monitoring well network and data collection methodology will be designed to establish background conditions for dissolved methane across the region, and to assess any potential association of elevated methane in groundwater proximal to oil and gas wells.

This paper describes progress made in year one of the three-year project. As per the proposal, progress planned for year one (i.e., 2018) is as follows:

- phase 1: experimental design finalization, site selection criteria development, desk study of currently existing data, work plan formulation and field campaign planning;
- phase 2: initial drilling and field campaign;
- phase 3: data analyses and interpretation, review of progress and methodology refinement.

Summary of Activities and Progress

Project Kick Off and Student Recruitment

The project officially commenced in January 2018, whereby a one-day kick-off meeting with the project principal investigator team (A.G. Cahill, R.D. Beckie, L. Welch, D. Kirste, B. Mayer) and select invited participants (from Geoscience BC and BC Ministry of the Environment and Climate Change Strategy) was held on January 30. During the kick-off meeting, multiple aspects of the project were discussed in-depth by the project team including 1) review of project proposal and concept; 2) review of existing chemistry data for the Peace region; 3) review of criteria for selecting background locations; 4) methods and approaches for drilling of background wells; 5) possible resampling of select existing domestic wells; and 6) identification of criteria for targeted monitoring wells proximal to oil and gas well sites. Additionally, various logistical aspects of the project were discussed including hiring of students, formation of a project technical advisory committee, budget tracking, project management and field and project safety. During the winter and spring of 2018, two students were identified and recruited to the project through which they would work toward their M.Sc. degrees. Firstly, M. Goetz received his undergraduate degree in Earth and Planetary Sciences from McGill University. He has four years of geoscience experience in the mining industry, primarily working as a site geologist/hydrogeologist at a copper porphyry-skarn mine in New Mexico. Secondly, A. Allen is a recent Simon Fraser University graduate, who completed his B.Sc. (Honours) in Earth Sciences. His thesis topic was sources and distribution of arsenic in groundwater on the Gulf Islands of BC. He has a diverse background across geosciences and geology, with particular expertise in hydrogeology, hydrogeochemistry and geographic information sciences and is experienced with laboratory experiments and analytical equipment.

Phase 1

Experimental Design Finalization and Site Selection Criteria Development

During phase 1, the experimental design and concept were further refined and developed. An internal report was generated as part of this process (available on request), the outcomes of which are summarized here. Site selection criteria were finalized for the first background monitoring wells (MW; approximately 8–10 planned), each of which will be either paired with an existing water well (e.g., a domestic water well, provincial observation well, industry water source well) or unpaired. Approximately six paired MW will be located in proximity (i.e., 500–1000 m) to an existing water well for which groundwater chemistry and dissolved hydrocarbon concentrations are available. All background wells should be at least 1.5 km away from an existing oil or gas well. Of the paired wells, half will be selected to be proximal to a water well with elevated levels of dissolved methane (i.e., above a determined threshold level) and half with lower levels of dissolved methane. Paired wells are employed to increase the chance of success with drilling and hitting water in what is a highly heterogeneous area. The four unpaired monitoring wells will not be associated with an existing water well and can therefore be placed in areas for which no data is currently available, thus increasing the geographic range of the MW network and allowing effective leveraging of other existing groundwater data for the region. The MW are proposed to be located in eight geographic areas within the Peace region based on draft selection criteria and design-concept outlines, which were confirmed as suitable in principle by the wider project team. These areas are shown in Figure 1 and summarized in Table 1.

Desk Study of Currently Existing Data

Following agreement on initial MW site locations and experimental concept design, desk studies were conducted for each area whereby existing geological and groundwater data were reviewed and compiled. Maps were subsequently generated, including buffer zones for proximity to oil and gas wells and existing water wells. These maps were used to preselect potentially suitable background monitoring well locations. An example of the results of the desk study for area 1 (Hudson's Hope–Beryl Prairie) is shown in Figures 2 and 3.

Work Plan Formulation and Field Campaign Planning

A flexible approach, which allowed plans to be revised and refined, maximized the chance of successfully completing a functioning monitoring well. Accordingly, five of the eight selected background areas were prioritized and a two-phased approach to the initial drilling plan was adopted. Drilling was planned to commence at areas 1 to 4 and 7 (i.e., Hudson's Hope–Beryl Prairie, Chetwynd, northwest of Fort St. John, west and northwest of Dawson Creek and Groundbirch field) in August 2018 with the remainder to be drilled in January 2019. The prioritized sites are shown in Figure 4.

Consequently, a field reconnaissance campaign was undertaken to scope and identify exact drilling sites at each area and assess enabling works needed to allow access. Where possible, sites adjacent to a road and within BC Ministry of Transportation land were selected and relevant permissions obtained. In several cases (i.e., Groundbirch field and west and northwest of Dawson Creek), an excavator was needed to clear the borehole location (Figure 5). Precise drilling sites are summarized in Table 2.

Phase 2

Sonic Drilling

Sonic drilling commenced on August 21 with a field plan to collect 10 cm core to total depth and install six multilevel MW (including shallow bedrock and soil gas sample points where possible). However, due to a number of factors including personnel and material delays by the drilling contractor and drilling method limitations (the sonic rig being unable to efficiently drill through bedrock), only four MW were completed. Based upon this experience, other drilling methods are being considered for future boreholes. Four wells (EERI-1–4) were completed, with core logged and samples taken for later analyses, and are summarized in Table 3. Photographs of the well installations and core are shown in Figures 6–8. Full geological logs and monitoring well installations are shown in Figures 9–12.

Monitoring Well Assessment and Sampling Campaigns

As it was not possible to determine accurate static water levels or take samples at each borehole location during the drilling campaign (i.e., due to the presence of drilling water), a field trip was made at the end of September. Water level information would be essential to guide selection of a sampling pump with sufficient lift and suitable flow rate. During this campaign, static water levels were assessed and other tasks performed as follows. A subfrost artesian packer was installed successfully in the artesian Groundbirch field well. Development of 7.5 cm polyvinyl chloride (PVC) wells was attempted using a 7.5 cm Grundfos Holding A/S SQE submersible pump with restrictor valve. Unfortunately, the pump (which has a flow rate of around 225 L/min) proved too powerful even with the flow restrictor applied fully (lowering flow rate to 22.5–45 L/min) whereby it dried the wells out within a few minutes, prohibiting full development and sampling. The only sample successfully obtained on this campaign was one from the 0.6 cm polyethylene tubing of EERI-4. Based on results of this campaign a new sampling pump is being purchased; one that is able to lift required head and at a variable and

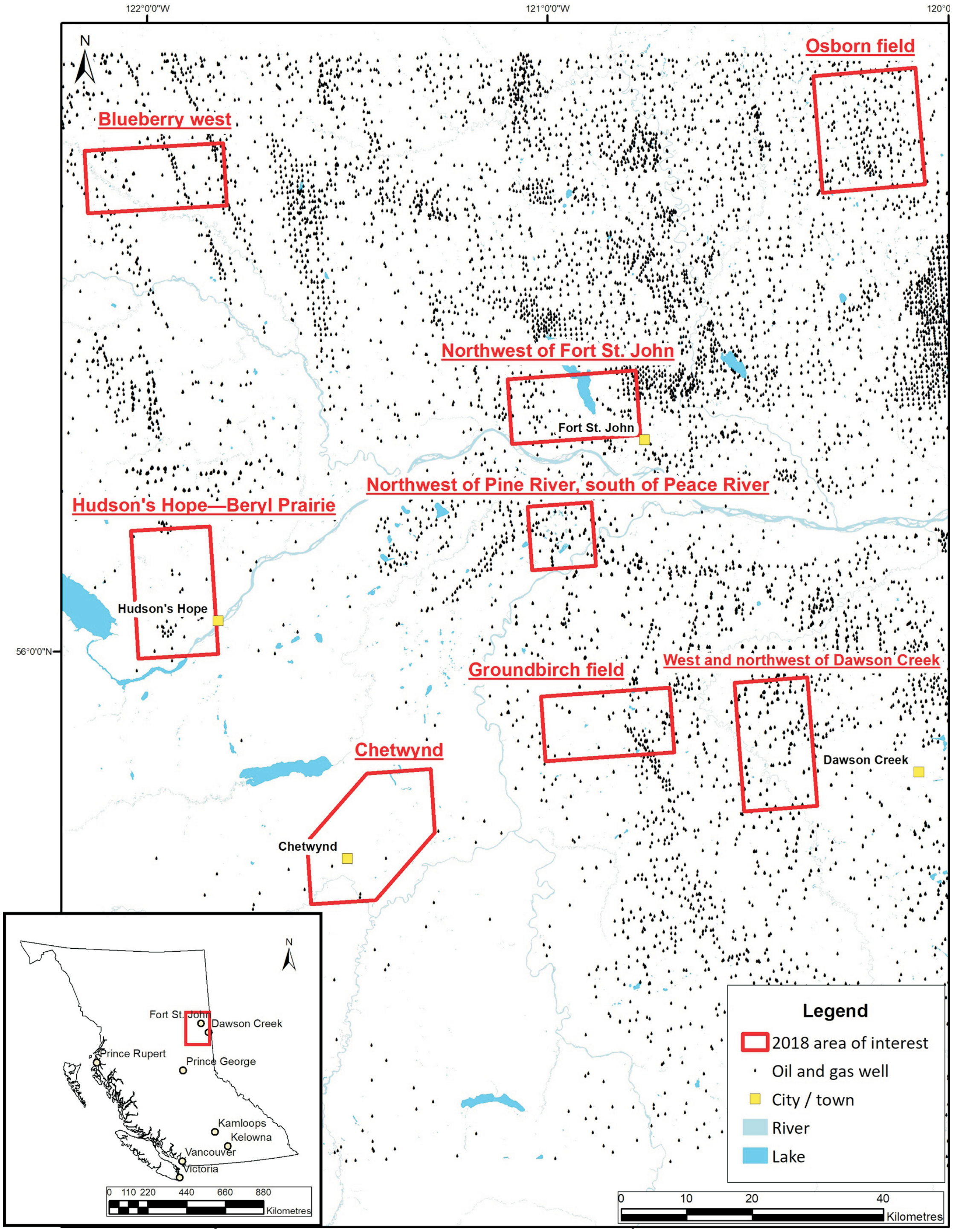

Figure 1. Regional map showing eight areas (red boxes) identified as potential sites for monitoring well installation, Peace region, British Columbia. Exact location of each well within each area will adhere to stated criteria and will be determined following desk study and site reconnaissance. Well data from BC Oil and Gas Commission (2018) and background data from DataBC (2018b).

Table 1. Areas selected for installation of background monitoring wells, Peace region, British Columbia. Note, Fort St. John Group, Cruiser Formation comprises fine clastic sedimentary rocks (mudstone, siltstone, shale); Dunvegan Formation comprises coarse clastic sedimentary rocks; Smoky Group, Kaskapau Formation comprises fine clastic sedimentary rocks (mudstone, siltstone, shale).

Area of interest	Area name	Surficial (SURF) and bedrock (BR) geology	Estimated depth to bedrock (BR) and groundwater (GW) in m
1	Hudson's Hope–Beryl Prairie	SURF: glaciofluvial fan deposits with lesser colluvial channels and alluvial terraces	35 (GW)
		BR: undifferentiated Fort St. John Group	32 (BR)
2	Chetwynd (Laser Farm and Campbell Road)	SURF: extremely varied area; mainly variations of glacial till > glaciolacustrine plains > alluvial plains > glaciofluvial plains > aeolian ridges	16 (GW)
	(2 MW)	BR: Fort St. John Group, Cruiser Formation	25 (BR)
3	Northwest of Fort St. John	SURF: mostly glacial till veneer, with lesser colluvial and glaciolacustrine deposits	25 (GW)
		BR: Dunvegan Formation	21 (BR)
4	West and northwest of Dawson Creek	SURF: glacial till plain, with similar amounts glaciolacustrine plain deposits, and minor alluvial plain deposits	8 (GW)
		BR: Smoky Group, Kaskapau Formation	16 (BR)
5	Blueberry west	SURF: glacial till, with lesser glaciolacustrine blanket deposits	NA (GW)
		BR: Dunvegan Formation or Fort St. John Group, Sully Formation	NA (BR)
			Limited data available
6	Osborn field	SURF: glacial till blanket, with lesser glaciolacustrine deposits	NA (GW)
		BR: Kotaneelee Formation	NA (BR)
			Limited data available
7	Groundbirch field	SURF: glacial streamlined till blanket, with lesser glaciolacustrine veneer deposits, and minor alluvial fan sediments	10 (GW)
		BR: Dunvegan Formation or Smoky Group, Kaskapau Formation	22 (BR)
8	Northwest of Pine River, south of Peace River	SURF: glaciolacustrine plain with lesser colluvial and alluvial terrace-plain sediments to the south	NA (GW)
		BR: Fort St. John Group	NA (BR)
			Limited data available

Abbreviations: MW, monitoring well; NA, not available.

Table 2. The six sites chosen for drilling in August 2018 (NAD 83, UTM Zone 10N).

Proposed drilling site area	Well	Easting	Northing
Hudson's Hope–Beryl Prairie	EERI-4	559562.81	6219144.64
Chetwynd (Laser Farm)	–	590854.62	6175341.25
Chetwynd (Campbell Road)	–	582343.78	6171309.31
Northwest of Fort St. John	EERI-3	623067.76	6239730.15
West and northwest of Dawson Creek	EERI-2	664110.19	6197643.10
Groundbirch field	EERI-1	625846.36	6191692.33

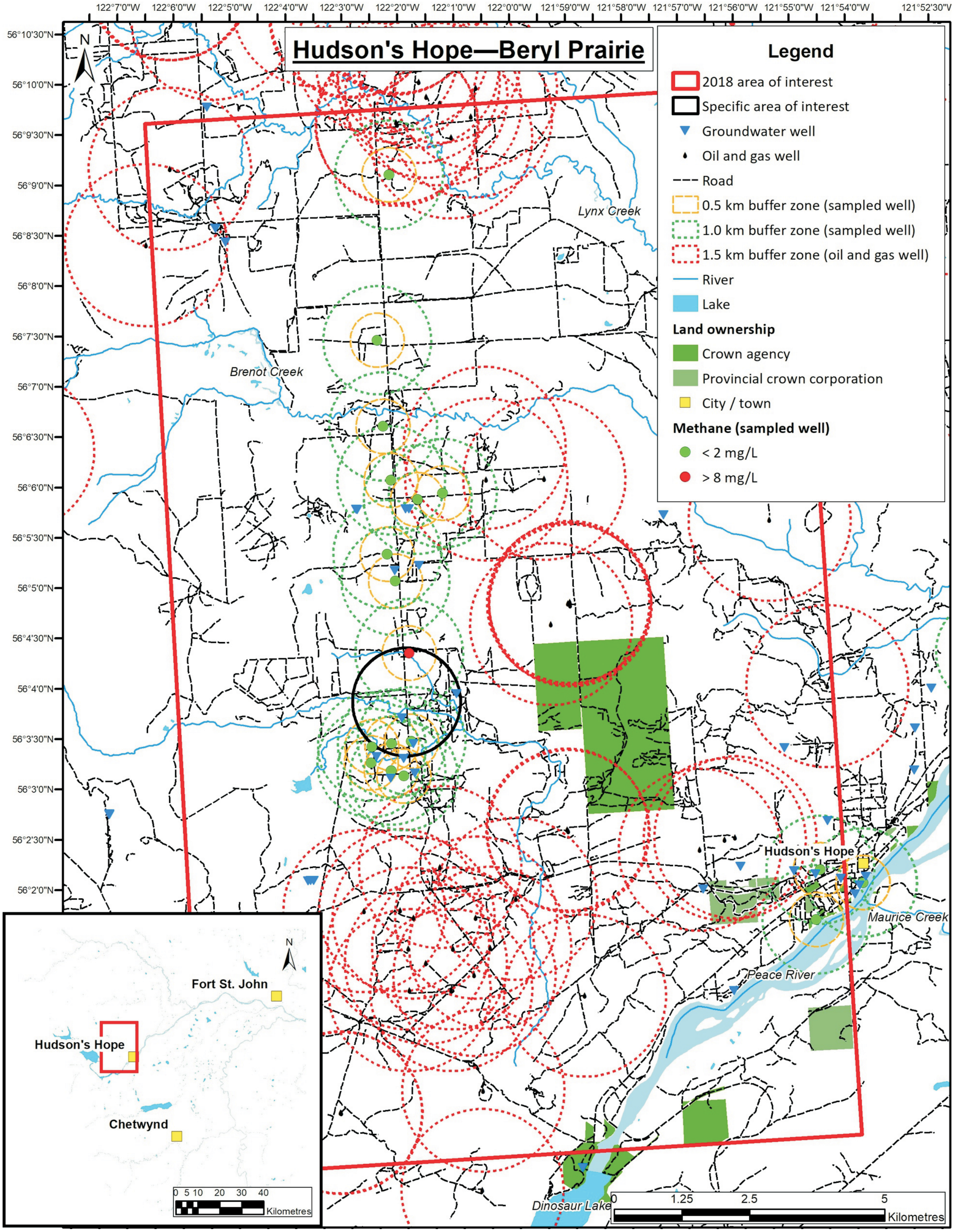

Figure 2. Map of area 1 (Hudson's Hope–Beryl Prairie) enclosed by red boundary, Peace region, British Columbia. Black circle indicates potential locations for paired well installation, red circles are 1.5 km buffer zones from oil and gas wells, orange and green circles indicate buffer zones (0.5 and 1.0 km, respectively) from sampled water wells. Well data from BC Oil and Gas Commission (2018) and DataBC (2018c) and background data from DataBC (2018a, b, d).

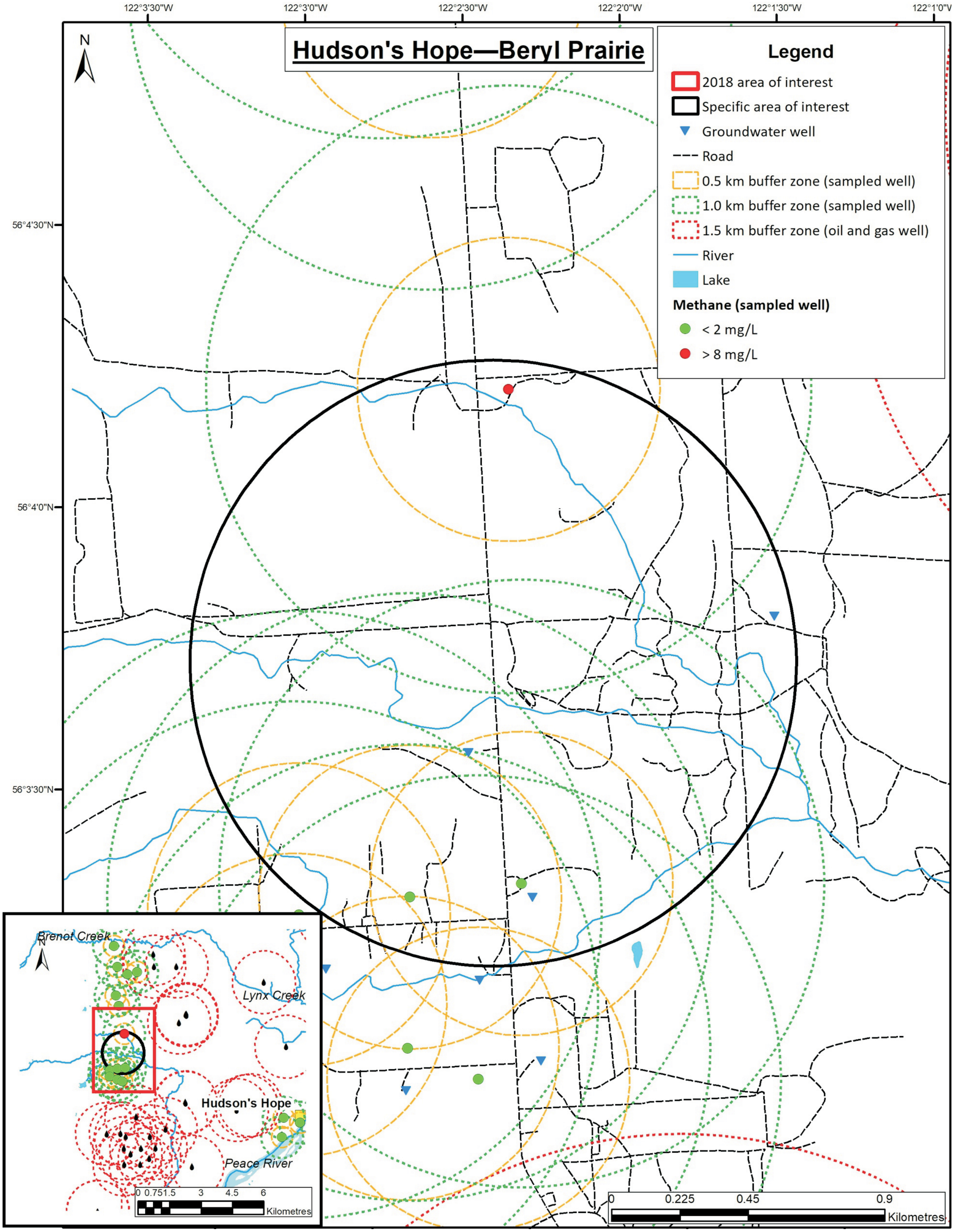

Figure 3. Detailed portion of area 1 (Hudson's Hope–Beryl Prairie), Peace region, British Columbia. Black circle indicates potential location for paired well installation, red circles are 1.5 km buffer zones from oil and gas wells, orange and green circles indicate buffer zones (0.5 and 1.0 km, respectively) from sampled water wells. Well data from DataBC (2018c) and background data from DataBC (2018a, b).

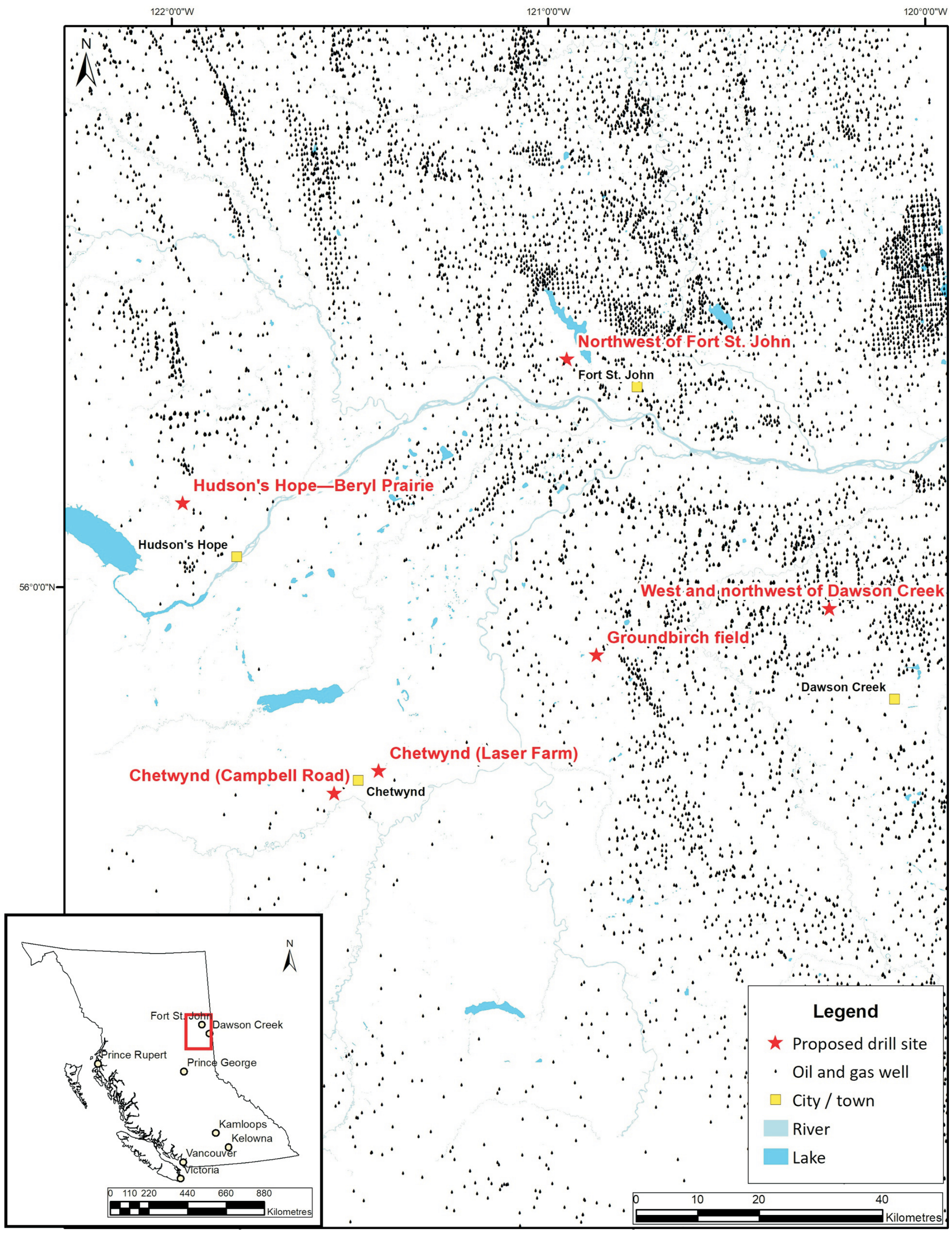

Figure 4. Map showing prioritized drilling sites, Peace region, British Columbia. Well data from BC Oil and Gas Commission (2018) and background data from DataBC (2018b).

Figure 5. Site preparation at Groundbirch field prior to drilling, Peace region, British Columbia.

Figure 6. Sonic drilling in progress at Groundbirch field, Peace region, British Columbia.

Figure 7. Sonic core composed of glacial clay/diamict, which dominates the upper portion of the Quaternary section throughout the Peace region, British Columbia.

Figure 8. Artesian well flowing (approximately 22.5–45 L/min) after completion at Groundbirch field, Peace region, British Columbia. The well was immediately and temporarily sealed with a polyvinyl chloride (PVC) end cap and subsequently permanently sealed with a subfrost artesian packer with built-in sampling valve during a follow-up fieldwork campaign.

Table 3. Summary of four wells completed during first drilling campaign in August 2018, Peace region, British Columbia.

Well	Area name	Total depth (m)	Generalized geology	Estimated depth to water (m agl)
EERI-1	Groundbirch field	66	43 m of diamict interlayered with silty clay, overlying 14 m of artesian (1.2 m agl of artesian pressure) sandy gravel, overlying 8 m of clay with lesser diamict	1.2
EERI-2	West and northwest of Dawson Creek	49	28 m of silty clay, overlying bedrock shale with lesser siltstone	-28.9
EERI-3	Northwest of Fort St. John	55	5 m of clay, overlying 21 m of diamict, overlying 22 m of medium sandstone, overlying 6 m of shale/siltstone	-46.51
EERI-4	Hudson's Hope–Beryl Prairie	51	10 m of clay, overlying a 11 m sequence of silt to medium sand, overlying 11 m of diamict, overlying 19 m of siltstone	-22.07

Abbreviation: agl, above ground level

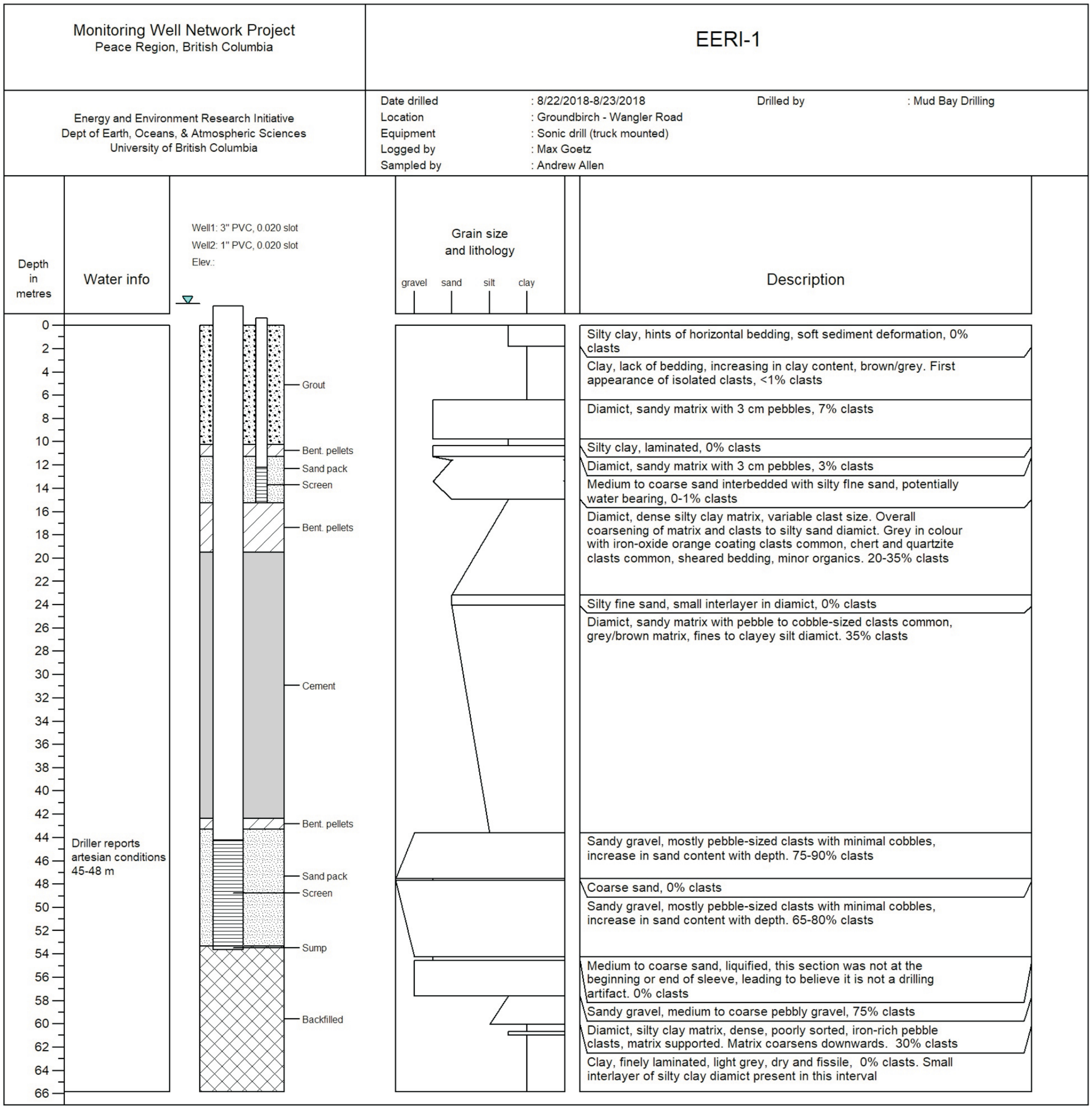

Figure 9. Well installation log for EERI-1, Groundbirch field, Peace region, British Columbia. Abbreviations: Bent., bentonite; PVC, polyvinyl chloride.

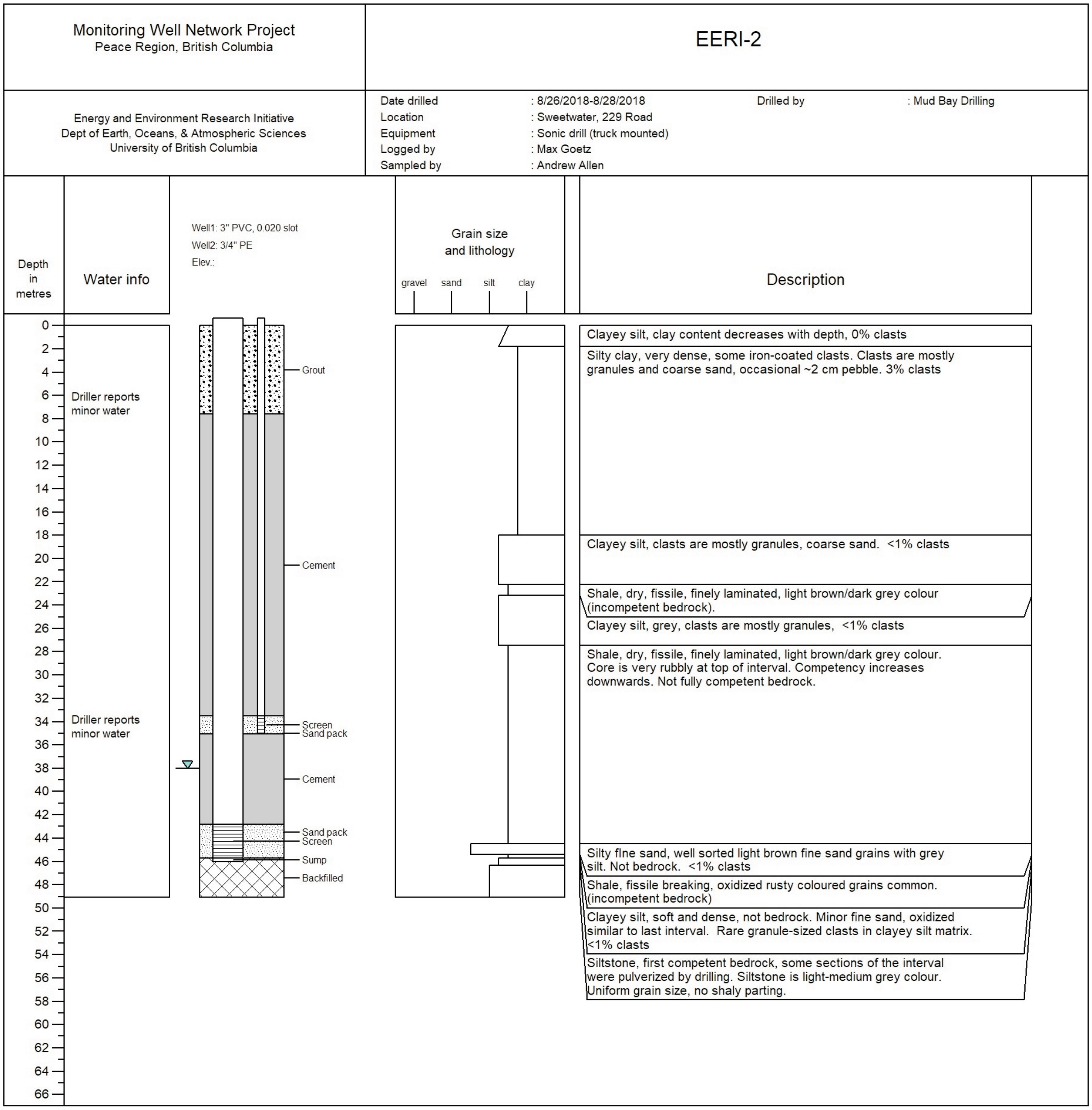

Figure 10. Well installation log for EERI-2, west and northwest of Dawson Creek, Peace region, British Columbia. Abbreviations: PE, polyethylene; PVC, polyvinyl chloride.

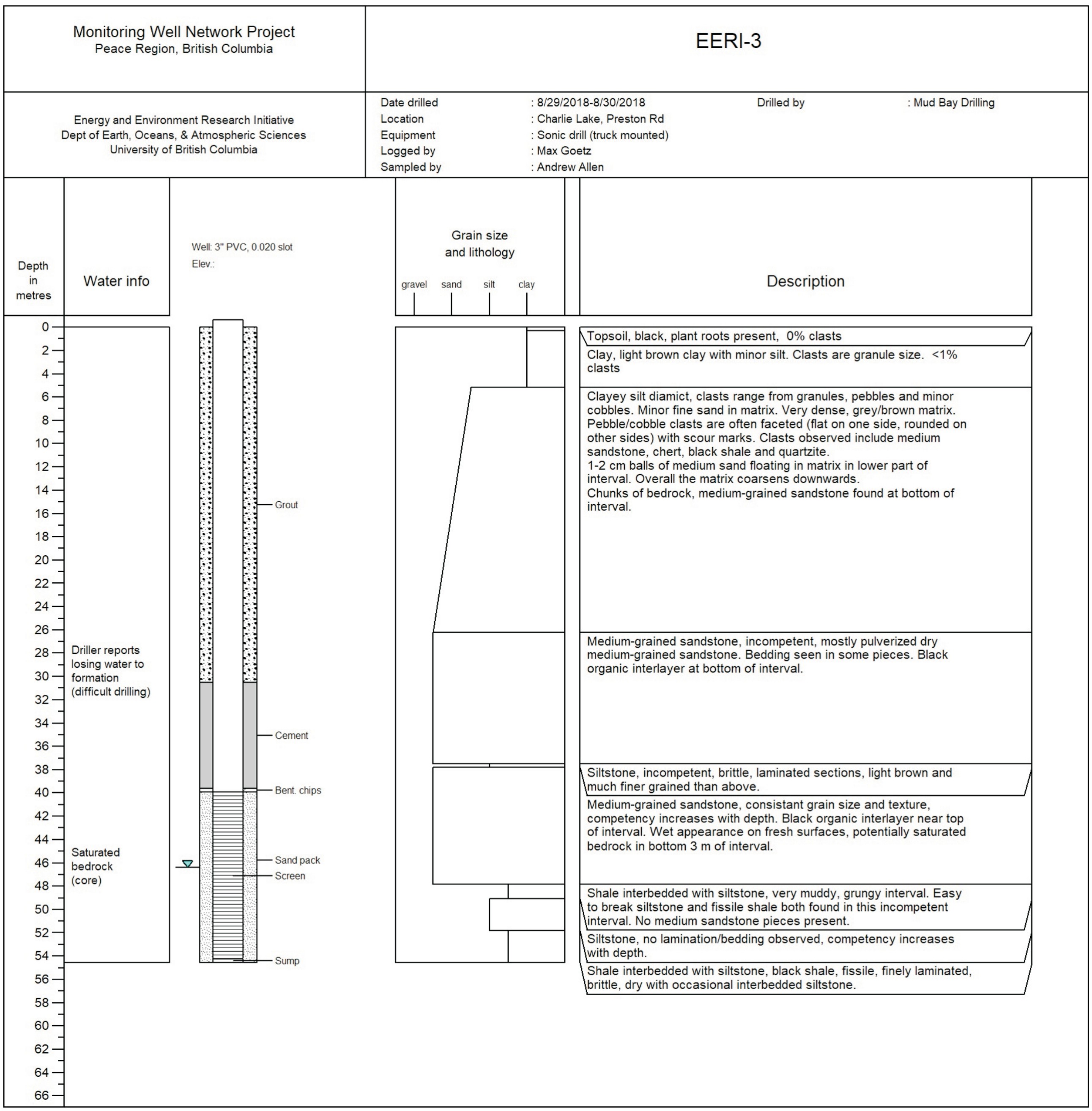

Figure 11. Well installation log for EERI-3, northwest of Fort St. John, Peace region, British Columbia. Abbreviations: Bent., bentonite; PVC, polyvinyl chloride.

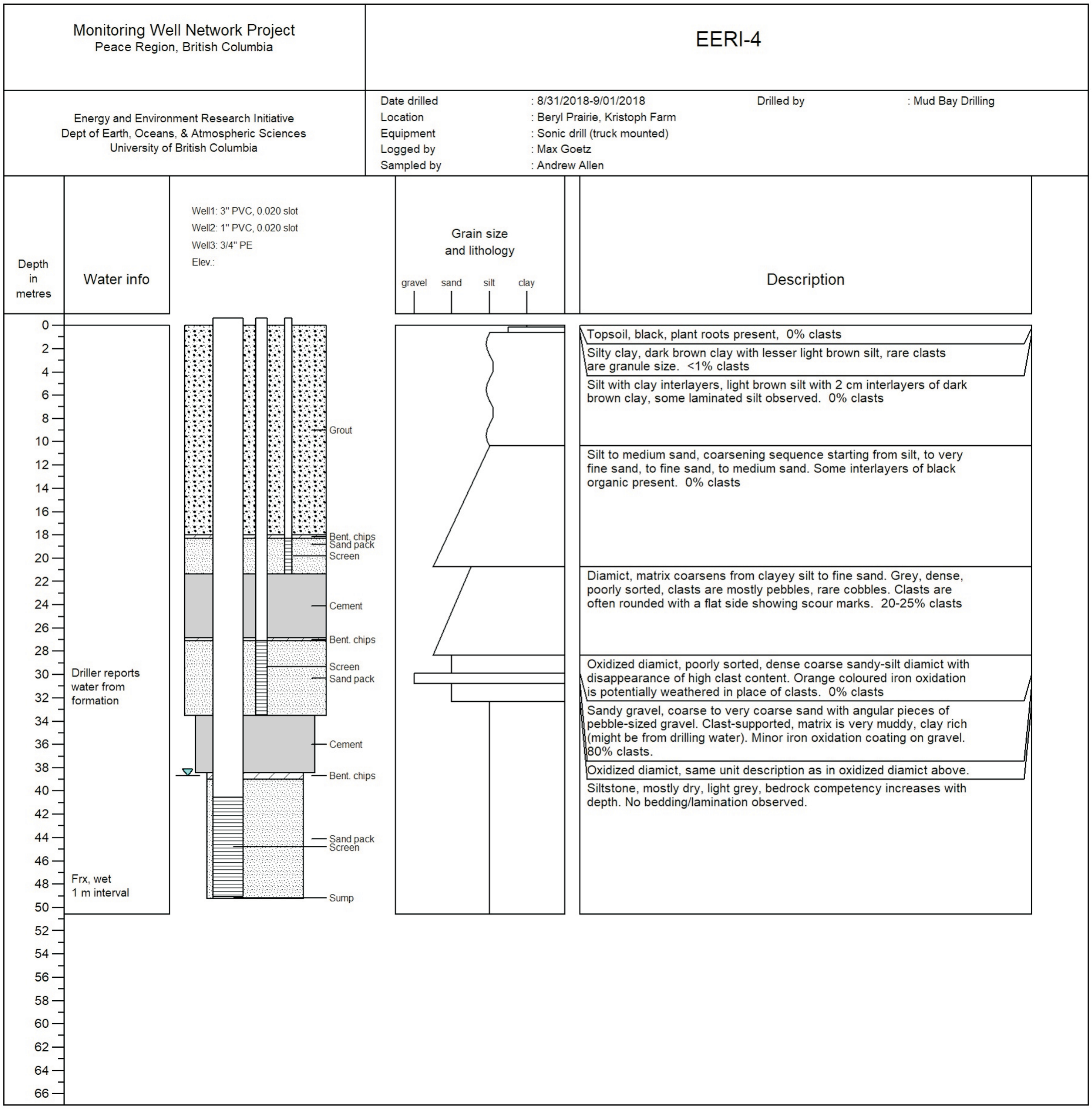

Figure 12. Well installation log for EERI-4, Hudson's Hope–Beryl Prairie, Peace region, British Columbia. Abbreviations: Bent., bentonite; Frx, fractured; PE, polyethylene; PVC, polyvinyl chloride.

Table 4. Analysis type and rationale for geological sample analyses program.

Analyses type	Information gained	Relevance to project and fugitive gas and/or gas migration
X-ray diffraction, SEM-EDX and total digestion (aqua-regia)	Grain structure and mineralogy	General hydrogeochemical information and indication of aquifer matrix reactivity
Targeted/sequential extractions	Elemental content by phase/reactivity	Identify presence and quantify reactive minerals potentially involved in methane mediated redox reactions
Cation exchange capacity (CEC)	Exchangeable cation composition and total capacity	Identify elements present and quantify CEC potentially involved in water quality changes associated with methane-associated redox reactions
Permeability and grain-size distribution	Indicate permeability	Indicate permeability with respect to groundwater and potential migration of fugitive gases

Abbreviation: SEM-EDX, scanning electron microscope–energy dispersive X-ray spectrometry

low flow rate. Currently plans are underway to sample wells and perform hydraulic testing before the end of 2018.

Phase 3

Geological Sample Analyses

During drilling a total of 181 samples were taken from the sonic core across the four holes. These samples are in the process of being analyzed in the laboratories at UBC and Simon Fraser University in order to determine a depth profile of various physical and chemical properties. Sample analyses and rationale are provided in Table 4. It is expected that these results will be available by the end of 2018.

Community and First Nations Engagement

Community engagement efforts have centred on two main strategies: newsletter dissemination and in-person community outreach events. Two newsletters were sent to eight First Nation communities along with the Treaty 8 Tribal Association and six municipal associations. The first was sent on March 2, 2018, which described the project, its goals and the plan for phases 1 and 2 of the project. The second newsletter was sent on May 23, 2018, outlining eight tentative areas to drill the first eight to ten wells, and invited feedback and input from the communities. These newsletters generated general interest and support, and resulted in a phone call from the West Moberly First Nations Chief and Council asking for further information.

On March 13, 2018, the UBC Energy and Environment Research Initiative's (EERI) team attended the Northeast Water Strategy meeting in Fort St. John, in which the Peace region groundwater monitoring well network was described to various stakeholders. The team was approached by the Doig River First Nation Chief, resulting in a visit to the Doig River community and a meeting with the Chief and Council, as well as a trip to a leaky well on their land. This has further informed the selection process for future drilling sites for the Peace region groundwater monitoring well network.

On June 13, 2018, a community engagement open house event was held in Fort St. John at the local Whole Wheat & Honey Cafe. Representatives from UBC, Geoscience BC and the BCOGC spoke about the different aspects and perspectives of the project, and more importantly, answered questions from the community. The event began with an Elder Welcoming from the Doig River First Nation, and over 35 people from the community attended. Overall, it was a successful event, with active participation and interest from the community. Comments and questions were recorded to be incorporated in project plans as the project progresses.

Summary of Progress and Ongoing Work

The following forms a summary of the progress made to date with respect to The University of British Columbia Energy and Environment Research Initiative's Peace region groundwater monitoring well network project:

- refined and finalized the experimental plan and concept for the background monitoring wells location with a paired and unpaired approach;
- eight areas were identified for the first monitoring wells and detailed desk studies on these areas were performed;
- five of the eight areas were prioritized and a field reconnaissance trip taken to plan and prepare for drilling;
- four boreholes were drilled by sonic method with full cores attained and ~180 samples taken for physical and chemical analyses; each borehole was completed with a custom-built multilevel sampling system; significant challenges were experienced during the sonic drilling program leading to consideration of alternative methods for ongoing drilling;

- an artesian gravel was encountered at the Groundbirch field site, subsequently sealed with a custom built subfrost artesian packer and sampling system; and
- static water levels were determined and development and sampling of new wells attempted; however, the currently available equipment was not optimal and it was not possible to take groundwater samples yet.

The following key tasks are in progress or ongoing:

- a field campaign is planned to sample the groundwater in wells EERI-1–4 using a suitable and newly purchased pump before the end of 2018;
- the four remaining background monitoring wells are planned to be drilled in January 2019 (using air rotary drilling method);
- sediment analyses is being undertaken;
- downhole and surface geophysics at the initial drill sites are being planned; and
- an integrated interpretation of all results in terms of geology, hydrogeology and groundwater conditions in the Peace region is ongoing.

Acknowledgments

Peer reviewed by L. Smith.

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