



enhance



**ENHANCE ENERGY CLIVE MMV PLAN
APPENDICES L:**

**Golder Associates
Baseline Shallow (non-saline)
Groundwater Monitoring**

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TECHNICAL MEMORANDUM

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TO Dave Hassan
Enhance Energy

CC Brendan McGowan

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BASELINE SHALLOW (NON-SALINE) GROUNDWATER MONITORING

As part of the Measurement, Monitoring and Verification (MMV) Plan for the secure storage of carbon dioxide (CO₂) and Enhance Oil Recovery project at Clive, Alberta, Enhance Energy (Enhance) has requested Golder Associates Ltd. (Golder) to assist with the selection of Landowner water wells and dedicated Project wells to be included in Enhance's baseline groundwater monitoring program.

The purpose of the shallow (non-saline) groundwater monitoring program is to establish baseline conditions for groundwater quality in the Project area, specifically within a 1.6-km radius from the three injection well surface locations at SW-02-040-24 W4M, NE-35-039-24 W4M and NE-26-039-24 W4M.

This memorandum outlines the approach and rationale involved in selecting representative groundwater sampling locations for baseline monitoring. It should be noted, however, that the selected Landowner water wells may be subject to change following an assessment of their current condition and/or Landowner commitment to participate in the baseline monitoring program.

Methodology

The selection of Landowner water wells for baseline groundwater monitoring included the following approach:

- reviewing the hydrogeological conditions of the Project area to identify sampling locations that are representative of the local groundwater system;
- identifying all registered water wells within a 1.6-km radius from the three injection well pads;
- reviewing the available water well drilling reports to identify completion zones; and
- selecting Landowner water wells that are representative of local hydrogeological conditions and are spatially distributed throughout the Project area.

Hydrogeological Setting

The three injection well surface locations are situated in the Central Clive Leduc Area, within the Lacombe County in south-central Alberta. The County lies within the Red Deer River watershed, which encompasses 11 sub-basins. Most of the Project area falls within the "Red Deer River Near Nevis" basin, as illustrated in Figure 1.

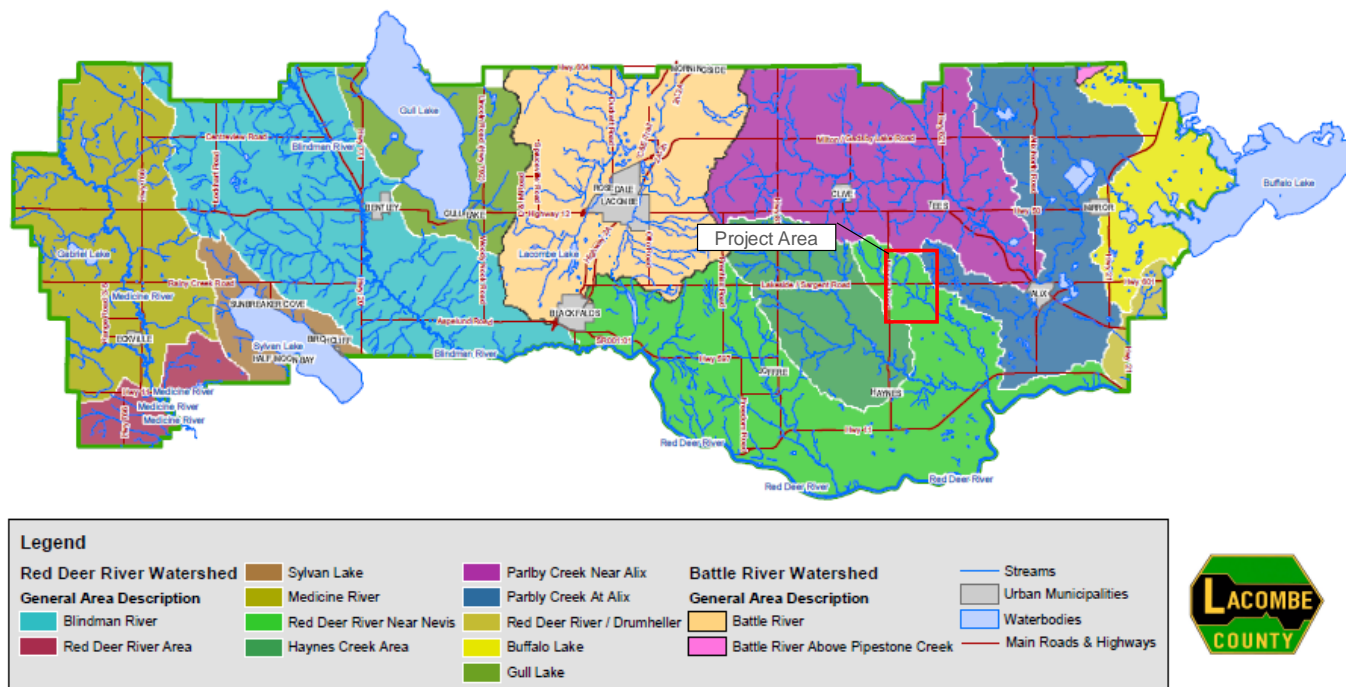


Figure 1: Lacombe County Drainage Basins (Lacombe County 2019, internet site)

Surficial Deposits

According to the Regional Groundwater Assessment completed for the Lacombe County (HCL 2001), surficial deposits in the County are typically less than 20 to 30 metres thick and include pre-glacial materials and pre-glacial fluvial and lacustrine deposits. Within the Project area, the main aquifers are shallow bedrock as the surficial sediments are either absent or relatively thin, i.e., up to 5 m in thickness (Figure 2).

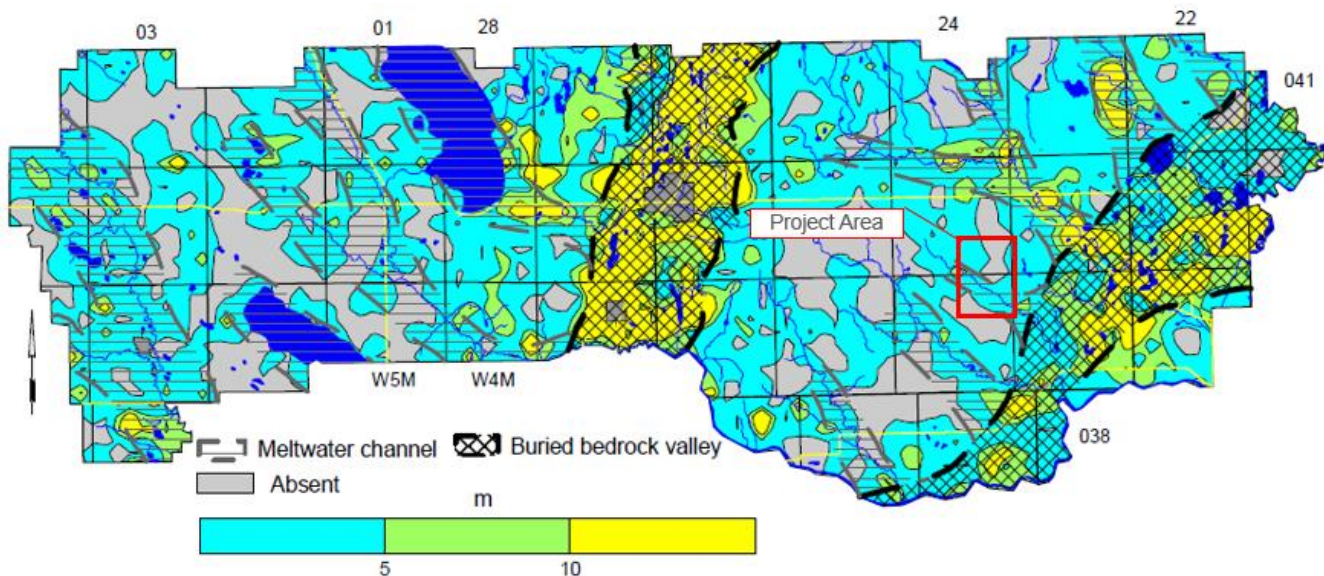


Figure 2: Thickness of Sand and Gravel Deposits (HCL 2001)

Water wells completed in surficial deposits are found primarily along the Buried Red Deer and Buffalo Lake valleys (eastern and central side of the County, respectively) and the Gilby Meltwater Channel (western side of the County). Within the Project area, however, there appears to be few (if any) water wells completed in surficial deposits (Figure 3), which may be explained by the absence or low thickness (<5 m) of sand and gravel deposits observed in the Project Area (refer to the previous Figure 2).

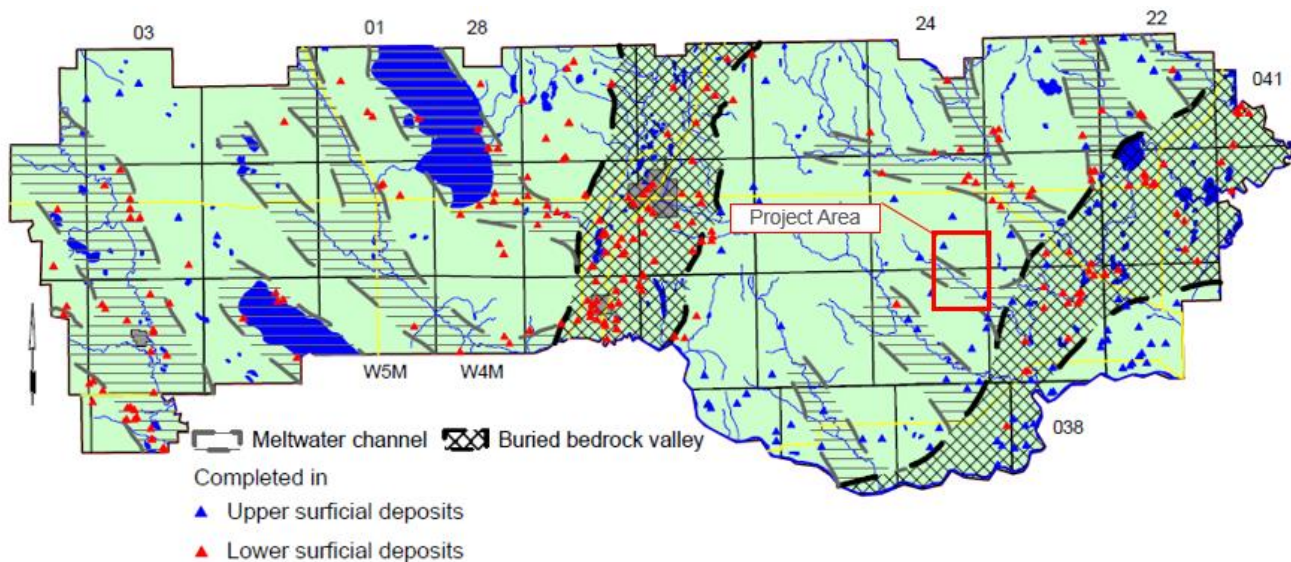


Figure 3: Water Wells Completed in Surficial Deposits (HCL 2001)

Bedrock Geology

The upper bedrock in the County consists of the Paskapoo, Scollard, Whitemud, Battle, and Upper Horseshoe Canyon Formations (HCL 2001). Of these, the project area is underlain by the Lower Lacombe and Haynes Member, both of which are members of the Paskapoo Formation (Figure 4).

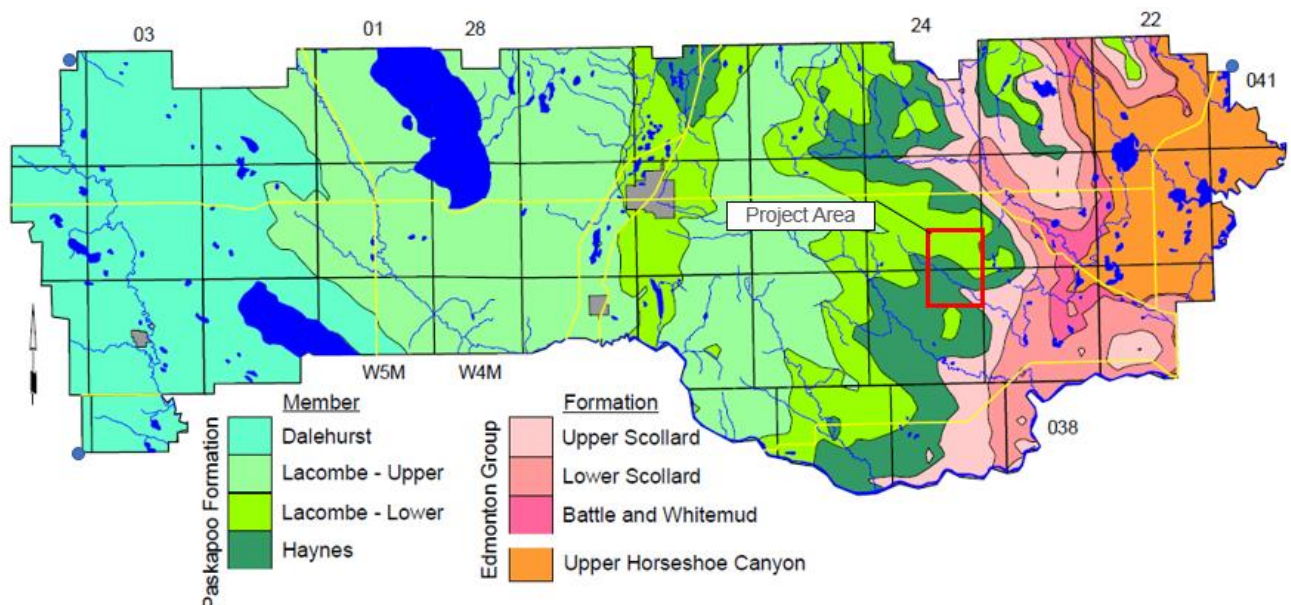


Figure 4: Bedrock Geology (HCL 2001)

The Lower Lacombe Member has a maximum thickness of about 100 m (average is 50 m) and is comprised of sandstone and a coal zone in the middle. The depth to the top of the Lower Lacombe Member ranges from less than 10 metres below ground surface (mbgs) in the eastern part of the County (Project area) to more than 250 mbgs in the western side of the County.

The Haynes Member (which lies underneath the Lacombe Member) has a maximum thickness of about 100 m (average is 40 m) and is comprised of sandstone with some siltstone, shale and coal. The depth to the top of the Haynes Member ranges from less than 10 mbgs in the eastern part of the County (Project area) to more than 300 mbgs in the western side of the County.

Bedrock water wells within Project area (Figure 5) are completed in the Lower Lacombe Member and Haynes Member, as previously shown in Figure 4.

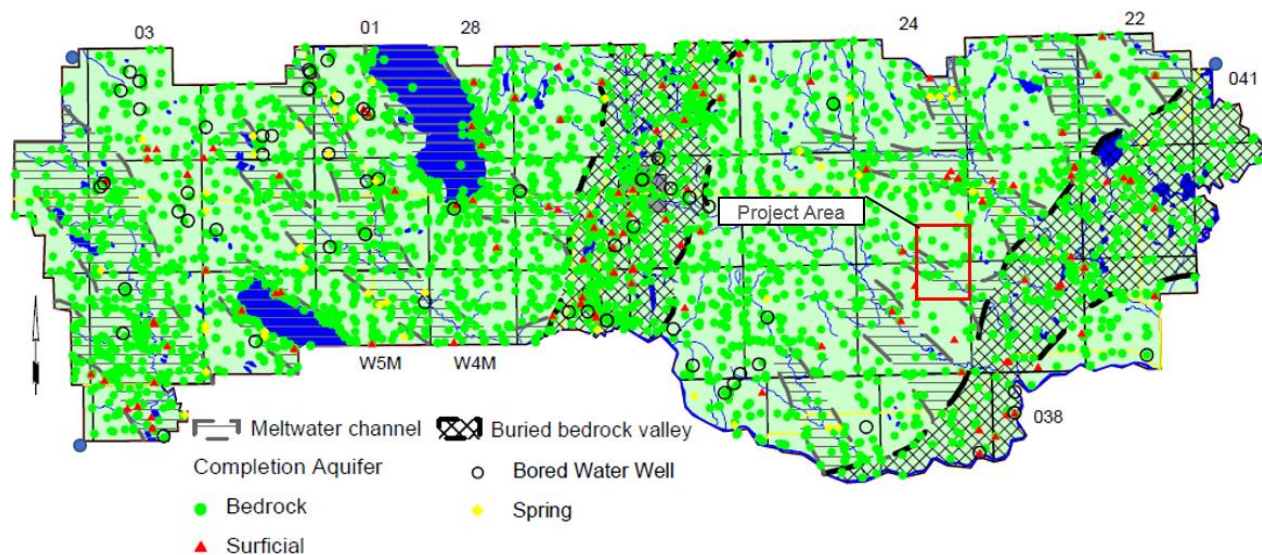


Figure 5: Water Wells Location (HCL 2001)

Registered Landowner Water Wells

According to Alberta's Water Well Information Database (AEP WWID 2019, internet site), there are currently 45 registered water wells within a 1.6-km radius from the three Project injection well pads. Of these, 25 were completed for domestic and/or stock use. The remaining wells (20) are listed as being primarily for industrial (17) purposes, as well as investigation (1), other (1) or unknown (1). A list of registered water wells for each 1.6-km radius is attached.

Based on the available drilling reports, the depth of the Landowner water wells (domestic & stock) ranges between 15 and 84 mbgs, with the majority (18) being completed in upper bedrock and below 20 mbgs. The following chart illustrates the number of Landowner water wells (domestic & stock) for different reported depths, including: <20 mbgs, >20 and <40 mbgs, >40 to 84 mbgs, and unknown.

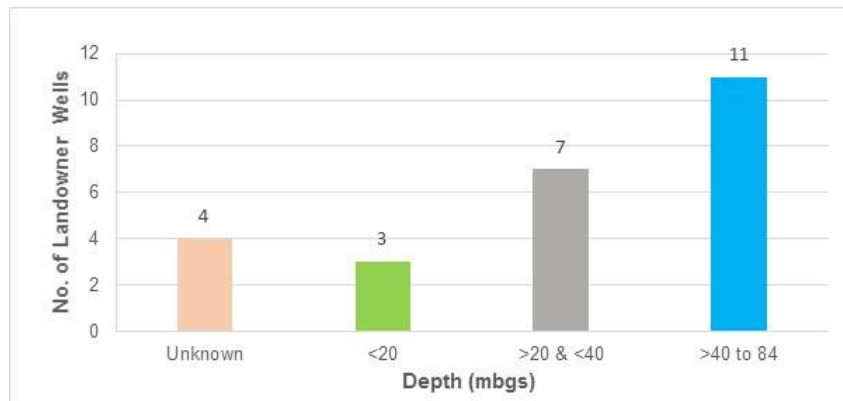


Figure 6: Number of Registered Landowner Water Wells within a 1.6-km Radius from Surface Injection Pads

Selected Landowner Water Wells and Dedicated Project Wells

A review of the hydrogeological information and the available water well drilling reports indicated that most Landowner water wells within the Project area (1.6-km radius from injection well pads) are completed in the Lower Lacombe Aquifer or Haynes Aquifer, both of which are members of the Paskapoo Formation. On this basis, a representative number (>25%) of Landowner water wells were selected for each depth ranges outlined earlier (i.e., <20 mbgs, >20 and <40 mbgs, >40 to 84 mbgs). In total, nine (9) Landowner water wells (36% of the total registered Landowner wells) are recommended for baseline groundwater monitoring. The recommended wells are representative of local geological conditions, are spatially distributed throughout the area of interest at a density of about four wells per 1.6-km radius, cover the depth range of domestic wells and include the two members of the Paskapoo Formation that are intersected by the registered domestic wells. A list of the selected wells is included in Table 1 and the associated drilling reports are attached.

Table 1: Recommended Landowner Water Wells for Baseline Sampling

GIC Well ID ^(a)	BWWT	CBM Testing	Reported Depth (m)	Drainage Basin	Inferred Surface Bedrock Geology ^(b)
97476	-	-	42.67	Red Deer River Near Nevis	Haynes
97505	1163875	Yes	27.43	Red Deer River Near Nevis	Lacombe
159670	1208075 & 2002341	Yes	24.38	Red Deer River Near Nevis	Lacombe
273119	-	-	15.24	Red Deer River Near Nevis	Lacombe
273122	-	-	73.15	Red Deer River Near Nevis	Haynes
273147	-	-	18.29	Red Deer River Near Nevis	Surficial deposits & Lacombe
286609	1194455	Yes	78.64	Red Deer River Near Nevis	Haynes
290202	-	-	73.15	Red Deer River Near Nevis	Haynes
297942	-	-	54.86	Red Deer River Near Nevis	Haynes

Notes:

^(a) GIC – Groundwater Information Centre; BWWT – baseline water well testing; “-” unknown

^(b) Inferred well completion bedrock geology based on reported water well depth and/or bedrock geologic map

The locations of the selected nine Landowner water wells are illustrated in Figure 7. It should be noted that the selected Landowner water wells may be subject to change following an assessment of their current condition and/or Landowner commitment to participate in the baseline monitoring program.

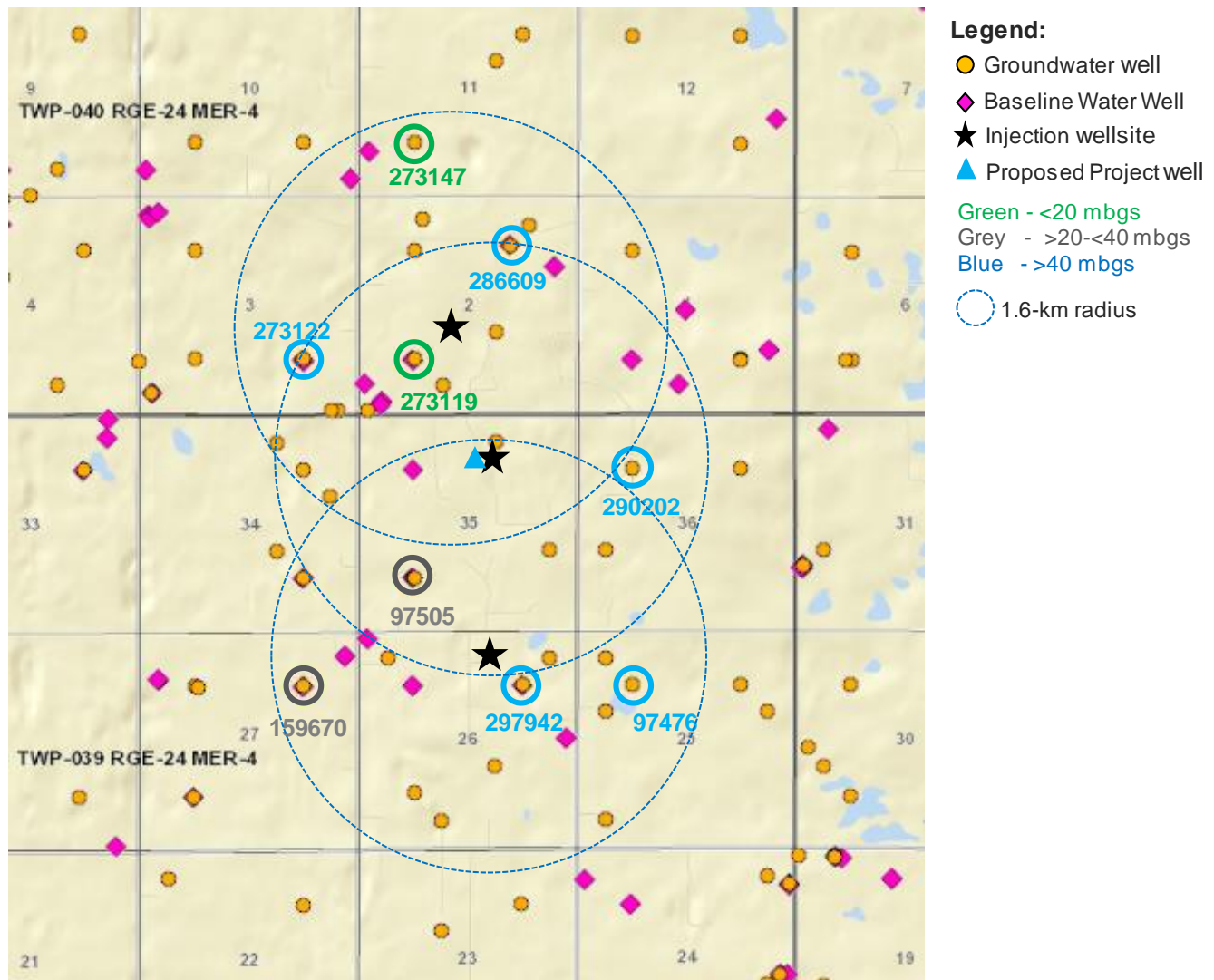


Figure 7: Location of Selected Domestic Water Wells for Baseline Monitoring (WWID 2019, internet site)

In addition to the selected Landowner water wells, three nested groundwater Project wells are recommended to be installed at one of the injections well pads. The purpose of the dedicated wells is to complement the groundwater quality information collected from the selected Landowner water wells.

Given the hydrogeological conditions of the area and the completion depths of Landowner water wells, it is recommended that the dedicated Project wells (3) are installed within the well pad at NE-35-039-24 W4M (in the middle of the Project area, see Figure 6) and completed in the Lower Lacombe and Haynes Aquifers, at preliminary depths of <20 mbgs, >20 and <40 mbgs, >40 to 84 mbgs, respectively, in order to capture representative geological conditions of the area. Given that the bedrock and topographic positions are similar

amongst the registered Landowner water wells, the main differentiator is depth. Therefore, the recommended three nested Project wells (completed at different screen intervals) will serve to capture water quality changes with depth.

Enhance should ensure that the selected well pad has not been impacted by current or previous operations.

Additional dedicated Project wells may be required during the operation of the project. The condition triggering the installation of new Project wells would be an indication of CO₂ leakage detected by the Coal Bed Methane (CBM) monitoring program. If CBM sampling results suggest a potential for CO₂ leakage, new Project well(s) will be installed near the area of CO₂ detection.

Baseline Monitoring Frequency

It is recommended that the baseline monitoring program for Landowner water wells be completed over an initial period of two years, including three consecutive events in 2019 and a quarterly sampling program in 2020, for a total of 7 events. At the end of the second year, the analytical data will be reviewed and evaluated using statistical solutions. If the evaluations indicate abnormal trends (e.g., statistically significant differences and/or significant increasing/decreasing concentrations), additional quarterly sampling will be conducted for one consecutive year, after which the data will be further evaluated using statistical techniques. Depending on the statistical results, additional sampling may or may not be required.

The recommended sampling frequency for the dedicated Project wells is a quarterly basis for a minimum of three consecutive years following well installation. If statistical evaluations of the data at the end of the third year show stable trends or no significant differences, indicating representative groundwater conditions, further sampling may not be required.

Following the completion of baseline data collection, the condition triggering the need for follow-up sampling would be an indication of CO₂ leakage detected by the CBM monitoring program. If CBM sampling results suggest a potential for CO₂ leakage, sampling will be performed in the wells relatively proximal to the suspected leakage.

Analytical Suite

The analytical suite will include a range of groundwater quality parameters that will serve to established baseline levels.

The analytical suite recommended to assess and establish baseline shallow groundwater quality include:

- Routine potability parameters: pH, alkalinity, bicarbonate, carbonate, hydroxide, electrical conductivity, fluoride, chloride, nitrite, nitrate, sulphate, calcium, magnesium, potassium, sodium, iron, manganese, Total Dissolved Solids (TDS), hardness, ion balance, nitrate+nitrite-N, nitrate-N, Nitrite-N, Sodium Adsorption Ratio (SAR).
- Dissolved Inorganic Carbon (DIC) and dissolved metals, particularly lead, cadmium, arsenic. In the unlikely event of CO₂ leakage, the pH of the formation water will decrease, and the carbonate content will increase. The acidification and alkalinity increase could result in the release of trace metals by dissolution (and/or desorption) and ion exchange reactions, which could mobilize heavy metals such as lead, cadmium and arsenic.

- Bromide. One of the tools used to assess source(s) of chloride in groundwater is the chloride/bromide (Cl/Br) weight ratio. Both chloride and bromide behave as conservative elements in relatively dilute groundwater, are not readily adsorbed by clay minerals and remain soluble under a range of reduction oxidation conditions. This allows these elements to act as tracers in groundwater, with their initial ratio at the source remaining largely preserved in the groundwater aquifer.
- Microbial parameters to address any potential Landowner concerns with respect to unusual odors and/or colour of groundwater, which may be associated with microbial activity. Recommended parameters include total sulfur, Iron-Related Bacteria (IRB), Sulfate-Reducing Bacteria (SRB), Slime-Forming Bacteria (SFB).
- Isotope Delta13C (and potentially Delta14C) in Dissolved Inorganic Carbon (DIC).

Closure

We trust the information presented in this memorandum meets your current requirements. Please contact the undersigned if you require additional information.

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Environmental Engineer

John Wozniwicz, M.Sc.
Principal, Hydrogeologist

JH/JW/

Attachments: References
List of Registered Water Wells for each 1.6-km Radius
Water Well Drilling Reports
Baseline Water Well Testing Reports

References

- AEP WWID (Alberta Environment and Parks Water Well Information Database). 2019. AEP online Water Well Information Database. Available at: <http://groundwater.alberta.ca/WaterWells/d/>. Accessed April 2019.
- HCL (Hydrogeological Consultants Ltd.). 2001. *Lacombe County, Regional Groundwater Assessment, Part of the Red Deer River Basin, Tp 038 to 041, R 21 to 28, W4M & Tp 038 to 041, R 01 to 04, W5M*. January 2001.
- Lacombe County. 2019. *Drainage Basins Within Lacombe County*. Available at <https://www.lacombecounty.com/>