Water budget for the Grimshaw gravels aquifer system

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Abstract

The Grimshaw Gravel Aquifer is an important water source in the Upper Peace Region of Alberta. The gravel deposits are often described as consisting of 'lobes', which have recently been shown to contain the highest the likelihood of having coarse-grained deposits occurring within sediments above bedrock. This confirms that the aquifer is productive and that there is spatial variation in its transmissivity (thickness and permeability). A water budget calculation, using two recent estimates for groundwater recharge, found that the Grimshaw Gravel Aquifer is neutral to net positive, meaning that aquifer sufficiently supports existing groundwater users, and most likely has some resilience to changes from increased pumping or reduction in groundwater recharge. Groundwater modelling demonstrates that from a long-term perspective, Cardinal Lake receives more groundwater than it loses to seepage, and can be considered a groundwater-dependent hydrologic feature in the region. Groundwater modelling also demonstrates that greater pumping is not expected to greatly decrease groundwater levels. The findings of the water budget calculation and groundwater modelling are corroborated by long-term observations of groundwater levels, which have been relatively stable for 40 years (1983 to 2023).

1 Introduction

The Upper Peace Region in northwestern Alberta has a mosaic of land uses (e.g., agriculture, rural residential, oil and gas), and the cumulative effects of population growth and economic development is increasing pressure on land and water resources. In some parts of the region, such as the Town of Grimshaw, groundwater is the sole source of water for residents. Often termed the 'Grimshaw Gravel Aquifer', this aquifer has excellent groundwater quality and high yield, making it the most economically viable water source within the region. Numerous communities with a total population of approximately 7000 residents rely on the aquifer as their drinking water source.

To coordinate watershed management efforts, the Mighty Peace Watershed Alliance (MPWA) and the Grimshaw Gravels Aquifer Management Advisory Association (GGAMAA) have developed plans related to Integrated Watershed Management (MPWA, 2018) and Source Water Protection (GGAMAA, 2019). These plans identify the importance of accounting for non-saline groundwater as part of understanding cumulative effects in the region, especially for the prominent Grimshaw Gravel Aquifer located west of the town of Peace River and adjacent to Cardinal Lake.

The objective of this report is to combine volumetric estimates of groundwater inflow and outflow to realize a complete water budget of the Grimshaw Gravel Aquifer and develop a numerical groundwater model. The purpose of the model is to integrate hydrogeological parameters of the physical environment with several water uses (e.g., groundwater pumping, dependent ecosystems), which will facilitate studying the effect of governance choices (e.g., indicators and thresholds) in a quantitative framework.

The outcomes of this project help support the Government Alberta's approach to managing groundwater quantity and management of cumulative effects. The project demonstrates how quantitative modelling can aid the development of an indicator and threshold approach for groundwater management frameworks in prioritized areas of the province, under the renewed Water for Life strategy.

2 Study Area

Several gravel deposits are located between the Whitemud Hills and the Peace River valley (Figure 1) that are important aquifers and aggregate resources in the region. Initially mapped by Tokarsky (1971), the gravel deposits are often referred to as 'lobes' (Figure 1; PFRA, 1998) and have recently been studied considerably to learn more about the geological and hydrogeological characteristics (Slomka and Hartman, 2018; Slomka et al. 2018; Klassen and Smerdon, 2020; Hartman et al., 2023a).

From a geological perspective, there are three separate gravel deposits that sit at different elevations adjacent to the Peace River valley. From highest to lowest elevation (from west to east) these are named the Grimshaw, Old Fort, and Shaftesbury gravels. The total thickness of sediments overlying the bedrock formations, including the gravel deposits, varies from 0 to greater than 50 m (Pawley et al., 2023) with the gravel deposits having an average thickness of 30, 9, and 8 m for the Grimshaw, Old Fort, and Shaftesbury gravels, respectively (Slomka and Hartman, 2018).

From a hydrogeological perspective, the gravel deposits have long been recognized as a productive aquifer system (Tokarsky, 1971; PFRA, 1998) and are a prominent aquifer in Alberta. Figure 2 shows the generalized extent of the sediments above bedrock that would favourably host an aquifer (Hartman et al., 2023b), combined with the distribution of sediment thickness over the bedrock formations (Pawley et al., 2023). Figure 2 also shows the location of three cross sections through the study area, with the thickness of sediments over the bedrock formations and approximate extent of the gravel lobes has been plotted on Figure 3.

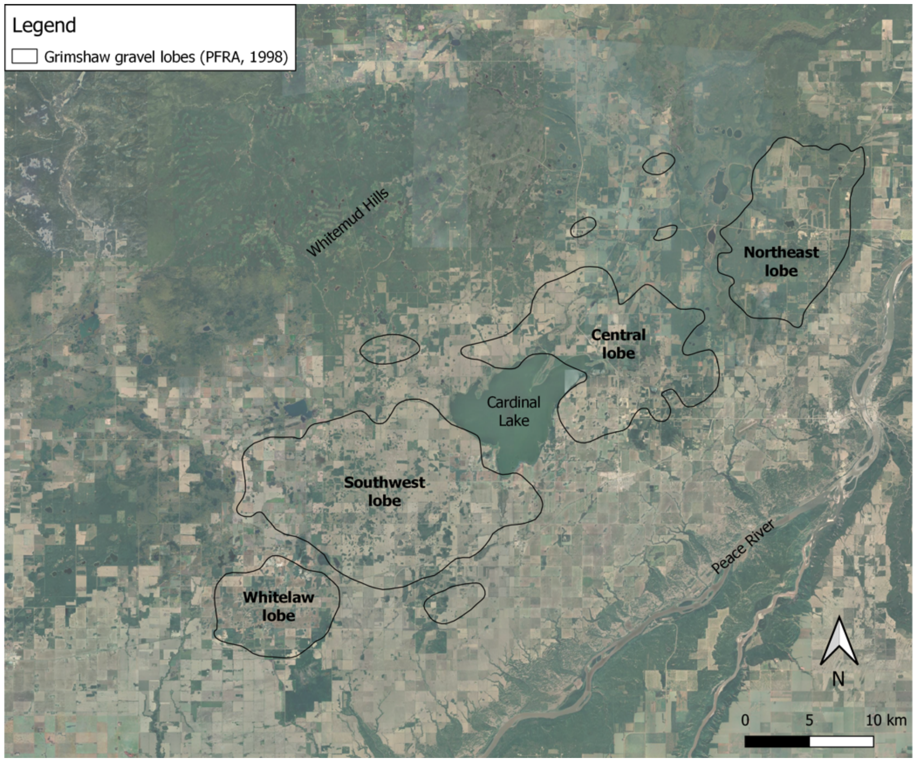

Figure 1. Grimshaw study area, including gravel lobes (PFRA, 1998).

Within the aquifer-hosting sediments (Figure 2), aquifer productivity will be spatially variable and depend on the thickness and fraction of the deposit that is gravel and coarse-grained sand compared to smaller sediments like silt and fine-grained sand. Figure 4 shows the likelihood of having coarse-grained deposits occurring within sediments above bedrock (Pawley et al., 2023). As expected, the areas with greater probability of having productive aquifers corresponds very well with the previously mapped gravel lobes.

Figure 4 also shows groundwater elevations calculated from the Alberta Water Well Information Database (AWWID; Alberta Environment and Protected Areas, 2023a) for the 2007 to 2022 period. As found previously, groundwater levels are relatively flat across the Grimshaw gravels (Klassen and Smerdon, 2020) with a gradient from the Whitemud Hills (northwest) to the Peace River valley (southeast).

Four long-term groundwater observation network wells (GOWN) operated by Alberta Environment and Protected Areas (2023b) are located in the Grimshaw area. Figure 5 shows the time series of groundwater levels for these observation wells for the 1983 to 2023 period. Generally, the groundwater levels have been relatively stable for this 40-year period and have fluctuations within a 1 m interval. Also shown on Figure 5 is the annual precipitation and snow water equivalent (SWE) from the Alberta Climate Information Service (ACIS) by Alberta Agriculture and Irrigation (2023) for the Grimshaw area. As found by Klassen and Smerdon (2020), groundwater levels appear to increase in the spring months and decrease throughout the remainder of each year. Demonstrated in Figure 5, for years that have higher precipitation and SWE, a greater increase in groundwater levels is observed (e.g., 1996 and 1997).

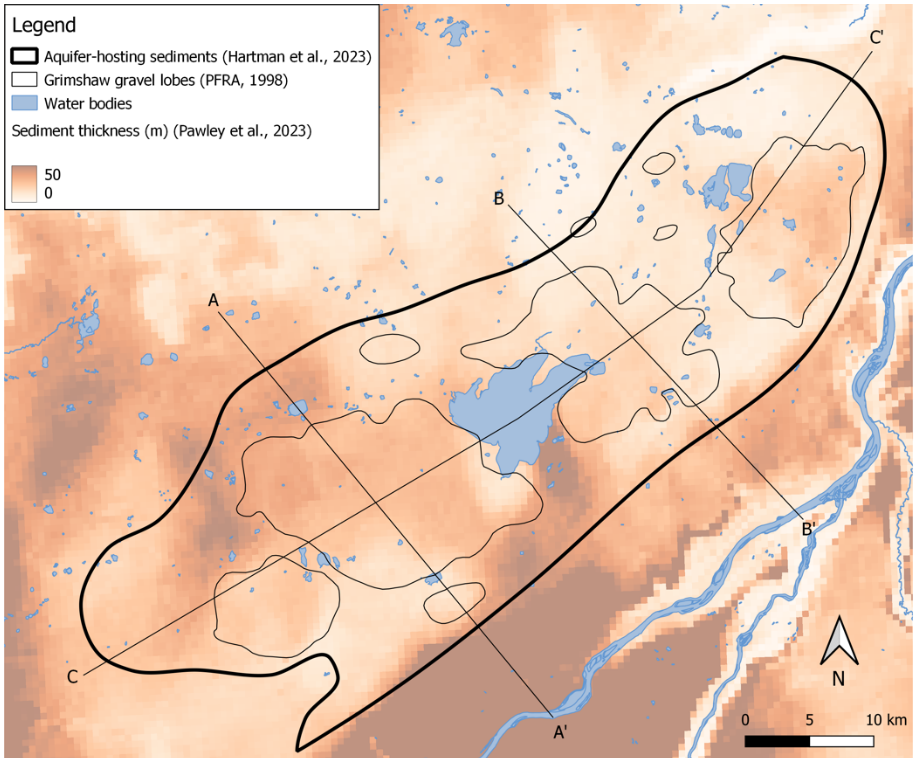

Figure 2. Distribution of sediment thickness above bedrock (Pawley et al., 2023) and locations of cross sections.

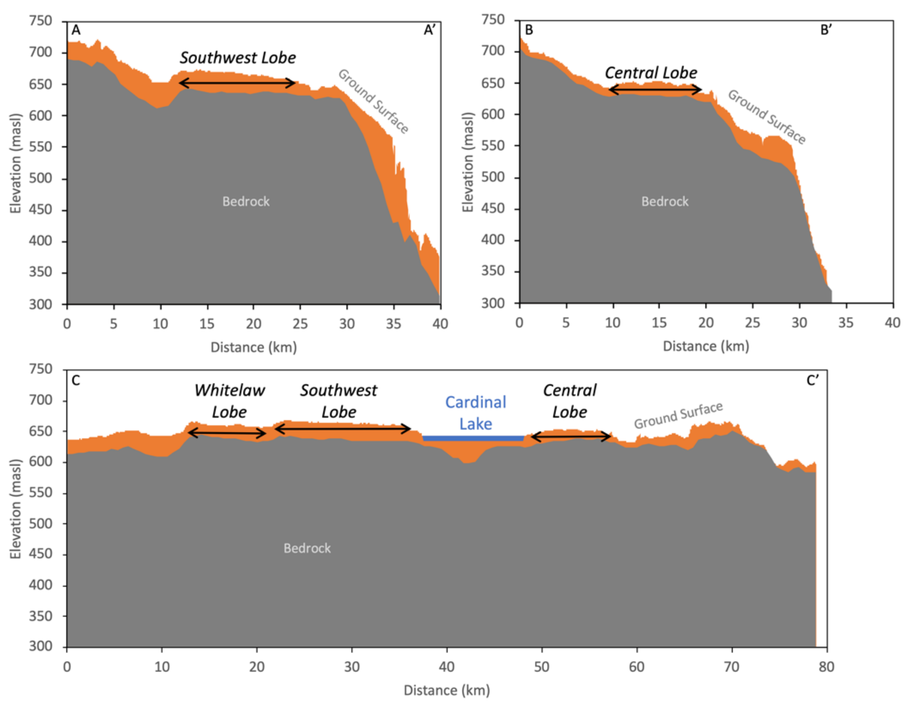

Figure 3. Cross sections illustrating sediment thickness (orange colour) from Pawley et al. (2023).

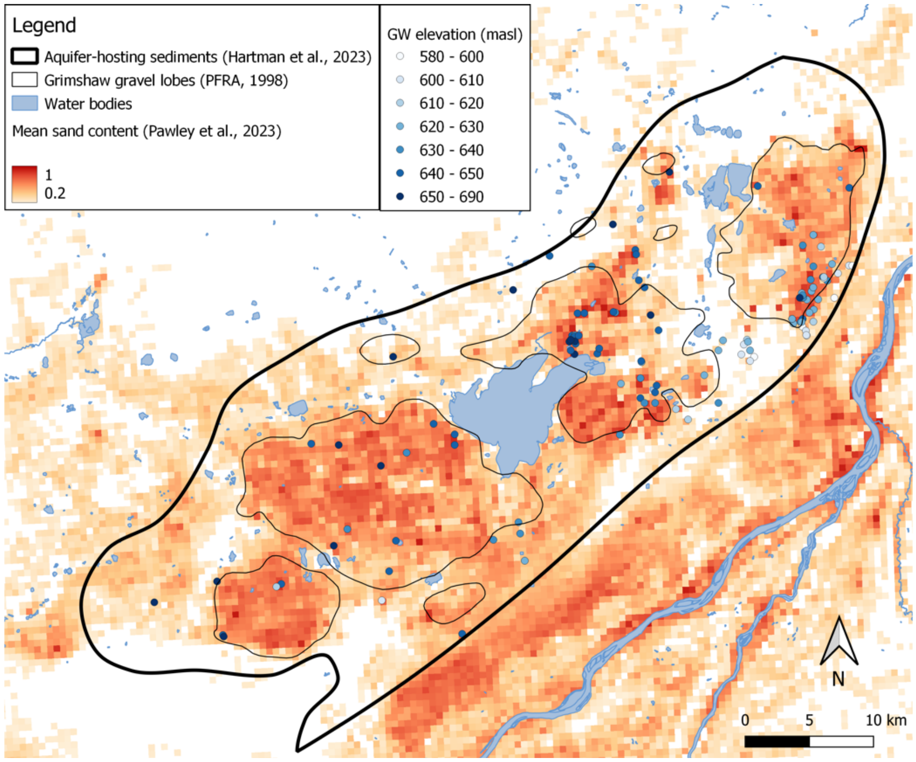

Figure 4. Likelihood of coarse-grained deposits occurring within sediments above bedrock (Pawley et al., 2023) and location of groundwater elevations recorded at water wells for the 2007 to 2022 period.

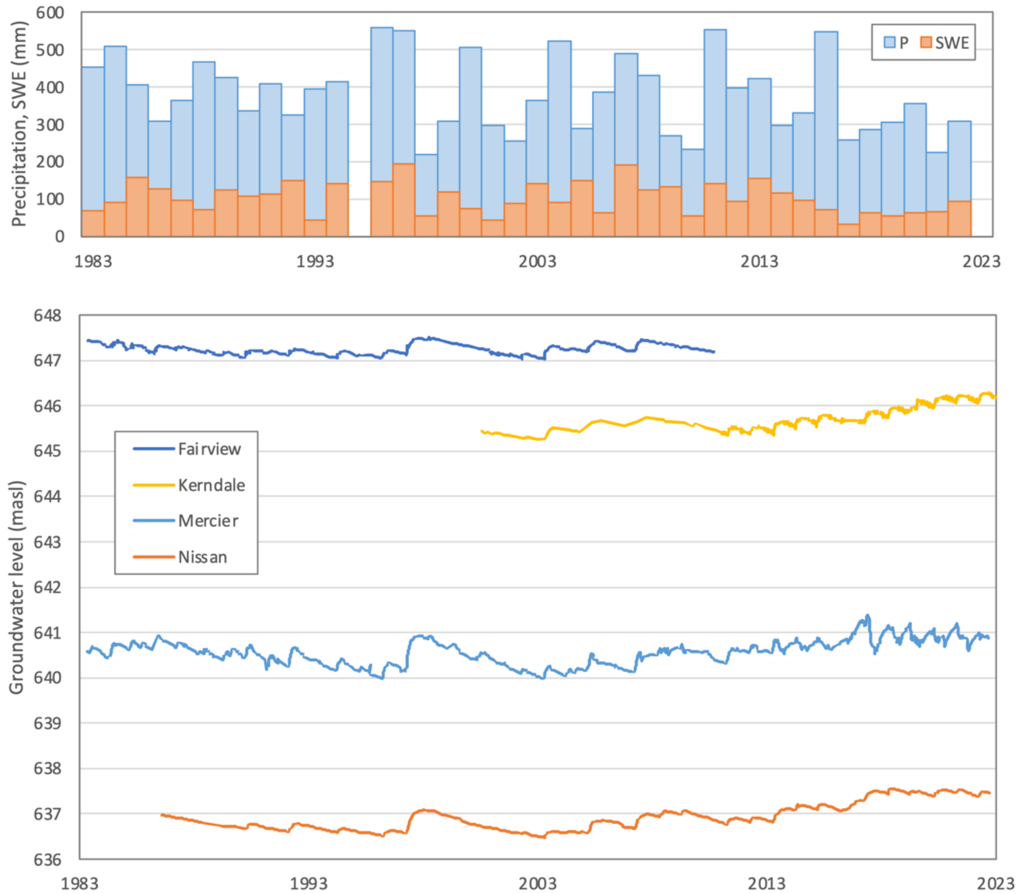

Figure 5. Annual precipitation and snow water equivalent (SWE) for the Town of Grimshaw and time-series of groundwater levels for each of the Groundwater Observation Well Network (GOWN) wells in the study area.

3 Aquifer Water Budget

A water budget for an aquifer summarizes volumetric estimates of groundwater inflows and outflows for a specified area (or aquifer volume). For the Grimshaw Gravel Aquifer, the extent of aquifer-hosting sediments (Figure 2) delineated by Hartman et al. (2023b) was used as the spatial extent for the water budget calculation and represents 1397 km^2. Inflow is only represented by groundwater recharge and assumes no groundwater movement from the adjacent bedrock formations of the Whitemud Hills. Outflow is represented by the sum of pumping from licensed water wells and unlicensed domestic water wells, and seepage occurring along the southeast margin of the Grimshaw Gravel Aquifer into the Peace River valley. A separate water budget was calculated for Cardinal Lake to estimate whether the lake is an inflow or outflow component of the aquifer water budget.

The aquifer water budget sums inflow and outflows, and results in a residual term as shown in Figure 6. Each component of the aquifer water budget is described in the following sections.

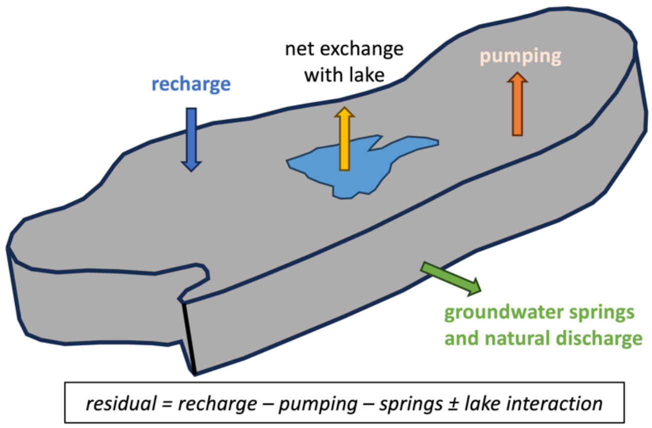

Figure 6. Aquifer water budget concept and residual calculation.

3.1 Groundwater Recharge

For the study area, two estimates of the rate of groundwater recharge have been made by the Alberta Geological Survey. Each rate (expressed in mm/yr) was calculated as a volumetric rate by considering the aquifer area shown in Figure 2.

Klassen and Liggett (2019) estimated recharge using a one-dimensional soil water balance model (Versatile Soil Moisture Budget; VSMB) that accounts for the process of depression-focused recharge (Pavlovskii et al., 2019; Noorduijn et al., 2018). For the study area, recharge was found to be 5 mm/yr using the soil water balance model. Klassen and Smerdon (2020) estimated recharge using the water table fluctuation method (Healy and Scanlon, 2010) that relies on observed seasonal increases of groundwater levels from the GOWN wells in the study area. For the 1983 to 2022 period, average recharge was found to be 18 mm/yr using the water table fluctuation method.

For the Grimshaw aquifer water budget, these two estimates provide a low (5 mm/yr) and high (18 mm/yr) value for inflow, which were considered as two water budget scenarios.

3.2 Pumping

Groundwater pumping occurs from licensed water wells and unlicensed domestic water wells located in the aquifer water budget area. Within the study area there are 721 unlicensed wells, which would each have an allocation of 1250 m^3/yr under the Water Act. For 198 locations that have a Water Act license within the study area, the consumptive allocation specified in the licence (Figure 7) was used for the water budget. To better account for actual groundwater use, rather than licensed allocation, well operation information from the MD of Fairview and MD of Peace was compared with allocation. For 2 wells operated by the MD of Fairview, approximate use was 14% and 58% of the licensed allocation. For 7 wells operated by the MD of Peace, total use compared to total licensed allocation was 51% of the licensed allocation.

For the aquifer water budget, three scenarios for pumping were considered assuming that the wells pumped 30%, 50% or 100% of the total allocation. For unlicensed wells 100% pumping was assumed to be 1250 m^3/yr and for licensed well the consumptive allocation value was used. Each pumping scenario was calculated for each of the recharge scenarios, resulting in six water budget estimates.

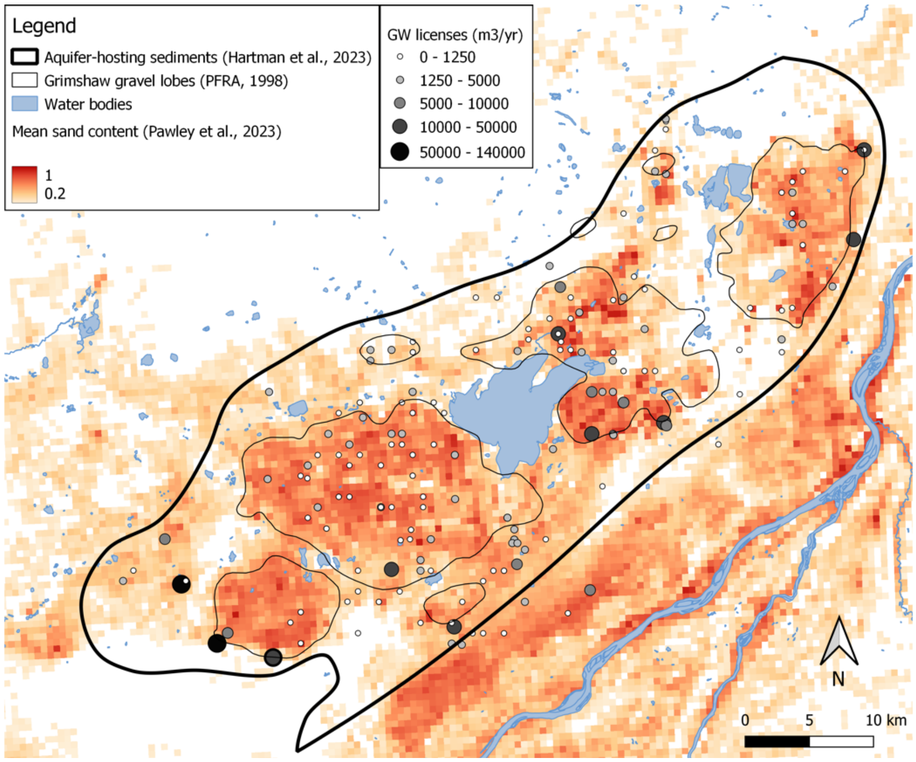

Figure 7. Distribution of water wells having a Water Act licence, shown with the coarse-grained deposits (Pawley et al., 2023).

3.3 Springs and Natural Discharge

The Grimshaw Gravel Aquifer also discharges groundwater naturally through springs and diffuse seepage along the southeast margin because of the Peace River valley. The decrease in ground surface topography associated with the valley creates a condition where the water table is located at (or above) the ground surface, which causes seepage to occur. To help quantify natural discharge, MPWA and GGAMAA mapped the location and rate of natural outflows (e.g., springs and visible seepage to creeks and wetlands) during the summer of 2022.

Spring locations were determined from a combination of searching the compilation of Alberta springs (Stewart, 2014), Google Earth imagery, and field reconnaissance by MPWA. Throughout the summer of 2022, MPWA coordinated access to private land and visited 11 springs. At each spring, the rate of groundwater discharge was measured, and a water sample was collected for analysis of major and minor ions (i.e., routine water chemistry), dissolved metals, and stable isotopes of water (^{18}O and ^{2}H).

Figure 8 shows the location of springs compared to the likelihood of coarse-grained deposits (Figure 4), with springs visited in 2022 having a unique location number. Other springs that were considered to likely exist are also shown for context; however, these have not been field-verified. Figure 8 clearly illustrates that some of the springs are located within the Grimshaw aquifer (sites 002A, 002B, 005, 020, 035, and 043) and some are located in other gravel deposits (sites 014, 015, 017, 018, 042).

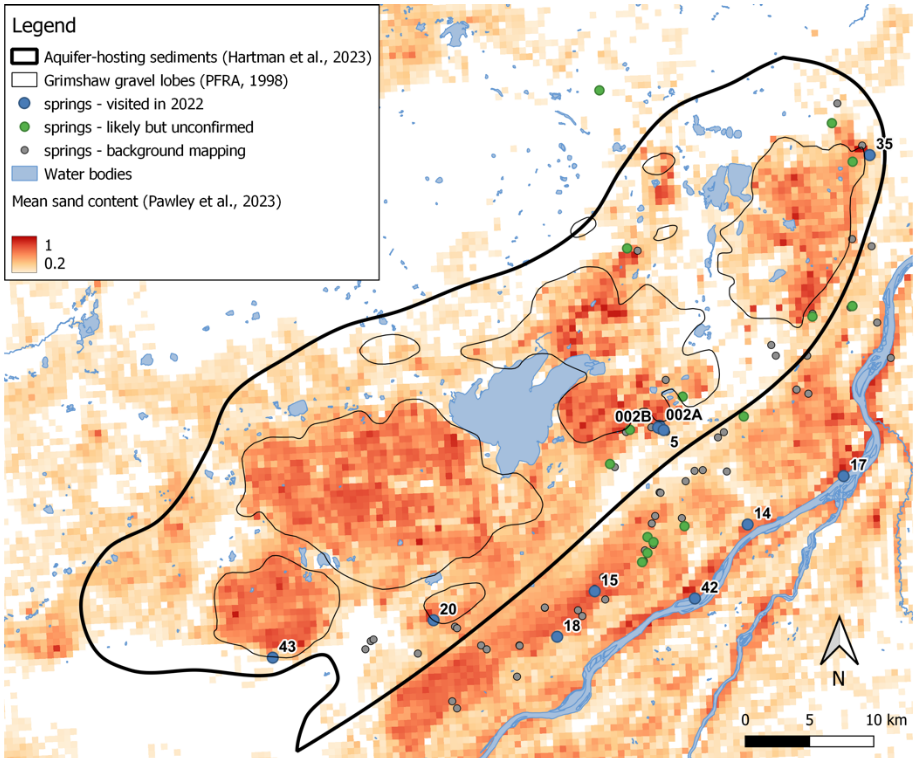

Figure 8. Distribution of springs, shown with the coarse-grained deposits (Pawley et al., 2023).

The results of chemistry and stable isotopic analysis (Figure 9) help confirm the source of water discharging at the springs. For major ions plotted on a piper diagram (Figure 9a), most of the spring water samples plot along a geochemical evolution from fresh water to more sulphate rich and appear similar to sulphate or sodium-sulphate groundwater in the study area (see Klassen and Smerdon, 2020). This result indicates that most of the spring samples have a similar chemical composition as groundwater in the Grimshaw gravel. Three of the spring water samples (sites 014, 017, 042) demonstrate a geochemical evolution toward a more sodium-rich composition, indicating that these waters are most likely sourced from bedrock formations. One spring water sample (site 035) has a composition very similar to fresh water and is likely sourced from local runoff rather than groundwater. The results of the stable isotopic analysis (Figure 9b) indicate that the spring water samples are similar to groundwater, rather than lake water.

The combination of knowing where the springs are located compared to greater likelihood of sand and gravel (Figure 8) and chemical composition (Figure 9a), help constrain the rate of natural groundwater discharge. Spring sites 002A, 002B, 005 and 043 appear to be natural discharge directly from the Grimshaw Gravel Aquifer, and have a combined discharge of 63 L/s. The spring at site 020 may also discharge from the aquifer; however, the measured rate is significantly higher than any other spring and requires further observation to confirm.

To validate the measured rate of natural discharge, a seepage estimate was made using Darcy's Law and the hydraulic gradient calculated across the southeast margin of the Grimshaw Gravel Aquifer from groundwater elevations shown on Figure 4. The horizontal hydraulic gradient varied from 0.004 to 0.023, and assuming a hydraulic conductivity of 1.7e-4 m/s, the seepage rate would be 51 L/s. This simplified calculation suggests that the observed spring discharge rate could be supported by the groundwater flow system. For the Grimshaw aquifer water budget, the observed rate of spring discharge (63 L/s) was used in the water budget.

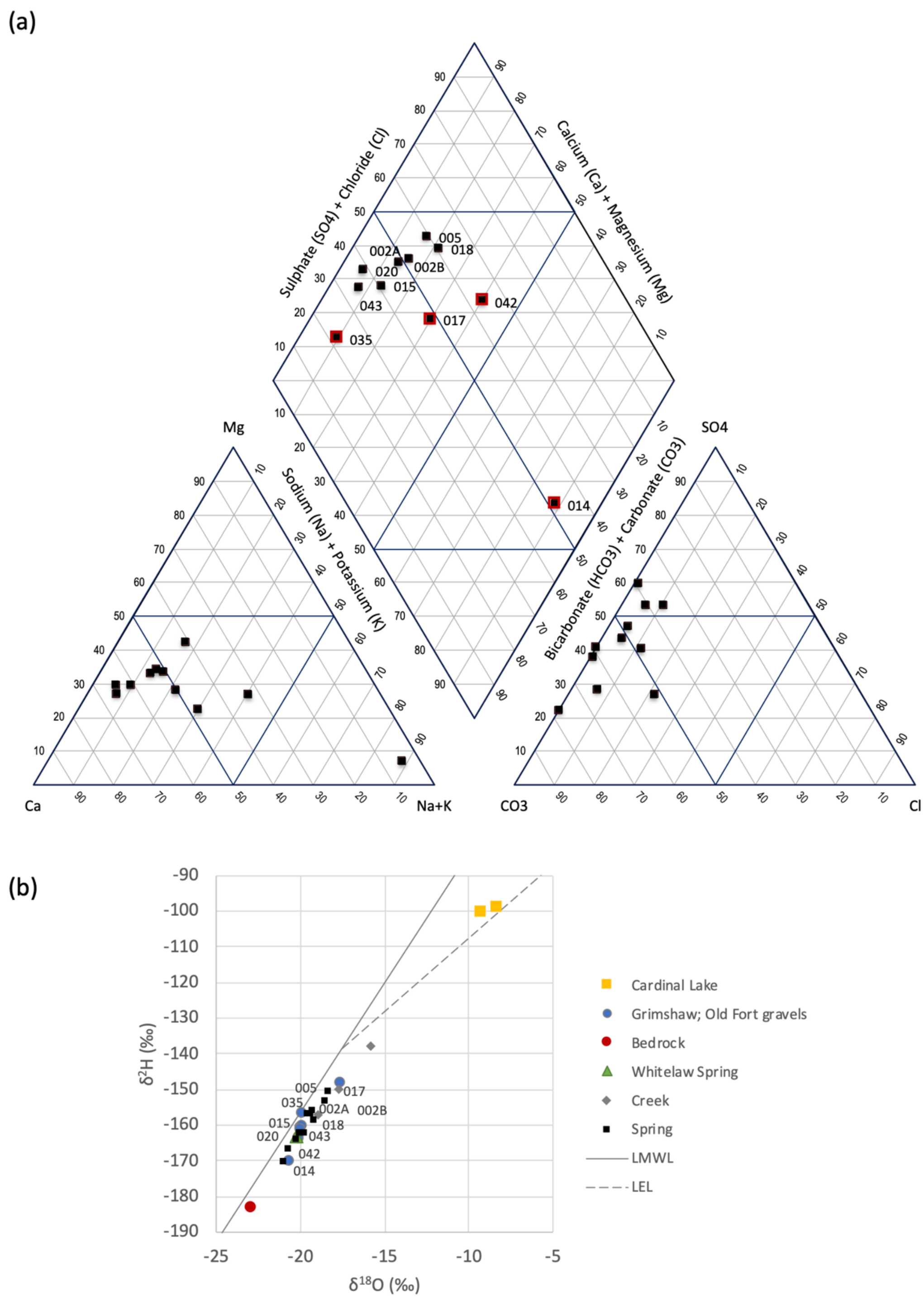

Figure 9. (a) Results of spring water analyses (black squares) illustrated on a Piper plot. (b) Results of stable isotopes of spring water (black squares) compared to sampling by Klassen and Smerdon (2020) and the local meteoric water line (LMWL) and local evaporative line (LEL).

3.4 Lake Interaction

To determine whether Cardinal Lake provides a long-term inflow or outflow for the aquifer, a similar water budget was completed. For the lake, inflows would be the sum of creek discharge and precipitation, and outflows would be creek discharge and evaporation.

Creek inflows and outflows were determined from the Alberta Flow Estimation Tool for Ungauged Watersheds (AFETUW; Alberta Environment and Protected Areas, 2023c), which provides an estimate of runoff based on watershed characteristics. For the 5 small creeks discharging into Cardinal Lake, the mean annual discharge (38 mm/yr) was estimated from AFETUW and assumed to represent inflow to the lake. Outflow from the lake (42 mm/yr) was also estimated from AFETUW following the same approach.

Mean annual precipitation (386 mm/yr) was determined from the Environment Canada weather station at Peace River, using the 1981 to 2000 climate normals. Shallow lake evaporation (607 mm/yr) was determined from the Morton method (Alberta Agriculture and Irrigation, 2013).

The basic water budget for Cardinal Lake has a residual term of -74 mm/yr, indicating that from the perspective of the lake, water is lost either to evaporation and/or groundwater recharge. For the aquifer water budget, it is assumed that 74 mm/yr would be a net outflow from the aquifer, through evaporative loss from the lake.

3.5 Water Budget

As noted earlier and shown in Figure 6, the aquifer water budget is a sum of inflow and outflows, and results in a residual term. With two recharge scenarios and three pumping scenarios (based on fraction of total allocation), six water budget calculations were made.

Figure 10 shows the aquifer water budget for the lower recharge value of 5 mm/yr. For the different pumping scenarios, the water budget residual is 0.3, 0.2, and -0.6 mm/yr. These results suggest that for the low recharge scenario, the aquifer water budget is neutral (i.e., residual close to 0). This finding indicates that groundwater recharge is similar to the sum of outflows for the long-term. For a higher recharge value (Figure 11), the water budget residual are 12.5, 12.2, and 11.5 mm/yr for the different pumping scenarios. These results suggest for the high recharge scenario, the aquifer water budget is net positive (i.e., residual greater than 0), and indicate that groundwater recharge is greater than the sum of outflows.

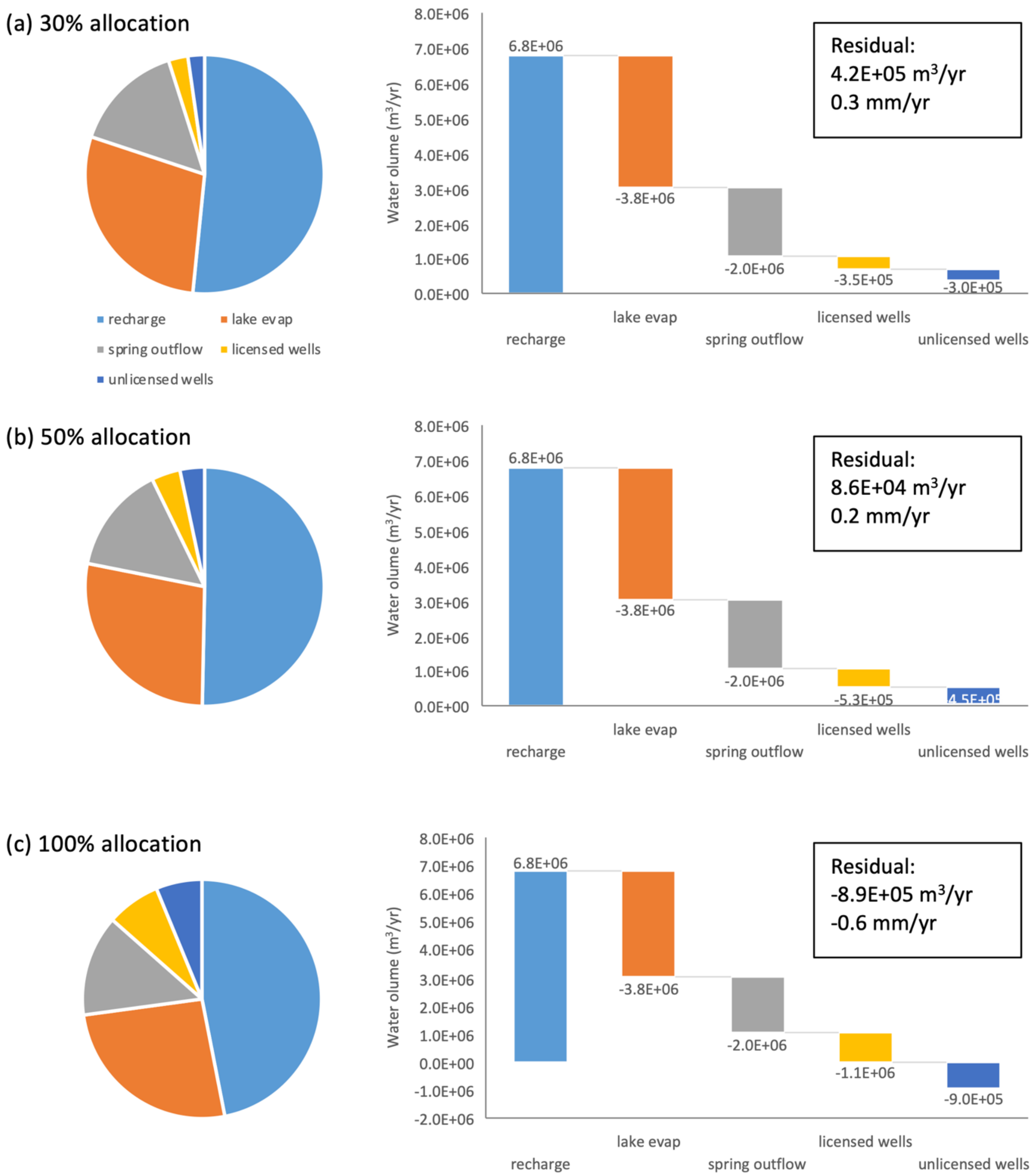

Figure 10. Grimshaw aquifer water budget for the lower recharge value of 5 mm/yr.

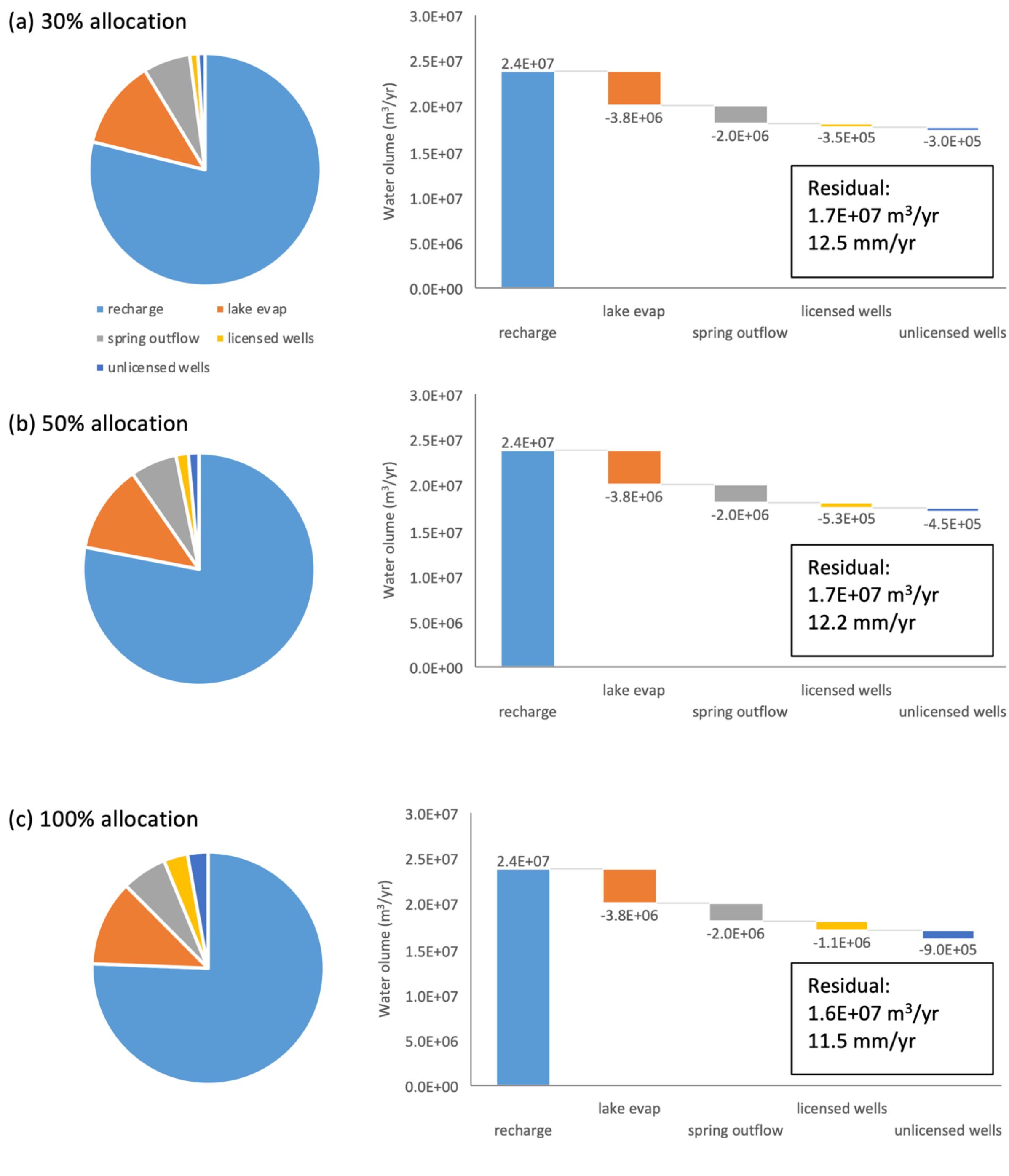

Figure 11. Grimshaw aquifer water budget for the higher recharge value of 18 mm/yr.

4 Groundwater Models

Two separate steady-state groundwater models were developed to integrate the hydrogeological parameters of the physical environment (e.g., recharge rate, transmissivity of the aquifer) with groundwater discharge. Each model was developed using the MODFLOW-2005 code (Harbaugh et al., 2017). Conceptually, as described above, groundwater discharge includes pumping, flow to springs and seepage areas, and interaction with Cardinal Lake. The first groundwater model included a realistic geometry with highly variable layer thicknesses to represent the variation in sediment thickness above bedrock (Figure 2). Challenging model convergence led to creating a second groundwater model with a simplified geometry to investigate scenarios.

4.1 Real-world Geometry

The real-world model domain corresponded to the extent of aquifer-hosting sediments (Figure 2), with some refinement along the south and southeast margins where the groundwater surface decreases into the Peace River valley. The model used a finite-difference discretization scheme with a grid spacing of 250 m in the horizontal dimensions and variable grid thickness in the vertical dimension. The elevation of the top of the model was defined by a 25 m DEM (Alberta Environment and Parks, 2017) and the top of the bedrock surface was defined by Pawley et al. (2023). The uppermost two model layers represent the sediments above bedrock and were of the same thickness at any given location; however, they varied in thickness across the model domain depending on the depth to bedrock. The third model layer represents the bedrock formations as a single unit.

Boundary conditions consisted of no-flow, specified flux, lake, specified head, drains, and wells. No-flow boundaries are applied along the lateral model boundary and the base of the model. Across the top of the model, specified fluxes were applied as recharge corresponding to the 18 mm/yr rate (Klassen and Smerdon, 2020) for most of the area, with a slightly lower rate of 12 mm/yr applied where surficial sediments were not sand or gravel to better represent sediments having a lower hydraulic conductivity. Cardinal Lake was represented using the lake boundary condition. Smaller ponds were represented by specified heads equivalent to the approximate elevation of the pond as determined from the DEM. To represent groundwater springs and seepage along the southeast margin of the aquifer system, which would supply small creeks and wetlands, a drain boundary condition was defined along segments of the southeast margin. Where the modelled water table reached the ground surface elevation, the drain boundary condition would allow discharge to occur. Pumping wells were implemented into layer 2 (the lower portion of the aquifer) for the 198 locations having water act licenses. The pumping rates were specified so that the total withdrawal was 30% of the allocation including both the licensed and unlicensed wells. Using this approach, each unlicensed well was not explicitly defined, but rather the influence of pumping was added to the locations where licensed wells existed.

Three hydrostratigraphic units were considered:

- Sediments above bedrock corresponding to the gravel lobes, where the likelihood of having coarse-grained deposits was high (Figure 2; Pawley et al., 2023). Horizontal and vertical hydraulic conductivity were assumed to be 25 m/d and 0.25 m/d, respectively.
- Sediments above bedrock that were not within the gravel lobes. Horizontal and vertical hydraulic conductivity were assumed to be 5 m/d and 0.05 m/d, respectively.
- Bedrock formations, grouped as a single unit within the real-world model. Horizontal and vertical hydraulic conductivity were assumed to be 0.05 m/d and 0.005 m/d, respectively.

Each hydrostratigraphic unit was assigned a hydraulic conductivity value that were adjusted slightly during calibration. Calibration was done by visually inspecting groundwater levels (GOWN and AWWID records shown in Figure 2) and adjusting the hydraulic conductivity to achieve the lowest residuals across the range of data.

For 70 observation points, the root mean squared error (RMSE) was 6 m (Figure 12). The distribution of modelled groundwater levels at steady state (Figure 13) were highest near elevated areas along the northwest margin associated with the Whitemud Hills and lowest along the southeast margin where the Peace River valley is located. Across the study area, the modelled groundwater levels were relatively level with a gentle gradient from northwest to southeast. The presence of Cardinal Lake is evident in the modelled groundwater elevations, indicating that groundwater discharges to the lake around most of the lake perimeter, except for the southeast shoreline where the lake supplies water to the aquifer. The lake boundary condition found that the lake received more groundwater inflow than was flowing from the lake toward the groundwater, and that lake evaporation maintains the lake level.

To evaluate the influence of pumping, the model was run without any pumping and the difference in groundwater levels were plotted to illustrate drawdown, or groundwater level decline, caused by pumping (Figure 14). For most of the study area the difference was less than 0.25 m, with between 0.25 and about 0.5 m difference occurring in the vicinity of Cardinal Lake and in the area associated with the Whitelaw lobe. Figure 14 depicts greater drawdown where some of the greater water allocations are located, which may have decreased groundwater levels by a few meters locally around the pumping wells (blue colours on Figure 14).

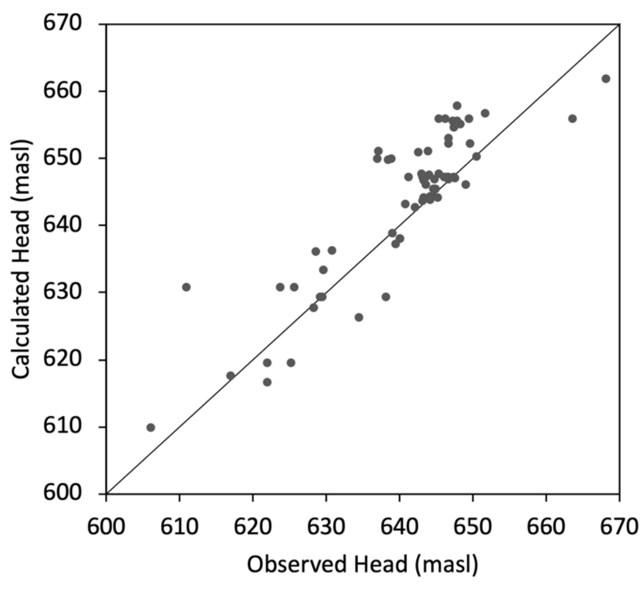

Figure 12. Calculated versus observed groundwater level for 70 water wells in the study area.

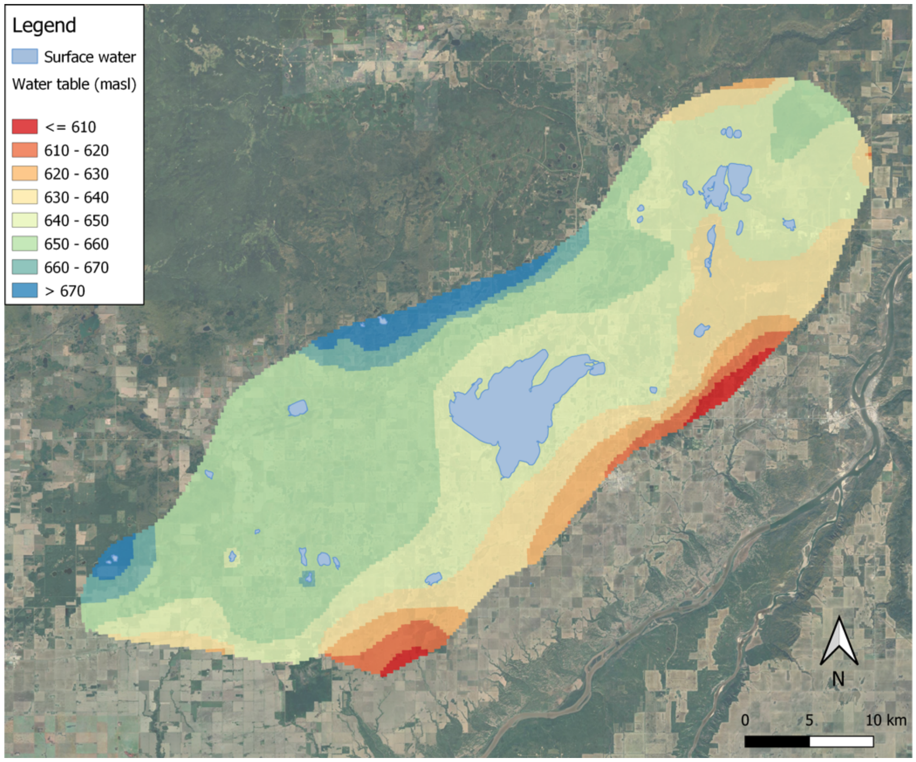

Figure 13. Distribution of modelled groundwater levels for the real-world model.

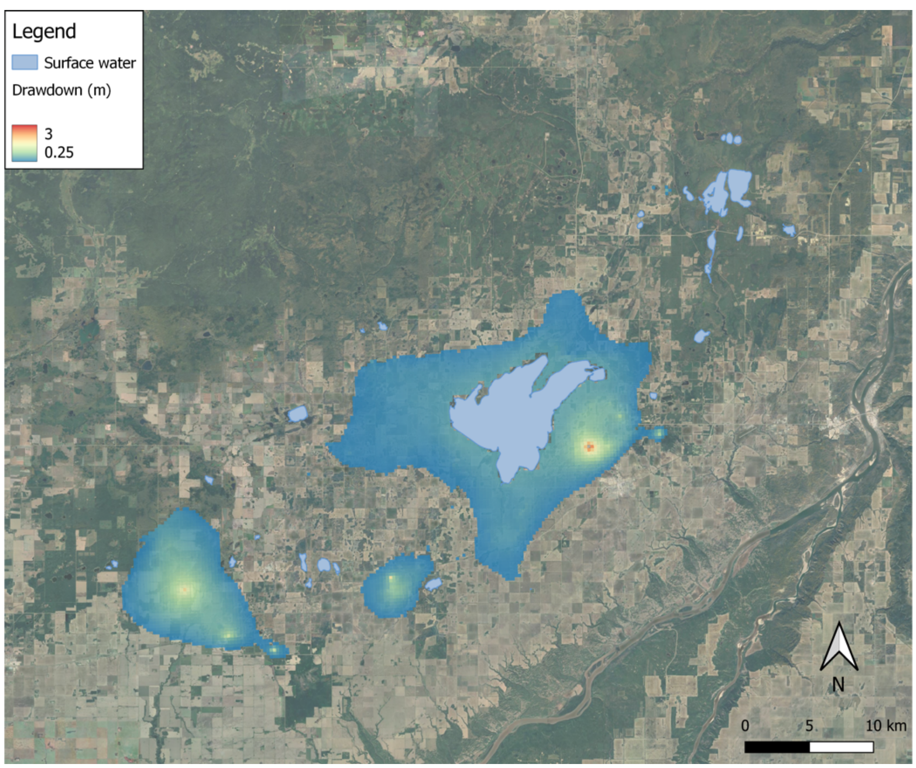

Figure 14. Distribution of groundwater level decline (drawdown) modelled for pumping at 30% of total allocation.

4.2 Simple Geometry

To reduce the complexity of highly variable layer thicknesses, which led to challenging model convergence, a simple model domain with uniform layer thickness was created to investigate alternative groundwater recharge rates, hydraulic conductivity, and pumping scenarios. The simple geometry model domain was a 45 km long and 18 km wide rectangular area that included the Central, Southwest, and Whitelaw lobes of the Grimshaw aquifer. The model had a grid spacing of 50 m in the horizontal dimensions and two flat model layers of 10 m thickness in the vertical dimension to represent 20 m aquifer thickness.

Boundary conditions and model parameters were nearly the same as the real-world model. Boundary conditions consisted of no-flow along the lateral model boundary and the base of the model, specified flux across the top of the model to represent recharge, drains along the southeast margin to represent groundwater springs and seepage, and the same distribution of wells. Cardinal Lake was represented as a specified head rather than using the lake boundary condition to maintain the same lake level for alternative model scenarios.

Using the simple model, a base case replicated the same set-up as the real-world geometry. For the base case conditions, four pumping scenarios were modelled as described in Table 1. Three other cases were created to investigate the influence of: (i) a lower recharge rate of 5 mm/yr, equivalent to the lower recharge rate used in the aquifer water budget; (ii) a lower hydraulic conductivity for the aquifer, which would enhance the effect of drawdown caused by pumping; and (iii) the combination of a lower recharge rate and lower hydraulic conductivity. For each case, 2 pumping rates were modelled that represent 50% and 100% of the allocation within the aquifer. Because the simple model used the same boundary conditions and parameters as the real-world model, it was not calibrated using groundwater observations, but rather used to investigate potential changes in groundwater levels under different scenarios.

Table 1. Summary of model cases (columns) and pumping scenarios (rows). Each is identified with a unique code (e.g., B.50) that is used in subsequent figures.

Base case	Lower groundwater recharge rate	Lower aquifer hydraulic conductivity	Lower recharge and hydraulic conductivity
B.50: Pumping rate is 50% of the total allocation	LowR.50: Pumping rate is 50% of the total allocation	LowK.50: Pumping rate is 50% of the total allocation	LowR.K.50: Pumping rate is 50% of the total allocation
B.100: Pumping rate is 100% of the total allocation	LowR.100: Pumping rate is 100% of the total allocation	LowK.100: Pumping rate is 100% of the total allocation	LowR.K.100: Pumping rate is 100% of the total allocation
B.50+1well: Pumping rate is 50% of the total allocation, plus a single well at 300 m^3/d in the Town of Grimshaw			
B.50+6wells: Pumping rate is 50% of the total allocation, plus 2 groups of 3 wells at 50 m^3/d (Southwest and Central gravel lobes)			

To evaluate the potential effect of each scenario, the change in groundwater level was relative to the non-pumping scenario in each case. Thus, each case identified in Table 1 (base case, lower recharge, etc.) would have a corresponding non-pumping scenario. This approach allows comparison between each scenario within a case, and between different cases. The comparative evaluation considered two metrics: (i) mean groundwater decline compared to non-pumping (i.e., drawdown reported in meters) and (ii) the net interaction with Cardinal Lake. Because the lake was maintained at a constant elevation, the interaction with the lake would vary between scenarios and cases, which informs potential change to this groundwater-dependent feature in the Grimshaw area.

Figure 15 shows the spatial results for the base case. For 50% and 100% allocation, the mean drawdown is 0.8 and 1.4 m, respectively (Figures 15a and 15b). In both scenarios, the drawdown is skewed to the west side of Cardinal Lake where groundwater recharge is assumed to be slightly less because of the presence of some surficial sediments with lower hydraulic conductivity. West of Cardinal Lake, the effect of pumping 50% of the total groundwater allocation would be a groundwater level decline of about 1 m compared to no pumping, or about 2 m decline for 100% allocation. However, in the vicinity of the Town of Grimshaw (east of Cardinal Lake), groundwater level decline is about 0.25 m for both the 50% and 100% allocation scenarios. The relative consistency of groundwater level decline east of the lake may be explained by an associated change in the net interaction with the lake (Figure 16). For the base case with groundwater pumping at 100% of the allocation, there is a slight decrease in groundwater discharge to lake compared to pumping at 50% of the allocation.

Figure 15 also shows the results for the base case when two alternative pumping scenarios are considered for the 50% allocation (Figure 15c and 15d). One scenario is an additional single well in the Town of Grimshaw having a pumping rate equivalent to the Town of Grimshaw (300 m3/d). The second scenario is a group of three wells in the Central lobe and group of three wells the Southwest lobe having a pumping rate of 50 m3/d each. As shown in Figure 15, these additional groundwater withdrawals would increase drawdown by about 0.01 m. Groundwater withdrawal from an additional single well in the Town of Grimshaw would also have a localized drawdown close to the well location. These two alternative pumping scenarios are not expected to change groundwater interaction with Cardinal Lake compared to the 50% allocation scenario (Figure 16).

Figure 16 also shows the mean groundwater decline for the cases where lower recharge and/or lower aquifer hydraulic conductivity were considered. The results for lower recharge or lower hydraulic conductivity were similar in terms of mean groundwater decline, which was 1.2 m for pumping at 50% of allocation and 2 m for pumping at 100% of allocation. However, for each of these cases, net interaction with Cardinal Lake was different. For the case of lower recharge, the distribution of groundwater levels around the lake were altered enough to reverse the interaction, whereby the lake became a source of recharge for the aquifer. For the case of lower hydraulic conductivity, groundwater discharge to the lake was enhanced compared to the base case. For the combination of lower recharge and lower hydraulic conductivity, mean groundwater decline was 2.1 m for pumping at 50% of allocation and 3.6 m for pumping at 100% of allocation. The combined case (lower recharge and hydraulic conductivity) also caused the lake to become a source of groundwater recharge, but to a lesser degree than the case with lower groundwater recharge.

The simple geometry model indicates that compared to non-pumping, typical scenarios of the base case pumping would not result in significantly different groundwater conditions and the exchange of groundwater with Cardinal Lake. If alternative recharge and/or lower aquifer hydraulic conductivity conditions exist, the effect of both groundwater decline and interaction with the lake are expected to change.

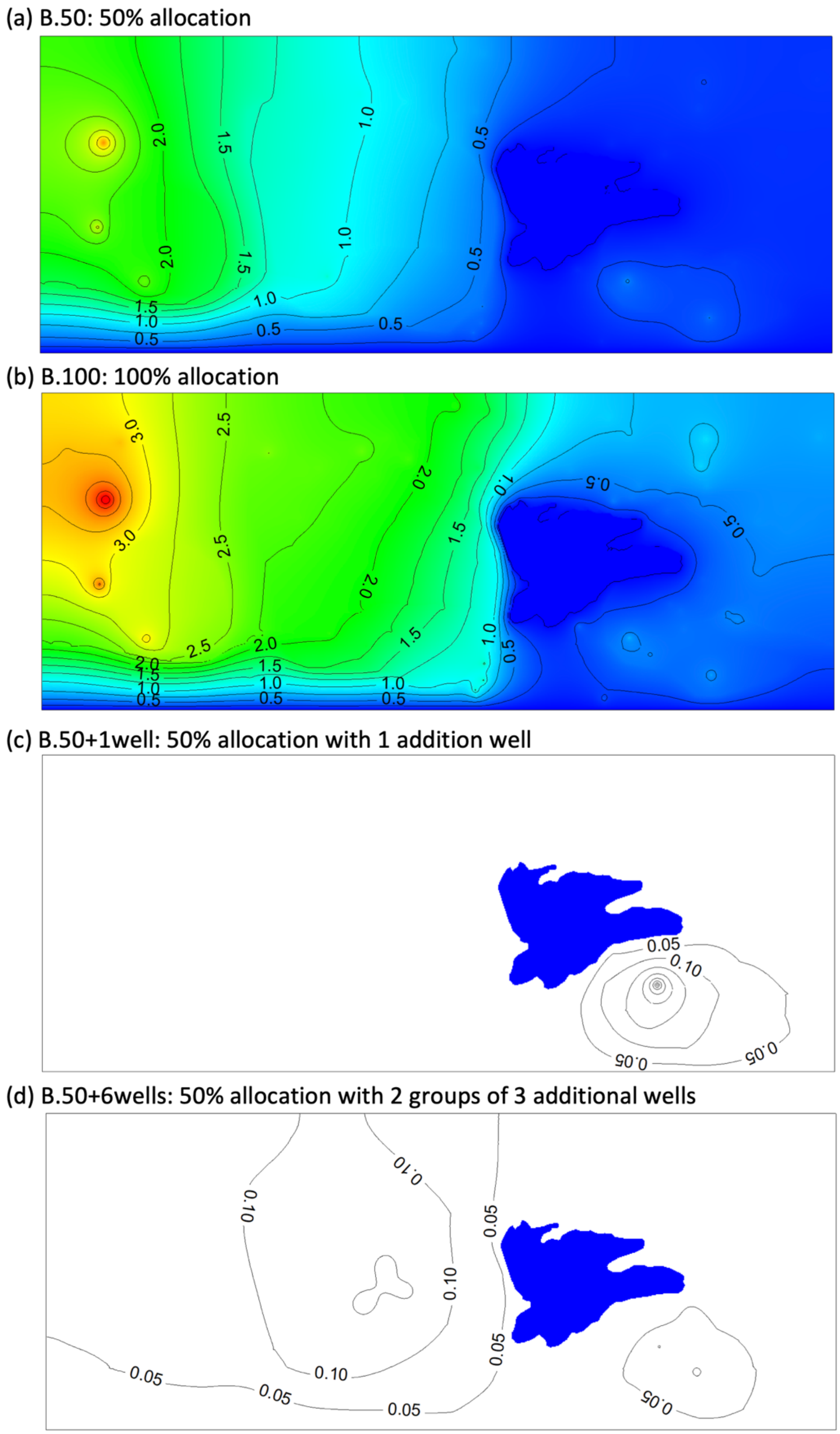

Figure 15. Distribution of groundwater level decline (drawdown) for (a) 50% allocation and (b) 100% allocation. Addition decline in groundwater level for (c) 1 additional well and (d) 2 groups of 3 wells compared to 50% allocation shown in (a).

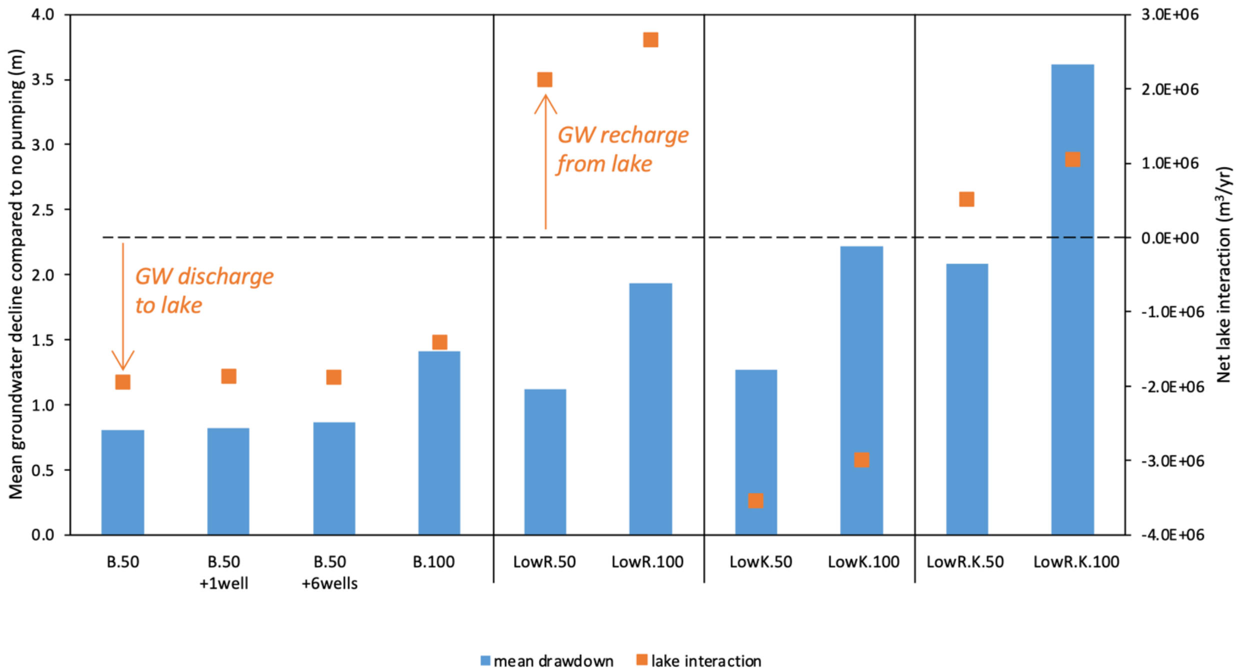

Figure 16. Summary of groundwater level decline and net interaction with Cardinal Lake for the difference cases and pumping scenarios identified in Table 1.

5 Findings and Recommendations

Investigation of the Grimshaw aquifer, through volumetric water budget calculations and the modelled response to various pumping scenarios, has resulted in the following key findings:

1. Based on the most up to date knowledge of groundwater inflows and outflow, the aquifer water budget is neutral to net positive. This result indicates that a decline in groundwater level is not expected for current and typical pumping scenarios.
2. From the long-term perspective, groundwater discharges to Cardinal Lake at a greater rate than lake water seeping into groundwater. This result indicates that the lake loses water through evaporation during summer months and is maintained by a combination of creek inflows, precipitation, and groundwater.
3. A greater concentration of water wells, and most water wells having a Water Act license appear to be in the parts of the aquifer that have a higher likelihood of coarse-grained deposits occurring within sediments above bedrock. This result indicates that groundwater users typically withdraw water from the more permeable parts of the aquifer system (i.e., the gravel lobes).
4. Groundwater modelling demonstrates that greater pumping is not expected to greatly decrease groundwater levels. This result indicates that the combination of current groundwater recharge and aquifer hydraulic conductivity are sufficient to support groundwater users, and that the Grimshaw aquifer system has some resilience.
5. Long-term monitoring demonstrates that groundwater levels have been relatively stable for 40 years (1983 to 2023). This result confirms that groundwater level decline has not occurred for current pumping.
6. Compared to the volume of licensed allocation, the actual amount of water use is uncertain. It is assumed that groundwater users with larger allocations likely have some knowledge of use.

The technical work completed in this project demonstrates that the combination of groundwater monitoring (i.e., GOWN) and modelling could inform establishing management actions, such as setting trigger levels. Recommendations to support cumulative effects management include:

1. Continued real-time monitoring of groundwater levels through the GOWN. The existing GOWN wells appear to be well-positioned compared to pumping locations and would be an integral part of establishing management actions.
2. Establish stage/level monitoring of Cardinal Lake. The position of the lake within the aquifer system and as a significant hydrologic entity in the region justify additional monitoring.
3. Establish a community-led initiative to better define groundwater use compared to licensed allocation for key groundwater users.
4. With new information, especially groundwater use estimates, develop a time-varying (transient) model to investigate the response of GOWN wells to pumping scenarios.

6 References

Alberta Agriculture and Irrigation (2013): Alberta Climate Information Service – Morton Evaporation; https://acis.alberta.ca/acis/docs/mortons/mortons-evaporation-facts.pdf

Alberta Agriculture and Irrigation (2023): Alberta Climate Information Service; https://acis.alberta.ca/

Alberta Environment and Protected Areas (2023a): Alberta Water Well Information Database; https://www.alberta.ca/alberta-water-well-information-database-overview.aspx

Alberta Environment and Protected Areas (2023b): Groundwater Observation Well Network; https://www.alberta.ca/lookup/groundwater-observation-well-network.aspx

Alberta Environment and Protected Areas (2023c): Alberta Flow Estimation Tool for Ungauged Watersheds (AFETUW) v. 2.0; https://afetuw.alberta.ca/

Grimshaw Gravels Aquifer Management Advisory Association (GGAMAA; 2019): Grimshaw Gravels Aquifer Source Water Protection Plan; 59p.

Harbaugh, A.W., Langevin, C.D., Hughes, J.D., Niswonger, R.N., and Konikow, L.F. (2017): MODFLOW-2005, the U.S. Geological Survey modular groundwater model: U.S. Geological Survey Software Release (Version 1.12.00), U.S. Geological Survey, http://dx.doi.org/10.5066/F7RF5S7G

Hartman, G.M.D., Pawley, S.M., Utting, D.J., Atkinson, N., and Liggett, J.E. (2023a): The Empress Group in Alberta, Canada. Canadian Journal of Earth Sciences. e-First, https://doi.org/10.1139/cjes-2022-0143

Hartman, G.M.D., Pawley, S.M., Liggett, J.E., Atkinson, N., and Utting, D.J. (2023b): Distribution of aquifer-hosting sediments above bedrock in Alberta; Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Map 632, scale 1:3 000 000. https://ags.aer.ca/publication/map-632

Healy, R. and Scanlon, B. (2010): Estimating groundwater recharge. Cambridge University Press, Cambridge, United Kingdom, 245 p. https://doi.org/10.1017/CBO9780511780745

Klassen, J. and Liggett, J.E. (2019): First-order groundwater availability assessment for the upper Peace region; Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Open File Report 2019-10, 28 p. https://ags.aer.ca/publication/ofr-2019-10

Klassen, J. and Smerdon, B.D. (2020): Hydrogeological characterization of the Grimshaw Area, northwestern Alberta; Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Open File Report 2019-11, 27 p. https://ags.aer.ca/publication/ofr-2019-11

Mighty Peace Watershed Alliance (MPWA; 2018): Integrated Watershed Management Plan, Peace and Slave Watersheds; 59p.

Noorduijn, S., Hayashi, M., Mohammed, G., and Mohammed A. (2018): A coupled soil water balance model for simulating depression-focused groundwater recharge; Vadose Zone Journal 17:170176, https://doi.org/10.2136/vzj2017.10.0176

Pavlovskii, I., Noorduijn, S., Liggett, J.E., Klassen, J., and Hayashi, M (2019): Quantifying terrain controls on runoff retention and routing in the Northern Prairies; Hydrological Processes 34: 473–484, https://doi.org/10.1002/hyp.13599

Pawley, S.M., Utting, D.J., Hartman, G., and Liggett, J.E. (2023): Thickness of sediments above bedrock and three-dimensional distribution of coarse-grained deposits in Alberta (gridded data, GeoTIFF format); Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Digital Data 2023-0014. https://ags.aer.ca/publication/dig-2023-0014

Prairie Farm Rehabilitation Administration (PFRA) (1998): Proposed community-focused management strategy for the Grimshaw Gravels Aquifer; Agriculture and Agri-Food Canada, technical report, 44 p. https://mdpeace.com/wp-content/uploads/2014/04/Grimshaw-Gravels-Aquifer-Tech-Report-1998-part-1.pdf

Slomka, J.M., and Hartman, G.M.D. (2019): Sedimentary architecture of a glaciolacustrine braidplain delta: proxy evidence of a pre-Middle Wisconsinan glaciation (Grimshaw gravels, Interior Plains, Canada). Boreas, 48: 215–235, https://doi.org/10.1111/bor.12355

Slomka, J.M., Hartman, G. and Klassen, J. (2018): Architecture and geometry of basal sand and gravel deposits including the 'Grimshaw gravels', northwestern Alberta (NTS 84C and 84D); Alberta Energy Regulator, AER/AGS Open File Report 2018-04, 44 p. https://ags.aer.ca/publications/OFR_2018_04.html

Stewart, S.A. (2014): Alberta Springs Compilation (tabular data, tab-delimited format); Alberta Energy Regulator, AER/AGS Digital Data 2014-0025. https://ags.aer.ca/publication/dig-2014-0025

Tokarsky, O. (1971): Hydrogeology of the Grimshaw–Chinook Valley area, Alberta; Research Council of Alberta, RCA/AGS Earth Sciences Report 1971-02, 22 p. http://ags.aer.ca/publications/ESR_1971_02.html