Modelling the Disposal of Highly Saline Wastewater in the Paddy and Cadotte Members, Northeastern British Columbia (NTS 093P)

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Introduction

The drilling and hydraulic fracturing of wells and subsequent hydrocarbon production often generates highly saline wastewater (Goss et al., 2015), with total dissolved solids (TDS) in excess of the typical value for seawater of 35 000 mg/L. The cumulative amount of wastewater produced from hydraulic fracturing is increasing rapidly with the steady appearance of new wells and a trend toward more water use per well (Alessi et al., 2017). In northeastern British Columbia (NEBC), an average of 75 m^3 of wastewater is generated for every million cubic metres of gas produced from the Montney play (IHS Energy, 2016), the most productive gas play in the province (BC Oil and Gas Commission, 2015). Although reuse and recycling is employed where practicable, ultimately large quantities of wastewater must be disposed of and the most viable method of disposal is injection into deep, permeable geological formations.

Disposal well operations in BC are regulated by the BC Oil and Gas Commission (BCOGC). Formations considered appropriate for hosting wastewater disposal are of high permeability (most commonly deep saline units or depleted hydrocarbon reservoirs) relative to confining layers (typically shale units) above and below them (BC Oil and Gas Commission, 2016). These confining layers have been demonstrated to be effective at limiting the vertical migration of groundwater (Hendry et al., 2013), and serve to restrict wastewater to the targeted disposal formation. Companies seeking approval for a disposal well must demonstrate that the confining layers are free of any preferential pathways (faults, fractures, abandoned and/or improperly cemented boreholes) by which wastewater could travel upward and contaminate shallower, potentially potable, groundwater. Additionally, the BCOGC restricts disposal formations to units that contain “deep groundwater” as defined in the BC *Water Sustainability Act* (Government of British Columbia, 2017), which begins 300–600 m below ground surface depending on local geology.

Throughout the life of a disposal well, certain pressure conditions must be met (BC Oil and Gas Commission, 2016). Firstly, the injection pressure at the wellhead should not exceed 90% of the formation fracture pressure, in order to avoid unintentionally fracturing the formation. Secondly, disposal well operations cannot increase the formation pressure beyond 120% of the initial virgin reservoir pressure (IVRP), that is, the pressure in the formation prior to any production or disposal. These pressure requirements increase confidence that wastewater is contained within the disposal formation, but also limit both the amount of wastewater that can be stored in a formation and the rate at which it can be injected.

This paper presents a numerical modelling study that investigates modifications to the formation/reservoir pressure at a disposal well in a deep formation as a result of wastewater disposal. This model will provide insights into factors that influence the potential for disposal well operations to exceed the required limit of 120% of IVRP in the Paddy and Cadotte members, NEBC. This study does not consider the fracture pressure requirement or aspects of potential well interference. Model parameterization is based on the Paddy and Cadotte members (see below), which have only recently (within the last five years) become a target for wastewater disposal. Previous work (Simons et al., 2017) used the same model to investigate the structure and extent of wastewater plumes created via disposal, but this paper focuses solely on disposal pressures and formation and fluid characteristics that have the potential to influence a wastewater plume. Simulated modelled pressures are compared to the IVRP to understand what factors can lead to formation pressures surpassing the 120% of IVRP limit imposed by the BCOGC. The models are not calibrated against pressure data, and thus cannot be used to make site-

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specific predictions. Instead, they provide insight as to the relative pressure changes in a formation as a response to varying formation and disposal characteristics. This is accomplished through a sensitivity analysis performed on a defined base case model to assess the influence of disposal rate, wastewater salinity, and formation permeability and thickness on reservoir pressures. The results are unconstrained due to the uncertainty in the outflow boundary condition. As such, an additional sensitivity analysis was conducted to evaluate the effect of different outflow boundary conditions on reservoir pressure buildup.

Disposal and Water Source Well Operations in the Paddy and Cadotte Members

To frame the relevance of this study, an overview is given of disposal and water source well operations targeting the Paddy and Cadotte members in NEBC. At present, disposal wells and water extraction/source wells in the Paddy and Cadotte members are focused within an approximate 120 km^2 area located approximately 20 km west of the City of Dawson Creek (Figure 1). Disposal wells and water source wells in this area began operating within the past five years, which, in combination with the relatively small number of wells targeting the formation, means that the Paddy and Cadotte members in this area have a much simpler disposal history than other disposal formations that may have been used for decades. The five disposal wells are vertical at this location and operate at 100–200 m^3/day (d), though one well (well authorization number 10677 [BC Oil and Gas Commission, 2017b] in Figure 1) operates at approximately 1000 m^3/d (IHS Energy, 2016). The six water source wells (which are all horizontal wells) operate at a rate of approximately 200 m^3/d. These source wells are not included in the model, but are described nonetheless as they will eventually be incorporated into a regional model of the area.

The injected wastewater is sourced primarily from the Montney Formation. This wastewater is a combination of flowback—water used for hydraulic fracturing that returns to the surface— and produced water—saline water that is extracted along with gas from shale formations. Except to define the regulatory category for disposal at the application stage (e.g., 'saline water' versus 'non-hazardous waste'), disposal well operators are not required to report chemistry of disposed wastewater in BC (Alessi et al., 2017). Salinity and chemistry may be variable and dependent on a number of factors, including variability in the produced water itself and any prior water recycling activities.

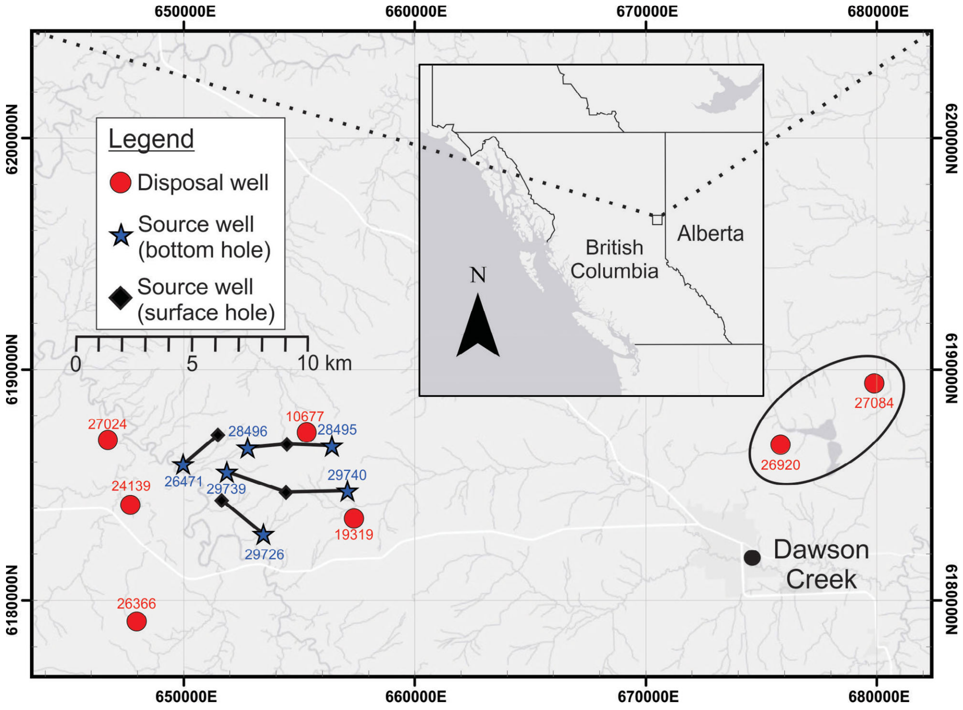

Figure 1. Map showing the locations of disposal wells (red dots), water source well bottom locations (blue stars) and water source well surface locations (black diamonds) targeting the Paddy and Cadotte members. Because the water source wells are horizontal, the location of both the surface hole and bottom hole locations are marked, with the surface hole being the location where drilling was initiated and bottom hole being the toe of the horizontal leg of the well. Wells are labelled according to their BC Oil and Gas Activities Act (OGAA) well authorization numbers (BC Oil and Gas Commission, 2017b). Note that some water source wells have proximal surface hole locations. Disposal wells 26920 and 27084 (circled to the east) are active disposal wells targeting the Paddy and Cadotte members but are not considered in this study due to their distance from the well field of interest. All co-ordinates are in UTM Zone 10.

As an indicator of potential chemistry of disposal water, available Montney Formation water analyses were compiled and found to be dominantly NaCl type, with TDS ranging from 50 to 300 g/L (BC Oil and Gas Commission, 2017a). The TDS concentration is used in the model to represent salinity (assumed to be entirely NaCl), making TDS and salinity equivalent in the context of this research. Both terms are used interchangeably.

Geology

The Paddy and Cadotte are members of the Peace River Formation (Figure 2), which was deposited during the middle to upper Albian at the southern end of the Hulcross Sea. Both members are interpreted to represent part of a major transgressive-regressive cycle (Buckley and Plint, 2013). The Paddy and Cadotte members are clastic units composed dominantly of quartz-rich sandstone sourced from the Rocky Mountain Cordillera to the west (Buckley and Plint, 2013). These units are bounded below by the Harmon Member shale and above by the Shaftesbury Formation shale, and are separated by a depositional hiatus, during which time the Cadotte Member was incised and the Paddy Member was deposited unconformably atop it (Leckie et al., 1990). The disposal wells indicated on Figure 1 target the Paddy and Cadotte members at depths of approximately 1 km below ground surface.

The Paddy Member is interpreted to have been deposited in a tidally influenced estuarine environment (Leckie et al., 1990), and is 25–40 m thick in the area of the five disposal wells shown on Figure 1. The Cadotte Member is a clastic shoreface deposit which coarsens upward into a pebbly conglomerate (Leckie et al., 1990). The Cadotte Member is 40–50 m thick, with the upper 15–25 m being of higher permeability relative to the rest of the Cadotte and Paddy members. This upper zone is the target horizon for wastewater disposal (Encana Corporation, 2014).

Hydrogeology

Available equivalent freshwater hydraulic head data in the Cadotte Member (Figure 3) and Paddy Member are similar, with a high of 600 metres above sea level (m asl) to the southwest and a low of 300 m asl to the northeast (Petrel Robertson Consulting Ltd. and Canadian Discovery Ltd., 2011). The interpreted groundwater flow direction in the area of the disposal wells, using the equivalent freshwater hydraulic head data, is to the east-northeast. The main productive horizon near the top of the Cadotte Member has porosity values of 20–30%, a thickness of 4–22 m, and perme-

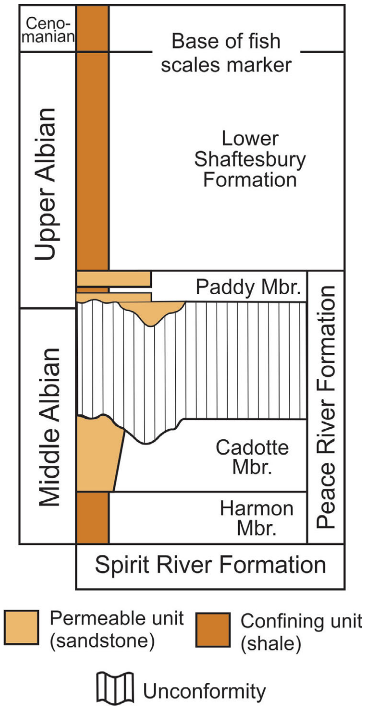

Figure 2. Stratigraphy of the middle to upper Albian in the plains area of northeastern British Columbia showing the positions and lithologies of the Harmon, Cadotte and Paddy members and Shaftesbury Formation. Modified from Leckie and Reinson (1993).

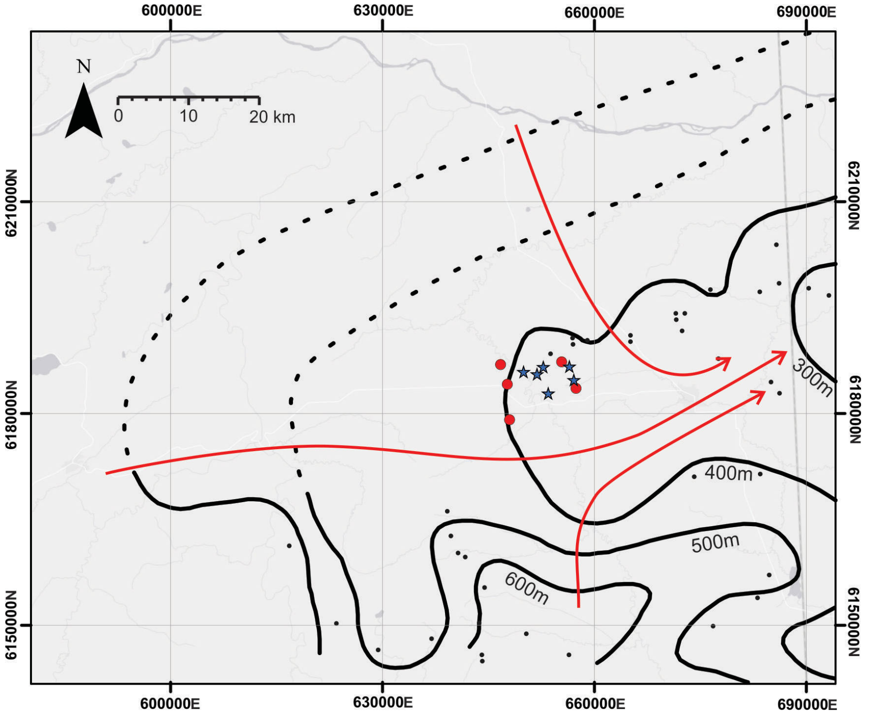

Figure 3. Equivalent freshwater hydraulic head contour map for the Cadotte Member (in metres above sea level). Red circles represent disposal wells, blue stars represent water source well bottom hole locations, black dots represent pressure measurement locations, which provided data that were converted to equivalent freshwater hydraulic head, and red arrows show representative interpreted groundwater flow directions. Contour interval is 100 m and dashed portions of contours represent poorly constrained head due to lack of data. Modified from Petrel Robertson Consulting Ltd. and Canadian Discovery Ltd. (2011). All co-ordinates are in UTM Zone 10.

ability in the range of 200–500 millidarcies (mD), whereas the Paddy Member and remaining lower section of the Cadotte Member have permeabilities that are approximately one order of magnitude lower (Petrel Robertson Consulting Ltd. and Canadian Discovery Ltd., 2011; IHS Energy, 2016). Formation water in the Paddy and Cadotte members is dominantly NaCl type and has a TDS of approximately 5–30 g/L in the study area (IHS Energy, 2016).

Methodology

Numerical modelling was completed using the groundwater modelling code FEFLOW (Diersch, 2014) to investigate the pressure increases caused by wastewater disposal. This code was chosen for its ability to simulate coupled density-dependent groundwater flow, and heat and mass transport, all of which have the potential to influence the distribution of formation pressure. The model domain is represented by a simple box model representing a cross-section through the Paddy and Cadotte members. An axisymmetric projection (Figure 4) was chosen as it has been shown to greatly reduce the computation time relative to an equivalent, full 3-D model (Langevin, 2008). A limitation of this projection type is that conditions must be assumed to be radially symmetric around the disposal well, meaning that a hydraulic gradient, variations in permeability and sloping topography cannot be simulated. These factors will be investigated in future models.

The construction of the base case model is presented here. The model domain was constructed to represent disposal into the Paddy and Cadotte members, and consists of a vertical cross-section 500 m long and 50 m high, with a vertical disposal well located along the length of the left-hand side (Figure 4). The length of the box model was selected so as to accommodate the anticipated plume size for the disposal time period chosen. The thickness of the model layer (50 m) was selected as it is approximately twice that of the horizon in the Paddy and Cadotte members used for wastewater disposal, based on geological logs in the area of the disposal wells. The domain was discretized using the triangle setting in FEFLOW's mesh generator. Higher discretization was used near the disposal well, for a total of 159 809 elements in the domain.

The top and base of the model represent the low permeability Shaftesbury Formation and Harmon Member shales, respectively, and were represented as no-flow boundaries. The left-hand side of the model represents the disposal well and was assigned flow, mass and heat boundary conditions. For flow, a well boundary condition with a conservative disposal rate of 100 m^3/d was chosen. This value was distributed along the 259 nodes defining the disposal well and then divided by 2π to account for the axisymmetric projection, resulting in a final disposal rate of 6.145×10^{-2} m^3/d per node. A constant mass boundary condition of 200 g/L and constant temperature boundary condition of 15°C were applied to each of these nodes as well, in order to give the injected water characteristics that are typical of wastewater that is disposed of in the Paddy and Cadotte members. This temperature was recommended by the Encana Corporation (pers. comm., 2017), as wastewater is commonly stored in tanks on the surface prior to disposal and has time to equilibrate to surface temperature. The right side of the model was set as a fluid-transfer boundary condition (similar to a general head boundary in MODFLOW; Langevin et al., 2017) with a reference head of 560 m, and the elements bordering this boundary were assigned an out-transfer rate of 9.867×10^{-10} s^{-1}. This out-transfer rate was determined by dividing the model hydraulic conductivity (see below) by the distance from the boundary at which the reference head is specified. In the base case, the reference head was assumed to be 1.5 km from the boundary, giving an effective domain length of 2 km, which was expected to be far enough from the injection well so as not to influence the results. It is important to note that no data could be used to constrain this boundary condition in the box models. Therefore, a sensitivity analysis was carried out to explore the influence of the boundary. Accordingly, the reference head was moved to 3 km from the edge, 100 km from the edge, and then changed to a no-flow boundary (no water can escape the model).

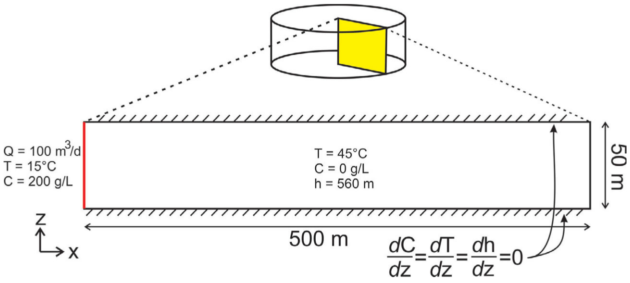

Figure 4. Axisymmetric projection showing a zoomed view of the model domain (yellow slice). The disposal well is simulated on the left boundary of the domain (red vertical line). Dots represent locations of modelled observation points. Vertical exaggeration is 1.7 times. Abbreviations: C, salinity concentration; d, day; *d*, derivative; h, hydraulic head; Q, disposal rate; T, temperature.

Additional parameter values selected for the model are shown in Table 1. Due to the axisymmetric nature of the model, an initial, uniform head distribution was required. Pressures measured in the Paddy and Cadotte members are roughly 5000 kilopascals (kPa), which, in the co-ordinate system selected for the model, translate to an equivalent freshwater hydraulic head value of approximately 560 m. This value was assigned as an initial condition to all elements in the domain.

A homogeneous permeability of 200 mD was selected for the model based on core permeability measurements for the disposal horizon in the Paddy and Cadotte members (IHS

Energy, 2016), which, in combination with the density and viscosity of FEFLOW's default reference water (freshwater at 10°C), is equivalent to a hydraulic conductivity of 1.48×10^{-6} m/s. Throughout the simulation, the code adjusts the hydraulic conductivity in each element based on the density and viscosity of the water in the element, which are dependent on temperature, pressure and solute concentration.

For this base case model, the initial solute concentration of the formation water was specified as 0 g/L and was not changed in the sensitivity analysis. Disposed wastewater salinity was specified at 200 g/L, based on available data for Montney Formation water chemistry. Water density values for the 0 g/L formation water and 200 g/L wastewater are 999.74 and 1126.1 kg/m^3, respectively, based on the pressure, temperature and salinity conditions (Driesner and Heinrich, 2007). This results in a density difference factor of 0.126.

Thermal parameter values of the solids were based on literature values for sandstone (Eppelbaum et al., 2014). Temperatures in the Paddy and Cadotte members are roughly 45°C (Encana Corporation, pers. comm., 2017), and so this temperature was assigned as an initial condition to the entirety of the model domain.

Disposal was simulated for 10 years of active injection, and the pressure values for each node along the disposal well, where increases are the greatest, were exported for analysis. For the base case model only, pressures were also exported for observation points located in the middle of the formation ($z = 25$ m) at increasing distances from the disposal well in order to assess the influence of disposal on pressures more distal to the well.

The base case model was then subjected to a sensitivity analysis in which disposal rate, permeability and wastewater salinity were varied within a reasonable range (reflecting conditions that could be encountered during disposal in the Paddy and Cadotte members) in order to understand their effect on disposal pressures in comparison to the base case. The values selected for these additional runs are presented in Table 2. An additional simulation was carried out for the base case model where the model height was reduced by 50% (50 to 25 m), so as to more accurately reflect the horizon targeted for disposal.

Results

The pressures simulated along the disposal well increase with depth, as is typical due to the hydrostatic gradient, though the shift in pressure throughout a model run is uniform at all depths. In order to obtain a metric that quantitatively represents a single pressure measurement at the well (allowing the comparison of the results of the sensitivity analysis and the investigation of influences on pressure values at the well relative to IVRP), a mean pressure value was calculated for each model node along the well at every time step for each simulation. This value was then normalized to the mean IVRP (calculated to be 5247 kPa for all models except the 25 m thick case, which had a mean pressure of 5370 kPa) in order to express changes in pressure as a percentage relative to this initial pressure in the model and evaluate it in relation to the regulatory requirement of remaining under 120% of IVRP. These values were plotted for each parameter investigated in the sensitivity analysis and are shown in Figure 5.

Table 1. Parameter values used in base case model. Abbreviations: K, Kelvin; K_x, hydraulic conductivity in x-direction; K_y, hydraulic conductivity in y-direction; J, joule; MJ, megajoule.

Parameter	Value
Fluid flow	
Hydraulic conductivity (m/s)	1.48×10^{-6}
Anisotropy of conductivity (K_y/K_x)	0.1
Density ratio	0.126
Specific storage (1/m)	0.00001
Mass transport	
Porosity	0.25
Molecular diffusion (m^2/s)	1.99×10^{-9}
Longitudinal dispersivity (m)	5
Transverse dispersivity (m)	0.5
Heat transport	
Porosity	0.25
Fluid heat capacity (MJ/m^3/K)	4.2
Solid heat capacity (MJ/m^3/K)	2.46
Fluid thermal conductivity (J/m/s/K)	0.65
Solid thermal conductivity (J/m/s/K)	1.79
Longitudinal dispersivity (m)	5
Transverse dispersivity (m)	0.5
Fluid properties	
Wastewater salinity (g/L)	200
Formation water salinity (g/L)	0
Wastewater density (kg/m^3)	1126.1
Formation water density (kg/m^3)	999.74
Formation water temperature (ºC)	45

Table 2. Parameters and their associated range of values investigated in the sensitivity analysis. Abbreviations: d, day; mD, millidarcies.

Parameter	Range	Base case value
Permeability (mD)	20–500	200
Disposal rate (m^3/d)	100–1000	100
Wastewater salinity (g/L)	50–300	200
Formation thickness (m)	25–50	50

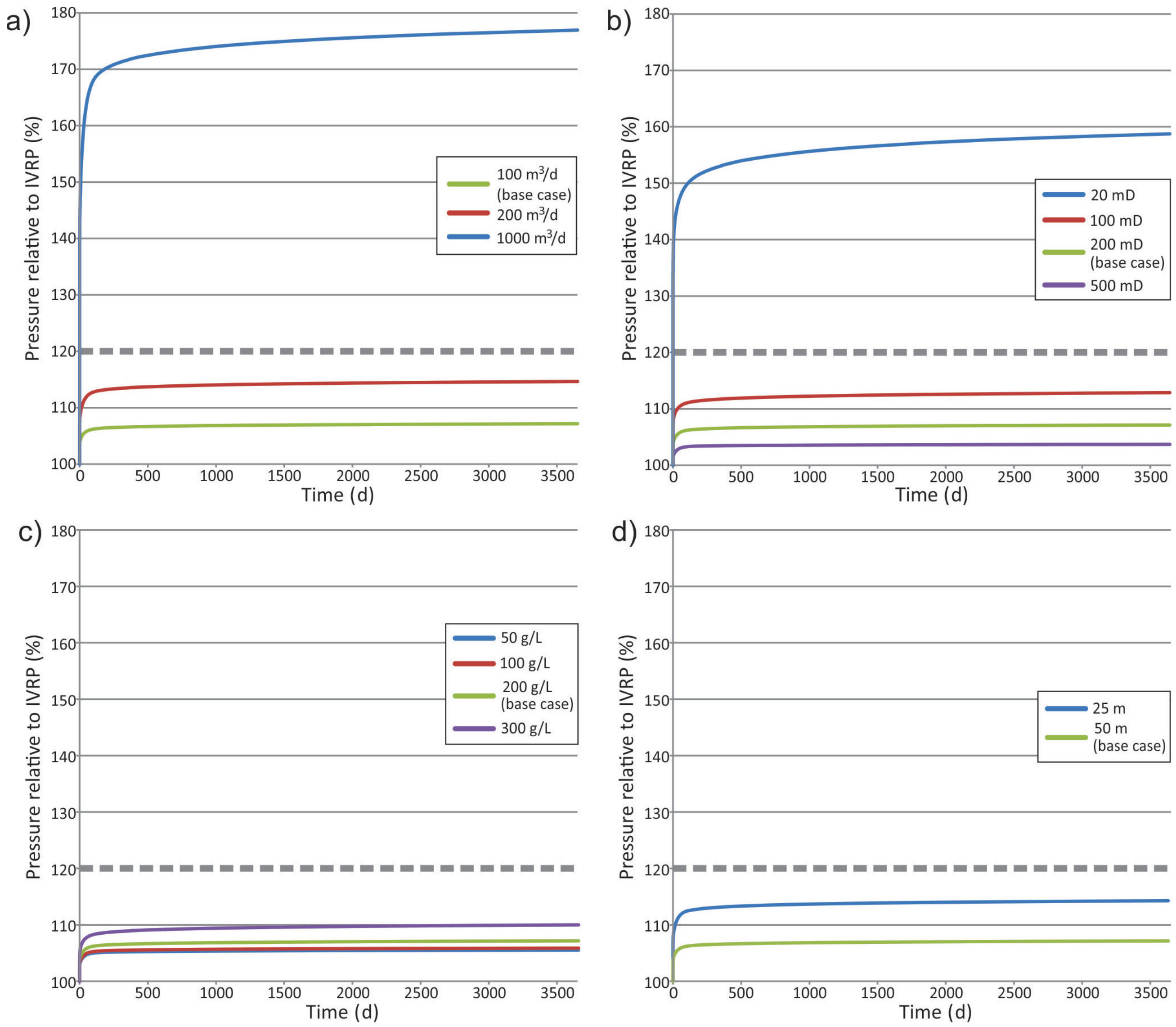

Figure 5. Mean percent change in pressure along the disposal well relative to the initial virgin reservoir pressure (IVRP) for different cases of **a)** disposal rate, **b)** formation permeability, **c)** injected wastewater salinity, and **d)** formation thickness. All base case results are shown in green. The 120% of IVRP value is marked by the thick dashed line. Abbreviations: d, day; mD, millidarcies.

Considering just the base case result, pressures increase most rapidly in the first 100 days after disposal begins. As injected wastewater begins to spread farther from the well, the pressure increase slows to a near steady rate, though this is difficult to discern in Figure 5. After 10 years of injection, pressures reach roughly 107% of IVRP, suggesting that, under the conditions chosen for the base case, the 120% of IVRP limit is not reached. Pressures were exported in the middle of the formation at increasing distance from the well, and it was found that just 5 m from the well pressures were reduced to 103.5% of IVRP. At 500 m from the disposal wells, pressures reached 101.4% of IVRP.

Disposal rates of 100 and 200 m^3/d are shown to produce pressure increases that are safely within the BCOGC's regulatory limit, reaching peak values of 115% of IVRP (Figure 5a). The 1000 m^3/d case surpasses this limit very early in the simulation, approaching 180% of IVRP after 10 years. This value was selected as a part of the analysis because one well targeting the Paddy and Cadotte members operates at this rate.

Formation permeability strongly influences disposal pressures (Figure 5b). Relative to the base case of 200 mD, the higher permeability (500 mD) results in a pressure that remains well below 120% of IVRP limit (103%). For a lower permeability of 100 mD, the pressure is 113% of IVRP, and for 20 mD, the pressure increases rapidly and reaches nearly 160% after 10 years.

Pressure was found to increase as the salinity was raised (Figure 5c). This occurs because, as salinity rises, so does

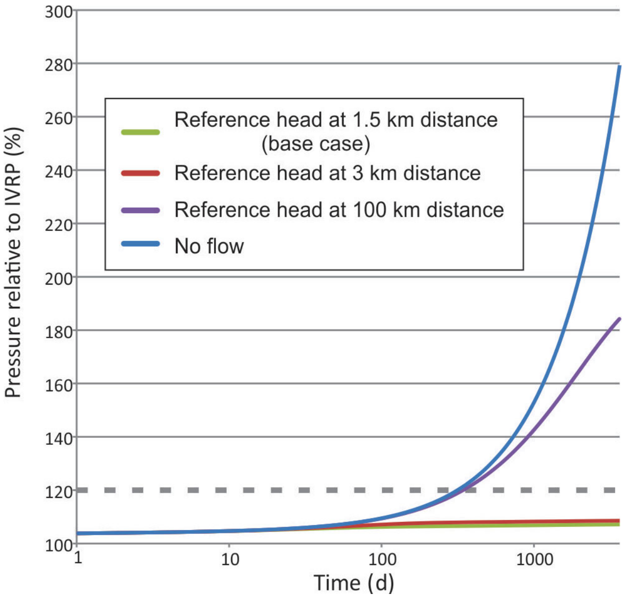

Figure 6. Mean percent change in pressure along the disposal well relative to the initial virgin reservoir pressure (IVRP) with modifications to the outflow boundary edge. The 120% of IVRP value is marked by the thick, dashed line. The x-axis is on a log scale.

the fluid density and viscosity, reducing the ease with which fluid travels through the disposal formation, leading to greater pressures. Wastewater salinity does not appear to have as significant an effect on the pressure increase relative to the IVRP as disposal rate or formation permeability does. There is a 3% difference in final reservoir pressure between the 200 and 300 g/L cases, and only a 1% difference between the 100 and 200 g/L cases. The 300 g/L salinity value represents an extreme case, and most of the water analyses compiled for this study fall in the 100–200 g/L range, indicating that only minor variation in formation pressures should be expected as a result of wastewater concentration.

Finally, the effect of reducing the model layer thickness to half that of the base case model (i.e., 25 m) was to increase the pressure to 114% of IVRP, whereas the 50 m thick model was 107% of IVRP (Figure 5d).

The results of modifying the outflow boundary of the model are shown in Figure 6. It is evident that this boundary exerts a strong control over simulated pressures. When the boundary reference head is closer to the model edge, as in the 1.5 and 3 km cases, pressures remain low. This boundary acts as a sink for pressure, preventing it from rising too high within the domain. In the extreme case, where the outflow boundary is replaced with a no-flow boundary, pressures rise indefinitely, never reaching a plateau as seen in Figure 5. Using a no-flow boundary within 500 m of the well simulates the pressure buildup in a closed system, which is likely not realistic. The intermediate case, with the reference head positioned 100 km from the model edge, simulates pressures that approach those seen in the no-flow boundary case. This suggests that, as the reference head is moved farther from the model edge, pressures more closely approximate those of the no-flow boundary case.

Discussion

The results of this model sensitivity analysis suggest that disposal rate, formation permeability and formation thickness are important factors to consider with respect to maximizing disposal potential at a well location while meeting the 120% threshold for increased pressure. The results further suggest that of the parameters varied, disposal well pressures are most sensitive to disposal rate and formation permeability, with lesser but some sensitivity to formation thickness. Formation pressure at the well was least sensitive to variability in disposal water density (salinity). The relatively strong dependency of formation pressure on permeability suggests that characterization of permeability and permeability variability (vertically and horizontally) is useful with respect to predicting disposal well performance in the short term and long term. The results also suggest that near-well formation pressures can be managed through adjustments to the disposal rate. For the base case (200 mD permeability, 50 m layer thickness), disposal rates greater than approximately 200 m^3/d caused increases in formation pressure approaching 120% of the specified IVRP. At this rate, the sensitivity analysis indicated that a reduction in permeability by more than 100 mD or a reduction in the layer thickness by one half caused the simulated pressures to approach this injection pressure threshold. The combination of factors (permeability, thickness) would result in a unique resulting pressure at the well, affecting the potential for the pressure threshold to be exceeded. This is particularly the case for areas near the disposal well, where the effects of pressure are most strongly manifested soon after disposal and where they are measured for compliance monitoring. Although this study did not consider the complexities of geological heterogeneities, the results suggest that small changes in permeability or layer thickness, which can reasonably be expected over a few hundred metres, could affect injection potential. For example, the model simulation using a disposal rate of 1000 m^3/d, resulted in very high simulated pressures, yet well 10677 actually operates at this rate, meeting BCOGC operational requirements with respect to pressure requirements. Thus, it is likely that the actual permeability near this particular well is higher than that used in the model. This supports the interpretation that the Paddy and Cadotte members are heterogeneous at the near-well scale.

This study was developed to provide a preliminary examination of potential factors affecting reservoir pressures near disposal wells in the Paddy and Cadotte members study area of NEBC, and the results provide preliminary insights in regard to potential factors influencing disposal well performance. The results do not imply conditions under which the pressure threshold could be exceeded in reference to any particular well. The results of modifying the outflow boundary condition demonstrate this, as pressures within the model were strongly influenced by moving the boundary farther from the disposal edge. Instead, this study provides insights into the sensitivity of disposal pressures to the different parameters tested. It is the relative change in pressure in response to modifying formation or disposal parameters that is important. Moreover, the modelled final well pressure does not accurately represent a measurement that is consistent with standardized methods for obtaining stabilized pressure measurements at a well for the purposes of establishing regulatory compliance.

Finally, this study did not consider layered heterogeneity, which can be expected due to differences in bed- to bedset-scale heterogeneity, or lateral changes in permeability (extending beyond the well field). Also, this study did not test the sensitivity to changes in specific storage, which also directly affects the pressure response to injection. The same value was used for all simulations, but, if the specific storage is reduced, the same volume of injected wastewater will lead to even higher pressures.

Conclusions

In this study, axisymmetric box models approximating the Paddy and Cadotte members of NEBC were used to simulate pressure changes as a result of wastewater disposal. Various parameters, including disposal rate, formation permeability, formation thickness and wastewater salinity (and resulting density), were varied in order to assess their control on formation pressure at a disposal well. The results were evaluated relative to the 120% of IVRP threshold imposed by the BCOGC. It was determined that in order to optimize disposal, operators must achieve a delicate balance between disposal rates and unit permeability and thickness. This result is not surprising as it is founded on well and reservoir hydraulic theory. What this sensitivity analysis demonstrates is that disposal well operation is quite sensitive to these parameters. A reduction in permeability by 100 mD or a two-fold reduction in thickness of the disposal unit resulted in injection pressures very close to the IVRP limit for the modelled scenario. Although this study did not model local or regional geological heterogeneities on disposal well performance, given the sensitivity of pressures at the well to reservoir permeability, pressure sensitivity to local or regional geological heterogeneities is inferred. As some uncertainty in local and regional geological heterogeneities is a reality for deep geological formations, the results emphasize the importance of pressure monitoring for maximizing disposal well efficiency and performance and ensuring compliance with pressure requirements.

In future work, a regional model of the Paddy and Cadotte members incorporating all wells shown in Figure 1 will be constructed. The aim of this model is to assess the influence of a regional hydraulic gradient, formation slope and proximal source water extraction on the overall distribution of disposed wastewater in the subsurface.

Acknowledgments

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