GS2025-15

Compilation of saline water analysis data from oil and gas wells and a case study of Duperow Formation data, southwestern Manitoba (parts of NTS 62F–K, N, O, 63C)

by E. Enaworu

In Brief:

- Saline water analysis data have been compiled into a user-friendly digital format
- Duperow Formation saline aquifers are dominated by sodium, potassium and chloride ions
- Total Dissolved Solids (TDS) concentrations and other water properties can inform hydrogeological evaluation of saline water aquifers

Citation:

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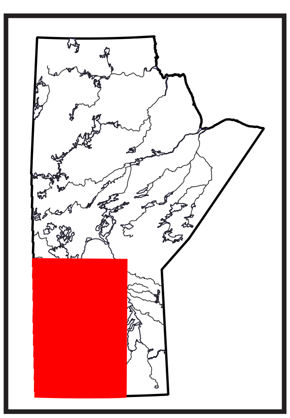

Summary

As part of an ongoing project initiated by the Manitoba Geological Survey (MGS) in 2023, this report details the completion of the compilation of water analysis data from oil and gas wells in southwestern Manitoba. In addition, the Duperow Formation data were used as a case study to show the usefulness of the compiled data in characterizing the saline aquifers of southwestern Manitoba. Preliminary results from the Duperow Formation classified the saline aquifers into highly saline to brine with sodium and potassium (combined) and chloride ions as the dominant salinity drivers. The dominance has led to the classification of the Duperow Formation water as a sodium-chloride–type formation water. The major cations and anions that contributed to the total dissolved solids (TDS) for each well were identified. Cations, anions and TDS concentrations varied amongst the stratigraphic members, with the lowest TDS value of 13 201 ppm occurring in the Seward Member and the highest value of 240 763 ppm reported in the middle Wymark Member. The water analysis data for the Duperow Formation suggests it has a relationship with the dolomitization and anhydrite formation observed in previous studies. Other data analyses trends and patterns were used to establish correlations/relationships that could possibly be used to predict water chemistry and petrophysical properties for areas without data or poor-quality data.

Introduction

In 2023, the MGS started compiling saline water analysis data for the subsurface saline aquifer formations located in southwestern Manitoba. This compilation entailed compiling saline water analysis data spanning over 70 years from oil and gas wells into a user-friendly digital format (Manitoba Business, Mining, Trade and Job Creation, 2025).

This study brings to the fore the completed compilation of saline water analysis data from 744 oil and gas wells in southwestern Manitoba. Multiple wells recorded multiple samples from different intervals in the well. For each sample, various information was captured, including oil and gas well licence number, unique well identifier (UWI), well name, location, bottom-hole latitude, bottom-hole longitude, DST number, sampling point, oil field name, depth intervals tested, subsurface formation assigned at the time of sampling, geological age, nature of liquid, total dissolved solids (TDS), primary salinity, secondary salinity, primary alkalinity, secondary alkalinity, chloride salinity, sulphate salinity, and cation and anion concentrations, among others. Water petrophysical properties such as conductivity, resistivity, density, pH, specific gravity, hardness and turbidity were also captured, when the information was available in the original reports.

This report details 1) the concluding phase (phase four) of the compiled saline water analysis data project for southwestern Manitoba, first introduced in Enaworu and Nicolas (2024), and 2) a case study using a subset of saline water analysis data from the Duperow Formation to evaluate data quality, relationships and trends.

Geology and stratigraphy

The Williston Basin consists of several geological formations deposited throughout the Paleozoic to Cenozoic eras. Within these geological formations are several saline aquifers, which vary in depth, TDS and ion concentrations, and water physical properties from one location to the next. The economic potential and growing need for saline aquifers due to their potential use as key sources for minerals/metals, carbon capture and storage and geothermal energy has spurred serious interest in the Williston Basin.

There are several Devonian formations deposited within the Williston Basin but the Duperow Formation was chosen for a case study because of its potential for lithium. The formation extends to other provinces, such as eastern Saskatchewan, but the case study only focused on the subsurface Duperow Formation in Manitoba. In southwestern Manitoba, the Duperow Formation is 122–195 m thick and thins laterally from the west to the east and consists of carbonate–evaporite successions. It is characterized by a thick stratigraphic interval composed of limestone, evaporite and dolostone units deposited within a semiconstrained, back-reef depositional setting in the Devonian Elk Point Basin; the Devonian Elk Point Basin extended and incorporated the Williston Basin as its southeastern sector (Anna et al., 2013; Chow et al., 2014; Eggie and Chow, 2024).

The Duperow Formation consists of three distinct members—from oldest to youngest—Saskatoon, Wymark and Seward members (Figure GS2025-15-1). The Wymark Member is the thickest member and has been stratigraphically divided from oldest to youngest into the lower, middle and upper units (Nicolas and Chow, 2018; Eggie and Chow, 2024). Eggie et al. (2012), Bates (2016) and Bates et al. (2016) identified three key lithofacies associations in the Duperow Formation—subtidal, intertidal and supratidal.

A recent study using petrophysical analysis of well logs in southwestern Manitoba defined the vertical and lateral arrangement of the carbonate cycles in the Duperow Formation (Fraino, 2025a; Fraino and Nicolas, 2025). Preliminary isopach maps in Fraino and Nicolas (2025) indicate differences in the thicknesses of these cycles with the thickest successions identified in Twp. 10–20, Rge. 20–29, W 1st Mer. Fraino and Nicolas (2025) also showed that facies-controlled diagenetic processes including dolomitization and dissolution contributed significantly to the enhancement of porosity and permeability within the Duperow Formation. Consequently, intervals rich in dolomite situated in intertidal and subtidal deposits were identified as being good intervals for brine aquifers because of their favourable reservoir properties.

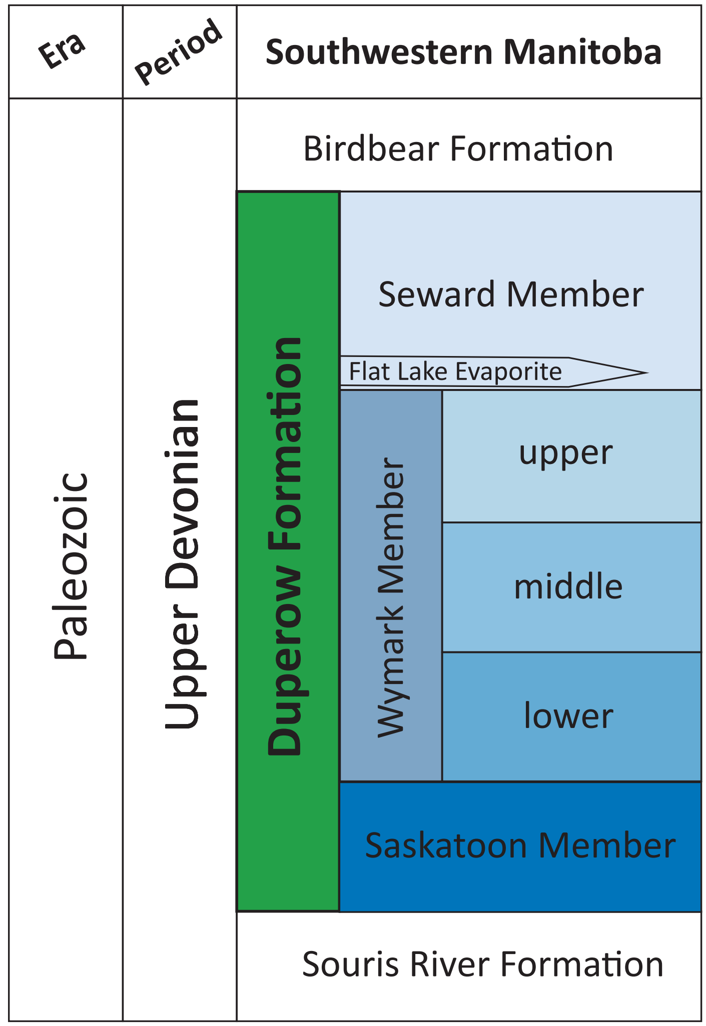

Figure GS2025-15-1: *Stratigraphy of the Upper Devonian Duperow Formation (modified from Nicolas and Barchyn, 2008).*

Hydrogeology

Palombi (2008) reported that within the central portion of the Williston Basin, the movement of fluids occur typically updip to the northeast, with vertical fluid movement noted toward the edge of the basin. Salt dissolution has been recognized as a major factor enhancing upward flow, with the Prairie Evaporite posing as a hydraulic barrier separating aquifers. The lower Paleozoic aquifer formation waters tend to follow a similar up-dip and northeast flow pattern heading toward subcrop and outcrop areas (Palombi, 2008).

Based on hydrochemical analyses of the waters within the saline aquifers of the Williston Basin across Saskatchewan and Manitoba, Palombi (2008) categorized the water composition into four types: type 1 (calcium-sulphate), type 2 (sodium-chloride), type 3 (sodium-bicarbonate) and type 4 (sodium-sulphate). Type 2 (sodium-chloride) is stated as being the most prevalent. For the lower Paleozoic aquifers, Palombi (2008) found that plots of major cations such as sodium against TDS revealed strong linear correlations, until approximately 200 g/L where Na concentrations began to drop. On the other hand, calcium within these aquifers exhibited a U-shaped trend with TDS. In terms of anion fractions, sulphate ions exhibited strong negative exponential relationships with TDS.

Palombi (2008) also noted in the Duperow Formation that variations in TDS values are uniform with other Paleozoic aquifers and they ranged from 5 to 330 g/L in northern (Twp. 46, Rge. 9, W 2nd Mer.) and southern (Twp. 6, Rge. 8, W 2nd Mer.) Saskatchewan, respectively.

The secondary porosity and permeability that occurs from dolomitization can increase reservoir rock quality. The occurrence of dolomitized units in the Duperow Formation has enhanced porosity and permeability and may lead to higher potential for petroleum (Bates et al., 2016) as well as improved fluid movement in these units. However, intercrystalline porosity may be reduced locally because of the effect of anhydrite and fine-crystalline gypsum cement (Eggie and Chow, 2024). There-fore, a sound knowledge of the dolomitization process and diagenetic and facies trends are key to predicting the distribution and location of the reservoir rock intervals with the best quality in the Duperow Formation (Eggie and Chow, 2024).

Methodology

This study was grouped into two stages, the completion of the compilation stage and the analysis stage, which used a subset of data from the Duperow Formation.

Compilation stage

The compilation stage was grouped into four phases, phases 1–3 were reported by Enaworu and Nicolas (2024) and this report focuses on phase four, which involved four main steps:

1) The original data were verified, which included identifying and removing data outliers and duplicates, verifying errors of omissions against original data and rectifying them, and standardizing units of measurement across the dataset and screening out parameters that were out of range.
2) Stratigraphic names and geological ages were assigned to each sampled interval. When sample depth and stratigraphic unit information was not available, the total depth and oldest formation penetrated were assigned to these wells. This step was accomplished using formation tops and bases within the software geoSCOUT™ by geoLOGIC systems ltd. Due to frequent inaccuracies provided on water analysis laboratory reports, this step was required to ensure the stratigraphic information was accurate and consistent across all wells and official Manitoba stratigraphic assignments were used.
3) The surface and bottom-hole geographic co-ordinates were assigned using data from the Manitoba Oil and Gas Well Information System (MOGWIS; Manitoba Business, Mining, Trade and Job Creation, internal database). All UTMs were recorded in Zone 14, NAD83, for both surface and bottom-hole co-ordinates for each well and converted to longitude and latitude using ArcGIS® Pro software by Esri®.
4) The dataset was checked to ensure that all oil and gas wells with saline water analysis data were included.

These steps were taken to ensure the reliability of the data, reduce human error and confirm that the dataset was ready for various statistical analyses, regulatory purposes and hydrogeological characterization.

A location map of all the oil and gas wells with saline water analysis data included in the dataset is shown in Figure GS2025-15-2.

Analysis stage

The analysis stage used a small subset of the compiled data to test the data quality and generate and analyze trends. These steps were part of the data quality checking and screening process, which is necessary to ensure consistency, accuracy and effective usability of the dataset. The following steps were undertaken:

1) Duperow Formation data were extracted from the compiled saline water analysis dataset (Figure GS2025-15-2). The Duperow Formation was selected for this test because of its potential for lithium; elevated lithium levels in the Duperow Formation have been reported in Manitoba (e.g., Fraino, 2025b, c) and in other provinces such as Saskatchewan (e.g., Rostron et al., 2002; Bishop and Robbins, 2023; Jensen et al., 2020).
2) Duperow Formation data quality was verified using cross-plots of TDS against ion concentrations (sodium, calcium, chloride, etc.) and physical properties (conductivity, resistivity and density).
3) Water salinity was classified into fresh, slightly saline, moderately saline, highly saline and brine using the criteria in Table GS2025-15-1.

Results

The saline water analysis dataset has 744 oil and gas wells, some with several sample intervals, and associated saline water analysis reports. From this dataset, a subset of nine wells with 12 sample intervals and associated saline water analysis data for the Duperow Formation were identified (Figure GS2025-15-2) and extracted for evaluation. A selection of physical properties and chemical analysis results from this subset are presented in Table GS2025-15-2 and Figures GS2025-15-3 to -5.

The chemical composition of water samples from the Duperow Formation varied across the 12 sample points and stratigraphic members. The TDS values ranged from 13 201 ppm to 240 763 ppm indicating highly saline to brine waters (Tables GS2025-15-1, -2). The highest TDS value was recorded in a sample from oil and gas well licence 763 (Manitoba Business, Mining, Trade and Job Creation, Winnipeg) at L.S. 7, Sec. 27, Twp. 10, Rge. 26, W 1st Mer. (abbreviated 7-27-10-26W1). The second highest TDS concentration (199 318 ppm) was recorded from the same well but at a different sample interval. Other well locations with high TDS values (>100 000 ppm) are oil and gas well licences 1783 (13-4-10-22W1), 19 (16-18-18-29W1), 640 (3-17-12-24W1) and 2452 (15-20-3-25W1). Oil and gas well licence 1876 (5-3-4-25W1) had the lowest value of 13 201 ppm.

Table GS2025-15-1: Salinity classification scale (Barlow, 2003; U.S. Geological Survey Water Science School, 2018).

Salinity classification	Total dissolved solids (ppm)
Fresh	<1000
Slightly saline	1000 to 3000
Moderately saline	3000 to 10 000
Highly saline	10 000 to 35 000
Brine	>35 000

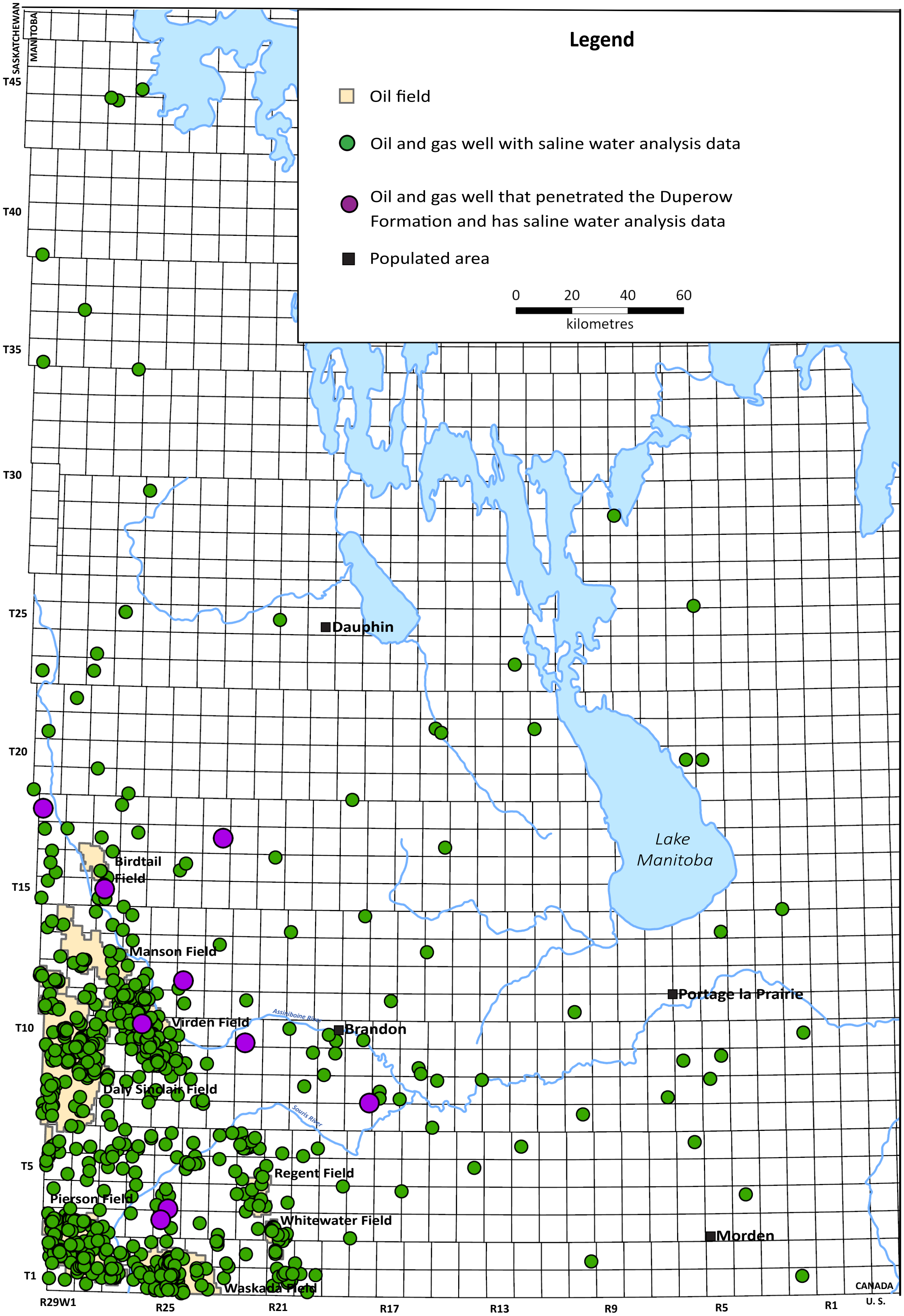

Figure GS2025-15-2: *Locations of oil fields, 744 oil and gas wells with saline water analysis data and the nine oil and gas wells that were used for the Duperow Formation case study, southwestern Manitoba (modified from Enaworu and Nicolas, 2024). Location based on bottom-hole co-ordinates. Oil field boundaries are from Fulton-Regula (2024) and well locations from Manitoba Business, Mining, Trade and Job Creation (2025).*

***Table GS2025-15-2:** Oil and gas well licence (Manitoba Business, Mining, Trade and Job Creation, Winnipeg) and location information linked to stratigraphic information and salinity classification for samples from the Duperow Formation in southwestern Manitoba (Manitoba Business, Mining, Trade and Job Creation, 2025).*

Oil and gas well licence	Bottom-hole longitude (NAD 83)	Bottom-hole latitude (NAD 83)	Location	Sample depth (m TVD)		KB (m asl)	Sample elevation (m bsl)		Stratigraphy		TDS (ppm)	Salinity classification
				Top	Bottom		Top	Bottom	Top	Bottom		
44	99.793964W	49.622682N	3-1-8-18W1	517.86	525.17	415.90	101.96	109.27	Seward Mb.	Seward Mb.	67 754	Brine
1876	100.779305W	49.272270N	5-3-4-25W1	1070.46	1071.07	462.70	607.76	608.37	Seward Mb.	Seward Mb.	13 201	Highly saline
2452	100.813461W	49.235660N	15-20-3-25W1	1130.50	1138.73	468.80	661.70	669.93	Seward Mb.	Seward Mb.	172 919	Brine
640	100.728729W	50.006604N	3-17-12-24W1	694.94	701.34	472.70	222.24	228.64	Seward Mb.	Flat Lake Evaporite	140 740	Brine
763	100.928778W	49.864542N	7-27-10-26W1	801.62	812.29	442.00	359.62	370.29	Upper Wymark Mb.	Upper Wymark Mb.	199 318	Brine
1235	100.545342W	50.467187N	6-23-17-23W1	588.26	595.58	567.50	20.76	28.08	Middle Wymark Mb.	Middle Wymark Mb.	27 537	Highly saline
763	100.928778W	49.864542N	7-27-10-26W1	842.77	853.44	442.00	400.77	411.44	Middle Wymark Mb.	Middle Wymark Mb.	240 763	Brine
19	101.456467W	50.547884N	16-18-18-29W1	676.96	681.53	486.80	190.16	194.73	Middle Wymark Mb.	Lower Wymark Mb.	155 156	Brine
1783	100.414289W	49.811008N	13-4-10-22W1	668.12	720.24	422.80	245.32	297.44	Middle Wymark Mb.	Lower Wymark Mb.	149 339	Brine
640	100.728729W	50.006604N	3-17-12-24W1	769.62	781.81	472.70	296.92	309.11	Middle Wymark Mb.	Lower Wymark Mb.	92 943	Brine
247	101.13402W	50.294247N	9-21-15-27W1	722.99	733.04	469.40	253.59	263.64	Lower Wymark Mb.	Lower Wymark Mb.	31 963	Highly saline
640	100.728729W	50.006604N	3-17-12-24W1	798.58	810.77	472.70	325.88	338.07	Saskatoon Mb.	Saskatoon Mb.	87 411	Brine

Abbreviations: 3-1-8-18W1, L.S. 3, Sec. 1, Twp. 8, Rge. 18, W 1st Mer.; bsl, below sea level; KB, kelly bushing; TDS, total dissolved solids; TVD, true vertical depth

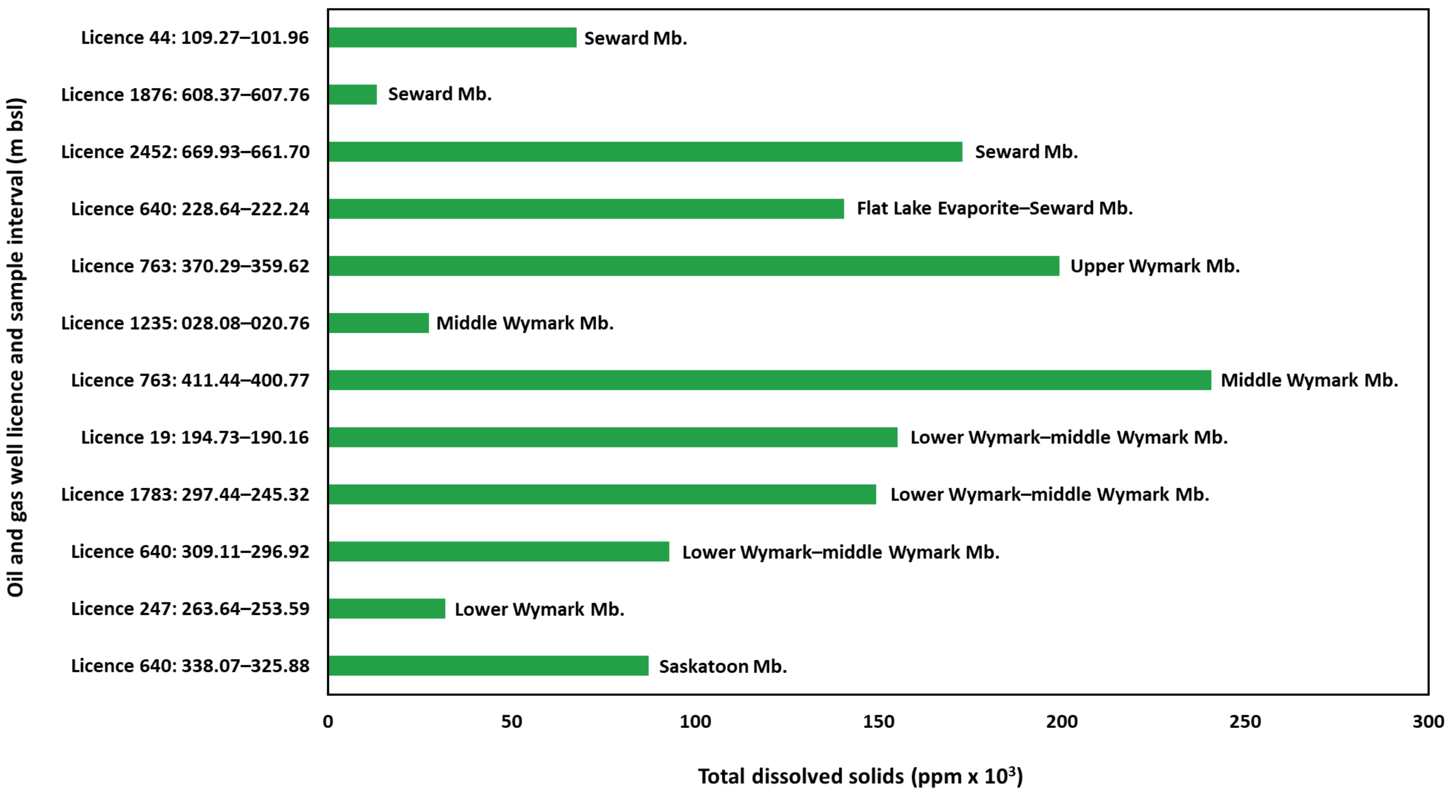

Figure GS2025-15-3: *Bar chart showing the total dissolved solids for each Duperow Formation sample with the stratigraphic assignment of each interval indicated, listed in order from the oldest (bottom) to youngest (top) strata (Manitoba Business, Mining, Trade and Job Creation, 2025). Oil and gas well licences are also included (Manitoba Business, Mining, Trade and Job Creation, Winnipeg). Abbreviation: bsl, below sea level.*

From Figure GS2025-15-3 there is no general trend/pattern in TDS concentrations with respect to sample depth or stratigraphy, as some member units recorded both high and low TDS concentrations. The middle Wymark Member reported high values in some locations and low values in other locations. A similar trend occurs in the Seward Member, which recorded the lowest value for the Duperow Formation but still reported one of the highest values in another well location. This same trend is seen for the lower–middle Wymark Member interval. Each of the Saskatoon Member, upper Wymark Member and Flat Lake Evaporite–Seward Member intervals only had an individual TDS value from a single sample interval.

The percentage contribution of each ion to the overall TDS for the Duperow Formation is seen in Figure GS2025-15-4, where Na^+ + K^+ and Cl^- contributed an average of over 30% and 50%, respectively, to overall TDS concentrations within the Duperow Formation. The ions Na^+ + K^+ and Cl^- combined contributed more than every other ion toward the TDS values for every sample. The ions Ca^{2+} and SO_4^{2-} report low average percentage contributions of 3.1% and 6.7%, respectively, whereas Mg^{2+} recorded the lowest average percentage contribution of 0.9%.

Figure GS2025-15-5a–c shows a strong correlation between TDS and conductivity, resistivity and density with a coefficient of determination (R^2) of 0.99 for all properties.

Ion concentrations vary within the Duperow Formation (Figure GS2025-15-5d–h), the Na^+ + K^+ concentration ranges from 3.6 x 10^3 to 84.9 x 10^3 ppm, whereas Cl^- concentrations range from 3.2 x 10^3 to 146.0 x 10^3 ppm. Both Na^+ + K^+ and Cl^- produced a good correlation with TDS, with a R^2 of 0.99. The cation concentrations for Ca^{2+} range from 0.67 x10^3 to 5.78 x 10^3 ppm and Mg^{2+} from 0.21 x 10^3 to 2.50 x 10^3 ppm, whereas anion concentrations of SO_4^{2-} range from 1.85 x 10^3 to 6.28 x 10^3 ppm. Weaker correlations with TDS concentrations are observed for Ca^{2+}, Mg^{2+} and SO_4^{2-}, with R^2 of 0.64, 0.79 and 0.65, respectively; there are also some scattered/inconsistent points (Figure GS2025-15-5e, f, h).

Overall, the data shows that there is no evidence of freshwater influence but the water is rich in major ions (Na^+ + K^+, Ca^{2+}, Mg^{2+}, Cl^- and SO_4^{2-}).

Discussion of Analysis

Based on the subset of data, the water within the aquifers of the Duperow Formation are classified as highly saline to brine (Tables GS2025-15-1, -2). The upper and middle Wymark Member have the highest TDS values (Figure GS2025-15-3) with Na^+, K^+ and Cl^- ions contributing the most to these high TDS numbers (Figure GS2025-15-4). Also, the dominance of Na^+ and Cl^- ions indicate a type 2 (Na-Cl) formation water (Khan, 2006; Palombi,

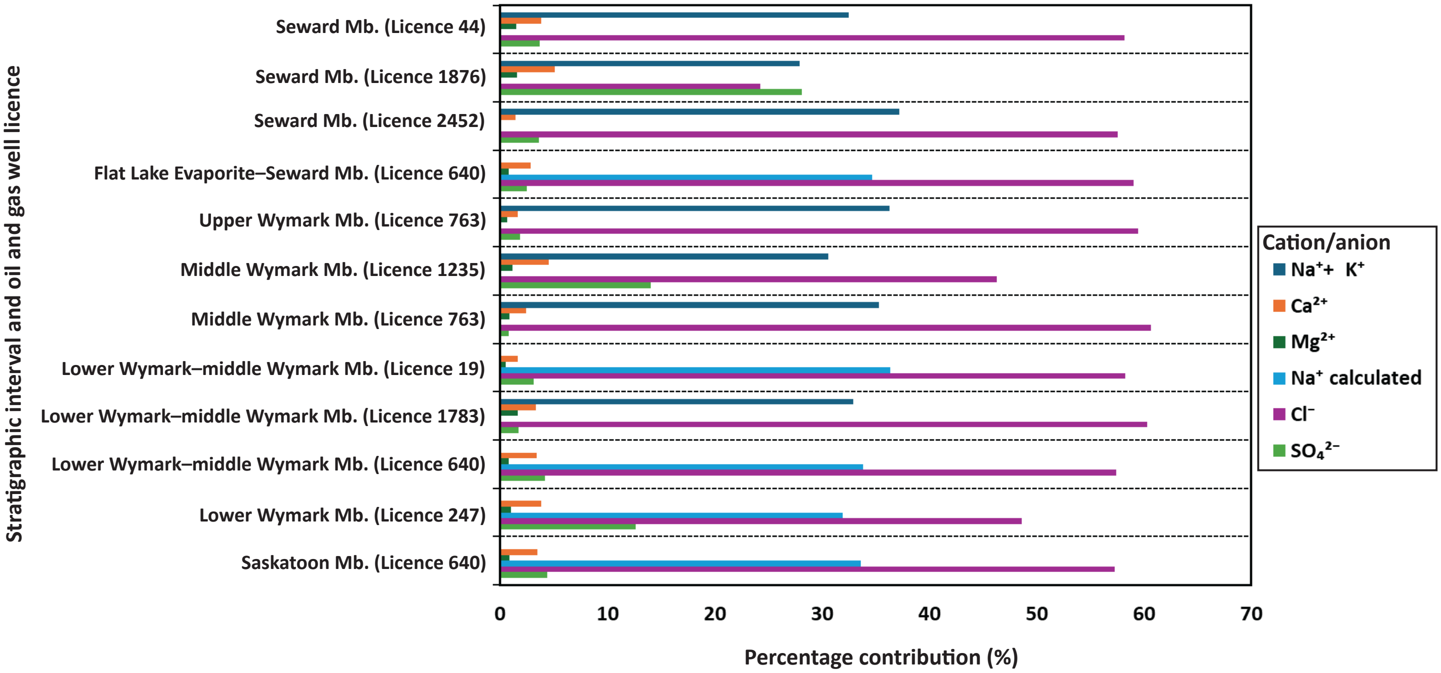

Figure GS2025-15-4: *Bar chart showing the percentage contribution of select cations and anions to each Duperow Formation sample, listed in stratigraphic order from the oldest (bottom) to youngest (top; Manitoba Business, Mining, Trade and Job Creation, 2025). Oil and gas well licences are also included (Manitoba Business, Mining, Trade and Job Creation, Winnipeg).*

2008). The K^+ ions combining with Na^+ could mean that K^+ occurs in much lower concentrations.

In Figure GS2025-15-5a and b, TDS shows a strong positive correlation with conductivity but an inverse relationship or negative correlation with resistivity. Conductivity increases with increasing TDS values as there are more dissolved salts and hence ions to carry electric charge. Resistivity decreases with increasing TDS values, as resistivity is a measure of how strongly the fluid resists an electrical current, more ions in solution means lower resistivity.

The plot of TDS versus density shows a good positive correlation and regression coefficient value (R^2 = 0.99; Figure GS2025-15-5c). This relationship is expected as higher TDS values mean more ions in solution (Na^+, K^+, Cl^-) without an increase in volume, and hence the density of the fluid increases.

In Figure GS2025-15-5d and g, there is a strong correlation between TDS and Na^+ + K^+ and Cl^- ion concentrations. As Na^+ + K^+ and Cl^- ions are the major drivers of the salinity, this relationship between Na^+ + K^+ and TDS is not unexpected and is consistent with Palombi (2008).

Weak correlations between TDS and Mg^{2+}, Ca^{2+} and SO_4^{2-} ion concentrations (Figure GS2025-15-5e, f, h) might be caused by secondary geochemical processes such as anhydrite precipitation and active dolomitization. This is corroborated with the stratigraphy and lithology of the Duperow Formation, where the presence and occurrence of anhydrite and dolomitization affects the porosity and permeability of the formation (Bates et al., 2016; Chow et al., 2019; Fraino and Nicolas, 2025). Although these correlations are noted, further work is required to determine if these ion concentrations are due to the presence of primary dolomites and anhydrites or are caused by secondary geochemical processes such as anhydrite precipitation and dolomitization.

Conclusion

A saline water analysis dataset has been created from the technical well files of 744 oil and gas wells in southwestern Manitoba. From this dataset, a subset of data points for the Devonian Duperow Formation has enabled the classification of the water within this aquifer into highly saline–brine types. With Na^+, K^+ and Cl^- ions as the dominant salinity drivers, the water has been further classified into a type 2 (Na-Cl) formation water. This has established the baseline water chemistry for this formation. Correlations between TDS and major ion concentrations and other physical properties was illustrated and can be used to inform hydrogeological evaluation of saline water aquifers. The correlations with high R^2 values, signifying a better fit, could be used to predict water chemistry in sampled intervals with poor water chemistry data or no data.

The procedures used in this study will be used to inform future studies of other saline aquifers within the Williston Basin in Manitoba. They will also assist in exploring for critical minerals and pore-space resource, informing regulatory decisions on

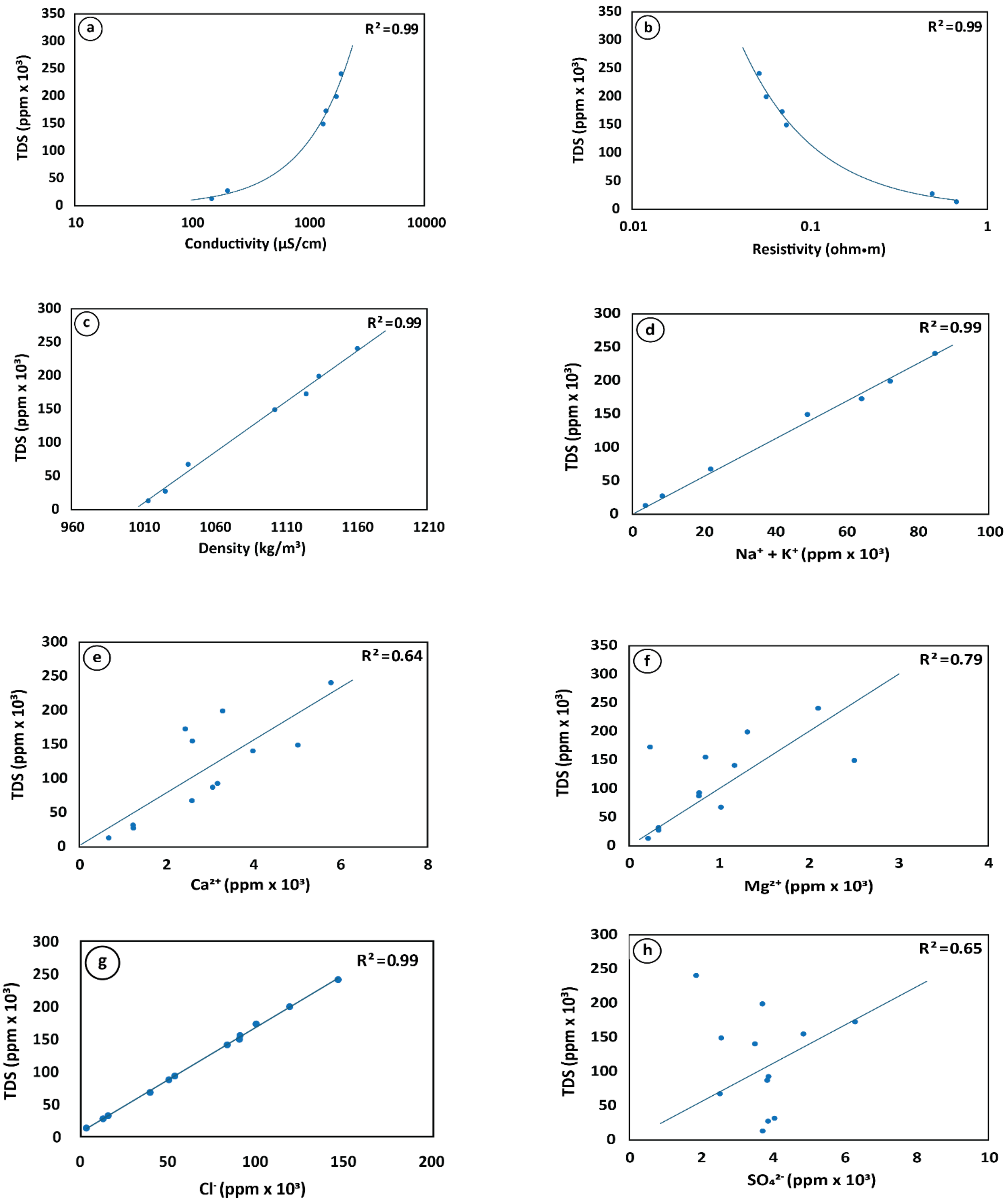

Figure GS2025-15-5: *Duperow Formation sample data cross-plots of total dissolved solids (TDS) concentration as it relates to water properties,* ***a)*** *conductivity,* ***b)*** *resistivity and* ***c)*** *density, and cation/anion concentrations,* ***d)*** *$Na^+ + K^+$,* ***e)*** *Ca^{2+},* ***f)*** *Mg^{2+},* ***g)*** *Cl^- and* ***h)*** *SO_4^{2-} (Manitoba Business, Mining, Trade and Job Creation, 2025). Abbreviation: S, siemen.*

land-use planning and helping to ensure the success of captured carbon and storage (CCS) projects and mitigate any associated risks. This information will also be used for future hydrogeological studies.

Future work

Going forward, this dataset will be used to create maps and conduct targeted hydrogeological investigations, including

- investigating weak correlations and inconsistent relationship patterns observed between TDS and ion concentrations and physical properties, which will increase the understanding of the hydrogeochemical processes occurring within saline aquifers;
- creating water property and chemistry maps by formation, which will provide a better understanding of the changes in water chemistry and physical properties in saline aquifers; and
- providing continued support for regulatory development and pore-space resource compliance to ensure accurate reporting and reservoir evaluation and maintenance of baseline hydrogeological data reporting.

Publication of the compiled dataset is planned for late 2025–early 2026, with the intent to update the dataset as new water analyses are reported.

Economic considerations

The saline aquifers of the Duperow Formation possess brine and pore-space resource potential. The occurrence of higher ion concentrations and the confirmed classification of the groundwater within the Duperow Formation to be highly saline–brine (predominantly brine) indicates it could serve as a source of industrial elements and compounds. For example,

- magnesium, which can be combined with sodium hydroxide to produce magnesium hydroxide for use in the chemical industry and for flame-retardant applications;
- calcium and sulphate ions under certain temperature conditions could be reprecipitated into gypsum or anhydrite, which are useful for cement and plaster production; and
- sodium chloride, which can be reprecipitated and used as a preservative (rock salt).

The dataset from the Duperow Formation serves as baseline data that would inform metal brine exploration, enhance well design and inform fluid migration models, CCS projects and potential geothermal projects. Work continues to quantify and map the concentrations of the valuable minerals in the Williston Basin.

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