Memo

To:	Andrew Baryla Hatch	From:	David Morgan Stantec – Winnipeg
File:	Surface Water and Groundwater Interactions at the LMOC Stantec File: 111475107-1200.1206 Hatch Document Number: E358159-1000-220-030-0003 Rev. 0	Date:	August 18, 2021

Reference: ~~Surface Water and Groundwater Interactions in the Region of the Lake Manitoba Outlet Channel~~

This memorandum has been developed in response to a request from Manitoba Infrastructure (MI) to understand the potential interactions between surface water and groundwater in the region of the Lake Manitoba Outlet Channel (the LMOC project). The analysis was completed to support the information request (IR) process for the environmental assessment of the effects of the Lake Manitoba Lake St. Martin Outlet Channels Project (the Project).

OVERVIEW

The LMOC project will require depressurization of the carbonate aquifer in the vicinity of the project during construction and operation to facilitate construction excavation work and maintain channel stability during operations. The depressurization works planned will involve a combination of active (pumped) as well as passive (pressure relief) systems that will reduce pressure in the LMOC area and redirect a portion of the aquifer groundwater to surface water bodies either directly or via the LMOC. This memorandum includes development of conceptual descriptions and quantitative analyses to describe the existing conditions and the potential effect of the LMOC-related groundwater effects on the quality of the receiving surface water bodies. Potential pathways are identified and described/summarized along with an evaluation of the relative potential for effect based on potential flow/volume proportion of the surface water body affected.

SCOPE OF WORK

This memorandum documents the following scope of work:

1. Identify water bodies to be analyzed in the LMOC area.
2. Identify conceptual effect pathways between the bedrock aquifer and surface water bodies by studying the geology in the LMOC area.
3. Review the groundwater pressure data to identify groundwater flow direction and implied locations of major groundwater discharge areas.
4. Conduct analyses on surface water quality and groundwater quality to quantify the nature/magnitude of the potential interactions.
5. Characterize the potential for groundwater/surface water (GW/SW) interactions based on the analyses completed.

ANALYSIS

IDENTIFICATION OF WATER BODIES OF INTEREST

This memo focuses on the interactions between the groundwater bedrock aquifer and key surface water bodies. Water bodies included in this study were selected from the LMOC surface water monitoring program (Stantec 2021a, 2021b) on the basis of potential to receive depressurization water from the LMOC project and the potential for the bedrock aquifer to interact with surface water bodies. Representative wetland lakes along Birch Creek and Watchorn Creek include Reed Lake (D3), Clear Lake (D4), and Water Lake (D10). Lake Manitoba (D1), Lake St. Martin (D9), and the LMOC (upstream and downstream of the water control structure, post LMOC project) are also included in the analyses (Map A-1). Groundwater wells proximate to the wetland lakes were selected from the LMOC groundwater monitoring program to be included in the analyses (Map A-1; Stantec 2021a, 2021b).

During 2019 and 2020 surface water monitoring activities, the total depth of the surface water body was recorded at each surface water sampling location by Stantec personnel. These surface water depths are summarized in Table 1.

Table 1 Surface Water Depths at Sampling Locations

Waterbody	Average Depth (m)	Minimum (m)	Maximum (m)
Lake Manitoba	2	1.8	2.1
Lake St Martin	3.7	3.5	3.8
Watchorn Creek	0.5	0.5	0.5
Reed Lake	0.7	0.57	0.75
Clear Lake	0.64	0.15	0.9
Water Lake	0.29	0.2	0.4
Goodison Lake Outlet	0.5	0.5	0.5
Birch Creek	0.5	0.5	0.5

IDENTIFICATION OF PATHWAYS FOR GROUNDWATER/SURFACE WATER INTERACTION

The potential for groundwater/surface water interaction was examined in the context of a number of factors including:

- subsurface geology and underlying overburden permeability,
- demonstrated groundwater pressure response,
- comparative differences between surface water and groundwater quality, and

- a water balance analysis.

Subsurface Geology and Underlying Overburden Permeability

Permeable strata that provide conduits for groundwater flow between the bedrock aquifer and the surface may provide pathways for GW/SW interaction. The potential for such permeable connections to exist in the LMOC area based on subsurface geology is examined below.

An overall description of the geology and hydrogeology in the area was provided in the environmental impact statement (EIS) (MI 2021a). A 3-D geological model of the LMOC area developed for the preliminary design was used to provide a conceptual understanding of geological stratigraphy in and around the LMOC. The model was based on subsurface, topographic and GIS data with the overburden in the model based on:

- borehole records from previous reports,
- publicly accessible well data from the provincial GWDrill database that includes data from the Groundwater Information Network from 1903 to 2017,
- previous investigations, and
- borehole logs from the 2019 field program along the proposed LMOC (Stantec 2020).

The model interpolates the results between boreholes to provide an estimate of the stratigraphy in the LMOC region. Other information used included earlier geological studies that indicated the locations of near surface (<3 m) bedrock. A further description of the geological units, aquifers, and aquitards in the LMOC region was also provided in the groundwater management plan (MI 2020). The cross-sections in the groundwater management plan illustrate the geological units, aquifers and aquitards that determine the potential for surface water and groundwater interactions under the LMOC and the wetland lakes along Birch Creek and Watchorn Creek.

The location of the LMOC, Birch and Watchorn Creek, and the small lakes and wetlands to the east of the LMOC are shown on Map A-1. The areas of near surface bedrock; where the bedrock is present within 3 m of the surface, are shown on Map A-2. The proposed LMOC location is west of the Birch and Watchorn Creeks, away from the areas of near surface bedrock.

A stratigraphical profile of the geological units under the LMOC was provided in the Groundwater Management Plan (MI 2020). To understand the geology under the wetlands/lakes along Birch and Watchorn Creeks a section showing the stratigraphy along the transect (see Map A-2), was developed, as shown in Figure 1. Under most of the lakes, the till layer ranges in thickness between 8 m and 12 m thick, providing a barrier to the vertical movement of groundwater. Near Reed Lake, the bedrock surface rises and the till layer thins to between 2 m and 3 m.

Reference: Surface Water and Groundwater Interactions in the Region of the Lake Manitoba Outlet Channel

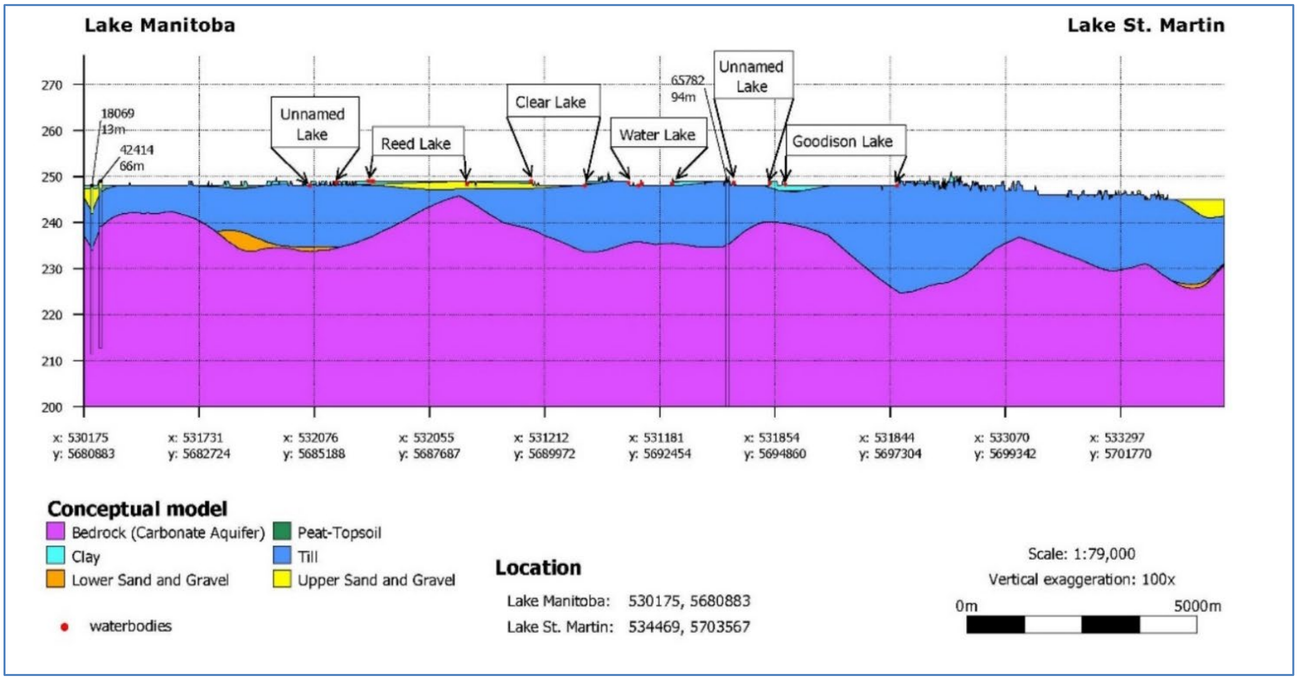

Figure 1 Stratigraphical Profile of Wetlands East of the LMOC

A second cross section perpendicular to the profile was developed through Reed Lake to illustrate the geology in the area (Figure 2). The LMOC is located on the west side of the Birch Valley (the borehole wells TREK-OW 22&23 in Figure 2 are in the LMOC RoW) and Reed Lake is in the center. Beneath Reed Lake a layer of clay overlies a sand and gravel layer. The bedrock rises on the east side of the valley immediately to the east of Reed Lake (see Figure 2 and Map A-2) to an area near the surface. This area of near surface bedrock is a natural recharge area.

Reference: **Surface Water and Groundwater Interactions in the Region of the Lake Manitoba Outlet Channel**

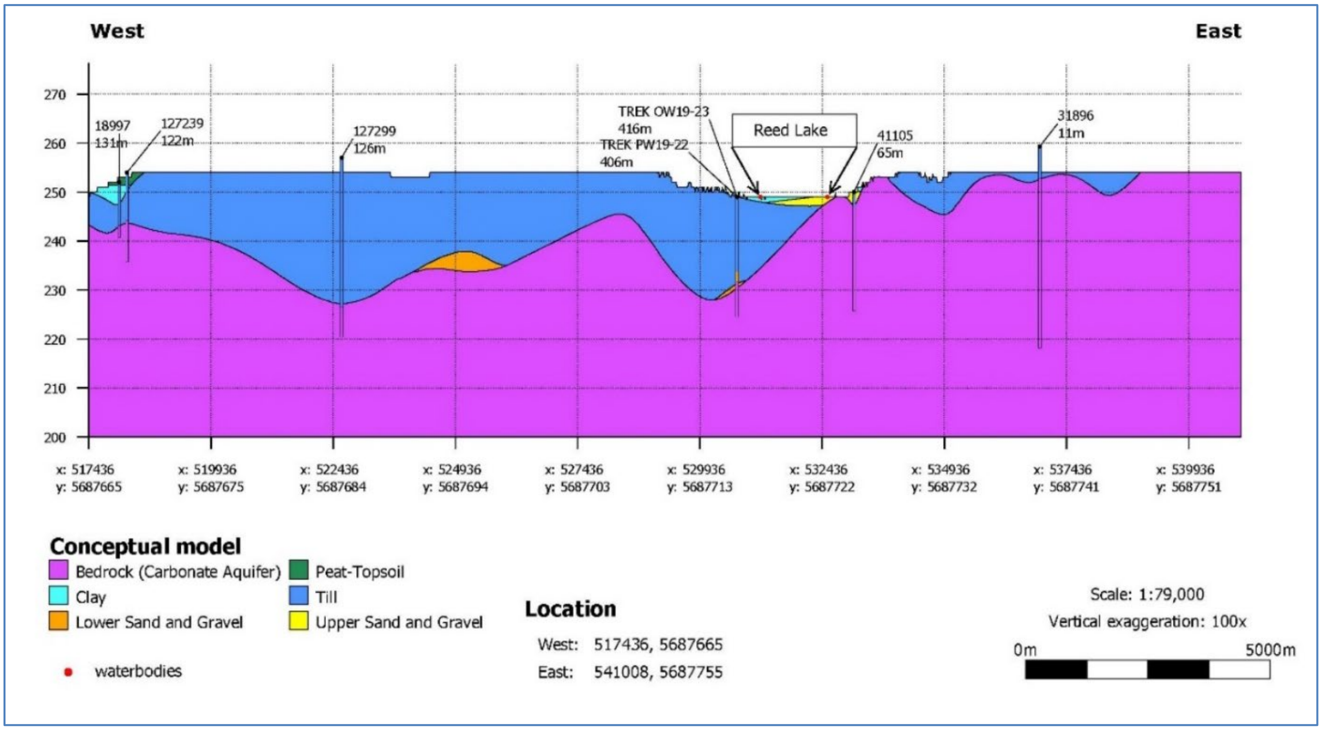

Figure 2 Stratigraphical Profile Crossing Reed Lake

Groundwater Pressure Response

Potential GW/SW interaction pathways can be inferred by examining the groundwater pressure responses to pump tests. Table 2 summarizes the sources of groundwater level data including data from LMOC project specific monitoring programs from 2016 to 2019. Data for two provincial wells (WRB-116766 and WRB-122050) located in the vicinity of the LMOC was provided by the Government of Manitoba (Hydata 2020) to provide long-term data from 2005 to present. These 16 wells were used to define the piezometric groundwater head in the region.

Table 2 Sources of Groundwater Level Data

Groundwater Level Data Source	Date Range	Wells Used
Government of Manitoba	2005 to 2019	WRB-116766 (G05LK001), WRB-122050 (G05LM001)
LMOC Project (KGS 2017)	2016 to 2019	TH-ED-01W (TH-ED-01P), 15-RD-PW1 (TH-GD-07)
LMOC Hatch (Stantec 2021a)	2019	PW19-17, OW19-16, OW19-18, PW19-06, OW19-05, OW19-07, PW19-22, OW19-23, OW19-24, PW19-39, OW19-40, OW19-41

Pump tests were conducted to determine the hydraulic conductivity of the bedrock in the area. Along with groundwater head measurements, the calculated hydraulic conductivity was used to determine the direction and rate of groundwater flow. If there was a location where discharge from the subsurface to the surface was occurring, drawdown of the piezometric surface would indicate discharge. Groundwater head elevations were plotted on graphs to illustrate the pressure head in the region of the LMOC and Birch Creek and identify areas of potential discharge. A numerical groundwater model was developed, calibrated to the local groundwater pressure head data.

The average annual groundwater pressure along the LMOC is plotted against the ground elevation in Figure 3. The pressure head remains about 3-4 m higher than ground level on average, indicating a relatively impermeable barrier between the bedrock aquifer and the surface. The groundwater pressure decreases along the profile moving north (towards Lake St. Martin) and south (towards Lake Manitoba), indicating groundwater flow moving in those directions.

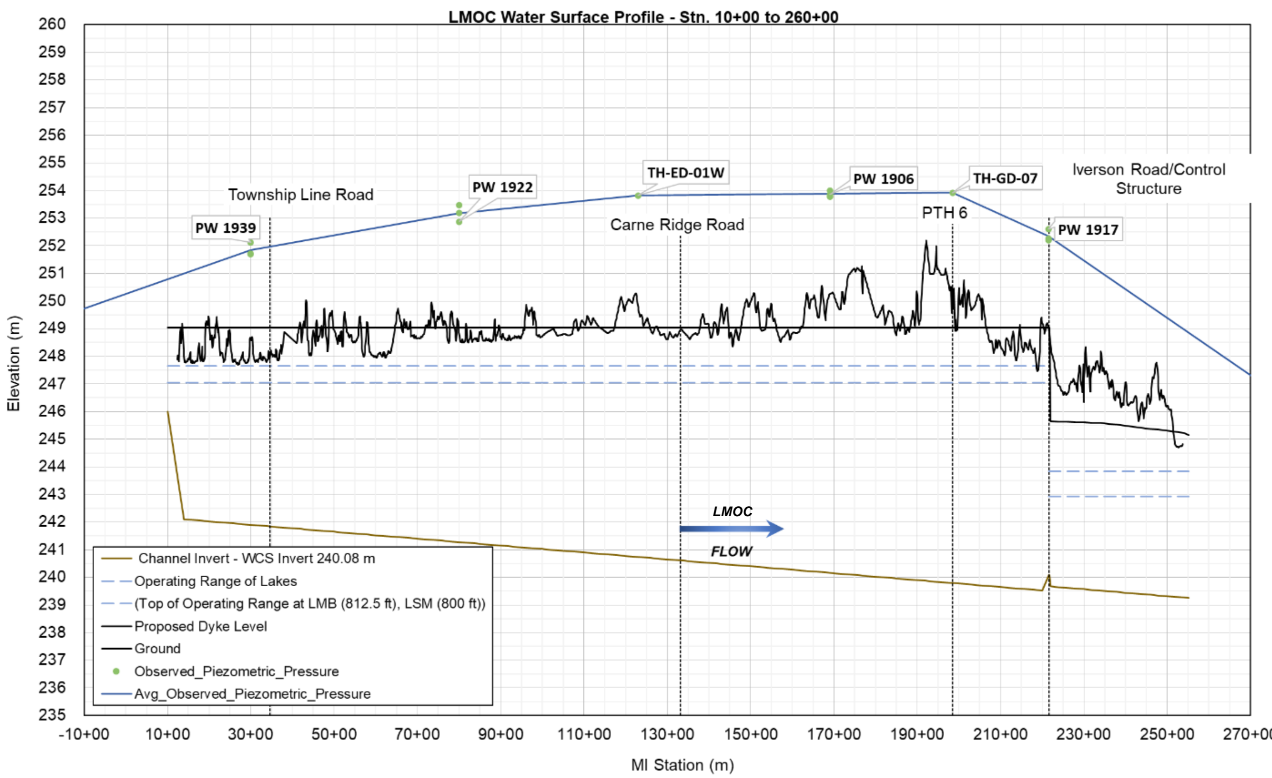

Figure 3 Groundwater Head Along the LMOC Profile

Reference: Surface Water and Groundwater Interactions in the Region of the Lake Manitoba Outlet Channel

The existing groundwater piezometric pressure head in the region of the LMOC and the wetland lakes is shown in Figure 4. The direction of groundwater flow is controlled by the pressure head with the flow moving downgradient, perpendicular to the piezometric pressure head contours. The groundwater flow direction in the vicinity of the LMOC is generally split to the north and northwest toward Lake St Martin and to the west and southwest towards Lake Manitoba.

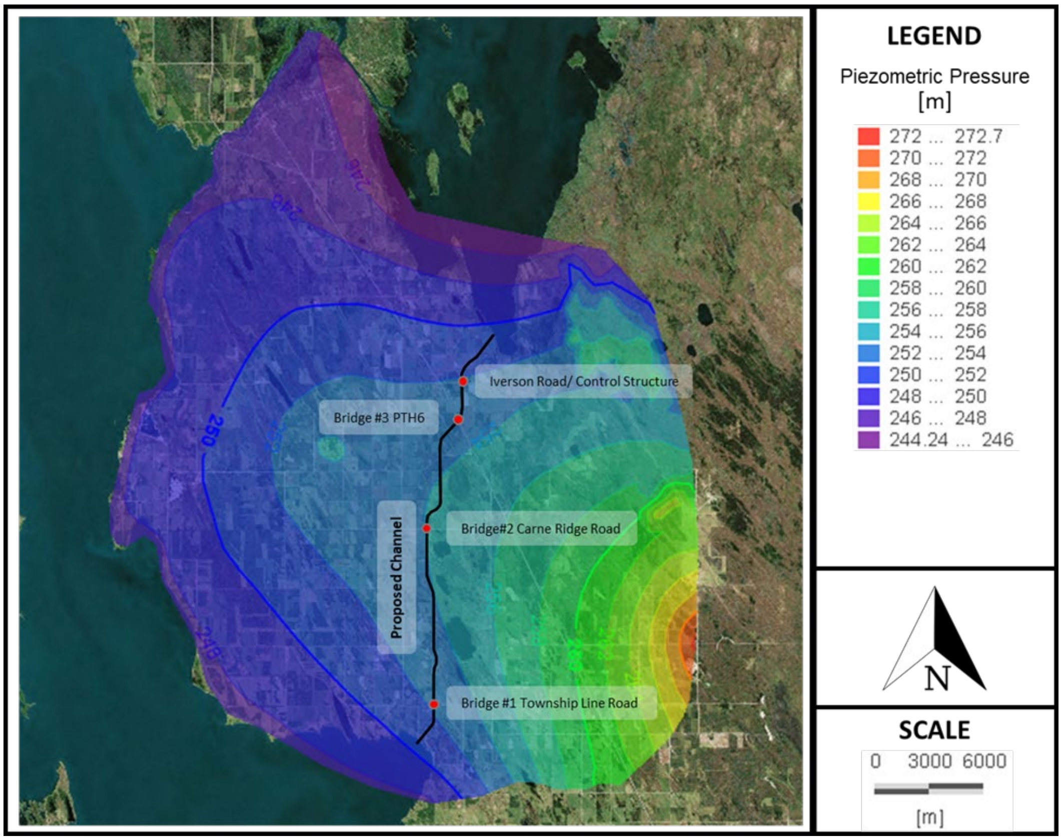

Figure 4 Existing Groundwater Pressure Head in the LMOC Area

The existing average annual piezometric head above ground surface is shown in Figure 5 ranging from 4 m to 8 m above ground surface in the area of the wetland lakes. The region with piezometric pressure above ground includes seepage areas and flowing wells that are discharging to the surface (flowing conditions). Although the flowing wells and seepage areas may be important to local landowners, the amount of flow is not sufficient to depressurize the aquifer and represents a small percentage of the overall groundwater flow that flows under the area and discharges into Lake St. Martin and Lake Manitoba.

If significant groundwater volumes were discharging to the Birch Creek wetland, a measurable drop in piezometric pressure would be evident. There is no evidence of such pressure reduction in the Birch Creek area.

Reference: Surface Water and Groundwater Interactions in the Region of the Lake Manitoba Outlet Channel

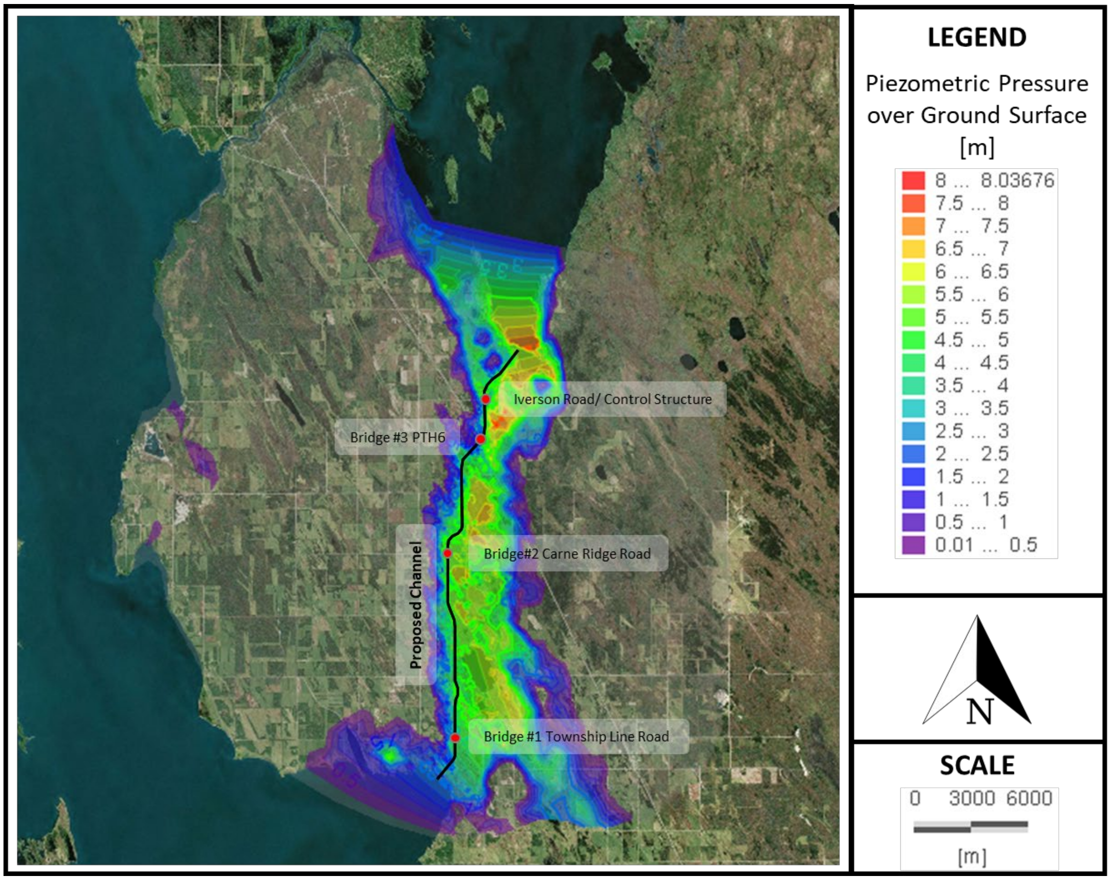

Figure 5 Existing Piezometric Pressure over Ground Surface in the LMOC Area

When the LMOC is depressurized, the artesian flow in some seepage areas and wells will cease but the horizontal groundwater flow will continue within the confined bedrock aquifer, discharging to the LMOC via the depressurization system.

Surface Water and Groundwater Quality

The presence of existing GW/SW interaction pathways in the LMOC area can be inferred based on evaluating differences in quality between surface water and groundwater sources. Data from the 2019 and 2020 LMOC surface water and groundwater monitoring programs were used to provide indications of existing water quality conditions (Map A-1; Stantec 2021a, 2021b, 2021c) and indicators of groundwater/surface water interactions.

Key parameters of interest were identified based on previously collected water quality data that exceeded referenced Canadian Water Quality Guidelines for the Protection of Freshwater Aquatic Life (CWQG-FAL) and Manitoba Standards, Objectives, and Guidelines for the protection of Freshwater Aquatic Life (MSOG--AL) (CCME 2020; MWS 2011). These included dissolved oxygen (DO) concentration data collected in the field, and laboratory analyses for fluoride and total phosphorus. Statistical summary data for these parameters at select surface water and groundwater sites in the LMOC area are provided in Table 3 and

Table 4, respectively. Additional information on Oxygen 18 (^{18}O) and Deuterium (^{2}H) Isotopes was also reviewed.

Dissolved Oxygen Concentration

The mean DO concentration was above the CWQG-FAL (> 5.5 mg/L) at all key surface water bodies in the LMOC area (Table 3). The minimum DO concentrations were below the CWQG-FAL at all of the wetland lakes (D3, D4, and D10) but above criteria at Lake Manitoba (D1) and Lake St. Martin (D9). Not unexpectedly, the mean DO concentration was below the referenced CWQG-FAL at all the monitored groundwater wells in close proximity to the wetland lakes (Table 4).

Total Phosphorus Concentration

The mean total phosphorus concentration was above the MSOG-FAL (0.025 mg/L) at all the key wetland lakes (D3, D4, D10), with the highest mean concentration at Clear Lake (D4; Table 3). Lake Manitoba (D1) and Lake St. Martin (D9) reported mean total phosphorus concentrations below the MSOG-FAL; however, the maximum concentration recorded at Lake St. Martin (D9) exceeded the referenced guideline. At groundwater sites near the wetland lakes, mean total phosphorus concentrations were below the referenced MSOG-FAL, however, maximum concentrations, measured in wells OW19-40 and OW19-23/PW19-22, exceeded the referenced guideline (Table 3).

Some surface water and groundwater samples analyzed for DO and total phosphorus reported concentrations that did not meet the referenced guidelines. However, because both DO and total phosphorus concentrations can be influenced by naturally occurring biological processes, they are not considered conservative indicator parameters. Conversely, fluoride is a conservative element in groundwater, and therefore can be used as an indicator parameter to understand potential groundwater contributions to surface water.

Table 3 Surface Water Quality Statistic Data for Key Surface Water Bodies in the LMOC Area from 2019 to 2020 (Stantec 2021c)

Site ID	Waterbody	Parameter	Units	CWQG-FAL[B]	MSOG-FAL[C]	CDWQ[F]	n	Min	Max	Mean	Standard Deviation
D1	Lake Manitoba	Dissolved Oxygen	mg/L	>5.5/6/6.5/9.5VAR	-	-	6	7.74	16.16	10.71	2.92
		Fluoride	mg/L	0.12	-	1.5	6	0.11	0.16	0.14	0.01
		Phosphorus, Total	mg/L	-	0.025	-	6	0.015	0.024	0.020	0.004
D3	Reed Lake	Dissolved Oxygen	mg/L	>5.5/6/6.5/9.5VAR	-	-	5	0.51	10.50	5.79	3.90
		Fluoride	mg/L	0.12	-	1.5	5	0.11	0.20	0.16	0.03
		Phosphorus, Total	mg/L	-	0.025	-	5	0.026	0.070	0.046	0.02
D4	Clear Lake	Dissolved Oxygen	mg/L	>5.5/6/6.5/9.5VAR	-	-	5	1.87	9.18	7.28	2.48
		Fluoride	mg/L	0.12	-	1.5	6	0.11	0.29	0.23	0.06
		Phosphorus, Total	mg/L	-	0.025	-	6	0.015	0.42	0.11	0.1
D10	Water Lake	Dissolved Oxygen	mg/L	>5.5/6/6.5/9.5VAR	-	-	6	2.57	11.29	7.38	3.10
		Fluoride	mg/L	0.12	-	1.5	6	0.14	0.43	0.28	0.09
		Phosphorus, Total	mg/L	-	0.025	-	6	0.026	0.12	0.062	0.039
D9	Lake St. Martin	Dissolved Oxygen	mg/L	>5.5/6/6.5/9.5VAR	-	-	6	7.12	12.02	9.70	1.77
		Fluoride	mg/L	0.12	-	1.5	9	0.091	0.18	0.14	0.02
		Phosphorus, Total	mg/L	-	0.025	-	9	0.009	0.039	0.022	0.008

Sites listed in order from south to north.

Notes:

CWQG-FAL Canadian Council of Ministers of the Environment

B: Canadian Environmental Quality Guidelines, Canadian Water Quality Guidelines for the Protection of Aquatic Life - Freshwater Aquatics Long Term

MSOG-FAL Manitoba Provincial Water Quality Guidelines

C: Tier I - Water Quality Guidelines - Freshwater Aquatic Life

F: Guidelines for Canadian Drinking Water Quality - Maximum Acceptable Concentration

6.5: Concentration exceeds the applicable guideline

-: no value

VAR: Lowest acceptable dissolved oxygen concentration: for warm water biota: early life stages = 6000 µg/L; for warm water biota: other life stages = 5500 µg/L; for cold water biota: early life stages = 9500 µg/L; for cold water biota: other life stages = 6500 µg/L

Reference: **Surface Water and Groundwater Interactions in the Region of the Lake Manitoba Outlet Channel**

Table 4 Groundwater Quality Statistic Data from Groundwater Wells Proximal to Key Surface Water Bodies in the LMOC Area from 2019 to 2020 (Stantec 2021c)

Site ID	Parameter	Units	CWQG-FAL[B]	MSOG-FAL[C]	CDWQ[F]	n	Min	Max	Mean	Standard Deviation
OW19-40	Dissolved Oxygen	mg/L	>5.5/6/6.5/9.5VAR	-	-	3	1.21	5.64	3.67	1.84
	Fluoride	mg/L	0.12	-	1.5	4	0.353	0.372	0.364	0.007
	Phosphorus, Total	mg/L	-	0.025	-	4	0.0053	0.0303	0.0121	0.0105
CH19-37	Dissolved Oxygen	mg/L	>5.5/6/6.5/9.5VAR	-	-	4	1.20	4.06	2.09	1.16
	Fluoride	mg/L	0.12	-	1.5	4	0.273	0.428	0.372	0.059
	Phosphorus, Total	mg/L	-	0.025	-	4	0.0005	0.0039	0.0018	0.0013
OW19-23 & PW19-22	Dissolved Oxygen	mg/L	>5.5/6/6.5/9.5VAR	-	-	6	1.60	10.80	4.76	3.14
	Fluoride	mg/L	0.12	-	1.5	8	0.750	0.840	0.795	0.031
	Phosphorus, Total	mg/L	-	0.025	-	8	0.0048	0.0304	0.0131	0.0072
BH19-29	Dissolved Oxygen	mg/L	>5.5/6/6.5/9.5VAR	-	-	6	1.32	5.82	2.59	1.54
	Fluoride	mg/L	0.12	-	1.5	6	0.756	0.855	0.811	0.030
	Phosphorus, Total	mg/L	-	0.025	-	6	0.0024	0.0071	0.0044	0.0016

Sites listed in order from south to north.

Notes:

CWQG-FAL Canadian Council of Ministers of the Environment

A: Canadian Environmental Quality Guidelines, Canadian Water Quality Guidelines for the Protection of Aquatic Life - Freshwater Aquatics Short Term

B: Canadian Environmental Quality Guidelines, Canadian Water Quality Guidelines for the Protection of Aquatic Life - Freshwater Aquatics Long Term

MSOG-FAL Manitoba Provincial Water Quality Guidelines

C: Tier I - Water Quality Guidelines - Freshwater Aquatic Life

D: Tier III - Water Quality Guidelines - Freshwater Aquatic Life

E: Guidelines for Canadian Drinking Water Quality - Aesthetic Objectives/ Operational Guidelines

F: Guidelines for Canadian Drinking Water Quality - Maximum Acceptable Concentration

6.5: Concentration exceeds the applicable guideline

-: no value

VAR: Lowest acceptable dissolved oxygen concentration: for warm water biota: early life stages = 6000 µg/L; for warm water biota: other life stages = 5500 µg/L; for cold water biota: early life stages = 9500 µg/L; for cold water biota: other life stages = 6500 µg/L

Fluoride Concentration

Fluoride in groundwater is typically derived from the dissolution and weathering of bedrock and soils containing fluoride-bearing minerals. Fluoride is a conservative element in groundwater, therefore a comparison of fluoride concentrations between surface water sites and proximal groundwater wells sampled in 2019 and 2020 can inform the contribution of groundwater discharge, if any, to the wetland lakes in the LMOC area (Map A-1; Stantec 2021a, 2021b).

Elevated fluoride concentrations in groundwater are found in a number of areas in Manitoba. In the LMOC project area, elevated fluoride concentrations in groundwater have been associated with fresh groundwater within sandstone and shale units of the Winnipeg Formation located along the western shore of Lake Winnipeg and south of the lake (Betcher 1995). Fluoride concentrations, up to 7 mg/L, have also been associated with groundwater in shattered and metamorphosed Precambrian basement rocks of the Lake St. Martin Complex (Betcher 1995). Work published in 2009 traces the possible source of high fluoride groundwaters in the Lake St. Martin area to phosphatic pellets, associated with phosphorites composed of carbonate fluorapatite, within shales of the Winnipeg Formation (Desbarats 2009).

Fluoride concentrations have been measured as part of routine analyses at surface water and groundwater sites in the LMOC area since 2016 (KGS 2017a, 2017b, 2018; Stantec 2021a, 2021b). Concentrations above the referenced CWQG-FAL guidelines (0.12 mg/L; CCME, 2020) in both groundwater and surface water have been recorded since the inception of monitoring programs in 2016 (KGS 2017a, 2017b, 2018; Stantec 2021a, 2021b). Unlike areas to the north and northeast, the possible source of high fluoride concentration in groundwater and surface water in the LMOC area has not been investigated. An expanded number of surface water and groundwater sites beyond the key water bodies of interest were used to evaluate spatial changes along the LMOC. Groundwater wells in close proximity to one another were grouped and a mean concentration value was calculated. In surface water and groundwater samples collected in 2019 and 2020, mean fluoride concentrations varied between groundwater and surface water samples and spatially from south to north (Table 5; Figure 6; Map A-1).

The mean fluoride concentration at surface water sites was lowest in Lake Manitoba (D1), Lake St. Martin (D9), and Reed Lake (D3) and highest in Birch Creek (D6 and D8), Water Lake (D10), and at the outlet of Goodison Lake (D12). The mean fluoride concentration in groundwater was lowest in the most southern (OW19-40 and CH19-37) and northern (CH19-08) wells monitored in the LMOC area. Wells directly west and northwest of Reed Lake (D3), Clear Lake (D4) and Water Lake (D10) in the south and central portion of the LMOC had the highest mean fluoride concentrations (OW19-23/PW19-22 and BH-19-29).

When comparing the mean fluoride concentration between surface water and proximal groundwater sites, most surface water sites in the LMOC area exhibited mean fluoride concentrations between 2-5 times lower than mean fluoride concentrations at the nearest groundwater wells. Exceptions to this include Watchorn Creek (D2), the outlet of Goodison Lake (D12), Birch Creek (D6 and D8), and Lake St. Martin (D9) where mean fluoride concentrations were 1.8 to 2.7 times lower and, in one case the surface water concentration was 12% higher (D8 and CH19-08).

Reference: Surface Water and Groundwater Interactions in the Region of the Lake Manitoba Outlet Channel

Table 5 Mean Fluoride Concentration at Surface Water Sites and Proximal Groundwater Wells for the LMOC Area from 2019 to 2020 (Stantec 2021c)

Waterbody	Surface Water Site ID	Mean Fluoride Concentration (mg/L)[A]	Proximal Groundwater Site ID(s)	Mean Fluoride Concentration (mg/L)[A]
Lake Manitoba	D1	0.14	OW19-40	0.364
Watchorn Creek	D2	0.20	OW19-40	0.364
Reed Lake	D3	0.16	CH19-37	0.372
			OW19-23 & PW19-22*	0.795
Clear Lake	D4	0.23	OW19-23 & PW19-22*	0.795
Water Lake	D10	0.28	BH19-29	0.811
Unnamed Lake Inlet	D11	0.22	BH19-29	0.811
Goodison Lake Outlet	D12	0.28	OW19-05 & PW19-06*	0.531
Birch Creek South	D6	0.29	BH19-12 & CH19-11*	0.54
Birch Creek North	D8	0.28	OW19-16*, OW19-18 & PW19-17*	0.751
			CH19-08	0.25
Lake St. Martin	D9	0.14	CH19-08	0.25

Sites listed in order from south to north.

Notes:

A: Fluoride CWQG-FAL: 0.12 mg/L CWQG-FAL Canadian Environmental Quality Guidelines, Canadian Water Quality Guidelines for the Protection of Aquatic Life - Freshwater Aquatics Long Term

6.5: Shaded cells indicate concentration exceeds the referenced guideline

*sampled in 2019 only

Reference: Surface Water and Groundwater Interactions in the Region of the Lake Manitoba Outlet Channel

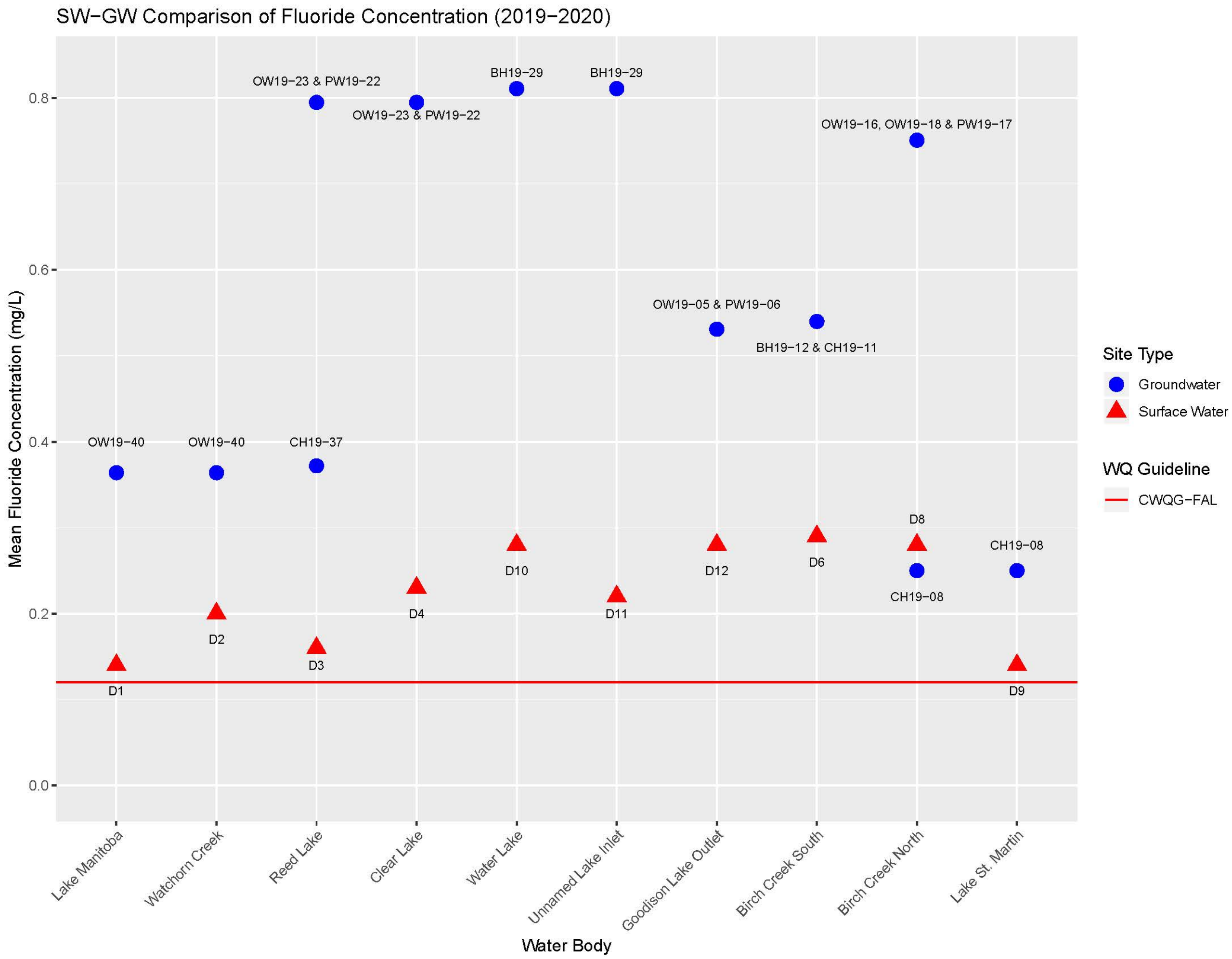

Figure 6 Comparison of Mean Fluoride Concentration at Adjacent Surface Water and Groundwater Sites in 2019 and 2020 (Stantec 2021b, 2021c)

In the LMOC area, fluoride enters the wetland lakes and Birch Creek system from groundwater or surface water sources. The mean fluoride concentration varies spatially with higher concentrations reported in small lakes and streams north of Reed Lake (D3) and lower concentrations in Lake Manitoba (D1) and Lake St. Martin (D9). Mean groundwater fluoride concentrations are typically between two and five times higher than in the proximal surface water bodies (Reed Lake (D3), Clear Lake (D4) and Water Lake (D10). This difference suggests that there could be a contribution of groundwater discharge to these lakes. Fluoride concentrations also increase downstream from 0.16 mg/L in Reed Lake, to 0.23 mg/L and 0.28 mg/L in Clear Lake (D4) and Water Lake. The trend in fluoride concentrations may indicate an increasing contribution of groundwater seepage in the waterbodies further downstream (Table 5, Figure 6) or it could also be a result of evapotranspiration. The evaporative loss of water from the lake will tend to concentrate the mass of fluoride in the lake thereby increasing its concentration.

A simple mass balance model was used to evaluate fluoride concentration results and estimate groundwater input along a transect through the wetland system from Reed Lake (D3) to Clear Lake (D4) to Water Lake (D10). The model considered evaporative loss rates of both 0% and 15%. Between Reed Lake (D3) and Clear Lake (D4), groundwater discharge contributes approximately 13% of total water flow in a scenario where evaporation is not considered (0%), and approximately 6% of total water flow with an assumed evaporative loss of 15%. Between Clear Lake (D4) and Water Lake (D10), groundwater discharge contributes approximately 10% of total water flow in a scenario where evaporation is not considered (0%), and approximately 1% of total water flow with an assumed evaporative loss of 15%. Downstream of Water Lake there appears to be no increase in fluoride suggesting limited to no influence from groundwater discharge.

Oxygen 18 (^{18}O) and Deuterium (^{2}H) Isotopes

A desktop review of previous reports containing materials on stable isotope analyses in the LMOC area was completed. The stable isotopes, oxygen 18 (^{18}O) and deuterium (^{2}H) were analysed as surface water tracers in preliminary engineering water quality studies in the LMOC area from 2016 to 2018 (KGS 2017a, 2017b, 2018). During this time period, water samples were collected from three groundwater wells (TH-ED-01-W, TH-GD-08, and 15-RD-PW1) as well as Lake Manitoba (D1), Clear Lake (D4), and Lake St. Martin (D9) (Map A-3 and A-4) for stable isotope analysis. Sample results are shown on Table 6 and plotted on Figure 7 (KGS 2018).

The review indicated that surface water containing fresh snowmelt during a spring runoff or flood would typically have more negative ^{18}O values, in comparison to other times of the year. Less negative ^{18}O values would be expected later in the season, particularly in lakes where evaporation occurs. Groundwater in areas of recent recharge would have less negative ^{18}O values, while more negative values would indicate older water.

Key findings from the analysis of stable isotope data collected between 2016 and 2018 include:

- The isotopic signatures from Lake Manitoba (D1) and Lake St. Martin (D9) differ slightly from samples collected from Clear Lake (D4) and were markedly different than those from groundwater wells in the LMOC area (TH-ED-01-W, TH-GD-08, and 15-RD-PW1), as shown in Table 6.
- The stable isotope signatures for groundwater collected from bedrock wells (TH-ED-01-W and 15-RD-PW1) and surface water in Clear Lake (D4) are vastly different, which suggests negligible contribution of groundwater discharge to Clear Lake (Table 6 and Figure 7).

A complete summary of stable isotope results is provided in the preliminary engineering reports (KGS 2017a, 2017b, 2018).

Reference: **Surface Water and Groundwater Interactions in the Region of the Lake Manitoba Outlet Channel**

Table 6 Stable Isotopes in Groundwater and Surface Water in the LMOC Area (Table D3-8, KGS 2018)

Sample	Date	Lab#	δ18O H_2O	Result VSMOW	Repeat	δ^2H H_2O	Result VSMOW	Repeat	pH	Conductivity µS/cm
Ground Water										
TH-ED-01W	26-Oct-16	373023	X	-14.72	-14.89	X	-113.02	-112.97	6.51	511
TH-ED-01W	23-May-17	381957	X	-15.14	-15.11	X	-114.18	-113.99	7.38	813
TH-ED-01W	2-Aug-17	384686	X	-14.91	-15.06	X	-113.94	-114.01	7.17	810
TH-ED-01W	4-Oct-17	386776	X	-15.05	-15.10	X	-113.88	-113.78	7.73	844
TH-ED-01W	29-May-18	403342	X	-14.88	-14.91	X	-113.74	-113.46	9.01	811
TH-GD-08	29-Oct-16	373025	X	-14.86	0.16	X	-113.64	-	-	*
15-RD-PW1	24-May-17	381958	X	-15.30	-	X	-115.05	-	7.33	817
15-RD-PW1	1-Aug-17	384687	X	-14.95	-	X	-115.42	-	7.32	792
15-RD-PW1	3-Oct-17	386777	X	-15.05	-	X	-114.78	-	7.71	808
15-RD-PW1	28-May-18	403343	X	-15.06	-	X	-114.82	-	8.94	767
Surface Water										
D-1 LMB	8-Nov-16	374371	X	-9.72	-	X	-75.68	-	8.05	492
D-1 LMB	25-May-17	381959	X	-8.83	-8.81	X	-75.80	-75.55	8.32	936
D-1 LMB	3-Aug-17	384688	X	-8.26	-8.42	X	-73.98	-73.79	8.01	932
D-1 LMB	5-Oct-17	386778	X	-8.09	-8.00	X	-72.38	-72.11	6.87	945
D-1 LMB	30-May-18	403344	X	-8.06	-8.01	X	-73.16	-72.56	7.15	849
D-4 Clear Lake	8-Nov-16	374374	X	-11.31	-11.29	X	-80.81	-80.67	8.84	532
D-4 Clear Lake	25-May-17	381960	X	-10.67	-	X	-90.14	-	8.33	696
D-4 Clear Lake DUP	25-May-17	381962	X	-10.68	-10.75	X	-89.83	-89.67	8.33	696
D-4 Clear Lake	3-Aug-17	384689	X	-9.02	-	X	-75.86	-	7.02	659
D-4 Clear Lake DUP	3-Aug-17	384691	X	-8.84	-9.06	X	-75.05	-75.18	7.02	659
D-4 Clear Lake	5-Oct-17	386779	X	-7.23	-	X	-66.07	-	6.93	731
D-4 Clear Lake DUP	5-Oct-17	386781	X	-7.19	-7.16	X	-65.85	-65.98	6.93	731
D-4 Clear Lake	30-May-18	403345	X	-10.31	-	X	-93.41	-	7.15	789
D-4 Clear Lake DUP	30-May-18	403347	X	-10.16	-10.20	X	-92.64	-92.86	7.15	789
D-9 LSM	8-Nov-16	374372	X	-8.46	-8	X	-72.86	-73.00	8.41	691
D-9 LSM-DUP	8-Nov-16	374373	X	-8.51	-	X	-72.83	-	8.41	691
D-9 LSM	25-May-17	381961	X	-9.00	-	X	-77.15	-	8.18	932
D-9 LSM	3-Aug-17	384690	X	-8.62	-	X	-75.34	-	7.2	970
D-9 LSM	5-Oct-17	386780	X	-8.25	-	X	-72.78	-	6.43	959
D-9 LSM	30-May-18	403346	X	-8.14	-	X	-73.23	-	6.48	960

Reference: Surface Water and Groundwater Interactions in the Region of the Lake Manitoba Outlet Channel

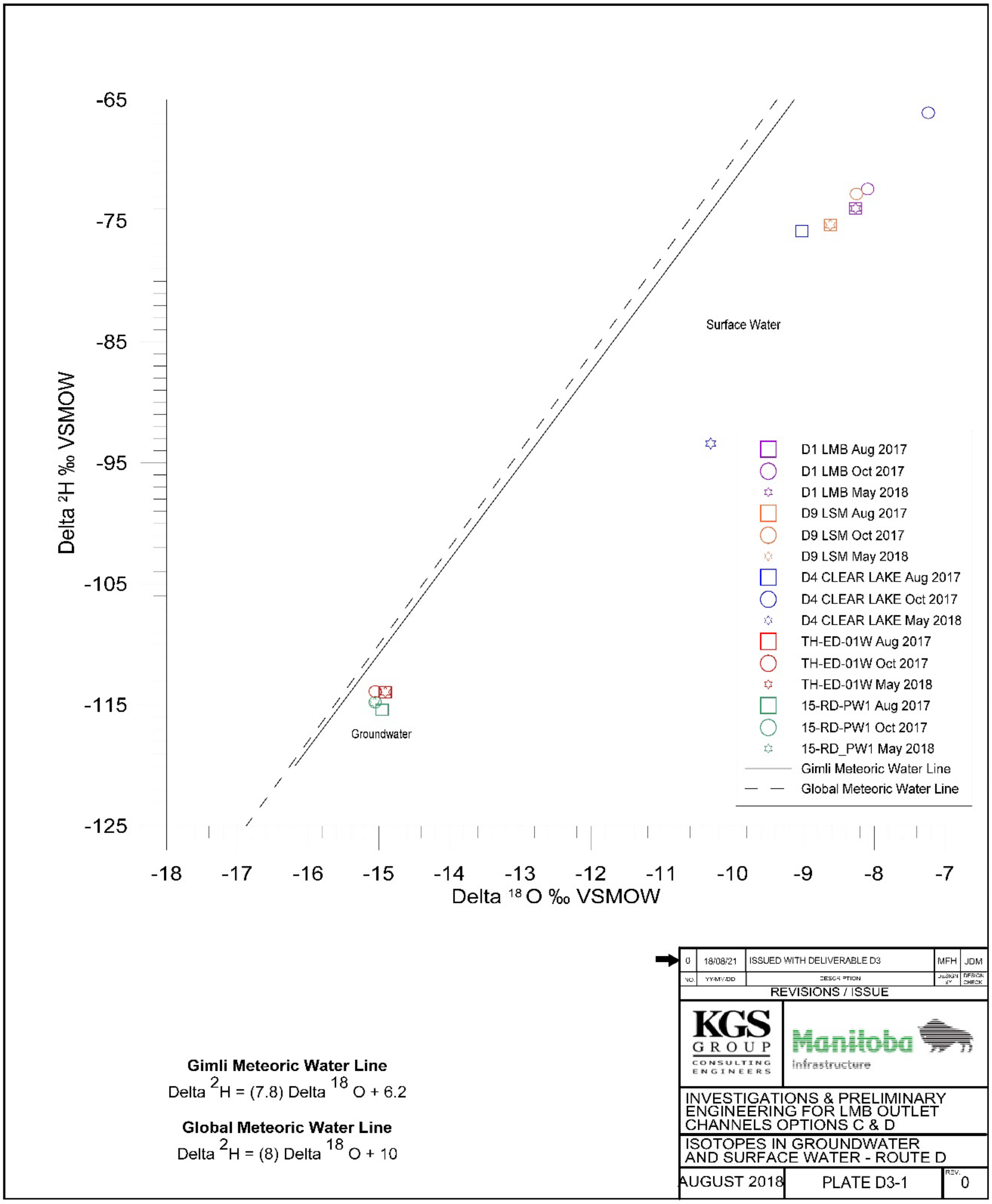

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Figure 7 Oxygen 18 (^{18}O) and deuterium (^{2}H) Isotopes in Groundwater and Surface Water in the LMOC Area (KGS 2018)

Water Balance Analysis

The relative proportion of groundwater inflow to the surface water bodies and wetland lakes is a key factor in the potential for changes in groundwater to affect surface water quality.

Wetland Lakes

To understand the relative volumes of surface water and groundwater flowing though the LMOC/Birch Creek /Watchorn Creek region, an estimate of groundwater and surface water flow was developed (Stantec 2021d). The groundwater flow through the region was estimated using the groundwater flow model derived from pump tests and monitoring in the region. The rate of groundwater recharge in the Birch Creek and Watchorn Creek sub-basins ranged from 2,761 m^3/d to 4,418 m^3/d or 0.03 to 0.05 m^3/s.

Surface water flow was based on data collected from long-term gauging stations; to develop average monthly runoff/area relationships for the region and an average annual flow for the Birch and Watchorn Creeks (Stantec 2021d). The average annual surface water flow in Birch Creek and Watchorn Creek is estimated to total 0.76 m^3/s (Stantec 2021d).

If a portion (even as high as 10%) of the expected groundwater flow from the sub-basins to the major lakes was to instead seep upwards into the Birch or Watchorn Creek systems, it would still represent a very small part (<1%) of the overall water balance of those creek systems and would be difficult to practically detect.

Lake St. Martin

As discussed in the regional groundwater balance memorandum (Stantec, 2021d), the average rate of groundwater seepage into Lake St. Martin is estimated as 5,689 m^3/d (0.07 m^3/s) with an estimated peak rate of 9,102 m^3/d (0.10 m^3/s) in summer. This is a negligible fraction of the 55 m^3/s average surface water flow rate through Lake St. Martin. As the rate of groundwater seepage is very small when compared to the surface water flow the effect of changes in groundwater seepage on the water quality of the lake will be small.

Lake Manitoba

As discussed in the regional groundwater balance memorandum (Stantec 2021d) the amount of groundwater discharging through the study area into Lake Manitoba is very small relative to the size of the lake and flow through the lake. Project-related changes in groundwater discharge to the lake would not produce detectable changes in water quality.

LMOC

When the LMOC is complete, depressurization groundwater will discharge into the LMOC. The rate of depressurization groundwater discharge will be very small when compared to the overall volume of water in the channel. Local rainfall and runoff into the channel may influence the water quality. When the water control structure gates are opened, water will enter from Lake Manitoba diluting any elevated fluoride concentrations from the groundwater input. No measurable changes in water quality, from the Lake Manitoba water quality baseline, are expected due to groundwater interactions.

POTENTIAL FOR SW/GW INTERACTIONS

In consideration of the factors examined, the potential for SW/GW interactions can be summarized.

Based on Geology

Investigation of the geology along Birch Creek and Watchorn Creek indicates that the creeks are underlain by a thick layer of till. Near-surface groundwater flow is limited within the discontinuous coarser sediment deposits within the till unit. The till unit is expected to prevent vertical groundwater discharge from the bedrock aquifer, therefore limiting direct exchange between surface water and groundwater. An exception to this is located east of Reed Lake, further from the LMOC project, where the bedrock surface rises and the thickness of the confining till layer reduces to 2-3 m. The decrease in till thickness suggests that groundwater discharge may have a higher influence in this area simply due to the combination of geology (thinning of confining layer, increased elevation of bedrock) and high piezometric pressure. Mass balance modeling along the Reed Lake – Clear Lake – Water Lake transect did support higher expected groundwater discharge between Reed Lake and Clear Lake, which is possibly related to the local geology. As bedrock nears the surface, there is also an increased potential for recharge of the aquifer to occur if the piezometric pressure drops below the ground elevation in that area. For the Lakes downstream of Reed Lake the impermeable thick till layer will limit upward seepage from the bedrock aquifer.

Based on Groundwater Pressure Response

Measurements of piezometric head in the LMOC region range between 4 m and 8 m above ground surface. There may be locations where high groundwater head may combine with fissures or sand lenses, or water wells that are not capped or sealed properly, to produce localized areas of upward flow (seepage). If the wetland lakes were fed by a major groundwater discharge area or seepage areas, then the local potentiometric surface in this area would be lower than is seen elsewhere in the Project study area. This circumstance has not been identified in the LMOC area.

Although the flowing wells may be important to local landowners, the flows from the wells and seepage areas represent a small percentage of the overall groundwater flow passing under the area, which discharges into Lake St. Martin and Lake Manitoba. Such groundwater discharge rates have not been substantial enough to cause a detectable change in the pressure head in this area.

Based on Water Quality

In the LMOC area, fluoride enters the wetland lakes and Birch Creek system from groundwater or surface water sources. Higher fluoride concentrations have been reported in small lakes and streams north of Reed Lake (D3) with lower concentrations in Lake Manitoba (D1) and Lake St. Martin (D9). Groundwater fluoride concentrations are typically between two and five times higher than the proximal surface water bodies. This difference combined with the surface water concentrations suggests that there could be a limited contribution of groundwater discharge to these lakes. The percentage of groundwater discharge in the upper reaches of the Birch Creek wetlands (from Reed Lake to Clear Lake) is likely small; in the range of 6% to 13% of the flow. Further downstream the percent of groundwater discharging into Birch Creek would be even less, representing <1% of the surface water flow.

Stable isotope analyses indicated only a limited general influence of groundwater on surface water quality in Clear Lake relative to Lake Manitoba and Lake St. Martin. The stable isotope signatures for groundwater collected from bedrock wells and surface water in Clear Lake were markedly different, which suggests a negligible contribution of groundwater discharge to Clear Lake.

Based on Water Balance

The overall rate of groundwater discharge from the bedrock aquifer to the surface in the LMOC area is very small compared to rainfall and surface water runoff within the area of the Birch Creek lakes and wetlands. The small proportion of surface water flows made up by potential groundwater discharges would make LMOC-related changes in groundwater discharge to surface difficult to practically detect in Birch or Watchorn Creek.

CONCLUSIONS

When the local confined aquifer is depressurized during construction of the LMOC, the existing artesian flow in some seepage areas and flowing wells will be reduced or stop. The groundwater that is pumped out to depressurize the aquifer will be discharged into the LMOC and then will flow via the channel into Lake Manitoba and Lake St. Martin.

Although the existing flowing wells and seepage areas do not account for a large volume of groundwater discharge, they are important to local landowners. While the piezometric head in the bedrock aquifer will decrease because of the LMOC project, it will remain sufficiently high to allow for access to groundwater in the bedrock aquifer. Should the piezometric pressure in the bedrock aquifer drop below the base of a well, a new well can/will be drilled to allow pumped water to be drawn for domestic or livestock use. Flowing wells that are not being used should be decommissioned as part of good practice to prevent localized groundwater contamination. Landowners will still be able to pump water up from the aquifer before it reaches the depressurization system and flows out to the discharge areas via the LMOC.

The Birch Creek and Watchorn Creek valley is in a region of high piezometric pressure (4 to 8 m above ground) from an underlying confined bedrock aquifer. A thick impermeable till layer is present under most of the valley, limiting upward groundwater seepage flow to surface. An exception exists to the east of Reed Lake, further from the LMOC, where bedrock is present closer to the surface. The change in fluoride concentrations in the downstream wetland lakes (from Reed Lake to Clear Lake to Water Lake) suggests some potential influence from groundwater discharge in this respect. The percentage of groundwater discharge in the upper reaches of the Birch Creek wetland lakes (from Reed Lake to Clear Lake) is likely small; in the range of 6% to 13% of the flow. Further downstream the percent of groundwater discharging into Birch Creek would be even less, representing <1% of the surface water flow. Therefore, effects of changes in groundwater discharge may be seen between Reed Lake and Clear Lake but are expected to be negligible downstream of Clear Lake.

For Lake Manitoba, Lake St. Martin and the proposed LMOC, the change in the rate of groundwater discharge into these waterbodies is/will be small relative to their volume of water and rate of surface water flow. Therefore, effects of changes in groundwater discharge in these water bodies would be nearly immeasurable under current conditions and operation of the Project.

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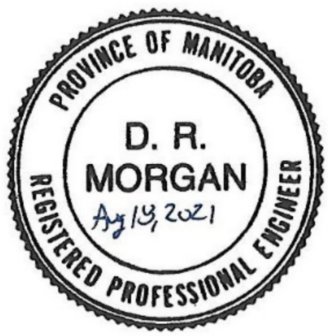
Reference: **Surface Water and Groundwater Interactions in the Region of the Lake Manitoba Outlet Channel**

Stantec Consulting Ltd.



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GEOSCIENTISTS
MANITOBA
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Geologist in Training
Phone: 431-588-9664
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Reference: Surface Water and Groundwater Interactions in the Region of the Lake Manitoba Outlet Channel

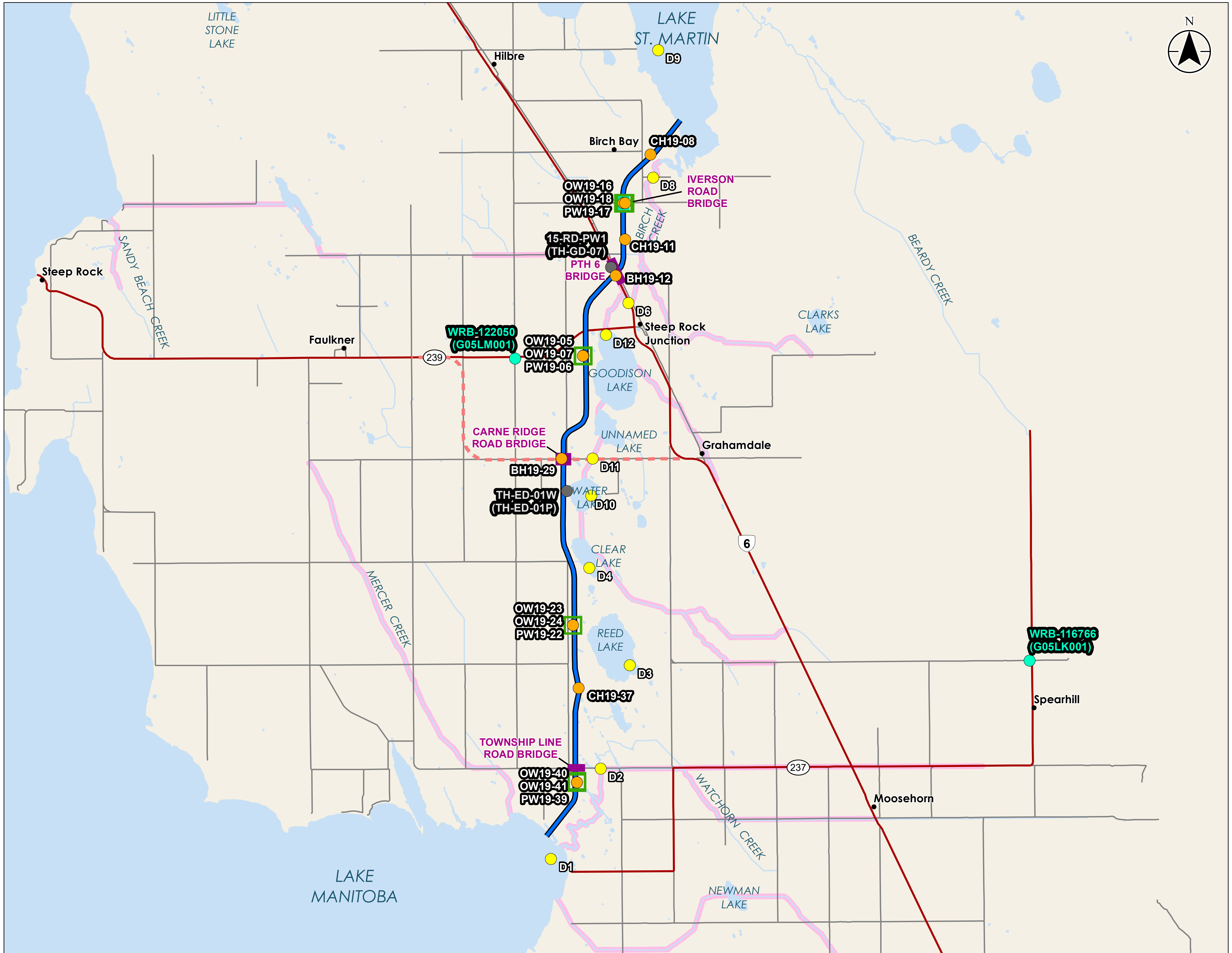
APPENDIX A – MAPS

Map A-1 – Surface Water and Groundwater Sample Locations in the LMOC Area (2019-2020)

Map A-2 – Near Surface Bedrock with Less Than 3 m Overburden

Map A-3 – Plate D4-6.1 – Groundwater and Surface Water Stable Isotope Sample Locations in the south LMOC Area (2016-2018)

Map A-4 – Plate D4-6.2 – Groundwater and Surface Water Stable Isotope Sample Locations in the north LMOC Area (2016-2018)



Stantec

Project Infrastructure

- Proposed Lake Manitoba Outlet Channel
- Proposed PR 239 Realignment
- Proposed Bridge
- Proposed Water Control Structure

Sample Site

- Surface Water Quality Site (Stantec)
- Groundwater Quality Site (Stantec)

Groundwater Level Site

- LMOC project (KGS 2017)
- Government of Manitoba
- LMOC Hatch (Stantec 2020a)

Landbase

- Community
- Highway
- Major Road
- Watercourse
- Provincial Waterway/Drain
- Waterbody

0 2.5 5 Kilometres

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Notes

1. Coordinate System: NAD 1983 UTM Zone 14N
2. Base features provided by the Government of Manitoba and the Government of Canada.

Project Location 111475107
Lake Manitoba and
Lake St. Martin Outlets

Prepared by ACampigotto on 2021-04-29
Technical Review by TStainton on 2021-04-29

Client/Project
MANITOBA INFRASTRUCTURE
Lake Manitoba Outlet Channel

Map No.
A1

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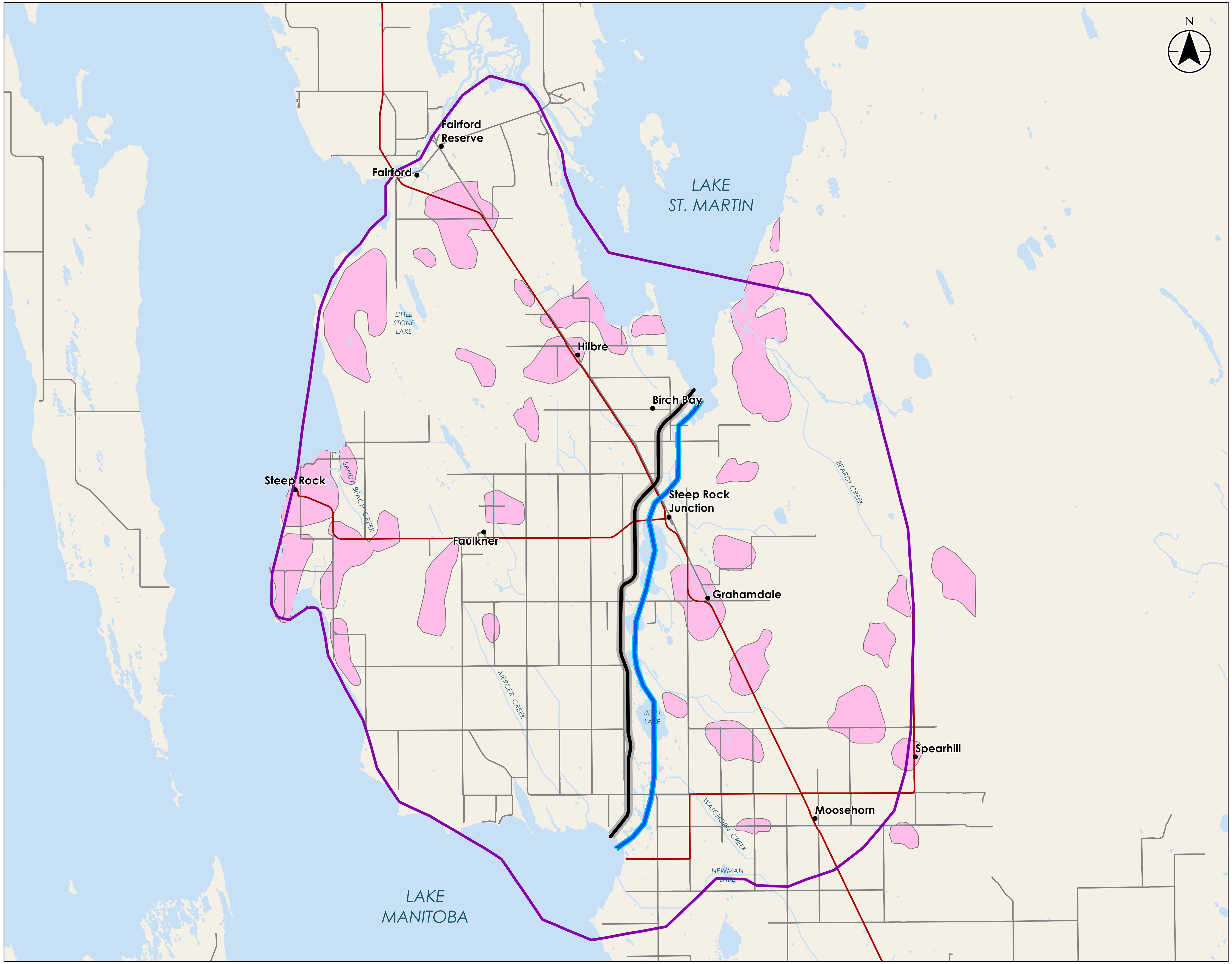
Surface Water and Groundwater Sample Locations in the LMOC Area (2019-2020)



Stantec

Project Infrastructure

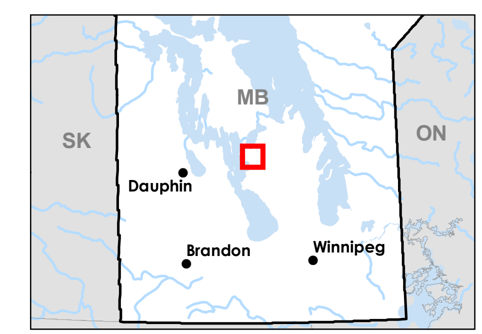
- Proposed Lake Manitoba Outlet Channel
- Channel RoW

Survey Locations

- Geologic Profile along Birch Creek
- Groundwater Model Domain
- Near Surface Bedrock

Landbase

- Community
- Highway
- Major Road
- Watercourse
- Waterbody



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Notes

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2. Base features provided by the Government of Manitoba and the Government of Canada.

Project Location 111475107
Lake Manitoba and
Lake St. Martin Outlets

Prepared by ACampigotto on 2021-03-23
Technical Review by DMorgan on 2021-03-23

Client/Project
MANITOBA INFRASTRUCTURE
Lake Manitoba Outlet Channel

Map No.
A2

Title
Near Surface Bedrock with Less than 3 m Overburden

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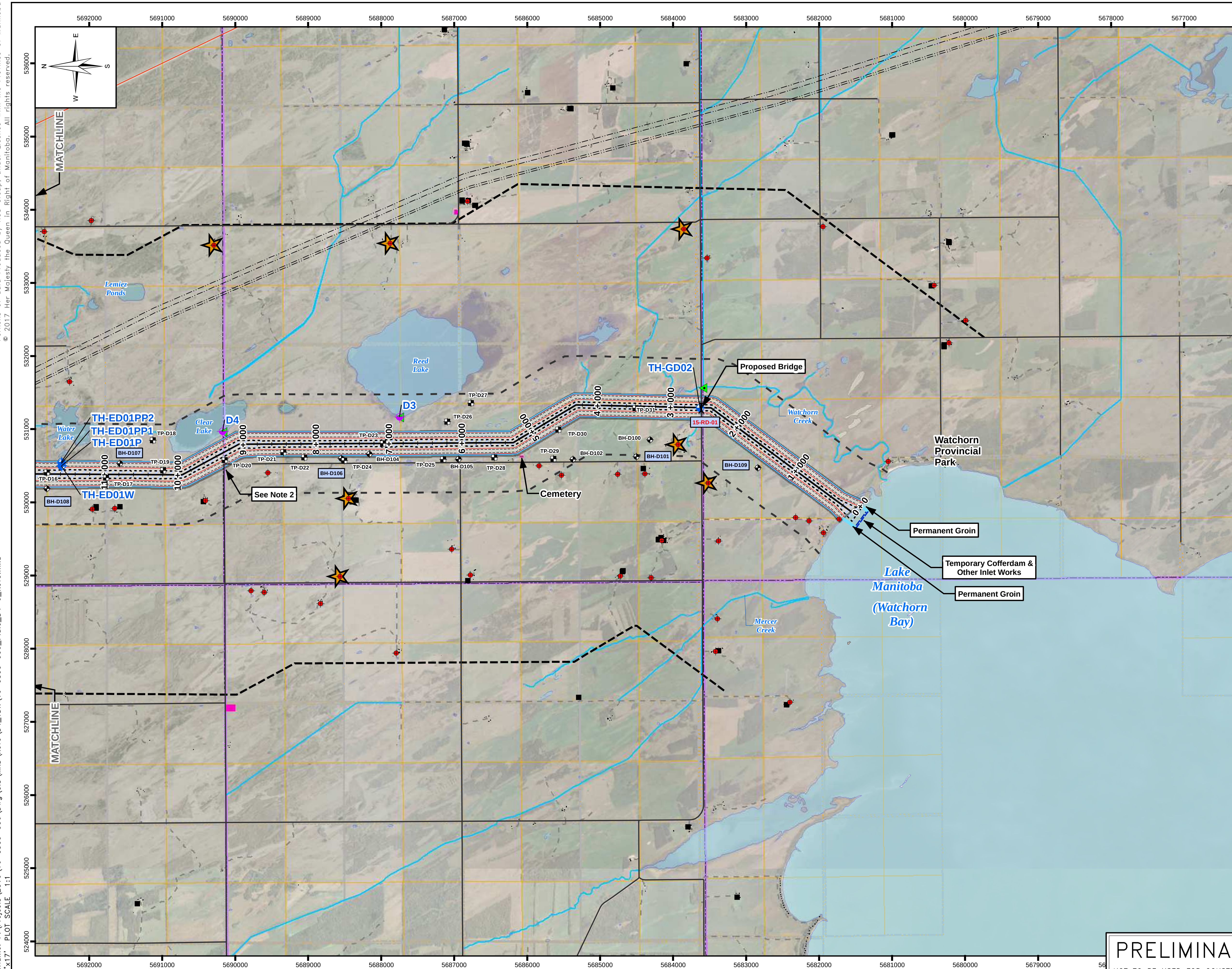

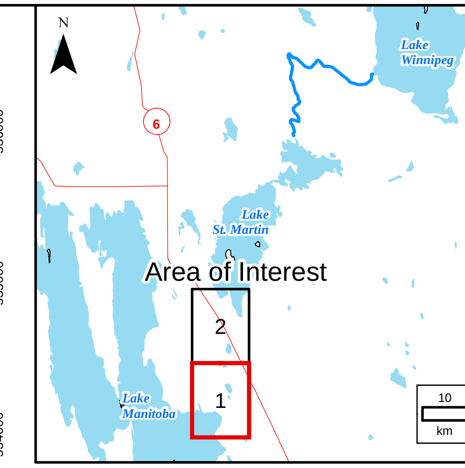

LEGEND:

- Potential Domestic Well Location (MI ID)
- Domestic Well Location (MI ID) In Well Inventory
- Surface Water Locations
- Logger (November, 2016)
- Testhole (November, 2016) (G:Geotechnical, E:Environmental)
- Test Hole (June, 2015)
- Borehole (2011)
- Test Pit (2011)

Utility Lines
- Transmission Line (Existing)

Roads
- Paved Road/Street (1 or more lanes)
- Gravel Road
- Dry Season Road
- Proposed Road Re-alignment

Water Features
- River/Stream/Ditch
- Lake

Boundaries
- Section
- Quarter Section
- Township
- First Nation
- 3 km channel buffer
- 500m distance from Channel ROW

NOTES:
1. Imagery is dated 2007 – 2011 and supplied by the Province of Manitoba, Manitoba Land Initiative.
2. Final channel and spoil pile alignment to accommodate bipole transmission line towers, road realignments, privately owned structures, etc.
3. All units are metric and in metres unless otherwise specified. Transverse Mercator Projection, NAD 1983, Zone 14. Elevations are in metres above sea level (MSL).

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Kilometres
SCALE: 1:50,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
0	17/05/10	ISSUED WITH DELIVERABLE D4	MFH	JDM

REVISIONS / ISSUE

KGS GROUP CONSULTING ENGINEERS
Manitoba Infrastructure

INVESTIGATIONS & PRELIMINARY ENGINEERING FOR LMB OUTLET CHANNELS OPTIONS C&D

POTENTIAL THIRD-PARTY WELL AND INVENTORY LOCATIONS ROUTE D

MAY 2017 | PLATE D4-6.1 | REV: 0

MAP A3

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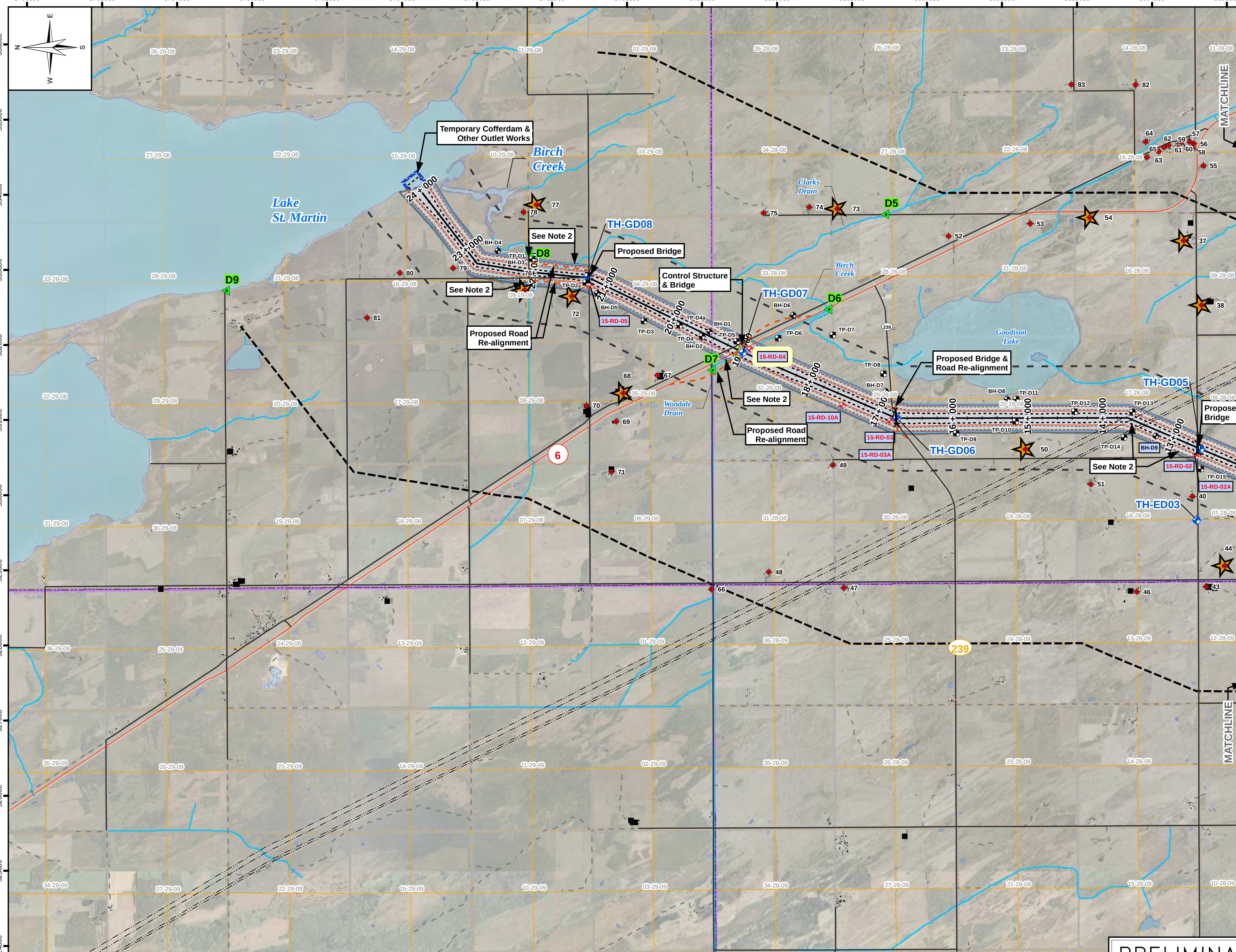

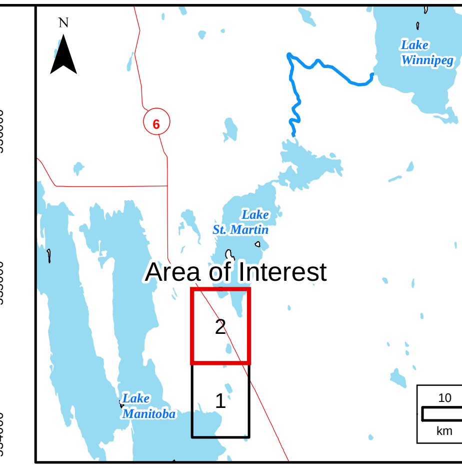

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- Township
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- 3 km channel buffer
- 500m distance from Channel ROW

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0.5 0 0.5 1 1.5 2

Kilometres

SCALE: 1:50,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
0	17/05/10	ISSUED WITH DELIVERABLE D4	MFH	JDM

REVISIONS / ISSUE

KGS GROUP CONSULTING ENGINEERS

Manitoba Infrastructure

INVESTIGATIONS & PRELIMINARY ENGINEERING FOR LMB OUTLET CHANNELS OPTIONS C&D

POTENTIAL THIRD-PARTY WELL AND INVENTORY LOCATIONS ROUTE D

MAY 2017

PLATE D4-6.2 REV: 0

PRELIMINARY

NOT TO BE USED FOR CONSTRUCTION

MAP A4

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