KGS GROUP

Memorandum

To:	James Betke, P.Eng.	**Date:**	July 29, 2021
		Project No.:	18-0300-005.1208
From:	Jason Mann, M.Sc., P.Geo.		
Re:	**Lake St. Martin Outlet Channel Groundwater Water Levels Assessment - Final Rev 0**		

1.0 INTRODUCTION

The following memo is the second part of a Lake St. Martin Outlet Channel (LSMOC) groundwater assessment. The first part of the assessment, "Lake St. Martin Outlet Channel Groundwater Quality Assessment" (Rev 0) dealing with regional and local water quality conditions will be issued as a reference report with the information response. A site plan of the area is given in Figure 1.

Some of the key highlights of the water quality assessment memo are as follows:

- The geochemistry of surface water samples collected from the perched peat deposits show a chemistry similar to the bedrock groundwater. Even in areas where the thick low permeability till aquitard prevents direct discharge of bedrock groundwater to the surface, the water quality in the peat and fens has a bedrock groundwater signature. This is due, presumably, to artesian spring discharge in other locations in the region of the LSMOC.
- Studies in the region show that the till has good integrity, and functions as an aquitard overlying the bedrock aquifer as shown by till thickness, geochemistry and hydraulic gradients. The till is generally thick and has a low permeability. The till groundwater geochemistry is unique from both the bedrock aquifer groundwater geochemistry and surface water geochemistry. Measurements in the till show upward gradients, to flowing artesian conditions, demonstrating a confined condition for the underlying bedrock aquifer throughout the region of the LSMOC.
- Bedrock groundwater geochemistry north of the Dauphin River in Dauphin River First Nation is distinct from groundwater found south of the river. This would indicate that the Dauphin River is a discharge boundary condition for the regional aquifer.
- Bedrock groundwater geochemistry along the LSMOC channel alignment is generally similar and consistent.
- Tritium and stable isotope results for δ18O indicate a generally recent recharge source for the groundwater system, and relatively short aquifer residence times, particularly in aquifer areas in the vicinity of the existing Reach 3 channel.

This memo characterizes the groundwater levels and typical aquifer water level characteristics of the groundwater system in the vicinity of the LSMOC, using the water level monitoring data available within this region.

1.1 Description of Regional Groundwater Aquifers

Two distinct groundwater systems are known to be present within the region of the LSMOC; an upper saturated peatland/fen system, and a lower confined carbonate bedrock aquifer. Glaciolacustrine clays/clay tills, and silt tills form a low permeability aquitard between the perched peat groundwater flow system, and the underlying confined carbonate bedrock aquifer system.

The upper, saturated peat and fen unit is perched above the clays (where present) and underlying till units. The peat is recharged directly from surface rainfall and snowmelt. Groundwater flows within the peat are locally controlled. Small-scale flow systems develop from raised bog/peat mound areas, flowing radially outward toward relatively lower-lying depressions and other associated open water areas. The water table within the peat is at, or near, ground surface, with an overall hydraulic gradient, including surficial flow, to the east.

Water levels within the perched peat and fen wetlands are largely impacted by surface water measures and drainage modifications described within the LSMOC Surface Water Management Plan. Any changes in bedrock piezometric pressures as a result of the LSMOC project are not estimated to cause measurable effects on the peatlands in areas in proximity to the LSMOC, due to the presence of the extensive silty clay and dense silt till aquitard in most of the project region. Changes in groundwater piezometric pressures within the bedrock aquifer could possibly alter the total discharge of groundwater to the surface wetlands and fens that are directly interconnected via artesian springs, such as in proximity to the Big Buffalo Lake complex and Big Buffalo Creek, and along the shores of Lake Winnipeg near Willow Point. These possible changes in baseflow discharge of bedrock aquifer groundwater to the surface water system could potentially impact the associated aquatic and terrestrial habitat.

Glaciolacustrine clays/clay tills, and silt tills form a low permeability aquitard between the perched peat and fen groundwater flow system, and the underlying confined carbonate bedrock aquifer system. The perched water levels in the surficial peat are maintained by the regional surface water drainage patterns combined with the influence of the underlying low permeability aquitard, restricting any downward drainage. The aquitard also maintains confined piezometric pressure, to flowing artesian pressures, within the bedrock aquifer. The piezometric pressures confined within the bedrock, over geologic time, have also given rise to relatively high piezometric pressures within the overlying till aquitard as well. Along the upper reaches of the LSMOC, piezometric pressures within the till aquitard are very near the top of the aquitard itself, and near the base of the overlying peat. In these areas there is an upward gradient between the bedrock aquifer and till aquitard piezometric pressures. In areas closer to the artesian spring sites and down channel from the existing Emergency Reach 3 channel, bedrock aquifer pressures remain confined but are somewhat reduced, due to the natural discharges at the spring sites. In these areas, the till and clay aquitard pressures are somewhat higher than those measured in the bedrock aquifer. Here, downward gradients from the aquitard to the bedrock aquifer are more common. Negligible recharge through the aquitard to the bedrock is expected, as recharge to the bedrock occurs regionally within bedrock outcrop areas, and/or where the bedrock topography is high, and the overlying till cover is thin.

1.2 Description of Regional Groundwater Flow System

Key regional recharge areas of note for the confined bedrock aquifer occur near Gypsumville, and along outcrop areas that occur immediately to the north-northwest and south of the Lake St. Martin Narrows. In addition, the high elevation bedrock bluff area approximately 10 km southeast of Lake St. Martin, also functions as a sub-regional bedrock aquifer recharge area. The bedrock surface in this location is situated well above the aquifer piezometric pressure surface. In the region of the LSMOC, in the Dauphin River area, (or in any location in proximity to Lake Winnipeg or Lake St. Martin) the confined piezometric pressure within the bedrock aquifer has been observed to be very near, and in some cases above, the ground surface (i.e., flowing artesian). This occurs because Lake Winnipeg and Lake St. Martin, and associated low-lying wet areas near the lakes, are key discharge areas for the bedrock aquifer. Because of this, a strong upward gradient for discharge is anticipated, and has been observed to be present, in areas close to Lake Winnipeg, including within the region of the Lake St. Martin Outlet Channel.

Detailed contours of the bedrock aquifer piezometric pressures observed in instrumented test holes and monitoring wells during 2019 monitoring activities have been contoured as part of Preliminary Design. A schematic of these contours is presented in Appendix A-1, along with the locations of artesian groundwater spring sites as interpreted from aerial photography and field observations. Discharge of the confined bedrock aquifer (in the form of artesian groundwater springs) is noted in the region of the LSMOC as follows:

- Discharge as baseflow to Lake St. Martin and Lake Winnipeg, limited by the overlying till aquitard that is found below the recent lake sediments.
- Discharge as baseflow through exposed bedrock to the existing Reach 3 Channel.
- Discharge as a series of flowing artesian springs draining northwesterly to Lake St. Martin. These springs discharge at ground surface elevations between approximately El. 250 m to El. 255 m at the west toe of slope of the high ground area located immediately east-southeast of Lake St. Martin narrows.
- Discharge as a series of flowing artesian springs draining northerly to Lake St. Martin in the vicinity of the north basin and forming tributaries of Bear Creek. These springs discharge at ground surface elevations of approximately El. 250 m at the west-northwest toe of slope of the high ground area located immediately east-southeast of Lake St. Martin Narrows and the north basin of the lake.
- Discharge as a series of flowing artesian springs draining easterly to the Mantagao River and discharging at ground surface elevations of approximately El. 255 m at the easterly toe of slope of the high ground area located immediately east-southeast of Lake St. Martin Narrows and the north basin of the lake.
- Inferred aquifer discharge condition at the Big Buffalo Lake Complex based on the peat morphology and surface water elevation relationships of the Big Buffalo Lake Complex (El. 240.9 m to El. 241.5 m), and bedrock piezometric pressure conditions measured along the LSMOC channel in adjacent areas (e.g., minimum of El. 242.6 m),
- Discharge as a series of flowing artesian springs draining northeasterly, forming tributaries that connect to Big Buffalo Creek. These springs discharge at ground surface elevations of approximately El. 235 m and are located north-northeast of the big Buffalo Lake Complex.
- Discharge as a series of flowing artesian springs draining northeasterly to Lake Winnipeg and forming tributaries of the Mantagao River. These springs discharge at ground surface elevations of approximately El. 220 m to El. 230 m, at the northern and northeasterly toe of slope located immediately along the shoreline of Lake Winnipeg, near Reedy Point.

2.0 INSTRUMENTATION LOCATIONS AND AVAILABLE DATA

2.1 Instrumentation Locations

There are a total of 58 standpipe piezometers (SPs) (24 installed in 2015 and 34 in 2019) and 32 vibrating wire piezometers (VWs) installed within the 46 test holes along the LSMOC alignment (Figure1). The Stratigraphic profile for the project is also included in Appendix A-1 showing details of the installations. A high-level summary of the instrumentation is as follows:

- Peat - 19 installations;
- Silty Clay / Clay Till – 8 installations;
- Silt Till - 36 installations;
- Sand - 2 installations (local to Station 5+606);
- Bedrock - 25 installations.

TABLE1: SUMMARY OF 2019 BASELINE BEDROCK AQUIFER PIEZOMETRIC PRESSURE RANGES

LSMOC Centerline Station Locations		Number of Bedrock Aquifer Monitoring Installations	Piezometric Pressure Elevation (m)	
			Minimum	Maximum
0+000	5+000	5	244.1	245.0
5+000	10+000	2	244.0 (Flowing)*	244.5 (Flowing)*
10+000	15+000	4	235.3	237.9
15+000	20+000	8	224.6	235.6
20+000	Lake Winnipeg	5	218.3	223.3

*Note: Flowing signifies flowing artesian conditions at the time of the monitoring event.

3.0 METHODOLOGY

Instrumentation and standpipes used in the analysis are shown on Figure 1. To detail the aquifer responses and demonstrate the functioning of the groundwater system in the vicinity of the LSMOC, hydrographs of groundwater data were compiled. The hydrographs allow for a visual representation of the data, with all the relevant combinations of datasets, for comparison and interpretation of the functioning of the groundwater system. The groundwater data is plotted with time, and by elevation, allowing for direct comparison of instrumentation installed within the various strata (e.g., bedrock, till, or peat) at the site. Other relevant data includes precipitation data available for the region, groundwater temperature, as measured by the installed instrumentation, and regional air temperature as measured at the weather station in Fisher Branch, Manitoba.

4.0 AQUIFER PIEZOMETRIC PRESSURE ASSESSMENTS

4.1 Aquifer Responses to Boundary Condition Changes

Prior studies in the vicinity of the channel projects (KGS Group, 2016) demonstrated that the confined bedrock aquifer system in the region of the LSMOC project responds to the seasonal, long-period oscillation (e.g. rise and fall) of the flow system over the seasons. The reference report is provided in Appendix B. Seasonal variability includes typically wetter summers, drier fall periods, an aquifer pressure rise observed during spring groundwater recharge events and changes due to variability in local lake levels. This response is measured within Provincial long-term bedrock monitoring wells at Hilbre, Manitoba for the Lake St. Martin area, and at Steep Rock, Manitoba, for the Lake Manitoba area. This response is characteristic of a confined aquifer system, considering that Lake Manitoba and Lake St. Martin form significant natural discharge areas for the confined aquifer system. A rise in the boundary condition for discharge at the lakes is accompanied by a piezometric pressure response rise of the confined bedrock aquifer, and an associated re-equilibration of the groundwater levels as measured in the wells. Similarly, a decline in lake levels will produce a decline in aquifer piezometric pressures.

Figure 2 shows available data from the Dauphin River sentinel wells, and the surface water levels for the Dauphin River (Big Bend), and Lake Winnipeg. The Dauphin River data is shown for interest or comparison purposes only, as it is data collected in an area far removed from the sentinel wells at Dauphin River. Sentinel well data was available between approximately November 2019 to March 2021 (SW19-KGS-02), and June 2020 to March 2021 (SW 19-KGS-01 and 03). The available data shows that the water levels in Lake Winnipeg did not vary significantly, likely a result of lake water level regulation of Lake Winnipeg. Correspondingly, the sentinel well data is also very consistent, with approximately one meter of variability noted over the measurement period. The bedrock aquifer piezometric pressures in the sentinel wells is greater than the level of Lake Winnipeg, indicating that the aquifer system discharges to Lake Winnipeg, and that Lake Winnipeg is a discharge zone for the aquifer system. In general, very subtle seasonal trends are suggested within the sentinel well data, with some limited response to summer precipitation events noted during July and August of 2020. In general, along with the very stable boundary condition of Lake Winnipeg, the nearby sentinel wells are very consistent, with some short-term small amplitude variation, and an overall slight decline in elevation over this period of measure, likely related to longer-term seasonal trends in regional aquifer recharge over multi-year timeframes.

In terms of groundwater temperature, aquifers tend to have a basic temperature that is similar to the mean annual air temperature. Here, these temperatures are approximately 5°C. Groundwater temperature responses are out of phase with air temperature data, which is typical, with groundwater temperatures being warmest during winter and spring seasons. Temperature variability was least at SW 19-KGS-02 (north side of the Dauphin River near the confluence of Big Buffalo Creek), and greatest at SW 19-KGS-01 (south side of the Dauphin River and in close proximity to Lake Winnipeg. The large shift in groundwater temperature seen at SW 19-KGS-01 suggests that the flow system is sensitive to seasonal variations in recharge, more so than the other two sentinel wells on the north side of the Dauphin River, which remained much more stable in temperature throughout the year. Importantly, SW 19-KGS-01 temperature increases are noted opposite to what would be expected with seasonal surface water or air temperature changes, illustrating that the well is not directly influenced or connected to the surface water system.

4.2 Pumping Test Responses

Water wells were drilled, and aquifer pumping tests were completed on the LSMOC at the location of the Water Control Structure (WCS) and at the existing Emergency Reach 3 channel. Figures 3 and 4 show the results for the pumping tests completed in the field. The results are summarized as follows:

- At the WCS (Figure 3), bedrock aquifer drawdown of approximately 13 m within the pumping well itself created only 4 m of piezometric pressure decline at the nearest bedrock monitoring well (at 2 m distance). Piezometric pressure responses in the bedrock aquifer were found to be less than 2 m decline at approximately 10 m distance from the pumping well, and less than 1 m pressure decline at any bedrock monitoring well more than 30 m away from the pumping well.
- Pressure responses in the till aquitard at the WCS (Figure 3) were limited to decreases of approximately 0.2 m to 0.25 m or less during the pumping test.
- At Reach 3 (Figure 4) bedrock aquifer drawdown of approximately 2.5 m within the pumping well itself created only approximately 1.1 m of piezometric pressure decline at the nearest bedrock monitoring well (at 6 m distance) with responses in the bedrock aquifer less than approximately 0.2 m piezometric pressure decline by approximately 80 m distance from the pumping well.
- Pressure responses in the till aquitard at Reach 3 (Figure 4) were limited to decreases of approximately 0.1 m to 0.15 m or less during the pumping test, and only at locations immediately adjacent to the pumping well. No other responses in the till aquitard were noted in the measured data.

Aquifer parameter calculations based on time drawdown, distance drawdown, and residual drawdown from these pumping tests, in both cases, are indicative of a low transmissivity bedrock aquifer, with limited propagation of drawdown effects with distance away from the pumping well. Pressure responses in the overlying till aquitard were noted in areas close to the pumping wells, as a natural response to the decline in the underlying driving head from the bedrock aquifer system. The decline in pressure in the till aquitard is a short-term pressure response and does not imply any significant drainage or leakage from the aquitard under the conditions experienced during the pumping tests completed. In all cases following the pumping tests, the bedrock aquifer and till aquitard pressures recovered to pre-test static conditions.

4.2 Groundwater Seepage into and out of the LSMOC at Reach 3

The creation of new groundwater discharge pathways into the LSMOC channel will locally increase the direct connection of exfiltrating groundwater to channel surface water, originating from the underlying bedrock aquifer. The bedrock aquifer in the region of the LSMOC is confined, and as such, the piezometric pressure responds quickly to changes in aquifer boundary conditions (i.e., changes to water levels or pressure conditions at aquifer recharge and discharge areas, and due to aquifer recharge events). The LSMOC is situated in an area of high confined bedrock aquifer groundwater pressures, which drive groundwater discharge to the LSMOC channel as baseflow, under virtually all scenarios of observed variability in aquifer boundary conditions to date.

However, during certain times of channel operation, such as the rapid staging of surface water within the channel as it is opened, downward vertical gradients may be developed temporarily between the surface water within the operating channel and the underlying bedrock groundwater aquifer, resulting in short-term (hours to days) and localized infiltration of surface water from the LSMOC channel to the bedrock aquifer. This will occur only in locations where there is a physical interconnection of the LSMOC channel to the bedrock through the till aquitard, (e.g., a fractured till area, a groundwater seepage site that develops during channel excavation, or where the aquitard is removed with channel construction) or where the bedrock aquifer is directly exposed within the LSMOC channel base. Furthermore, it will occur only during the limited period when the water level within the LSMOC channel is higher in elevation than the piezometric pressure of the underlying and adjacent confined bedrock aquifer.

Part of the consideration under the detailed design phase of the channel at the existing LSMOC Reach 3 area is to minimize the channel operating water level, to be slightly above the existing bedrock aquifer groundwater pressures at the reaches of the Reach 3 channel area. Specifically:

- The existing confined bedrock aquifer piezometric pressures in the vicinity of the Reach 3 channel are typically measured between El. 232.4 m to El. 232.5 m in and around approximately Sta. 17+500 of the LSMOC (or greater, in the order of El. 235 m to El. 236 m at approximately Sta. 15+000, in up-channel Reach 3 areas).
- The design operating channel surface water level is in the order of approximately 233.4 m at Sta. 15+000 (e.g., approximately 1.6 m to 2.6 m below the typical surrounding bedrock aquifer piezometric pressures), and El. 233.1 m at Sta. 17+500 (to be finalized at completion of detailed design). As such, the maximum differential between the channel surface water during LSMOC operation to the current bedrock aquifer piezometric pressure is approximately 0.6 m at Sta. 17+500.

Limiting the differential between the operating channel water levels, and the bedrock aquifer pressures in these areas where there are direct interconnections with bedrock exposed in the base of the channel is estimated to have the following effects:

- Any driving gradients for infiltration from the LSMOC channel into the aquifer will be reduced, because the differential between the channel operating water level and surrounding bedrock aquifer is approximately 0.6 m.
- The aquifer piezometric pressure will respond quickly to the change in the channel water levels, and the bedrock pressures in the surrounding aquifer will rise in response to the operation of the channel and re-equilibrate to the new boundary condition of the full channel.
- The initiation of re-equilibration of the aquifer will occur relatively quickly (e.g. hours to days, based on observed responses of the aquifer hydrographs to recharge boundary condition changes available to date, and as described in this memorandum) because the differential between the existing aquifer piezometric pressure and channel operating water levels are less than approximately 0.6 m. This change of approximately 0.6 m is well within typical aquifer pressure responses observed seasonally in the confined bedrock aquifer, which are in the order of 1.5 m +/- 0.5 m. The estimated 0.6 m change is also less than observed shorter term aquifer pressure responses to high intensity rainfall events, which can be observed in the order of 1.0 m of aquifer pressure increase.

Water level monitoring data available in the vicinity of the Reach 3 area of the LSMOC (Figures 5 and 6) demonstrates that:

- Bedrock and till piezometric pressures are higher than the surface water levels in the Reach 3 channel at all times of year, indicating bedrock aquifer discharge to the channel at Reach 3 occurs under all channel conditions observed to date.
- Bedrock and till piezometric pressures respond very quickly to high intensity and short-term precipitation events, which recharge the bedrock aquifer system regionally.
- Bedrock piezometric pressures can rise by up to approximately 1 m in response to regional rainfall events. Reach 3 channel surface water levels may only rise by approximately 0.2 m during these events (e.g. during the fall of 2019), based on observed data to date.
- The spring recharge event in 2020 (i.e., February to May 2020) demonstrated a peak of approximately 0.5 m of surface water flow through the Reach 3 channel during this period. The bedrock aquifer system responded similarly with a rise in piezometric pressure and maintained a discharge groundwater aquifer condition to the Reach 3 channel throughout. The rise in the bedrock pressures close to the channel and within the shallow bedrock during this event (e.g., PW-19-KGS-03 and TH-KGS-15) was probably a combination of response to the channel surface water levels, and response to the concurrent overall spring recharge that was occurring to the bedrock aquifer system regionally. Monitoring wells further from the channel and at higher groundwater pressures (e.g., above El. 232 m) responded differently, maintaining relatively stable, to declining, piezometric pressures (e.g., TH-KGS-16) during the spring 2020 recharge event.
- Bedrock groundwater piezometric pressures in areas distant to the Reach 3 channel (e.g., TH-KGS-16 on the west-northwest shoulder of the Reach 3 channel, and at TH-KGS-14 at the channel right of way, south-southeast of the channel) are well above (e.g., 2 m or more) the typical surface water elevations recorded in the Reach 3 Emergency channel.
- Bedrock groundwater piezometric pressures in areas close to the Reach 3 channel (e.g., pumping well PW-19-KGS-03 and TH-19-KGS-15) are also above the channel surface water levels, typically by approximately 0.1 m to 0.2 m during “dry channel” periods (e.g. June to September of 2019), and up to approximately 1.0 m higher during the fall of 2019 rainy period, when seasonal regional aquifer recharge would have occurred.
- Monitoring data within the peatlands/fen and shallow till immediately below the peat (e.g. TH-KGS-16 (till), and 16a (peat)) demonstrate very strong responses to short term high intensity rainfall (e.g. fall of 2019), since this flow system is perched above the till aquitard.

The bedrock aquifer piezometric pressure conditions at the LSMOC will rise in response to the change in boundary conditions – such as the staging or rise of surface water within the LSMOC channel in these interconnected channel areas; thus returning the bedrock aquifer system to a discharge (exfiltrating) condition at the channel locally. With repeated, short-lived pressure conditions favoring infiltration from the LSMOC channel to the bedrock aquifer, development of a localized influx of infiltrated channel surface water, local to the channel and moving further downgradient in the bedrock aquifer groundwater system near the LSMOC channel, is a possibility. These mixed surface waters and groundwaters would migrate through the aquifer system to the next available discharge area, located either within the LSMOC channel itself, at an existing downgradient artesian spring site, or longer term possibly as groundwater baseflow to Lake Winnipeg.

Repeated infiltration of small quantities of surface water may cause local and short-lived water quality changes to the regional bedrock aquifer resource in close proximity to the LSMOC. It is important to distinguish that infiltration may only occur in areas where there is a physical connection from the channel to the bedrock aquifer. These interconnections are localized and will occur only where the till aquitard has been fractured or heaved during excavation of the channel, or where bedrock is exposed within the channel (such as at Reach 3, currently). There are, however, no nearby domestic well users and the overall hydraulic gradient (groundwater flow direction) in the area is to the east-northeast, with discharge to existing downgradient artesian spring sites, and ultimately into Lake Winnipeg.

4.3 Example Case Study – Red River Floodway

The type of aquifer pressure response described above has been measured and quantified on other similar projects, notably the Red River Floodway Expansion Project [(1)]. During the significantly large spring flood event of 2009 (KGS Group, 2012) the aquifer response to floodway channel staging was measured, including the infiltration and exfiltration gradient changes at a spring site in the base of the floodway channel. During this Red River Floodway event, infiltration occurred at the channel base spring site for approximately one month, between the first week in April, and the first week in May, of 2009. Details of this response were as follows:

- The 2009 spring floodway event was significantly large, with channel operating water levels rising to a peak elevation approximately 6.5 m above the base of the floodway channel at the spring site. This differential on the LSMOC is far less, at approximately 0.6 m (based on current channel design).
- The measurement of the bedrock aquifer response occurred at the nearest available Provincial bedrock aquifer monitoring well, which was hundreds of meters away from the spring site.
- Approximately 2.5 m of channel surface water above the spring site was necessary prior to the vertical gradients shifting to favor infiltration from the channel to the bedrock (via the spring site).
- There was surface water in the channel above the spring site for approximately 3 weeks prior to the vertical gradient change to favor infiltration to the bedrock aquifer.
- Surface water in the channel, above the spring site, remained for approximately 3.5 to 4 weeks following the return of vertical gradients to favor bedrock aquifer discharge to the channel (e.g., exfiltration conditions).
- A short-term rain event in June of 2009 demonstrated that the bedrock aquifer rose quickly to maintain bedrock aquifer discharge conditions at the spring site.

The durations and dynamics of the channel/aquifer responses in a scenario like this are dependent on the nature of the interconnection and overall bedrock aquifer transmissivity, the differentials in head generated between the channel and the bedrock aquifer, and the duration of the event. In the case of the 2009 Red River Floodway event, infiltration conditions from the channel to the bedrock aquifer were observed for approximately 1/3 of the time the channel held surface water; specifically 4 weeks of the approximately 12 total weeks the Red River Floodway channel contained surface water, at levels above the elevation of the channel base spring site. Again, the 2009 flood event was quite substantial in terms of duration and surface water level changes within the floodway channel.

5.0 SUMMARY

Prior studies in the vicinity of the projects (Appendix B - KGS Group, 2016) demonstrated that the confined bedrock aquifer system in the region of the LSMOC project responds to the seasonal, long-period oscillation (e.g., rise and fall) of the flow system and variability in local lake levels, as measured within Provincial long-term monitoring wells at Hilbre for the Lake St. Martin area, and at Steep Rock, for the Lake Manitoba area. This response is characteristic of a confined aquifer system, considering that Lake Manitoba and Lake St. Martin form significant natural discharge areas for the confined aquifer system. A rise in the boundary condition for discharge at the lakes is accompanied by a piezometric pressure response rise of the confined bedrock aquifer, and an associated re-equilibration of the groundwater levels as measured in the wells. Similarly, a decline in lake levels will produce a decline in aquifer piezometric pressures.

The overall behavior of the aquifers in the region are as expected for aquifer systems of this nature. Aquifer recharge areas occur under unconfined conditions where bedrock elevations are relatively high and sediment cover is thin to non-existent. Groundwater discharge occurs in low lying areas where aquifers are confined by overlying low permeability sediments, with discharge to artesian spring sites, and various bogs, fens, streams, and lakes, and most notably to Lake St. Martin. Changes in these discharge boundary conditions (i.e., lake level changes, rising or falling) do produce a re-equilibration piezometric pressure response of the aquifer system.

All monitoring wells examined record aquifer piezometric pressures that rise and fall seasonally, according to the recharge that occurs to the aquifer from spring snowmelt and additional short-term summer to fall precipitation events, along with some contribution from the seasonal variability in lake levels that occur at Lake St. Martin and Lake Manitoba. The total seasonal variability in lake levels is typically less than the seasonal piezometric pressure variability measured within the aquifer system; the difference being attributable to seasonal aquifer recharge. In addition, aquifer piezometric pressure declines measured within all wells during the winter months are greater than the changes observed in lake levels, where Lake St Martin levels respond in an opposite manner and rise slightly during to winter ice staging along the Dauphin River (Appendix B KGS Group, 2016). This further emphasizes the significant connection of the aquifer system to seasonal recharge contributions. For a flood stage condition on the lake(s), it would be expected that the rise in the discharge boundary condition (i.e., lake levels) would contribute to a rise in aquifer piezometric pressure; however, the associated snowmelt and rainfall aquifer recharge that would accompany a flood stage year would also have a significant role in driving up aquifer piezometric pressures.

Over multi-year timeframes, the aquifer groundwater levels will also vary, following consecutive years of "wet" or "dry" conditions, based on precipitation levels that are more than, or less than, the typical average for the region. This phenomenon has been described for the area, and the responses of the aquifer system to these effects lag by months in time.

6.0 CONCLUSIONS

1. The groundwater system around the Lake St. Martin Outlet Channel (LSMOC) is characterized by local groundwater recharge in high elevation ground areas surrounding Lake St. Martin (particularly

to the south-southeast of the north basin of Lake St. Martin), and a discharge groundwater system with boundary conditions including Lake St. Martin and Lake Winnipeg. Regional groundwater discharge occurs to Lake St. Martin, and to Lake Winnipeg. Dauphin River, and the artesian spring sites throughout the region (including to the east along the Mantagao River), also are a significant part of the aquifer discharge system.

2. Strong upward gradients between the piezometric surface of the bedrock aquifer and the overlying till aquitard indicate groundwater discharge conditions, to flowing artesian conditions for the bedrock aquifer throughout most of the channel alignment from Lake Saint Martin to approximately channel Sta. 18+500. In the downstream areas of the existing Reach 3 channel, upward gradients are not as strong, and there are locally downward gradients between the till aquitard and bedrock aquifer downstream of approximately Sta. 18+500 of the LSMOC. These downstream areas of the LSMOC are within a zone of pressure relief for the regional bedrock aquifer groundwater discharge system, a natural result of the many groundwater artesian spring discharge sites near Lake Winnipeg. The bedrock aquifer remains confined by the till aquitard including within areas of artesian spring site discharge, (i.e., the bedrock aquifer piezometric pressure rises above the bedrock-till stratigraphic contact), and throughout the region of the LSMOC.
3. The bedrock aquifer is covered by a thick deposit of till, forming a low permeability aquitard, except along Reach 3 where bedrock is shallower and is exposed within the existing Reach 3 Emergency channel. Despite the bedrock exposure and the upward gradients from the bedrock aquifer to the channel in this area, baseflows of bedrock aquifer groundwater to the channel measured by KGS Group were low, indicating very low bedrock transmissivity in this area.
4. An extensive system of artesian groundwater springs is present in the region and has been documented by previous researchers, including southwest of Buffalo Creek between the channel alignment and the Dauphin River, east of the channel alignment draining to Mantagao River, along the shores of Lake Winnipeg, and on the southeast side of the north basin of Lake St. Martin. These spring sites are direct discharges of the bedrock aquifer system to the surface water system. The Big Buffalo Lake wetland system is also thought to be groundwater fed, though there has been limited water quality sampling available for geochemical analyses in this area to confirm this conclusively, to date.
5. The available data shows that the water levels in Lake Winnipeg, in particular, did not vary significantly, likely a result of lake water level regulation of Lake Winnipeg. Correspondingly, the sentinel well data at Dauphin River is also very consistent, with approximately a meter of variability noted over the measurement period. The bedrock aquifer piezometric pressures in the sentinel wells is greater than the level of Lake Winnipeg, indicating that the aquifer system discharges to Lake Winnipeg, and that Lake Winnipeg is a discharge zone for the aquifer system. In general, very subtle seasonal trends are suggested within the sentinel well data, with some limited response to summer precipitation events noted during July and August of 2020.
6. Data collected from the bedrock aquifer and till aquitard during pumping tests at the WCS and at the existing Reach 3 channel indicate that the aquifer is of low transmissivity and that the drawdown effects in the bedrock aquifer with pumping dissipate quickly with distance away from the pumping well. Pressure responses are measurable in the till aquitard near the bedrock pumping well, however they are not observed at distance from the pumping well. All bedrock

aquifer and till aquitard piezometric pressures recover to static conditions following the pumping tests.

7. At the existing Emergency Reach 3 channel, bedrock and till piezometric pressures are higher than the surface water levels in the Reach 3 channel at all times of year, indicating bedrock aquifer discharge to the channel at Reach 3 occurs under all channel conditions observed to date. Bedrock and till piezometric pressures respond very quickly to high intensity and short-term precipitation events, which recharge the bedrock aquifer system regionally. Bedrock piezometric pressures can rise by up to approximately 1 m in response to regional rainfall events. Reach 3 channel surface water levels may only rise by approximately 0.2 m during these events (e.g., during the fall of 2019), based on observed data to date. Bedrock groundwater piezometric pressures in areas distant to the Reach 3 channel (e.g., TH-KGS-16 on the west-northwest shoulder of the Reach 3 channel, and at TH-KGS-14 at the channel right of way, south-southeast of the channel) are well above (e.g., 2 m or more) the typical surface water elevations recorded in the Reach 3 emergency channel.
8. The bedrock aquifer piezometric pressure conditions at the LSMOC will rise in response to the change in boundary conditions – such as the staging or rise of surface water within the LSMOC channel in these interconnected channel areas; thus, returning the bedrock aquifer system to a discharge (exfiltrating) condition at the channel in these interconnected channel areas. With repeated, short-lived pressure conditions favoring infiltration from the LSMOC channel to the bedrock aquifer, development of a localized influx of infiltrated channel surface water, local to the channel and moving further down gradient in the bedrock aquifer groundwater system near the LSMOC channel, is a possibility. These mixed surface and ground waters will migrate through the aquifer system to the next available discharge area, located either within the LSMOC channel itself, at an existing downgradient artesian spring site, or possibly in the longer term as groundwater baseflow to Lake Winnipeg.

7.0 REFERENCES

1. Red River Floodway Expansion Project Groundwater Spring Treatment Trial Construction Program, March 2009- Memo Reference: 3705102.05 HM55, Final September 2009, Issued October 12, 2012, prepared by KGS Group.

Prepared By:

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Environmental Engineer

Approved By:

Jason Mann, M.Sc., P.Geo.
Environmental Department Head/
Associate Principal

PROVINCE OF MANITOBA
JDM
J. D.
MANN
Member
22697
REGISTERED PROFESSIONAL GEOSCIENTIST
July 29/21

MFH/jr

List of Figures

List of Appendices

STATEMENT OF LIMITATIONS AND CONDITIONS

Limitations

This report has been prepared for Manitoba Infrastructure (MI) in accordance with the agreement between KGS Group and MI (the "Agreement"). This report represents KGS Group's professional judgment and exercising due care consistent with the preparation of similar reports. The information, data, recommendations, and conclusions in this report are subject to the constraints and limitations in the Agreement and the qualifications in this report. This report must be read as a whole, and sections or parts should not be read out of context.

This report is based on information made available to KGS Group by MI. Unless stated otherwise, KGS Group has not verified the accuracy, completeness, or validity of such information, makes no representation regarding its accuracy and hereby disclaims any liability in connection therewith. KGS Group shall not be responsible for conditions/issues it was not authorized or able to investigate or which were beyond the scope of its work. The information and conclusions provided in this report apply only as they existed at the time of KGS Group's work.

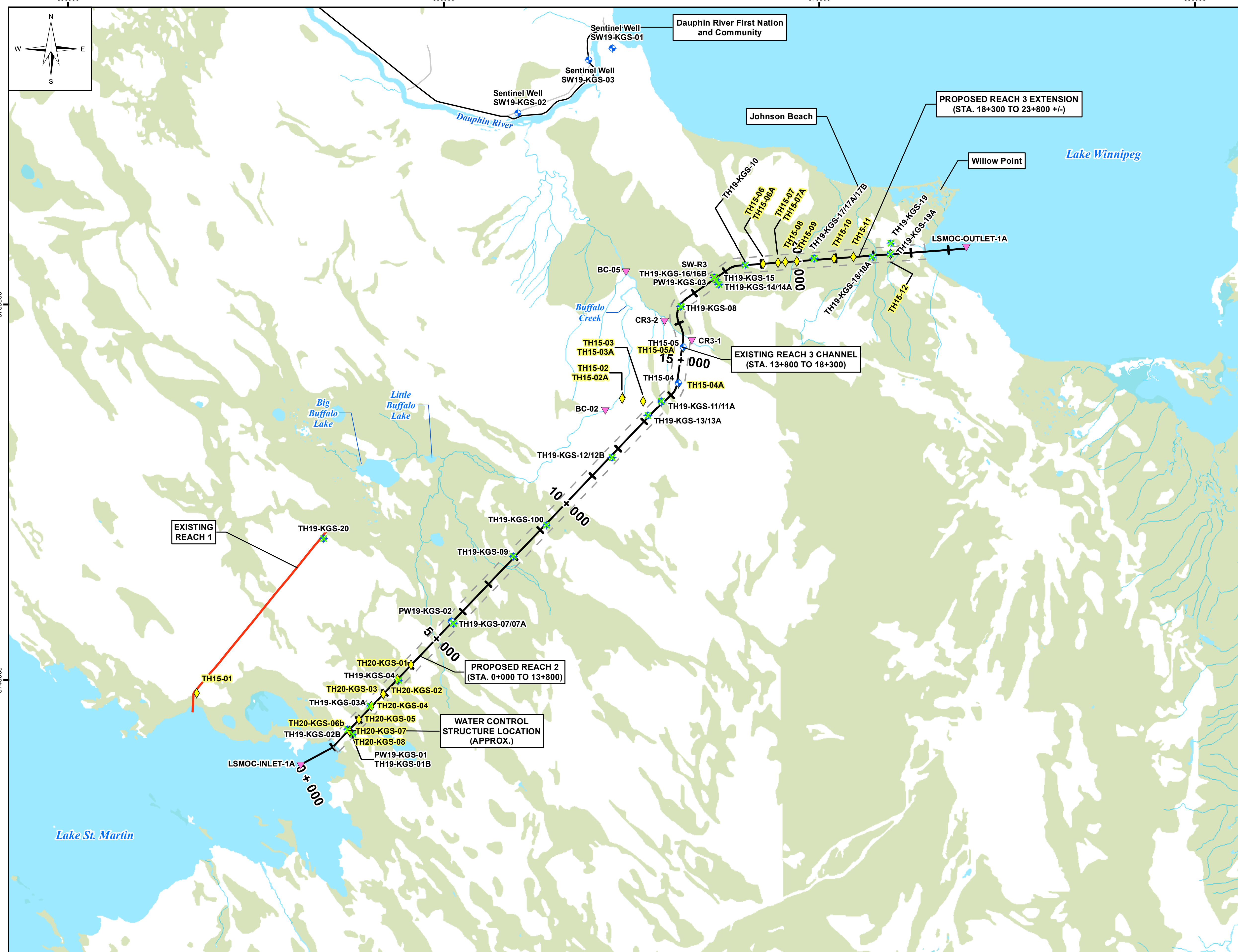
Third Party Use of Report

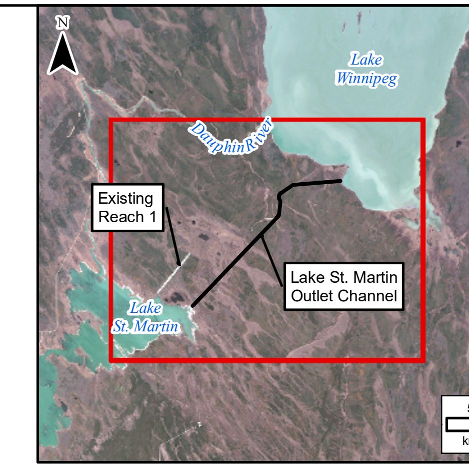
Any use a third party makes of this report or any reliance on or decisions made based on it, are the responsibility of such third parties. KGS Group accepts no responsibility for damages, if any, suffered by any third party because of decisions made or actions undertaken based on this report.

Geo-Environmental Statement of Limitations

KGS Group prepared the geo-environmental conclusions and recommendations for this report in a professional manner using the degree of skill and care exercised for similar projects under similar conditions by reputable and competent environmental consultants. The information contained in this report is based on the information that was made available to KGS Group during the investigation and upon the services described, which were performed within the time and budgetary requirements of [Insert client's short name]. As this report is based on the available information, some of its conclusions could be different if the information upon which it is based is determined to be false, inaccurate, or contradicted by additional information. KGS Group makes no representation concerning the legal significance of its findings or the value of the property investigated.

FIGURES





LEGEND:

- Surface Water Sampling Location
- Groundwater Sampling Location
- Standpipe with Vibrating Wire
- Standpipe
- LSMOC Alignment
- 400m Right Of Way

NOTES:
1. Locations with water quality samples have been labelled. For all other locations see the Geotechnical Data Report (KGS Group, October 2019).
2. Wetland, watercourse, and waterbody layers shown were obtained from NRCAN 1:50,000 data.
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).

1 0 1 2 3 4

Kilometres

SCALE: 1:100,000 METRIC 11"x17"

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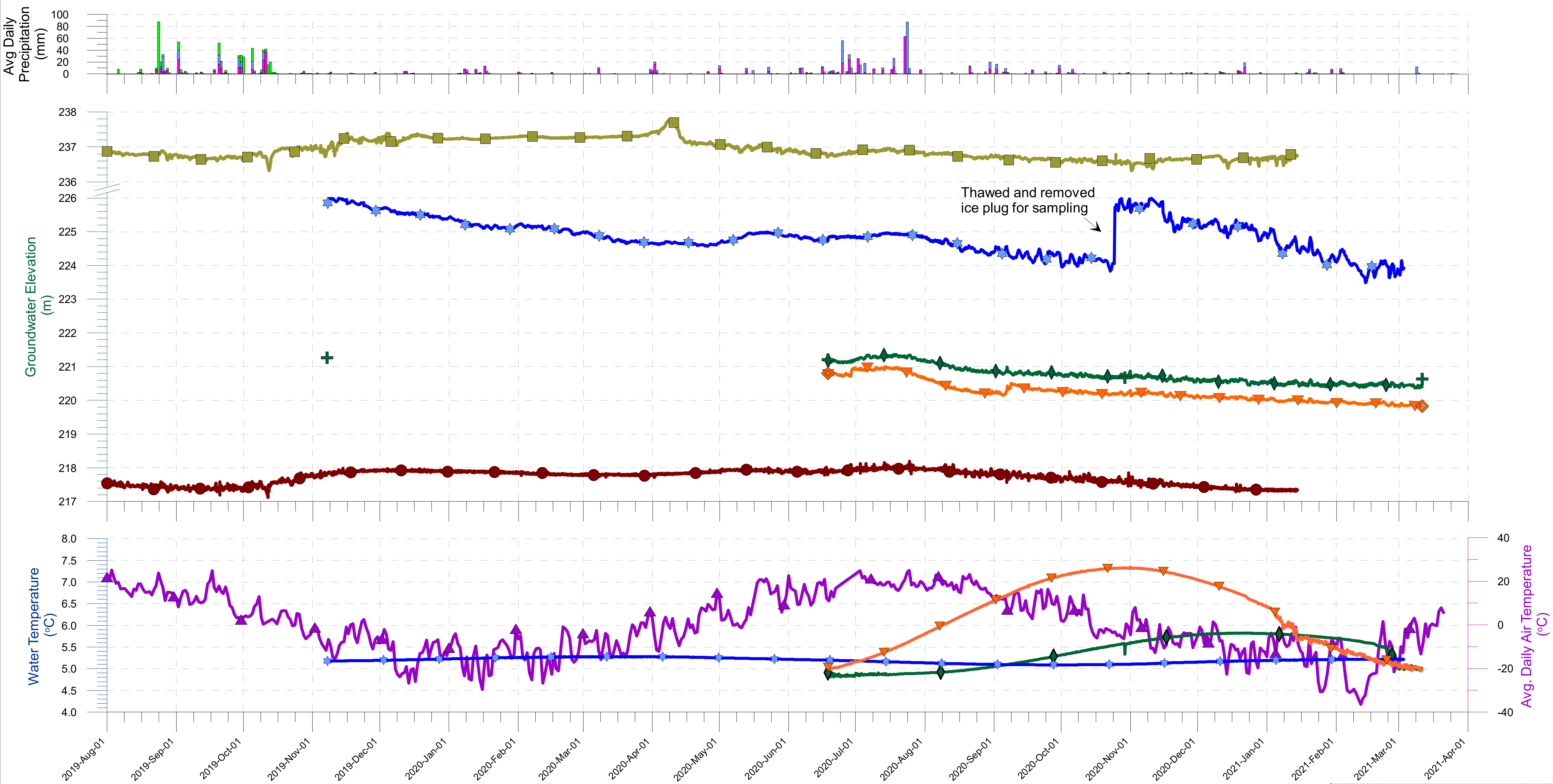
LAKE ST. MARTIN OUTLET CHANNEL
GROUNDWATER AND SURFACE WATER
SAMPLING SITES OF THE LSMOC PDA

GROUNDWATER AND SURFACE WATER
SAMPLING SITE LOCATION PLAN

JULY 2021 | FIGURE 1 | REV: 0

FileName: P:\Projects\2018\18-0300-005\Dwg\GIS\MXD\Detailed Design\Conceptual_Groundwater_Model_for_EIS\18-0300-005_Fig01.mxd
11"x17" PLOT SCALE 1:1



Notes:
1. Transducer water elevation data compensated with barometric pressure data from on-site barometric pressure logger.
2. Average daily air temperature and precipitation data was collected from the Fisher Branch (AUT) and Hodgson (3) weather stations (Environment and Climate Change Canada - ECCC), and the on-site weather station.

Precipitation
- On-Site Weather Station
- Fisher Branch (ECCC)
- Hodgson (ECCC)

Groundwater Elevation (Transducer)
- SW19-KGS-01
- SW19-KGS-02
- SW19-KGS-03

Groundwater Elevation (Manual Readings)
- SW19-KGS-01
- SW19-KGS-03

Surface Water Elevation
- SW - Dauphin River
- SW - Lake Winnipeg

Temperature
- Air Temperature (°C) (Fisher Branch AUT)
- Water Temperature SW19-KGS-01 (Transducer)
- Water Temperature SW19-KGS-02 (Transducer)
- Water Temperature SW19-KGS-03 (Transducer)

NO.	YY/MM/DD	DESCRIPTION	DESIGN BY	DESIGN CHECK
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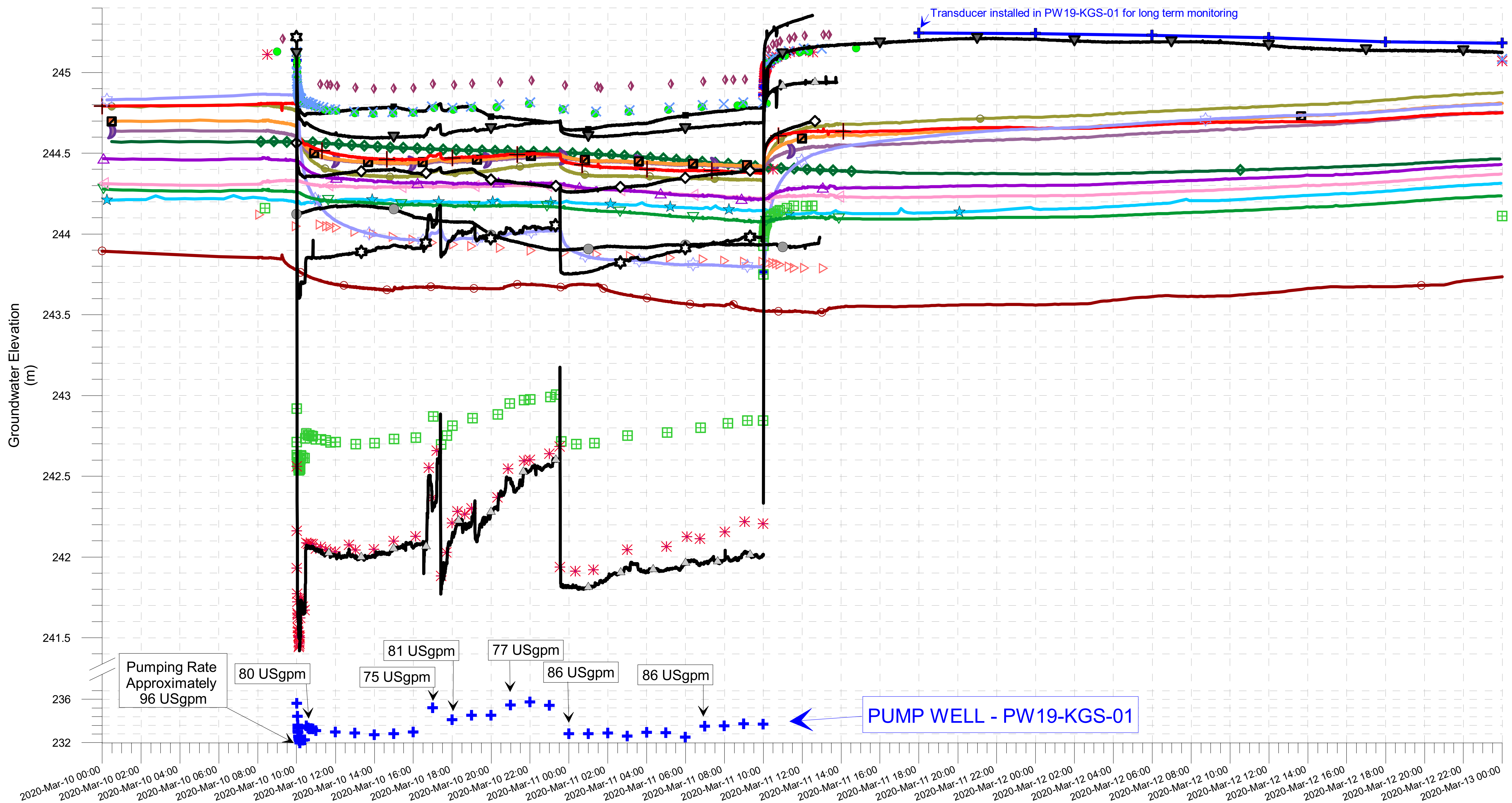
LAKE ST. MARTIN OUTLET CHANNEL
PRELIMINARY DESIGN

WATER ELEVATION AND TEMPERATURE READINGS AT SENTINEL WELLS
SW19-KGS-01, SW19-KGS-02, SW19-KGS-03

JUNE 2021 | FIGURE 2 | REV: 0



Notes:

MR - Manual Reading
VW - Vibrating Wire Piezometer
TD - Transducer

1. Transducer water elevation data compensated with barometric pressure data from on-site barometric pressure logger.

- PW19-KGS-01 - (Bedrock) Pump Well - MR
- TH19-KGS-01 (Bedrock) - TD
- TH19-KGS-01 (Bedrock) - VW1900190
- TH19-KGS-01 (Bedrock) - MR
- TH19-KGS-02 (Bedrock) - TD
- TH19-KGS-02 (Silt Till) - VW1900095
- TH19-KGS-02 (Silt Till) - VW1900205
- TH19-KGS-02 (Bedrock) - MR
- TH19-KGS-02b (Silt Till) - TD
- TH19-KGS-02b (Silt Till) - MR
- TH20-KGS-06b (Bedrock) - MR
- TH20-KGS-06 (Bedrock) - TD
- TH20-KGS-06b (Silt Till) - VW2000136
- TH20-KGS-06b (Silt Till) - VW2000138
- TH20-KGS-06b (Silt Till) - VW2000135
- TH20-KGS-07 (Bedrock) - TD
- TH20-KGS-07 (Silt Till) - VW2000352
- TH20-KGS-07 (Silt Till) - VW2000353
- TH20-KGS-07 (Silt Till) - VW2000355
- TH20-KGS-07 (Bedrock) - MR
- TH20-KGS-08 (Bedrock) - TD
- TH20-KGS-08 (Silt Till) - VW2000349
- TH20-KGS-08 (Silt Till) - VW2000354
- TH20-KGS-08 (Silt Till) - VW2000351
- TH20-KGS-08 (Bedrock) - MR

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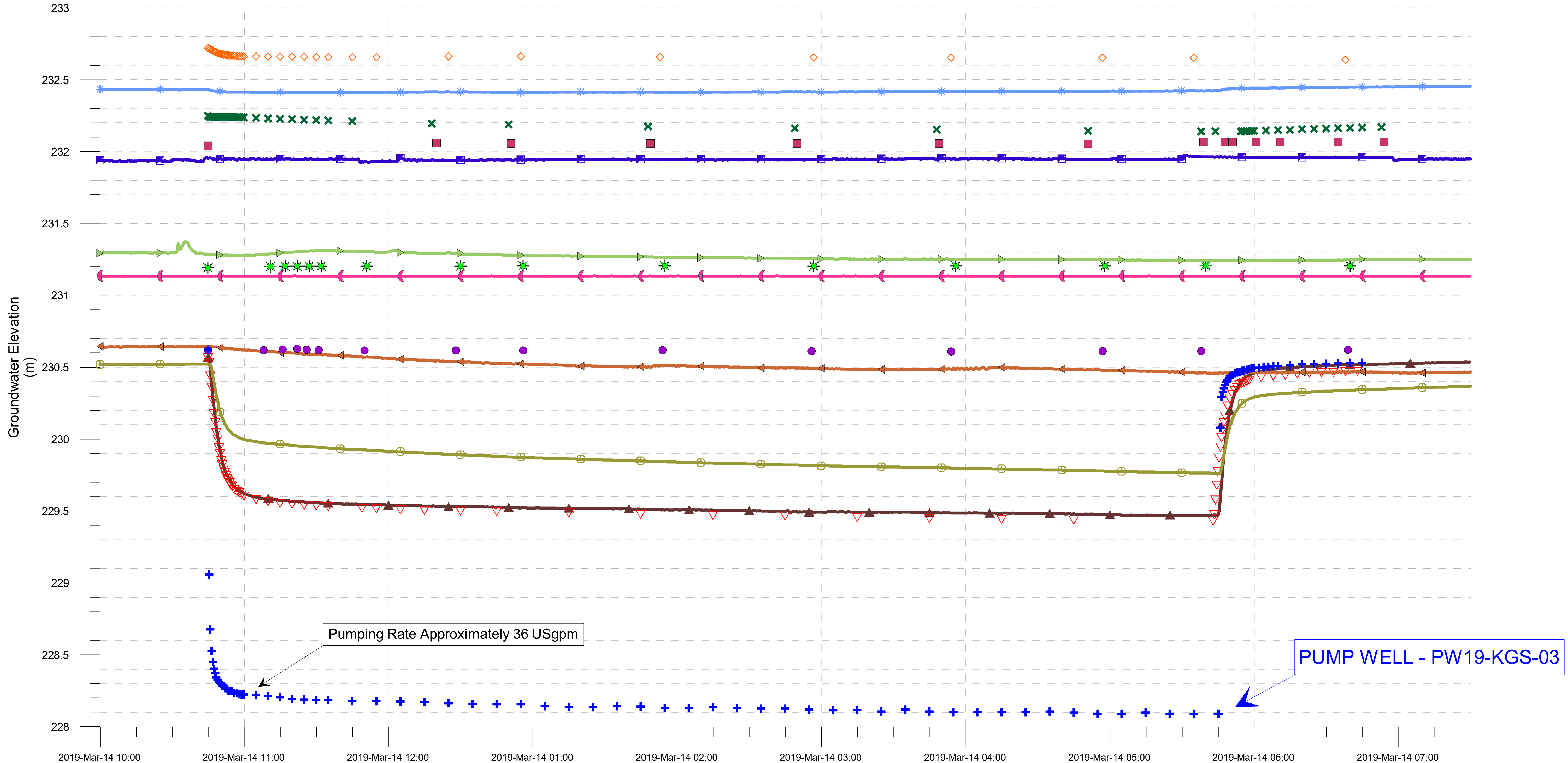
LAKE ST. MARTIN OUTLET CHANNEL
PRELIMINARY DESIGN

WELL PW19-KGS-01 PUMP TEST
GROUNDWATER ELEVATIONS

JULY 2021 | FIGURE 3 | REV: 0



Notes:

MR - Manual Reading
VW - Vibrating Wire Piezometer
TD - Transducer

1. Transducer water elevation data compensated with barometric pressure data from on-site barometric pressure logger.

Water Elev

- PW19-KGS-03 (Bedrock) - Pump Well - MR
- PW19-KGS-03 (Bedrock) - TD
- TH19-KGS-14 (Silt Till) - VW1900196
- TH19-KGS-14 (Bedrock) - MR
- TH19-KGS-14a (Peat) - MR
- TH19-KGS-15 (Bedrock) - TD
- TH19-KGS-15 (Bedrock) - MR
- TH19-KGS-15 (Bedrock) - VW1900194
- TH19-KGS-15 (Silt Till) - VW1900191

Water Elev

- TH19-KGS-16 (Bedrock) - VW1900096
- TH19-KGS-16 (Bedrock) - Manual Readings
- TH19-KGS-16 (Silt Till) - VW1900098
- TH19-KGS-16a (Peat) - Manual Readings
- TH19-KGS-16a (Silt Till) - VW1900214
- TH19-KGS-16b (Silt Till) - Manual Readings

NO	YY/MM/DD	DESCRIPTION	DESIGN BY	DESIGN CHECK
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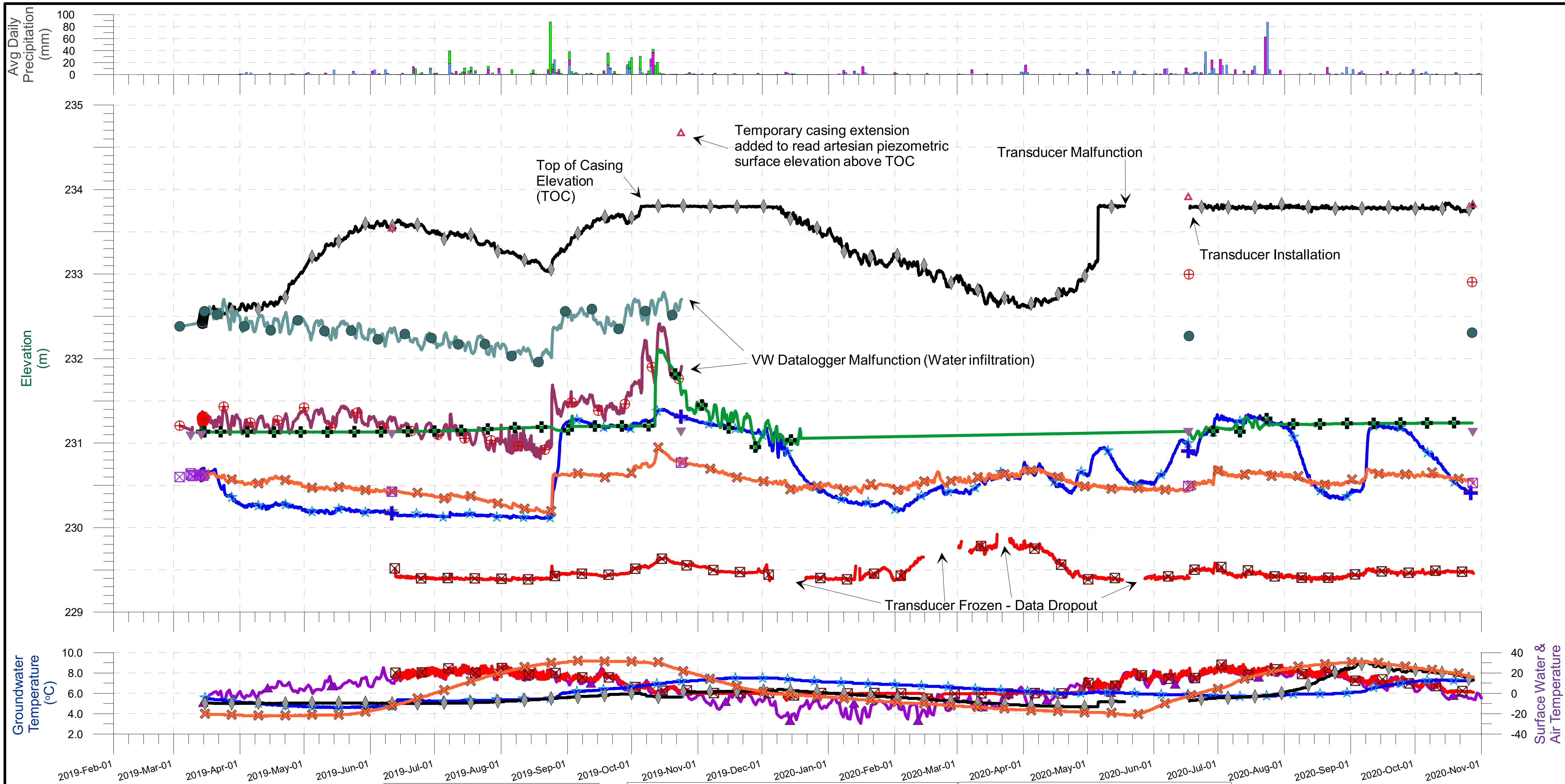
LAKE ST. MARTIN OUTLET CHANNEL
PRELIMINARY DESIGN

REACH 3
WELL PW19-KGS-03 PUMP TEST
GROUNDWATER ELEVATIONS

JULY 2021 | FIGURE 4 | REV: 0



Notes:
MR - Manual Reading
VW - Vibrating Wire Piezometer
TD - Transducer

1. Transducer water elevation data compensated with barometric pressure data from on-site barometric pressure logger.
2. Average daily air temperature and precipitation data was collected from the Fisher Branch (AUT) and Hodgson (3) weather stations (Environment and Climate Change Canada - ECCC), and the on-site weather station.

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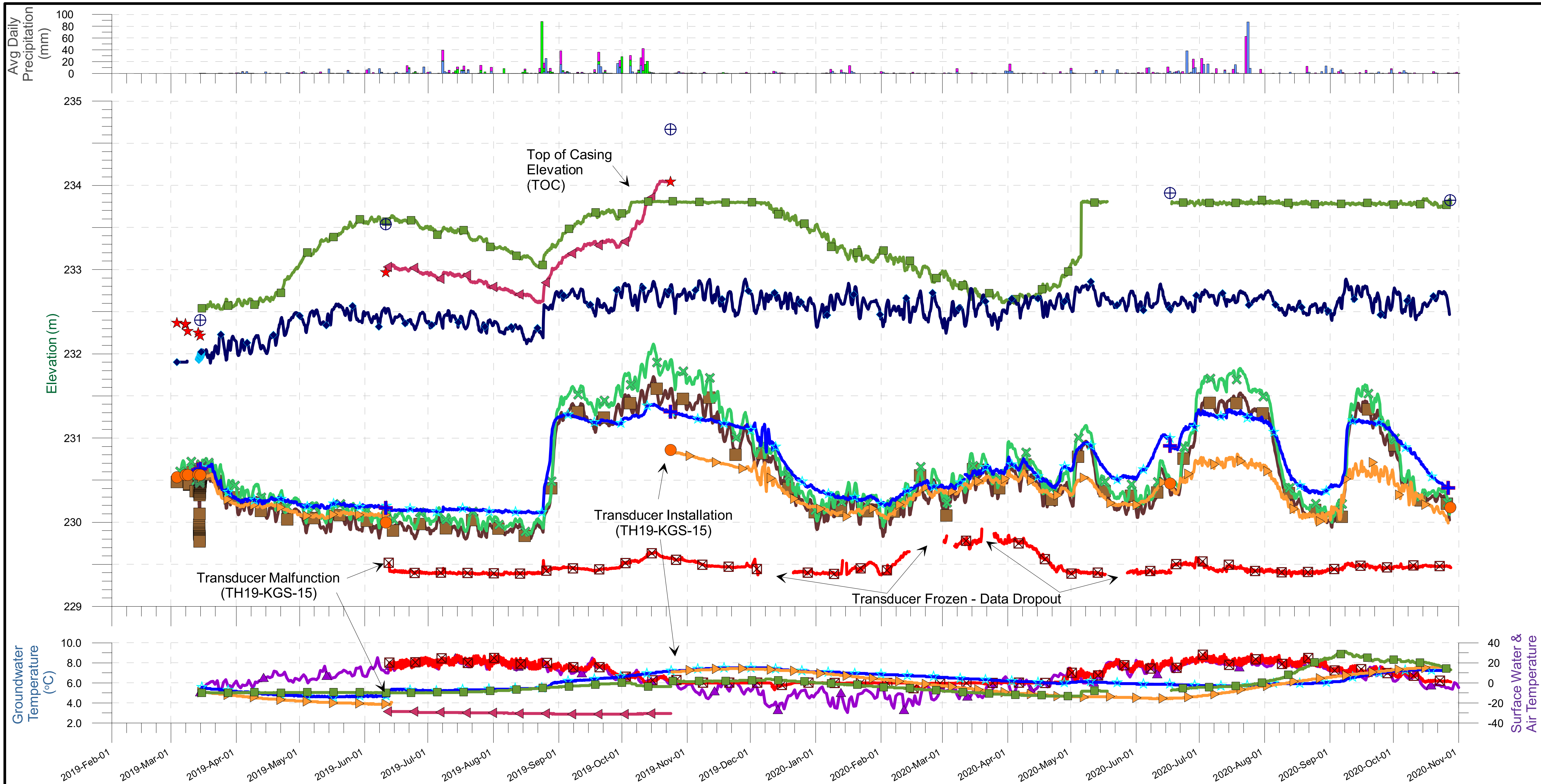
LAKE ST. MARTIN OUTLET CHANNEL
PRELIMINARY DESIGN

WATER ELEVATION AND TEMPERATURE READINGS AT WELL PW19-KGS-03, SW-R3, & TH19-KGS-16, 16a, 16b

JULY 2021 | FIGURE 5 | REV. 0



Precipitation
- On Site Wthr Stn
- Fisher Branch (ECCC)
- Hodgson (ECCC)

Water Elev
- PW19-KGS-03 (Bedrock) - TD
- PW19-KGS-03 (Bedrock) - MR
- TH19-KGS-14 (Bedrock) - TD
- TH19-KGS-14 (Bedrock) - MR
- TH19-KGS-15 (Bedrock) - TD
- TH19-KGS-15 (Bedrock) - MR
- TH19-KGS-15 (Bedrock) - VW1900194
- TH19-KGS-15 (Silt Till) - VW1900191

Water Elev
- TH19-KGS-16 (Bedrock) - TD
- TH19-KGS-16 (Bedrock) - MR
- TH19-KGS-16 (Bedrock) - VW1900096
- SW-R3 (Surface Water) - TD

Temperature
- AirTemp - Fisher Branch
- SW-R3 (Surface Water) - TD
- PW19-KGS-03 (Bedrock) - TD
- TH19-KGS-15 (Bedrock) - TD
- TH19-KGS-14 (Bedrock) - TD
- TH19-KGS-16 (Bedrock) - TD

Notes:
MR - Manual Reading
VW - Vibrating Wire Piezometer
TD - Transducer

1. Transducer water elevation data compensated with barometric pressure data from on-site barometric pressure logger.
2. Average daily air temperature and precipitation data was collected from the Fisher Branch (AUT) and Hodgson (3) weather stations (Environment and Climate Change Canada - ECCC), and the on-site weather station.

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LAKE ST. MARTIN OUTLET CHANNEL
PRELIMINARY DESIGN

WATER ELEVATION AND TEMPERATURE READINGS AT WELL PW19-KGS-03, SW-R3, TH19-KGS-14 (BR), TH19-KGS-15(BR,ST) & TH19-KGS-16 (BR)

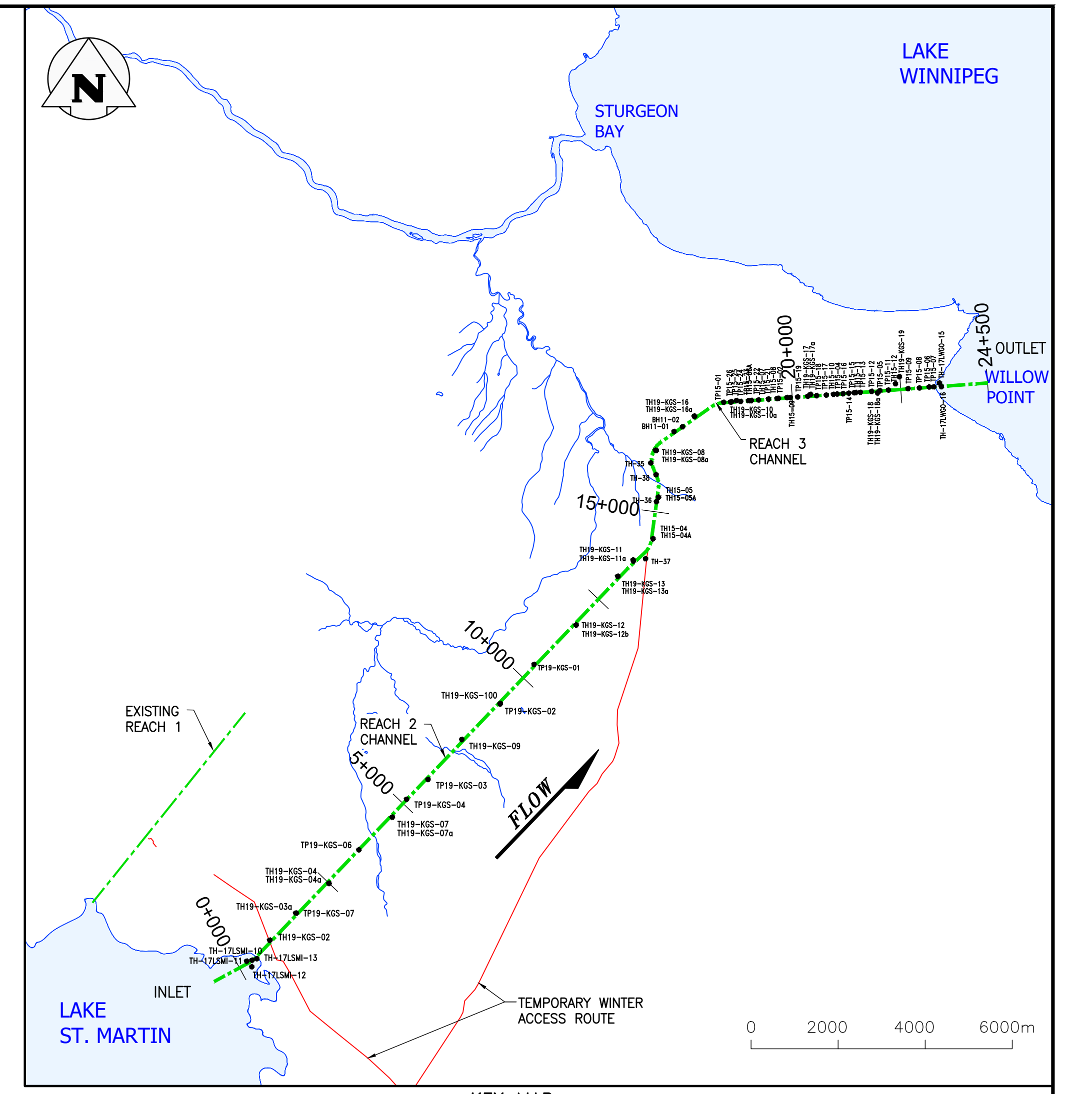
JULY 2021 | FIGURE 6 | REV 0

APPENDIX A

Supplemental Figures

NOTES:

1. THE EXISTING GROUND SURFACE AT THE CHANNEL CENTERLINE WAS DERIVED FROM NUMEROUS DATA SOURCES INCLUDING:
   - JULY 2017 LIDAR DATA PROVIDED BY MI
   - MARCH 2019 TOPOGRAPHIC SURVEY INFILL BY KGS GROUP
   - 2017 BATHYMETRIC SURVEY PROVIDED BY MI (INLET)
   - 2013 AND 2018 BATHYMETRIC SURVEY PROVIDED BY NORTH/SOUTH CONSULTANTS INC. (INLET AND OUTLET)
2. THE ORIGINAL GROUND SURFACE AT THE CHANNEL CENTERLINE IN THE VICINITY OF THE EXISTING EMERGENCY REACH 3 CHANNEL WAS DERIVED FROM LIDAR DATA CAPTURED IN 2011.
3. THE PEAT SURFACE SHOWN IS BASED ON AVAILABLE PEAT PROBES, HAND AUGER TEST HOLES, TEST HOLES AND TEST PITS IN THE VICINITY OF THE CHANNEL. PEAT PROBES AND HAND AUGER TEST HOLES ARE NOT SHOWN ON THE PROFILE FOR CLARITY.
4. THE PIEZOMETRIC ELEVATIONS SHOWN ARE BASED ON READINGS COLLECTED IN MARCH 2019.
5. THE PIEZOMETRIC ELEVATION SHOWN FOR PW19-KGS-02 IS BASED ON A STATIC MEASUREMENT COLLECTED ON JUNE 11, 2019.
6. THE SEISMIC VELOCITY LAYERS SHOWN ARE BASED ON THE FOLLOWING GEOPHYSICAL SURVEYS:
   - 2011 – GEOPHYSICS GPR INTERNATIONAL INC.
   - FEBRUARY/MARCH 2019 – FRONTIER GEOSCIENCES INC.
7. REFER TO THE LAKE ST. MARTIN OUTLET CHANNEL GEOTECHNICAL DATA REPORT FOR LOCATION PLANS, BOREHOLE LOGS, GEOPHYSICAL SURVEY RESULTS, AND LABORATORY TEST RESULTS.



KEY MAP

LEGEND:

- NO RECOVERY
- ICE
- WATER
- PEAT
- ORGANICS
- FILL
- CLAY
- SILTY CLAY
- CLAYEY SILT
- SILTY CLAY TO SILTY CLAY TILL
- SILTY CLAY TILL
- SAND
- SILTY SAND
- SILTY SAND TILL
- SAND AND GRAVEL
- COBBLE AND GRAVEL
- SILT
- SILT TILL
- BEDROCK
- SL-8 SEISMIC LINE No. 8
- DS-1 DROP STRUCTURE
- WCS WATER CONTROL STRUCTURE
- ESTIMATED STRATIGRAPHIC CONTACT
- SEISMIC REFRACTION SURVEY VELOCITY LAYERS (2011 AND 2019)
- PIEZOMETRIC GROUNDWATER LEVEL (MARCH 2019)
- DRILL HOLE
- VIBRATING WIRE PIEZOMETER
- GROUNDWATER MONITORING ZONE

PRELIMINARY
NOT TO BE USED FOR CONSTRUCTION

SCALE: 1:125 (24"x100") VERTICAL

SCALE: 1:12500 (24"x100") HORIZONTAL

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A	19/12/19	ISSUED WITH DRAFT REPORT	SGB	RKe

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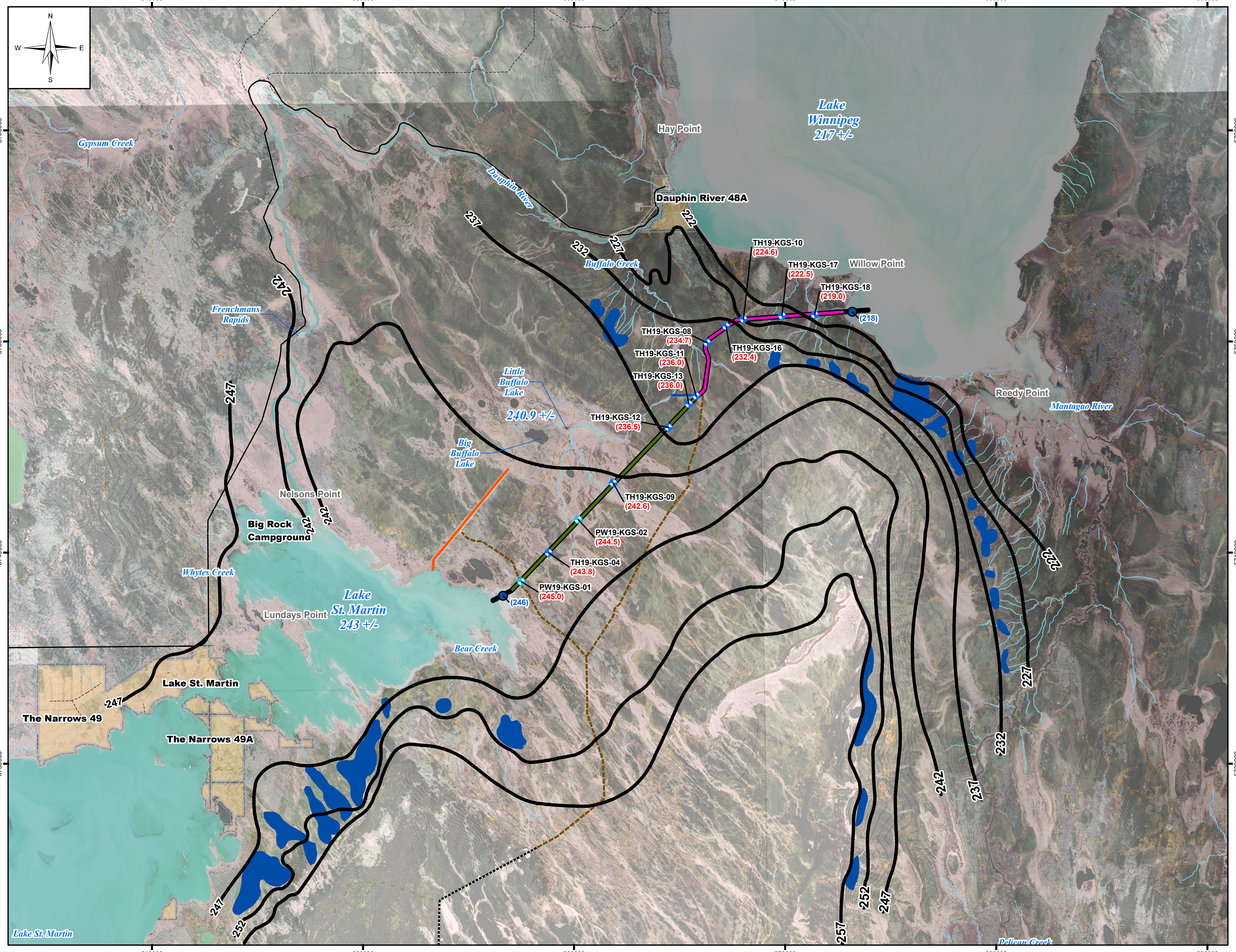
Manitoba Infrastructure

LAKE ST. MARTIN OUTLET CHANNEL
PRELIMINARY DESIGN
PRELIMINARY DESIGN REPORT

STRATIGRAPHIC PROFILE ALONG CHANNEL CENTRELINE

JANUARY 2021 | PLATE 06.1 | REV: B

FileName: P:\Projects\2018\18-0300-005\Dwg\GIS\MXD\Groundwater_Management_Plan\18-0300-005_Fig05.mxd
11"x17" PLOT SCALE 1:1



LEGEND:

- LSMOC Alignment
- Reach 1 Channel – Existing
- Proposed Reach 2 Alignment
- Reach 3 – Existing
- Reach 3 – Proposed
- Existing Transmission Line
- Existing Winter Access Road Alignment
- Forestry Road
- Highway
- Municipal Road
- Limited Use Road
- Trail
- Watercourse
- First Nation
- Artesian Groundwater Spring Sites
- (218) Bedrock Piezometric Pressure estimated during Inlet and Outlet Drilling Programs (by MI)
- (222.5) Bedrock Piezometric Pressure (June, 2019)

NOTE:
1. Instrumented Testholes include standpipes or standpipes and vibrating wire piezometers. See Geotechnical Data report for Details.
2. Wetland, Watercourse and Waterbody layers shown were obtained from NRCAN 1:50000 data.
3. All units are metric and in metres unless otherwise specified. Transverse Mercator Projection, NAD 1983 CSRS, Zone 14. Elevations are in metres above sea level (MSL) and are referencing Canadian Geodetic Vertical Datum 1928 (CGVD28).

DRAFT

2 0 2 4 6 8
Kilometres

SCALE: 1:175,000 METRIC 11"x17"

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KGS GROUP CONSULTING ENGINEERS

Manitoba Infrastructure

LAKE ST. MARTIN OUTLET CHANNEL PRELIMINARY DESIGN

REGIONAL ARTESIAN SPRING SITES AND BEDROCK AQUIFER PIEZOMETRIC PRESSURES

OCTOBER 2019	FIGURE 05	REV. A

APPENDIX B

Lake St Martin Reference Report

Kontzamanis Graumann Smith MacMillan Inc.

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August 22, 2016

File No. 12-0300-011

Manitoba Infrastructure
Region 4 - West Central Region
257 Industrial Road
Dauphin, Manitoba
R7N 3B3

ATTENTION: Mr. Mark Allard

RE: Lake St. Martin Area Groundwater Hydrograph Interpretation

Dear Mr. Allard:

1.0 INTRODUCTION

KGS Group is pleased to provide this final letter report regarding analysis of groundwater aquifer water level fluctuations in the vicinity of Lake Manitoba, Lake Pineimuta, and Lake St. Martin. Manitoba Infrastructure (MI) provided KGS Group with continuously monitored water level records, for a series of 14 wells, with data collected between approximately September 1998 and May 2001, and between January 2013, and January 2016. Figure 1 provides a general site plan for the region, including locations of surface and groundwater monitoring sites.

2.0 GEOLOGICAL SETTING

All of the wells monitored by MI, except for G05LM012, are located within the footprint of a structurally disturbed bedrock zone associated with the Lake St. Martin Impact Structure. Uplift and fracturing of the country rock caused by the meteorite impact, and the nature of the sediments that subsequently filled the crater, have resulted in a unique geological environment for the establishment of groundwater flow conditions. Between 1998 and 2001, the Geological Survey of Canada conducted hydrogeological and hydrochemical investigations in the Gypsumville-Lake St. Martin areas. Data provided from that study (Desbarats and Pyne, 2004), is used as a basis for interpretation within this summary report, used in conjunction with the groundwater monitoring data provided by MI.

Based on the locations provided, the wells monitored by MI are situated within the following regional geological units (listed in order from oldest to youngest, geologically; see also Table 1 and the sketch included in Appendix A):

Ordovician Red River Formation (Orr)

Comprised of a thick (up to 95 m in the region) sequence of mottled dolomitic limestones, cherty dolomites, and dolomites with argillaceous marker beds. The uppermost Fort Garry member is known to be a zone of enhanced permeability, likely due to karst development. The uplifted formation surrounding the impact structure is believed to outcrop beneath the overburden cover in a concentric belt. Monitoring well G05LM011 is installed within this bedrock zone.

Silurian Interlake Group (S)

Comprised mainly of buff colored, microcrystalline and sparsely fossiliferous dolomites, with shaly interbeds. Thickness of the Interlake Group in the region varies between 15 m and 45 m. The upper portion of the unit has been truncated by the present day erosional surface, and paleo-karst features are common, infilled with Cretaceous-aged shales and lignite. Due to these paleo-karst features and impact-related fracturing, this unit is highly permeable in the uplift zone surrounding the impact structure.

By location, monitoring wells G05LM002, 003, and 012 are installed within this bedrock zone. While these wells are in general situated toward the periphery of the impact crater, note that only well 012 is installed outside of the assumed highly structurally disturbed bedrock zone. GWDRILL logs are available for 002 and 012, indicating well installations within the carbonate bedrock (Table 1).

Triassic St. Martin Complex (Cbx)

Bedrock here is comprised of highly permeable carbonate brecchias derived from the impacted carbonate bedrock sequence, found in the south and western portion of the impact crater, and within which monitoring well G05LM015 is assumed to be installed. At depths of over 300 m, shock-metamorphosed, brecciated granitic gneiss, intruded by a glass-like rock (pseudotachylyte), found in the central uplifted core of the structure and near its bottom.

Jurassic Amaranth Formation (Rb and Ev members)

These are a sequence of crater-fill sediments, resting unconformably on the breccia of the St. Martin Complex. The contact elevation is quite variable, suggestive of a highly dissected erosional surface. The lower Red Bed member is up to 40 m thick, comprised of red dolomitic shales, siltstones and sandstones, with few conglomeratic beds and black organic-rich layers. The red beds grade laterally and vertically into the upper Evaporite member, comprised of red-brown argillaceous dolomite, anhydrite, and gypsum, with shaly interbeds. The Evaporite member outcrops in the northern part of the impact structure, and are extensively karstic.

By location, monitoring wells G05LM004 to 010, 013, and 014 are installed within this bedrock zone. Note that where logs are available, well installations are described within dolomitic bedrock and sands (004), or entirely within the overburden within boulder tills and gravels (008), possibly a result of the variable erosional surface of the bedrock in the area (See also Table1).

Overburden Deposits

Overburden in the region is primarily comprised of silty sandy tills, with inter-till granular zones. These deposits are up to 50 m in thickness along the north shore of Lake St. Martin, in the vicinity of the southeast quadrant of the Lake St. Martin impact structure crater. In these areas, thick tills are interbedded with gravel and boulder interbeds, making for difficult drilling and well completions. Glaciolacustrine silts and clays are found in low-lying agricultural lands north of Lake Pineimuta. Low bedrock ridges in the uplands area north and northeast of Gypsumville are extensively karstified, and are covered by thin overburden granular deposits.

3.0 HYDROGEOLOGICAL SETTING

The Lake St. Martin Impact Structure disrupts the normal succession of gently dipping carbonate bedrock in the Interlake region. In general, the regional bedrock aquifers flow from high bedrock elevation upland recharge areas (where sediment cover is discontinuous), to low elevation areas, discharging to lakes, streams and low-lying swamps.

Except within upland recharge areas, the bedrock aquifer is confined by the overlying tills and glaciolacustrine silts and clays. Upland areas are typically comprised of partial or complete bedrock outcrop, sometimes capped with thin granular overburden. Due to the thin overburden cover and relatively high permeability of the underlying carbonate bedrock (often with enhanced permeability due to karstic and paleokarst features), these upland zones are recharge areas for the carbonate aquifer, and are generally unconfined. Extensive groundwater recharge areas of note are located north and northwest of Gypsumville, and within another area of relatively high elevation bedrock capped by thin till, situated between Lake Manitoba and Lake Pineimuta (specifically in the region of G05LM002).

Discharge areas are characterized by lakes and relatively low-lying areas covered by organic deposits such as swamps, marshes and bogs. A key discharge area is associated with the drainage basin surrounding Lake Pineimuta, where ground surface and bedrock surface elevations are low, confining overburden clays and silts are relatively thick, and flowing artesian well conditions in the bedrock are noted.

Permeability of the carbonate aquifer can be quite high due to karstic features, but also due to impact related fracturing within the disturbed zone surrounding the Lake St. Martin Impact Structure. Within the impact structure, the main aquifer is within the highly permeable brecciated carbonate units, and within granitic microbreccias, however due to the high permeabilities of both these units, aquifer heads are in general continuous and they are considered a single aquifer system. The brecciated aquifers are confined by the Amaranth Formation red bed units.

The main features of groundwater flow in the region are as follows (also see Figure 1):

- From recharge upland areas northwest of Gypsumville (piezometric elevations between approximately El. 256 m +/- and El. 258 m+/-), flowing to discharge to the southwest toward Lake Manitoba (piezometric elevations <El. 250 m +/-),and to the southeast toward Lake Pineimuta (piezometric elevations <El. 248 m +/-) and Lake St. Martin (piezometric elevations <El. 246 m +/-);

- From the local recharge zone (bedrock ridge) between Lake Manitoba and Lake Pineimuta, forming a recharge mound (as measured at G05LM002, with piezometric elevations in the order of El. 254 m +/-) flowing radially outward to discharge towards adjacent Lakes Manitoba, Pineimuta, and St. Martin, and various wetland areas (piezometric elevations <El. 250 m +/- to <El. 248 m +/-); and

- A third significant recharge area is noted within the Lake St. Martin Impact Crater near Gypsumville, where groundwater recharge enters the bedrock aquifer as leakage through the Jurassic Red Beds from the overlying karstic evaporite aquifer zone. Groundwater in this recharge area (with piezometric elevations at El. 252 m +/-), flows southward to discharge in the vicinity of Lake Pineimuta and at Lake St. Martin, where groundwater elevations are in the order of El. 246 m +/- to El. 244 m +/-.

During the GSC groundwater study (1998 – 2001), bedrock groundwater levels in upland recharge areas were noted to fluctuate as much as 5 m, whereas in low lying discharge areas, groundwater levels fluctuated in the order of 1 m. This relationship of magnitude in water level fluctuations within groundwater recharge versus discharge areas is also common within the MI supplied monitoring data, and is discussed in further detail below.

4.0 ANALYSIS OF GROUNDWATER PIEZOMETRIC PRESSURES

4.1 CALCULATION OF GEODETIC GROUNDWATER PIEZOMETRIC PRESSURE ELEVATIONS

MI provided KGS Group with several electronic data files, which included transducer readings, survey information, and transducer installation details that are required for calculating final geodetic groundwater elevations. The following details are noted (see also Table 1):

- In all cases, the 2016 casing elevation surveys were used to calculate geodetic groundwater elevations, with the exception of G05LM002, 003, and 010 (where a 2016 survey elevation was not provided);

- The “SDBTC” (Sensor Depth Below Top Of Casing) measurement provided by MIT was used to calculate the sensor tip elevation;

- The height of water column measured by the transducer is added to the sensor tip elevation to determine geodetic elevation;

- At G05LM002, 003, and 010, a 2016 casing elevation survey was not provided. At these locations, the top of casing datum provided in the original 1998-2001 datasets was applied; and

- The 2016 survey data, with the exception of G05LM002, 003, and 010, was also applied to 1998 – 2001 era data, by adjusting the older data by the difference in the casing elevation datum from the 2016 surveys, in comparison to the 1998 – 2001 datum surveys. The difference in the datum is given on Table 1, for reference. This difference varies from approximately -1.7 m to +2.9 m.

Subsequent to issue of the draft report, MI provided updated survey datums for wells G05LM002, 003, and 009. This final report reflects adjustment of these well datums (see Tables 1 and 2, and Figures 2 through 5). While the shifts in well datums were fairly significant (e.g. -0.686 m for well G05LM002, -0.76 m for well 003, and -3.275 m for well 009), the overall interpretations of the groundwater system for this study do not change. In fact, these well datum shifts improve the data quality, for example bringing groundwater elevation data for well G05LM009 (located in a groundwater discharge area adjacent to Lake St. Martin) into better measurement agreement with adjacent and similarly installed wells (e.g. wells G05LM014, 015).

Lake Manitoba Water levels were compiled from the hydrometric station near Steep Rock (05LK002). Lake St. Martin water levels were compiled from the hydrometric station near Hilbre (05LM005). The locations of these hydrometric stations are also shown on Figure 1.

4.2 OBSERVATION WELL RESPONSES

The focus for interpretation of the dynamics of observation well responses, and the relationship to lake level and/or precipitation events is based on data collected between 2013 and 2016, since this dataset is the most complete (see Figure 2), and includes detailed continuous monitoring of lake levels at Lake Manitoba and Lake St. Martin. Precipitation data was collected for the nearest weather station (Moosehorn) with continuous data, from Manitoba Agriculture, Food, and Rural Development data. Note that this station data does not always include precipitation data for the winter months. Other weather station data available from Environment Canada (which includes year-round precipitation data) is located approximately 80 km away, and is much less applicable to the analysis.

Aside from the physical aquifer properties such as geological setting, characteristics of overburden cover, bulk aquifer permeability, fracture interconnections, etc., there are two “boundary condition” mechanisms that will affect piezometric pressure levels within the aquifers:

- Lake levels within groundwater discharge zones; and

- Amount and patterns of annual precipitation/snowmelt that recharge the aquifer systems.

4.2.1 Well Responses to Lake Level Variability

All wells respond to the seasonal, long-period oscillation (rise and fall) of local lake levels, as measured at Hilbre for Lake St. Martin, and at Steep Rock, for Lake Manitoba. This response is characteristic of a confined aquifer system, considering these lakes (along with Lake Pineimuta) form significant natural discharge areas for the confined aquifer system. A rise in the boundary condition for discharge at the lakes is accompanied by a piezometric pressure response rise, and an associated re-equilibration of the groundwater levels as measured in the wells. Similarly, a decline in lake levels will effect a decline in aquifer piezometric pressures.

A summary of lake drainage conditions for the years included in the groundwater analysis is as follows:

- 2013/2014 and 2015/2016 were representative of typical conditions, with Lake Manitoba flowing through the Fairford control structure in a fully open configuration, thus leading to normal wintertime staging on Lake St. Martin, due to ice conditions on the Dauphin River; and

- 2014/2015 included a reduction in flows through the Fairford control structure and operation of the Reach 1 channel under emergency conditions, with some discharge capacity reduction at Dauphin River due to ice staging.

Based on the available data (2013 – early 2016), the total range in lake levels measured within the dataset is as follows:

- For Lake St. Martin (measured near Hilbre), minimum and maximum lake elevations varied between El. 243.85 m and El. 245.08 m, a difference of 1.23 m (see also Figure 2); and

- For Lake Manitoba (Steep Rock), minimum and maximum lake elevations varied between El. 247.29 m and El. 248.39 m, a difference of 1.10 m (see also Figure 2).

As shown on Figure 2, note that piezometric pressures for wells G05LM007, 011, 013, 014, and 015 plot below typical Lake Manitoba water levels; however this group of wells is located within relatively low elevation areas associated with the Lake St. Martin Impact Structure and within regional groundwater discharge areas immediately adjacent to Lake St. Martin. As such, this relationship is expected. Periodically, well G05LM013 (located close to Lake St. Martin, also within a groundwater discharge area) plots below the level of Lake St. Martin. This is likely due to its very close proximity to the lake (i.e. the well piezometric pressure condition is very near lake level), and due to a possible variability in lake level measurements (e.g. wind setup etc.) with lake level being measured relatively far to the south, near Hilbre (i.e. more than 20 km away from well G05LM013).

To quantify aquifer responses to lake levels changes, data trends during winter months were analyzed (see also Figures 3 – 5). This approach is necessary to isolate aquifer responses from the driving boundary condition of snowmelt and precipitation (recharge) which directly affects aquifer piezometric pressures, but also at the same time can effect seasonal changes in lake levels (often associated with a lag from the occurrence if any one short-term precipitation event).

A summary of well responses is provided in Table 2, for the winters of 2013/2014 (a normal year of operations at the Fairford control structure) and for 2014/2015 (a year which included a reduction of flow at Fairford, and emergency operation of the Reach 1 channel). The following is noted:

- Lake levels for Lake St. Martin rose between approximately 0.1 m and 0.2 m due to ice staging on the Dauphin river during these winter discharge events;

- Lake levels for Lake Manitoba declined by approximately 0.1 m to 0.2 m during these winter discharge events; and

- All aquifer piezometric pressures measured within the monitored wells declined by between approximately 0.2 m and 1.2 m, with the largest declines noted within regional groundwater recharge areas (i.e. wells G05LM002 and 005).

The steady decline in aquifer piezometric pressures, with relatively little change in lake level boundary conditions for aquifer discharge, illustrates the sensitivity of the aquifer system to regional snowmelt and rainfall contributions to groundwater recharge that typically occur between April and October.

4.2.2 Well Responses to Precipitation

Recharge to the groundwater system is linked to the amount of precipitation and precipitation patterns, unsaturated zone properties, and hydraulic conductivity of geological materials. Typical patterns for aquifers in Manitoba include a recharge reaction (i.e. rising water levels) in spring in response to snow melt and spring rain, with groundwater levels declining the remainder of the year. The gradual decline phase is periodically interrupted by short–term recharge response to summer and fall precipitation events. All of the wells monitored by MI, and as analyzed for this study, show this response to seasonal recharge. In terms of the context of the monitoring data provided, the seasonal cycle for the groundwater system observed is defined by the timing for the observation of the lowest groundwater piezometric pressures measured within recharge groundwater areas (e.g. at G05LM002), with the lowest groundwater levels typically observed during the month of April (the lowest piezometric pressures measured immediately prior to the onset of the spring recharge event), and forms the basis for the generation of Figures 3, 4, and 5 which show the monitoring data from April to late March for the monitoring years 2013 – early 2016.

Annual groundwater elevations are also variable relative to years of below normal precipitation when (for example) the spring recharge event may be muted and groundwater levels may decline throughout the year. Aquifer water levels also show longer term responses to decadal changes in precipitation that may be more or less than the long term precipitation average, referred to as “wet” or “dry” cycles. This phenomenon was quantified and illustrated for all major aquifer systems in Manitoba, including for the carbonate aquifer in the Interlake, by Wang and Betcher (2011). In the Interlake area, the lag time between the observation of a “wet” or “dry” year may take up to 8 months to be noticeable in the aquifer piezometric pressure record. Overall, the results of this work indicate that since approximately 1991, following a long period of generally declining aquifer levels between the 1960’s to about 1990, aquifer water levels in Manitoba have risen, corresponding to a “wet” cycle on the prairies.

As discussed, all wells monitored as part of this study show distinct seasonality and aquifer responses to annual (and short-term summer) precipitation events as described above, with water levels directly linked to the quantity of precipitation available for recharge to the groundwater system.

Based on responses to spring recharge/precipitation events, there are several classes of wells:

1. Wells located within recharge areas with thin overburden cover, that respond strongly to spring recharge events and are located in relatively high elevation bedrock areas (i.e. G05LM002, 004, 005, and 010);

2. Wells located proximal to main groundwater discharge areas such as Lake Pineimuta, however are locally upgradient of the discharge zones and respond strongly to spring recharge/precipitation events (i.e. G05LM011 and 012);

3. Well G05LM003 responds like classes 1 and 2 above but is in an area immediately downgradient of a significant recharge zone, and periodically is under flowing artesian conditions;

4. Wells G05LM006, 008, 009, 013 and 015 piezometric pressures, like all the other monitoring wells, show the seasonal long-term rise and fall with lake levels and recharge, with a significantly muted or lagged response to individual short term precipitation events in comparison to classes 1 – 3 above. Well G05LM008 (an overburden well installed within deep granular fills in the Lake St. Martin Impact Structure) responds similarly to this class of bedrock aquifer wells, illustrating a direct interconnection of these bedrock and impact structure infill aquifer systems, at least in the vicinity of this well. Of this group, wells G05LM009 and 015 respond the most directly to short term precipitation events, perhaps due to installation within a very pervious portion of the Amaranth formation (well 009), and within impact fractured carbonate breccia aquifer zones (well 015); and

5. Wells G05LM007 and 014 are anomalous. The record for well 007 is short (early 2013 only), and piezometric pressures vary somewhat erratically by approximately 0.5 m, apparently in response to precipitation. Well 014 tends to show a similar long-term rise and fall as with the other wells, however short-term water level fluctuations are masked by an apparent response to a nearby pumping well, as evidenced by the repeated pumping/recovery cycles displayed within the well 014 hydrograph trace.

Table 2 details the well responses to a short-term, though intense, precipitation event that occurred between June 26 and July 1, 2014 (see Figure 4). The following was noted:

- Total precipitation falling between June 26 and July 1, 2014 was 125.6 mm;

- Lake levels on Lake St. Martin appear to respond nearly immediately with a rise of 0.3 m;

- Lake levels on Lake Manitoba appear to fluctuate slightly, though the lake level was on an overall upward trend, with slight fluctuations in the order of approximately 0.1 m; and

- All aquifer piezometric pressures measured within the monitored wells increased by between approximately 0.2 m and 1.8 m, with the largest increases noted within regional groundwater recharge areas (i.e. wells G05LM002).

The nearly immediate and measurable increase in aquifer piezometric pressures, accompanied by a relatively limited change in lake level boundary conditions within aquifer discharge zones, illustrates the sensitivity of the aquifer system to short-term and intense rainfall recharge events that typically occur during the summer and fall seasons. Besides the clear response of recharge area wells such as G05LM002 (1.8 m rise) where bedrock outcrop elevations are high and sediment cover is very thin allowing for nearly direct infiltration, variability in the magnitude of well responses to these short term precipitation events are likely attributable to differences in geological and hydrogeological aquifer conditions at individual well sites (i.e. G05LM009, 011), and possibly lag times for the full effect of these precipitation events to impact the aquifer system. In nearly all cases (except for within recharge areas) the well piezometric pressure responses are less than to equal to the change observed in lake level conditions, suggesting an imperfect interconnection of the aquifer system to the surface water system. Further analysis may be necessary to confirm this supposition.

Going one step further, over the longer timeframe, Figure 2 illustrates an important relationship between lake and aquifer levels and the role of seasonal recharge. In all cases, the range in aquifer piezometric pressures as a result of spring recharge (snowmelt and rainfall) plus annual short-term summer to fall precipitation events are greater than the range in lake level variation. Thus it is clear that annual recharge is a significant and variable factor directly driving the total variation in aquifer piezometric pressures within this aquifer system.

5.0 SUMMARY

KGS Group completed a preliminary assessment of aquifer piezometric conditions and lake levels in the Lake Manitoba and Lake St. Martin areas, based on data collected and provided by MIT. While the geological setting for each of the wells varies, due to the presence of the Lake St. Martin Impact Structure, the aquifer piezometric pressure responses are generally consistent and comparable, due to the interconnectedness of the various aquifer systems in the area. The largest variability in aquifer responses are related to wells measuring groundwater levels in recharge versus discharge areas.

The overall behavior of the aquifers in the region are as expected for aquifer systems of this nature. Aquifer recharge areas occur under unconfined conditions where bedrock elevations are relatively high and sediment cover is thin to non-existent. Groundwater discharge occurs in low lying areas where aquifers are confined by overlying low permeability sediments, with discharge to bogs, streams, and lakes, most notably Lake Manitoba, Lake St. Martin, and Lake Pineimuta. Changes in these discharge boundary conditions (i.e. lake level changes, rising or falling) do effect a re-equilibration piezometric pressure response of the aquifer system.

All wells record aquifer piezometric pressures that rise and fall seasonally, importantly according to the recharge that occurs to the aquifer from spring snowmelt and additional short-term summer to fall precipitation events, along with some contribution from the seasonal variability in lake levels that occur at Lake St. Martin and Lake Manitoba. The total seasonal variability in lake levels measured between 2013 and the winter of 2015 is less than the seasonal piezometric pressure variability measured within the aquifer system; the difference being attributable to seasonal aquifer recharge. In addition, aquifer piezometric pressure declines measured within all wells during the winter months outstrip the changes observed in lake levels, in particular where Lake St Martin levels respond in an opposite manner and rise slightly during to winter ice staging along the Dauphin River. This further emphasizes the significant connection of the aquifer system to seasonal recharge contributions. For a flood stage condition on the lake(s), it would be expected that the rise in the discharge boundary condition (i.e. lake levels) would contribute to a rise in aquifer piezometric pressure; however, the associated snowmelt and rainfall aquifer recharge that would accompany a flood stage year would also have a significant role in driving up aquifer piezometric pressures.

Over multi-year timeframes, the aquifer groundwater levels will also vary following consecutive years of "wet" or "dry" conditions, based on precipitation levels that are more than, or less than, the typical average for the region. This phenomenon has been described for the area, and the responses of the aquifer system to these effects lag by months in time.

6.0 REFERENCES

Desbarats, A.J., and Pyne, M. (2004). Groundwater Resources of the Lake Saint Martin Area, Manitoba, Geological Survey of Canada Open File 4624, 6 Sheets, Scale 1:100 000.

Wang, J, and Betcher, R.N. (2011). Groundwater, drought/wet cycle and climate change, Southern Manitoba, Canada. Joint Meeting of the Canadian Quaternary Association and the Canadian Chapter of the International Association of Hydrogeologists. Quebec City, August 28-31, 2011. Proceedings.

Should you require any clarifications, or have questions regarding this preliminary analysis, please do not hesitate to contact the undersigned.

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TABLES

TABLE 1 - Monitoring Well Installation Summary

Station Name	UTM -Y	UTM - X	GWDRILL Well PID	Geological Setting Based on Regional Mapping	Within Impact Structure Disturbance Zone?	Well Site Stratigraphy Based on Regional Mapping [1]		Well Survey Details						Geology and Well Completion Details (GWDRILL Logs)					Groundwater Monitoring Summary			
						Overburden Thickness (m)	Bedrock Surface Elevation (m)	June 2016 Survey Well Datum Elevation (m)	Spring 2016 Survey Ground Surface Elevation (m) [2]	Spring 2016 Survey Well Datum Elevation (m)	1998-2001 Data Well Datum Elevation (m)	Difference in Well Datum (1998-2001 vs Spring 2016) (m)	Casing Stickup (m)	Overburden Thickness (m)	Bedrock Surface Elevation (m) [3]	Monitoring Zone Top (Depth, m)	Monitoring Zone Bottom (Depth, m)	Geology Within Monitored Zone	Piezometric Pressure MAX (m)	Date (MAX)	Piezometric Pressure MIN (m)	Date (MIN)
G05LM002	5724133	518053	104475	Silurian Interlake Group Carbonates	Y	<5	260 +	264.357	**264.7**	n/a	265.043	n/a	0.33	0.9	263.8	9.3	24.4	limestone bedrock	257.5	July 12, 2014	249.8	April 4, 2001
G05LM003	5729917	518207	n/a	Silurian Interlake Group Carbonates	Y	~ 10	~ 240	250.705	n/a	n/a	251.465	n/a	n/a	n/a	n/a	n/a	n/a	n/a	251.4	May 16, 2001	249.7	March 25, 2001
G05LM004	5737321	523778	16325	Jurrasic Amaranth Formation Evaporites	Y	~ 10	~ 240	n/a	253.185	253.288	254.971	-1.683	0	9.8	243.4	12.2	68	limestone bedrock, sands	253.0	June 26, 2013	249.3	October 1, 1998
G05LM005	5736907	525859	145140	Jurrasic Amaranth Formation Evaporites	Y	~ 5	~ 250	n/a	258.142	258.465	258.285	0.180	0.33	no detailed log	no detailed log	no detailed log	no detailed log	no detailed log	254.8	May 9, 2001	248.8	March 26, 2001
G05LM006	5734001	527304	n/a	Jurrasic Amaranth Formation Red Beds	Y	~ 15	~ 235	n/a	252.679	252.977	254.300	-1.323	0.3	n/a	n/a	n/a	n/a	n/a	249.8	June 23, 2013	247.9	October 10, 1998
G05LM007	5732637	531315	n/a	Jurrasic Amaranth Formation Red Beds	Y	~ 35	~ 210	n/a	247.656	248.307	n/a	n/a	0.45	n/a	n/a	n/a	n/a	n/a	248.0	April 28, 2013	246.7	April 23, 2013
G05LM008	5732673	533510	72417	Jurrasic Amaranth Formation Red Beds	Y	~ 45	~ 200	n/a	249.028	249.529	n/a	n/a	0.5	> 49.4	< 199.6	44.8	47.9	boulder till and gravels	248.8	June 27, 2013	247.8	March 31, 2014
G05LM009	5729065	529238	n/a	Jurrasic Amaranth Formation Red Beds	Y	~ 25	~ 230	248.526	250.826	251.801	248.927	2.874	0	n/a	n/a	n/a	n/a	n/a	247.8	June 27, 2013	245.1	March 30, 1999
G05LM010	5730775	526042	n/a	Jurrasic Amaranth Formation Red Beds	Y	~ 15	~ 240	n/a	n/a	n/a	255.742	n/a	n/a	n/a	n/a	n/a	n/a	n/a	248.9	May 31, 2001	247.5	October 10, 1998
G05LM011	5725501	526042	n/a	Ordovician Red River Formation Carbonates	Y	< 10	240 +	n/a	247.612	247.858	247.196	0.662	0.25	n/a	n/a	n/a	n/a	n/a	246.7	June 29, 2014	243.5	October 27, 2000
G05LM012	5717262	520349	4200	Silurian Interlake Group Carbonates	N	~ 15	~ 235	n/a	249.573	251.054	n/a	n/a	1.219	15	234.6	15.9	26.5	limestone bedrock	249.7	May 13, 2013	247.5	January 17, 2014
G05LM013	5730656	532181	n/a	Jurrasic Amaranth Formation Red Beds	Y	~ 45	~ 205	n/a	246.061	246.281	n/a	n/a	0.2	n/a	n/a	n/a	n/a	n/a	245.3	May 14, 2013	243.2	July 27, 2015
G05LM014	5729100	530665	n/a	Jurrasic Amaranth Formation Red Beds	Y	~ 40	~ 210	n/a	247.838	248.303	n/a	n/a	0.45	n/a	n/a	n/a	n/a	n/a	247.8	May 9, 2013	246.8	May 27, 2013
G05LM015	5729034	525597	n/a	Triassic St. Martin Complex Carbonate Breccia	Y	~ 15	~ 235	n/a	248.033	248.208	n/a	n/a	0.3	n/a	n/a	n/a	n/a	n/a	247.6	June 29, 2014	245.9	March 31, 2014

NOTES:

1. Data compiled from Desbarats and Pyne, 2004.
2. Where bold, ground surface claculated from casing datum less well stickup measurement.
3. Bedrock surface elevation calculated from 2016 ground surface survey less overburden thickness from GWDRILL logs.

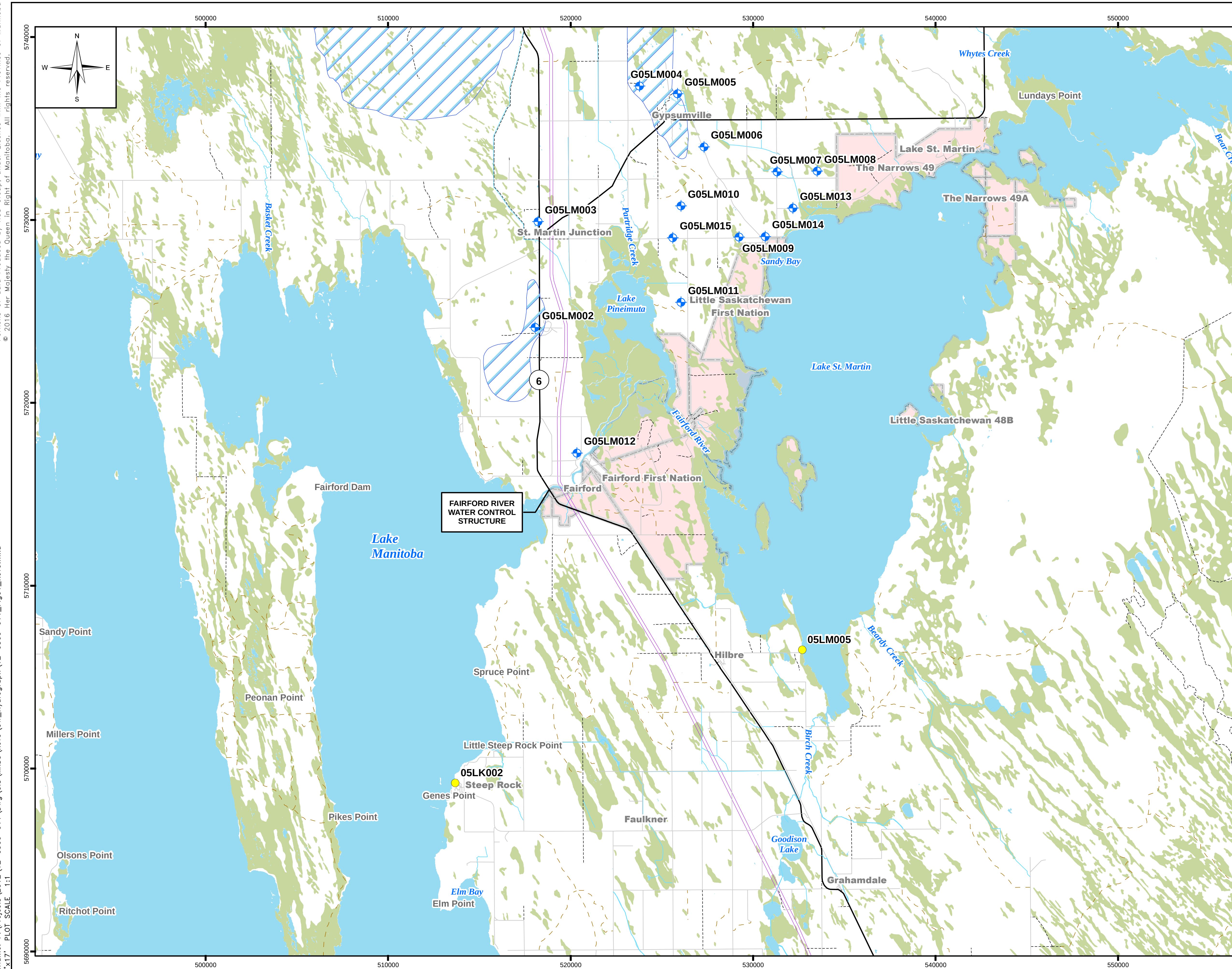
TABLE 2 - Well Responses to Lake Level Changes and Short-Term Precipitation Events

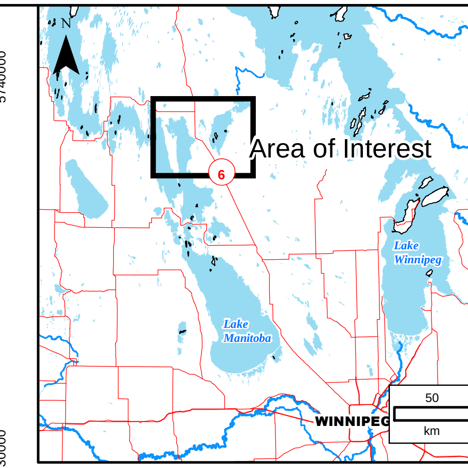
	RESPONSE TO LAKE LEVELS DURING WINTER MONITORING PERIODS						2014 Rainfall Event [2]		
LOCATION	(2013/2014) 23-Nov-2013 Elevation (m)	(2013/2014) 29-Mar-2014 Elevation (m)	2013/2014 Difference (m)[1]	(2014/2015) 1-Dec-2014 Elevation (m)	(2014/2015) 15-Mar-2015 Elevation (m)	2014/2015 Difference (m)[1]	Max. Elevation (m)	Min. Elevation (m)	Difference (m)
Lake St. Martin	244.257	244.456	0.20	244.34	244.43	0.09	245.08	244.77	0.30
Lake Manitoba	247.583	247.462	-0.12	248.02	247.83	-0.20	248.07	247.98	0.09
G05LM002	251.94	250.78	-1.16	252.55	251.57	-0.98	257.00	255.19	1.81
G05LM005	251.869	250.721	-1.15	252.43	251.69	-0.74	252.74	252.56	0.18
G05LM006	249.266	249.02	-0.25	249.63	249.47	-0.16	249.69	249.48	0.21
G05LM008	248.222	247.861	-0.36	248.54	248.32	-0.22	248.77	248.60	0.17
G05LM009	246.846	246.173	-0.67	247.16	246.71	-0.45	247.66	247.14	0.53
G05LM011	245.365	244.555	-0.81	245.36	244.93	-0.43	246.68	246.28	0.40
G05LM012	247.871	247.548	-0.32	248.48	247.97	-0.52	n/a	n/a	n/a
G05LM013	244.611	243.639	-0.97	244.24	243.56	-0.68	244.91	244.73	0.18
G05LM015	246.927	246.041	-0.89	246.83	246.45	-0.39	247.62	247.34	0.28

Notes:

1. Negative value indicates a decrease in lake or groundwater levels.
2. Short-term rainfall event analysed occurred between 26-Jun and 1-Jul, 2014.

FIGURES





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LEGEND:

- Lake Gauge
- Monitoring Well
- Municipal Road
- Highway
- Limited Use Road
- Trail
- Existing Transmission Line
- Watercourse
- Waterbody
- Wetlands
- First Nation
- Major Localized Groundwater Recharge Areas (Approx., After Desbarats and Pyne, 2004)

2 0 2 4 6 8
Kilometres

SCALE: 1:200,000 METRIC 11"x17"

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)

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
0	16/08/19	ISSUED WITH FINAL REPORT	JDM	MSW

REVISIONS / ISSUE

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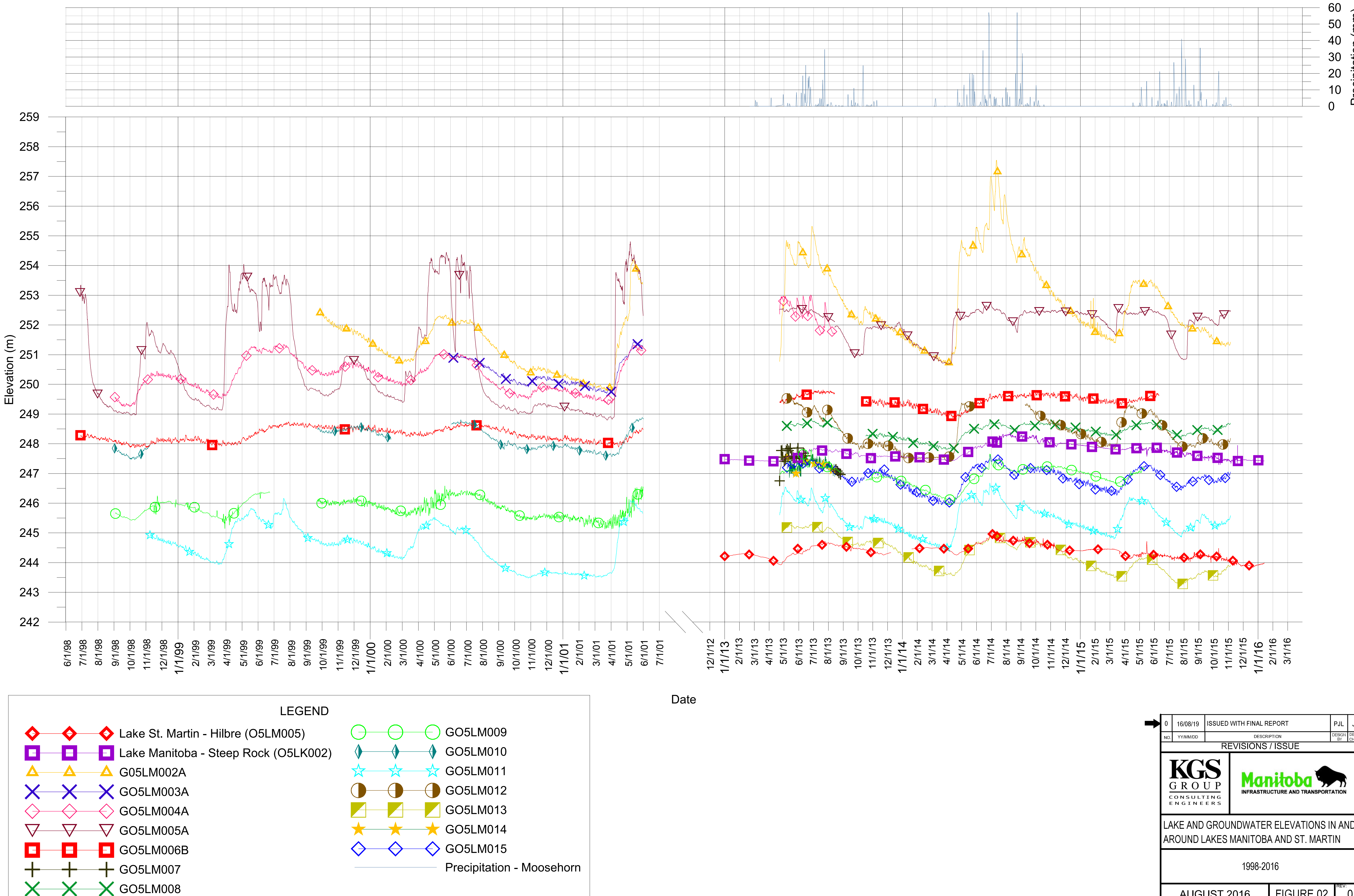
Manitoba INFRASTRUCTURE AND TRANSPORTATION

LAKE ST. MARTIN AREA
GROUNDWATER HYDROGRAPH
INTERPRETATION

SITE PLAN INCLUDING
MONITORING LOCATIONS

AUGUST 2016 | FIGURE 01 | REV: 0



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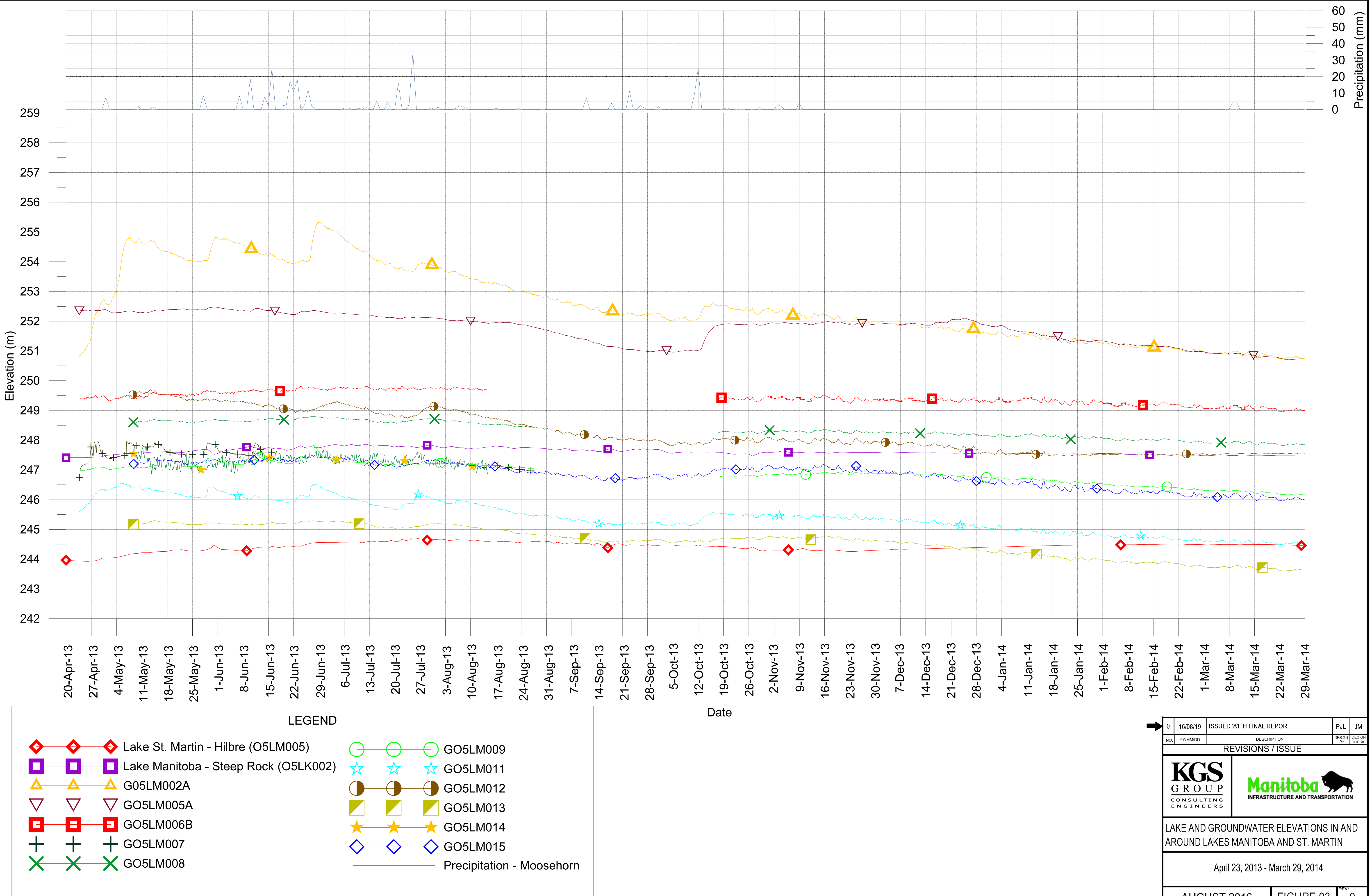
Manitoba INFRASTRUCTURE AND TRANSPORTATION

LAKE AND GROUNDWATER ELEVATIONS IN AND AROUND LAKES MANITOBA AND ST. MARTIN

1998-2016

AUGUST 2016 | FIGURE 02 | REV. 0



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0	16/08/19	ISSUED WITH FINAL REPORT	PJL	JM
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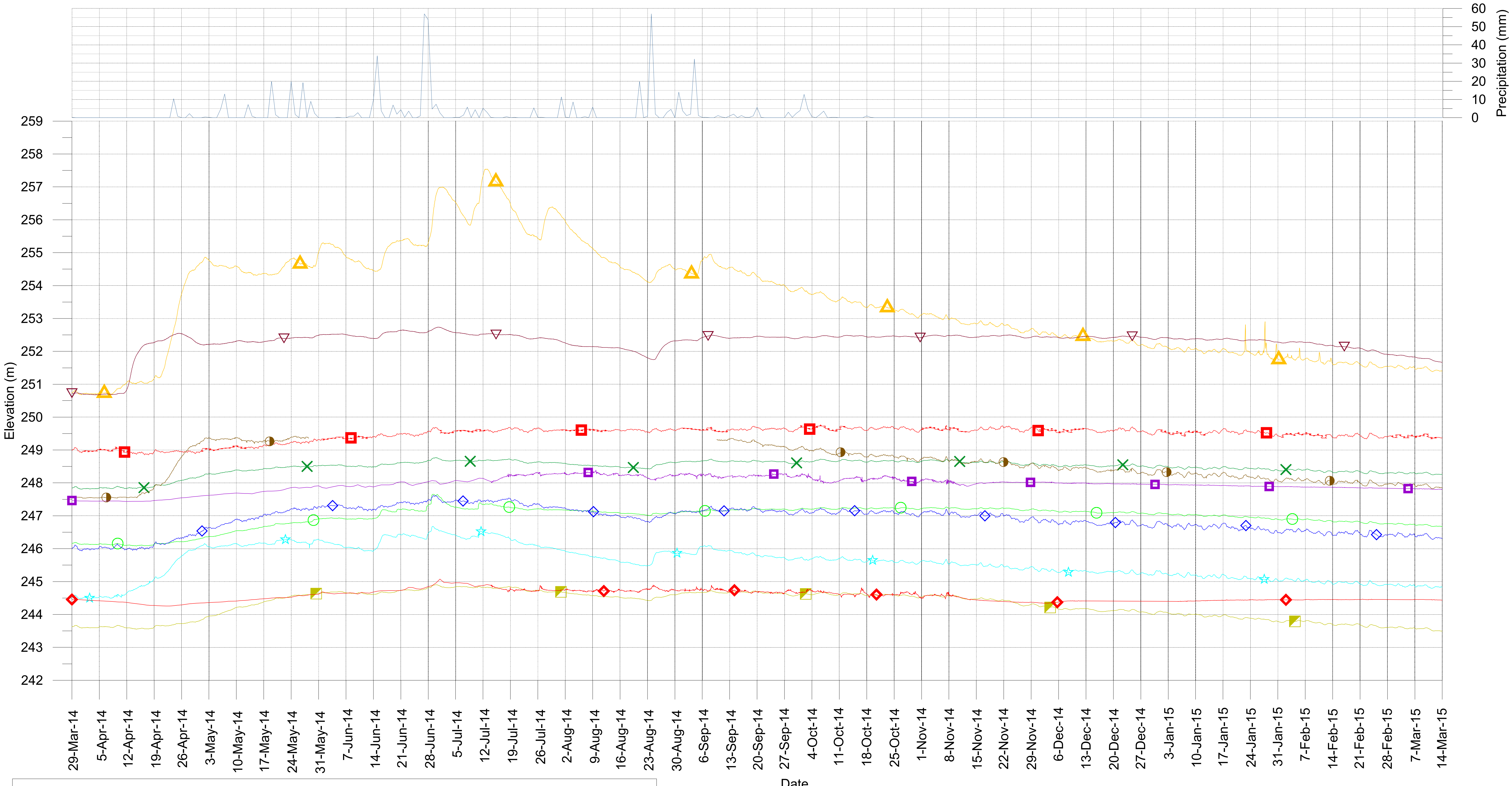
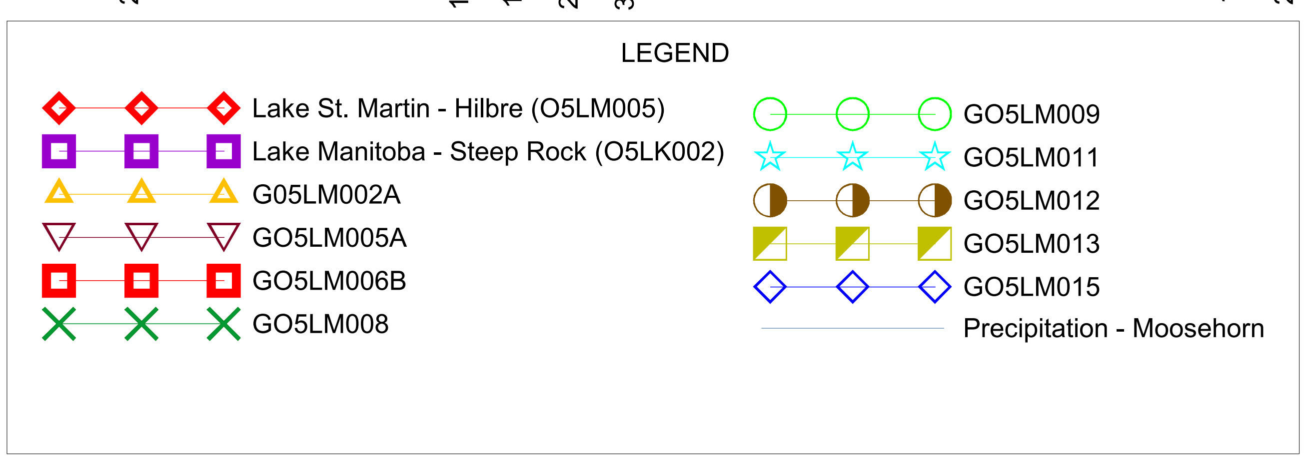
Manitoba INFRASTRUCTURE AND TRANSPORTATION

LAKE AND GROUNDWATER ELEVATIONS IN AND AROUND LAKES MANITOBA AND ST. MARTIN

April 23, 2013 - March 29, 2014

AUGUST 2016 | FIGURE 03 | REV. 0





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LAKE AND GROUNDWATER ELEVATIONS IN AND AROUND LAKES MANITOBA AND ST. MARTIN

March 29, 2014 - March 14, 2015

AUGUST 2016 | FIGURE 04 | REV. 0

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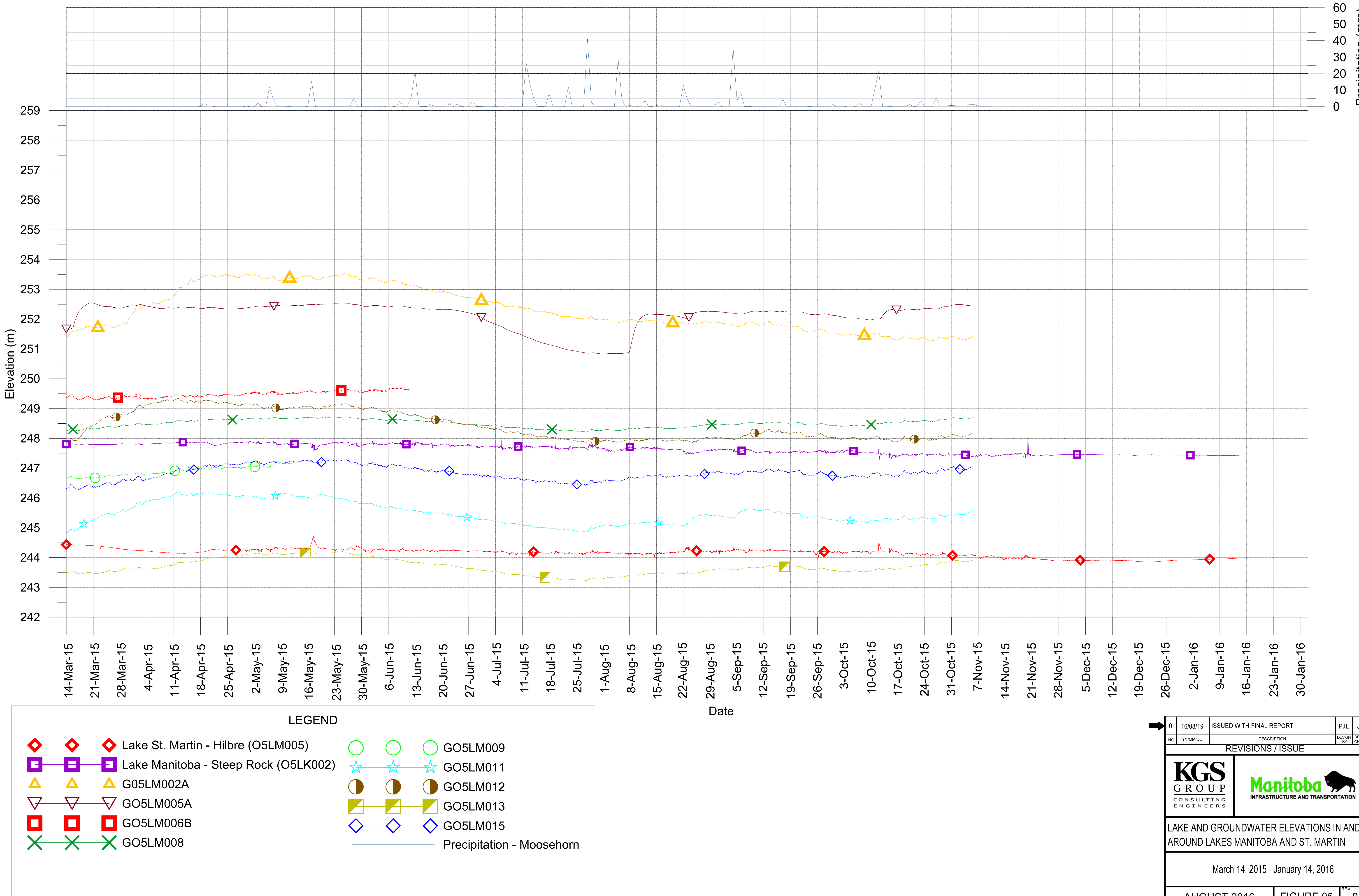

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Manitoba INFRASTRUCTURE AND TRANSPORTATION

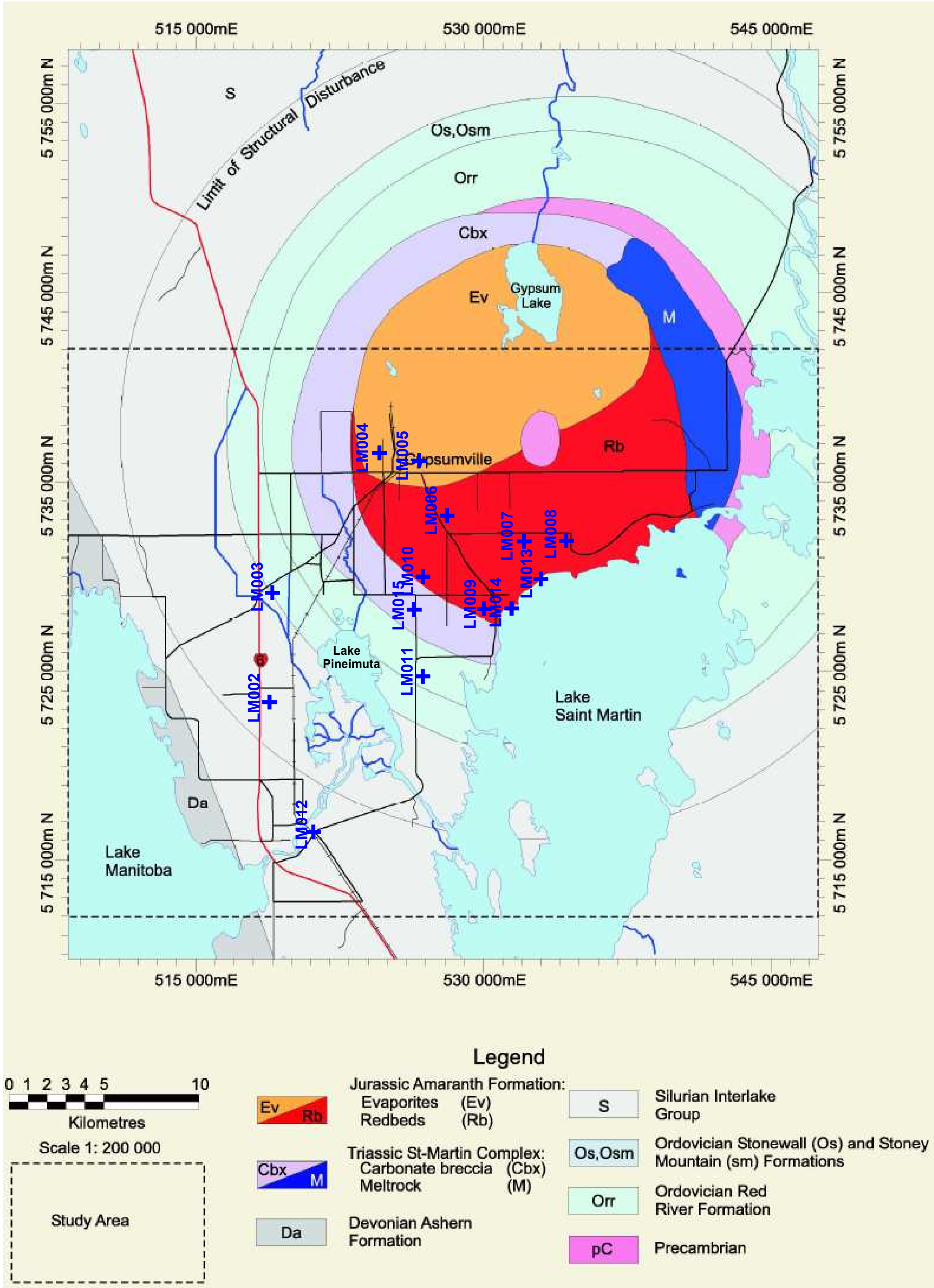
LAKE AND GROUNDWATER ELEVATIONS IN AND AROUND LAKES MANITOBA AND ST. MARTIN

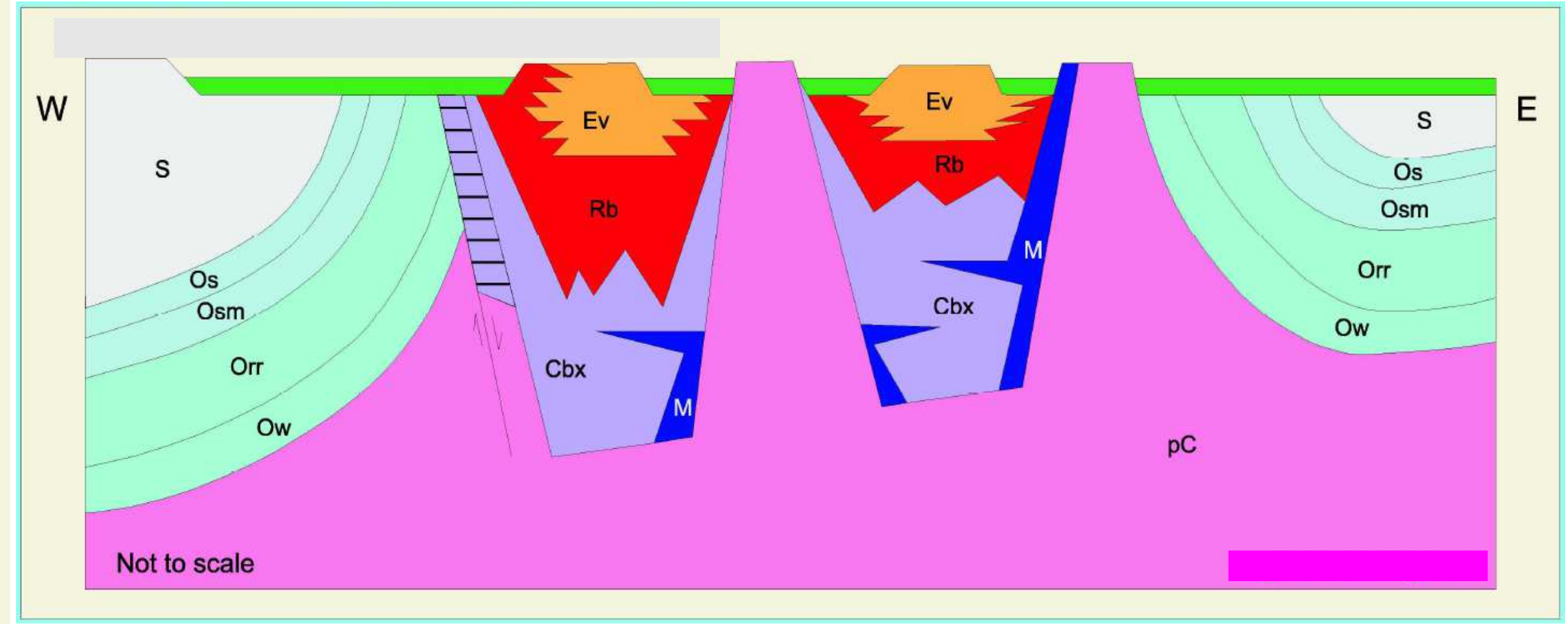
March 14, 2015 - January 14, 2016

AUGUST 2016 | FIGURE 05 | REV. 0

APPENDIX A

GEOLOGICAL SKETCH





Appendix A - Sketch

Geological map of the study region (left), including monitoring well locations.
Schematic east-west cross section of Lake St. Martin Impact Structure (above, right).
Original images from Desbarats amd Pyne (2004).