Kontzamanis Graumann Smith MacMillan Inc.

KGS
GROUP
CONSULTING
ENGINEERS

3rd Floor
865 Waverley Street
Winnipeg,
Manitoba
R3T 5P4
204.896.1209
fax: 204.896.0754
www.kgsgroup.com

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.

Prepared By: <Original signed by>

Jason Mann P.Geo.
Senior Geologist/Hydrogeologist
Enclosures

Approved By: <Original signed by>

J. Bert Smith, P.Eng., FEC
Principal

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.

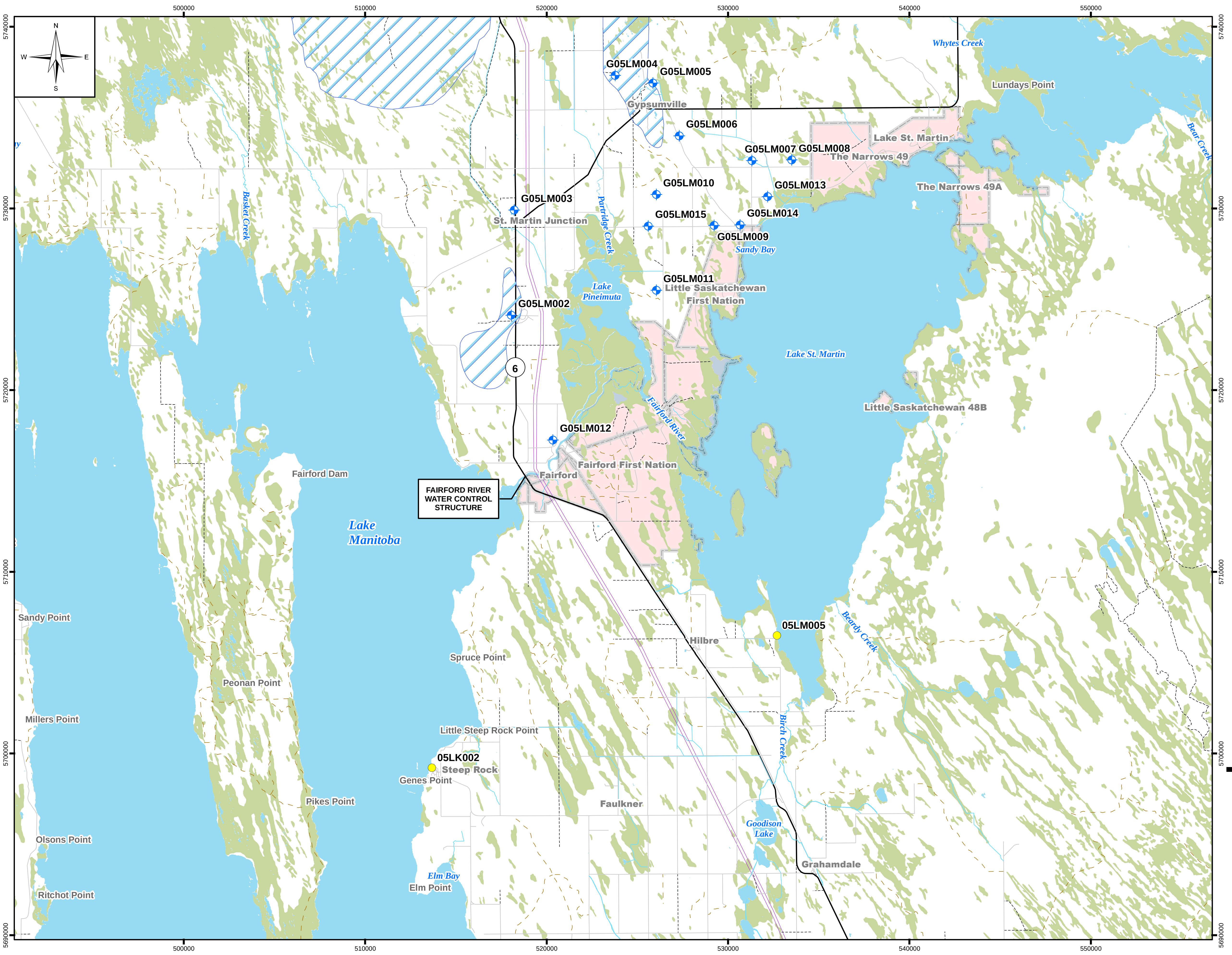
TABLE 2 - Well Responses to Lake Level Changes and Short-Term Precipitation Events

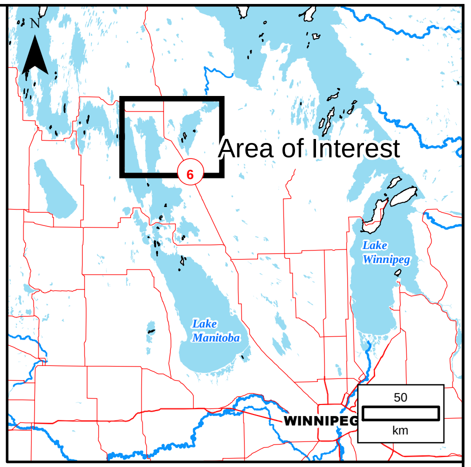
	RESPONSE TO LAKE LEVELS DURING WINTER MONITORING PERIODS						2014 Rainfall Event (2)		
LOCATION	**(2013/2014) 23-Nov-2013 Elevation (m)**	**(2013/2014) 29-Mar-2014 Elevation (m)**	**2013/2014 Difference (m)(1)**	**(2014/2015) 1-Dec-2014 Elevation (m)**	**(2014/2015) 15-Mar-2015 Elevation (m)**	**2014/2015 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





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

KGS GROUP
CONSULTING ENGINEERS

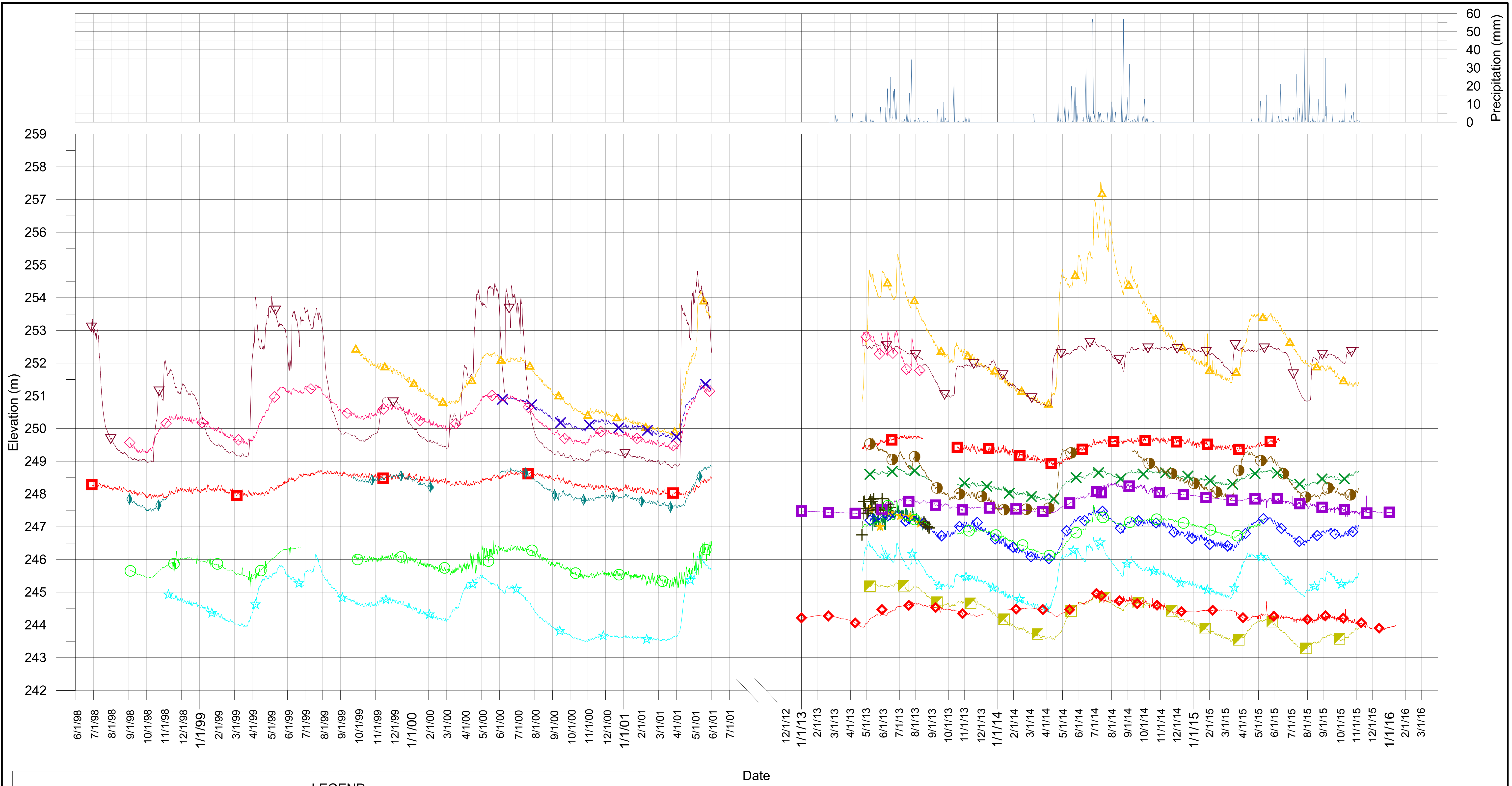
Manitoba
INFRASTRUCTURE AND TRANSPORTATION

LAKE ST. MARTIN AREA GROUNDWATER HYDROGRAPH INTERPRETATION

SITE PLAN INCLUDING MONITORING LOCATIONS

AUGUST 2016
FIGURE 01
REV: 0

FileName: P:\Projects\2012\12-0300-011\Dwg\GIS\MXDs\Rev0\GW_Hydrograph\12-0300-011_Fig01_Rev0.mxd
11"x17" PLOT SCALE 1:1



LEGEND

- ◇ Lake St. Martin - Hilbre (O5LM005)
- □ Lake Manitoba - Steep Rock (O5LK002)
- △ G05LM002A
- × GO5LM003A
- ◇ GO5LM004A
- ▽ GO5LM005A
- □ GO5LM006B
- + GO5LM007
- × GO5LM008
- ○ GO5LM009
- ◆ GO5LM010
- ☆ GO5LM011
- ◐ GO5LM012
- ◪ GO5LM013
- ★ GO5LM014
- ◇ GO5LM015
- — Precipitation - Moosehorn

0	16/08/19		PJL	JM
NO.	YY/MM/DD	DESCRIPTION	DESIGN BY	DESIGN CHECK

REVISIONS / ISSUE

KGS GROUP
CONSULTING ENGINEERS

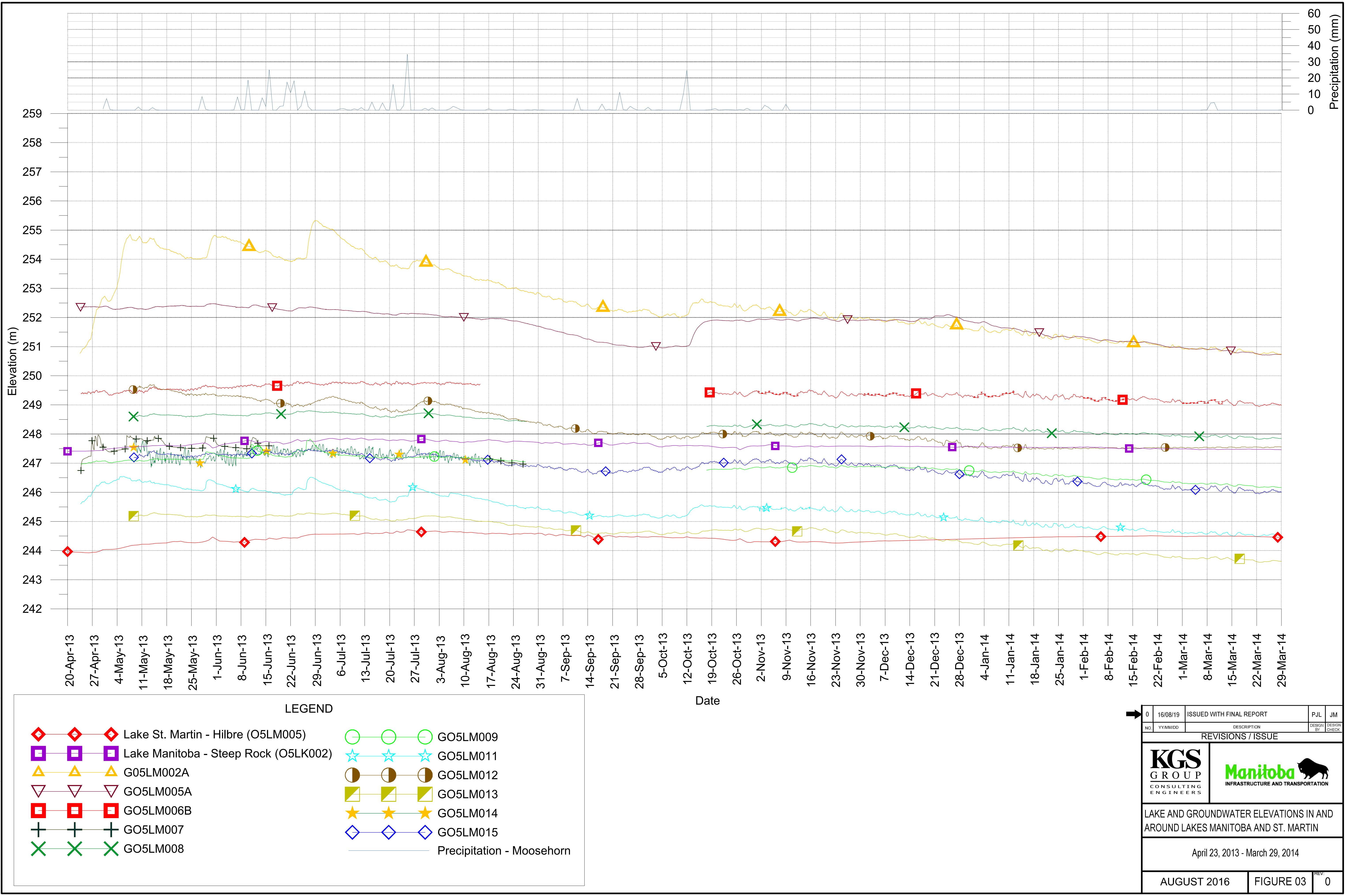
Manitoba
INFRASTRUCTURE AND TRANSPORTATION

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

1998-2016

AUGUST 2016	FIGURE 02	REV. 0

P:\Projects\2012\12-0300-011\Design\Env\GW level monitoring LSM\Grapher\



P:\Projects\2012\12-0300-011\Design\Env\GW level monitoring LSM\Grapher\

0	16/08/19	ISSUED WITH FINAL REPORT	PJL	JM
NO.	YY/MM/DD	DESCRIPTION	DESIGN BY	DESIGN CHECK

REVISIONS / ISSUE

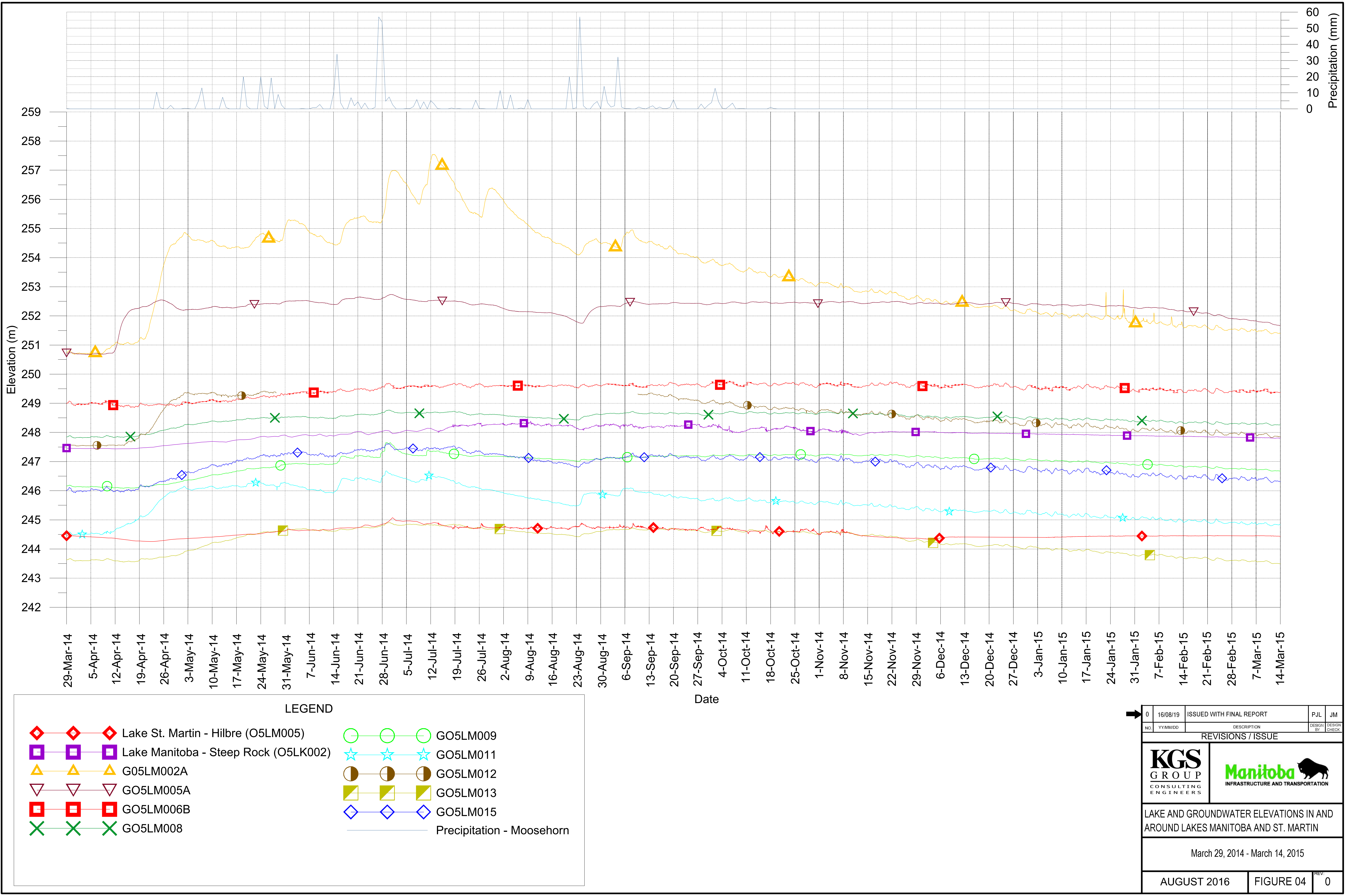
KGS GROUP
CONSULTING ENGINEERS

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



0	16/08/19	ISSUED WITH FINAL REPORT	PJL	JM
NO.	YY/MM/DD	DESCRIPTION	DESIGN BY	DESIGN CHECK

REVISIONS / ISSUE

KGS GROUP CONSULTING ENGINEERS

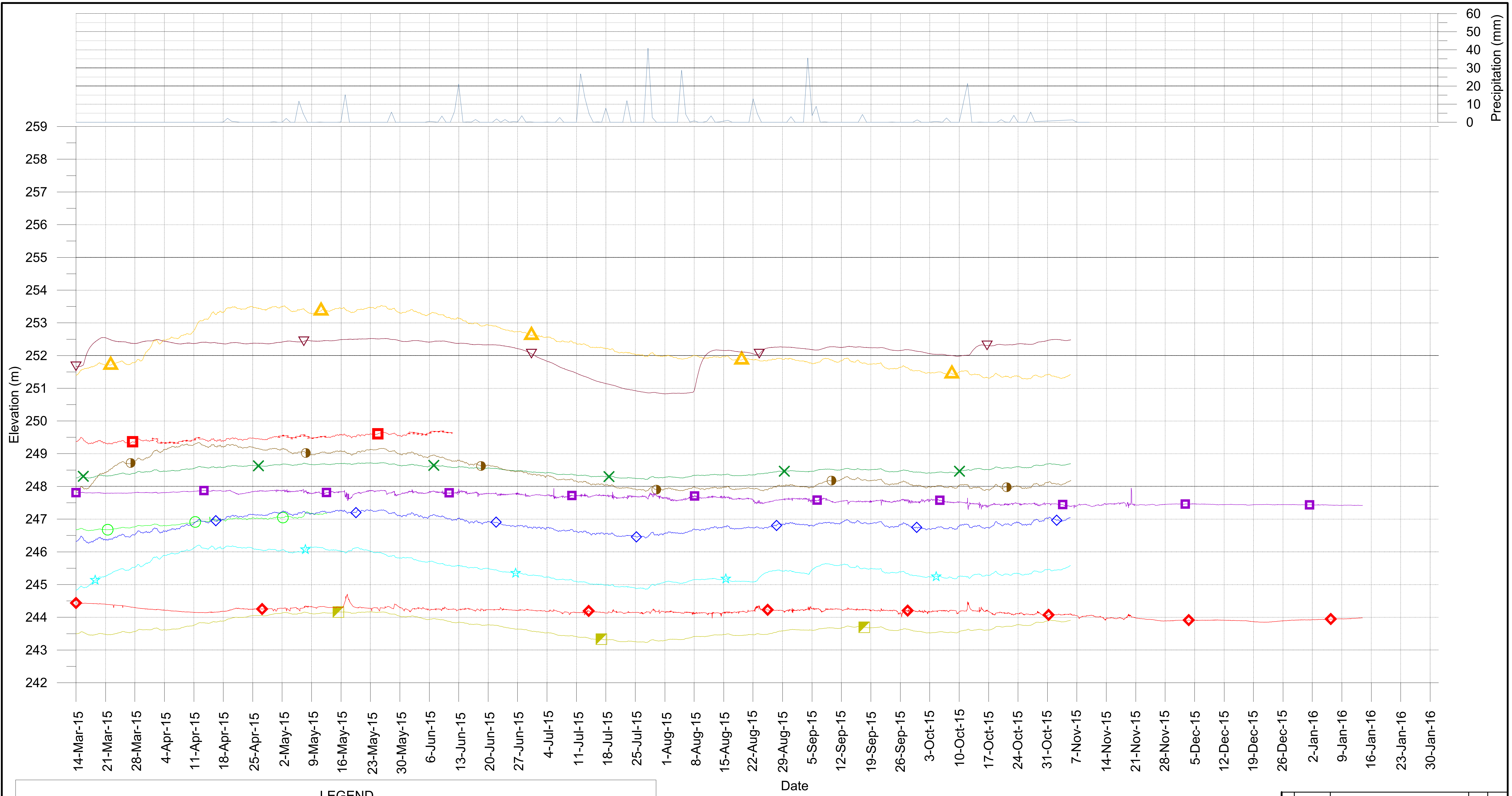
Manitoba INFRASTRUCTURE AND TRANSPORTATION

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

March 29, 2014 - March 14, 2015

AUGUST 2016 | FIGURE 04 | REV. 0

P:\Projects\2012\12-0300-011\Design\Env\GW level monitoring LSM\Grapher\



LEGEND

◇ Lake St. Martin - Hilbre (O5LM005)
□ Lake Manitoba - Steep Rock (O5LK002)
△ GO5LM002A
▽ GO5LM005A
□ GO5LM006B
✕ GO5LM008
○ GO5LM009
☆ GO5LM011
◐ GO5LM012
◩ GO5LM013
◇ GO5LM015
— Precipitation - Moosehorn

P:\Projects\2012\12-0300-011\Design\Env\GW level monitoring LSM\Grapher\

NO.	YY/MM/DD	DESCRIPTION	DESIGN BY	DESIGN CHECK
0	16/08/19	ISSUED WITH FINAL REPORT	PJL	JM

REVISIONS / ISSUE

KGS GROUP
CONSULTING ENGINEERS

Manitoba
INFRASTRUCTURE AND TRANSPORTATION

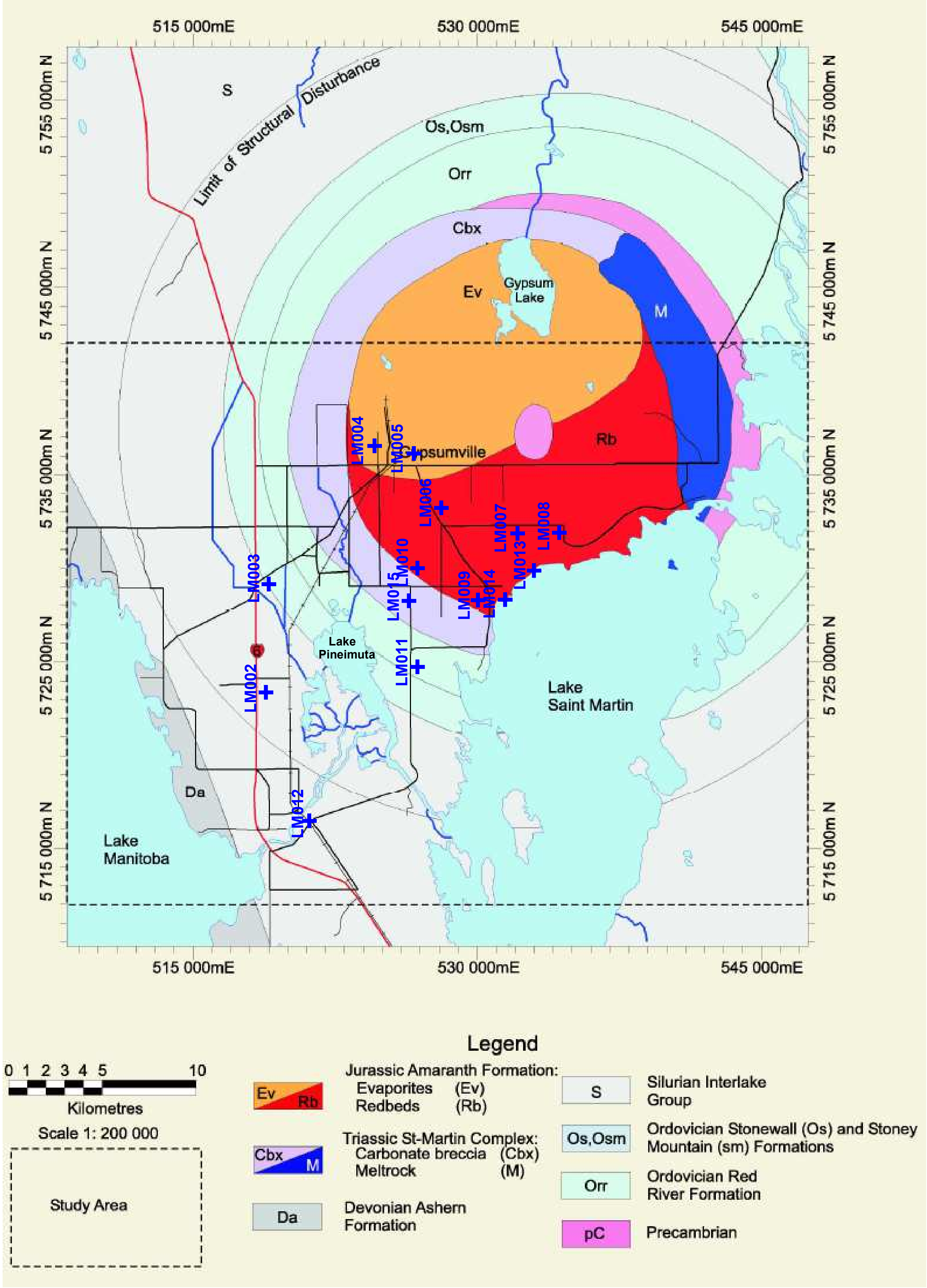
LAKE AND GROUNDWATER ELEVATIONS IN AND AROUND LAKES MANITOBA AND ST. MARTIN

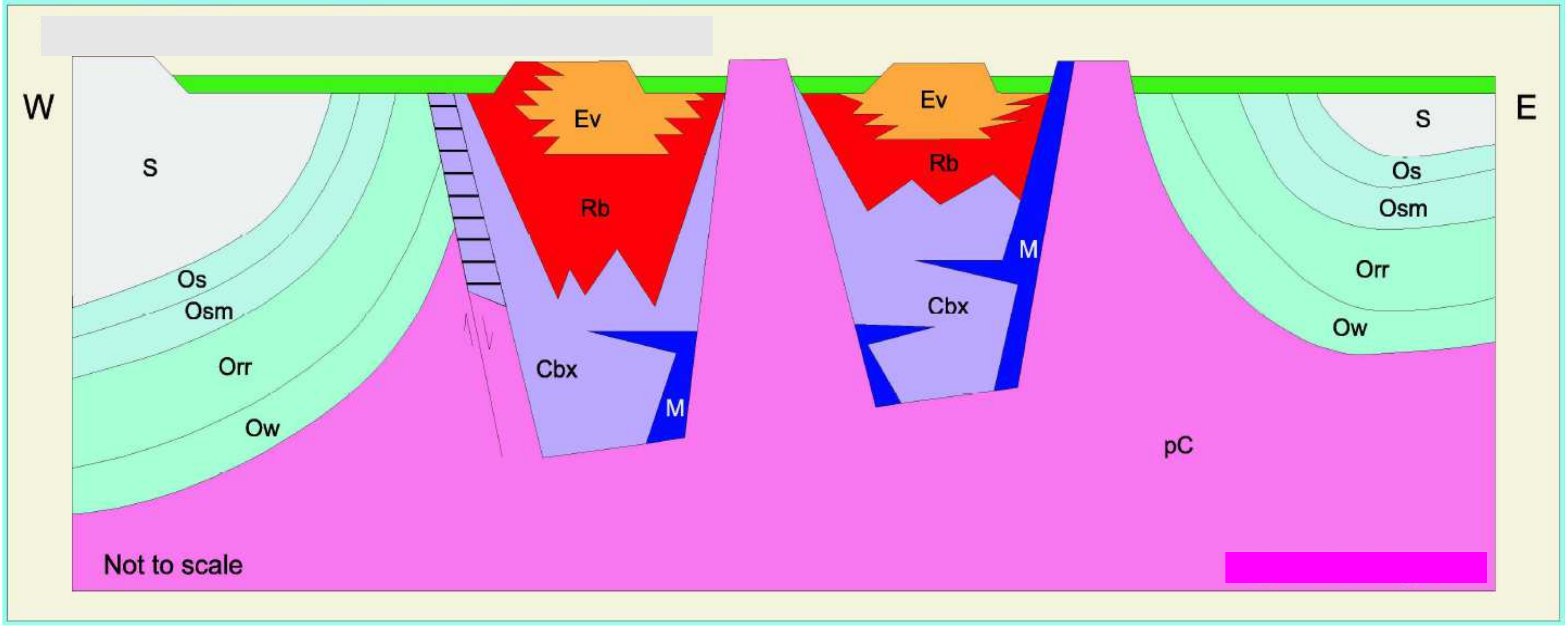
March 14, 2015 - January 14, 2016

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).