KGS GROUP

Memorandum

To:	James Betke, P.Eng.	**Date:**	August 27, 2021
		Project No.:	18-0300-015.1208
From:	Jason Mann, P.Geo.	**Cc:**	
Re:	LSMOC Bedrock Aquifer Depressurization Estimates Memo, Rev 0		

1.0 INTRODUCTION

An Information Request (IR) was filed on the Lake Saint Martin Outlet Channel (LSMOC), as part of the Environmental Impact Statement (EIS) process which is underway for the project. Within IR-21, the Regulators requested an assessment of bedrock aquifer drawdown that will occur during construction and operation of the LSMOC. This memo and accompanying Figures provide background and a visualization of analytical calculations performed during the Preliminary Design phase of the LSMOC. Please note that this memo should be read in conjunction with the details provided in the KGS Group Preliminary Design Report for the LSMOC (Ref.1).

2.0 ANALYSIS METHODOLOGY

As part of the Preliminary Design of the LSMOC, KGS Group performed various pumping tests and in-situ permeability tests of the confined bedrock aquifer within the region of the LSMOC (Ref.1). From these tests, a series of representative bedrock aquifer parameters were calculated using log-normal plots (and for permeability tests, the software program AQTESOLV was applied), summarized as follows:

- Bulk transmissivity values of approximately 10,000 USgpd/ft in the region of the Water Control Structure (WCS).
- Storativity values of approximately 1 $x10^{-4}$ in the vicinity of the WCS.
- Bulk transmissivity values of approximately 6,400 USgpd/ft and 7,100 USgpd/ft in the region of the existing Reach 3 channel (where the bedrock aquifer is currently exposed).
- Storativity values of approximately 2 $x10^{-3}$ and 5 $x10^{-3}$ in the region of the existing Reach 3 channel.

Aquifer parameters were calculated using the Theis methodology (Ref. 2), and log-normal plots of time drawdown, and recovery portions of the available field pumping tests. The Theis solution carries the following assumptions:

- The aquifer is confined with infinite areal extent and no vertical leakage, or recharge.
- The aquifer is homogeneous and isotropic with uniform thickness.
- The potentiometric surface of the aquifer is generally horizontal (prior to pumping).
- The pumping well has a small radius, is fully penetrating, and discharges at a constant rate.
- Aquifer flow is horizontal and laminar.
- Drawdown in the aquifer varies with time.

From these aquifer parameters, calculated using the Theis method described above, type curves for distance drawdown are also calculated that allow for some predictive analysis of the aquifer response to varying groundwater withdrawal rates, and durations of time. This allows for an analytical approach to predicting the aquifer drawdown in the project area of the LSMOC, by simulating a well or series of wells (e.g. method of cumulative drawdowns) at pumping locations during WCS construction and/or bedrock aquifer/channel interconnections (e.g. basal heave/blowout areas, or at Reach 3), where passive interconnections of the bedrock aquifer to the LSMOC may occur. Where multiple point sources are estimated, superposition of distance drawdown curves was used to predict overall aquifer drawdown conditions in the vicinity of the LSMOC.

Note that seasonal aquifer piezometric pressure variability due to regional boundary conditions such as recharge areas to the south-southwest of Lake St. Martin, and discharge areas at existing artesian spring sites, Lake St. Martin, Lake Winnipeg, and the Dauphin River, are not directly addressed here. There are clear pressure responses in the confined bedrock aquifer with changes in regional recharge and atmospheric precipitation events (with nearly direct infiltration in bedrock recharge areas), and also with variability in the levels of the lakes and rivers that form discharge boundary conditions for the confined aquifer in the region of the LSMOC (Ref.3).

3.0 CONSTRUCTION PHASE ANALYSIS

Figure 1 illustrates the combined estimated confined bedrock aquifer drawdown during construction of the LSMOC. Please note that all channel activities and WCS construction activities are estimated to be concurrent in this analysis. Based on actual construction staging, not all areas of the channel (and hence not all possible drawdown centres) may be under construction at the same time as the WCS. During the construction phase of the project, active depressurization (i.e. active pumping of the bedrock aquifer using wells) will be necessary during excavation and initial construction of the LSMOC WCS. Based on the Preliminary Design (Ref. 1), the following apply:

- Approximately 9 m to 10 m of temporary depressurization is necessary at the WCS.
- A series of 12 active pumping wells laid out on the approximate 105 m by 110 m footprint of the WCS will be necessary.

- Based on estimated aquifer parameters, each well will be pumped at approximately 25 USgpm (300 USgpm total).

Currently under the Detailed Design phase of the Project, the means and methods in depressurizing the excavation for the WCS are under a design optimization. This modification has not been finalized at this time, however it is reasonable to estimate that the Detailed Design approach currently under development to depressurize the bedrock aquifer at the WCS, should have a net result of less overall active pumping for depressurization, than estimated herein. As such, this current estimation, based on the Preliminary Design approach to depressurization at the WCS, would be considered conservative. Please note that bedrock consolidation grouting and an upstream grout curtain is planned for the WCS. The effects of grouting on the bedrock aquifer in the immediate vicinity of the WCS are not accounted for in this analysis. In addition, and especially due to planned grouting activities, the specific capacity of each well during active pumping is expected to vary over short timeframes. As the aquifer pressures drop, constant adjustment of individual wells will be necessary during active depressurization at the WCS to maintain the necessary depressurization as the discharge rate of each well will vary (typically decline) in time with pressure decreases in the aquifer.

Along the LSMOC, there are existing exposures of the bedrock aquifer at the existing Reach 3 channel (and where drop structure 4 will be constructed). With analysis of basal heave (Ref. 1), it is estimated that there will be interconnections to the bedrock aquifer and/or limited pumping necessary at channel drop structures 1 through 7. Based on the difference between the current piezometric pressure of the bedrock aquifer, and the invert of the planned channel excavation, between approximately 3 m and 9 m of bedrock aquifer depressurization will occur along the channel at these point locations of groundwater discharge. The estimated drawdown cone developed along the channel is visualized in Figure 1, along with the depressurization cone estimated from pumping at the WCS.

Equivalent flow rates were estimated between approximately 30 Ugpm (3 m to 4 m of required depressurization at drop structures 1, 2, 5, 6, and 7), to approximately 60 USgpm (7 m to 8 m of required depressurization at drop structure 3), and up to approximately 80 USGPM each in the region of the existing Reach 3 channel and drop structure 4.

In total, the current estimate of groundwater baseflow to the LSMOC project during the construction phase is approximately 670 USgpm, comprised of 300 USgpm at the WCS, and approximately 370 USgpm at the point sources along the channel.

The distance drawdown type curves used to estimate depressurization along the channel are based on a time frame of 6 months to 1 year worth of time (e.g. a pseudo equilibrium condition). This was done to be conservative and estimate what the depressurization conditions might be along the channel during a lengthy construction period, and during a time when all areas are active concurrently. Note that the aquifer parameters calculated from current available testing data indicate that the depressurization effects along the channel within the channel Right of Way are larger than the estimated variability in seasonal aquifer water level fluctuations. However, the larger areas of the depressurization drawdown effects away from the LSMOC are in general within the conservative variability estimated for the regional aquifer system of approximately 1.5 m +/- 0.5 m (Refs. 1 and 3). Aquifer piezometric pressure variability is larger than that discussed here in aquifer recharge areas, for example, however this is not deemed overall representative to typical regional aquifer piezometric pressures that vary over the year with changes in lake and river boundary conditions levels, and with short term but high intensity precipitation events.

4.0 OPERATIONS PHASE ANALYSIS

Figure 2 illustrates the combined estimated confined bedrock aquifer drawdown, long term, of the LSMOC. Note that while an equivalent well analysis was done in this analytical estimation, there is no active pumping for depressurization planned for the long term on the LSMOC. it is anticipated that passive drainage at the WCS and at the relevant drop structures 1 through 7 will occur, and that aquifer pressures at the LSMOC will re-re-equilibrate to the “dry” channel water levels within the LSMOC.

Based on the Preliminary Design (Ref. 1), the following apply at the WCS:

- Approximately 2 m to 3 m of long-term depressurization may occur at the WCS.
- As an equivalent check, the same series of 12 active pumping wells was used in the operations phase calculation, though it is recognized that the actual realized condition will likely be passive seepage through random bedrock interconnections that remain surrounding the WCS after construction.
- Based on estimated aquifer parameters, each well equivalent for seepage at the WCS is approximately 9 USgpm (108 USgpm total).

Please note that bedrock consolidation grouting and an upstream grout curtain is planned for the WCS. The effects of grouting on the bedrock aquifer in the immediate vicinity of the WCS are not accounted for in this analysis. As such, this estimation would be considered conservative, as the effects of grouting at the WCS are estimated to result in a reduction of total groundwater seepage at the WCS during the long term.

Along the LSMOC, there are existing exposures of the bedrock aquifer at the existing Reach 3 channel (and where drop structure 4 will be constructed). With analysis of basal heave (Ref. 1), it is estimated that there will be long-term interconnections to the bedrock aquifer at channel drop structures 1 through 7. Based on the difference between the current piezometric pressure of the bedrock aquifer, and the water levels in the “dry” channel of the LSMOC, long term there will be approximately between 1 m and 7 m (largest differences are at drop structure 3 and drop structure 4 at Reach 3) of bedrock aquifer depressurization at these point locations of groundwater discharge. The estimated long-term operational drawdown cone developed along the channel is visualized in Figure 2, along with the long-term depressurization cone estimated from passive groundwater seepage at the WCS.

Equivalent flow rates were estimated between approximately 20 USgpm (up to approximately 2.5 m of required depressurization at drop structures 1, 5, 6 and 7), 30 USgpm (up to 4 m of required depressurization at drop structure 2), to approximately 60 USgpm (7 m of required depressurization at drop structures 3 and 4). Baseflow from existing Reach 3 is estimated at approximately 60USgpm. The distance drawdown type curves used to estimate depressurization along the channel are based on a time frame of 6 months to 1 year worth of time (e.g. a pseudo equilibrium condition).

In total, the current estimate of groundwater baseflow to the LSMOC project during the operation phase is approximately 400 USgpm, comprised of 108 USgpm at the WCS, and approximately 292 USgpm at point sources along the channel.

5.0 DISCUSSION

A series of analytical calculations were performed to determine an estimation of the bedrock aquifer depressurization response that will occur with the construction and operation of the LSMOC. Aquifer parameters derived from field pumping test data using log normal plots and the Theis method, were used to derive a series of distance drawdown curves (which could be varied for estimates of aquifer discharge rates and time). The method of cumulative drawdowns and the distance drawdown curves were then used to estimate the resultant aquifer depressurization response in the region of the LSMOC.

The representations for the construction phase and long-term operations phase of the LSMOC are illustrated in Figures 1 and 2. Note that this analysis was somewhat conservative, in that the interaction of regional recharge and discharge aquifer boundary conditions were not fully accounted for, the concurrent full channel excavation and WCS construction were assessed (which may vary with actual construction staging), and that the effects of lowering the aquifer transmissivity at the WCS due to planned consolidation and curtain grouting was not represented herein. Point sources as wells, as described above, were applied in the analyses.

Overall, the analysis, based on information available to date, indicates relatively limited areal extents of depressurization responses in and around the LSMOC. It is important to note that the spatial pressure response of the confined bedrock aquifer is a direct reflection of the low calculated confined aquifer transmissivities and storativities determined from available testing data to date, and will also be influenced by the lakes and rivers that form its boundary conditions in the region of the LSMOC. Accordingly, the estimated groundwater discharge volumes which accompany the calculated pressure responses, are relatively low, and as described within this memorandum. It is important to note that while the bedrock aquifer everywhere in the region of the LSMOC project is confined by the overlying till and clay aquitard, the naturally occurring depressurizing effects of artesian spring sites that are present in close proximity to Lake Winnipeg are noticeable in the naturally occurring bedrock aquifer groundwater pressures. Bedrock aquifer pressures which are in the order of El. 232 m or higher in the region of the Reach 3 channel (or higher back toward Lake St. Martin), decline to pressures of approximately El. 225 m (or less) in down-channel areas below Reach 3, and toward Lake Winnipeg.

During construction, areas closest to the LSMOC (specifically at the WCS) will experience temporary depressurization responses in excess of naturally observed aquifer piezometric pressure variability. However, based on this current analysis, using data available to date, there are no bedrock aquifer depressurization conditions estimated in excess of naturally observed aquifer piezometric pressure variability (i.e. 1.5 m +/- 0.5 m; Refs. 1 and 3) in any areas that will have a substantive effect on the Big Buffalo Lake complex, artesian spring sites, or nearby communities, as examples. In the longer term, based on this current analysis, estimated aquifer depressurization responses with construction of the LSMOC project, outside of the LSMOC right of way (but within approximately 1 km to 1.5 km of the LSMOC channel centerline in affected areas) are estimated to be well within the observed natural seasonal aquifer pressure variability of 1.5 m +/- 0.5 m.

The aggregate point source estimates of baseflow determined in this analysis are within the order of magnitude observed and measured within the existing Reach 3 channel, which provides some confirmation of the assumptions and estimates made, with respect to the overall low transmissivity of the aquifer observed to date in the vicinity of the LSMOC (Ref. 1), and the relatively limited propagation of depressurization responses away from the LSMOC.

With any changes to the LSMOC project design through the ongoing Detailed Design phase, as new information becomes available, and/or as additional groundwater assessment is required or is completed at the LSMOC, these bedrock aquifer depressurization estimations may vary. As described earlier, current optimizations for bedrock aquifer depressurization at the WCS (currently underway as part of Detailed Design), may reduce the amount of active pumping depressurization required at the WCS. In addition, natural aquifer variability outside of the conditions applied herein, may result in a different aquifer response than that depicted here.

To allow monitoring the aquifer conditions for the nearby community of Dauphin River, sentinel wells on the project side and community side of the Dauphin River are in place, measuring baseline water level and water quality data. These wells, along with other monitoring locations planned to be installed as part of the Adaptive Management process described within the Groundwater Management Plan, will assist with measuring any changes to the groundwater aquifer in the region of the LSMOC, and will inform the actions to be taken should any be necessary during the construction and operation phases of the project.

6.0 REFERENCES

- KGS Group, (2020). Preliminary Design of Lake St. Martin Outlet Channel, Final Report – REV. 0., July 31, 2020.
- Theis, C.V., 1935. The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage, Am. Geophys. Union Trans., vol. 16, pp. 519-524.
- KGS Group, (2016). Lake St. Martin Area Groundwater Hydrograph Interpretation, Letter Report, August 22, 2016.

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Attached

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Dave MacMillan, P.Eng.
Project Manager / Principal

STATEMENT OF LIMITATIONS AND CONDITIONS

Limitations

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

This memorandum is based on information made available to KGS Group by Manitoba Infrastructure. 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 memorandum apply only as they existed at the time of KGS Group's work.

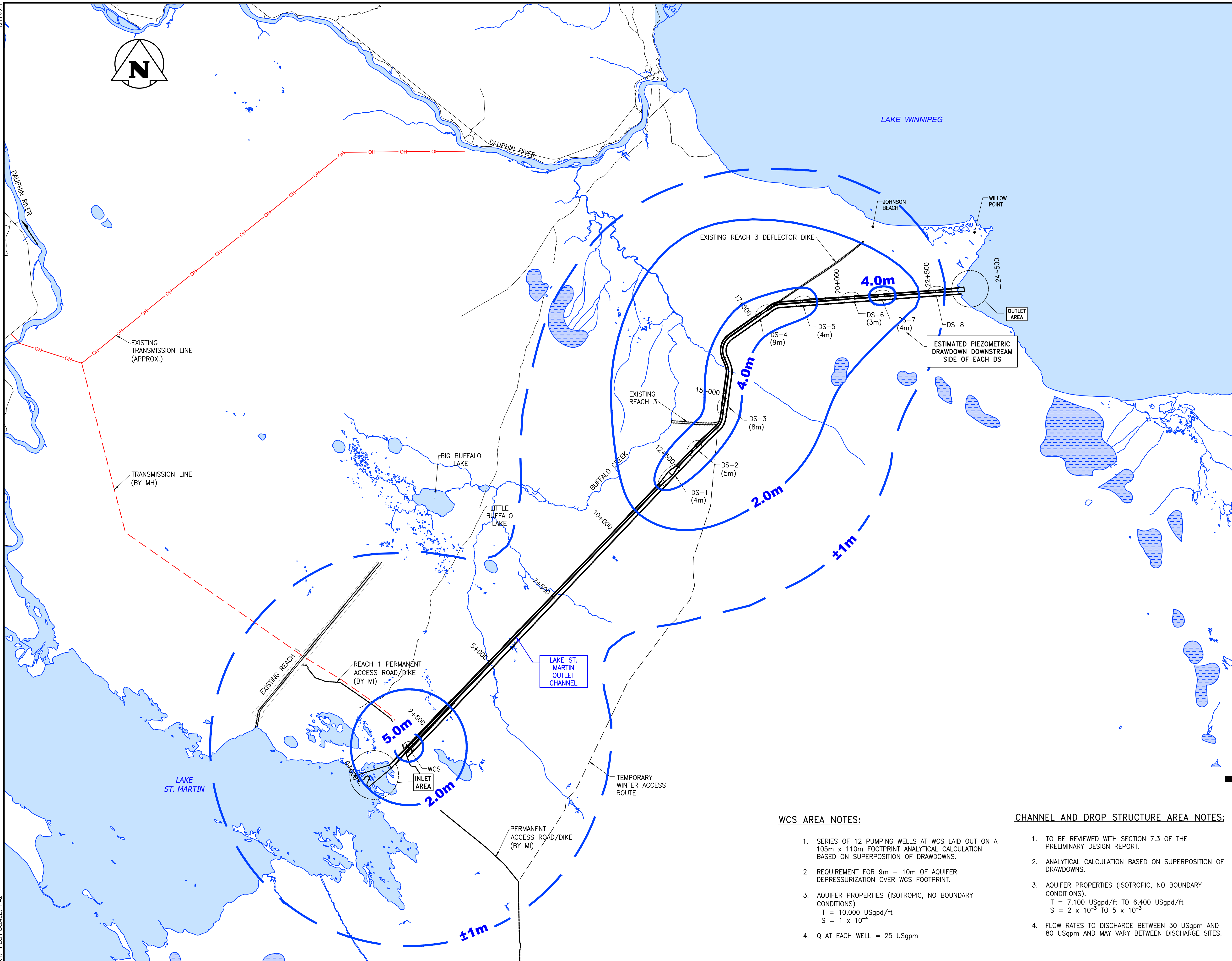
Third Party Use of Memorandum

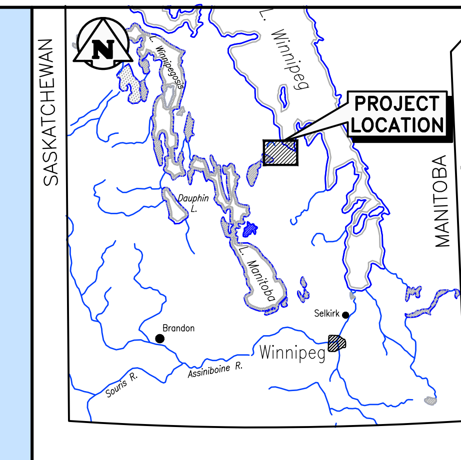
Any use a third party makes of this memorandum or any reliance on or decisions made based on it, are the responsibility of such third parties. KGS Group accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions undertaken based on this memorandum.

Geo-Environmental Statement of Limitations

KGS Group prepared the geo-environmental conclusions and recommendations for this memorandum 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 memorandum 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 Manitoba Infrastructure. As this memorandum 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





KEY MAP

LEGEND:

WCS	– WATER CONTROL STRUCTURE
DS (4M)	– DROP STRUCTURE (4m DRAWDOWN AT STRUCTURE)
15+000	– STATION ALONG CHANNEL CENTRELINE
- 2.0m -	– AQUIFER PIEZOMETRIC DRAWDOWN CONTOUR (2 METRES)
(symbol)	– NATURALLY OCCURRING ARTESIAN SPRING SITES

NOTES:

1. ALL UNITS ARE METRIC AND IN METRES UNLESS OTHERWISE SPECIFIED. TRANSVERSE MERCATOR PROJECTION, AND 1983 CSRS, ZONE 14. ELEVATIONS ARE IN METRES ABOVE SEA LEVEL (MSL) AND ARE REFERENCING CANADIAN GEODETIC VERTICAL DATUM 1928 (CGVD28).

WCS AREA NOTES:

1. SERIES OF 12 PUMPING WELLS AT WCS LAID OUT ON A 105m x 110m FOOTPRINT ANALYTICAL CALCULATION BASED ON SUPERPOSITION OF DRAWDOWNS.
2. REQUIREMENT FOR 9m – 10m OF AQUIFER DEPRESSURIZATION OVER WCS FOOTPRINT.
3. AQUIFER PROPERTIES (ISOTROPIC, NO BOUNDARY CONDITIONS)
   $T = 10{,}000$ USgpd/ft
   $S = 1 \times 10^{-4}$
4. Q AT EACH WELL = 25 USgpm

CHANNEL AND DROP STRUCTURE AREA NOTES:

1. TO BE REVIEWED WITH SECTION 7.3 OF THE PRELIMINARY DESIGN REPORT.
2. ANALYTICAL CALCULATION BASED ON SUPERPOSITION OF DRAWDOWNS.
3. AQUIFER PROPERTIES (ISOTROPIC, NO BOUNDARY CONDITIONS):
   $T = 7{,}100$ USgpd/ft TO $6{,}400$ USgpd/ft
   $S = 2 \times 10^{-3}$ TO 5×10^{-3}
4. FLOW RATES TO DISCHARGE BETWEEN 30 USgpm AND 80 USgpm AND MAY VARY BETWEEN DISCHARGE SITES.

PRELIMINARY
NOT TO BE USED FOR CONSTRUCTION

1 0 1 2 3 4km
SCALE: 1:100000

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
0	21/08/27	ISSUED WITH FINAL MEMORANDUM	JDM	CMS

REVISIONS / ISSUE

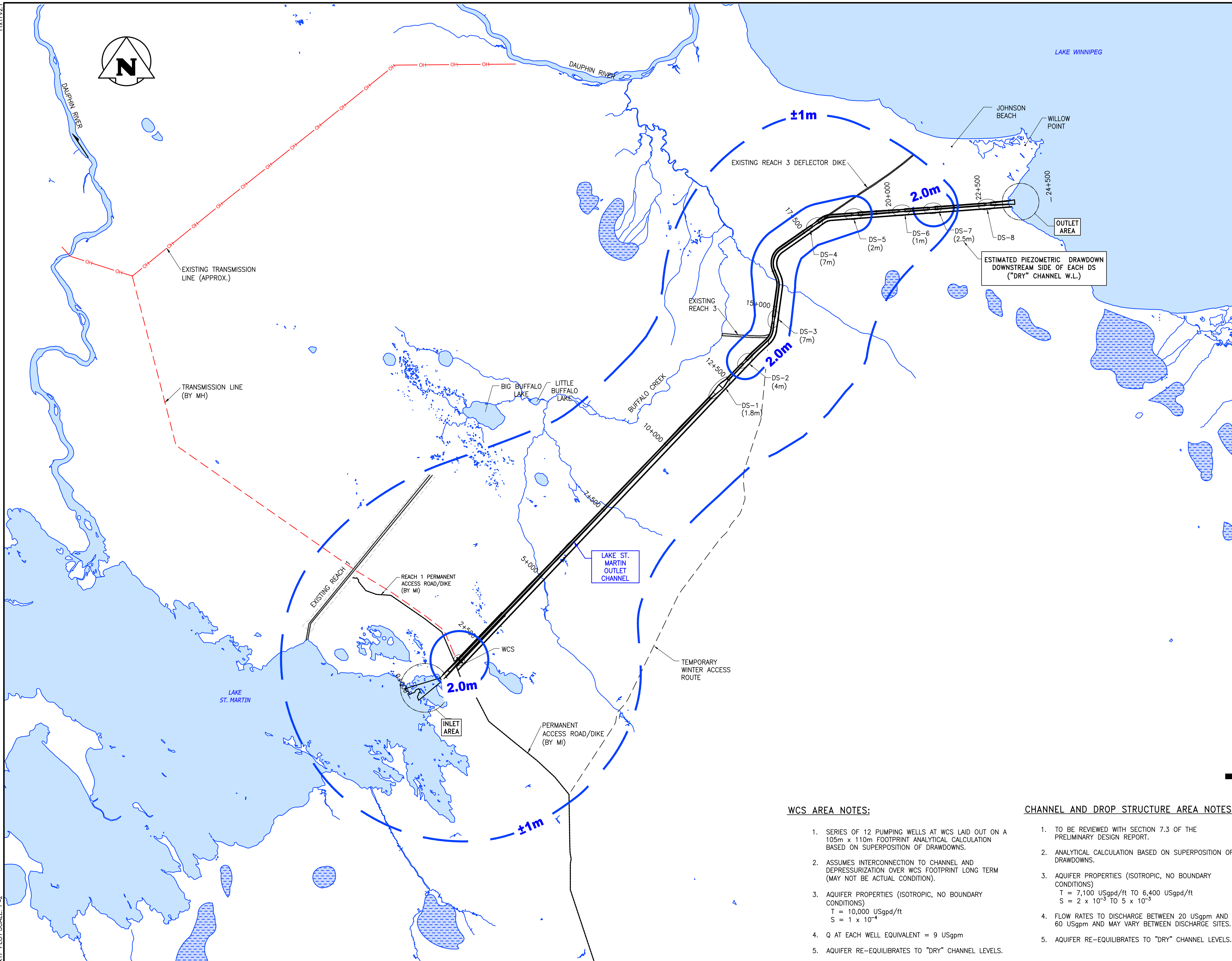
KGS GROUP
Manitoba Infrastructure
Water Management and Structures

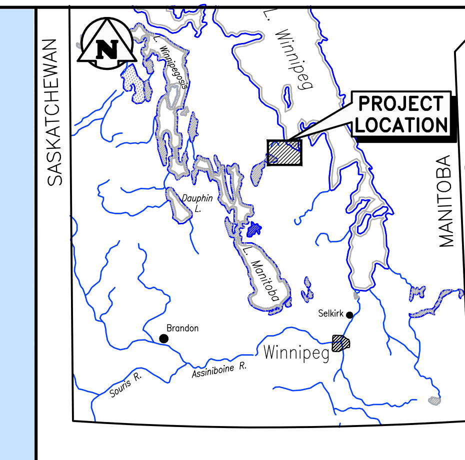
LAKE ST. MARTIN OUTLET CHANNEL
BEDROCK AQUIFER DEPRESSURIZATION
ESTIMATE MEMO

AQUIFER PIEZOMETRIC DRAWDOWN
CONTOURS IN CHANNEL VICINITY
(SHORT TERM DURING CONSTRUCTION)

AUGUST 2021 | FIG 01 | REV. 0

11x17V2.1
Filename: \\k-file-4p-data\Projects\2018\18-0300-005\Dwg\Geo\Initial Design\IR No21\Bedrock Depressurization Rev 0\18-0300-005_FIG 01 - Tab:Rev0 Plotted By: TVanwert 21/08/27 [Fri 1:55pm]
11x17" PLOT SCALE: 1"=2'





KEY MAP

LEGEND:

- WCS – WATER CONTROL STRUCTURE
- DS (4M) – DROP STRUCTURE (4m DRAWDOWN AT STRUCTURE)
- 15+000 – STATION ALONG CHANNEL CENTRELINE
- 2.0m – AQUIFER PIEZOMETRIC DRAWDOWN CONTOUR (2 METRES)
- NATURALLY OCCURRING ARTESIAN SPRING SITES

NOTES:

1. ALL UNITS ARE METRIC AND IN METRES UNLESS OTHERWISE SPECIFIED. TRANSVERSE MERCATOR PROJECTION, AND 1983 CSRS, ZONE 14. ELEVATIONS ARE IN METRES ABOVE SEA LEVEL (MSL) AND ARE REFERENCING CANADIAN GEODETIC VERTICAL DATUM 1928 (CGVD28).

PRELIMINARY
NOT TO BE USED FOR CONSTRUCTION

1 0 1 2 3 4km
SCALE: 1:100000

WCS AREA NOTES:

1. SERIES OF 12 PUMPING WELLS AT WCS LAID OUT ON A 105m x 110m FOOTPRINT ANALYTICAL CALCULATION BASED ON SUPERPOSITION OF DRAWDOWNS.
2. ASSUMES INTERCONNECTION TO CHANNEL AND DEPRESSURIZATION OVER WCS FOOTPRINT LONG TERM (MAY NOT BE ACTUAL CONDITION).
3. AQUIFER PROPERTIES (ISOTROPIC, NO BOUNDARY CONDITIONS)
   T = 10,000 USgpd/ft
   S = 1 x 10^{-4}
4. Q AT EACH WELL EQUIVALENT = 9 USgpm
5. AQUIFER RE-EQUILIBRATES TO "DRY" CHANNEL LEVELS.

CHANNEL AND DROP STRUCTURE AREA NOTES:

1. TO BE REVIEWED WITH SECTION 7.3 OF THE PRELIMINARY DESIGN REPORT.
2. ANALYTICAL CALCULATION BASED ON SUPERPOSITION OF DRAWDOWNS.
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   T = 7,100 USgpd/ft TO 6,400 USgpd/ft
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4. FLOW RATES TO DISCHARGE BETWEEN 20 USgpm AND 60 USgpm AND MAY VARY BETWEEN DISCHARGE SITES.
5. AQUIFER RE-EQUILIBRATES TO "DRY" CHANNEL LEVELS.

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
0	21/08/27	ISSUED WITH FINAL MEMORANDUM	JDM	CMS

REVISIONS / ISSUE

KGS GROUP
Manitoba Infrastructure
Water Management and Structures

LAKE ST. MARTIN OUTLET CHANNEL
BEDROCK AQUIFER DEPRESSURIZATION ESTIMATE MEMO

AQUIFER PIEZOMETRIC DRAWDOWN CONTOURS IN CHANNEL VICINITY
(LONG TERM POST CONSTRUCTION)

AUGUST 2021 | FIG 02 | REV. 0

11x17V2:1

Filename: \\k-file-4\p-data\Projects\2018\18-0300-005\Dwg\Geo\Initial Design\IR No21\Bedrock Depressurization Rev 0\18-0300-005_FIG 02 - Tab:Rev0 Plotted By: TVanwent 21/08/27 [Fri 1:54pm]
11x17" PLOT SCALE: 1"=2"