KGS GROUP
CONSULTING ENGINEERS

Science | Imagination | Collaboration

QUILL LAKES
FLOOD MITIGATION STUDY
CONCEPT DESIGN REPORT

Water Security Agency

KGS GROUP PROJECT
15-0673-009
Final - Rev 0

November 2016

Kontzamanis | Graumann | Smith | MacMillan | Inc.

www.kgsgroup.com

KGS GROUP
CONSULTING ENGINEERS

Water Security Agency

QUILL LAKES FLOOD MITIGATION STUDY
CONCEPT DESIGN REPORT

FINAL – REV 0

KGS Group 15-0673-009
November 2016

PREPARED BY:

Patrice Leclercq, P.Eng.
Water Resources Engineer

APPROVED BY:

David S. Brown, P. Eng.
Senior Water Resources Engineer

PROFESSIONAL ENGINEER
D.S. BROWN
MEMBER 26612
16 11 04
YR. MN. DAY
SASKATCHEWAN

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

November 4, 2016

File No. 15-0673-009

Water Security Agency
400-111 Fairford Street East
Moose Jaw, Saskatchewan
S6H 7X9

ATTENTION: Mr. Clinton Molde, P.Eng.
Director, Strategic Integration

RE: Quill Lakes Flood Mitigation Study
Concept Design Report
Final – Rev 0, November 2016

Dear Mr. Molde:

KGS Group is pleased to submit an electronic pdf copy of our final concept design report for the Quill Lakes Flood Mitigation Study. The final report has incorporated all comments and feedback received from WSA.

The report details the various flood mitigation options that were considered in the study, describes the numerical models used to simulate the options, and provides model results. Environmental and cost considerations were also provided for the options. Each option was evaluated using an evaluation matrix.

The design concepts described in this report were high level reviews. As such, if WSA chooses to move forward with any of the options, further refinement will be required, possibly including additional data collection, environmental impact assessments, and detailed cost estimates.

We appreciate the opportunity to have worked with WSA on this project and look forward to any future projects. Should you have any questions regarding the enclosed deliverable please do not hesitate to contact me.

Sincerely,

David S. Brown, P.Eng.
Project Manager

MH/ama
Enclosure

EXECUTIVE SUMMARY

The Quill Lakes area is a wetland complex in Saskatchewan that consists of Big Quill Lake (BQL), Mud Lake, and Little Quill Lake (LQL). The lakes are located within a semi-closed drainage basin in which Big Quill Lake is the near-terminal water body.

The Quill Lakes basin is currently in a wet cycle and has been particularly wet for the last decade. Water levels have risen to record levels in 2016 and are threatening private and Crown lands, private industry, grid roads including Grid Road 640, the CP rail line between Lanigan and Wynyard, and Provincial Highways 6, 16 and 35. Should the lake levels continue to rise, the Quill Lakes will eventually spill at the natural outlet, discharging water into Saline Creek and eventually Last Mountain Lake.

The Quill Lakes are generally fairly saline in nature. Measured total dissolved solids (TDS) data indicates that concentrations can range between roughly 7,500 mg/L and 70,000 mg/L, depending on the lake level. In comparison, the measured average TDS in Last Mountain Lake is 1,400 mg/L. Since water from Big Quill Lake has a TDS concentration several times greater than that of Last Mountain Lake, movement of water from Big Quill Lake to Last Mountain Lake will potentially affect downstream water quality.

To address the concerns associated with the high water levels on the Quill Lakes, the Saskatchewan Water Security Agency (WSA) has been considering implementing flood mitigation measures within the Quill Lakes basin. As a result, several studies investigating the feasibility of various flood mitigation measures have previously been completed by KGS Group and other consultants. Based on preliminary studies, the Kutawagan Creek diversion channel project was selected as a preferred alternative and was further studied in 2015. However based on feedback and concerns arising from public consultations, the Kutawagan Creek project did not proceed forward.

For the current study, KGS Group was retained to complete a conceptual level review of numerous flood mitigation options to address the continuing rise of water levels in the Quill Lakes. The mitigation options considered in this study were identified by WSA in conjunction with KGS Group and included the following:

- **Do Nothing or “Base Case” –** The existing basin conditions, referred to as the “base case scenario”, was considered to be the situation where no measures are taken to mitigate flooding on the Quill Lakes. The lakes would be left to rise and fall naturally and could eventually overtop their natural spill points should the current wet cycle continue.

- **Hold water in Quill** Lakes – These options involved retaining water in one or both of the Quill Lakes via the construction of a containment dike. The two options that were considered were (1) blocking the natural outlet of Big Quill Lake to hold water in Big Quill Lake and (2) constructing a dike between Big Quill Lake and Little Quill Lake in order to contain water in Little Quill Lake.

- **Inflow Diversion –** The construction of a diversion channel would ideally stabilize and eventually reduce long-term Quill Lakes levels by diverting some of the tributary inflows away from the lakes. Seven diversion channel alignments were identified in previous studies and were built upon for the current study.

- **Upland Storage –** Twelve potential upland storage areas have been identified as potential locations to store water. The intent with creating upland storage areas would be to maximize surface area upstream of the Quill Lakes to increase evaporation, thereby reducing inflows to the lakes.

- **Removal of Water from Quill Lakes –** Five options for removing water from the Quill Lakes and discharging it to another location were considered, including: (1) The Landowner Proposal, (2) deep well injection, (3) pumping water to another watershed, (4) withdrawing water for the BHP Jansen Lake Mine and (5) withdrawing water for the Karnalyte Potash Mine.

- **Inflow Reduction –** Two options were considered to reduce the inflow to the Quill Lakes: (1) restoration of partially drained and drained wetlands and (2) closure of drainage works. Both options could potentially mitigate flooding on the Quill Lakes by providing additional wetland storage area upstream of the lakes, reducing the total volume of water reaching the lakes.

- **Legislative Policy –** Four legislative policy options for flood mitigation on the Quill Lakes were considered, including (1) drainage enforcement, (2) a drainage moratorium, (3) development of a watershed management policy and working group, and (4) responsible drainage plans.

Two numerical models were used to aid in the evaluation of the flood mitigation options listed above: (1) a water balance model and (2) an autoregressive model. The water balance model was developed by KGS Group to simulate changes in lake level caused by the hydrologic conditions within the Quill Lakes basin. The basis of the model was the law of continuity such that the volume of water discharged in a specific time period was equal to the volume of water inflow minus the change in storage.

The autoregressive model utilized the Stochastic Analysis, Modeling, and Simulation (SAMS) software, developed by the Colorado State University and the US Bureau of Reclamation. The model analyzed the stochastic features of the historical data and generated synthetic hydrologic time series using principals of a “Monte Carlo” procedure.

Based on the water balance model and the record of water levels, evaporation and precipitation for the period of 1975 to present, historic runoff values for Big Quill Lake and Little Quill Lake were calculated. The historical runoff and evaporation minus precipitation (E-P) values then formed the basis for the autoregressive model to generate 1000 synthetic series of runoff and (E-P) series, 50 years in length. The methods applied by the autoregressive model allowed to simulate periods of dry and wet conditions that were deemed representative of the historical record.

The large array of synthetic runoff and (E-P) sequences were simulated with the water balance model to generate the corresponding Quill Lakes water levels for each flood mitigation option to assess possible future lake levels. The results of simulations were used to analyze the risk of the Quill Lakes water levels exceeding key target elevations.

The results indicated that the trends in the data for both Big Quill Lake and Little Quill Lake were similar. For the base case, the average water in the first year was calculated to be 520.60 m (1708.01 ft). The averages did not fluctuate notably within the first 10 years, but decreased to

519.59 m (1704.69 ft) within 50 years on Big Quill Lake. It was found that within the first 5 years, 87% of the simulated water levels did not exceed the natural spill elevation of El. 521.47 m (1710.86 ft), which would cause water to spill from Big Quill Lake to Saline Creek and Last Mountain Lake. This percentage was essentially the same after 50 years of simulations at 86%.

The model results indicated that the short term (5 year) average reduction in water level on Big Quill Lake between the base case and the various options ranged between 0 m and 0.42 m, with about half of the options only having a minor overall reduction of 0.06 m or less. The percentage of simulated water levels that did not exceed El. 521.47 m ranged between 86% and 96% within the first 5 years of simulations. The long term results (50 years) did not differ significantly from the short term results. Over the next 50 years, the percentage of simulated water levels that did not exceed El. 521.47 m ranged between 83% and 98%.

High level cost estimates were prepared for the options which was intended to be used to compare options on a magnitude basis. Various types of costs were considered depending of the flood mitigation options, including direct costs, indirect costs, a contingency. The estimated range in cost between options varied significantly from approximately $5-$15 million for the lowest cost option to $920 - $1200 million for the most expensive option. The short term average flood mitigation cost savings were estimated to range between approximately $0 and $17 million for all options with the exception of the two Kutawagan Creek inflow diversion options which were estimated to range between approximately $40 and $80 million. These costs savings were typically about 10 times less than the estimated project costs, except for the two Kutawagan Creek inflow diversion options which were approximately half the estimated projects costs. Although mitigation costs only included damages to infrastructure (roads, railways, dikes) and farmyards, it is anticipated that a detailed economic analysis of the options would most likely conclude that none of the flood mitigation options should be selected based solely on economic factors.

An evaluation matrix was developed in order to objectively compare each flood mitigation option against the base case using a defined set of criteria, including:

- **Average Reduction of Inflows to the Lake –** The average reduction in runoff volume that could potentially be produced by the option over the next 50 years. These values were compared to the base case, where the reduction of inflow is zero.

- **Change in Average Lake Level –** The difference in average lake level between the base case and each option. This metric helps to identify options that would result in the largest overall reduction of lake level. Averages were calculated over the next 50 years of simulated water levels.

- **Project Cost –** A high level assessment of capital cost of the project. In order to compare the capital cost of each option on a magnitude basis, cost ranges were assigned a rating of “low”, “moderate”, “high”, or “very high”.

- **Operation Cost –** The operation costs of the various options were only compared qualitatively. Rather than assigning a dollar value to the operation of each option, a rating of “low”, “moderate”, or “high” was assigned to reflect the amount of effort or resources that would be required to maintain operation of the option.

- **Environmental Considerations & Social Acceptance –** Many of the options evaluated in this study had environmental concerns that must be considered. The social acceptance of the options was based on how the public may perceive each option. The following categories were identified and used for comparison in the matrix:
    - Potential for Natural Overflow
    - Average Volume of Natural Overflow
    - Transfer of Water
    - Average Volume of Diversion.
    - Increased Flooding of Headlands
    - Increased Flooding around the Quill Lakes
    - Average Volume of Available Storage
    - Wetland Restoration
    - Reduction of Land Drainage

It was evident from the evaluation matrix that each option provides some benefit to reducing water levels, but comes with a set of environmental and social implications that may or may not be acceptable to WSA and the stakeholders. Overall, the reduction of water level on the lakes resulting from the flood mitigation options was small and the costs, particularly in comparison to the flood mitigation cost savings, were high.

The results of this study do not indicate a clear choice for the optimum flood mitigation option to proceed with. All options considered have significant cost associated with them, and all provide a range of benefits including reductions to the overall water levels on the Quill Lakes. The selection of the preferred alternative by WSA should consider all of the categories outlined in the evaluation matrix.

TABLE OF CONTENTS

STATEMENT OF LIMITATIONS AND CONDITIONS IX

1.0 INTRODUCTION 1

1.1 FLOODING CONCERNS ON THE QUILL LAKES 1
1.2 PREVIOUS STUDIES 3
1.2.1 Preliminary Assessment of Flood Mitigation Options – Golder 3
1.2.2 Detailed Design of Kutawagan Creek Diversion Channel – KGS Group .. 5
1.2.3 Feasibility of Deep Well Injection – SNC Lavalin 5
1.3 PROJECT SCOPE 6

2.0 NUMERICAL MODELS 8

2.1 WATER BALANCE MODEL 9
2.1.1 Time Step 9
2.1.2 Quill Lakes Water Levels 10
2.1.3 Precipitation and Evaporation 12
2.1.4 Runoff Computation 16
2.1.5 Disaggregation of Annual Runoff and E-P Data 19
2.1.6 Computation of Water Levels 20
2.1.7 Calibration of Water Balance Model 21
2.2 AUTOREGRESSIVE MODEL 22
2.2.1 Stochastic Analysis of Annual Flow Data 23
2.2.2 Synthetic Flow Series Generation 23
2.2.3 Synthetic Water Level Computation 24
2.3 MODELLING ASSUMPTIONS AND CONSIDERATIONS 24

3.0 EXISTING FLOOD CONDITIONS 27

3.1 HYDROLOGIC ASSESSMENT OF FUTURE WATER LEVEL REGIME 28
3.2 SENSITIVITY ANALYSIS OF STARTING LAKE LEVEL 36

4.0 FLOOD MITIGATION OPTIONS 38

4.1 HOLD WATER IN QUILL LAKES 39
4.1.1 Block Natural Outlet 39
4.1.2 Hold Water in Little Quill Lake 40
4.2 INFLOW DIVERSION OPTIONS 40
4.2.1 Ponass Lake Diversion 41
4.2.2 Kutawagan Creek Diversion 42
4.2.3 Kutawagan Creek Diversion with Hwy 16 Diversion 43
4.2.4 Jansen Lake Diversion 44
4.2.5 Jansen Lake Diversion with Romance Creek 45
4.2.6 Jansen Lake Diversion with Romance Creek and Ironspring Creek 46
4.2.7 Jansen Lake Diversion with Romance Creek, Ironspring Creek, and Wimmer Brook 47
4.3 UPLAND STORAGE OPTIONS 49
4.3.1 Ponass Lakes Storage 50
4.3.2 Other Storage Areas 51
4.4 REMOVAL OF WATER FROM QUILL LAKES 51
4.4.1 Landowner Proposal (Plan B) 52
4.4.2 Deep Well Injection 53
4.4.3 Pump and Discharge Water to another Watershed 54

4.4.4 Withdraw Water for BHP Jansen Lake Mine 55
4.4.5 Withdraw Water for Karnalyte Potash Mine 55
4.5 INFLOW REDUCTION OPTIONS 56
4.5.1 Restoration of Partially Drained and Drained Wetlands 56
4.5.2 Closure of Drainage Works 58
4.6 LEGISLATIVE POLICY OPTIONS 60
4.6.1 Drainage Enforcement 61
4.6.2 Invoke Drainage Moratorium 61
4.6.3 Develop Watershed Management Policy and Working Group 62
4.6.4 Responsible Drainage 62
5.0 NUMERICAL MODEL ASSESSMENT OF FLOOD MITIGATION OPTIONS 63
6.0 COST COMPARISONS OF FLOOD MITIGATION OPTIONS 68
6.1 PROJECT COSTS 68
6.1.1 Direct Costs 68
6.1.2 Indirect Costs 72
6.1.3 Project Contingency 72
6.2 OPERATION COSTS 72
6.3 FLOOD MITIGATION COSTS 73
6.4 SUMMARY OF PROJECT COSTS 76
7.0 COMPARISON MATRIX OF FLOOD MITIGATION OPTIONS 79
8.0 CONCLUSIONS 85
9.0 REFERENCES 87

PLATES
APPENDIX A – SAMPLE RUNOFF CALCULATION
APPENDIX B – REVIEW OF LANDOWNER PLAN B

LIST OF TABLES

1. Key Elevations For The Quill Lakes
2. Summary Of Model Results – Base Case
3. Summary Of Inflow Diversion Projects
4. Summary Of Upland Storage Options
5. Wetland Restoration Summary
6. Closure Of Drainage Works Summary
7. Flood Mitigation Options Comparison - Modelled Water Levels on Big Quill Lake
8. Likelihood Of Big Quill Lake Level Remaining and/or Receding Below Key Elevations
9. Summary Of Quantities For Stage Damage Relationship
10. Summary Of Costs For Stage Damage Relationship
11. Summary Of Estimated Project Costs
12. Rating Categories For Project Cost
13. Evaluation Matrix

LIST OF FIGURES

1. Recorded Annual Average Water Levels of the Quill Lakes From 1885
2. Numerical Modelling Process
3. Recorded Water Levels on Big Quill Lake – 1975 to Present
4. Recorded Water Levels on Little Quill Lake – 1975 to Present
5. Calculated Depth of Evaporation Minus Precipitation on the Quill Lakes
6. Quill Lakes Backwater Rating Curve
7. Big Quill Lake Overflow Rating Curve
8. Stage-Storage Curves for the Quill Lakes
9. Annual Runoff Volume for the Quill Lakes – 1975 to Present
10. Median Monthly Runoff to the Quill Lakes
11. Median Monthly Evaporation Minus Precipitation to the Quill Lakes
12. Comparison of Observed and Simulated Water Levels – 1975 to Present
13. Estimated Big Quill Lake Water Level for Base Case (200 of 1000 Series)
14. Estimated Big Quill Lake Water Level for Base Case (5 of 1000 Series)
15. Statistics of Simulated Water Level on Big Quill Lake (Base Case)
16. Statistics of Simulated Water Level on Little Quill Lake (Base Case)
17. Big Quill Lake Water Level Duration Curves (Base Case)
18. Simulated Average Annual Volume of Natural Overflow (Base Case)
19. Sensitivity Analysis of Starting Lake Level
20. Stage-Damage Relationship

LIST OF PLATES

1. Drainage Basin Map
2. Flooded Area Map
3. Diversion Options
4. Potential Upland Storage Areas
5. Wetland Inventory
6. Model Results – Existing Condition
7. Model Results – Block the Natural Outlet Option

LIST OF PLATES CONTINUED

8. Model Results – Isolate Little Quill Lake Option
9. Model Results – Ponass Lakes Diversion Option
10. Model Results – Kutawagan Creek Diversion Option
11. Model Results – Kutawagan Creek and Hwy 16 Diversion Option
12. Model Results – Jansen Lake Diversion Option
13. Model Results – Jansen Lake and Romance Creek Diversion Option
14. Model Results – Jansen Lake, Romance Creek and Ironspring Creek Diversion Option
15. Model Results –Jansen Lake, Romance Creek, Ironspring Creek, and Wimmer Brook Diversion Option
16. Model Results – Ponass Lakes Storage Option
17. Model Results – Other Storage Option
18. Model Results – Landowner Proposal (Plan B) Option
19. Model Results – Deep Well Injection Option (0.47 m^3/s)
20. Model Results – Deep Well Injection Option (4.4 m^3/s)
21. Model Results – Pump and Discharge Water to another Watershed Option (0.47 m^3/s)
22. Model Results – Pump and Discharge Water to another Watershed Option (4.4 m^3/s)
23. Model Results – Withdraw Water for BHP Jansen Lake Mine Option
24. Model Results – Withdraw Water for Karnalyte Potash Mine Option
25. Model Results – Restoration of Partially Drained and Drained Wetlands Option (5,000 dam^3)
26. Model Results – Restoration of Partially Drained and Drained Wetlands Option (15,000 dam^3)
27. Model Results – Closure of Drainage Works Option

STATEMENT OF LIMITATIONS AND CONDITIONS

THIRD PARTY USE OF REPORT

This report has been prepared for the Water Security Agency to whom this report has been addressed and 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 as a result of decisions made or actions undertaken based on this report.

CAPITAL COST ESTIMATE STATEMENT OF LIMITATIONS

The cost estimates included with this report have been prepared by KGS Group using its professional judgment and exercising due care consistent with the level of detail required for the stage of the project for which the estimate has been developed. These estimates represent KGS Group's opinion of the probable costs and are based on factors over which KGS Group has no control. These factors include, without limitation, site conditions, availability of qualified labour and materials, present workload of the Bidders at the time of tendering and overall market conditions. KGS Group does not assume any responsibility to the Client, in contract, tort or otherwise in connection with such estimates and shall not be liable to the Client if such estimates prove to be inaccurate or incorrect.