4.0 FLOOD MITIGATION OPTIONS

Brainstorming sessions between WSA and KGS Group lead to the development of numerous feasible flood mitigation options for the Quill Lakes basin. Ultimately, six different categories of flood mitigation strategies were defined and within each category two or more mitigation options were evaluated. These options, which are described in the following sub-sections, are as follows:

- **Do Nothing or "Base Case"**
- **Hold water in Quill Lakes**
  - Block the natural outlet
  - Isolate Little Quill Lake from Big Quill Lake
- **Inflow Diversion**
  - Ponass Lakes diversion
  - Kutawagan Creek diversion
  - Kutawagan Creek and Hwy 16 diversion
  - Jansen Lake diversion
  - Jansen Lake and Romance Creek diversion
  - Jansen Lake, Romance Creek and Ironspring Creek diversion
  - Jansen Lake, Romance Creek, Ironspring Creek and Wimmer Brook diversion
- **Upland Storage**
  - Ponass Lakes
  - Other storage
- **Removal of Water from Quill Lakes**
  - Landowner Plan B
  - Deep well injection
  - Pump and treat water
  - Withdraw water for BHP Jansen Lake Mine
  - Withdraw water for Karnalyte Potash Mine
- **Inflow Reduction**
  - Restoration of partially drained and drained wetlands
  - Closure of drainage works
- **Legislative Policy**
  - Drainage enforcement
  - Invoke drainage moratorium
  - Develop a Watershed Management Policy and Working Group
  - Responsible drainage

The Do Nothing scenario was described in Section 3.1 and is used as a base case condition to compare to all other options.

4.1 HOLD WATER IN QUILL LAKES

Two flood mitigation options involving retaining water in one or both of the Quill Lakes were evaluated in this study: (1) blocking the natural outlet of Big Quill Lake and (2) holding water in Little Quill Lake by constructing a containment dike. These two options are described in detail in the following sections.

4.1.1 Block Natural Outlet

When the water level on the Quill Lakes exceeds the elevation of the natural spill point (El. 521.47 m or 1710.86 ft), the Quill Lakes have the potential to spill into Saline Creek and eventually into Last Mountain Lake. Outflows from the Quill Lakes are expected to have a TDS concentration of approximately 7,500 mg/L by the time the water level reaches the spill elevation, which far exceeds the average TDS concentration in Last Mountain Lake of approximately 1,400 mg/L. Blocking the natural outlet would allow the lakes to continue to rise while preventing downstream releases of high TDS, saline water from the Quill Lakes from entering Last Mountain Lake.

In order to block the natural outlet and prevent the natural downstream release of water from Big Quill Lake, an earth dike or similar structure would need to be constructed at the outlet. Depending on how the structure is designed, it is possible that water could still be allowed to spill at a certain elevation through the construction and operation of a control structure in the dike. However, this has not been considered as part of the analysis for this option.

Blocking the outlet would ultimately lead to further water level increases on Big Quill Lake, should the water level reach or exceed the elevation of the spill point. In this case, flood damages to land, properties, and infrastructure surrounding the lake would increase. These damages could potentially be mitigated by raising the CP railway and nearby highways, possibly including Grid Rd. 640, Hwy 6, Hwy 16, and Hwy 35. It is also possible that the construction of dikes could protect buildings and properties in the vicinity of the lakes.

4.1.2 Hold Water in Little Quill Lake

Currently, the water level in the Quill Lakes is so high that Big Quill Lake and Little Quill Lake have the same water level and rise and fall in unison. However, in order to mitigate flooding, some consideration has been giving to constructing a dike between Big Quill Lake and Little Quill Lake. This could prevent flow between the two water bodies and allow them to rise and fall independently of each other.

The isolation of Little Quill Lake is potentially advantageous for several reasons. There is significantly more Crown land surrounding Little Quill Lake than Big Quill Lake. As a result, allowing the water level on Little Quill Lake to rise and flood the surrounding land could result in less financial damages than if Big Quill Lake rose and flooded the surrounding private land and farmlands. In addition, isolating the two lakes would ideally keep the water level on Big Quill below the spill elevation and prevent outflows to Last Mountain Lake. However, if the current wet cycle continues and water levels on Big Quill Lake exceed El. 521.47 m (1710.86 ft), it would still be free to spill.

In order to isolate Little Quill Lake, a dike would be constructed between Big Quill Lake and Little Quill Lake, likely along the Grid Rd. 640 alignment. The dike could potentially be designed with a control structure that could be operated to allow flow between the two lakes if desired. However, this has not been considered in the analysis of this option.

4.2 INFLOW DIVERSION OPTIONS

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. Several feasible diversion channel alignments were identified in Golder's preliminary study and were built upon for this study [1]. A summary of the diversion options that were evaluated is presented in Table 3 and their locations are shown on Plate 3. Each of the diversion options that were evaluated are described in detail in the following sub-sections.

The total volume of water diverted away from the Quill Lakes would vary from year to year depending on runoff. For conceptual design, it was assumed that the percent reduction of inflow to the Quill Lakes would be approximately equal to the percent reduction in gross drainage area that resulted from the construction of the diversion. Although considered valid at this stage of design, this assumption could be verified in the next stages of design, with considerations given to using the effective area of the basin rather than the gross area and calculating diversion volumes based on stream flows. It has also been assumed that diversion channels would be in operation regardless of the elevation of the Quill Lakes to simulate the maximum reduction in water levels that could be achieved by the option.

TABLE 3
SUMMARY OF INFLOW DIVERSION PROJECTS

Inflow Diversion Project	Gross Drainage Area (km^2)	Percent Of Total Gross Drainage Area	Percent Of Big Quill Gross Drainage Area	Percent Of Little Quill Gross Drainage Area
Ponass Lake Diversion	156	2.2%	n/a	3.1%
Kutawagan Creek Diversion	1104	11.7%	29.2%	n/a
Kutawagan Creek / Highway 16 Area Diversion	1283	13.9%	33.9%	n/a
Jansen Lake Diversion	265	3.0%	7.0%	n/a
Jansen Lake / Romance Creek Diversion	419	4.8%	11.1%	n/a
Jansen Lake / Romance Creek / Ironspring Creek Diversion	846	13.0%	22.4%	n/a
Jansen Lake / Romance Creek / Ironspring Creek / Wimmer Brook Diversion	1041	15.1%	27.6%	n/a

Note: 1 km^2 = 0.386 mi^2

4.2.1 Ponass Lake Diversion

The Ponass Lakes, shown on Plate 3, are located on the north-west end of the Quill Lakes watershed, approximately 10 km (6.2 mi) west of the Community of Rose Valley, and have a combined surface area of approximately 3,000 ha (7413 ac) [8]. The gross drainage area of the lakes is approximately 156 km^2 (60 mi^2) and they discharge into Clair Brook, a tributary of Little Quill Lake. The Ponass Lakes have been regulated by Ducks Unlimited since 1983 [8].

The diversion concept would consist of constructing an approximately 11 km (6.8 mi) long channel [1] from the Ponass Lakes to the south-east along Ponass Lake Road and an existing water course towards the community of Fosston. The channel would then naturally discharge into the Pipestone Creek drainage network and then towards Nut Lake and the Red Deer River, as shown on Plate 3. The diversion channel would be approximately 1.5 m (4.9 ft) deep, 18 m (59 ft) wide, with a 0.01% slope, and would have a design capacity of approximately 11 m^3/s (388 cfs) [2]. Four road crossings would be required along the channel and a control structure would be constructed on Clair Brook to divert flows away from the Quill Lakes [1].

Since the Ponass Lake diversion area is approximately 2.2% of the total Quill Lakes drainage area, it was assumed that this option would lead to approximately a 2.2% reduction of the total Quill Lakes tributary inflow

The proposed diversion concept would divert water from the Quill Lakes Basin to the Red Deer River Basin. Since there are no known saline water concerns with the Ponass Lakes (unlike the Quill Lakes), it was assumed that the transfer of water from one basin to another would be acceptable. However, this would have to be evaluated further if WSA decides to move forward with this option. The Ponass Lakes diversion would also change existing flow patterns on both Pipestone Creek and Clair Brook which may result in some environmental concerns such as erosion or potential impacts to fish habitat. This would have to be addressed if WSA moves forward with this option.

4.2.2 Kutawagan Creek Diversion

As discussed in Section 1.2.2, the Kutawagan Creek Diversion option, was investigated in 2015 as a potential flood mitigation solution for the Quill Lakes. However, based on the feedback and concerns from public consultations that were held in the fall of 2015, this option was not selected to proceed forward. None-the-less, details and model results for this option are provided within this report, but solely for comparison purposes.

Kutawagan Creek is located on the southwest shore of Big Quill Lake, as shown in Plate 3. Under natural conditions, it collects runoff and discharges into Big Quill Lake. The gross drainage area of Kutawagan Creek is approximately 1104 km^2 (426 mi^2).

This diversion concept would require the construction of a dike east of Highway 6 along the southwest shoreline of Big Quill Lake and the construction of a diversion channel that would be utilized to temporarily divert the inflow to the Quill Lakes from Kutawagan Creek. The diversion channel would be approximately 42 km (26 mi) long and extend from the dike to Peter Lake. Thirteen culvert crossings, a Ducks Unlimited (DU) control structure, the Quill Lakes Dike control structure, and the Highway 744 control structure would be required. In addition, there would be three culvert crossings downstream of Highway 744 that would have to be enlarged; two on Peter Lake and at Highway 15, as well as possible excavated channels upstream and downstream of Peter Lake. The alignment of the Kutawagan Creek diversion channel is shown on Plate 3.

The portion of the channel between the Quill Lakes Dike and Peter Lake would be constructed with a bottom width of 15 m (49 ft), while the section of the channel between Peter Lake and Last Mountain Lake would have a reduced bottom width of 4 m (13 ft). The channel would have 3H:1V side slopes and would be horizontal, with an invert elevation of 518.5 m (1701.1 ft). This channel geometry would allow the channel to pass the design flow of 4 m^3/s (141 cfs). Since the Kutawagan Creek diversion area is approximately 11.7% of the total Quill Lakes drainage area, it was assumed that this option would lead to approximately a 11.7% reduction of the total Quill Lakes tributary inflow.

The proposed diversion concept would divert water from the Quill Lakes Basin to the Last Mountain Lake Basin. The Kutawagan Creek diversion would also change existing flow patterns on Kutawagan Creek, Saline Creek, and Peter Lake, possibly resulting in some environmental concerns, such as erosion, changes to water level regimes and potential impacts to fish habitat.

4.2.3 Kutawagan Creek Diversion with Hwy 16 Diversion

The Kutawagan Creek Diversion with Hwy 16 Diversion concept is similar the Kutawagan Creek Diversion concept detailed in Section 4.2.2. However, this option also includes the diversion of approximately an additional 179 km^2 (69 mi^2) drainage area south of Hwy 16. As mentioned in Section 4.2.2, the Kutawagan Creek Diversion option was not selected to proceed forward based on feedback and concerns arising from public consultations. Since this option is a slight variation of the Kutawagan Creek Diversion option, it would also likely not be selected to proceed forward. None-the-less, details and model results for this option are provided within this report, but solely for comparison purposes.

Southeast of Big Quill Lake there are many small streams, lakes, and wetland areas that drain to the north and discharge into Big Quill Lake. The construction of a diversion channel to the south of Hwy 16 would collect much of this water and divert it into the Kutawagan Creek diversion channel and ultimately discharge the water into Last Mountain Lake. The Hwy 16 diversion channel would be approximately 30 km (18.6 mi) in length and would extend from just southwest of the intersection of Hwy 16 and Grid Rd. 640 to the Kutawagan Creek diversion channel, as shown on Plate 3.

The drainage area of this diversion option is approximately 1283 km^2 (495 mi^2), or 13.9% of the drainage area for the Quill Lakes. As a result, it was assumed that there would be approximately a 13.9% reduction in inflow to Big Quill Lake.

Similar to the Kutawagan Creek diversion, this proposed diversion concept would divert water from the Quill Lakes Basin to the Last Mountain Lake Basin and also change existing flow patterns on Kutawagan Creek, Saline Creek, and Peter Lake.

4.2.4 Jansen Lake Diversion

Jansen Lake is a 200 to 500 m (650 to 1650 ft) wide, approximately 15 km (9.3 mi) long water body located approximately 15 to 20 km (9.3 to 12.4 mi) west of Big Quill Lake, as shown on Plate 3. The gross drainage area of Jansen Lake is approximately 265 km^2 (102 mi^2). Naturally, water from the lake discharges to the northeast through Romance Creek, which is a tributary of Big Quill Lake.

The Jansen Lake diversion concept would consist of constructing an approximately 9.8 km long channel [2] from the south end of Jansen Lake to the west into Lanigan Creek. The channel alignment would follow low lying terrain and a small intermittent stream, and would intercept a few small pothole marshes as shown on Plate 3. The channel would then naturally discharge into Lanigan Creek, a tributary to Last Mountain Lake. The diversion channel would be approximately 2.5 m deep, 22 m wide, with a 0.05% slope, and would have a design capacity of approximately 60 m^3/s [2]. Three road crossings would be required as well as two embankment dams to contain flows within the channel.

The gross drainage area of the Jansen Lake diversion represents approximately 3.0% of the total drainage area for the Quill Lakes. As a result, it was assumed that the total Quill Lakes inflows would be reduced by 3.0% if the diversion channel was constructed. It was assumed that the diversion channel would be in operation at all times, regardless of the water level on the Quill Lakes.

The proposed diversion concept would divert water from the Quill Lakes Basin to the Last Mountain Lake Basin. Since there are no known saline water concerns with Jansen Lake (unlike the Quill Lakes), it was assumed that the transfer of water from one basin to another would be acceptable, however this would have to be evaluated further should WSA choose to move forward with this option. Additionally, the Jansen Lake diversion would increase flows on Lanigan Creek, possibly increasing water levels and causing erosion downstream of the diversion channel. Flows would be reduced on Romance Creek and approximately 500 ha (1235 ac) of land would be flooded along the proposed diversion route [2]. Other environmental concerns may include changes to the Jansen Lake water level regime and potential impacts to fish habitat. Each of these environmental considerations would need to be considered further if this option moves forward to preliminary design.

4.2.5 Jansen Lake Diversion with Romance Creek

Romance Creek is a tributary of the Quill Lakes and is located to west of Big Quill Lake, as shown on Plate 3. It has an approximately 595 km^2 (230 mi^2) [2] gross drainage area which includes Jansen Lake.

The Romance Creek diversion concept would consist of adding on to the proposed Jansen Lake diversion concept (detailed in Section 4.2.4) by constructing an approximately 16 km long channel [2] that would divert flows from the upstream reach of Romance Creek into Jansen Lake. The downstream reach of Romance Creek would continue to flow naturally into Big Quill Lake. The diversion channel would have its inlet located about 6 km (3.7 mi) south-west of the Town of Watson and have an alignment that would follow low lying terrain along small intermittent streams and through multiple pothole marshes, as shown on Plate 3. The diversion channel would discharge into Jansen Lake about 6 km (3.7 mi) south of the Town of Leroy. Ultimately, water from Jansen Lake would be diverted into Lanigan Creek via the proposed Jansen Lake diversion channel.

The Romance Creek diversion channel would be approximately 2.5 m (8.2 ft) deep, 20 m (66 ft) wide, with a 0.04% slope, and would have a design capacity of approximately 48 m^3/s (1700 cfs) [2]. Ten road crossings would be required as well as four embankment dams to contain flows within the channel. A control structure would also be constructed on Romance Creek to divert flows away from the Quill Lakes [1].

The gross drainage area of the Jansen Lake/Romance Creek diversion represents approximately 4.8% of the total drainage area for the Quill Lakes. As a result, it was assumed that the total Quill Lakes inflows would be reduced by 4.8% if the diversion channels were constructed.

Since there are no known water quality concerns with Romance Creek or Jansen Lake, it was assumed that the transfer of water from the creek to the lake would be acceptable; however this would have to be evaluated further considering potential impacts to fish habitat in both the lake and the creek. The additional inflow to Jansen Lake, combined with its new outlet, could also result in changes to the lake's natural water level regime. Other environmental concerns include approximately 200 ha (500 ac) of flooded land along the proposed diversion channel route as well as reduced flows on Romance Creek. Each of these environmental concerns would have to be considered further if this concept moves forward to preliminary design.

4.2.6 Jansen Lake Diversion with Romance Creek and Ironspring Creek

Ironspring Creek is located northwest of Big Quill Lake just north of the Romance Creek basin, as shown on Plate 3. It is a tributary of the Quill Lakes with a gross drainage area of approximately 952 km^2 (368 mi^2) [2].

The Ironspring Creek diversion concept would consist of adding on to the proposed Jansen Lake and Romance Creek diversion concepts by constructing an approximately 14 km (8.7 mi) long channel [2] that would divert flows from the upstream reach of Ironspring Creek into the Romance Creek diversion channel. The downstream reach of Ironspring Creek would continue to flow naturally into Big Quill Lake. The inlet to the diversion channel would be located approximately 6 km (3.7 mi) north of the Town of Watson and would have an alignment that would follow low lying terrain along small intermittent streams and through multiple pothole marshes, as shown on Plate 3. The Ironspring Creek diversion channel would connect with the proposed Romance Creek diversion channel inlet approximately 6 km (3.7 mi) southeast of the Town of Watson. Flows would continue towards Jansen Lake and would be diverted into Lanigan Creek via the proposed Jansen Lake diversion channel.

The Ironspring Creek diversion channel would be trapezoidal shaped, approximately 2 m (6.5 ft) deep, 29 m (95 ft) wide, with a 0.06% slope, and would have a design capacity of approximately 32 m^3/s (1130 cfs) [2]. Six road crossings would be required as well as a control structure on Ironspring Creek to divert flows away from the Quill Lakes [1].

The gross drainage area of the Jansen Lake / Romance Creek / Ironspring Creek diversion represents approximately 13.0% of the total drainage area for the Quill Lakes. As a result, it was assumed that the total Quill Lakes inflows would be reduced by 15.1% if the diversion channels were constructed.

Similar to the Romance Creek diversion concept, the environmental concerns for the proposed Ironspring Creek diversion include the transfer of water from the creek to Jansen Lake and potential changes to the Jansen Lake natural water level regime. Other environmental concerns also include approximately 200 ha (500 ac) of flooded land along the proposed diversion channel route as well as reduced flows on Ironspring Creek. These environmental concerns would have to be considered further if this concept moves forward to preliminary design.

4.2.7 Jansen Lake Diversion with Romance Creek, Ironspring Creek, and Wimmer Brook

Wimmer Brook is located to north of Big Quill Lake just east of the Ironspring Creek basin, as shown in Plate 3. It is a tributary to the Quill Lakes with a gross drainage area of approximately 208 km^2 (80 mi^2) [2].

The Wimmer Brook diversion concept would consist of adding on to the proposed Jansen Lake, Romance Creek and Ironspring diversion concepts by constructing an approximately 11 km (6.8 mi) long channel [2] that would divert flows from the upstream reach of Wimmer Brook into the Ironspring Creek diversion channel. The downstream reach of Wimmer Brook would continue to flow naturally into Big Quill Lake. The inlet to the diversion channel would be located about 10 km (6.2 mi) east of the Town of Watson and the alignment would follow low lying terrain on agricultural land, intersecting multiple pothole marshes, as shown on Plate 3. The diversion channel would connect with the proposed Ironspring Creek diversion channel inlet approximately 6 km north of the Town of Watson. Flows would continue towards Jansen Lake and would then be diverted into Lanigan Creek via the proposed Jansen Lake diversion channel.

The Wimmer Brook diversion channel would be trapezoidal shaped, approximately 1.5 m (4.9 ft) deep, 3.5 m (11.5 ft) wide, with a 0.04% slope, and would have a design capacity of approximately 5 m^3/s (180 cfs) [2]. Eight road crossings would be required as well as three embankment dams to contain flows within the channel. A control structure on Wimmer Brook would also be constructed to divert flows away from the Quill Lakes [1].

The gross drainage area of the Jansen Lake, Romance Creek, Ironspring Creek, and Wimmer Brook diversion represents approximately 15.1% of the total drainage area for the Quill Lakes. As a result, it was assumed that the total Quill Lakes inflows would be reduced by 15.1% if the diversion channels were constructed.

Similar to the Ironspring Creek diversion concept, the environmental concerns for the proposed Wimmer Brook diversion include the transfer of water from the creek to Jansen Lake and potential changes to the Jansen Lake natural water level regime. Other environmental concerns also include approximately an additional 150 ha of flooded land along the proposed diversion channel route as well as reduced flows on Wimmer Brook. These environmental concerns would have to be considered further if this concept moves forward to preliminary design.

4.3 UPLAND STORAGE OPTIONS

Upland storage was considered as an option to mitigate flooding of the Quill Lakes. 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. At this conceptual phase of study, it was assumed that the storage reservoirs would be operated constantly, regardless of the water level on the Quill Lakes. However, when the storage reservoirs reach maximum capacity, any additional runoff would flow into the Quill Lakes. The water contained in the storage reservoirs would be stored until it evaporates. Other operational methods could also be considered, such as releasing water from the reservoirs when the Quill Lakes levels are low, or alternatively in a timed manner in an attempt to reduce peak flows to the lakes. However WSA indicated these methods were not preferred at this time.

Twelve potential upland storage areas have been identified and are shown on Plate 4. A summary of the characteristics of each storage area is provided in Table 4. The Ponass Lakes storage option has recently generated a lot of interest from stakeholders as a viable flood mitigation option. As a result, the Ponass Lakes storage option was evaluated independently (option 1), while the remaining eleven storage areas were combined into a single option (option 2).

The reduction of inflow to the Quill Lakes due to the construction of the storage reservoirs was calculated based on the gross drainage area of the basin upstream of each storage reservoirs. For conceptual design, it was assumed that the percent reduction of inflow to the Quill Lakes would be approximately equal to the percent reduction in gross drainage area that resulted from the construction of the storage reservoir. Although considered valid at this stage of design, this assumption could be verified in the next stages of design, with considerations given to the using effective area of the drainage basin rather than the gross area and calculating storage volumes based on stream flows.

TABLE 4
SUMMARY OF UPLAND STORAGE OPTIONS

Storage Option	Capacity (dam^3)	Area (ha)	Outlet Stream	Sub-Basin	Receiving Lake	Average Depth (m)	Basin Area (km^2)
Ponass Lakes	20,000	4,900	Clair Brook	Clair Brook	Little Quill	0.4	179
Connell Project	1,800	270	Ponass Lakes	Clair Brook	Little Quill	0.7	18
Presco/Pikor Project	2,400	370	Ponass Lakes	Clair Brook	Little Quill	0.6	12
Barber's Lakes	1,600	300	Unamed	Quill Creek	Little Quill	0.5	78
Spalding Storage	9,000	900	Ironspring Creek	Ironspring Creek	Big Quill	1.0	337
Jansen Lake	13,600	1,000	Romance Creek	Romance Creek	Big Quill	1.4	265
Pel and Kutawagan Lakes	20,600	2,500	Kutawagan Creek	Kutawagan Creek	Big Quill	0.8	709
Sutton Project	800	82	n/a	Big Quill South	Big Quill	1.0	81
Kandahar Project	200	22	n/a	Big Quill South	Big Quill	0.9	35
Foam Lake	16,000	1,700	Milligan Creek	Milligan Creek	Little Quill	0.9	1041
Strembicki Project	900	95	Milligan Creek	Milligan Creek	Little Quill	0.9	8
Milligan Creek Storage	9,000	900	Milligan Creek	Milligan Creek	Little Quill	1.0	47

Note: 1 m = 3.28 ft
1 dam^3 = 0.81 ac-ft
1 km^2 = 0.386 mi^2
1 ha = 2.47 ac

4.3.1 Ponass Lakes Storage

The first upland storage option that was considered was the Ponass Lakes storage area. The Ponass Lakes storage area is one of the original Heritage Marshes in Saskatchewan and has recently generated interest from local stakeholders. This storage project is considered advantageous because it would flood primarily Crown Land.

The Ponass Lakes storage option would collect and retain water from a drainage area of 179 km^2 (69 mi^2), representing approximately 2% of the total Quill Lakes drainage area. The storage area would have a surface area of 4,900 ha (12,100 ac) and a capacity of 20,000 dam^3 (16,200 ac-ft), assuming an average depth of 0.4 m (1.3 ft). Water would discharge from the storage area to Little Quill Lake via Clair Brook.

This option was modelled assuming that the available upland storage would begin to fill up immediately. Once activated, total inflow would generally be reduced by 2%. However, inflows would not be reduced if the maximum available storage volume is exceeded. The available storage volume was determined based on the available storage at the end of the previous year and the reservoir inflow, while taking into account evaporation minus precipitation occurring over the Ponass Lakes. Water would not be released from the reservoir, regardless of the water level on the Quill Lakes.

4.3.2 Other Storage Areas

The second option that was considered was a combination of all remaining eleven storage areas (excluding Ponass Lakes) identified in Table 4. The location and characteristics of each storage area is shown on Plate 4.

Option 2 would collect and retain water from a total drainage area of approximately 3630 km^2, representing approximately 30% of the total Quill Lakes drainage area. The storage area would have a surface area of 8,140 ha (20,100 ac) and a capacity of 75,900 dam^3 (61,500 ac-ft), assuming the average depths shown in Table 4.

Similar to Option 1, this option was modelled assuming that the available upland storage would begin to fill up immediately. Once activated, total inflow would generally be reduced by 30%. However, inflows would not be reduced if the maximum available storage volume is exceeded. The available storage volume was determined based on the available storage at the end of the previous year and the reservoir inflow while taking into account evaporation minus precipitation occurring over the storage areas. Water would not be released from the reservoirs, regardless of the water level on the Quill Lakes.

4.4 REMOVAL OF WATER FROM QUILL LAKES

Five options for removing water from the Quill Lakes and discharging it 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. The options are detailed in the following sections.

4.4.1 Landowner Proposal (Plan B)

The Landowner Proposal (Plan B) was a concept developed by a local landowner as an alternative to the Kutawagan Creek Diversion Project that was considered by WSA in the summer of 2015.

As part of the scope of this project, WSA requested a technical review of the landowner proposal. The details of that technical review are not described in this report, but rather only a description of the option. The findings of our technical review were documented in a separate letter report to WSA. The draft letter report has been attached to this draft report in Appendix B.

The concept consists of constructing a channel along Kutawagan Creek from the Quill Lakes to Highway 16 to the drainage basin divide into Saline Creek (Nokomis Spill Point). A control outlet would be constructed at Highway 744 which would provide a control for the Quill Lakes during periods of high runoff and high water levels on Quill Lakes.

The channel would be approximately 40 km (25 mi) long from Quill Lakes to Hwy 744, of which approximately 30 km (19 mi) would require excavation to provide the required discharge capacity. Upgrades to thirteen culvert crossings would also be required. The channel alignment would follow the existing water course comprised of many lakes, ponds and channels to minimize excavation quantities. The channel would be constructed with sufficient depth to provide the flow capacity during winter with an ice cover.

There are several environmental concerns with transferring water from Quill Lakes into Last Mountain Lake due to high salinity levels and concentrations of Total Dissolved Solids (TDS). To deal with these concerns, the channel has been proposed to be operated as much as possible during the winter to reduce the level of TDS due to reduction in stratification. However, detailed analyses would be necessary to confirm whether this operating strategy would sufficiently improve water quality. Additional details on concerns that could lead to the proposal not being feasible are described in the KGS Group letter attached in Appendix B.

In the open water period from April to November, the channel was proposed to be operated to mix the surface runoff from Kutawagan drainage area with flow released from the Quill Lakes in order to maintain the same water quality that would have overflowed naturally without the outlet. However, this would require extensive monitoring of the water quality in order to ascertain that the water quality goals would be achieved and would likely require considerable fluctuations in the flow releases.

The total volume of water that would be diverted from the Quill Lakes and the effect on the water level on the lakes would depend on the channel design capacity and the adopted operating strategy. The required capacity would have to be sufficient to maintain or lower the level on the Quill Lakes. To be consistent with the Kutawagan Creek diversion project considered by KGS Group in 2015, a capacity of 4 m^3/s (140 cfs) was assumed for the channel during winter ice period with the Quill Lakes at elevation 520.5 m (1707.7 ft). Larger capacities could also be considered but would require additional excavation costs.

To model this option, it was assumed that the channel would be primarily operated in winter between November 1st and March 31st. During this time, the channel would have a capacity of 4 m^3/s (140 cfs) at El. 520.5 m (1707.7 ft). In the summer, between April 1st and October 31st, it was assumed that the channel would only be operated when the water level on the Quill Lakes is above the natural spill point, El. 521.47 m (1710.86 ft), in order to maintain the same water quality that would have overflowed naturally. It was also assumed that, on average, only 25% of the channel capacity would be utilized in the summer to account for constraints on water quality and TDS loads reaching Last Mountain Lake.

4.4.2 Deep Well Injection

Deep well injection is a flood mitigation option that was investigated by SNC-Lavalin in 2015 in the report titled "Prefeasibility Study for Deep Formation Water Disposal" [5].

Both the Basal Deadwood aquifer and the Manneville aquifer may be suitable injection disposal horizons for excess water from the Quill Lakes. SNC-Lavalin's analysis evaluated two injection volumes: 15,000 dam^3/year (12,200 ac-ft/year) and a maximum potential injection volume of 140,000 dam^3/year (113,500 ac-ft/year).

According to SNC-Lavalin's analysis, the Basal Deadwood aquifer potentially has sufficient injection capacity to dispose of 2,280 dam^3/year (1,850 ac-ft) per well. As a result, a minimum of seven disposal wells would be required to inject 15,000 dam^3/year (12,200 ac-ft) and a minimum of 62 wells would be required to inject 140,000 dam^3/year (113,500 ac-ft). The Mannville aquifer potentially has sufficient injection capacity to dispose of 400 dam^3/year (320 ac-ft) per well. As a result, a minimum of 38 disposal wells would be required to inject 15,000 dam^3/year (12,200 ac-ft) and a minimum of 354 disposal wells would be required to inject 140,000 dam^3/year (113,500 ac-ft).

In order to avoid potential issues associated with incompatible fluids, including clay swelling and well failure, the Quill Lakes water will likely require treatment before it can be injected into either the Basal Deadwood aquifer or the Mannville aquifer. SNC-Lavalin found that the salinity of the water initially injected into the Mannville aquifer would have to be increased from approximately 10,000 mg/L to 50,000 mg/L. As water levels on the Quill Lakes decrease, treatment may no longer be necessary. Similarly, for injection into the Basal Deadwood aquifer, SNC-Lavalin found that the salinity Quill Lakes water would have to be increased from approximately 10,000 mg/L to 135,000 mg/L.

To model this option, it was assumed that the injection wells would be operated constantly, regardless of the water level on the Quill Lakes The annual injection volumes of 15,000 dam^3/year (15,200 ac-ft) and 140,000 dam^3/year (113,500 ac-ft) were converted to constant flow rates of 0.47 m^3/s (17 cfs) and 4.4 m^3/s (155 cfs), respectively, and it was assumed that this water would be withdrawn from Big Quill Lake.

4.4.3 Pump and Discharge Water to another Watershed

The water level on the Quill Lakes could be reduced by actively pumping water to an adjacent drainage basin. Golder suggested that the best possible route for a pipeline is likely along the edge of the flat corridor running southwest of Big Quill Lake to Peter Lake and the Saline Creek drainage basin [1]. However, pumping water from Big Quill Lake into the Peter Lake and Saline Creek watershed will result in water with elevated TDS concentrations reaching Last Mountain Lake. As a result, it is likely that the Quill Lakes water will need to be treated prior to discharging it to another watershed and disposal options will need to be considered for the salt that is removed from the water.

This option was evaluated using two different potential outflow pumping rates. For consistency, the same flow rates considered for the deep well injection option were considered for this option: 0.47 m^3/s (17 cfs) and 4.4 m^3/s (155 cfs). It was assumed that water would constantly be pumped from Big Quill Lake, regardless of the lake level.

4.4.4 Withdraw Water for BHP Jansen Lake Mine

BHP Billiton is in the process of constructing a large potash mine just east of Jansen Lake. Production is slated to begin in approximately 2020 and the mine will require water for various daily processes.

BHP has indicated that the total annual requirement for the Jansen Lake Mine project is approximately 7,000 dam^3/year (5,700 ac-ft/year) at full production, representing a continuous demand of approximately 0.22 m^3/s (8 cfs). However, BHP is still several years away from operation and would likely gradually scale up their water use once the mine opens and they increase production. Further, the salinity of the Quill Lakes water will likely make it difficult to use the water for the various processes and purposes required by the mine, including boiler feed, metallurgy, sanitary, potable, irrigation, and fire suppression and may require treatment.

This option was modelled assuming a constant outflow from Big Quill Lake of 0.22 m^3/s (8 cfs), regardless of the water level on the Quill Lakes, as it would have to be an annual firm water demand. Additionally, it was assumed that the withdrawal of the full water demand (0.22 m^3/s or 8 cfs) begins immediately.

4.4.5 Withdraw Water for Karnalyte Potash Mine

Karnalyte Resources Inc. (Karnalyte) plans to begin construction on a new potash mine, the Wynyard Carnallite Project, in the fall of 2016. The mine will be located approximately 0.5 km (0.3 mi) south of Hwy 16 near the Town of Wynyard, SK.

Karnalyte indicated that the total annual requirement for the Carnallite Project is approximately 8000 dam^3/year (6,500 ac-ft/year) at full production, representing a continuous demand of approximately 0.28 m^3/s (10 cfs). However, Karnalyte has estimated that construction of the mine will take approximately 30 months and that the mine will be built in phases, with each phase increasing the capacity of the mine. Additionally, Karnalyte has indicated that they would be willing to accept the saline water from the Quill Lakes without treatment.

This option was modelled assuming a constant outflow from Big Quill Lake of 0.28 m^3/s (10 cfs) regardless of the water level on the Quill Lakes, as the mine has a firm water demand. Additionally, it was assumed that the withdrawal of the full water demand (0.28 m^3/s or 10 cfs) begins immediately.

4.5 INFLOW REDUCTION OPTIONS

The following two options were considered to reduce the inflow to the Quill Lakes:

1) **Restoration of partially drained and drained wetlands.** This option would be a program that would consist of restoring a pre-determined number of wetlands anywhere in the basin at locations that were strategically selected to obtain the highest benefit, and in agreement with stakeholders. Further details on this option are provided in Section 4.5.1.
2) **Closure of drainage works.** This option would consist of closing all illegal drainage works that have been constructed throughout the basin in the past several decades. Closures would be dictated by WSA over a longer period of time. Further details on this option are provided in Section 4.5.2.

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.

4.5.1 Restoration of Partially Drained and Drained Wetlands

Rather than choosing particular wetlands to restore and completing an analysis on individual wetlands, the effects of restoring two different volumes of wetlands, 5,000 dam^3 (4,100 ac-ft/year) and 15,000 dam^3 (12,200 ac-ft/year), were evaluated. It has been assumed that if WSA moves forward with this option, a sufficient number of suitable wetlands will be restored to meet either the 5,000 dam^3 (4,100 ac-ft/year) or 15,000 dam^3 (12,200 ac-ft/year) volume requirement.

The total wetland area restored is distributed between the different classes of wetland size based on the existing distribution from the wetland inventory for drained and partially drained wetlands. The distribution is shown in Table 5.

TABLE 5
WETLAND RESTORATION SUMMARY

Wetland Size Distribution Classes	Average Storage Volume Per Wetland (dam^3)	Average Depth Of Wetland (m)	5,000 Dam^3 Option			15,000 Dam^3 Option		
			Estimated Number of Wetlands	Area (ha)	Volume (dam^3)	Estimated Number of Wetlands	Area (ha)	Volume (dam^3)
Less than 0.1 ha not included	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
0.1 to 0.2 ha	0.3	0.19	431	65	122	1,292	195	367
0.2 to 0.4 ha	0.7	0.22	378	115	252	1,134	344	755
0.4 to 1.0 ha	1.9	0.26	262	185	489	785	556	1,468
1.0 to 2.0 ha	4.7	0.31	99	150	470	297	451	1,410
2.0 to 4.0 ha	11.0	0.36	54	165	601	163	496	1,804
4.0 to 10 ha	31.0	0.44	29	203	890	86	609	2,671
10 to 20 ha	78.7	0.52	9	133	687	26	398	2,062
20 to 40 ha	183	0.60	3	104	627	10	311	1,881
40 to 80 ha	427	0.70	1	58	405	3	173	1,214
80 to 120 ha	728	0.72	0.3	27	196	0.8	82	588
120 to 160 ha	1,016	0.72	0	0	0	0	0	0
Greater than 160 ha	1,303	0.72	0.2	36	260	0.6	109	780
Totals			1,266	1,241	5,000	3,799	3,724	15,000

Note: 1 m = 3.28 ft
1 dam^3 = 0.81 ac-ft
1 ha = 2.47 ac

Since only the flooded area of the wetlands was known, the storage volume was calculated using formulae derived as part of the Upper Assiniboine River Basin Study [9]. These formulae were assumed to produce reasonable approximations of wetland storage volumes in the Quill Lakes basin. For wetlands with surface areas less than 70 ha (170 ac), the storage volume was calculated as:

$$V = 2.85A^{1.22}$$

For wetlands with surface areas greater than 70 ha (170 ac), the storage volume was calculated as:

$$V = 7.1A + 9.97$$

Once the area and volume of the wetlands were known, the approximate depth of the wetland was calculated.

In order to model this option, it was assumed that all of the designated wetlands would be restored immediately and that the entire storage of wetlands would be available in the first year. It has been assumed that there would be sufficient inflow upstream of the wetlands to fill up the available storage each year. Following the first year, the available storage was calculated based on the difference between the evaporation and precipitation multiplied by the area of the wetlands, but was constrained to the depth of the wetland. The depth of evaporation and precipitation for the wetlands was assumed to be the same depth used in the Quill Lakes water balance model. The available storage was then subtracted from the total Quill Lakes inflow, and the remainder of the inflow would flow into the Quill Lakes.

4.5.2 Closure of Drainage Works

Agricultural drains have been constructed over the years throughout the Quill Lakes watershed. The drains tend to increase the peak flow in the spring and otherwise deliver some water to Quill Lake that might otherwise evaporate, contribute to soil moisture, or be taken up by plants. One flood mitigation option that was considered as part of the study is to manage or close the agricultural drains. Infilling drainage works would allow the wetland areas to store water and likely result in a reduction to the overall water volume reaching the Quill Lakes.

Wetland and drainage inventory coverage, shown in Plate 5, was only available for approximately 35% of the Quill Lakes watershed. In order to evaluate the inflow reduction options, the distribution of inventoried wetlands was projected over the remainder of the drainage basin, assuming that the distribution of wetland sizes and type (drained and partially drained) in the inventoried area was representative of the distribution over the entire basin. The resulting estimates of drained and partially drained wetland area, depth and volume are summarized in Table 6.

TABLE 6
CLOSURE OF DRAINAGE WORKS SUMMARY

Wetland Size Distribution Classes	Average Storage Volume per Wetland (dam^3)	Average Depth of Wetland (m)	Inventoried Wetlands		Total Quill Lakes Watershed		
			Total Area of Drained and Partially Drained Wetlands (ha)	Estimated Volume of Drained and Partially Drained Wetlands (dam^3)	Estimated Number of Wetlands	Estimated Total Area of Drained and Partially Drained Wetlands (ha)	Estimated Volume of Drained and Partially Drained Wetlands (dam^3)
less than 0.1 ha not included	n/a	n/a	n/a	n/a	n/a	n/a	n/a
0.1 to 0.2 ha	0.3	0.19	654	1,230	12,367	1,869	3,516
0.2 to 0.4 ha	0.7	0.22	1,154	2,529	10,859	3,296	7,226
0.4 to 1.0 ha	1.9	0.26	1,862	4,919	7,512	5,320	14,055
1.0 to 2.0 ha	4.7	0.31	1,512	4,724	2,847	4,321	13,498
2.0 to 4.0 ha	11.0	0.36	1,661	6,043	1,563	4,745	17,266
4.0 to 10 ha	31.0	0.44	2,041	8,948	823	5,831	25,565
10 to 20 ha	78.7	0.52	1,332	6,906	251	3,806	19,732
20 to 40 ha	183.3	0.60	1,043	6,301	98	2,981	18,002
40 to 80 ha	427.0	0.70	578	4,068	27	1,653	11,623
80 to 120 ha	728.3	0.72	274	1,970	8	7,82	5,629
120 to 160 ha	1015.6	0.72	0	0	0	0	0
Greater than 160 ha	1303.0	0.72	365	2,613	6	1,043	7,464
Totals			12,477	50,252	36,362	35,648	143,576

Note: 1 m = 3.28 ft
1 dam^3 = 0.81 ac-ft
1 ha = 2.47 ac

Since only the flooded area of the wetlands was known, the storage volume was calculated using formulae derived as part of the Upper Assiniboine River Basin Study [9] as discussed in Section 4.5.1.

This option was modelled assuming that the closures would occur over 30 years and that each year an additional 1/30th of the storage would be available. A shorter time period would increase the cumulative benefits of the closures. The wetlands were modelled as a single reservoir with no limitations on the upstream flow. In reality, the inflow to each individual wetland (and thus how much water is stored) would be limited by the size of the drainage area upstream of each wetland. Furthermore, it was assumed that prior to closing the drainage works (ie: the base case scenario), there would be no evaporation occurring over the drained and partially drained wetlands. It is likely, however, that evaporation would occur over these drained and partially drained wetlands for parts of the year while they gradually empty (partially or completely) due to the drainage works. These assumptions have likely contributed to an optimistic estimate of the inflow reduction benefits associated with this option. The actual benefits would be highly variable from year to year from perhaps significant in one year to next to nil in another year. For example, in dry cycles, the wetlands will have lower water levels allowing for a higher retention volume, with dryer atmospheric conditions for higher evaporation rates which creates larger storage volumes in the subsequent year. Conversely, in wet cycles, the wetlands will have higher water levels, potentially even being full of water with no ability to further store water. This combined with increased with increased frequency of precipitation and less evaporation potential would result in next to no ability to attenuate and store runoff in the subsequent year.

Simulations were started by assuming that the entire wetland storage volume would be available on the first year of closure. Following the first year, the available storage was calculated based on the difference between the evaporation and precipitation calculations multiplied by the area of the wetlands, but was constrained to the depth of the wetland. The depth of evaporation and precipitation for the wetlands was assumed to be the same depth used in the Quill Lakes water balance model. Finally, it was assumed that there would be sufficient inflow upstream of the wetlands to fill the available storage every year. The available storage was then subtracted from the total Quill Lakes inflow, and the remainder of the inflow would flow into the Quill Lakes.

4.6 LEGISLATIVE POLICY OPTIONS

Several legislative policy options for flood mitigation on the Quill Lakes were considered. These options are policy, rather than project, orientated and were therefore not formally modelled. Furthermore, WSA has not yet formed detailed policies or operating rules for each option, resulting in some uncertainty in how much money and manpower may be dedicated to them. As a result, it is difficult to quantify the effects that these policies would have on the lake levels, and also difficult to develop a high level cost estimate for each. Rather, a brief description of each option is provided below.

4.6.1 Drainage Enforcement

Over the past several decades, it is likely that many agricultural drains have been constructed by landowners to drain farmland and produce more crops. Over time, the construction of these drains has possibly led to increased inflows to the Quill Lakes and contributed to higher peak water levels. Closing the drains would re-establish some natural storage on the land around the Quill Lakes and likely lead to more evaporation and reduced inflows to the lakes. Implementing a drainage enforcement policy would likely yield similar results as the Closure of Drainage Works option detailed in Section 4.5.2. WSA has indicated that the landowner would be responsible for constructing ditch closures.

This flood mitigation option would require government officials to monitor and enforce drainage within the Quill Lakes basin. The effectiveness of this policy will be largely dictated by the number of officials that are assigned to monitor drainage concerns and how quickly drains can be closed.

4.6.2 Invoke Drainage Moratorium

In order to mitigate flooding on the Quill Lakes, WSA could invoke a drainage moratorium within the Quill Lakes basin. This would entail prohibiting the construction of any new drainage systems that could further exacerbate flood concerns. Similar to the Drainage Enforcement option, government officials would be required to monitor the basin to ensure that the moratorium was being followed. Again, the effectiveness of this policy will be largely dictated by the number of officials that are assigned to monitor the moratorium and how quickly issues can be identified and addressed. Furthermore, a drainage moratorium would not address the effects of illegal drainage works that have occurred in the past, nor would it address existing flooding problems on the Quill Lakes.

4.6.3 Develop Watershed Management Policy and Working Group

This flood mitigation option involves developing a group to oversee and plan drainage and retention projects that would be in the best interest of the entire basin. A watershed management policy would be developed cooperatively by government and stakeholders, defining specific goals and outlining actions to manage land, water, and related resources within the watershed. It is likely that government officials will be required to enforce the watershed management policy. The effectiveness of this flood mitigation option would depend on the actions defined by the working group and would likely take many years before they would be implemented.

4.6.4 Responsible Drainage

WSA has considered implementing a Responsible Drainage program within the Quill Lakes basin. Although no formal rules or procedures have been developed, the program would generally entail implementing a land-owner to land-owner flood mitigation approach that would address impacts and overcome, in a reasonable manner, the effects that drainage has caused in the basin. Policies would be set to define the terms of the program and to determine when and if land owners qualify.