Saskatchewan
Watershed
Authority

Agricultural Drainage Impacts on Fishing and Waldsea Lakes

Saskatchewan Watershed Authority

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1.0 Introduction

1.1 Background to Flooding Issue

In the spring of 2007, numerous lakes and streams across central and eastern Saskatchewan experienced high levels and flows. For terminal lakes such as Waldsea, and near-terminal lakes such as Deadmoose, Houghton, and Fishing lakes, this marked the continuation of high inflows that had begun with above normal rainfalls in the fall of 2005. Other lakes that have been affected by this same weather pattern include Duck, Big Quill, Humboldt and Wolverine lakes.

At Waldsea and Fishing lakes, a large number of seasonal and permanent homes were affected by the high lake levels in 2007. These homes were either flooded or at risk of flooding. In response to the 2007 flooding on these lakes, the Government of Saskatchewan committed to providing emergency flood berms, developing long-term flood proofing plans for the affected cottage areas, and a review of the impact of agricultural drainage on the lake water levels.

As of September 2008, the emergency berms are in place and long-term flood mitigation planning is underway. A technical report on the number, size and location of drained wetlands in the Waldsea, Deadmoose, Houghton and Fishing lake watersheds has been completed. This report builds on the technical report by examining the impact of wetland drainage on Fishing and Waldsea lake levels.

1.2 Response of Closed and Semi-Closed Basin Lakes to Drainage

Fully enclosed terminal lakes, such as Waldsea Lake, have no recorded or historic instances of outflow in the current climatic regime. Generally, their outlet level is well above the observed range of water levels. Hydrologically, these lakes have a long-term memory in that successive years of high runoff and/or low evaporation cumulate into rising levels. Conversely, successive low runoff years and/or high evaporation years result in declining water levels. Thus, the water level at any time reflects the cumulative balance over time between inflows into the lake and outflow due to evaporation. Inflows are made up of surface runoff, any ground water contribution, and rain and snow falling directly onto the lake surface. Any systematic shift in any of the components of the lake water balance will result in an upward or downward trend in lake levels until a new dynamic equilibrium is established between inflow and evaporation.

The response of semi-closed basin lakes, such as Fishing Lake, is similar to that of fully enclosed lakes, except that once the overflow level is reached, the lake will discharge surplus water via its outlet in addition to evaporation. During periods when a semi-closed lake is at or above its overflow level, it behaves as a normal lake and the maximum flood level of the lake is governed by the discharge capacity of the outlet relative to the inflow and the area of the lake.

Wetland drainage in a closed or semi-closed basin has the effect of systematically shifting the water balance of the lake. Surface water inflows to the lake will be increased. In response, the average lake level will rise. As the lake level rises, the surface area of the lake will also increase, thus also increasing the amount of water lost to evaporation. The average lake level will increase until the lake surface area has increased sufficiently to evaporate the additional inflow due to drainage. In the case of a semi-closed lake, the upward shift in water levels may increase the frequency that the overflow level is reached and increase the volume of water that is passed downstream once that overflow level is reached.

1.3 Other Factors that Influence Lake Levels

Changes in other components of the water balance of a closed or semi-closed lake can also result in upward or downward shifts in water levels. For example, consumptive water use projects such as irrigation, industrial or municipal water use will reduce flows into the lake. Climatic shifts to warmer and/or drier conditions will reduce levels both by reducing runoff and by increasing evaporation. Conversely, climate shifts to cooler and/or wetter conditions will increase levels by increasing runoff and reducing evaporation.

Ground water inflows (or outflows) to a closed or semi-closed basin are often unknown, and may change over time in response to a number of factors including seasonal and climatic variability, ground water use, and lake water levels.

Finally, changes in land cover and farming practices across the watershed can also impact runoff rates from the land surface. For example, the shift to conservation tillage and zero-till will tend to reduce surface runoff in the long-term by increasing soil infiltration capacity. Conversion of cropped land into permanent cover will also tend to reduce surface runoff.

2.0 Fishing Lake

2.1 Impact of Agricultural Drainage on Fishing Lake

2.1.1 Extent of Drainage, Size and Number of Wetlands, Increase in Effective Area

The drainage assessment report identified 2,640 wetlands impacted by drainage works with a cumulative surface area of 1,526 hectares (ha) and estimated volume of 5,860 cubic decametres (dam^3). By comparison, the normal surface area of Fishing Lake is 3,310 ha, a little more than twice the size of the total impacted wetland area. The report found the original effective area of Fishing Lake to be 304.7 square kilometres (km^2). The current effective drainage area with agricultural drainage is 430.6 km^2, an increase of 125.9 km^2 or 41%. The gross drainage area is 620.5 km^2.

The following two charts show the cumulative wetland area in the Fishing Lake watershed starting with the largest impact wetlands and proceeding to the smallest. The second chart in particular shows for instance that the largest 10% of wetlands account for 65% of the impacted wetland area, and that the largest 20% of wetlands account for close to 80% of the wetland area. Another observation is that the smallest 60% of the wetlands together only account for 10% of the total wetland area.

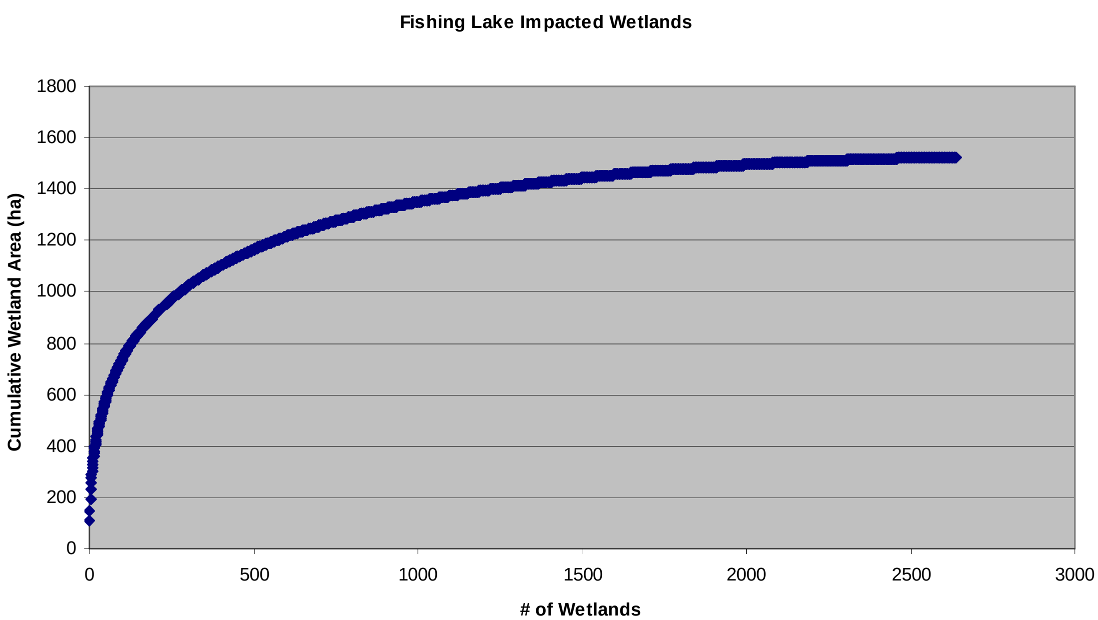

Figure 1: Fishing Lake Impacted Wetlands (by Hectare)

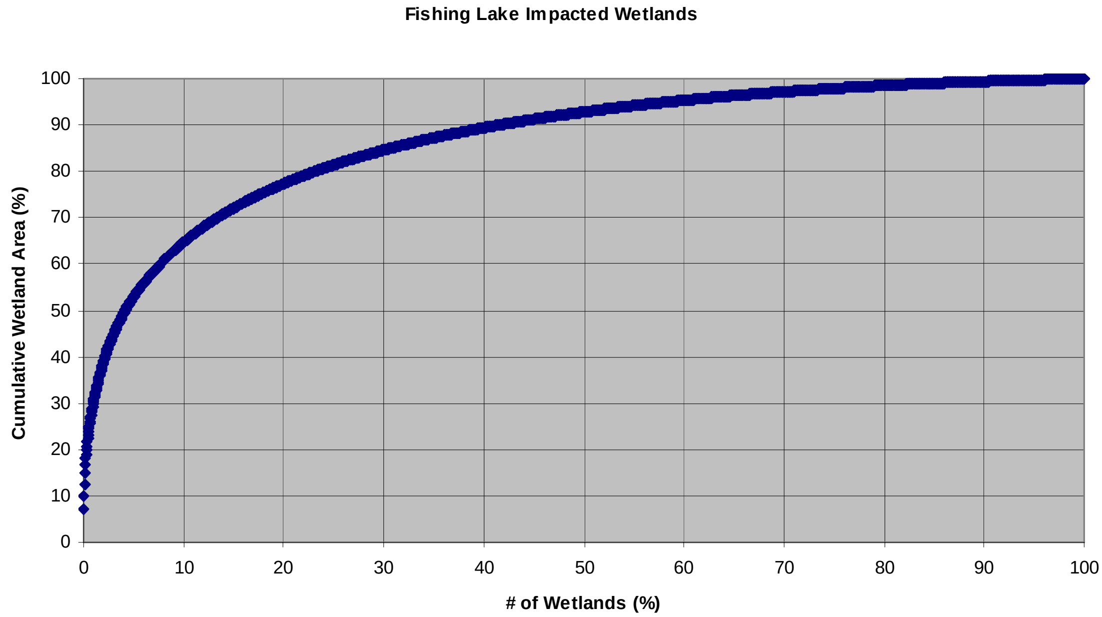

Figure 2: Fishing Lake Impacted Wetlands (by Percent)

2.1.2 Impact of Current Drainage on Fishing Lake Inflow Volumes

The development of artificial drainage networks to drain wetlands impacts watershed hydrology in a number of ways. In the methodology used to assess the impact of drainage on volumes of water passed downstream that would otherwise remain in the wetland, two mechanisms were considered. One mechanism was the increase in drainage area contributing to the downstream lake. The second mechanism was the net reduction in evaporation loss from the drained wetlands.

Table 1 below lists the estimated inflow volumes under both the current drainage conditions and an undrained condition, and lists the absolute and relative difference in inflow volumes for inflow events ranging from the median event (1:2) up to the 1:100 event. The greatest relative impact at 50% for the median event represents the type of year with largest difference in contributing drainage area between the current condition and the undrained condition and the greatest difference in net evaporation reduction. With higher runoff events, the difference in both these mechanisms diminishes and so the relative difference in inflow volume also diminishes.

The absolute differences in inflows shown in the fourth column of Table 1 at first increase with increasing inflows, then reach a maximum at around the 1:25 event. The differences diminish for the higher events as the difference in contributing drainage area converges, and as the net evaporation loss effect is reduced in wetter years as well.

Table 1: Fishing Lake Inflow Volume Frequency

Return Period	Inflow Volume without Drainage (dam^3)	Inflow Volume under Current Conditions (dam^3)	Change in Inflow (dam^3)	% Change in Inflow
1:2	5,480	8,200	2,720	+50%
1:5	13,000	16,500	3,500	+27%
1:10	18,100	22,300	4,200	+23%
1:25	27,600	32,000	4,400	+16%
1:50	36,000	40,000	4,000	+11%
1:100	44,300	48,000	3,700	+ 8%

2.1.3 Impact of Current Drainage on Peak Water Levels

The increase in volume flowing into Fishing Lake will result in increased peak water levels given the same starting elevation. Two cases were examined. The first had a starting elevation of 528.5 metres (m), which represents a typical lake level and is not associated with either flooding concerns, or low water issues. As shown in the table below, the incremental change in water levels ranges between eight centimetres (cm) and 13 cm with the maximum impact around the 1:10 event. One factor in this is that the Change in Inflow (Table 1) is at a maximum at the 1:25 event. The other factor is that as the lake level gets higher, its storage capacity increases. Thus, more water is required to raise the lake by one centimetre at elevation 529.50 m than at 528.50 m.

Table 2: Fishing Lake Peak Water Levels with Starting Elevation of 528.5 m

Return Period	Peak Water Level with No Drainage (m)	Peak Water Level with Current Drainage (m)	Incremental Increase in Water Level Due to Drainage (cm)
1:2	528.67	528.75	8
1:5	528.89	529.00	11
1:10	529.05	529.18	13
1:25	529.32	529.44	12
1:50	529.55	529.66	11
1:100	529.78	529.88	10

The second case examined used a starting elevation of 529.8 m. This is just above the Fishing Lake overflow elevation of 529.74 m and is the starting elevation used in calculating the Estimated Peak Water Level for the lake. Comparison of Tables 2 and 3 will show that the water level increase over the starting elevation is less in Table 3 than the corresponding increase in Table 2. This is because of the increased lake storage capacity at the higher starting elevation.

Table 3: Fishing Lake Peak Water Levels with Starting Elevation of 529.8 m

Return Period	Peak Water Level with No Drainage (m)	Peak Water Level with Current Drainage (m)	Incremental Increase in Water Level Due to Drainage (cm)
1:2	529.95	530.03	8
1:5	530.15	530.24	9
1:10	530.28	530.38	10
1:25	530.51	530.61	10
1:50	530.70	530.78	8
1:100	530.88	530.96	8

2.1.4 Impact of Current Drainage on the Estimated Peak Water Level (EPWL)

Table 3 above shows that for the 1:100 inflow event, there is an eight centimetre difference due to the influence of drainage. This assumes that in either case, with or without drainage, the starting elevation would be 529.8 m. This is a reasonable assumption given the outlet elevation of 529.74 m, historic evidence of lake levels exceeding the outflow elevation in the 1920s, and commonly observed water level increases over the winter.

For the Estimated Peak Water Level calculation, a 1:100 calm level of 530.90 m was used in recognition that some outflow and evaporation would occur prior to the lake reaching the peak level. The peak water levels in Table 3 have not been adjusted for outflow and evaporation. If outflow and evaporation effects were included in the Table 3 calculations, the incremental increase in water level due to drainage for the 1:100 event would be less than eight centimetres.

2.1.5 Impact of Drainage on 2007 Peak Water Level

The total impact of drainage on the peak water level observed in 2007 of 530.60 m has not been determined. To do so would require a simulation of inflows, outflows, and evaporation starting in at least 1964 and perhaps as early as the 1920s and running through to 2007. In each year of the simulation, an estimate would have to be made of the inflow volume without drainage. To do so requires the level of wetland drainage to be estimated in each year and the observed inflow volume adjusted for the drainage volume effect.

It can be said based on the results in Table 3 that the impact of the 2007 runoff was less than eight centimetres. However, this is likely small relative to the cumulative impact of drainage since at least 1964 when water levels first started being collected.

2.1.6 Impact of Drainage on Frequency of Outflow and Outflow Volume

A simulation of Fishing Lake water levels has been made going back to 1910 (Figure 3). Inflow estimates prior to 1964 were originally based on regional streamflow records transferred to the Fishing Lake watershed. The inflows and evaporation were then adjusted so that the simulated levels reasonably matched the observed water levels in the mid-1960s. From the mid-60s on, the inflows were adjusted to closely match the observed water levels. Thus, the simulated levels do not reflect either the current level of drainage in the watershed or a condition of no drainage. Rather, they reflect the increasing level of drainage since at least 1964.

Nevertheless, some comments can be made on the frequency and volume of outflow from Fishing Lake:

- Outflow occurs only following and during a series of high inflow, low evaporation years. The early 1910s, the 1920s, the 1950s, the mid-1970s, the mid-1990s and the recent several years represent such periods. Thus, there have been six sequences of high years over the past century. In four of those six sequences, levels have reached and/or exceeded the overflow level of 529.74 m.
- Significant outflow volumes have occurred during three of the six sequences of high flow years; the early 1910s, the 1920s, and the recent several years.
- The outflow volume in 2007 is roughly estimated to have been between 25,000 dam^3 and 30,000 dam^3.
- The outflow volume in 1997 was not significant.
- It is most likely that Fishing Lake would not have reached the outflow level in 1997 without the cumulative additional water due to wetland drainage.
- With drainage, the lake has exceeded the overflow level for four sequences over the past century, with three of those occurrences having significant outflow volume.
- Without drainage, the lake would still have exceeded the overflow level in at least two, and perhaps three, but not four sequences over the past century, and in only two of those occasions would there have been significant outflow volumes.
- Barring other hydrologic influences in the watershed such as climate change and land use change, the level of Fishing Lake will tend to be higher if current drainage conditions persist than the levels experienced prior to drainage development. This will mean increased frequency of sequences of years at or above the overflow level. It will also mean the reduced likelihood of water levels as low as seen in the early 1960s and simulated in the 1940s.

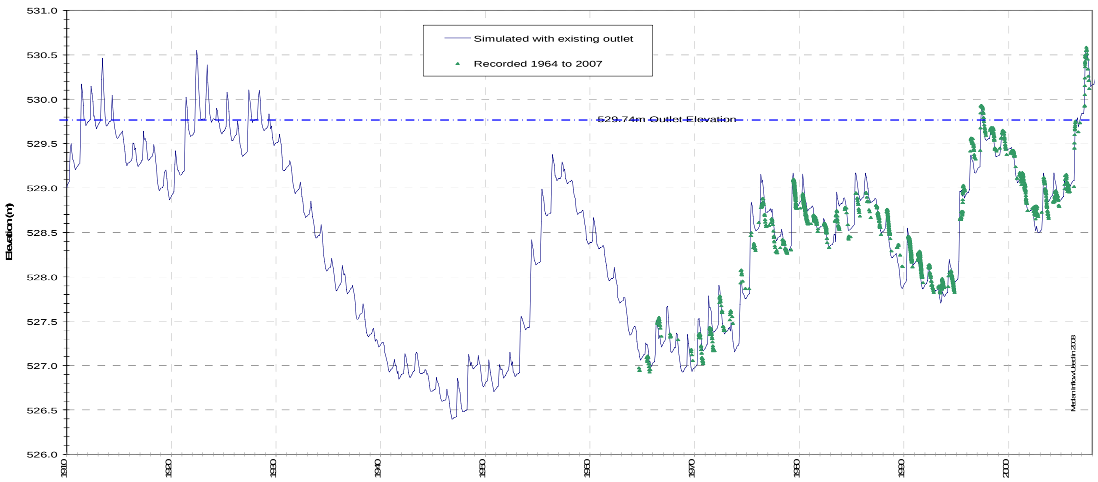

Figure 3: Simulated and Recorded Fishing Lake Levels

2.2 Comment on Wetland Mitigation Options in the Fishing Lake Watershed.

Mitigation options can be considered to fall into four broad categories:

- Accept current level of impact,
- Mitigate impacts,
- Restore wetlands to natural, and
- Restore wetlands with controlled outlets

Acceptance of the current level of impact is not acceptable to property owners around the lake, nor to the Government of Saskatchewan. As discussed in the introduction, emergency actions have been taken to mitigate the immediate flood threat to property around Fishing Lake, and long-term options are being identified and evaluated.

Current efforts at Fishing Lake have focused on mitigating the flood damage impact around Fishing Lake caused by a series of high runoff years and exacerbated by additional inflow volume due to wetland drainage. Long-term options for mitigation of inflow volumes due to drainage will also need to consider water quality implications, and impacts on aquatic ecology in the lake and downstream.

The option of restoring drained wetlands to their natural condition would obviously mitigate the impact of drainage. This implies permanent closure of the outlet ditches and restoration of the wetland outlet to its natural spill level. However, it is likely not possible to restore all wetlands. For a restoration program to be most effective in reducing drainage volumes, the wetlands with the largest surface areas should be targeted first. The ideal targets should be larger wetlands that command a significant drainage area. The 2007 imagery and subsequent mapping of wetlands impacted by drainage should be of great assistance should this option be pursued. As well, the methodology developed to assess the volume impact of wetland drainage could be used to assess the potential benefit of restoration of each wetland considered. While this option would have many benefits, a disbenefit is the increased possibility that Fishing Lake levels may again approach the lows seen in the early 1960s and simulated in the 1940s.

The option of restoring wetlands using controllable outlet works would provide many of the mitigation benefits of permanent restoration, but would add the ability to let water out of the wetlands when desirable to do so. From the perspective of lake level management, it may be desirable to allow water to be released from wetlands when lake levels are below a desired range. The complicating factor of this option over the permanent closure option would be to work out acceptable operating rules for the works and then ensure continued compliance to those rules over long-term hydrologic cycles.

3.0 Waldsea Lake

3.1 Impact of Agricultural Drainage on Waldsea Lake

3.1.1 Extent of Drainage, Size and Number of Wetlands, Increase in Effective Area

The Prairie Farm Rehabilitation Administration (PFRA) lists the effective drainage area for Waldsea Lake as 42.9 km^2. The current effective drainage area is 67.1 km^2 due to projects and drainage works in the watershed, an increase of 24.2 km^2, or 56.4%. The Waldsea Lake watershed has a gross drainage area of 208.6 km^2, of which 92.2 km^2 is landlocked.

The analysis of the Waldsea Lake watershed identified 363 wetlands potentially impacted by drainage works with a cumulative surface area of 129.5 ha and an estimated volume of 371 dam^3.

The following two charts show the cumulative wetland area in the Waldsea Lake watershed, starting with the largest impact wetlands and proceeding to the smallest. The second chart in particular shows for instance that the largest 10% of wetlands account for 50% of the impacted wetland area, and that the largest 20% of wetlands account close to 70% of the wetland area. Another observation is that the smallest 50% of the wetlands together only account for 10% of the wetland area.

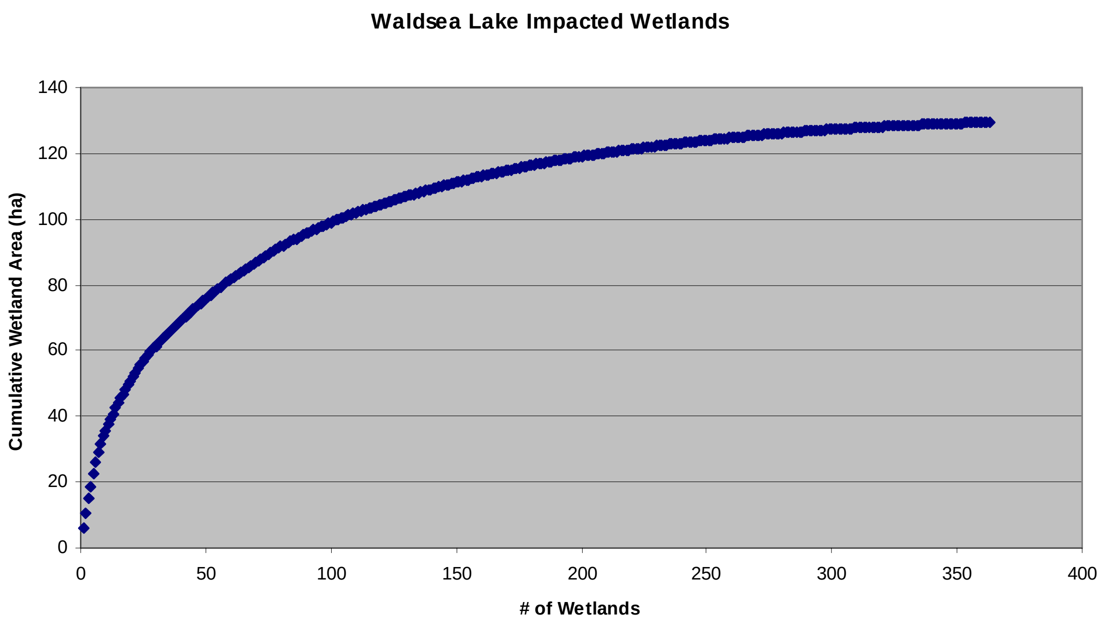

Figure 4: Waldsea Lake Impacted Wetlands (by Hectare)

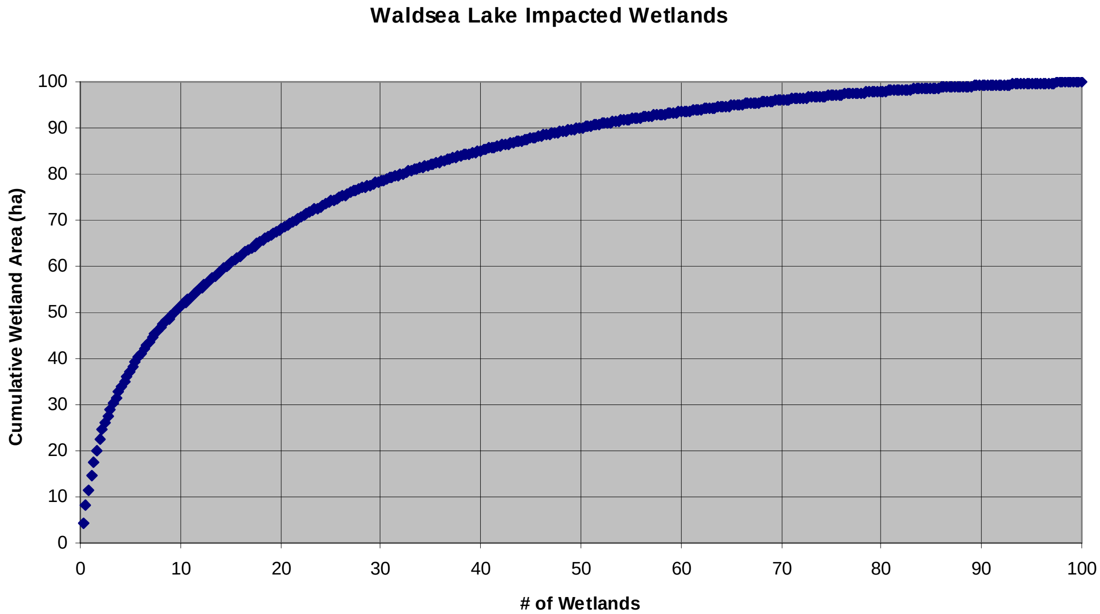

Figure 5: Waldsea Lake Impacted Wetlands (by Percent)

3.1.2 Impact of Current Drainage on Waldsea Lake

The development of artificial drainage networks to drain wetlands impacts watershed hydrology in a number of ways. In the methodology used to assess the impact of drainage on volumes of water passed downstream that would otherwise remain in the wetland, two mechanisms were considered. One mechanism was the increase in drainage area contributing to the downstream lake. The second mechanism was the net reduction in evaporation loss from the drained wetlands.

Table 4 lists the estimated inflow volumes under both the current drainage conditions and an undrained condition, and lists the absolute and relative difference in inflow volumes for inflow events ranging from the median event (1:2) up to the 1:100 event. The greatest relative impact at about 80% for the median event represents the type of year with largest difference in contributing drainage area between the current condition and the undrained condition and the greatest difference in net evaporation reduction. With higher runoff events, the difference in both these mechanism diminishes and so the relative difference in inflow volume also diminishes.

The absolute differences in inflows shown in the fourth column of Table 4 at first increase with increasing inflows, then reach a maximum at around the 1:10 event. The differences diminish for the higher events as the difference in contributing drainage area converges, and as the net evaporation loss effect is reduced in wetter years as well.

Table 4: Waldsea Lake Inflow Volume Frequency

Return Period	Inflow Volume without Drainage (dam^3)	Inflow Volume under Current Conditions (dam^3)	Change in Inflow (dam^3)	% Change in Inflow
1:2	800	1,450	650	+81%
1:5	2,060	2,800	740	+36%
1:10	3,030	3,800	770	+25%
1:25	4,300	5,000	700	+16%
1:50	5,390	6,000	610	+11%
1:100	6,650	7,200	550	+ 8%

3.1.3 Impact of Current Drainage on Peak Water Levels

The increase in volume flowing into Waldsea Lake will result in increased peak water levels given the same starting elevation. The effect of the difference in inflow volume on water levels was examined using a starting elevation of 532.5 m, which represents a typical lake level and is not associated with either flooding concerns, or low water issues. As shown in the table below, the incremental change in water levels ranges between 13 cm and 17 cm with the maximum impact around the 1:5 and 1:10 events. One factor in this the Change in Inflow (Table 4 above) is at a maximum at the 1:10 event.

Table 5: Waldsea Lake Peak Water Levels with Starting Elevation of 532.5 m

Return Period	Peak Water Level with No Drainage (m)	Peak Water Level with Current Drainage (m)	Incremental Increase in Water Level Due to Drainage (cm)
1:2	532.68	532.83	15
1:5	532.97	533.14	17
1:10	533.20	533.37	17
1:25	533.49	533.65	16
1:50	533.74	533.88	14
1:100	534.03	534.16	13

3.1.4 Effect of Closing Brockman Slough Diversion into Waldsea Lake

Between 1967 and 1997, an additional 25.9 km^2 were contributing to Waldsea Lake through the Brockman Slough diversion ditch constructed by the Waldsea Lake Regional Park. That ditch had been constructed in response to perceived low water levels through the early and mid 1960s. Under natural conditions, Brockman Slough overflows to Deadmoose Lake.

In 1999, a hydrology study of Waldsea Lake was completed by SaskWater which investigated probable causes of high water levels experienced in 1996-97. While above normal precipitation from 1991 through 1997 was the most direct cause, the report also found that three identifiable projects increased the water levels by 2.5 m. The diversion of Brockman Slough outflow from the Deadmoose Lake watershed into Waldsea Lake starting in 1967 was found to have raised Waldsea Lake by a cumulative effect of 2.0 m by 1997 over what would have occurred without the diversion. The permanent closure of the Brockman Slough diversion should result in a gradual reduction in average water levels by up to 2 m.

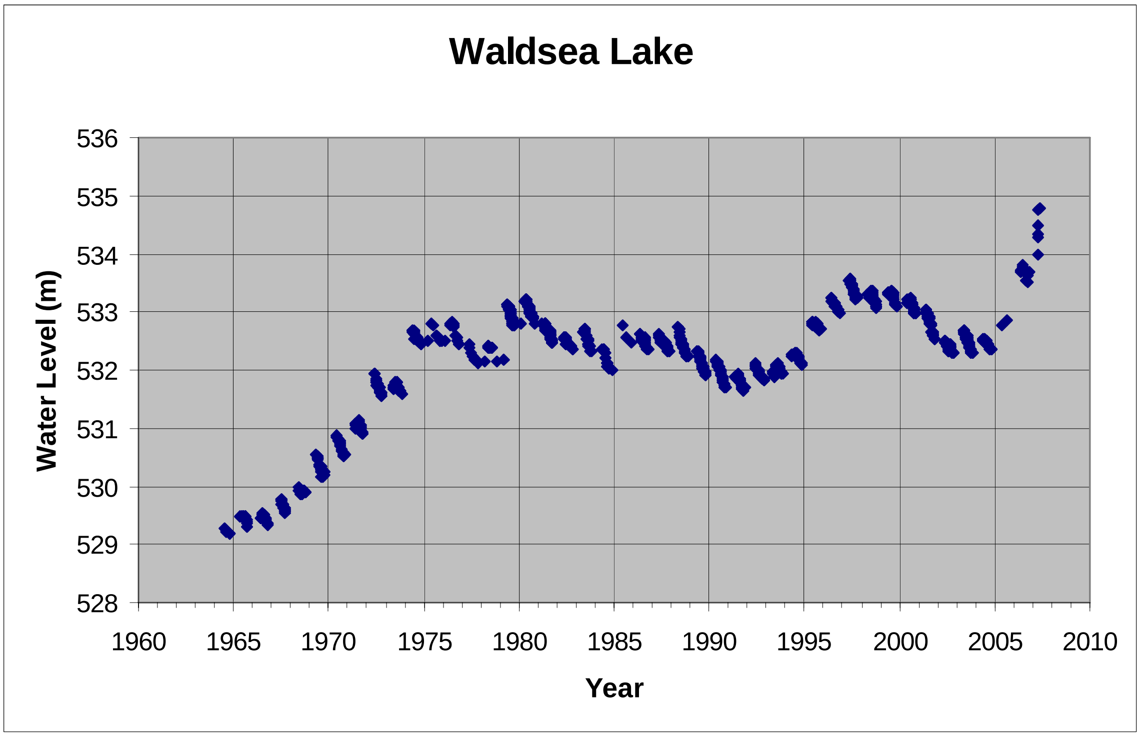

Figure 6: Simulated and Recorded Waldsea Lake Levels

3.2 Comment on Wetland Mitigation Options in the Waldsea Lake Watershed

Mitigation options can be considered to fall into four broad categories:

- Accept current level of impact,
- Mitigate impacts,
- Restore wetlands to natural, and
- Restore wetlands with controlled outlets.

Consideration of any mitigation option discussed below should be tempered by the expectation that Waldsea Lake levels over the long-term should decline with the permanent closure of the diversion from Brockman Slough. As stated earlier, the permanent closure of the Brockman

Slough diversion should result in a gradual reduction in average water levels by up to 2 m. However, the time scale for this effect is likely in the order of decades rather than years.

Acceptance of the current level of impact is not acceptable to property owners around Waldsea Lake, nor to the Government of Saskatchewan. As discussed in the introduction, emergency actions have been taken to mitigate the immediate flood threat to property around Waldsea Lake, and long-term options are being identified and evaluated.

Current efforts at Waldsea Lake have focused on mitigating the flood damage impact around Waldsea Lake caused by a series of high runoff years and exacerbated by additional inflow volume due to wetland drainage. Long-term options for mitigation of inflow volumes due to drainage will also need to consider water quality implications, and impacts on aquatic ecology in the lake.

The option of restoring drained wetlands to their natural condition would obviously mitigate the impact of drainage. This implies permanent closure of the outlet ditches and restoration of the wetland outlet to its natural spill level. However, it is likely not possible to restore all wetlands. For a restoration program to be most effective in reducing drainage volumes, the wetlands with the largest surface areas should be targeted first. The ideal targets should be larger wetlands that command a significant drainage area. The 2007 imagery and subsequent mapping of wetlands impacted by drainage should be of great assistance should this option be pursued. As well, the methodology developed to assess the volume impact of wetland drainage could be used to assess the potential benefit of restoration of each wetland considered. While this option would have many benefits, a disbenefit is the increased possibility that Waldsea Lake levels may again approach the lows seen in the early 1960s.

The option of restoring wetlands using controllable outlet works would provide many of the mitigation benefits of permanent restoration but would add the ability to let water out of the wetlands when desirable to do so. From the perspective of lake level management, it may be desirable to allow water to be released from wetlands when lake levels are below a desired range. The complicating factor of this option over the permanent closure option would be to work out acceptable operating rules for the works and then ensure continued compliance to those rules over long-term hydrologic cycles.