State of Lake Diefenbaker

Prepared for:
Consultation Meeting on
Document was edited and revised on October 19, 2012
Executive Summary
The purpose of this report is to provide the stakeholders with some context of the South Saskatchewan River project, the management issues associated with the operation of the Gardiner and Qu’Appelle River Dams, and the health of Lake Diefenbaker and the Lake Diefenbaker Watershed. This report summarizes the management activities associated with the operation of the South Saskatchewan River Project and the potential outcomes related to these management activities. Information within this report provides a basis for evaluating the management objectives and setting priorities for the operation of the Project. Table 1 outlines the various reservoir management activities and the resulting consequences of these activities.

The South Saskatchewan River Project, of which Lake Diefenbaker and the Gardiner and Qu’Appelle River Dams are the primary components, is a critical water resource for the province of Saskatchewan. The South Saskatchewan River Project is currently owned and managed by the Water Security Agency of Saskatchewan for multiple services, including irrigation, municipal and industrial water supply, hydroelectric power generation, recreation, aquatic and wildlife habitat, and downstream flood control. The services provided by the Project are fundamental to the province’s economic, social and environmental well being.

Lake Diefenbaker construction started after an agreement between the province of Saskatchewan and the Government of Canada, which was signed in 1958. The initial purpose of the project was to form a reservoir that could provide source water to irrigate approximately 200,000 hectares of farmland in central Saskatchewan and the Qu’Appelle Valley. Other benefits from the reservoir formation included: a source of hydroelectric power generation that produced a minimum operating head of 200,000 horsepower; water for municipalities and industry; flood control; and recreation (Prairie Farm Rehabilitation Administration 1980). The operation of the reservoir continues to be based on the 1958 agreement. Lake Diefenbaker was envisioned to fill annually, reserving water for future irrigation and hydroelectric generation purposes. Table 1 outlines the various reservoir management activities and the resulting consequences of these activities.
Table 1. Management activities and potential issues associated with the operation of the South Saskatchewan River Project.

<table>
<thead>
<tr>
<th>Management activities</th>
<th>Corresponding Management issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir water level</td>
<td>Managed for multiple purposes, requires tradeoffs between conflicting management objectives.</td>
</tr>
<tr>
<td></td>
<td><strong>High water levels</strong> - benefit hydropower production, irrigation, water diversions, and boaters. However, high water levels reduce the potential for downstream flood mitigation and reduce the reservoir’s beach habitat used by the endangered Piping Plovers and recreational users.</td>
</tr>
<tr>
<td></td>
<td><strong>Low water levels</strong> – provide downstream flood protection benefits, provide more beach area along the reservoir for recreation and increased nesting habitat utilized by the Piping Plovers. However, low water levels may limit the water supply for irrigation, industry and municipal use and reduce the amount of hydropower produced.</td>
</tr>
<tr>
<td>Downstream flows</td>
<td>Managed for multiple purposes, requires tradeoffs between conflicting management objectives.</td>
</tr>
<tr>
<td></td>
<td><strong>High flows</strong> – increased downstream erosion potential within the first few kilometres of Gardiner Dam and flooding of downstream agricultural land. Under high extreme flows low lying areas within Saskatoon could also flood.</td>
</tr>
<tr>
<td></td>
<td><strong>Low flows</strong> – a minimum discharge requirement from Lake Diefenbaker of 42.5 m$^3$/s has been established. However, this discharge rate may be insufficient to meet the downstream needs for irrigation, municipal and industrial water requirements and instream flow needs.</td>
</tr>
<tr>
<td>Flow regulation</td>
<td>Optimization of hydroelectric generation results in downstream river flows that are modified compared to unregulated rivers.</td>
</tr>
<tr>
<td>Diversion of flows from the South Saskatchewan River</td>
<td>Water diversion from the South Saskatchewan River system within Saskatchewan, currently includes diversions to the Qu'Appelle River and the Saskatoon South East Water Supply System, and has the potential for additional diversions to proposed potash and irrigation developments.</td>
</tr>
<tr>
<td></td>
<td>There is potential that in drought years the low water supply may not meet all of the water diversion demands.</td>
</tr>
<tr>
<td>Flood Protection Benefits: Spilling of water through the Gardiner Dam Spillway</td>
<td>Lake Diefenbaker was designed to fill annually, reserving water for future irrigation and hydroelectric generation purposes. Lake Diefenbaker can and does provide some additional benefits, such as flood protection, because even when full, it does reduce downstream peak flow rates during large runoff events.</td>
</tr>
<tr>
<td></td>
<td>The spilling of water through the Gardiner Dam Spillway results in a loss of Hydroelectric potential revenue; increases the downstream flow and erosion of adjacent land; and can cause impacts to downstream recreational use.</td>
</tr>
</tbody>
</table>
Aquatic Ecosystem Health of Lake Diefenbaker

From the review of available data for Lake Diefenbaker few data were found to draw robust conclusions about the ecological health status of Lake Diefenbaker. It was apparent that few historical studies and little historical water quality and benthic invertebrate data have been collected from the lake. A water quality study on Lake Diefenbaker and the upper South Saskatchewan River conducted between 1984 and 1985 found the quality of these water bodies satisfactory for present and foreseeable uses and the nutrient level and productivity (trophic status) to range from moderate nutrient levels (mesotrophic) to low nutrients levels (oligotrophic). Recommendations from this report focused around the monitoring of total phosphorus loading into Lake Diefenbaker (Saskatchewan Environment and Public Safety and Environment Canada 1988). The study found that the mean annual total phosphorus load between 1975 and 1985 was 1229 tonnes (Saskatchewan Environment and Public Safety and Environment Canada 1988), although more recent studies have suggested loading values close to 500 tonnes (Parker 2010). In the fall of 2009 the Water Security Agency initiated a water quality monitoring program on Lake Diefenbaker and in the spring of 2011 the Global Institute for Water Security initiated a detailed water quality study of Lake Diefenbaker. Given the short time-frame that these water quality monitoring programs have been operating, recent water quality data of Lake Diefenbaker is available, but has not been interpreted. Recent localized benthic invertebrate data were collected and analyzed by Fisheries and Oceans Canada in relation to an application by Wild West Steelhead, a fish aquaculture company, for a new trout aquaculture site in Lake Diefenbaker (Sweeney International Management Corp. and SIMCorp Marine Environmental Inc. 2010). No recent lake-wide benthic macroinvertebrate assessments have been collected. Therefore, due to the limited amount of recent and historical data collected on Lake Diefenbaker, we were unfortunately unable to conduct a meaningful aquatic health assessment of Lake Diefenbaker. See Appendix A for a more detailed discussion of the aquatic ecosystem health of Lake Diefenbaker.

The health of all of the six Canadian sub-watersheds of the Lake Diefenbaker Watershed were assessed, as 98% of the water that flows into Lake Diefenbaker originates in Alberta. The health of Lake Diefenbaker can be influenced by activities occurring within the watershed. The flow of water does not stop at political boundaries and the action or change in resource use in one location has the potential to influence the health within another area of the watershed.

The Lake Diefenbaker Watershed

The Lake Diefenbaker Watershed originates in the Rocky Mountains and extends across the prairie ecozone. It has a gross drainage area of approximately 14,760,000 hectares. The watershed is comprised of seven primary sub-watersheds that drain ground water and surface water from Montana, Alberta, and Saskatchewan, to Lake Diefenbaker. Nearly 80 percent of the Lake Diefenbaker watershed lies within Alberta, 20 percent in Saskatchewan, and one percent in Montana (Figure 1). The seven sub-watersheds that comprise the Lake Diefenbaker Watershed
include the St. Mary River (found in MT), the Oldman River (found in AB), the Bow River (found in AB), the Red Deer River (found in AB), the Alberta portion of the South Saskatchewan River (found in AB), the Saskatchewan portion of the South Saskatchewan River (found in SK), and the Swift Current Creek (found in SK) Sub-watersheds (Figure 1).

Figure 1. The Lake Diefenbaker Watershed with outlines of sub-watersheds.
Indicators
To assess the health of Lake Diefenbaker and the Canadian sub-watersheds within the Lake Diefenbaker Watershed, six condition indicators were developed (See Appendix B). Due to data limitations and availability only the health of Lake Diefenbaker’s seven Canadian sub-watersheds were assessed, the health of St. Mary River in Montana was not assessed.

Of the six condition indicators used, four have ecologically-based and scientifically-defensible rating schemes that allow for comparative assessments of sub-watershed health. Therefore, only the four condition indicators for which rating schemes have been developed (Surface Water Quality Indicator; Aquatic Benthic Macroinvertebrate Indicator [where benthic macroinvertebrates are invertebrates that are large enough to see without a microscope, such as crayfish or mayflies]; Riparian Areas Indicator [where riparian areas are transition zones between aquatic and terrestrial areas along a water body/waterway]; and Rangeland Health Indicator) were used in determining the overall health rating of each sub-watershed.

A number of datasets were used to develop these four condition indicators. Data was not available/applicable for all of the four condition indicators for each of the sub-watersheds (Figure 2). The Saskatchewan portion of the South Saskatchewan River sub-watershed was the only sub-watershed where all of the four condition indicators were applicable and datasets were available. Data were available for on average three of the four (75%) condition indicators for the seven sub-watersheds assessed.
Limitations
The intention of each condition indicator is to be representative so that sub-watersheds with a lower health can be identified. The methods used to calculate the condition indicators have several limitations, including:

- The indicators are estimates, and they should be thought of accordingly.
- The rating schemes are intended to be used to compare all sub-watersheds within the Lake Diefenbaker Watershed.

Condition indicator values for the sub-watersheds were grouped into one of three classes, **healthy**, **stressed** or **impacted**. These classes are based on ecosystem services, ecosystem function, and the sub-watershed’s resistance and resilience to change. A sub-watershed was rated as:

- **Healthy** – if the sub-watershed has no apparent change in function or services provided by water, and the system is both resistant and resilient to change.
- **Stressed** – if the sub-watershed has no degradation in function and/or services it provides, but it has lost resistance to change.
• **Impacted** – if the sub-watershed has a change and/or degradation in function and/or services.

### Table 2. Select criteria to assign sub-watershed health grades to condition indicators.

<table>
<thead>
<tr>
<th>Condition Indicators</th>
<th>Indicator Descriptions</th>
<th>Impacted</th>
<th>Stressed</th>
<th>Healthy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Water Quality</td>
<td>The Water Quality Indicator is an assessment of the chemical, biological and physical constituents within the water.</td>
<td>&lt; 45</td>
<td>45 to 79</td>
<td>80 to 100</td>
</tr>
<tr>
<td>Aquatic Benthic Macroinvertebrates</td>
<td>The Aquatic Benthic Macroinvertebrates Indicator assesses health using aquatic benthic macroinvertebrates communities as the indicator.</td>
<td>≤ 10%</td>
<td>11% to 89%</td>
<td>≥ 90%</td>
</tr>
<tr>
<td>Riparian Health</td>
<td>Riparian Health Indicator measures the ability of a riparian area to perform the essential functions of trapping sediment, filtering runoff, stabilizing stream banks, recharging ground water, and providing wildlife habitat.</td>
<td>&lt; 60%</td>
<td>60% to 79%</td>
<td>80% to 100%</td>
</tr>
<tr>
<td>Riparian Buffer</td>
<td>Riparian Buffer Indicator measures the percent of permanent cover within a 40 metre strip of the adjacent waterway.</td>
<td>&lt; 25%</td>
<td>25% to 74%</td>
<td>75% to 100%</td>
</tr>
<tr>
<td>Rangeland Health</td>
<td>Rangeland Health Indicator measures the ability of a rangeland to perform the essential functions of reducing soil erosion, increasing water infiltration and reducing runoff.</td>
<td>&lt; 50%</td>
<td>50% to 74%</td>
<td>75% to 100%</td>
</tr>
</tbody>
</table>

The overall health of each Canadian sub-watershed was determined using the four condition indicators for which scientifically defensible rating schemes have been developed (Table 2). These indicators include: Surface Water Quality Indicator; Aquatic Benthic Macroinvertebrate Indicator; Riparian Areas Indicator; and Rangeland Health Indicator.

The health of each sub-watershed was determined by the sub-watershed’s lowest health rating for any of the four condition indicators with rating schemes. Therefore, a sub-watershed was rated as impacted if at least one of the four condition indicators had a rating of impacted; stressed if the lowest rating for at least one of the four condition indicators had a rating of stressed; or healthy if all of the four condition indicators had a rating of healthy.
Based on this assessment, all of Lake Diefenbaker’s Canadian sub-watersheds were identified as stressed (Figure 3 and Table 3). Due to data limitation and availability issues, the health of the St. Mary River Sub-watershed, in Montana, was not assessed.

See Appendix B for a detailed assessment of the condition indicators used to determine the health rating of Lake Diefenbaker’s sub-watersheds.
Table 3. Sub-watershed Report card for condition indicators.

<table>
<thead>
<tr>
<th>Sub-watershed</th>
<th>Surface Water Quality</th>
<th>Aquatic Benthic Macroinvertebrate</th>
<th>Riparian Areas</th>
<th>Rangeland Health</th>
<th>Health Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alberta’s portion of the South Saskatchewan River</td>
<td>Healthy</td>
<td>NA*</td>
<td>Stressed</td>
<td>Healthy</td>
<td>Stressed</td>
</tr>
<tr>
<td>Bow River</td>
<td>Healthy</td>
<td>NA*</td>
<td>Stressed</td>
<td>Healthy</td>
<td>Stressed</td>
</tr>
<tr>
<td>Oldman River</td>
<td>Healthy</td>
<td>NA*</td>
<td>Stressed</td>
<td>Stressed</td>
<td>Stressed</td>
</tr>
<tr>
<td>Red Deer River</td>
<td>Stressed</td>
<td>NA*</td>
<td>Stressed</td>
<td>Stressed</td>
<td>Stressed</td>
</tr>
<tr>
<td>Saskatchewan’s portion of the South Saskatchewan River</td>
<td>Healthy</td>
<td>Healthy</td>
<td>Stressed</td>
<td>Stressed</td>
<td>Stressed</td>
</tr>
<tr>
<td>Swift Current Creek</td>
<td>Stressed</td>
<td>Stressed</td>
<td>Stressed</td>
<td>NA*</td>
<td>Stressed</td>
</tr>
</tbody>
</table>

*NA indicates that data are either unavailable or not applicable for that sub-watershed.

Stressors to Lake Diefenbaker and the Lake Diefenbaker Watershed

To better manage and protect the Lake Diefenbaker Reservoir for future use it is also important to determine the human activities (stressors) that are affecting or have the potential to affect the system. Some of the human activities that are impacting or have the potential to impact the health of Lake Diefenbaker and the Lake Diefenbaker Watershed include, surface water quantity, surface water allocation, aquatic fragmentation, nutrient loading, shoreline erosion and sedimentation.

- **Surface water quantity** – The natural flow regimes in all of Lake Diefenbaker’s Sub-watersheds have been altered by changes in land use, water withdrawals, and structures such as dams and low-level crossings. The Red Deer River Sub-watershed has had the least amount of flow alteration.

- **Surface water allocations** – The ratio of allocated surface water withdrawal licenses to naturalized flow provides information on the level of human activity within the watershed. Three of the highly allocated sub-watersheds (The Oldman River, Bow River, and Swift Current Creek Sub-watersheds) have more than 40% of their naturalized flow allocated in surface water licenses. The remaining three Canadian sub-watersheds, the Red Deer River Sub-watershed, the Alberta portion of the South Saskatchewan River Sub-watershed, and the Saskatchewan portion of the South Saskatchewan River Sub-watershed each have less than 20% of the naturalized flow allocated in surface water licenses.

- **Aquatic fragmentation** – Given the large number of dams and the various construction dates of the dams it was difficult to assess the alteration of the fluctuation of flow caused
by dams upstream of Lake Diefenbaker. However, the impacts of flow regulation, caused by Gardiner and Qu’Appelle River Dams has resulted in statistically significant increases in median monthly flow and alteration of natural seasonal flow downstream of the dam along the Qu’Appelle and South Saskatchewan Rivers, respectively.

- **Nutrient loading** – Nutrient concentrations of nitrogen and phosphorus have been measured since the late 1960’s by the Prairie Provinces Water Board (PPWB) at their Alberta/Saskatchewan border sites on the South Saskatchewan River and the Red Deer River. The length of this record allows for assessment of long-term trends on these rivers. The PPWB recently undertook such an exercise and found slight but significant decreasing trends for total and dissolved phosphorus concentrations at both the Saskatchewan and Red Deer River sites. Trends in total nitrogen were only analyzed since the early 1990’s due to a change in analytical methods at that time. Since the early 1990’s total nitrogen was not found to change significantly at the Red Deer River site and to have significantly increased at the South Saskatchewan River site. Salinity was also found to have significantly increased at both sites since 1980 (John Mark Davies 2012).

To better understand how nutrient inputs can affect water quality researchers often study all the major nutrient sources and losses to lakes and reservoirs by undertaking nutrient mass balance studies. Such detailed nutrient mass balance budgets have not previously been investigated at Lake Diefenbaker. Likewise, few studies have examined in detail the spatial and temporal extent of nutrient limitation in the lake. In 2011 research was initiated through the University of Saskatchewan to better understand hydrologic and nutrient mass balances, nutrient limitation, sedimentation, and algal species found within the lake. These studies are designed to increase our understanding of the state of water quality in Lake Diefenbaker and its susceptibility to changes in flow and nutrient inputs.

- **Shoreline erosion** – Few studies have assessed shoreline erosion along Lake Diefenbaker. Penner (1993) conducted research at select sites along Lake Diefenbaker between 1991 and 1993 that focused on understanding the relationship between wave energy, soil types and erosion rates. Through this study an erodibility coefficient was estimated for common shore material around the lake. Based on the findings Penner (1993) estimated that between 1968 and 1992 shoreline erosion rates were typically between 1 to 3 m/yr, with rates up to 6 m/yr occurring over short timeframes on some of the higher exposed slopes.

- **Sedimentation** – Currently information on the amount of sedimentation within Lake Diefenbaker is unknown and is classified as a data gap. However, historical and current data have been/are being collected, including: 1) historical data collected from 1965-1985 within Lake Diefenbaker. This data includes approximately 30 cross-sections, from...
Gardiner Dam to Saskatchewan Landing, that were sampled every five years between 1965 and 1985. Once analyzed, this data would provide baseline sedimentation information, as well as the sedimentation rate in the reservoir in the first 15 years of operation; and 2) sedimentation data is currently being collected by the Limnology Lab, aligned with the Global Institute for Water Security.

**Knowledge Gaps**

There are few data with which to draw robust conclusions about the ecological health status of Lake Diefenbaker. From the review of available data for Lake Diefenbaker it was apparent that few historical studies and little historical water quality and benthic invertebrate data have been collected from the lake. Given the importance of water quality and aquatic health for key management objectives this represents a fundamental data gap in the ongoing management of the system. The report identifies several areas that would provide valuable data with which to assess the health status and condition of the reservoir. Some data gaps include: 1) improved water quality data, although it is noted that the Water Security Agency initiated a long-term monitoring program in 2009 and the Global Institute for Water Security (University of Saskatchewan) is presently undertaking detailed water quality research on the lake; and 2) lake-wide benthic macroinvertebrate [invertebrate that is large enough to see without a microscope, such as a crayfish or mayfly] data to assess biotic health. The advantages of using benthic macroinvertebrates as an indicator of ecosystem health include the species present reflect site specific ecosystem characteristics and they form an important link in the food web between the primary producers (phytoplankton) and secondary consumers (fish); and 3) riparian health assessments that would provide a means for evaluating the shoreline condition of the reservoir and the human activities that may potentially be affecting the quality of the lake.
## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Executive Summary</td>
<td>i</td>
</tr>
<tr>
<td>Introduction</td>
<td>8</td>
</tr>
<tr>
<td>- Problem Statement</td>
<td>8</td>
</tr>
<tr>
<td>- Purpose</td>
<td>9</td>
</tr>
<tr>
<td>History of the South Saskatchewan River Project</td>
<td>10</td>
</tr>
<tr>
<td>- Lake Diefenbaker Water Supply</td>
<td>10</td>
</tr>
<tr>
<td>Operations</td>
<td>13</td>
</tr>
<tr>
<td>Physiochemical Characterizations of Lake Diefenbaker</td>
<td>14</td>
</tr>
<tr>
<td>- Thermal Regime</td>
<td>15</td>
</tr>
<tr>
<td>- Dissolved Oxygen</td>
<td>15</td>
</tr>
<tr>
<td>- Phosphorus and Nitrogen</td>
<td>15</td>
</tr>
<tr>
<td>Biological Characteristics of Lake Diefenbaker</td>
<td>16</td>
</tr>
<tr>
<td>- Fish Community and Fisheries</td>
<td>16</td>
</tr>
<tr>
<td>- Benthic Macroinvertebrates</td>
<td>18</td>
</tr>
<tr>
<td>- Phytoplankton</td>
<td>18</td>
</tr>
<tr>
<td>- Chlorophyll $a$ and Trophic Status</td>
<td>19</td>
</tr>
<tr>
<td>Meteorology of Lake Diefenbaker</td>
<td>19</td>
</tr>
<tr>
<td>Lake Diefenbaker Operation</td>
<td>19</td>
</tr>
<tr>
<td>- Saskatoon South East and South Saskatchewan River Irrigation District Water Supply Systems</td>
<td>20</td>
</tr>
<tr>
<td>Monitoring and Research on Lake Diefenbaker</td>
<td>21</td>
</tr>
<tr>
<td>The Lake Diefenbaker Watershed</td>
<td>25</td>
</tr>
<tr>
<td>Effects of the Construction of Lake Diefenbaker</td>
<td>26</td>
</tr>
<tr>
<td>- Flow Regulation</td>
<td>26</td>
</tr>
<tr>
<td>- River Ice</td>
<td>27</td>
</tr>
<tr>
<td>- Retention Time</td>
<td>27</td>
</tr>
<tr>
<td>- Sedimentation and Channel Erosion</td>
<td>27</td>
</tr>
<tr>
<td>- Shoreline Erosion</td>
<td>28</td>
</tr>
<tr>
<td>- Ground water</td>
<td>28</td>
</tr>
<tr>
<td>Effects of Lake Diefenbaker Operation</td>
<td>28</td>
</tr>
<tr>
<td>- Variation in Flow</td>
<td>28</td>
</tr>
<tr>
<td>- Flood Control</td>
<td>29</td>
</tr>
<tr>
<td>- Water Quality</td>
<td>30</td>
</tr>
<tr>
<td>- Water Use</td>
<td>30</td>
</tr>
<tr>
<td>- Minimum Flow</td>
<td>34</td>
</tr>
<tr>
<td>- Master Agreement on Apportionment</td>
<td>37</td>
</tr>
<tr>
<td>- Canada-Saskatchewan South Saskatchewan River Basin Study</td>
<td>37</td>
</tr>
<tr>
<td>- South Saskatchewan River Watershed Plan</td>
<td>38</td>
</tr>
<tr>
<td>Issues Associated with Lake Diefenbaker and its Operation</td>
<td>38</td>
</tr>
<tr>
<td>- Irrigation</td>
<td>38</td>
</tr>
<tr>
<td>- Recreation Uses</td>
<td>39</td>
</tr>
<tr>
<td>- Hydroelectric Power Generation</td>
<td>39</td>
</tr>
<tr>
<td>- Piping Plover</td>
<td>39</td>
</tr>
<tr>
<td>- Regional Development</td>
<td>40</td>
</tr>
<tr>
<td>- Saskatoon South East Water Supply (SSEWS) System Issues</td>
<td>41</td>
</tr>
<tr>
<td>- Flooding</td>
<td>42</td>
</tr>
<tr>
<td>- Drought Resilience</td>
<td>42</td>
</tr>
<tr>
<td>- Eutrophication</td>
<td>42</td>
</tr>
</tbody>
</table>
Shoreline Management and Reservoir Development Areas .................................................. 43
Riparian Areas .................................................................................................................. 45
**Water Supply Issues** ........................................................................................................ 45
Climate Change ............................................................................................................. 45
Irrigation .......................................................................................................................... 47
Electric Power Generation ............................................................................................... 48
Fish, Wildlife and Historic Resources ............................................................................. 49
Interests Downstream of Gardiner Dam ........................................................................... 49
Qu'Appelle River Diversion ............................................................................................... 50
East Side Pumping Plant Diversions ................................................................................ 50
New Water Diversions, Economic Development and Interjurisdictional Issues .............. 50
**Stressors to Lake Diefenbaker and the Lake Diefenbaker Watershed** ....................... 51
Alteration of Surface Water Flow within the Lake Diefenbaker Watershed .................... 51
Surface Water Allocation within the Lake Diefenbaker Watershed .................................. 52
Aquatic fragmentation within the Lake Diefenbaker Watershed ....................................... 54
Nutrients within the Lake Diefenbaker Watershed ........................................................... 54
Shoreline Erosion along Lake Diefenbaker ..................................................................... 55
Sedimentation within Lake Diefenbaker .......................................................................... 56
Stressors on aquatic systems downstream of the South Saskatchewan River Project .......... 56
  Alteration of Flow Downstream of the South Saskatchewan River Project ................. 56
  Alteration of Water Temperature Downstream of the South Saskatchewan River Project ................................................................. 60
Sedimentation downstream of Gardiner Dam .................................................................. 60
Appendix A ......................................................................................................................... 61
**Aquatic Ecosystem Health of Lake Diefenbaker** .............................................................. 61
Appendix B ......................................................................................................................... 63
**The State of the Lake Diefenbaker Watershed** ............................................................... 63
**Condition Indicators** .................................................................................................... 63
Surface Water Quality Indicator ..................................................................................... 64
Aquatic Benthic Macroinvertebrate Indicator .................................................................. 71
Riparian Areas Indicator .................................................................................................. 77
Rangeland Health Indicator ............................................................................................. 84
Land Cover Indicator (under construction) ..................................................................... 88
Species at Risk Indicator (under construction) .................................................................. 91
**Glossary** ....................................................................................................................... 95
References ......................................................................................................................... 96
List of Figures

Figure 1. The Lake Diefenbaker Watershed with outlines of sub-watersheds........................................iii
Figure 2. Indicator data availability and applicability by sub-watershed..............................................v
Figure 3: Health of sub-watersheds in the Lake Diefenbaker Watershed based on condition indicators....vii
Figure 4: South Saskatchewan River Project.........................................................................................12
Figure 5. Annual water level fluctuations on Lake Diefenbaker (1980-2009). Lower quartile, upper quartile and median daily water elevations throughout the year. Points plotted represent elevations considered during the operation of Lake Diefenbaker (a) Irrigation minimum; (b) Navigation; (c) Optimal recreation use; and (d) Maximum for Piping Plover.................................................................14
Figure 6: Monitoring stations on Lake Diefenbaker.............................................................................24
Figure 7: The Lake Diefenbaker Watershed with outlines of sub-watersheds. .......................................26
Figure 8. Lake Diefenbaker water balance for low flow year.................................................................33
Figure 9. Lake Diefenbaker water balance for median flow year............................................................33
Figure 10. Lake Diefenbaker water balance for high flow year.............................................................33
Figure 11: Water Use in the South Saskatchewan River Basin in Saskatchewan.....................................36
Figure 12: Lake Diefenbaker Reservoir Development Area....................................................................45
Figure 13: WQI values at water quality sampling locations within the Lake Diefenbaker Watershed: 2005 to 2010...............................................................................................................................65
Figure 14: Six-year average of Water Quality Index values calculated by Watershed: 2005 to 2010 ......66
Figure 15: Biotic condition evaluated by sample location within the Lake Diefenbaker Watershed.......72
Figure 16: Biotic condition assessed by sub-watershed within the Lake Diefenbaker Watershed.........73
Figure 17: Average lotic riparian health assessment ratings by sub-watershed.......................................79
Figure 18: Average lentic riparian health assessment ratings by sub-watershed...................................80
Figure 19. Percent of permanent cover within a 40 metre buffer of a waterway or water body: 2000......81
Figure 21: Average native range condition and health scores by sub-watershed: 2002-2008 .............85
Figure 22: Average tame rangeland health assessment scores by rural sub-watershed: 2002-2008......86
Figure 23: Land cover of the Lake Diefenbaker Watershed based on 2000 AAFC ................................89
Figure 24: Estimate of percent of land cover classified as permanent cover at the sub-watershed level: 2000..........................................................................................................................................90
Figure 25: Number of species at risk with breeding ranges that overlap the Lake Diefenbaker Watershed. ........................................................................................................................................92
List of Tables

Table 1. Management activities and potential issues associated with the operation of the South Saskatchewan River Project...........................................................................................................i
Table 2. Select criteria to assign sub-watershed health grades to condition indicators.................................................................vi
Table 3. Sub-watershed Report card for condition indicators...........................................................................................................i
Table 4. Target Elevations for the Operation of Lake Diefenbaker.................................................................................................14
Table 5: Mean Daily Air Temperature Normals (°C; 1956 to 2010) for Lake Diefenbaker at Elbow........19
Table 6: Major Uses of Lake Diefenbaker Water .................................................................................................................................32
Table 7: Trends in Southern Alberta Streamflows.........................................................................................................................47
Table 8: Mean annual recorded and naturalized flow volume of Lake Diefenbaker’s Sub-watersheds.....52
Table 9: Percent of naturalized flow that is allocated in surface water licenses..............................................................53
Table 10: Variation in South Saskatchewan River flow downstream of Gardiner Dam pre and post dam construction......................................................................................................................................57
Table 11: Variation in South Saskatchewan River inflow to Lake Diefenbaker compared to outflow downstream of Gardiner Dam post dam construction........................................................................................................58
Table 12: Variation along the Qu’Appelle River flow downstream of Buffalo Pound Lake pre and post Qu’Appelle River Dam construction .................................................................................................................................59
Table 13: Variation along the Qu’Appelle River flow downstream of Eyebrow Marsh pre and post Qu’Appelle River Dam construction .................................................................................................60
Table 14: Water quality parameters used for calculating the Water Quality Index ..........................................................68
State of Lake Diefenbaker

Introduction
In 1958 the governments of Canada and Saskatchewan agreed to “. . . undertake the development of an irrigation and agricultural rehabilitation project incorporating certain power facilities to be known as the South Saskatchewan River Project” (Government of Saskatchewan 1959). Centrepiece of the completed project is Lake Diefenbaker, an enormous reservoir created by the construction of the Gardiner and Qu’Appelle River dams. The project was originally envisioned as a multipurpose development that would provide an array of benefits, including hydropower, recreation, municipal and industrial water supplies, flood control and a reliable source of water to the Qu’Appelle River. The primary purpose of the new reservoir, however, was to permit the development of some 200,000 hectares of irrigated land (Prairie Farm Rehabilitation Administration 1980).

Many of the expected benefits of the project have been realized since its official opening in 1967, but apart from hydropower, none to the level originally anticipated. The overall development of irrigation farming, in particular, has fallen far short of the goals outlined by the Royal Commission on the South Saskatchewan River Project in 1952. Currently, the South Saskatchewan River Project provides irrigation water to approximately 24,000 hectares (60,000 acres) compared to the 200,000 hectares it was built to irrigate (Derdall 2012).

The last four decades have seen many changes (or refinements) regarding what people expect of the project and how its water should be used. Increased demands for current and proposed industrial and municipal water supply, increased flows for instream needs, specific flows for aesthetics, adjustments to reservoir levels and timing to better meet the needs of endangered bird species and releases timed for maximum hydropower generation all have their champions. The original purposes of the project were frequently in conflict with one another; today, the increased demands on reservoir water and how the project is operated have made those conflicts even more sharply defined and challenging to manage.

Problem Statement
There is a high level of public interest in water management activities at Lake Diefenbaker, and in the South Saskatchewan River in general. There is a lack of political and public awareness and understanding of how the South Saskatchewan River in Saskatchewan is managed and the ongoing work that is undertaken by the Water Security Agency (Agency) to oversee the resource. There is, therefore, a significant need to demonstrate that the Authority has sufficient processes in place to collect the required information for decision making and to make informed choices about the management of this important resource.
Purpose
The purpose of this report is to provide an overview of the South Saskatchewan River project, of which Lake Diefenbaker and the Gardiner and Qu’Appelle River dams are the primary components, and to explore the various issues associated with the lake and its operation. To this end, historical project development information, including a discussion of the rationale behind the project construction and an overview of the technical investigations undertaken at that time are provided. In addition, economic development expectations and anticipated project operational issues such as erosion problems associated with reservoir development are described. Overviews of the Canada-Saskatchewan South Saskatchewan River Basin study and development of the South Saskatchewan River Basin watershed plan are also included. When finalized, this report will be one of the three primary communication materials the Water Security Agency has been involved in compiling to provide context and material about the South Saskatchewan River Project for the targeted stakeholder consultation/engagement process.

Stakeholder Consultation/Engagement
This report and the stakeholder consultation/engagement process are key tools in improving stakeholders’ awareness of the Authority’s activities to manage and protect this important resource. The Water Security Agency is in the process of conducting targeted stakeholder consultation/engagement meetings to assist in the review and renewal of Lake Diefenbaker’s Reservoir Operating Plan (ROP). The Authority held an initial meeting with all of the stakeholders, in May 2012, to explain the stakeholder consultation/engagement process, distribute the communication material, and conduct a few presentations related to the communication material.
History of the South Saskatchewan River Project

The South Saskatchewan River basin has been considered as a location for water development projects since before the area was first settled by European settlers in the mid-19th century. Captain John Palliser was first to explore the area and document his observations in a detailed and impartial manner in his expedition of 1857 - 1860 (Spry 1968). Palliser was followed by Henry Hind who was given responsibility by the government to investigate the potential of a prairie steamship route. Hind proposed a project near the elbow in the South Saskatchewan River that would increase the usefulness of the plains area south and east of the river by irrigation and transportation. This would be accomplished by building a dam to divert water from the South Saskatchewan River to the Qu’Appelle River, producing a navigable route (by means of the Qu’Appelle River) from Lake Winnipeg to the Rocky Mountains (Hind 1860). Construction of the Canadian Pacific Railway through the region in 1882 - 1885 made the project unnecessary.

Repeated droughts led to repeated calls for government to dam the river to develop a secure source of water for the area. Large scale evacuations of farmers from the driest portions of the prairies had been considered by governments at the peak of the drought years of the 1930s, but instead the decision was made to enthusiastically promote irrigation development and thus “conquer drought”. This decision led to a recommendation in 1947 by the federal government that the South Saskatchewan Project be developed. The project was originally envisioned as a multipurpose development that would provide an array of benefits, including hydropower, recreation, municipal and industrial water supplies, and flood control. Further studies, including a Report of a Royal Commission in 1952, culminated in an agreement in 1958 between the governments of Canada and Saskatchewan to “… undertake the development of an irrigation and agricultural rehabilitation project incorporating certain power facilities to be known as the South Saskatchewan River Project” (Prairie Farm Rehabilitation Administration 1980).

Construction began in 1959 and the impounding dams were complete by 1967. Centrepiece of the completed project is Lake Diefenbaker, an enormous reservoir created by the construction of the Gardiner and Qu’Appelle River dams that permitted the potential development of 200,000 hectares of irrigated land.

Lake Diefenbaker Water Supply

The South Saskatchewan River has its headwaters in Alberta’s Rocky Mountains and flows eastward, across the prairies. It joins the North Saskatchewan east of Prince Albert and continues on as the Saskatchewan River through the Cumberland Delta and into Lake Winnipeg. From Lake Winnipeg water flows to Hudson Bay via the Nelson River. The South Saskatchewan River is the only large, reliable supply of high quality water in the southern half of Saskatchewan.

The South Saskatchewan River drains an area of about 120,000 km², the western portion of which is the eastward facing slopes of the Rocky Mountains and foothills. The Alberta portion of
the basin represents much of the southern part of the province, from Red Deer to Calgary and south to Lethbridge and Medicine Hat. The major tributaries include the Red Deer, Bow, and Oldman rivers. The eastern slopes and foothills area is a highly productive runoff area, producing virtually all of the flow received at the Alberta-Saskatchewan border. Average annual natural flow of the river at this location is 9.2 billion m$^3$, ranging from a low of 4.6 billion m$^3$ in dry years to 16 billion m$^3$ in wet years. On average, about two-thirds of the runoff occurs in the May to August period and less than ten percent occurs in the December to March period.

In Saskatchewan, the South Saskatchewan River flows through a region of very low runoff. On average, the local runoff augments the natural flow by about two percent, with half of this local flow originating in Swift Current Creek.
Lake Diefenbaker and its Dams
Lake Diefenbaker was formed by construction of the 64 metre high earthfill Gardiner Dam across the South Saskatchewan River valley 100 km upstream of Saskatoon. Since filling reservoir would have spilled east down the Qu’Appelle River valley, the project included another earthfill structure, the 27 metre high Qu’Appelle River Dam. Figure 4 is a base map of the South Saskatchewan Project and provides details of important aspects like provincial parks and the main irrigation district.

Figure 4: South Saskatchewan River Project.
Lake Diefenbaker has a surface area of 43,000 hectares, about 800 kilometres of shoreline and, when full, varies in depth from 60 metres at Gardiner Dam to zero at a point 230 km upstream. The lake has a total capacity of 9.36 billion m$^3$ and a usable (or “live”) storage of 4.01 billion m$^3$. This means that Lake Diefenbaker has the capacity to store about half of the available annual inflow, an average of 7 billion m$^3$, of the South Saskatchewan River.

The maximum normal operating level or full supply level (FSL) is at an elevation of 556.87 metres above sea level. The lower limit of safe operation during the open water season is at an elevation of about 548 m above sea level or approximately 4.0 metres above the bottom of the erosion protection on the face of the dams.

Gardiner Dam has five gated conduits, three of which supply hydroelectric turbines. Under normal conditions, all releases of water to the South Saskatchewan River are made through the turbines. Only during high inflow events when capacity of the power generating station is inadequate to pass flows is the gated concrete chute spillway used. The Qu’Appelle River Dam has a gated conduit which allows controlled releases to be made from Lake Diefenbaker into the Qu’Appelle River. Maximum discharge capacity of this dam is 68 m$^3$/s. Given the conveyance capacity of the Qu’Appelle River, discharges from this dam are limited to 14 m$^3$/s.

**Operations**

Inflows to the reservoir remain modest until snowmelt on the prairies and the mountains occurs, which along with spring rains create the higher flows from April through June, allowing the reservoir to be replenished. Filling of the reservoir is projected using forecasted inflows and attempts to balance ensuring the reservoir indeed does fill while still providing flood protection downstream of the reservoir through to Manitoba and protection of shoreline habitat on Lake Diefenbaker.

The stored water is depleted through evaporation and use. The uses include downstream flows (maintaining downstream flows for recreation, river aesthetics, aquatic habitat, electrical generation at the Coteau Creek, E.B. Campbell and Nipawin hydroelectric stations and withdrawal uses along the river for irrigation, industrial and municipal uses), withdrawals for irrigation, industrial, mining and municipal uses (either directly from the lake or through the Saskatoon South East Water Supply (SSEWS) system) and supplementation of flows in the Qu’Appelle River System for irrigation, recreation, and municipal supplies.

Water levels increase in Lake Diefenbaker during the spring and early summer from the runoff due to snow pack from the eastern slopes of the Rocky Mountains. The average annual water levels and the target elevations that the dam operators try to reach during the summer are listed in Table 4 and plotted on Figure 5 (1980-2009). The values in Table 4 are elevation targets for filling the reservoir, not requirements for reservoir operation. The May 1$^{st}$ irrigation target of
551.0 m is exceeded in most years, however, the May 15th Elbow Harbour target of 552 is not often exceeded. The maximums for both Piping Plover and recreational use are exceeded on July 1st about half (50%) of the time, but more frequently they are exceeded later than the July 1st target date (Saskatchewan Watershed Authority 2012).

Table 4. Target Elevations for the Operation of Lake Diefenbaker

<table>
<thead>
<tr>
<th>Date</th>
<th>Target Elevation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 1</td>
<td>551.0 m</td>
<td>Minimum acceptable water level for irrigation intake</td>
</tr>
<tr>
<td>May 15</td>
<td>552.0 m</td>
<td>Required at Elbow Harbour for launching boats</td>
</tr>
<tr>
<td>July 1</td>
<td>555.0 to 555.3</td>
<td>Optimal water level for recreational use</td>
</tr>
<tr>
<td>July 1</td>
<td>555.3</td>
<td>Maximum for Piping Plover</td>
</tr>
</tbody>
</table>

Figure 5. Annual water level fluctuations on Lake Diefenbaker (1980-2009). Lower quartile, upper quartile and median daily water elevations throughout the year. Points plotted represent elevations considered during the operation of Lake Diefenbaker (a) Irrigation minimum; (b) Navigation; (c) Optimal recreation use; and (d) Maximum for Piping Plover.

Physiochemical Characterizations of Lake Diefenbaker

The physiochemical characteristics of Lake Diefenbaker are from previous limnology studies (Saskatchewan Environment and Public Safety and Environment Canada 1988), a fisheries study (Wallace et al. 2010) and a water quality monitoring program initiated by the Water Security Agency (formerly Saskatchewan Watershed Authority) in 2009.
**Thermal Regime**

Water temperature of Lake Diefenbaker is typical of river-reservoirs. Water temperature during the spring is generally warmer at upstream sites due to the inflowing water and cooler near the dams. Downstream sites, including those near Gardiner Dam, do not typically stratify until mid-summer. When temperature stratification develops, it is typically deep with temperature measurements suggesting thermoclines [a temperature gradient that results in the separation of the warmer water above from the colder water below] developing around 15m. According to Wallace et al (2010), limnological parameters [physico-chemical water parameters used to assess freshwater lakes, such as dissolved oxygen, pH, turbidity, specific conductivity] have remained similar since the formation of the reservoir.

Water leaving the reservoir has altered temperature from what would have been the temperature in the river prior to construction of Lake Diefenbaker. During summertime, the water leaving Gardiner Dam is cooler than the water entering the reservoir. This results in the downstream portion of the South Saskatchewan River taking approximately 110 km before the temperature increases until the temperature becomes significantly similar to the temperature observed in Leader, SK (Phillips et al., in press). During winter the reservoir experiences reverse stratification under-ice. The importance of temperature and mixing in the reservoir is presently being examined in greater detail as part of the limnology studies at the University of Saskatchewan through the Global Institute of Water Security and the Biology Department. This includes examining the thermal stability in coulees and continuous monitoring of water temperature at five strategically located sites; Riverhurst, Elbow, Kadla Coulee, Qu’Appelle and Gardiner Dams.

**Dissolved Oxygen**

Oxygen levels in Lake Diefenbaker are classified as excellent for aquatic life and fisheries and meet Saskatchewan’s Water Quality Objectives for the protection of aquatic life. During periods of stratification, either in the summer or in late winter, dissolved oxygen concentrations decrease near the sediment. This is typical of lakes because of the higher oxygen demand associated with sediments. Immediately after the reservoir was filled, oxygen deficiencies were observed (1967 to 1969). These deficiencies were attributed to the decomposition of terrestrial vegetation flooded by the reservoir (Royer 1972). The current University of Saskatchewan study will provide data with greater spatial and temporal resolution to better understand oxygen changes in the reservoir.

**Phosphorus and Nitrogen**

Given the variability of inflowing water volumes and water quality the external nutrient loading to Lake Diefenbaker can be quite variable. A study found that the mean annual total phosphorus load between 1975 and 1985 was 1,229 tonnes (Saskatchewan Environment and Public Safety and Environment Canada 1988), although more recent studies have suggested loading values
close to 500 tonnes (Parker 2010). Lake Diefenbaker generally acts as a total nutrient sink for nitrogen and phosphorus. However, a portion of the inflowing nutrients may be biologically unavailable and settle to the bottom as flow decreases from the upstream to the downstream portion of the reservoir. The influence of the reservoir on the more biologically available fraction of nutrients is not presently as well understood. The current University of Saskatchewan study being conducted through the Global Institute for Water Security and the Biology Department is aiming to better understand Lake Diefenbaker’s nutrient budget and water column nutrient cycling. This will provide a basis for better evaluating limiting factors to phytoplankton growth and sensitivity of the ecosystem to climate variability, notably variability of inflow volumes.

**Biological Characteristics of Lake Diefenbaker**

**Fish Community and Fisheries**

Lake Diefenbaker provides habitat for both cold and warm water fish species. To assess the fish populations, assessments have been conducted by Saskatchewan Ministry of Environment since the reservoir was created in 1967. The original fisheries assessment captured twenty-five species of fish, including lake sturgeon (*Acipenser fulvescens*), lake whitefish (*Coregonus clupeaformis*), rainbow trout (*Oncorhynchus mykiss*), lake char (*Salvelinus namaycush*) previously known as lake trout, northern pike (*Esox lucius*), goldeye (*Hiodon alosoides*), mooneye (*Hiodon tergisus*), burbot (*Lota lota*), yellow perch (*Perca flavescens*), walleye (*Sander vitreus*), sauger (*Sander canadensis*), shorthead redhorse (*Moxostoma macrolepidotum*), longnose sucker (*Catostomus catostomus*), white sucker (*Catostomus commersoni*), quillback (*Carpiodes cyprinus*), flathead chub (*Platygobio gracilis*), lake chub (*Couesius plumbeus*), spottail shiner (*Notropis hudsonius*), emerald shiner (*Notropis atherinoides*), river shiner (*Notropis blennius*), fathead minnow (*Pimephales promelas*), brook stickleback (*Culaea inconstans*), Iowa darter (*Etheostoma exile*), trout-perch (*Percopsis omiscomaycus*), and spoonhead sculpin (*Cottus ricei*) (Royer 1972).

Based on the fisheries assessments, though water levels and methods of collection have varied throughout the years, there appears to be strong trends in some fish populations, including:

- northern pike and goldeye populations have decreased since the initial assessments (Royer 1972; Wallace et al 2010). The decline in the northern pike and goldeye populations following impoundment can be explained by the species’ habitat preference. Northern pike are benthic fish that prefer clear, warm, slow, heavily vegetated rivers or warm weedy bays of lakes less than 5 m in depth (Scott and Crossman 1973; Lanhorne et al. 2001). There is a limited amount of this type of habitat in Lake Diefenbaker (Chen 1983). Northern pike populations may also be failing due to a lack of spawning habitat. Northern pike are spring spawners that prefer shallow flooded vegetation, this type of spawning habitat is most readily available in Lake Diefenbaker in the fall, not the spring (Jensen 2004). Goldeye prefer large, turbid rivers and have been found to be more abundant around the Saskatchewan Landing portion of Lake Diefenbaker. It is also possible that the populations of these species are being understated as the majority of fish assessment test nets are set in deep waters, whereas pike and goldeye prefer shallow waters (Pogorzelec 1990).
walleye, lake whitefish, yellow perch and cisco populations have increased since the initial assessments (Royer 1972; Wallace et al 2010). Saskatchewan Ministry of Environment operates a spring spawn camp, at Coteau Bay on Lake Diefenbaker, where they annually collect walleye eggs (Wallace 2010). The walleye eggs collected are used for the entire provincial stocking program. Walleye populations within Lake Diefenbaker would be self sustaining, but because of the removal of eggs during the spawn camp walleye have been stocked annually since 1969. Lake whitefish were stocked for a few years between 1969 and 1972, but appear to be reproducing successfully. The increase in the yellow perch and cisco populations following impoundment can be explained by the species’ habitat preference. Yellow perch have a high affinity for lake habitats in all life stages and cisco are primarily found in pelagic zones of lakes (Scott and Crossman 1973).

sauger and sucker populations have remained constant since they were first assessed in 1967 (Royer 1972; Wallace et al 2010).

all other fish species have no obvious population trends across the assessment years (Royer 1972; Wallace et al 2010).

To establish and maintain fish populations for angling the Saskatchewan Ministry of Environment, in addition to relying on natural reproduction of certain fish species, has stocked Lake Diefenbaker with a number of fish species, including: walleye (1969-present); lake whitefish (1969-1972); lake trout (1970-1975); rainbow trout (1987-2005); northern pike (2000-2003); and brown trout (1987) (Wallace et al. 2010). Unintentional escapes of rainbow trout from the local aquaculture operation, in 1994 and 2000, have also assisted in increasing Lake Diefenbaker’s rainbow trout population.

Recreational angling is an important tourist attraction for Saskatchewan. Lake Diefenbaker is one of the top five most frequently fished water bodies in Saskatchewan (Duffy 2006). In 1983, to assess recreational fishing pressure on Lake Diefenbaker, a creel survey was conducted. Based on the angler interviews conducted, Chen (1983) found that the fishing success was on average 1.45 fish per angler or 0.55 fish per hour fished. In 1984, another creel survey was conducted. This survey found that fishing pressure and success in 1984 was 6.2 fish per angler and a catch rate of 1.55 fish per hour, which is higher than the same measures in 1983. It is thought that these higher numbers are not likely an actual increase in the number of fish caught between the two years, but rather that the 1984 creel survey was more thorough (Merkowsky and Chen 1985). In 1983 they interviewed 372 anglers, and in 1984 they interviewed 1,200 anglers. In 2004, a third creel survey was conducted on Lake Diefenbaker, which interviewed 1,161 anglers and found the fishing success to be 0.45 fish per hour, and additionally a shift in the proportion of fish species caught on Lake Diefenbaker has observed. The most frequently caught fish in 1983 and 1984 were walleye (66% and 50%, respectively), pike (23% and 8%, respectively), and perch (6% and 31%, respectively) (Chen 1983 and Merkowsky and Chen 1985). Based on the 2004
creel survey, the most frequently caught fish were walleye (25%), rainbow trout (29%), and goldeye (24%) (Wallace et al. 2010).

In addition to supporting a successful sport fishery, Lake Diefenbaker has also supported other types of fisheries over the years, including commercial aquaculture, a commercial fishery and spawn camps. Commercial aquaculture has been in operation on Lake Diefenbaker since 1993 with the opening of the Wild West Steelhead operation (formerly CanGro Fish Farm) at Lucky Lake, SK. A commercial fishery of whitefish was initiated on Lake Diefenbaker in the fall of 1978, but was closed in 1986 due to concerns about the reduction in size and numbers of whitefish. Since 1991, Saskatchewan Ministry of Environment has operated a spring spawn camp and been involved in annually collecting walleye eggs from Coteau Bay on Lake Diefenbaker (Wallace 2010).

**Benthic Macroinvertebrates**

Benthic macroinvertebrates are invertebrates that live in or on the bottom substrates. They form an important link in the food web between the primary producers (plankton) and secondary consumers (fish).

 Shortly after impoundment, an assessment of the benthic macroinvertebrates was conducted. This assessment found Lake Diefenbaker to have a low benthic invertebrate biomass compared to other Saskatchewan lakes at similar latitude. However, it had similar biomass values to Tobin Lake, another Saskatchewan reservoir, formed in 1963 by the E.B. Campbell Dam. This assessment also found that between 1967 and 1969, the dominant benthic macroinvertebrates in all regions of the lake were chironomid larvae and oligochaetes (Royer 1972). No recent benthic macroinvertebrate assessments could be obtained to assess the current biotic condition of Lake Diefenbaker.

**Phytoplankton**

Phytoplankton are microscopic algae suspended in the water column of water bodies around the world. Like plants, phytoplankton use sunlight to grow and are therefore form part of the base of the food web. The phytoplankton composition of Lake Diefenbaker was described in the mid-1980s as being quite diverse, with over 100 different taxa observed (Saskatchewan Environment and Public Safety and Environment Canada 1988). As is typical in lakes and reservoirs the type of algae change with season. The Saskatchewan Environment and Public Safety and Environment Canada 1988 study found phytoplankton abundance was greatest in July and August. Anecdotal observations have noted algal blooms in late summer and early autumn. Phytoplankton biomass is low during the ice covered season principally due to low light from ice and snow, less turbulent water to keep algae suspended and lower temperatures.
Chlorophyll a and Trophic Status
A common measurement of phytoplankton biomass is determining the amount of chlorophyll a. Saskatchewan’s Interim Surface Water Quality Objective for chlorophyll a is 50 µg/L (Saskatchewan Environment 2006a). All of the chlorophyll a samples collected by the Water Security Agency (formerly Saskatchewan Watershed Authority) in 2010 were below the Surface Water Quality Objective. Samples collected from Saskatchewan Landing for all dates were consistently higher than the other three sites where chlorophyll a was sampled. The 1984-85 water quality study also found this trend with the chlorophyll a samples that were collected. The 1984-85 study classified the trophic status of Lake Diefenbaker, with the exception of Saskatchewan Landing, to be oligotrophic to mesotrophic. Saskatchewan Landing was determined to be mesotrophic to enriched in nutrients [eutrophic] (Saskatchewan Environment and Public Safety and Environment Canada 1988). Ongoing monitoring of Lake Diefenbaker is required to assess whether the trophic status is changing through time and what effect climate variability (e.g., high versus low flow years) will have on water quality.

Meteorology of Lake Diefenbaker
Air temperatures at Elbow have fluctuated over the past 29 years (1982-2010) but no trends are apparent. Mean daily air temperature normals between 1982 and 2012 range from winter lows of -20°C to summer highs of 25°C (Table 5).

Table 5: Mean Daily Air Temperature Normals (°C; 1956 to 2010) for Lake Diefenbaker at Elbow.

<table>
<thead>
<tr>
<th>Month</th>
<th>Minimum Temperature (°C)</th>
<th>Maximum Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>-20</td>
<td>-10</td>
</tr>
<tr>
<td>February</td>
<td>-18</td>
<td>-7</td>
</tr>
<tr>
<td>March</td>
<td>-10</td>
<td>0</td>
</tr>
<tr>
<td>April</td>
<td>-2</td>
<td>11</td>
</tr>
<tr>
<td>May</td>
<td>4</td>
<td>18</td>
</tr>
<tr>
<td>June</td>
<td>9</td>
<td>23</td>
</tr>
<tr>
<td>July</td>
<td>12</td>
<td>26</td>
</tr>
<tr>
<td>August</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>September</td>
<td>5</td>
<td>19</td>
</tr>
<tr>
<td>October</td>
<td>-1</td>
<td>11</td>
</tr>
<tr>
<td>November</td>
<td>-9</td>
<td>0</td>
</tr>
<tr>
<td>December</td>
<td>-17</td>
<td>-7</td>
</tr>
</tbody>
</table>

(Data source: Canada's National Climate Archive at: http://www.climate.weatheroffice.gc.ca/advanceSearch/searchHistoricData_e.html)

Lake Diefenbaker Operation
The Water Security Agency is responsible for operating Lake Diefenbaker and allocating the water resources of Saskatchewan’s portion of the South Saskatchewan River. The Authority
monitors weather and hydrologic conditions in the Alberta headwaters of the basin on a daily basis. The hydrometric and meteorological data are used to develop streamflow and water supply forecasts for inflow to Lake Diefenbaker. The Authority develops both short and long range operation plans to optimize the value of the available water to all users. These plans include those for releases through the Coteau Creek hydroelectric generating station, spillway operations and releases through the Qu’Appelle River Dam outlet works.

The Authority’s philosophy for operation of Lake Diefenbaker is simple: manage the reservoir to achieve the maximum overall benefits for the people of Saskatchewan. Actual operation, however, is very complex. Operation must accommodate many uses such as power generation, municipal and industrial use, irrigation, recreation, flood control, the maintenance of minimum downstream flows and augmentation of flow in the Qu’Appelle River. Operation planning must consider the variability of runoff, variable water uses, upstream demands in Alberta, conflicts in water use, physical constraints which exist in the various works and structures, maintenance requirements, integration of Lake Diefenbaker operation and releases through the Coteau Power Plant with the downstream E.B. Campbell power plant, the special needs of construction projects at the reservoir and downstream along the river, the requirements of the Master Agreement on Apportionment and the safety and structural integrity of Gardiner Dam.

Recreation use is an example of the many factors to be considered in the operation plan. Low water elevations and fluctuations in water levels during the recreation season are not great for recreational use. Ideally, the reservoir should be relatively stable during the recreation period, but that objective may conflict with the use of the reservoir for flood control and the objective of having a near full reservoir in the fall so that water will be available for release during the winter months for power production and forward drought resilience for water supply. Water is also diverted to the Qu’Appelle River as well as the Saskatoon Southeast Water Supply (SSEWS) canal to improve recreational opportunities along these systems. There is, however, a discrete, quantifiable economic cost to these diversions in terms of recreation levels on Lake Diefenbaker, power production and direct uses from the lake.

**Saskatoon South East and South Saskatchewan River Irrigation District Water Supply Systems**

The SSEWS and the South Saskatchewan River Irrigation District (SSRID) water delivery systems transports water to a variety of users via a series of canals and six reservoirs extending from Lake Diefenbaker to Dellwood Brook Reservoir near Lanigan. The system delivers an average of 77 million m$^3$ of water annually. The major uses of the conveyed water are irrigation, industries, municipalities, recreation and waterfowl/wildlife projects. Municipal water users include the communities of Hanley, Guernsey, and Lanigan as well as the Rural Municipality of Dundurn. Three potash mines are the primary industrial water users of the SSEWS system. The
South Saskatchewan Irrigation District No. 1 is the largest irrigation project supplied by the systems having an irrigated area of approximately 16,000 ha.

**Monitoring and Research on Lake Diefenbaker**
Several fisheries studies have been conducted on Lake Diefenbaker since it was first impounded. Between 1967 and 1969 fisheries assessments were conducted to document physical, chemical and biological characteristics of the lake. In 1973 an investigation was conducted to assess the fish populations in the lake. Routine fish management investigations were conducted in 1977, 1980, 1988, 1992 and 1995. Between 2001 and 2003, studies were initiated to assess the impact of spawn-taking operations on walleye in Lake Diefenbaker. In 2004, in response to concerns over the status of game fish populations an assessment of fish populations in the lake was conducted (Wallace et al. 2010).

Limited historical water quality monitoring occurred on Lake Diefenbaker. Some of the historical research on Lake Diefenbaker includes:

1) Between 1984 and 1985, the Water Quality Branch of Saskatchewan Environment and Public Safety jointly with the Water Quality of Inland Waters Directorate, Environment Canada conducted a water quality study on the Upper Saskatchewan River and Lake Diefenbaker. Objectives of the study were to:
   - describe the physical, chemical and biological properties of the water bodies;
   - quantify the trophic status of Lake Diefenbaker; and
   - assess the water quality based on current and future uses.
   The study assessed water quality at thirteen sites, seven sites were along rivers (including the South Saskatchewan River, Red Deer River and Qu’Appelle River) and six were sites on Lake Diefenbaker (Saskatchewan Environment and Public Safety and Environment Canada 1988).

2) In the spring of 2008, researchers at the Toxicology Centre at the University of Saskatchewan, initiated a study that “focused on the nutrient content and nutrient limitation of algal growth in Lake Diefenbaker”. The study involved collecting water samples from the lake to determine nutrient concentrations and field measurements of chemical and physical limnological parameters. Water samples were collected once a month from June to October 2008 (Giesy et al. 2009).

Some of the current research around Lake Diefenbaker includes:

1) In 2008, as part of the federal Lake Winnipeg Basin Initiative, Environment Canada initiated a study to assess nutrient sequestration in the lakes and reservoirs of the Lake Winnipeg watershed. The objective of the study was to estimate the quantity of phosphorus and nitrogen sequestered, if any, in larger lakes and reservoirs in the
greater Lake Winnipeg Basin. Lake Diefenbaker was one of the reservoirs included in this study (Environment Canada and Manitoba Water Stewardship 2011).

2) In the fall of 2009, the Water Security Agency (formerly Saskatchewan Watershed Authority) began a water quality monitoring program to assess changes in water quality over time. This monitoring program was initiated to assess long-term changes in water quality for the lake as a whole and for specific near-shore regions of the lake as issues are identified. The data gathered from this program provides the information needed to address both short- and long-term management issues relating to water quality in Lake Diefenbaker so that the lake continues to be a source of high economic, social and recreational value to the province.

3) In March 20011, the Global Institute for Water Security was officially launched at the University of Saskatchewan. The institute promotes interdisciplinary science, and provides funding to work with provincial and federal partners in support of large projects, such as assessing nutrient loading of Lake Diefenbaker. As part of this Lake Diefenbaker project a number of research programs were initiated including:

   a) In the spring of 2011, researchers at the University of Saskatchewan began a program

   “that utilizes a community-based participatory research (CBPR) approach to emphasize a partnership between stakeholders of Lake Diefenbaker and researchers. The purpose of the program is to understand the contribution of point and diffuse source nutrients to the nutrient enrichment [eutrophication] of Lake Diefenbaker. The program creates an opportunity for stakeholders to: 1) partner and actively participate with researchers (Canada Excellence Research Chair and others) in understanding nutrient contributions to Lake Diefenbaker; 2) become educated on water resource issues, the scientific methods of water resource research, and the interpretation of results; and 3) facilitate development of new policy and management ideas that address all stakeholders in decision making and that account for local industrial, community and agricultural arrangements. The overall objectives of this study are: to characterize and quantify major nutrient inputs into Lake Diefenbaker over spatial and temporal scales; and to characterize the frequency and intensity of bacteria and algae blooms and the role of nutrients, and the spatial variability of algal and bacterial blooms and how it changes through time. The insight gained from this research will provide essential baseline information to guide the development of modeling tools, methods of communicating water risks; decisions for cost effective and efficient management, and monitoring of
the water system, as well as guide policy decision makers and regulators at both provincial and federal levels” (Bharadwaj et al. 2011).

b) To assess if algal blooms are indeed increasing, as anecdotal observations suggest, researchers at the University of Saskatchewan have initiated a paleolimnological investigation (the study of ancient lakes from their sediments and fossils) of Lake Diefenbaker. Objectives of the study include:

- reconstructing and interpreting the past nutrient status of Lake Diefenbaker, using a paleolimnological approach (i.e., sediment core analyses for diatom community composition, biogenic silica, and class-specific algal/cyanobacterial pigments);
- identifying and prioritizing anthropogenic contaminants in the South Saskatchewan River system;
- identifying sources and management practices that have resulted in nutrient contamination of the river system; and,
- investigating the natural bioavailability of a given contaminant to decrease and the potential for nutrient enrichment to impact contaminant fate processes (Jones et al. 2011).

- In the spring of 2011, a sensitivity analysis study was initiated to assess the contribution of point and diffuse sources of nutrients to Lake Diefenbaker. The objectives of the study are: to characterize and quantify major nutrient inputs into Diefenbaker Lake over variable spatial and temporal scales; to characterize bacteria and algal sensitivity to nutrient inputs; and, to characterize algal and bacterial groups (pathogens). Figure 6 provides the network of monitoring stations used to undertake this study.

- Each of these objectives will be studied by a post-graduate student over a two year period, to capture some of the environmental variability in this system (e.g., due to climate and changing water flow) (Hudson et al. 2011).
c) In the spring of 2011, a study began to assess the effects of urbanization and agriculture on Swift Current Creek, a tributary that empties into Lake Diefenbaker. The study is looking at both nutrient and pharmaceutical components of the creek. Specifically, the study will:

- conduct seasonal monitoring of nitrogen (ammonia, nitrate+nitrite, total N), phosphorus (total P, total dissolved P and soluble reactive P) and other water quality variables (temperature, specific conductance, pH and oxygen) at a control site and an agricultural site upstream of the City of Swift Current;
- assess the risk presented by NH$_3$-N, from the City of Swift Current Creek’s sewage treatment plant released to Swift Current Creek, to aquatic biota;
- determine stream nutrient retention efficiency by calculating net nutrient uptake length in those reaches affected by agriculture and the sewage treatment plant;
- estimate in situ nitrification and denitrification rates;
- use stable nitrogen isotopes to track fate of nitrogen released from the sewage treatment plants;
• use molecular techniques to quantify the presence of microbial denitrification and nitrification genes;
• assess the effect of sewage treatment plants and non-point source loading on overall ecosystem functioning;
• monitor pharmaceutical concentrations in the creek, upstream and downstream of sewage treatment plant on a seasonal basis;
• run in situ laboratory experiments to look at effects of pharmaceuticals that are always present and persistent in the creek on creek microbial communities using rotating annular reactors; and
• investigate the incidence of antibiotic resistance in bacteria in treated sewage effluent as well as creek water and sediments” (Waiser et al. 2011).

The Lake Diefenbaker Watershed
The Lake Diefenbaker Watershed originates in the Rocky Mountains and extends across the prairie ecozone, with a gross drainage area of approximately 14,760,000 hectares. The watershed is comprised of seven primary sub-watersheds that drain ground water and surface water from Montana, Alberta, and Saskatchewan, to Lake Diefenbaker. Nearly 80 percent of the Lake Diefenbaker Watershed lies within Alberta, 19 percent in Saskatchewan, and one percent in Montana. The seven sub-watersheds that comprise the Lake Diefenbaker Watershed include the St. Mary River (found in MT), the Oldman River (found in AB), the Bow River (found in AB), the Red Deer River (found in AB), the Alberta portion of the South Saskatchewan River (found in AB), the Saskatchewan portion of the South Saskatchewan River (found in SK), and the Swift Current Creek (found in SK) Sub-watersheds (Figure 7). On average, runoff in Saskatchewan contributes to approximately two percent of the natural flow into the Lake Diefenbaker Watershed, half of which originates from Swift Current Creek (The Partners FOR the Saskatchewan River Basin 2009). The remaining ninety-eight percent of the flow is from Alberta (89%) and Montana (9%). Within Alberta the Bow River Sub-watershed accounted for 40 percent of discharges to Lake Diefenbaker, the Oldman River Sub-watershed 32 percent, the Red Deer River Sub-watershed 26 percent, and the Alberta portion of the South Saskatchewan River Sub-watershed two percent (Water Survey of Canada).
Figure 7: The Lake Diefenbaker Watershed with outlines of sub-watersheds.

The Lake Diefenbaker Watershed is a large watershed that has many different land uses and subsequently land covers. Examining the different types of land cover within a watershed can provide important information about potential sources of contamination to water bodies. See Appendix B - Land Cover Indicator.

Effects of the Construction of Lake Diefenbaker
Flow Regulation
Gardiner Dam and its reservoir are the only works on the South Saskatchewan River that regulate flows. Annual inflows to Lake Diefenbaker are highly variable, and since development
in 1967 have ranged from a low of approximately 3,000,000 dam$^3$ to a high of approximately 12,000,000 dam$^3$ in 2011 (Water Survey of Canada). Storage within the usual operating range of the reservoir (551.0 to 556.87 masl) is roughly half of the average annual inflow volume. Given that the vast majority of annual inflows occurs over a two month period from snowmelt and rainfall runoff in the Rocky Mountains and foothills, a significant ability generally exists, when storage is available in the reservoir, to reduce peak flows which otherwise would occur downstream of the reservoir. Total flows passed downstream are also reduced due to evaporation losses off Lake Diefenbaker, diversions to the Qu’Appelle and SSEWS systems, and consumptive uses directly from the reservoir (principally irrigation).

**River Ice**
The South Saskatchewan River below Gardiner Dam carries winter flows that are augmented by water released from storage in Lake Diefenbaker. These discharges are usually four to five times higher than the natural winter inflows. Ice conditions on the river have changed as a result. The water released in winter from Gardiner Dam is warmer than the surrounding air, resulting in an open-water downstream reach that extends 8 to 30 km, depending on the severity of the winter (Environment Canada and Saskatchewan Water Corporation 1986).

The larger-than-natural-winter discharge delays freeze-up of the river which typically used to occur in the mid-November to mid-December period. By maintaining high and relatively constant releases at the onset of winter freeze-up, creation of winter ice jamming has largely been avoided. Having the ability to control discharges during spring break-up has also eliminated the incidences of ice jams.

**Retention Time**
Prior to the construction of Gardiner Dam, water travelled through this reach of the river in about two days. Following development of Lake Diefenbaker, the retention time, or average time water spends in Lake Diefenbaker, is approximately 2.5 years (Wikipedia 2012).

**Sedimentation and Channel Erosion**
Prior to the construction of Lake Diefenbaker the South Saskatchewan River carried a relatively large amount of sediment. When impoundment of Lake Diefenbaker was initiated in 1964, the sediment load downstream from the dam began to decrease. By 1967 the lake was big enough to trap all incoming sediment. As all suspended sediments entering Lake Diefenbaker are now being deposited in the lake, the storage volume of the lake is being reduced by about 0.07 percent annually (Smith and Wigham 1989).

Since the sediment is trapped in the reservoir, the discharge water is clear and capable of eroding the river channel downstream. To date, monitoring has confirmed that erosion has been most active in the first few kilometres downstream of the dam. The erosion process will eventually...
stabilize but high flows, such as releases of water though the spillway, can restart the erosion process. As a result, monitoring is important following major flood events.

Shoreline Erosion
The side slopes of the South Saskatchewan River Valley were essentially stable (some areas experienced very slow creep failures) under the dry conditions that prevailed prior to filling of Lake Diefenbaker. The new lake environment created a shoreline that was no longer in a state of equilibrium. This situation is changing less and less over time, as the annual rise and fall cycle of the reservoir levels smooths the shoreline, however erosion will continue for a very long time going forward.

Ground water
The South Saskatchewan River acts as a natural drain for the regional ground water. Prior to the filling of Lake Diefenbaker, piezometers (instruments that measure ground water pressures) were installed adjacent to the lake to monitor the effect the reservoir would have upon the regional ground water system. This monitoring showed that the direction of regional ground water flow remains towards the reservoir and that the rate of ground water discharge to the reservoir has been reduced. Ground water contributes an insignificant amount of water to Lake Diefenbaker (Clifton Associates Ltd. 1988).

Effects of Lake Diefenbaker Operation
Each user, whether of the project or the river system itself, has a preferred flow and water level that best suits their particular needs. The regulation of flows and water levels at Lake Diefenbaker affects all users. Reservoir operation plans attempt to maximize the economic and social benefits associated with the project by considering the interests of all users.

Variation in Flow
The South Saskatchewan River Basin is a heavily developed river system. There are numerous dams on its tributaries in Alberta which permit, to a certain extent, control of the flow of the river. These dams permit water users in Alberta to store a portion of the high flows that occur in spring and early summer so that they can be used for municipal, industrial, agricultural, recreational and other uses. This flow regulation in Alberta has resulted in changes to the flow regime of the river as it enters Saskatchewan.

Gardiner Dam has also resulted in changes to the downstream flow regime. Because of its large storage capacity, the operation of Lake Diefenbaker is planned on an annual basis. Water is stored in the lake during the spring and early summer periods when inflows are highest. During the fall and winter months, discharge through the Coteau hydropower generating station, other uses and evaporation exceeds inflows and the reservoir is drawn down. Typically the reservoir level bottoms out at the end of March. As a consequence, the seasonal flow pattern of the South
Saskatchewan River has been vastly altered and it is now very consistent from year to year. From April to August flows downstream of the reservoir are reduced and below natural values while from October to March they exceed natural flows. In September the change in the flow pattern is positive in some years and negative in others.

The highest reservoir inflows occur from late May to mid-July. It is during this period when the bulk of the reservoir storage occurs resulting in a substantially large reduction in the downstream flows along the South Saskatchewan River. On average, only about one-third of the inflow is released in this period. During the July through September period, the proportion of inflow released rises until releases from storage result in augmented outflows. This augmentation peaks in January when maximum hydroelectric generation results in flows more than four times that which would have occurred under natural (i.e., pre-dam) conditions. Through February and March the rate of release from storage declines. See the River Flow Alteration Indicator found in Appendix B for further details on the impact of the Gardiner and Qu’Appelle River dams on the South Saskatchewan and Qu’Appelle Rivers, respectfully.

In summary, the establishment of Lake Diefenbaker has resulted in much less seasonal variation in the flow of the South Saskatchewan River. Winter flows are much higher and early summer flows are much lower.

**Flood Control**

Because of its large storage capacity, Lake Diefenbaker reduces the severity of floods downstream from Gardiner Dam. Flood peaks are lower, which in turn lessens the damages associated with flooding and lowers the cost of flood protection measures. Lake Diefenbaker cannot, however, be operated to maximize flood control benefits without conflicting with other uses based on water supply (e.g., hydroelectric power generation).

Prior to the construction and operation of Lake Diefenbaker there were a number of flood events that had flows greater than 3,000 m$^3$/s, including 1923, 1929, 1932, and 1953. Since the project has been in operation, the flow range has been significantly narrower. The minimum release of 42.5 m$^3$/s has always been met since the fall of 1968. The maximum flow since the project was in operation was 1,900 m$^3$/s on June 26, 1975. This release occurred when a flood inflow was passed through the hydro turbines, supplemented by use of the spillway. Without Gardiner Dam, the flow downstream would have been 2,760 m$^3$/s. In recent summers, the maximum flows in 2005 was 1,830 m$^3$/s on June 22, 2005 and 1,570 m$^3$/s on June 18, 2011. Had it not been for the operation of Lake Diefenbaker the flows through Saskatoon would have been 3,711 m$^3$/s and 4,373 m$^3$/s, respectively (Water Survey of Canada).
**Water Quality**

The quality of water in the main stem of the South Saskatchewan River is very good, meeting the requirements of all existing and projected users. Upstream of Lake Diefenbaker the water quality varies by season with the rate of flow, but in the lake itself seasonal variations are reduced by the mixing of the water. The result of this process is that water downstream of Gardiner Dam is of relatively uniform quality.

In the SSEWS system, the quality of water at the upstream end is equal to that of the mainstem since it is drawn from Lake Diefenbaker. As the water moves downstream in the system, local surface and ground water inflows of less desirable quality are added and evaporation concentrates impurities resulting in a lower quality of water. Although less than ideal in the more distant reaches of the conveyance system, the quality of the water remains satisfactory for the uses made of it.

The vast distances and large volume of Lake Diefenbaker have kept pollution problems on the reservoir itself to minor levels. The erosion danger and resulting land use controls have benefitted water quality by keeping shoreline developments back from the lake so that wastes generated by human activities are less likely to reach the water, Bacteria levels are very low on most of the lake; the only bacterial pollution that has been identified is limited to the area near beaches that receive heavy public use.

Lake Diefenbaker shows some signs of nutrient enrichment (eutrophication) but this is mostly limited to the shallower (and warmer) west end of the lake. This area has elevated nutrient levels relative to the rest of the lake and isolated cases of near shore alga blooms have been noted. See the Water Quality Index found in Appendix B for further details on the water quality in the Lake Diefenbaker Watershed.

**Water Use**

In Alberta the water of the South Saskatchewan River is used for irrigation, municipal, industrial, hydroelectric power generation, fish, wildlife and recreation uses. On average, the flow of the river is reduced by about 1.9 billion m$^3$ per year, with irrigation taking about 95 percent of this water.

The largest water uses of the South Saskatchewan River in Saskatchewan are centred on Lake Diefenbaker. In an average year the total water losses from Lake Diefenbaker average about 400 million m$^3$ (400,000 dam$^3$) per year, with evaporation from Lake Diefenbaker accounting for about half of this amount. Evaporation losses average about 194 million m$^3$ per year but may approach 305 million m$^3$ or more in an extremely dry year - an amount roughly equivalent to one metre or more of water off the top of the reservoir. Diversion to the Qu'Appelle River and the East Side Pump Station (SSRID & SSEWS) are in average years 108,000 dam$^3$ and 77,500 dam$^3$. 
which together account for 2.8% of the inflow into Lake Diefenbaker, respectively (Table 6 and Figure 8).

Direct water use of Lake Diefenbaker, for irrigation, municipal and industrial uses, is around 52,600 dam$^3$, which is less than one percent of the inflow (Table 6).
### Table 6: Major Uses of Lake Diefenbaker Water

<table>
<thead>
<tr>
<th></th>
<th>Low Flow scenario</th>
<th>Median Flow Year</th>
<th>High Flow Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basis</td>
<td>1(^{(\text{dam}^3)})</td>
<td>2(^{(\text{m}^3/\text{s})})</td>
</tr>
<tr>
<td><strong>Inflow</strong></td>
<td>2001</td>
<td>2,672,000</td>
<td>84.7</td>
</tr>
<tr>
<td><strong>Net Evaporation (loss)</strong></td>
<td>1988</td>
<td>305,000</td>
<td>9.7</td>
</tr>
<tr>
<td><strong>Qu’Appelle Release</strong></td>
<td>1989</td>
<td>196,000</td>
<td>6.2</td>
</tr>
<tr>
<td><strong>East Side Pump</strong></td>
<td>1988</td>
<td>155,000</td>
<td>4.9</td>
</tr>
<tr>
<td><strong>Direct Use</strong></td>
<td>2007-2010</td>
<td>52,600</td>
<td>1.7</td>
</tr>
<tr>
<td><strong>Total uses and loss</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Outflow</strong></td>
<td>Inflow minus use</td>
<td>1,963,000</td>
<td>62.3</td>
</tr>
<tr>
<td><strong>Minimum Flow</strong></td>
<td>Operating Plan</td>
<td>1,340,000</td>
<td>42.5</td>
</tr>
<tr>
<td><strong>Hydro generation flow</strong></td>
<td>1,963,000</td>
<td>62.3</td>
<td>6,456,000</td>
</tr>
<tr>
<td><strong>Spill</strong></td>
<td>1988</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

1\(^{(\text{dam}^3)}\) - represents a volume of 1 cubic decametre, which is equivalent to 1,000 cubic metres.
2\(^{(\text{m}^3/\text{s})}\) – cubic metres per second.
Figure 8. Lake Diefenbaker water balance for low flow year (Low flow – 2,672,000 dam$^3$, 85 m$^3$/s).

Figure 9. Lake Diefenbaker water balance for median flow year (Median – 6,887,000 dam$^3$, 218 m$^3$/s).

Figure 10. Lake Diefenbaker water balance for high flow year (High flow – 11,900,000 dam$^3$, 377 m$^3$/s).
Figure 8 provides the water balance of Lake Diefenbaker in a low flow scenario, where annual inflow into the reservoir is 2,672,000 dam$^3$, 85 m$^3$/s. During low flow years the net evaporation from the reservoir can account for as much as 11% of the inflow. Water diversions in low flow years can almost double those of median flow years. In the low flow scenario the minimum flow requirement was 50% of the annual inflow. Figure 10 provides the water balance of Lake Diefenbaker in a high flow scenario, where annual inflow is 11,900,000 dam$^3$, 377 m$^3$/s. In the high flow scenario the minimum flow requirement is 11% of the annual inflow. In the median flow scenario (Figure 9), where annual flow is 6,887,000 dam$^3$, 218 m$^3$/s. The minimum flow requirement for median flow years is 20% of the annual inflow.

There are a number of non-consumptive uses of Lake Diefenbaker water. These include the generation of hydropower directly at the Coteau Creek hydroelectric station and indirectly at the downstream E.B. Campbell and Nipawin hydroelectric stations. The Coteau Creek station can generate hydroelectric power at flows ranging from 42.5 to 425 m$^3$/s; in most years all of the inflow to Lake Diefenbaker is used to generate electricity.

Lake Diefenbaker’s size and extensive shoreline offer enormous potential for water-based recreation activities like swimming, boating and fishing. Three provincial parks are located on the shore of the lake along with a number of cottage and beach developments.

Other non-consumptive uses of Lake Diefenbaker include its support of a baitfish fishery and as wildlife habitat. The aesthetic value provided by such a large body of water is perhaps Lake Diefenbaker’s greatest, yet unquantifiable, benefit.

**Minimum Flow**

One of the most important factors affecting Lake Diefenbaker operation relates to the minimum flow which must be maintained in the river downstream of Gardiner Dam. A detailed study was undertaken in 1963 to determine minimum flow requirements (Blackwell 1963). Factors evaluated during the study included:

- the water requirements for sewage effluent dilution of Saskatoon;
- elevations of water intakes at the Queen Elizabeth Power Station and at water intakes for Outlook, Saskatoon, St. Louis and the many private irrigators along the river;
- operation of ferries which cross the river;
- recreation use;
- fishery requirements; and,
- hydropower generation considerations at the Coteau Creek power station.

The study concluded that a minimum daily flow of 42.5 m$^3$/s at Saskatoon was appropriate (Blackwell 1963). This was then set as the minimum flow that would be permitted and operation plans were designed to meet this value. This minimum flow requirement was subsequently re-evaluated by an independent study in 1982 and the legitimacy of the 42.5 m$^3$/s value confirmed.
The natural flow regime varied significantly between 1912 (when flow records were first collected on the South Saskatchewan River at Saskatoon) until the mid 1960s, when Lake Diefenbaker began influencing the flow. The lowest flow ever measured, 14.2 m$^3$/s, occurred December 12, 1936. The highest flow occurred June 15, 1953, when 3,936 m$^3$/s was measured. The median low flow was 31 m$^3$/s and the median annual maximum flow was 1,275 m$^3$/s. Since the project has been in operation, the flow range has been significantly narrower. The minimum release of 42.5 m$^3$/s from Lake Diefenbaker has always been met since the fall of 1968. The maximum flow since the project was in operation was 1,900 m$^3$/s on June 26, 1975.

In summary, the daily mean flow extremes which ranged from 14.2 to 3,936 m$^3$/s prior to the project now range from 42.5 to about 2,500 m$^3$/s and the normal or median range which was from 31 m$^3$/s to 1,275 m$^3$/s is now from 70 to 400 m$^3$/s. The minimum flows are two to three times higher now and the maximum flows are one-third to two-thirds of the pre-project conditions. The median maximum daily flow historically exceeded the minimum daily flow by a factor of 41. The ratio is now six.

The new higher minimum flow makes the river a better and more convenient water supply source and a more reliable assimilator of sewage effluent and other pollutants. The lower flood peaks make the river and its floodplain less hazardous and reduce the costs of downstream bridges. In general, reducing the extremes of flow improves the river's compatibility with human activity.
Figure 11: Water Use in the South Saskatchewan River Basin in Saskatchewan.
Master Agreement on Apportionment
In 1969, the governments of Canada and the three Prairie Provinces reached an agreement on an equitable formula for sharing the water resources of the Saskatchewan River system. The Master Agreement on Apportionment, administered by the Prairie Provinces Water Board, governs the quantity and quality of water in all interprovincial eastward flowing streams including the South Saskatchewan River. In general terms, it specifies that:

- Alberta must pass half of the natural flow in the river to Saskatchewan;
- Alberta is allowed to consume 2.6 million dam\(^3\) of water annually, even if this exceeds half of the flow;
- Alberta must maintain a minimum flow of 42.5 m\(^3/\)s to Saskatchewan or half the minimum flow, whichever is less; and,
- Saskatchewan must pass to Manitoba half of the flow it receives from Alberta and half of all flow originating in the Saskatchewan portion of the basin.

Accordingly, operation of Lake Diefenbaker must meet Saskatchewan's commitment to Manitoba. This obligation has not been a significant constraint to reservoir operations. However, apportionment needs may become an increasingly important aspect to reservoir operations as development and use of this water resource in Saskatchewan continues to grow.

Canada-Saskatchewan South Saskatchewan River Basin Study
The Canada-Saskatchewan South Saskatchewan River Basin Study was a joint, five-year study focussed on the Saskatchewan portion of the basin that began in 1986 (Canada-Saskatchewan. 1991). Several events in the early 1980s led to increasing concern about the ability of the river to meet future needs, and, ultimately, to the decision to undertake a comprehensive study of the basin’s water resources and use. Figure 11 provides readers with an understanding of how and where water is used in Saskatchewan’s portion of the South Saskatchewan River Basin.

The water resources of the South Saskatchewan River are extensively used by Alberta where more than 500,000 hectares of land are under irrigation (Technology & Innovation Branch of Alberta Agriculture and Food 2000). Alberta studies in the 1980s suggested it was possible to increase the land area being irrigated in the basin.

At the same time in Saskatchewan, planning studies were promoting further development based on the water resources of the South Saskatchewan River, particularly Lake Diefenbaker. These plans included significant irrigation development along with proposals to continue developing the recreation potential of the reservoir.

While further development was being considered for both the Alberta and Saskatchewan portions of the river basin, several drought years occurred. Not unexpectedly, the droughts led to increased demand for water while supply was reduced, in turn leading to concerns in
Saskatchewan that Lake Diefenbaker might be unable to support continued development. Exacerbating these supply concerns were fears that dropping water quality in the lake were a signal that long term quality was at risk.

The possibility of increased development, coupled with reduced supply, led to general concerns over the possible effects on existing users should the various proposed diversions of water from the South Saskatchewan River proceed. It became evident that a comprehensive study was needed to collect new information to accurately assess the importance of the basin’s water resources to existing and future water users.

In addition to commissioning a number of technical investigations, the study undertook three separate planning exercises with different timeframes: a short term (year 2000), a long term (year 2020) and a system limit. The latter helped set the context of the long term planning exercise by identifying the development limits of the Saskatchewan portion of the basin.

South Saskatchewan River Watershed Plan
The purpose of the South Saskatchewan River Watershed Background Report (Saskatchewan Watershed Authority 2006a) was to provide contemporary information on the physical, social and economic characteristics of the watershed that would subsequently be used to assist in the formulation of a watershed management plan. The background report provides information on population and demographics, economic activities and land use, climate, physical and topographical characteristics including soils, surface and ground water availability, water allocations, trends in water use and wastewater disposal and treatment. Information about inter-provincial water management agreements, ecosystem health, sound wetland and riparian management, and wildlife biodiversity is also included as a discussion of real or perceived threats to source waters.

The South Saskatchewan River Watershed Source Water Protection Plan, drawing in large measure on information provided in the background report, identifies issues and interests related to source waters, and provides strategies for addressing them (Saskatchewan Watershed Authority 2007a). The plan’s focus is source water protection and includes an analysis of the issues and perceived threats, a commitment to action, timelines and responsibilities, and a means of measuring and evaluating the results.

Issues Associated with Lake Diefenbaker and its Operation

Irrigation
Irrigation projects that use the lake as a water source benefit from a lake level that is high and stable throughout the irrigation season. This reduces the difference in elevation between the lake and the irrigated area and, thus, the cost of pumping water. In contrast, irrigation projects along
the river downstream of Lake Diefenbaker benefit from stable river flows that provide a constant supply to water intakes.

A lake level that changes significantly over the course of a year requires expensive intake works to accommodate the variations. The irrigation season in the Lake Diefenbaker area runs from May to September. Operating for high lake levels throughout this period would conflict with, and compromise, flood protection and hydropower production.

**Recreation Uses**
Recreation uses around the lake favour stable levels. However, as with irrigation, maintaining a stable reservoir elevation limits opportunities to meet the needs of other users. During the development of Lake Diefenbaker, the wide range of lake levels that occur as the reservoir is operated were anticipated and most recreation facilities were designed to accommodate the variations. In addition, shoreline developments are controlled through land use regulations to prevent developments that would conflict with the operation of the project for all users.

**Hydroelectric Power Generation**
Hydroelectric power generation at Lake Diefenbaker benefits from flow regulation and the resulting seasonal lake and daily river fluctuations. Electricity is most valuable when demand is highest and alternative energy sources are most expensive. Energy demands vary widely with the time of day, day of the week, and season. Using the storage of Lake Diefenbaker to provide hydropower to coincide with peak electricity demands can result in significant savings in generation costs at other power stations that use coal or natural gas to produce electricity. These reservoir operations and the storage of water in Lake Diefenbaker has a compounding benefit for power production at downstream hydro stations.

**Piping Plover**
The Piping Plover (*Charadrius melodus*) is an endangered shorebird. A small sand-coloured, sparrow-sized bird, the Piping Plover nests and feeds along coastal sand and gravel beaches in North America. Currently, there are approximately 6,000 Piping Plovers in the world, and about one-third of the Great Plains population lives in Saskatchewan. Lake Diefenbaker is one of the most important breeding sites for the Piping Plover in North America (Dunlop 2001).

Piping Plovers typically nest on beaches and are attracted to the wide beaches normally found at Lake Diefenbaker in the spring. Since the majority of the lake's inflow comes from mountain run-off, water levels are typically the lowest in early spring, and begin to rise until full supply levels are met in early to mid-July. The change in water levels is typically about six metres. As water levels rise with spring run-off, nests can be flooded and the habitat for chicks can disappear. Predators can also spot the birds more easily when the beach area is reduced due to
high water levels. Water level fluctuation can dramatically reduce the birds’ reproductive success in some years.

Piping Plover success at Lake Diefenbaker was first studied by Rick Espie (1994) as a follow up to the 1991 International Piping Plover Census. There have been various studies since then. However, intensive ongoing monitoring and management of the reproductive success of Piping Plover at Lake Diefenbaker did not begin until 1997. Between 1997 and 2004, the Canadian Wildlife Services (CWS) monitored Piping Plovers. In 2005, the CWS and the Saskatchewan Watershed Authority jointly monitored the Piping Plover population. Since 2006, the Water Security Agency (formerly Saskatchewan Watershed Authority) has been responsible for monitoring the Lake Diefenbaker population (Corie White, 2012).

A number of tools have been used in an attempt to improve the reproductive success of the Piping Plovers nesting along Lake Diefenbaker’s beaches, including:
- the use of predator control exclosures;
- translocation of nests that are at risk for flooding; and,
- use of a Mylar Flagging grid to prevent nesting in low lying areas susceptible to flooding.

A draft Conservation plan has been developed to guide risk reduction and management activities for Piping Plovers at Lake Diefenbaker. The objective of this Conservation Plan is to establish a decision-making process and strategies that effectively balance the regulatory and conservation requirements of Piping Plovers with existing multi-purpose water management objectives for Lake Diefenbaker, and coordinate the activities of responsible agencies.

Within the Lake Diefenbaker Watershed, critical habitat for the Piping Plover has been identified around six water bodies, including: two lakes in Saskatchewan: Lake Diefenbaker and Freefight Lake; and four lakes in Alberta, including: Dowling, Handhills, Little Fish and Chain #4 Lakes (Environment Canada 2009a and 2009b). In addition to nesting within the Lake Diefenbaker Watershed, Piping Plovers also occasionally nest on sand bars downstream of Gardiner dam along the South Saskatchewan River.

**Regional Development**

A reliable supply of good quality water is a prerequisite for all types of economic growth and development. New industries provide jobs and incomes and benefit not only workers but also the communities and regions in which they live. Not surprisingly, municipalities are acutely aware of the important role water supplies play, not only in their survival, but also in their continued growth.

Since the South Saskatchewan River is the only large, reliable source of good quality water in the southern part of the province, it is regarded as a regional resource. It has supplied water to
Regina, Moose Jaw and nearby communities since the mid-1950s, after the needs of population and industrial growth exceeded the local water supplies. Similar water supply limitations restricting the development of potash mining southeast of Saskatoon and led to the construction of the SSEWS system which made a reliable and good quality water supply available from Lake Diefenbaker.

In addition to the passive role that water can play in the regional economy, water resource development can be used as a means of actively promoting regional economic growth. This approach involves the development of new economic enterprises that are heavily dependent on water; examples include irrigation, hydro-electric power generation and tourism. In addition to the direct outputs, these initiatives introduce diversity, and thereby stability, to the regional economy.

One of the major water based economic initiatives with a focus on Lake Diefenbaker has been irrigation development. A central part to the original concept of the South Saskatchewan Project examined by the Royal Commission in 1949, a comprehensive plan for irrigation development was again revisited in 1986. That year the Governments of Saskatchewan and Canada concluded an agreement that would see them provide $75 million over a five-year period for the development of new irrigation with Lake Diefenbaker as the source of water.

Saskatchewan also promoted tourism with the development of: three Provincial Parks (Danielson, Douglas and Saskatchewan Landing); the harbour, golf course and campground complex at Elbow; various regional parks (Cabri, Coteau Beach, Eston Riverside, Herbert Ferry Park, Hitchcock Bay, Outlook, Palliser, Prairie Lake); and subdivisions along the shores of Lake Diefenbaker. Lake Diefenbaker has considerable unrealized recreational potential that can be developed within the existing water resource infrastructure.

**Saskatoon South East Water Supply (SSEWS) System Issues**

This system has some unique water resource management issues. Ground water inflow, saline conditions in the soils and high evaporative losses on the SSEWS system result in declining water quality as the water moves through the system. This reduced water quality has potential implications for recreational, irrigation and municipal water users located along the system.

Potential water supply shortages are another issue. During the drought of 1984, it became necessary to ration water on the SSEWS system. This shortage was determined to be insufficient pump capacity and was addressed with the installation of another pump. The longer-term issue, however, is the limitation imposed by the conveyance capacity of the canals. Eventually, the SSEWS system will not be able to supply increasing demands.
**Flooding**
The largest flood since Gardiner Dam was constructed was in 1975 when the outflow from Gardiner Dam peaked at 1,900 m$^3$/s, compared to flows before the construction of Gardiner Dam. However, Lake Diefenbaker is neither designed nor operated solely as a flood control project. While the Watershed Authority will make every effort to use Lake Diefenbaker to reduce the impact of a serious flood, the reservoir cannot eliminate flooding. In the event of an extreme flood, the project will reduce damages but will not eliminate them.

The impacts of flooding can be reduced in two ways. In the short term, flood effects can be reduced through forecasting. Flood forecasts provide a basis for appropriate adjustment in the operation of the reservoir, taking advantage of available storage capacity to attenuate peak flows. Forecasting also provides lead time for landowners and municipalities adjacent to the river to prepare and take appropriate action. Advance warning reduces the potential for property damage and loss of life.

The second way in which flood effects can be reduced involves a long-term, integrated approach that employs both structural and non-structural methods. Typically, municipal zoning bylaws are used to prevent the location of buildings or other structures prone to flood damage in the flood hazard area. Zoning controls are often supplemented with structural measures such as dyking and wet proofing of structures to further reduce flood risk. The Water Security Agency (formerly Saskatchewan Watershed Authority) has also mapped flood risk in areas of the South Saskatchewan River Valley around the city of Saskatoon and surrounding RM$s$. Saskatoon and surrounding RM$s$ do have bylaws controlling development within the identified flood risk zones.

**Drought Resilience**
Drought is a critical consideration for the operation of Lake Diefenbaker. Droughts impact society, the economy, and the environment. To mitigate the impacts of drought on water users it is vital that the reservoir be operated for drought resilience. The best way to mitigate for drought resilience is to not carry water deficits forward to future years. Multiple years of drought and water supply restrictions have and can have significant economic and convenience impacts on water users. However, managing for drought does have to be done with consideration of other operational objectives. For example, if water levels are kept high to provide drought protection the ability to provide flood protection is reduced. To provide some protection from either drought or flood the reservoir operators use river forecasting to try and operate to maximize total benefits.

**Eutrophication**
Lake Diefenbaker is beginning to show signs of eutrophication. The west end of the lake has elevated nutrient levels relative to the rest of the lake and isolated cases of near shore alga blooms have been noted. There is concern that with time the enrichment may spread to other
areas of the lake.

Plant productivity in a lake is controlled by factors such as temperature, light penetration and availability of nutrients. Nitrogen and phosphorus, the major plant nutrients, originate from both human and natural sources. Phosphorus is the limiting nutrient in Lake Diefenbaker, entering the reservoir as a result of upstream municipal and agricultural activities. Most of the phosphorus is attached to sediments carried by the South Saskatchewan River and deposited in the lake.

Lake Diefenbaker is a phosphorus sink; that is, more phosphorus enters than leaves. Most of the phosphorus in the river sediments is trapped in the lake and the majority of the dissolved phosphorus is consumed by algal growth. On average, only 16 tonnes of dissolved phosphorous were discharged with the river water at Gardiner Dam compared to the 58 tonnes arriving from upstream.

**Shoreline Management and Reservoir Development Areas**

Lake Diefenbaker is located in a region with few natural lakes and recreation was one of the primary benefits identified from construction of the South Saskatchewan River project. Ensuring that this recreational potential is achieved without compromising the other critical water supply and flow regulation purposes of the lake is an on-going water management issue.

Shoreline development can generate water and noise pollution and result in conflicts among different uses. Fortunately, the lake’s long shoreline provides an opportunity for incompatible users to distance themselves from each other. As use grows, however, conflicts may develop.

During construction, extensive studies and planning for the reservoir’s development were completed. This work indicated that erosion of the valley walls would give the lake a very active shoreline. Since water levels fluctuate through a range of seven to eight metres in most years, the wave action on the shore is not limited to one level; erosion occurs over the full range.

On mature lakes, beaches develop which help absorb the force of waves and provide reasonably effective shoreline protection. The original valley walls were quite irregular in alignment but water erosion attacks headlands and fills bays. Erosion will, in time, provide Lake Diefenbaker with a normal shoreline that offers flat beaches and a smooth alignment. During construction, it was recognized that typical shoreline developments characterized by ‘lakefront’ cottages built close to the shore would be impractical as they would be destroyed by erosion. Several strategies were implemented to address the problem.

First, the land purchased for the lake included a generous erosion allowance to minimize any effects on private land. Secondly, legislation and regulations to establish land use control through
the establishment of Reservoir Development Areas (RDAs) were passed. The RDAs encourage appropriate shoreline development in specific, designated areas where shoreline erosion can be accommodated.

In spite of the comprehensive planning and controls, problems have occurred. The land purchase provided adequate setback between the lake and private land along most of the shore but erosion had exceeded the take line in a few locations by 1979 and small additional land areas were purchased. All significant erosion is now limited to project lands (Figure 12).

Anecdotal information indicates problems with shoreline erosion at Elbow Harbour and the Elbow Harbour Golf Course within the Elbow Recreation Site. Observations also indicate significant erosion has also occurred in the foreshore areas adjacent to the Resort Village of Coteau Beach. In both instances, engineered shoreline protection measures have been necessary.

An additional effect of the ongoing shoreline erosion has been the exposure of historic artifacts and sites of archaeological significance.
Figure 12: Lake Diefenbaker Reservoir Development Area.

Riparian Areas

Riparian areas within the Lake Diefenbaker Watershed have been impacted by flooding, erosion, flow regulation and agriculture. To understand the impacts these stressors have had on these ecosystems, 463 lotic and 74 lentic riparian health assessments have been conducted within the Lake Diefenbaker Watershed. However, only a handful of these health assessments were conducted along Lake Diefenbaker (see Riparian Areas Indictor in Appendix “A”). To further understand the health of riparian areas around Lake Diefenbaker and to identify the sites highly susceptible to erosion additional riparian health assessments need to be conducted around Lake Diefenbaker’s shorelines.

Water Supply Issues

Climate Change

Climate change is a relatively new factor that has become part of the water supply equation. Current climate change research suggests that the total amount of precipitation in the South Saskatchewan River basin is unlikely to change significantly over the next 40 years. However,
there is considerable uncertainty about the effects and estimates range from an increase in flows of some eight percent or a decline of 22 percent.

The most probable effect of climate change in this region is an alteration in the timing and amount of water flows through the year. Climate models further suggest that higher temperatures will be experienced, increasing evaporation and reducing soil moisture reserves. The frequency of extreme weather events, such as heavy rains or droughts, may increase and droughts may become longer and more severe.

Changes in the timing and quantity of water flows will likely first be felt in the area of instream requirements and the minimum flows needed to maintain a healthy ecosystem. A warming climate means rising water temperatures; warmer water usually means declining water quality. Offsetting these effects would probably require an increase in minimum flows which, of course, reduces the water available for other uses.

A changing climate will alter the demand for water, both in Saskatchewan and upstream in Alberta. There will likely be a demand for more irrigation in both provinces as the higher evaporation rates associated with warmer temperatures increases the benefits of irrigation over dryland agriculture and an increased risk of droughts makes irrigation a better hedge against the weather. Longer growing seasons may allow farmers to select higher-value crops that also increase irrigation water demands.

To understand the potential impacts of climate change on Lake Diefenbaker we need to further understand the impact of climate change on stream flow in Alberta, as approximately 98 percent of inflow to Lake Diefenbaker comes from Alberta. One such study, conducted by St. Jacques et al. (2010), analyzed historical streamflow records from southern Alberta and environs to determine if significant trends in flow existed which could be attributable to global warming. Their research found that streamflows were declining at seven of the 12 gauges they monitored (see Table 7).
Table 7: Trends in Southern Alberta Streamflows

<table>
<thead>
<tr>
<th>Flow Record</th>
<th>Record Period</th>
<th>Significant Linear Trend in Actual Recorded Flow</th>
<th>Percentage Change/Year in Actual Recorded Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Castle River Near Beaver Mines</td>
<td>1945-2007</td>
<td>none</td>
<td>-0.04</td>
</tr>
<tr>
<td>2) Highwood River At Diebel's Ranch</td>
<td>1952-2007</td>
<td>none</td>
<td>0.43</td>
</tr>
<tr>
<td>3) Bow River At Calgary</td>
<td>1912-2007</td>
<td>decreasing</td>
<td>-0.16</td>
</tr>
<tr>
<td>4) Elbow River Below Glenmore Dam</td>
<td>1911-2007</td>
<td>decreasing</td>
<td>-0.7</td>
</tr>
<tr>
<td>5) Spray River At Banff</td>
<td>1911-2007</td>
<td>decreasing</td>
<td>-2.2</td>
</tr>
<tr>
<td>6) Bow River at Banff</td>
<td>1911-2007</td>
<td>decreasing</td>
<td>-0.12</td>
</tr>
<tr>
<td>7) Red Deer River At Red Deer</td>
<td>1912-2007</td>
<td>decreasing</td>
<td>-0.22</td>
</tr>
<tr>
<td>8) Oldman River Near Lethbridge</td>
<td>1912-2007</td>
<td>increasing</td>
<td>-0.76</td>
</tr>
<tr>
<td>9) Waterton River Near Waterton Park</td>
<td>1912-2007</td>
<td>none</td>
<td>-0.05</td>
</tr>
<tr>
<td>10) Belly River Near Mountain View</td>
<td>1912-2007</td>
<td>none</td>
<td>0.02</td>
</tr>
<tr>
<td>11) St. Mary River At International Boundary</td>
<td>1903-2007</td>
<td>decreasing</td>
<td>-0.46</td>
</tr>
<tr>
<td>12) South Saskatchewan River at Medicine Hat</td>
<td>1912-2007</td>
<td>decreasing</td>
<td>-0.36</td>
</tr>
</tbody>
</table>

Source: St. Jacques et al. 2010.

Irrigation

As already described, studies examining the potential for the South Saskatchewan River Project identified 200,000 ha of suitable land that was irrigable from Lake Diefenbaker. Currently, 41,000 ha of land are irrigated in the Lake Diefenbaker Development Area and an additional 13,000 ha is irrigated upstream and downstream of the development area. These areas use 196 million m³ of water annually and irrigation around the lake is valued at approximately $75 million each year.

Factors contributing to the slower-than-expected development of irrigation include reluctance among some farmers to adopt new technologies or to pursue a substantially different type of agriculture from the dryland techniques with which they are familiar, uncertain economic benefits of irrigation, and the lack of financial success experienced by some early irrigators, and the large capital cost of developing new irrigation areas.

The potential for the development of new irrigated areas extends well beyond the immediate areas around Lake Diefenbaker. Studies from the late 1970s and 1980s were undertaken to evaluate irrigation development proposals in adjacent watersheds that would also use Lake Diefenbaker as a water source. Some 60,000 ha of land in the Souris River basin of Saskatchewan were judged suitable for irrigation, and could be irrigated by means of a water
supply canal from Lake Diefenbaker. Another 25,000 ha of land suited to irrigation was identified along the Qu'Appelle River. More recent work suggests 45,000 to 55,000 ha of potentially irrigable land is located along the top of the Qu’Appelle River valley between Lake Diefenbaker and Buffalo Pound Lake.

The high costs of constructing and operating inter-basin canal and pumping systems make it unlikely that such infrastructure could be justified to support only irrigation. However, a multipurpose diversion scheme that supported not only irrigation but also provided water for municipal and industrial use might provide the basis for a viable business plan. In any case, the development of a large-scale diversion scheme would have significant economic, social and environmental effects on both the donor and receiving basins.

The effects of a diversion would be felt immediately as water supplies were reduced in the donor basin. Less water in Lake Diefenbaker would affect water supplies all the way downstream to Manitoba. More land being irrigated would translate into less electricity being produced (and, in particular, “clean” electricity generated without burning fossil fuels). Increased water withdrawal from Lake Diefenbaker will affect recreation, wildlife, and the environment, and the potential for increased nutrient enrichment and contamination of the river.

**Electric Power Generation**
From the perspective of an electrical utility the value of water can be defined as the equivalent megawatt hour of thermal generation required to replace hydro power during periods when hydro power is not available to meet customer demand. Hydro power provides approximately 26 percent of SaskPower’s total electrical generating capacity of 3,371 megawatts.

It is to SaskPower’s economic advantage to use its limited supply of hydro energy at those times when generating electricity by other means is more expensive. The company has, therefore, three major interests in Lake Diefenbaker and its operation. The first is the overall supply of water, a function of precipitation, runoff, upstream uses in Alberta and direct uses from Lake Diefenbaker, including evaporation. A second interest is the timing of releases through Gardiner Dam to maximize the net worth of the available water. Ideally, this would require the flexibility to release water during the periods of the hour, day or year when the alternative sources of energy are expensive and reservoir levels were high. Such flexibility, however, does not fully exist, as the needs of the other users of Lake Diefenbaker water have to be considered. The final interest is the absolute level of the lake, as the higher the level the more head available for turbines and thus the more energy can be produced. The conflict among users is well illustrated by normal hydro operation. Over winter the release of water to generate electricity draws the reservoir down. In the spring, the lake is refilled by runoff to the optimum summer levels for recreation and irrigation users. Unfortunately, not all years are the same - and in a low runoff year the lake cannot fill to the preferred summer levels.
Fish, Wildlife and Historic Resources

Although three provincial and three regional parks have been developed around Lake Diefenbaker, considerable opportunities remain to develop the lake into a major recreation base for both local residents and those living in Regina, Saskatoon, Moose Jaw and Swift Current. Because the area is largely undeveloped for tourism, substantial public investment in road, sewer, water supply infrastructure and facilities is likely required to induce private investment in recreation facilities.

The lake’s operation plan recognizes the benefit of high lake levels to recreational uses and calls for lake elevations of 1.6 to 1.9 m below full supply level by July 1st. However, this is not always possible and is particularly unlikely during low runoff years. Low lake levels have a variety of adverse effects on recreation uses, including the exposure of mud flats on the shoreline, blowing sand in exposed beach areas, increased distance to the water's edge and unusable boat ramps. Low water levels also cause problems for boating and sport fishing due to submerged trees and debris in the reservoir. Fish reproduction requires the maintenance of suitable lake levels during the spawning period.

Interests Downstream of Gardiner Dam

Water users downstream of Gardiner Dam have a variety of concerns related to the range, seasonal distribution and fluctuation of flows in the South Saskatchewan River. The concerns center on how the operation of Lake Diefenbaker, limited by years of high and low runoff, meets their water and flow requirements.

Some downstream interests believe the current minimum discharge from Lake Diefenbaker of 42.5 m$^3$/s is inadequate, particularly for the reach through Saskatoon, and should be increased.

Many irrigators use pipelines and portable pumps located on the water's edge to draw water directly from the South Saskatchewan River. Water levels that are too low or levels that fluctuate frequently cause operational problems. High flows can cause flooding problems for irrigators located in lower areas. Overbank flooding occurs in the Pike Lake-Moon Lake area at open river flows of about 1,000 m$^3$/s where up to 16,000 ha of agricultural land are at risk of flooding.

Low flows and water levels cause problems at permanent intake locations like the Queen Elizabeth thermal power plant, diversions to potash plants and Pike Lake and at municipal intakes. The problems range from the river shifting away from intakes to intakes plugging with sand and debris. Similarly, low flows can affect ferry crossings where minimum flows result in shallow water and exposed rocks.

Lake Diefenbaker operations significantly affect downstream recreational uses. For example, tourism in Saskatoon and at downstream sites like Batoche benefit from robust river flows and a healthy valley environment. In Saskatoon, the Meewasin Valley Authority has undertaken
considerable development along the river corridor as part of its long-term plans, resulting in a rejuvenated and accessible river valley through the city that is hugely popular with both local residents and visitors.

**Qu'Appelle River Diversion**
Construction of the Qu'Appelle River Dam included outlet works which could release sufficient water to the Qu'Appelle River to meet all existing and future needs to the year 2000. Needs that were considered in the planning studies of the early 1960s included the municipal requirements of the cities of Regina and Moose Jaw, industrial requirements like those of potash producer Mosaic, irrigation in the Qu'Appelle Valley and the maintenance of the eight lakes in the Qu’Appelle River valley for recreation use.

Although the dam was constructed with a discharge capacity of 68 m$^3$/s, the original water demand studies anticipated a probable upper limit for releases of approximately 21.6 m$^3$/s. Releases to the Qu'Appelle River began in 1968 when Lake Diefenbaker filled to an elevation that enabled gravity releases, and have occurred every year since. Releases can be made over the entire operating range of Lake Diefenbaker with the maximum flow rate limited to the capacity of the Qu'Appelle River channel. Since 1980, the maximum annual release was 196,000 dam$^3$, or 6.2 m$^3$/s continuous, and the average annual release has been 110,000 dam$^3$, or 3.5 m$^3$/s continually.

**East Side Pumping Plant Diversions**
The East Side pumping plant at Lake Diefenbaker was designed so that water can be pumped with a reservoir level as low as 545.6 masl. However, from a dam safety perspective, the lowest the reservoir level would be drawn down in the open water season would be 548.0 masl. Originally constructed to permit the diversion of water for irrigation, the pumping plant and its associated delivery works became operational in 1967. During 1967 and 1968, the SSEWS system extended the system to deliver water for irrigation, municipal, industrial, recreation and wildlife purposes. Currently, a median annual flow volume of 49 million m$^3$ is diverted each year through the East Side pumping plant for the SSEWS system and Outlook area irrigation projects during the May to September period. This volume is considerably less than the pump plant’s capacity of 180 million m$^3$ over the five-month period.

**New Water Diversions, Economic Development and Interjurisdictional Issues**
The Saskatchewan River system crosses provincial boundaries and downstream jurisdictions naturally have concerns over water use and developments that affect water quantity and quality. Increasing development tends to complicate management of any resource and water is no exception. The Prairie Provinces Water Board (PPWB) and the Master Agreement on Apportionment between Canada, Alberta Saskatchewan and Manitoba address these issues. Fortunately, there has always been a spirit of co-operation between the three Prairie Provinces and all are strongly committed to making the Apportionment Agreement work. The provinces are
aided in resolving water resource disputes by the federal government, which has direct responsibilities for inter-jurisdictional waters, monitoring stream flow and as a partner in the Apportionment Agreement and the PPWB.

Currently, new uses for Lake Diefenbaker water involve the water supply needs of proposed potash and irrigation developments. These projects either would draw water from a new canal from the reservoir or would use water from an already existing source such as Buffalo Pound Lake that would then be replaced with water from Lake Diefenbaker.

Preliminary studies are currently underway to evaluate a proposed channel project that would connect Lake Diefenbaker to Buffalo Pound Lake. This channel would run adjacent to the Qu’Appelle River, but on top of the valley and could provide water to irrigate 45,000 to 55,000 hectares of land. The proposed channel, some 12 m wide and 3 m deep, could convey up to 70 m$^3$/s and be supplied by a battery of pumps drawing from Lake Diefenbaker near the Qu’Appelle River Dam. Most of this water (30 to 45 m$^3$/s) would be used for irrigation while the remainder (20 to 25 m$^3$/s) would supplement Buffalo Pound Lake for uses further downstream in the Qu’Appelle River system.

A project of this scale would take ten or more years to construct and could cost in excess of $1 billion. Securing the needed financing would be a daunting task; nevertheless, the desire for new supplies of water is well established in semi arid environments like the southern prairies.

**Stressors to Lake Diefenbaker and the Lake Diefenbaker Watershed**

To better manage and protect the Lake Diefenbaker Reservoir for future use it is also important to determine the human activities (stressors) that are affecting the system and the impacts the South Saskatchewan River Project may be having on downstream ecosystems. Some of the stressors impacting Lake Diefenbaker, the Lake Diefenbaker Watershed, and downstream of the South Saskatchewan River Project include, surface water quantity, surface water allocation, aquatic fragmentation, nutrient loading, sedimentation, shoreline erosion, and climate change.

**Alteration of Surface Water Flow within the Lake Diefenbaker Watershed**

The natural flow regime in all of Lake Diefenbaker’s Sub-watersheds has been altered by changes in land use, water withdrawals, and structures such as dams and low-level crossings. To assess the amount of flow alteration that has occurred, Table 8 compares the difference between the average annual naturalized flow to the average annual recorded flow for Lake Diefenbaker’s seven Canadian sub-watersheds.
Table 8: Mean annual recorded and naturalized flow volume of Lake Diefenbaker’s Sub-watersheds

<table>
<thead>
<tr>
<th>Sub-watershed</th>
<th>Mean annual recorded flow¹ (dam³)</th>
<th>Mean annual naturalized flow² (dam³)</th>
<th>Percent of recorded flow/naturalized flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oldman River</td>
<td>2,011,000*</td>
<td>3,462,000*</td>
<td>58.09</td>
</tr>
<tr>
<td>Bow River</td>
<td>2,548,000*</td>
<td>3,951,000*</td>
<td>64.49</td>
</tr>
<tr>
<td>Red Deer River</td>
<td>1,804,000*</td>
<td>1,837,000*</td>
<td>98.20</td>
</tr>
<tr>
<td>Alberta’s portion of the South Saskatchewan River</td>
<td>4,734,000* (4,559,000)***</td>
<td>7,425,000* (7,413,000)***</td>
<td>63.76</td>
</tr>
<tr>
<td>Saskatchewan’s portion of the South Saskatchewan River</td>
<td>6,480,000**</td>
<td>8,510,000**</td>
<td>76.15</td>
</tr>
<tr>
<td>Swift Current Creek</td>
<td>37,000**</td>
<td>82,600**</td>
<td>44.79</td>
</tr>
</tbody>
</table>

Sources: Alberta Environment 2005a* and Alberta Environment 2005b* and Saskatchewan Watershed Authority 2010**

¹Annual recorded flow is the actual mean flow is the actual median flow volume recorded.
²Annual naturalized flow is the estimated mean flow in the absence of any human modification (e.g., dams, reservoirs, irrigation, allocation).
³dam³ represents a volume of 1 cubic decametre, which is equivalent to 1,000 cubic metres.

*** The Alberta portion of the South Saskatchewan River Sub-watershed originates at the confluence of the Bow and Oldman Rivers. Flow of Alberta’s portion of the South Saskatchewan River is, essentially, the sum of flow from the Oldman and Bow Rivers.

Annual flow at the outlet of the Red Deer River Sub-watershed was similar to the naturalized flow indicating very low net human water consumption from the river for this area. Annual recorded flow within the South Saskatchewan River Sub-watershed was also high relative to the naturalized flow, with the majority of water loss along this river reach occurring as a result of evaporative losses from Lake Diefenbaker and water diversion to the Qu’Appelle River. The other sub-watersheds in Alberta had average annual flow between 58 and 65% that of naturalized flow. This indicates that average net consumption of water from these sub-watersheds is close to 50% (See Table 9). As you can see from Table 9, the Alberta portion of the South Saskatchewan River has very little surface water allocation (~4%). However, because the Alberta portion of the South Saskatchewan River Sub-watershed originates at the confluence of the Bow and Oldman Rivers, it is the allocation within the Bow River and Oldman River Sub-watersheds that have resulted in the average annual flow being as low as 64% of the naturalized flow. The Swift Current Creek Sub-watershed had an average annual recorded flow less than 50% of the naturalized flow, indicating that this watershed also has a high amount of surface water allocation.

Surface Water Allocation within the Lake Diefenbaker Watershed

As indicated above surface water use is one of the primary stressors that have resulted in alterations of the annual natural flow within some of Lake Diefenbaker’s sub-watersheds. To
assess surface water use we are using the licensed allocation from each watershed. Allocation and use are not synonymous: allocation refers to the volume of water that a project is allowed to withdraw; use refers to the volume that is actually withdrawn. However, because use data are not as easy to obtain we are using allocation data to assess water use.

Table 9: Percent of naturalized flow that is allocated in surface water licenses.

<table>
<thead>
<tr>
<th>Sub-watershed</th>
<th>(^1)Average annual naturalized flow (dam(^3))</th>
<th>Licensed Allocation (dam(^3))</th>
<th>Percent of allocation/naturalized flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oldman River</td>
<td>3,462,000*</td>
<td>2,231,400***</td>
<td>64.45</td>
</tr>
<tr>
<td>Bow River</td>
<td>3,951,000*</td>
<td>2,561,200***</td>
<td>64.82</td>
</tr>
<tr>
<td>Red Deer River</td>
<td>1,837,000*</td>
<td>335,200***</td>
<td>18.25</td>
</tr>
<tr>
<td>Alberta’s portion of the South Saskatchewan River</td>
<td>7,425,000*</td>
<td>278,000***</td>
<td>3.74</td>
</tr>
<tr>
<td>Saskatchewan’s portion of the South Saskatchewan River</td>
<td>8,510,000**</td>
<td>817,744**</td>
<td>9.61</td>
</tr>
<tr>
<td>Swift Current Creek</td>
<td>82,600**</td>
<td>36,090**</td>
<td>43.69</td>
</tr>
</tbody>
</table>

Sources: Alberta Environment 2005\(^a\) and Alberta Environment 2005\(^b\), Saskatchewan Watershed Authority 2010\(^*\), and Alberta Environment 2007\(^***\)

\(^1\) Annual naturalized flow is the estimated mean flow in the absence of any human modification (e.g., dams, reservoirs, irrigation, allocation).

The Oldman River, Bow River, and Swift Current Creek Sub-watersheds all have more than 40% of their naturalized flows allocated through surface water licenses. This indicates that each of these watersheds have a high amount of water consumption within their boundaries. The Red Deer River, the Alberta portion of the South Saskatchewan River, and the Saskatchewan portion of the South Saskatchewan River Sub-watersheds all have a lower surface water allocation ratio. They each have less than 20% of the naturalized flow allocated in surface water licenses (Table 9).

In addition to allocations directly out of the South Saskatchewan River System there is also the possibility of future water diversions in Alberta and Saskatchewan from the South Saskatchewan River System. These projects would place added stress on the system by withdrawing additional water from the system.
Aquatic fragmentation within the Lake Diefenbaker Watershed
Upstream and downstream ecosystems can be ecologically impacted by intersecting barriers or control structures such as dams, weirs, drop structures, and other man-made systems which modify hydrologic flow. Some of the potential environmental impacts include: altered flow regimes; changes in water temperature; altered riparian communities due to changes in flooding patterns; and changes in habitat and migration patterns of fish and other aquatic species.

Five of the seven sub-watersheds have major dams that alter the flow of the mainstem rivers. The sub-watershed that does not have any major dams within its border is Alberta’s portion of the South Saskatchewan River Sub-watershed. The major dams in the Alberta portion of the Lake Diefenbaker watershed include: Ghost, Bearspaw, Glenmore and Bassano dams in the Bow River sub-watershed; Oldman River, Waterton River and St. Mary River Dams in the Oldman River sub-watershed; Dickson Dam in the Red Deer River sub-watershed; Gardiner and Qu’Appelle River Dams in the Saskatchewan portion of the South Saskatchewan River sub-watershed; and, Duncairn Dam in the Swift Current Creek Sub-watershed. Given the large number of dams and the various construction dates of the dams it was difficult to assess the alteration of the fluctuation in flow caused by the dams. However, in the next section, Alteration of Flow, the monthly natural fluctuations in downstream flows pre and post-construction of the South Saskatchewan River Project are assessed. One way to mitigate aquatic fragmentation includes building water control structures that incorporate a fish passageway.

Nutrients within the Lake Diefenbaker Watershed
Phosphorus and nitrogen are key nutrients associated with lake productivity. Greater concentrations of these nutrients are generally associated with increased algae and algal blooms. Large algal blooms result in decreased light penetration in lakes, decreased dissolved oxygen concentrations when blooms decompose, increased potential of algal toxin production, and decreased aesthetic value.

The headwaters and principal water source for the major rivers of the Saskatchewan River system occur in the mountains on the western side of Alberta. These headwaters have low nutrient concentrations. In contrast, prairie soils are naturally rich in nutrients and water draining these soils has correspondingly high nutrient concentrations. By the time the water reaches Lake Diefenbaker the nutrient concentrations are intermediate between these sources. This reflects both the inflow of higher nutrients from prairie soils and human activities that can also result in increased nutrient levels in rivers. Human activities known to increase nutrients in surface waters include effluent discharge from waste water treatment plants; fertilizers used by homeowners and agricultural producers; manure from livestock and livestock operations; industry and aquaculture.
Nutrient concentrations of nitrogen and phosphorus have been measured since the late 1960’s by the Prairie Provinces Water Board (PPWB) at their Alberta/Saskatchewan border sites on the South Saskatchewan River and the Red Deer River. The length of this record allows for assessment of long-term trends on these rivers prior to entering Lake Diefenbaker. The PPWB recently undertook such an exercise and found slight but significant decreasing trends for total and dissolved phosphorus concentrations at both the Saskatchewan and Red Deer River sites. Trends in total nitrogen were only analyzed since the early 1990’s due to a change in analytical methods at that time. Since the early 1990’s total nitrogen was not found to change significantly at the Red Deer River site and to have significantly increased at the South Saskatchewan River site. Salinity was also found to have significantly increased at both sites since 1980 (Citation).

To better understand how nutrient inputs can affect water quality researchers often study all the major nutrient sources and losses to lakes and reservoirs by undertaking nutrient mass balance studies. Such detailed nutrient mass balance budgets have not previously been investigated at Lake Diefenbaker. Likewise, few studies have examined in detail the spatial and temporal extent of nutrient limitation in the lake. In 2011 research was initiated through the University of Saskatchewan to better understand hydrologic and nutrient mass balances, nutrient limitation, sedimentation, and algal species found within the lake. These studies are designed to increase our understanding of the state of water quality in Lake Diefenbaker and its susceptibility to changes in flow and nutrient inputs.

**Shoreline Erosion along Lake Diefenbaker**

Lake Diefenbaker is a young reservoir with sandy soils and steeply sloped shorelines, in many areas, that are susceptible to erosion and slumping. Shoreline erosion and slumping can cause detrimental environmental impacts to aquatic ecosystems and recreational developments. Some of the aquatic ecosystem concerns of shoreline erosion include sedimentation and increased turbidity resulting in the reduction of photosynthesis and ultimately reduced dissolved oxygen.

Shoreline erosion is a natural process. However, the rate of shoreline erosion can be increased by some human activities, including:

1) Removal of rocks, trees, and other vegetation along the shoreline;
2) Waves created by watercraft;
3) Building of docks and boat launches;
4) Livestock access to the lake; and
5) Fluctuations in water levels due to the use of the reservoir for hydroelectric purposes.

Few studies have assessed shoreline erosion along Lake Diefenbaker. Penner (1993) conducted research at select sites along Lake Diefenbaker between 1991 and 1993 that focused on understanding the relationship between wave energy, soil types and erosion rates. Through this
study an erodibility coefficient was estimated for common shore material around the lake. Based on their findings Penner (1993) estimate that between 1968 and 1992, shoreline erosion rates were typically between 1 to 3 m/yr, with rates up to 6 m/yr occurring over short timeframes on some of the higher exposed slopes.

**Sedimentation within Lake Diefenbaker**
Sedimentation is caused by the transport of sediment along the river channel (bed load transport), from beach and bank erosion, and in land runoff. Sedimentation can result in silt burying benthic invertebrate communities and embedding fish spawning areas.

Currently information on the amount of sedimentation within Lake Diefenbaker is unknown, and is classified as a data gap. However, historical and current data have been/are being collected, including: 1) historical data collected, from 1965-1985, within Lake Diefenbaker is available. Historical data includes approximately 30 cross-sections, from Gardiner Dam to Saskatchewan Landing, that were sampled every five years between 1965 and 1985. Once analyzed, this data would provide baseline sedimentation information, as well as the sedimentation rate in the reservoir in the first 15 years of operation; and 2) sedimentation data is currently being collected by the Limnology Lab, aligned with the Global Institute for Water Security.

**Stressors on aquatic systems downstream of the South Saskatchewan River Project**

**Alteration of Flow Downstream of the South Saskatchewan River Project**
The natural fluctuations in stream flows are integral for sustaining the biodiversity and the health of connected ecosystems, such as flood plains, wetlands, and riparian areas. Changes in flow regimes affect the aquatic ecology of these ecosystems, and may result in alterations in aquatic habitat; aquatic communities; riparian zones, floodplains and wetlands; the stability of river channels; and water levels.

**Downstream of Gardiner Dam**
A Wilcoxon signed-rank test was used to assess significant change in monthly pre- and post-dam construction flows downstream of the Gardiner Dam. The Wilcoxon test is a non-parametric test used for comparing two related measures.

The impacts of flow regulation, caused by the hydroelectric development of Gardiner Dam and the Coteau Creek Generating Station, has resulted in statistically significant increases in median monthly flow and alteration of natural seasonal flow along the South Saskatchewan River downstream of the dam. The Wilcoxon Sign-Rank Test found that the median monthly flow of the South Saskatchewan River downstream of Gardiner Dam differed significantly for all months, except September and October, when comparing flow post dam construction versus flow prior to the dam being constructed (Table 10).
Table 10: Variation in South Saskatchewan River flow downstream of Gardiner Dam pre and post dam construction

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>October</td>
<td>138</td>
<td>157</td>
<td>0.24</td>
</tr>
<tr>
<td>November</td>
<td>103.1</td>
<td>217</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>December</td>
<td>69.65</td>
<td>238</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>January</td>
<td>62.75</td>
<td>276</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>February</td>
<td>64.55</td>
<td>271</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>March</td>
<td>81.7</td>
<td>211</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>April</td>
<td>272.8</td>
<td>134.5</td>
<td>0.01</td>
</tr>
<tr>
<td>May</td>
<td>362.5</td>
<td>98.6</td>
<td>0.01</td>
</tr>
<tr>
<td>June</td>
<td>728.5</td>
<td>165.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>July</td>
<td>498.5</td>
<td>162</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>August</td>
<td>231</td>
<td>150</td>
<td>0.01</td>
</tr>
<tr>
<td>September</td>
<td>160.8</td>
<td>128.5</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Note: Median flow is calculated using the median daily flow.

The operation of Gardiner Dam has resulted in altered natural flows for nine months of the year, with the exception of August, September and October. Not surprisingly, comparison of inflows and outflows after construction of Gardiner Dam (1967-2009) found significant differences between November and March, when the Coteau Creek Generating Station produces most of its electricity - outflows were significantly greater than inflows. During the months of April to July, when the reservoir is being filled, the inflows were significantly greater than the outflows (Table 11). Production of electricity is accordingly lower.
Table 11: Variation in South Saskatchewan River inflow to Lake Diefenbaker compared to outflow downstream of Gardiner Dam post dam construction

<table>
<thead>
<tr>
<th>Monthly flows</th>
<th>Post median inflow (m³/s): 1967-2010</th>
<th>Post median outflow (m³/s): 1967-2010</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>86.9</td>
<td>309</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>February</td>
<td>96.205</td>
<td>277.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>March</td>
<td>126.8</td>
<td>211</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>April</td>
<td>200.85</td>
<td>136.75</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>May</td>
<td>235.7</td>
<td>104.3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>June</td>
<td>573</td>
<td>156.75</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>July</td>
<td>286.05</td>
<td>136</td>
<td>&lt;0.004</td>
</tr>
<tr>
<td>August</td>
<td>155.8</td>
<td>130</td>
<td>0.092</td>
</tr>
<tr>
<td>September</td>
<td>119.35</td>
<td>121.5</td>
<td>0.732</td>
</tr>
<tr>
<td>October</td>
<td>123.7</td>
<td>157</td>
<td>0.072</td>
</tr>
<tr>
<td>November</td>
<td>118.7</td>
<td>219</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>December</td>
<td>84.35</td>
<td>242</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Note: Median flow is calculated using the median monthly flow.

In 2008, the Watershed Authority initiated a risk assessment to investigate the current or potential impact of water control structures on downstream environments. The risk assessment was conducted on 43 of the 45 water control structures that are owned and operated by the Authority. Five criteria were used to assess the water control structures, including:

- impoundment services (captured size and use of structure and reservoir);
- issue scope (captured political and regulatory implications of the structure);
- mitigation opportunities (captured flexibility and potential for change for a structure);
- hydrological impact (captured the impact of the structure on flow over time and space); and,
- watershed response (captured potential impact of structure on local ecology, water quality and potential future risk).

Based on the preceding five criteria, the Gardiner and Qu’Appelle River dams were ranked first and fourth, respectively, in terms of the highest potential environmental impact they may cause to the receiving water bodies (Pollock 2009). To further assess the ten dams that were ranked in the top ten, the Watershed Authority has been conducting environmental flow assessments to address environmental and ecological concerns related to control structures. (Pollock et al. 2011).
In the summer of 2008, to further evaluate in-stream flow along the North, South and Saskatchewan Rivers the Water Security Agency (formerly Saskatchewan Watershed Authority) initiated a survey of 15 locations along these rivers to assess the valuable foraging areas for lake sturgeon (*Acipenser fulvescens*), and associated fish species (Pollock et al. 2009). This study continues to be a focus for the Authority with year-round telemetry work and summer/fall lake sturgeon habitat surveys continue to be conducted.

**Downstream of the Qu'Appelle River Dam**

A Wilcoxon signed-rank test was used to assess significant change in monthly pre- and post-dam construction flows downstream of the Qu’Appelle River Dam (Table 12 and Table 13). The Wilcoxon test is a non-parametric test used for comparing two related measures.

**Table 12: Variation along the Qu’Appelle River flow downstream of Buffalo Pound Lake pre and post Qu’Appelle River Dam construction**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>October</td>
<td>0.08</td>
<td>0.77</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>November</td>
<td>0.11</td>
<td>0.8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>December</td>
<td>0.09</td>
<td>0.66</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>January</td>
<td>0.06</td>
<td>0.66</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>February</td>
<td>0.04</td>
<td>0.74</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>March</td>
<td>0.09</td>
<td>0.95</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>April</td>
<td>3.84</td>
<td>4.56</td>
<td>0.45</td>
</tr>
<tr>
<td>May</td>
<td>0.79</td>
<td>5.61</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>June</td>
<td>0.48</td>
<td>2.85</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>July</td>
<td>0.38</td>
<td>2.02</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>August</td>
<td>0.14</td>
<td>1.43</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>September</td>
<td>0.14</td>
<td>0.94</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Note: Median flow is calculated using the median daily flow.
Table 13: Variation along the Qu’Appelle River flow downstream of Eyebrow Marsh pre and post Qu’Appelle River Dam construction

<table>
<thead>
<tr>
<th>Monthly Flows</th>
<th>Median flow (m³/s) pre-impact period (1958-1966)</th>
<th>Median flow (m³/s) post-impact period (1967-2011)</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>October</td>
<td>0.42</td>
<td>1.75</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>November</td>
<td>0.43</td>
<td>1.41</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>December</td>
<td>0.22</td>
<td>1.22</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>January</td>
<td>0.22</td>
<td>1.21</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>February</td>
<td>0.17</td>
<td>1.28</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>March</td>
<td>0.18</td>
<td>1.73</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>April</td>
<td>7.48</td>
<td>10.46</td>
<td>0.2</td>
</tr>
<tr>
<td>May</td>
<td>2.54</td>
<td>8.11</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>June</td>
<td>1.33</td>
<td>5.06</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>July</td>
<td>1.1</td>
<td>3.83</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>August</td>
<td>0.58</td>
<td>2.68</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>September</td>
<td>0.5</td>
<td>2.07</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Note: Median flow is calculated using the median daily flow.

Comparing flow after dam construction versus flow prior to the dam being constructed revealed that the median monthly flow of the Qu’Appelle River downstream of both Eyebrow Marsh and Buffalo Pound Lake was significantly greater for all months, except April. Before construction of the Qu'Appelle River Dam, flow in the Qu’Appelle River was intermittent and, historically, had no flow in November, December, January or February.

Alteration of Water Temperature Downstream of the South Saskatchewan River Project
Phillips et al. (In Press) conducted a study to assess the effects of Gardiner Dam on the downstream temperature and biotic condition of the South Saskatchewan River. This study found that Gardiner Dam significantly decreased the temperature regime of the South Saskatchewan River up to 110 km downstream of Gardiner Dam, and consequently significantly impacted the health of the downstream benthic macroinvertebrate assemblages.

Sedimentation downstream of Gardiner Dam
Currently information on the amount of sedimentation downstream of Gardiner Dam is unavailable, and is classified as a data gap. However, we do have historical data collected from 1965-1990 downstream of Gardiner Dam to Saskatoon. This data includes approximately 30 cross-sections, from Gardiner Dam to Saskatoon, that were sampled every five years between 1965 and 1985. Once analyzed, this data would provide baseline sedimentation information, as well as the sedimentation rate downstream of Gardiner Dam in the first 15 years of the operation of the South Saskatchewan River Project.
Appendix A

Aquatic Ecosystem Health of Lake Diefenbaker
This section of the report will discuss the aquatic ecosystem health of Lake Diefenbaker.

A healthy aquatic ecosystem is one where human activities have caused no apparent change in function or services provided by water, and the system is both resistant and resilient to change. The health of Lake Diefenbaker’s aquatic ecosystem is important both locally and provincially. Lake Diefenbaker is a critical water resource that provides recreational opportunities, an irrigation and drinking water source, and other support services for over half of Saskatchewan’s population. The health of Lake Diefenbaker is a vital component for making informed management decisions.

To determine the health of aquatic ecosystems, physical, chemical, biological or socio-economic indicators that best represent the key elements of a complex ecosystem should be used. Nationally and internationally there are many programs that exist for assessing the health of surface water ecosystems.

To provide an initial assessment of the aquatic ecosystem health of Lake Diefenbaker the Water Security Agency (formerly Saskatchewan Watershed Authority) evaluated and synthesized existing water quality and benthic invertebrate data collected from Lake Diefenbaker. The initial step found that historically water quality data was collected sporadically both temporally and spatially; and there is very little historic or current benthic invertebrate data.

Between 1970 and 1992 water quality data was collected anywhere from one to nine times within a year from three to four sites along the lake. More recently water quality data has been collected by the Water Security Agency (formerly Saskatchewan Watershed Authority) and the University of Saskatchewan. In November 2009, the Water Security Agency (formerly Saskatchewan Watershed Authority) initiated a water quality monitoring program to collect water samples four times a year at four sites on Lake Diefenbaker. In the spring of 2011 the University of Saskatchewan initiated a sensitivity analysis study to assess the contribution of point and diffuse sources of nutrients to Lake Diefenbaker. Utilizing the water quality data collected in 2010 and 2011 and the Water Quality Index (methods are described in the Surface Water Quality Indicator section on page 53), the surface water quality of Lake Diefenbaker was rated as healthy.

Shortly after impoundment, an assessment of the benthic macroinvertebrates was conducted. This assessment found that between 1967 and 1969, the dominant benthic macroinvertebrates in all regions of the lake were chironomid larvae and oligochaetes (Royer 1972). Recent localized benthic invertebrate data were collected and analyzed by Fisheries and Oceans Canada in
relation to an application by Wild West Steelhead, a fish aquaculture company, for a new trout aquaculture site in Lake Diefenbaker (Sweeney International Management Corp. and SIMCorp Marine Environmental Inc. 2010). No recent lake-wide benthic macroinvertebrate assessments have been collected. Therefore, the health of the benthic invertebrate community of Lake Diefenbaker cannot be assessed.

While attempting to assess the health of Lake Diefenbaker it became apparent that data gaps existed. Due to the limited amount of data that have been collected, the aquatic ecosystem health of Lake Diefenbaker cannot be properly assessed. To properly assess the health of Lake Diefenbaker biological, chemical and physical data must be collected from a number of sites throughout the lake. As of the spring of 2011, some of these data gaps were being filled by the Global Institute for Water Security’s work to assess nutrient loading of Lake Diefenbaker. The data this organization is collecting includes: water quality data; paleolimnological sediment core data; and algal and bacterial data. Data that still needs to be collected to further understand the aquatic ecosystem health of Lake Diefenbaker includes benthic invertebrate data.
Appendix B

The State of the Lake Diefenbaker Watershed
This section of the report will assess the health of the Lake Diefenbaker watershed. The State of the Lake Diefenbaker Watershed section provides a benchmark for assessing the health of the watershed now and in the future. The report is based on scientific data and information available from the Water Security Agency (formerly Saskatchewan Watershed Authority), other government and non-government organizations. It is an indicator-based assessment with a rating system for each indicator. Data were assessed against a rating scheme and using geographical information systems (GIS)-based technology, easy-to-understand maps were produced highlighting the condition of the rural municipalities within the watershed. This reporting system will provide a basis for governments, decision-makers and the community to act in the long-term interest of the health of the Lake Diefenbaker watershed.

Condition Indicators
Condition indicators assess the health of the Lake Diefenbaker watershed at the sub-watershed level and were classified into three classes: Healthy, Stressed and Impacted.
Where we define a sub-watershed as:
● Healthy – if the sub-watershed has no apparent change in function or services provided by water, and the system is both resistant and resilient to change.
● Stressed – if the sub-watershed has no degradation in function and/or services it provides.
● Impacted – if the sub-watershed has a change and/or degradation in function and/or services.
Surface Water Quality Indicator
This indicator reports on the water quality in the Lake Diefenbaker Watershed.

| Indicator           | Status: In November 2009, the Water Security Agency (formerly Saskatchewan Watershed Authority) initiated intensive water quality monitoring on Lake Diefenbaker. Sites are sampled three to four times per open water season, including a spring, summer and autumn sample. The fourth sample is collected in conjunction with non-typical flow events (heavy inflow from rainfall or during high flow years) or water quality event (e.g., concerns related to water quality issues). |

The Issue
The quality of water affects is essential for supporting aquatic ecosystems and terrestrial ecosystems as well as providing the ecosystem services that support the beneficial use of water by humans, such as agriculture, aquaculture, fishing, recreation, tourism and swimming.

Geology, climate, ground water interactions, biotic processes and land-use practices all affect water quality. The ability to assess the state of water quality is important for evaluating lake, riverine and watershed health.
Figure 13: WQI values at water quality sampling locations within the Lake Diefenbaker Watershed: 2005 to 2010.

*Fewer than three of the six years have calculated Water Quality Index values.

Between 2005 and 2010, water quality samples were collected from 14 sites within Saskatchewan’s and 18 sites within Alberta’s portion of the Lake Diefenbaker watershed (Figure 13). All sub-watersheds had water quality samples taken during this timeframe. Of the 14 water quality sites in Saskatchewan, seven were monitored by the Swift Current Creek Watershed Stewards; four were monitored by the Water Security Agency (formerly Saskatchewan Watershed Authority) as part of the Lake Diefenbaker Water Quality Monitoring program; two were monitored by the Water Security Agency (formerly Saskatchewan Watershed Authority) in conjunction with Saskatchewan Ministry of Agriculture as part of the Baseline Environmental Monitoring of Lower Order Streams in Saskatchewan (BEMLOSS) program; and one was monitored by Saskatchewan Ministry of Environment as part of their Surface Water Monitoring Program. Of the 18 sites within Alberta, 16 are monitored by Alberta Ministry of Environment and two were monitored by Environment Canada as part of the Prairie Provinces Water Board.
The water quality data that were collected from four deep-water sites along Lake Diefenbaker, monitored by the Water Security Agency (formerly Saskatchewan Watershed Authority) as part of the Lake Diefenbaker Water Quality Monitoring program, do not currently have average WQI values for the past six years as they were only collected between November 2009 and December 2010. Of the one-year of water quality data for the four sites that had water quality samples collected along Lake Diefenbaker between November 2009 and December 2010, three had a WQI value of 90 or higher, indicating these sites were rated as healthy. The fourth site had a WQI that fell within the stressed category.

Figure 14: Six-year average of Water Quality Index values calculated by Watershed: 2005 to 2010.
Note: numbers within the watershed boundaries represent the number of sites with WQI values that were used to calculate the six-year average WQI value for the watershed.

Of the six sub-watersheds for which a six-year average WQI value could be calculated, the average WQI value is classified as healthy for four sub-watersheds and stressed for the Red Deer River and Swift Current Creek Sub-watersheds (Figure 14).
Within the Red Deer River Sub-watershed, historic and recent (1999-2003) water quality data exhibited a spatial trend of increasing Total Phosphorus and Total Nitrogen concentrations as you move from the headwaters downstream to the Alberta/Saskatchewan border. It is thought that this trend was likely due to agricultural and municipal nutrient inputs (North/South Consultants Inc. 2007).

**Indicator**
The Water Quality Index (WQI) is an effective means for summarizing a large number of water quality parameters. The WQI was created in 1997 by the Canadian Council of Ministers of the Environment. It is based on a formula developed by the British Columbia Ministry of Environment, Lands and Parks (Canadian Council of Ministers of the Environment 2005).

In the application of the WQI, values for various water quality parameters (e.g. dissolved oxygen, nutrients, fecal coliform) are compared to the Surface Water Quality Objectives for Saskatchewan (Saskatchewan Environment 2006a). The results of the comparisons are combined to provide a water quality ranking (e.g., Good, Fair, Poor) for individual water bodies. The advantages of this index are that it summarizes multiple water quality parameters in a single number, and it is effective as a communication tool. When the same objectives and variables are used, the index can be used to convey relative differences in water quality between sites and over time [care must be taken when comparing among sites because of natural variability in water quality constituents (e.g. a naturally saline lake would naturally have high concentrations of dissolved ions compared to a freshwater lake)]. The disadvantages of using the index include a loss of information, the sensitivity of the results to the formulation of the index, the reliance on objectives as a basis for assessing water quality, and the loss of information on interactions between variables.

The water quality parameters and associated objectives used for calculating the Water Quality Index are outlined in Table 14.
Table 14: Water quality parameters used for calculating the Water Quality Index.

<table>
<thead>
<tr>
<th>Water Quality Parameter</th>
<th>Non-compliance if:</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic Total</td>
<td>&gt; 5</td>
<td>µg/L</td>
</tr>
<tr>
<td>Chloride Dissolved</td>
<td>&gt; 100</td>
<td>mg/L</td>
</tr>
<tr>
<td>Chromium Total</td>
<td>&gt; 1</td>
<td>µg/L</td>
</tr>
<tr>
<td>Mercury</td>
<td>&gt; 0.026</td>
<td>µg/L</td>
</tr>
<tr>
<td>Unionized Ammonia</td>
<td>&gt; 19</td>
<td>µg/L</td>
</tr>
<tr>
<td>Oxygen Dissolved (Field)</td>
<td>&lt; 5.5</td>
<td>mg/L</td>
</tr>
<tr>
<td>pH</td>
<td>&lt; 6.5 or &gt; 9</td>
<td>Unit</td>
</tr>
<tr>
<td>Sodium Dissolved</td>
<td>&gt; 100</td>
<td>mg/L</td>
</tr>
<tr>
<td>2’-4-D</td>
<td>&gt; 4</td>
<td>µg/L</td>
</tr>
<tr>
<td>MCPA</td>
<td>&gt; 0.025</td>
<td>µg/L</td>
</tr>
<tr>
<td>Aluminum Total</td>
<td>&gt; 0.1</td>
<td>mg/L</td>
</tr>
<tr>
<td>Sulphate</td>
<td>&gt; 1000</td>
<td>mg/L</td>
</tr>
<tr>
<td>Coliforms Fecal</td>
<td>&gt; 1000</td>
<td>units/100mL</td>
</tr>
<tr>
<td>Phosphorous Total</td>
<td>&gt; 0.1</td>
<td>mg/L</td>
</tr>
<tr>
<td>Nitrogen Dissolved NO₃ &amp; NO₂</td>
<td>&gt; 2.9</td>
<td>mg/L</td>
</tr>
<tr>
<td>E. Coli</td>
<td>&gt; 200</td>
<td>units/100mL</td>
</tr>
<tr>
<td>Chlorophyll a (For lakes only)</td>
<td>&gt; 50</td>
<td>µg/L</td>
</tr>
</tbody>
</table>

**Indicator**

The index is calculated using three components that relate to water quality objectives:

**Scope** - How many? - The number of water quality variables that do not meet objectives in at least one sample during the index period, relative to the total number of variables measured.

**Frequency** - How often? – The number of individual measurements that do not meet objectives, relative to the total number of measurements made in all samples for the index period of interest.

**Amplitude** - How much? - The amount by which measurements which do not meet their objectives depart from those objectives (Davies 2006).

**Rating Scheme**

The Water Quality Index values range between 0 and 100, with zero representing the worst water quality and 100 representing the best water quality. Once the WQI value has been calculated, the value can be further simplified by assigning it to one of several descriptive categories (Canadian Council of Ministers of the Environment 2005):
Excellent: (WQI value 95-100) – water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels. These index values can only be obtained if all measurements are within objectives virtually all of the time.  
Good: (WQI value 80-94) – water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.  
Fair: (WQI value 60-79) – water quality is usually protected but occasionally threatened or impacted; conditions sometimes depart from natural or desirable levels.  
Marginal: (WQI value 45-59) – water quality is frequently threatened or impacted; conditions often depart from natural or desirable levels.  
Poor: (WQI value 0-44) – water quality is almost always threatened or impacted; conditions usually depart from natural or desirable levels.

For this document condition indicators are grouped into three categories: healthy, stressed, and impacted. Therefore, for this indicator the WQI categories have been grouped together into the following three categories:

| Water Quality Index | Healthy: The Water Quality Index value is between 80 and 100. | Stressed: The Water Quality Index value is between 45 and 79. | Impacted: The Water Quality Index value is less than 45. |

Data Source: Water Quality Index values are from Saskatchewan Ministry of the Environment’s Surface Water Monitoring Program; the Prairie Provinces Water Board’s Monitoring Program; the Water Security Agency’s (formerly Saskatchewan Watershed Authority) River and Lake Water Quality Monitoring; and the Water Security Agency’s (formerly Saskatchewan Watershed Authority) Lake Stewardship Monitoring Program.

Data Handling: Water Quality Index values are based upon multiple sampling dates per year. To ensure consistency of reporting, only sites with at least three water quality samples per year are included in this indicator. Yearly Water Quality Index values from 1993 to 2002 were averaged to obtain the ten-year values, and Water Quality Index values from 2003 to 2007 were averaged to obtain the five-year values.

Data Quality/Caveat: There are limitations in the representation of this indicator by watershed. The watersheds are shaded based on the average Water Quality Index value for all of the water quality sampling locations within that watershed. However, the Water Quality Index for any one watershed may be based on one water quality sampling location.

Response to the Issue  
Various studies have measured and continue to measure water quality in Lake Diefenbaker. These include: historic samples collected by Saskatchewan Environment (available in SEEMS),
sampling by the Buffalo Pound water treatment plant, from the Riverhurst Ferry (usually surface water during the spring), specific studies (e.g., University of Saskatchewan (Giesy 2009), lake sampling undertaken by Dr. Leavitt at the University of Regina, Environment Canada’s present examination of nutrient sequestration by Lake Diefenbaker (upstream/downstream sampling) and by SaskPower (Parker 2010)).

There has been, and continues to be, greater emphasis on monitoring upstream and downstream water quality in the South Saskatchewan River and on the Qu’Appelle River than on understanding the water quality in Lake Diefenbaker itself.

In November 2009, the Water Security Agency (formerly Saskatchewan Watershed Authority) initiated water quality monitoring on Lake Diefenbaker. This monitoring program was initiated to assess long-term changes in water quality for the lake as a whole and for specific near-shore regions of the lake as issues are identified. The data gathered from this program provides the information needed to address both short- and long-term management issues relating to water quality in Lake Diefenbaker so that the lake continues to be a source of high economic, social and recreational value to the province.

The specific objectives of the Lake Diefenbaker Monitoring program include:

1) to more clearly define changes in nutrient concentrations within Lake Diefenbaker and provide a basis for assessing the potential risk from various human activities;
2) to provide water quality data to better evaluate management for downstream in-stream flow needs;
3) to test the water for agro-chemicals. If none are found at or above detection limit this analysis will only be undertaken on an intermittent basis;
4) to identify and assess water quality at specific near-shore areas where higher-risk activities are occurring and compare them to reference sites and deep-water stations; and to collect sufficient water quality parameters so as to fit the requirements for federal reporting, including nutrients, metals, bacteria, major ions, and dissolved oxygen.

In March 2011, the Global Institute for Water Security was officially launched at the University of Saskatchewan. The institute promotes interdisciplinary science, and provides funding to work with provincial and federal partners in support of large projects, such as assessing nutrient loading of Lake Diefenbaker.
**Aquatic Benthic Macroinvertebrate Indicator**
This indicator was developed to assess the health of aquatic benthic macroinvertebrates in Saskatchewan.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Status: In Saskatchewan, the health and status of aquatic benthic macroinvertebrates have been collected and assessed in waterways since 2006. However, in Alberta, as of 2007, insufficient recently collected benthic invertebrate data was available to assess the biotic condition within the four Lake Diefenbaker Sub-watersheds.</th>
</tr>
</thead>
</table>

**The Issue**
Aquatic benthic macroinvertebrates are the small animals living amongst the sediment and stones in the bottom of a water body. Members of the benthic macroinvertebrate community include insects such as midges and mayflies, snails, clams, aquatic worms, and crayfish. These aquatic organisms are used because they are sensitive to the chemical and physical stressors in the habitats they reside, and they respond in different ways depending on the stressor. Examining organisms collected from a water body can indicate the quality of surface water.

Aquatic ecosystem health is an important indicator of the condition of watersheds, and setting water quality objectives should involve biological criteria in addition to traditional chemical surrogates (Canadian Council of Ministers of the Environment 2006). Biological characteristics, functions (such as filtering), and health all respond to changes in water quality, and are a valuable proxy for the ultimate consequences of human activity on ecosystems.
Figure 15: Biotic condition evaluated by sample location within the Lake Diefenbaker Watershed.

* Insufficient recently collected benthic invertebrate data was available
Figure 16: Biotic condition assessed by sub-watershed within the Lake Diefenbaker Watershed.
*Insufficient recently collected benthic invertebrate data was available to assess biotic condition

Saskatchewan
Three benthic invertebrate samples were taken within the Saskatchewan portion of the Lake Diefenbaker Watershed, between 2006 and 2008, and all three sites had their biotic condition classified as healthy (Figure 15).

One benthic invertebrate sample was collected within each of the South Saskatchewan River and Swift Current Creek Sub-watersheds to assess the health of aquatic benthic macroinvertebrates using the reference condition approach. The biotic condition of each of the two sites was assessed as healthy (Figure 16). This health rating indicates that the abundance, diversity, richness and community composition of the benthic communities did not differ significantly from the reference condition sites that we used to compare to these sites.

Currently, we cannot assess the biotic macroinvertebrate health of Lake Diefenbaker, as no macroinvertebrate samples have recently been collected within the lake.
Alberta
As of 2007, insufficient recently collected benthic invertebrate data was available to assess biotic condition within Alberta’s portion of the Lake Diefenbaker Watershed (North/South Consultants Inc. 2007).

There was insufficient recently collected data within the Red Deer River Sub-watershed to rate biotic condition (North/South Consultants Inc. 2007). Historically, the Red Deer River had relatively uniform benthic invertebrate community composition and diversity along the whole length of the river, with the exception of a site immediately downstream of the City of Red Deer’s Waste Water Treatment Plant (Reynoldson 1973). The site downstream of Red Deer had an increase in the abundance of benthic invertebrate, indicative of nutrient enrichment, as observed in more recent studies (Cross 1991; Shaw and Anderson, 1994).

There was insufficient recently collected data within the Bow River Sub-watershed to rate biotic condition (North/South Consultants Inc. 2007). However benthic invertebrate data has been collected along the Bow River as early as the 1970s. Based on data that were collected in the 1980s, 1990s and early 2000s, the benthic invertebrate communities within the Bow River are considered to be diverse and the habitat is complex. These studies also found that invertebrate communities downstream of town sites had a higher percentage of tolerant species and fewer pollution sensitive species, likely due to nutrient enrichment from municipal wastewater effluent (North/South Consultants Inc. 2007).

There was insufficient data within the Oldman River Sub-watershed to rate the biotic condition. Studies in 1997 and 2002 found mean density and richness to be high, and the proportion of pollution sensitive species to be variable among all sites sampled (North/South Consultants Inc. 2007).

There was insufficient data available within the South Saskatchewan River Sub-watershed to rate biotic condition. Benthic invertebrates were sampled in the spring and fall at one site (Bridge on Highway 41) within the sub-watershed between 1983 and 1987. Findings from these data indicate that total invertebrate numbers were highly variable and they attributed this to changes in flow. With a higher total number of invertebrates with lower flow (North/South Consultants Inc. 2007).

Indicator
This biotic condition indicator reports on the overall ecosystem health at an individual site in a water body within a watershed. The indicator has been constructed to evaluate how human activities (e.g. addition of nutrients, sediment, etc.) change downstream biotic characteristics and ultimately impact the integrity of the ecosystem relative to ‘reference’ conditions. These
‘reference’ conditions were characterized using sites that have been influenced least by human activities. This method, known as the biotic integrity method, has been used elsewhere to: 1) differentiate healthy sites from degraded sites, 2) identify which ecosystem characteristics distinguish a particular site as degraded, and 3) identify the stressor(s) driving the degradation.

### Indicator

The indicator is calculated using four components that respond to human activity in a predictable way:

- **Abundance**: The total abundance of benthic macroinvertebrates in a river typically increases with stressors such as organic pollution and decreases with stressors such as pesticides.
- **Richness**: The total number of species present at a site and is expected to decrease with stressors such as organic pollution and pesticides.
- **Diversity**: This measure incorporates both abundance and richness to provide a measure of balance in the community (Does the group of invertebrates have many organisms dominated by only one or two types of individuals?). Typically disturbance drives a group of aquatic invertebrates to be composed of a few species that are tolerant of the conditions, and who increase in abundance relative to the other species present.
- **Aquatic Invertebrate Composition**: Similarity in the composition of species at a site of interest relative to reference sites is an overall gauge of change. This measure often identifies unexpected biological changes and is sensitive to a wide range of stressors.

At each site, the value for each of the components (abundance, richness, diversity, and aquatic invertebrate composition) is compared to the values at reference sites that have comparable habitat (such surrounding soil type and geology). A value of total condition is used to summarize the four components at each site and is evaluated based on the degree to which it deviates from the average reference condition and the probability it differs from the range of reference conditions (Bowman and Somers 2006).

### Rating scheme

Overall biotic condition was determined by calculating the magnitude of difference between a site of interest and the average reference condition and statistically evaluating the probability that this difference falls outside the range of variation in condition at those reference sites. The degree of impact was categorized as follows:

<table>
<thead>
<tr>
<th>Biotic Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy (Within Reference Condition)</td>
<td>Site condition is typical of best available reference sites; has $\geq 90%$ chance of being in reference condition.</td>
</tr>
<tr>
<td>Stressed (Different from Reference)</td>
<td>Site condition deviates from average reference condition; has 11 - 89% chance of being in reference condition.</td>
</tr>
<tr>
<td>Impacted (Significantly Different from Reference)</td>
<td>Site Condition is impacted relative to the range at reference sites; has $\leq 10%$ chance of being in reference condition.</td>
</tr>
</tbody>
</table>
Data Source(s):
The biotic values in Saskatchewan are from the Water Security Agency’s (formerly Saskatchewan Watershed Authority) ongoing monitoring and assessment activities. Alberta’s aquatic benthic macroinvertebrate data are from a number of sources, which are summarized in Information Synthesis and Initial Assessment of the Status and Health of Aquatic Ecosystems in Alberta: Surface Water Quality, Sediment Quality and Non-Fish Biota (North/South Consultants Inc. 2007).

Response to the Issue
The Saskatchewan Watershed Authority Act, 2005, administered by the Water Security Agency (formerly Saskatchewan Watershed Authority), promotes the adoption of research and conservation programs that ensure Saskatchewan’s source water, watersheds, and related lands are managed and protected.

In Saskatchewan, as is the case with most provinces in Canada, biomonitoring activities are undertaken without legislated biocriteria targets (Canadian Council of Ministers of the Environment 2006). However, in response to the Saskatchewan Watershed Authority Act, 2005, the Water Security Agency (formerly Saskatchewan Watershed Authority) has been evaluating the potential utility of a biomonitoring tool to assess the biotic integrity of aquatic ecosystems across southern Saskatchewan since the summer of 2006. The development of this biomonitoring tool mirrors that of Environment Canada’s Canadian Aquatic Biomonitoring Network (CABIN) Program. Both the CABIN program and the Water Security Agency’s (formerly Saskatchewan Watershed Authority) biomonitoring tool model the relationship between environmental variables and biological communities at least-impacted reference sites (Environment Canada 2010). The CABIN program has not yet been applied to the Northern Great Plains regions and results presented here are a product of the first phase of developing a biotic condition tool for agricultural regions in Saskatchewan. Information provided by this tool will enable watershed managers to assess watershed health, target the highest priority stressors, reduce their impact, and monitor effectiveness by tracking recovery of the ecosystem. The community structure of benthic macroinvertebrates in least-impacted sites can be predicted using simple physical characteristics of a water body. Site-specific biological objectives can then be set for sites based on their habitat characteristics and provide an appropriate reference for identifying when degradation is occurring because of human influence.

Between 2007 and 2009, the Water Security Agency (formerly Saskatchewan Watershed Authority) conducted a study to assess the impact Gardiner Dam was having on downstream temperature and benthic macroinvertebrate assemblages. The results of the study indicate that Gardiner Dam affects the temperature regime of the South Saskatchewan River, consequently
increasing the density, lowering the diversity and altering the composition of the downstream benthic macroinvertebrate assemblage (Phillips et al. In press)

Although a strong foundation for assessing the biotic integrity of riverine systems in southern Saskatchewan has been constructed, more research is needed to refine this tool. Future development of the biomonitoring tool, including the geographic scale, resolution, and ability to forensically identify particular stressors, needs to be improved as follows:

- Include information gathered in 2008, 2009 and subsequent years;
- Collect samples representative of all watersheds in southern Saskatchewan;
- Increase the compliment of reference sites;
- Evaluate and articulate the predictive capacity for particular stressors;
- Develop new measures of the benthic invertebrate fauna for stressor-specific identification;
- Re-sample sites of concern to identify changes through time; and
- Publish findings in peer-reviewed forum.

Additional benthic macroinvertebrate collection to compliment other Water Security Agency (formerly Saskatchewan Watershed Authority) monitoring and assessment activities includes:

- Qu’Appelle Suspended Sediment Study – Qu’Appelle River Watersheds – collaboration with the Prairie Adaptation Research Collaborative (PARC) to research the effect suspended sediment associated with erosion has on the benthic macroinvertebrate assemblage, interactions with nutrients and estimated flow conditions under climate change forecasts, 2007 – present.
- The Water Security Agency (formerly Saskatchewan Watershed Authority) has been collecting both temperature and benthic invertebrate data to assess the effects the Gardiner Dam has on the temperature and biotic condition in the Saskatchewan River systems (Phillips et al. In press).
- Since 2008, the Water Security Agency (formerly Saskatchewan Watershed Authority) has been conducting environmental flow assessments on some of the Water Security Agency (formerly Saskatchewan Watershed Authority) dams, including Gardiner Dam and Qu’Appelle River Dam (Pollock et al. 2011).

Riparian Areas Indicator
This indicator was developed to assess the health of riparian areas within the Lake Diefenbaker Watershed using riparian health assessment data.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Status: Data is currently available for 463 lotic health assessments which were conducted between 1996 and 2008 in all of Lake Diefenbaker’s Canadian sub-watersheds.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lotic Riparian</td>
<td></td>
</tr>
<tr>
<td>Health</td>
<td></td>
</tr>
<tr>
<td>Lentic</td>
<td>Data is currently available for 74 lentic health assessments which were</td>
</tr>
</tbody>
</table>


### Riparian Health

Conducted between 1996 and 2008 in five of the six Canadian sub-watersheds.

### Riparian Buffer

**Status:** On average, all of Lake Diefenbaker’s sub-watersheds have a stressed health rating.

---

**The Issue**

Riparian areas are transitional zones between aquatic and terrestrial habitats along the shoreline of a water body or waterway. These include any terrestrial areas located adjacent to surface water that are influenced by flooding or elevated water tables. Riparian areas can play an important role in movement of terrestrially-derived materials (e.g. sediment, nutrients) to surface water.

To assess the health of riparian areas within the Lake Diefenbaker Watershed two methods were used, riparian health assessments and riparian buffer widths.

Riparian health assessments use established protocols to evaluate the status of riparian vegetation, soil and hydrology in relation to their functional abilities. Current management activities and ecological factors within the riparian area are also considered. The biotic and abiotic information are weighted, combined, and rated to produce an overall assessment of riparian health (Fitch et al. 2001; and Prairie Conservation Action Plan 2008a). The riparian health assessments measure the ability of riparian areas to perform many functions, including:

- improving water quality through the filtration of nutrients and contaminants from runoff;
- reducing erosion by dissipating stream and wave energy associated with high water levels;
- trapping sediment and capturing streambed load;
- stabilizing stream banks and shorelines; ground water recharge; and
- enhancing aquatic and terrestrial habitat (Hansen et al. 2000).

Riparian buffer widths were the second method used to assess the health of riparian areas. The effectiveness of riparian buffers in protecting water quality depends on many factors, including vegetation type, vegetation width, soil type, slope, and adjacent land uses. Although riparian buffer widths are limited in their ability to assess the health of riparian areas, most scientific research and management recommendations focus on buffer widths to assess the effectiveness of a buffer for protecting water quality. A couple of the big advantages of using riparian buffer widths to assess the effectiveness of riparian areas are that 1) the assessment can be done using GIS and land cover and water network datasets and 2) it can assess the entire riparian area within a watershed, not just the watersheds or areas within the watershed where riparian health assessments were conducted.
Between 1996 and 2008, a total of 463 lotic riparian assessments were conducted within the six sub-watersheds of the Lake Diefenbaker Watershed. All of the six sub-watersheds had average lotic riparian health values classified as stressed (Figure 17).
Between 1996 and 2008, a total of 74 lentic riparian assessments were conducted within five of the six Canadian sub-watersheds that comprise the Lake Diefenbaker Watershed. Of the five sub-watersheds: the Saskatchewan portion of the South Saskatchewan River Watershed had an average lentic riparian assessment score of healthy; the Oldman River and Red Deer River Sub-watersheds were rated as stressed; the Bow River and Swift Current Creek Sub-watersheds had fewer than 10 lentic riparian assessments and therefore no average health rating was calculated; and no data was available on lentic riparian health assessments in the Alberta portion of the South Saskatchewan River Sub-watershed (Figure 18).

The data used to calculate this indicator for the sub-watersheds in Saskatchewan currently only includes riparian health assessments collected by the Water Security Agency (formerly Saskatchewan Watershed Authority). To further understand the health of riparian areas around Lake Diefenbaker and to identify the shoreline sites highly susceptible to erosion additional riparian health assessments need to be conducted around the Lake Diefenbaker shorelines.
However, prior to conducting these additional assessments, riparian health assessments conducted by other organizations, such as: Ducks Unlimited Canada and the Nature Conservancy of Canada, should be obtained to see if areas around the lake have already been assessed and this would potentially reduce the amount of effort required to assess.

The data used to calculate this indicator for the sub-watersheds in Alberta are from two documents (Sandi Riemersma and Shilo Andrews, and Palliser Environmental Services Ltd. 2007; Cows and Fish - Alberta Riparian Habitat Management Society. 2005). These documents provided information on the riparian assessments conducted in Alberta between 2001 and 2006.

Figure 19. Percent of permanent cover within a 40 metre buffer of a waterway or water body: 2000.

The percent riparian buffer width in each of the Canadian sub-watersheds was classified as stressed (Figure 19).
Rating Scheme
The rating scheme used in the State of the Watershed Report to calculate the health of the watershed based on the riparian health indicator is as follows:

<table>
<thead>
<tr>
<th>Riparian Health</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy (Proper functioning condition) (80-100%): Riparian area performs all of its functions and is considered to be stable.</td>
</tr>
<tr>
<td>Stressed (Function at risk) (60-79%): Riparian area performs many functions, but signs of degradation are visible.</td>
</tr>
<tr>
<td>Impacted (Non-functional) (Less than 60%): Riparian area has lost most of its ability to perform its functions and is now considered to be degraded.</td>
</tr>
</tbody>
</table>

The riparian rating scheme is an established rating scheme based on Alberta’s Cows and Fish Program.

<table>
<thead>
<tr>
<th>Riparian Buffer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy: (30 m and over): (PRB value 75 – 100%): A buffer width within this range maintains the physical, chemical and ecological components of many wetlands and streams, and has consistently high percent reduction of nutrients, sediment and pesticides.</td>
</tr>
<tr>
<td>Stressed: (Between 10-29 m): (PRB value 25 – 74.9%): A buffer width within this range has consistently high percent reduction of nutrients, sediment and pesticides, but it is not sufficiently wide to protect the ecological integrity of the water body.</td>
</tr>
<tr>
<td>Impacted: (Less than 10 m): (PRB value 0 – 24.9%): A buffer width within this range is considered unstable and unsustainable. It is unable to provide adequate shade and moderate stream temperatures, and it is highly variable in percent reduction of Nitrate, Total Nitrogen, Phosphate, Total Phosphorus, sediment, and pesticides.</td>
</tr>
</tbody>
</table>

Data Source(s):
Riparian Health - In Saskatchewan, 165 lotic and 20 lentic riparian health assessments were conducted in Saskatchewan by the Water Security Agency (formerly Saskatchewan Watershed Authority) between 1996 and 2008. In Alberta, 348 riparian sites, 298 lotic and 55 lentic, were assessed between 2001 and 2006 by a number of organizations, including: Nature Conservancy of Canada, Alberta Conservation Association; Conservation Coordinator, Red Deer County; Smoky Applied Research and Demonstration Association (SARDA); Little Red Deer River Watershed Initiative (LRDRWI), Jacques Whitford – AXYS. These assessments were used to calculate the average riparian health scores at the sub-watershed level (Whitford 2005; Sandi Riemersma and Shilo Andrews, and Palliser Environmental Services Ltd. 2007; Cows and Fish - Alberta Riparian Habitat Management Society. 2005).

Riparian Buffer - the Atlas of Canada 1,000,000 Hydrology - Drainage Network for Saskatchewan and Alberta was used to calculate the 40 metre buffer of the mainstems within the six Canadian Lake Diefenbaker sub-watersheds. The AAFC_30m_2000 raster file was used to determine the area of permanent cover within the 40 metre buffer for the six Canadian sub-
Response to the Issue
Sediment deposition caused by the removal of riparian vegetation can impact surface water quality and aquatic habitat. Surface water quality is protected under the Interim Surface Water Quality Objectives (Saskatchewan Environment 2006a). The Fisheries Act protects fish habitat from the deposition of deleterious substances, such as sediment. The Environmental Management and Protection Act, 2002, administered by the Saskatchewan Ministry of Environment, controls activities and the disposal of deleterious substances that are harmful to air, land and water resources.

Riparian areas within Saskatchewan provincial crown forested areas are managed to Forest Management Agreement Area standards and guidelines or to Area Based Term Supply standards and guidelines, where specific conditions apply within riparian management areas.

In 1992, the Alberta Cows and Fish Program was established with the purpose of promoting a better understanding of how to improve management in riparian areas. Through this program numerous awareness and educational materials have been produced. Some of the tools this multi-partnership program has developed to achieve their goal include: publishing a number of riparian health assessment manuals such as: Riparian Health Assessment for Lakes, Sloughs and Wetlands – Field Workbook (Ambrose et al. 2004), Riparian Areas: A User’s Guide to Health (Fitch and Ambrose 2003), Caring for the Green Zone: Riparian areas and grazing management- Third Edition (Fitch et al. 2003), Riparian Health Assessment for Streams and Small Rivers – Field book (Fitch et al. 2001); conducting riparian health assessments (and through local community effort, the establishment of demonstration sites throughout Alberta. These demonstration sites illustrate and assess various riparian grazing strategies, and monitor and define the costs and benefits of riparian grazing., including Caring for the Green Zone: Riparian areas and grazing management.

There are numerous organizations in Saskatchewan, both government and non-government, that are involved in promoting, assessing, and rehabilitating riparian areas, e.g., Nature Conservancy of Canada; Nature Saskatchewan,

In Saskatchewan, the Prairie Conservation Action Plan (PCAP) has been actively involved in the conservation of native prairie and Species at Risk (SAR). The PCAP is the only forum in Saskatchewan that brings together 28 partners representing producers, industry, provincial & federal governments, nongovernment organizations and research/educational institutes working
towards a common vision of native prairie and Species at Risk conservation in Saskatchewan. The PCAP reduces redundancy, fills in gaps in native prairie research/activities, develops and implements actions to address conservation and sustainable management of native prairie, increases communication and sharing amongst partners and improves public understanding of native prairie and Species at Risk.

The Water Security Agency (formerly Saskatchewan Watershed Authority), coordinates the Prairie Stewardship Program, a partnership program that encourages stewards, through voluntary agreements, to maintain and protect riparian areas. The goal of the Prairie Stewardship Program is to increase awareness of the importance, value, and function of riparian and native prairie ecosystems.

To promote the management of riparian areas along agricultural lands, the Saskatchewan Soil Conservation Association has developed a soil factsheet related to riparian areas, entitled “Economical Alternatives to Cropping Adjacent to Riparian Areas” This fact sheet can be found on the Saskatchewan Soil Conservation Association’s website at: http://www.ssca.ca/agronomics/pdfs/rprnfactsheet.pdf.

**Rangeland Health Indicator**
The rangeland health indicator reports on the health of native and tame rangelands, or the uplands, within a sub-watershed.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native Rangeland Health</td>
<td>Data is currently available for 1,632 native health assessments which were conducted between 2002 and 2008 in all of Lake Diefenbaker’s six Canadian sub-watersheds.</td>
</tr>
<tr>
<td>Tame Rangeland Health</td>
<td>Data is currently available for 281 native health assessments which were conducted between 2002 and 2008 in all of Lake Diefenbaker’s six Canadian sub-watersheds.</td>
</tr>
</tbody>
</table>

**The Issue**
Healthy rangelands maintain a diversity of plant species, including grasses, herbs, shrubs and trees, through the efficient cycling of nutrients and the capture and slow release of water. They also function to improve water quality by reducing sediment deposition and soil erosion (Adams et al. 2005).

Traditionally, rangelands have been evaluated using the Range Condition Method. This method compares the resemblance of the observed plant species composition to that of an ecologically desirable species composition. In the last few years, range health methods that measure ecosystem function have been widely adopted across North America (Pellant et al. 2000). Range health assessments evaluate tame (introduced) and native (indigenous) pastures using select indicators and a scoring system. Range health assessment indicators focus on:
- species composition;
- community structure;
- invasive species;
- site stability; and

**Figure 20: Average native range condition and health scores by sub-watershed: 2002-2008.**

Note: the numbers shown within the sub-watersheds are the number of assessments used to calculate the average rangeland health assessment scores. The rangeland health assessment scores for sub-watersheds with fewer than 10 assessments were not averaged across the sub-watershed.

The number of native range assessments that were conducted in the Saskatchewan and Alberta Sub-watersheds, between 2002 and 2008, were 164 and 1,468 respectively. The average native range health score for Saskatchewan’s portion of the South Saskatchewan River, the Red Deer River and the Oldman River Sub-watersheds were rated as stressed. The average health score for the Swift Current Creek, Bow River and Alberta’s portion of the South Saskatchewan River Sub-watersheds were calculated as healthy. The average health score for the Swift Current Creek
Sub-watershed couldn’t be calculated, as fewer than 10 rangeland assessments were conducted in the sub-watershed (Figure 21).

Figure 21: Average tame rangeland health assessment scores by rural sub-watershed: 2002-2008.

Note: the numbers shown within the sub-watersheds are the number of assessments used to calculate the average rangeland health assessment scores. The rangeland health assessment scores for sub-watersheds with fewer than 10 assessments were not averaged across the sub-watershed.

The number of tame range health assessments that were conducted in the Saskatchewan and Alberta Sub-watersheds, between 2002 and 2008, were 8 and 273 respectively. Within Saskatchewan, no sub-watersheds had an average tame rangeland health score, as average rangeland health scores were only calculated for sub-watersheds that had at least ten assessments conducted within them. The average health rating of the tame ranges assessed within the Oldman River and Alberta’s Portion of the South Saskatchewan sub-watersheds were rated as healthy. In Alberta, the Bow River and Red Deer River Sub-watersheds were rated as stressed (Figure 22).

Rating Scheme
The rangeland health assessment ratings range from 0% to 100%, with less than 50% representing an impacted range and a score of 75% or more representing a healthy range (see Adams et al. 2005).

<table>
<thead>
<tr>
<th>Rangeland Health</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Healthy</strong></td>
<td>A health score of 75 to 100%: All of the key functions of a healthy rangeland are being performed.</td>
</tr>
<tr>
<td><strong>Stressed</strong></td>
<td>A health score of 50 to 74%: Most, but not all, key functions of a healthy rangeland are being performed.</td>
</tr>
<tr>
<td><strong>Impacted</strong></td>
<td>A health score of less than 50%: Few of the functions of a healthy rangeland are being performed.</td>
</tr>
</tbody>
</table>

**Data Source:** The data summarized in Figures 21 and 22 are from rangeland health assessments that have been conducted in Saskatchewan and Alberta. In Saskatchewan the rangeland health assessments were conducted on private land by the Water Security Agency (formerly Saskatchewan Watershed Authority). In Alberta the rangeland health assessments were conducted on public land by the Alberta Government through the Ministry of Sustainable Resource Development (Adams 2011).

**Response to the Issue**
To promote rangeland health on Agriculture Crown lands in Saskatchewan, both the provincial and federal governments have established grazing programs:

- In 1922, the Saskatchewan Ministry of Agriculture initiated the Saskatchewan Pastures Program. This program promotes environmental and agricultural sustainability of marginal Crown lands through the incorporation of rangeland planning and forage management. The program provides grazing services for cattle, horses and sheep and a breeding service for cattle. The program consists of 54 pastures covering an area of 333,866 ha (825,000 ac) (Saskatchewan Ministry of Agriculture 2007).

- In the 1930’s, Agriculture and Agri-Food Canada - Prairie Farm Rehabilitation Administration initiated the Community Pasture Program to reclaim badly eroded areas. The program provides grazing services for cattle and horses and a breeding service for cattle. Within Saskatchewan, the Program includes 62 pastures covering an area of 698,375 ha (1,725,714 ac). The primary objective of the program is: to manage healthy rangelands through the balance of environmentally responsible land use practices that complement livestock production (Agri-Food Canada - Prairie Farm Rehabilitation Administration 2009).

The Prairie Conservation Action Plan (PCAP) has been actively involved in native prairie and Species at Risk conservation in Saskatchewan. The PCAP is the only forum in Saskatchewan that brings together 28 partners representing producers, industry, provincial & federal
governments, nongovernment organizations and research/educational institutes working towards a common vision of native prairie and Species at Risk conservation in Saskatchewan. The PCAP reduces redundancy, fills in gaps in native prairie research/activities, develops and implements actions to address conservation and sustainable management of native prairie, increases communication and sharing amongst partners and improves public understanding of native prairie and Species at Risk.

**Land Cover Indicator (under construction)**

The land cover indicator reports on the type of land cover, within the Lake Diefenbaker Watershed at the sub-watershed level. Land cover is the material that covers the surface of the earth. The Lake Diefenbaker Watershed has a wide variety of land covers, from barren land to forested areas and everything in between. Examining the different types of land cover within a watershed provides important information about the condition of the environment, potential sources of contamination to water bodies, habitat availability, and watershed hydrology.

Typically, forest, and native grassland have minimal effects on water quality. Wetlands have been found to improve water quality. However, agricultural land (cropped and pasture) and urban land can affect water quality by increasing concentrations of nitrogen, phosphorus and pesticides to surface water from precipitation, runoff and irrigation from land that has had fertilizers and/or pesticides applied to it (Donaldson 2005; Kroll et al. 2009). While relationships between land cover and water quality have been demonstrated elsewhere, the relationships between these parameters and the magnitude of their effect have not been investigated fully in Saskatchewan.

For the purposes of this indicator, land cover is described by nine classes: annual cropland; forest; grassland; perennial crops and pasture; developed land (urbanized areas); water; wetlands; shrubland and barren land (rocky outcrops). Of the nine land cover classes, five classes are considered permanent cover, including: forest, grassland, perennial crops/pasture, shrubland, and wetlands.

Based on Agriculture and Agri-Food Canada’s Land Cover Classification, using circa 2000 landsat imagery, the land cover within the Lake Diefenbaker Watershed was classified as 56% permanent cover. Land cover consisted of 39% annual and perennial cropland; 16% perennial crops/pasture; 25% native grassland; 9.5% forested area; 3% barren land (typically rock); 3% shrubland; 2% water; 1.5% wetlands; and 1% developed land (urban areas and roads).
Figure 22: Land cover of the Lake Diefenbaker Watershed based on 2000 AAFC
Based on the 2000 Landsat data, the Oldman River, Bow River, and Red Deer Sub-watersheds and Alberta’s portion of the South Saskatchewan River Sub-Watershed all had more than 46% of their land cover classified as permanent cover (forest, grassland, perennial crops/pasture, shrubland, and/or wetland). The Swift Current Creek Sub-watershed and the Saskatchewan portion of the South Saskatchewan River Sub-watershed were the two sub-watersheds that had less than 46% of their land cover were classified as permanent cover (Figures 23 and 24).

**Rating Scheme**

Greater than 50% of the watershed land cover is permanent cover.
Between 27% and 46% of the watershed land cover is permanent cover.
Less than 27% of the watershed land cover is permanent cover.

Data Source: Land cover data for the Lake Diefenbaker watershed were obtained from the AAFC_2000_v11 raster shapefile. The AAFC_2000_v11 was compiled by Agriculture and Agri-Food Canada (AAFC) through the National Land and Water Information Service (NLWIS). The land cover was classified based on the use of Landsat imagery from circa 2000.

Response to the Issue
Numerous programs have been initiated to convert marginal annually cropped land to perennial cover. Some of these programs include:
- Agriculture and Agri-Food Canada - Prairie Farm Rehabilitation Association’s (AAFC-PFRA) Greencover Canada Program – land conversion component (April 2004 – March 2009);
- Agriculture and Agri-Food Canada - Prairie Farm Rehabilitation Association’s (AAFC-PFRA) Permanent Cover Program I and II (1989-1993);
- Water Security Agency’s (formerly Saskatchewan Watershed Authority) Prairie Stewardship Program;
- Prairie Habitat Joint Venture encourages provincial governments to develop programs that convert cropland to ecologically appropriate perennial cover through incentives;
- Ducks Unlimited Canada’s securement programs; and
- Saskatchewan Agriculture’s Conservation Cover Program (June 2001 – March 2005)

Species at Risk Indicator (under construction)
This indicator was developed to identify areas in the Lake Diefenbaker Watershed with high densities of Species at Risk. No rating scheme has been developed to calculate sub-watershed health values for this indicator; therefore this indicator will not be used in this report to assess the health of Lake Diefenbaker’s sub-watersheds.

The Issue
Species at Risk are defined as indigenous organisms (plant, animal, fungus or micro-organism), that have been assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), found to be at some risk of declining and/or disappearing from the wild in Canada (COSEWIC 2009). COSEWIC categorizes Species at Risk into one of five categories: extinct, extirpated, endangered, threatened, or special concern.

Some of the broad-scale human activities that can impact the status of a species include: habitat disturbance, loss and fragmentation; over-harvesting; introduction of invasive alien species;
climate change; and the release and deposition of pollutants, such as pesticides (Thorpe and Godwin 1999).

Figure 24: Number of species at risk with breeding ranges that overlap the Lake Diefenbaker Watershed.

Figure 25 highlights the number of species that have a breeding range that is within a given sub-watershed that are endangered, threatened or of special concern as listed in Schedule 1 or 2 of the Species at Risk Act. All seven sub-watersheds have between 20 and 30 species at risk that breed within their boundaries.

Rating Scheme
There is currently no rating scheme associated with this indicator, due to the complexity of classifying watersheds with low or high numbers of species at risk. As the United States Environmental Protection Agency (2006) notes: “The presence of rare or endangered species in a watershed is not necessarily an indication of poor watershed conditions. Indeed, it more likely indicates the opposite: in many instances these species persist only in areas of exceptionally high quality habitat. The presence of species at risk in a watershed indicates, however, that these
watersheds are especially vulnerable to future water quality or habitat degradation, which could jeopardize the maintenance or recovery of these organisms”.

**Data Source:** Breeding range data summarized in Figure 25 was obtained from:
- COSEWIC shapefiles;
- Digitizing SARA registry PDF maps; and
- NatureServe.

**Data Quality/Caveats:** There is currently no rating scheme associated with this indicator, due to the complexity of classifying watersheds with low or high numbers of species at risk.

The method used by COSEWIC to assess the number of species that are at risk in Canada should be used with caution:
1) Temporal trends cannot be made based on the increasing number of species that are added to COSEWIC’s species at risk categories. The increase in the number of species added to the at-risk categories (special concern, threatened, and endangered) is typically a reflection of the pace that species are investigated and designated, and not the speed at which their at-risk status is changing. The inflation of species-at-risk can occur due to COSEWIC’s assessment process.
   a) COSEWIC first assesses the entire population of a species, and if necessary will assess a subpopulation of that species. Occasionally, two subpopulations of the same species may both be listed as at-risk.
   b) There are a number of species that are listed as at-risk in Canada; however, Canada represents the northernmost extent of their range.

**Response to the issue**
In 1996 Canada’s federal, provincial and territorial governments agreed to the national *Accord for the Protection of Species at Risk*. The accord outlines a national commitment to designate species at risk, protect their habitats and develop recovery plans (Canadian Wildlife Service 2009).

The federal *Species at Risk Act* (SARA) was passed in June 2003. The act is one component of Canada’s three-part Strategy for the Protection of Species at Risk that also includes the *Habitat Stewardship Program for Species at Risk* and the *Accord for the Protection of Species at Risk*.

Numerous assessments have been conducted and documents compiled outlining the status of species at risk in Canada (Canadian Endangered Species Conservation Council 2001; and Cannings et al. 2005). In Saskatchewan there are 66 species of wildlife that are at-risk and are designated as extirpated (3 species), endangered (17 species), threatened (22 species), and special concern (23 species), and non-active (1 species) as designated by COSEWIC.

Once a species is listed as endangered or threatened under SARA, recovery strategies and action plans are developed for species at risk in Canada that are listed in Schedule 1 of SARA (Species
at Risk Public Registry 2009). Critical Habitat for SARA listed species is identified and defined in the recovery process, either in the recovery strategy, recovery plan or within the courts.
Glossary

**Dam**³ - represents a volume of 1 cubic decametre, which is equivalent to 1,000 cubic metres.

**Eutrophic** – a water body that is enriched in dissolved nutrients and highly productive.

**FSL** - Full supply level is the maximum normal operating level of a reservoir behind a dam. For Lake Diefenbaker the full supply level is 556.87 m.

**Limnological parameters** - physico-chemical water parameters used to assess freshwater lakes, such as dissolved oxygen, pH, turbidity, and specific conductivity.

**m³/s** - cubic metres per second is a measure of flow rate, with dimensions.

**Macroinvertebrate** - invertebrate that is large enough to see without a microscope, such as a crayfish or mayfly.

**masl** – metres above sea level.

**Mesotrophic** – a water body with a moderate nutrient and productivity levels.

**Oligotrophic** – a water body with low nutrient and productivity levels.

**Paleolimnology** - the study of ancient lakes from their sediments and fossils.

**SSEWS** - Saskatoon South East Water Supply System

**SSRID** - South Saskatchewan River Irrigation District

**Thermocline** - a temperature gradient that results in the separation of the warmer water above from the colder water below.

**Trophic status** – the nutrient status and productivity of a water body.

**WQI** – Water Quality Index
References


The Partners FOR the Saskatchewan River Basin. 2009. From the Mountains to the Sea. 166 pp.


