AAMD&C Northern Zone
Part of the Peace River Basin
Tp 065 to 107, R 05 to 27, W5M and Tp 069 to 087, R 01 to 13, W6M
Regional Groundwater Assessment

In conjunction with:

Agriculture and Agri-Food Canada
Prairie Farm Rehabilitation Administration

Agriculture et Agroalimentaire Canada
Administration du rétablissement agricole des Prairies

Prepared for:

AAMD&C EST.1909

May 2004

PERMIT TO PRACTICE

HYDROGEOLOGICAL CONSULTANTS LTD.

Signature__________________________________________________

Date____________________________________________________

PERMIT NUMBER P 385
The Association of Professional Engineers, Geologists and Geophysicists of Alberta

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**HCL ground water consulting environmental sciences**

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Mr. John Walker – AAFC-PFRA
Mr. Tony Cowen – AAFC-PFRA
Mr. Kirby Rietze - AAFC-PFRA
1. Project Overview

“Water is the lifeblood of the earth.” - Anonymous

How a Study Area or Municipality takes care of one of its most precious resources - groundwater - reflects the future wealth and health of its people. Good environmental practices are not an accident. They must include genuine foresight with knowledgeable planning. Implementation of strong practices not only commits to a better quality of life for future generations, but also creates a solid base for increased economic activity. Though this report’s scope is regional, it is a first step for the Peace River Basin Study Area in managing their groundwater. It is also a guide for future groundwater-related projects.

1.1 Purpose

This project is a regional groundwater assessment of part of the Peace River Basin (designated as the ‘Study Area’) prepared by Hydrogeological Consultants Ltd. (HCL) with financial and technical assistance from the Prairie Farm Rehabilitation Administration arm of Agriculture and Agri-Food Canada (AAFC-PFRA). The regional groundwater assessment provides the information to assist in the management of the groundwater resource within the Study Area. Groundwater resource management involves determining the suitability of various areas within the Study Area for particular activities. These activities can vary from the development of groundwater for agricultural or industrial purposes, to the siting of waste storage. Proper management ensures protection and utilization of the groundwater resource for the maximum benefit of the people of the Study Area.

The regional groundwater assessment will:

- identify the aquifers¹ within the surficial deposits² and the upper bedrock
- spatially identify the main aquifers
- describe the quantity and quality of the groundwater associated with each aquifer
- identify the hydraulic relationship between aquifers
- identify possible groundwater depletion areas associated with each upper bedrock aquifer.

Under the present program, the groundwater-related data for the Study Area have been assembled. Where practical, the data have been digitized. These data are then used in the regional groundwater assessment for the Peace River Basin Study Area.

¹ See glossary
² See glossary
1.2 The Project

This regional study should only be used as a guide. Detailed local studies are required to verify hydrogeological conditions at given locations.

The present project is made up of eight parts as follows:

Task 1 – Completed as an earlier task
Task 2 – Completed as an earlier task
Task 3 – Hydrogeological Evaluation and Preparation of Report
Task 4 – Groundwater Information Query Software
Task 5 – Review of Draft Report and GIS Data Files
Task 6 – Report Presentation and Familiarization Session
Task 7 – Provision of Report, Maps, Data Layers and Query
Task 8 – Provision of Compact Disk for Sale to General Public

This report and the accompanying maps represent Task 3.

1.3 About This Report

This report provides an overview of (a) the groundwater resources of the Peace River Basin Study Area, (b) the processes used for the present project, and (c) the groundwater characteristics in the Study Area.

Additional technical details are available from files on the CD-ROM to be provided with the final version of this report. The files include the geo-referenced electronic groundwater database, maps showing distribution of various hydrogeological parameters, the groundwater query, ArcView files and ArcExplorer files. Likewise, all of the illustrations and maps from the present report, plus additional maps, figures and cross-sections, are available on the CD-ROM. For convenience, poster-size maps and cross-sections have been prepared as a visual summary of the results presented in this report.

Appendices A, B and C are provided in a tabloid-size format, are separate from the report and are as follows:

- Appendix A features tabloid-size copies of the general hydrogeological maps and figures within the report plus additional maps and cross-sections. An index of the tabloid-size maps, figures and cross-sections is given at the beginning of Appendix A.

- Appendix B provides tabloid-size copies of the hydrogeological maps and figures related to the surficial deposits in the Study Area that were used in the report. An index of these maps and figures is given at the beginning of Appendix B.

- Appendix C provides tabloid-size copies of the hydrogeological maps and figures related to the bedrock formations found in the Study Area. An index of the maps and figures is given at the beginning of Appendix C.
2. Introduction

2.1 Setting

The Peace River Basin Study Area is situated in northwestern Alberta as shown on the adjacent index map (also on page A-2). Most of this area is part of the northwest Boreal region. The Study Area boundaries follow the borders between the Public Lands General Classification White Areas and Green Areas, established by Agriculture, Food and Rural Development. The assessment area includes the White Areas within the following:

- Co. of Grand Prairie No. 1
- M.D. of Greenview No. 16
- Birch Hills County No. 19
- Saddle Hills County No. 20
- M.D. of Clear Hills No. 21
- M.D. of Northern Lights No. 22
- M.D. of Mackenzie No. 23
- Northern Sunrise County No. 131
- M.D. of Spirit River No 133
- M.D. of Fairview No. 136
- M.D. of Peace No. 135

Statistical data for the M.D. of Big Lakes and the M.D. of Smoky River No. 130, with regard to the numbers of water wells of various types, licensing and registration, have been included in the various analyses for the following report, although the MDs are not participating in the overall study.
2.2 Topography

Regionally, the topographic surface varies between 200 and 1,200 metres above mean sea level (AMSL). The lowest elevations occur mainly in the northern part of the Study Area, and the highest elevations are in the south-western parts of the Study Area as shown on Figure 2 (also page A-3). The southern part of the Study Area is well drained by numerous streams and rivers, the main ones being the Peace River and the Smoky River. The northern part of the Study Area has poor drainage, resulting in low, marshy areas.

2.3 Climate

The Peace River Basin Study Area lies within the continental Dfb climate. This classification is based on potential evapotranspiration values determined using the Thornthwaite method (Thornthwaite and Mather, 1957), combined with the distribution of natural ecoregions in the area. The ecoregions map (Strong and Leggat, 1981) shows that the majority of the Study Area is located in the Low- to Mid-Boreal Mixedwood region, with the southern and eastern portions located in the Lower and Upper Boreal-Cordilleran regions.

A Dfb climate consists of long, cool summers, severe winters and no dry season. The mean monthly temperature drops below -15°C in the coolest month, and exceeds 15°C in the warmest month.

The mean annual precipitation averaged from six meteorological stations within the area measured 436 millimetres (mm), based on data from 1961 to 1993. The mean annual temperature averaged 1.0°C, with the mean monthly temperature reaching a high of 15.9°C in July, and dropping to a low of -16.3°C in January. The calculated annual potential evapotranspiration is 498 millimetres.
2.4 Background Information

2.4.1 Number, Type and Depth of Water Wells

There are currently records for 13,032 water wells in the groundwater database for the Study Area. Of the 13,032 water wells, 12,189 have the purpose specified; 11,331 of the water wells with the purpose specified are for domestic, stock or domestic/stock purposes. The proposed use for 858 water wells included a variety of uses, including municipal, observation, industrial, irrigation, investigation, dewatering and others; 843 water wells had no purpose specified. Of the 11,331 domestic and/or stock water wells, 8,415 have a value for completed depth; 4,844 (58%) are completed at depths of less than 50 metres below ground level. Details for lithology are available for 5,406 domestic and stock water wells.

2.4.2 Number of Water Wells in Surficial and Bedrock Aquifers

There are 7,551 water well records with completion interval and/or lithologic information, such that the aquifer in which the water wells are completed can be identified. The water wells that were not drilled deep enough to encounter the bedrock plus water wells that have the bottom of their completion interval above the top of the bedrock are water wells completed in surficial aquifers.

Of the 7,551 water wells for which aquifers could be defined, 2,256 are completed in surficial aquifers, with 705 (31%) having a completion depth of less than 15 metres below ground level. The adjacent map shows that the water wells completed in the surficial deposits occur mainly along the Peace River, the Smoky River and in the linear bedrock lows. Within the Study Area, casing-diameter information is available for 1,942 of the 2,256 water wells completed in the surficial deposits; of the 1,942 surficial water wells with casing diameter information, 1,499 have a casing diameter of less than 275 millimetres and are assumed to be drilled water wells.

The data for 5,295 water wells show that the top of the water well completion interval is below the bedrock surface, indicating that the water wells are completed in at least one bedrock aquifer. From Figure 3 (also page A-4), it can be seen that most of the water wells completed in bedrock aquifers occur in the southern part of the Study Area. Within the Study Area, casing-diameter information is available for 5,235 of the water wells completed below the top of bedrock. Of these 5,235 bedrock water wells, 5,209 have surface-casing diameters of less than 275 mm and these bedrock water wells have mainly been completed with either a perforated liner or as open hole. There are 40 bedrock water wells completed with a water well screen.

Figure 3. Location of Water Wells and Springs

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4 See glossary
There are currently records for 180 springs in the groundwater database, including 32 springs that were documented by Borneuf (1983). The locations of the springs are shown on Figure 3 above. There are 110 springs having at least one total dissolved solids (TDS) value, of which 70 have TDS concentrations of less than 4,000 milligrams per litre (mg/L). There are 21 available flow rates for springs within the Study Area, ranging from 4.8 to 912 litres per minute (lpm). The largest flow rate is for a spring located at 15-14-082-24 W5M, southwest of the Town of Peace River.

### 2.4.3 Casing Type

Data regarding casing details are available for 8,353 water wells. The casing diameters of greater than 275 mm are mainly bored or dug water wells and those with a surface-casing diameter of less than 275 mm are drilled water wells.

In the Study Area, steel, galvanized steel and plastic surface casing materials have been used in 92% of the water wells over the last 40 years. Until the mid-1960s, information on the type of surface casing used in water wells was largely unavailable. Steel casing was in use in the 1950s and is still used in the majority of the water wells being completed in the Study Area, as shown on Figure 4. The use of galvanized steel casing has decreased while the use of plastic surface casing (PVC) has increased when completing new water wells. Ninety percent of the water wells completed since the beginning of 2000 have either steel or plastic casing. No use of galvanized steel for the completion of water wells in the Study Area has been reported since 1995.

Steel casing has been dominant in the Study Area probably because it has resisted corrosion and also because water well drillers may be reluctant to use PVC if there have been no documented problems with steel casing in the area.

### 2.4.4 Dry Water Test Holes

In the Study Area, there are 19,709 records in the groundwater database. Of these 19,709 records, 706 are indicated as being dry or abandoned with “insufficient water”. Also included in these dry test holes is any record that includes comments that state the water well goes dry in dry years.

### 2.4.5 Requirements for Groundwater Licensing

Water wells used for household needs in excess of 1,250 cubic metres per year (m³/year) (750 imperial gallons per day)⁵ and all other groundwater use, with some exceptions, must be licensed. Groundwater diversions that do not need licensing are (1) household use of up to 1,250 m³/year, (2) groundwater with total dissolved solids in excess of 4,000 mg/L, (3) water wells eligible for registration, but not registered or licensed, can continue to be used without authorization but without the protection of the Water Act, and (4) some exempted diversions such as water supply wells with hand pumps, drainage of water for the purpose of dewatering a construction site, and some uses of groundwater for oil rig and camp water supply. In the last update from the Alberta Environment (AENV) groundwater database in March 2003, 1,554 groundwater diversion authorizations (licences and registrations for Traditional Agriculture Use) were shown to be within the Study Area. Of the 1,554 authorized groundwa-

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⁵ see conversion table on page 77
ter users, 1,248 (80.3% of all licensed water wells) could be linked to the AENV groundwater database. Of the 1,554 authorized groundwater users, 1,287 are registrations of Traditional Agriculture Use, 109 are licences for agricultural purposes, 87 are licences for municipal purposes, 21 are licences for commercial purposes, 27 are licences for industrial purposes, 15 are licences for recreation purposes, and the remaining eight are licences for dewatering, irrigation, wetland, fish management and ‘other’ purposes.

Groundwater authorized by registration as Traditional Agriculture Use is primarily used for watering livestock, but can also be used for applying pesticides to crops. Agricultural use of groundwater includes groundwater used for stock watering and for feedlots. Municipal use of groundwater includes groundwater used by hamlets, villages, summer villages, towns, cities, and rural residential subdivisions (with central distribution systems). Commercial use of groundwater provides for the use of groundwater for gardens, greenhouses, sod and tree farms, golf courses, parks, aggregate washing, water bottling and cooling. Industrial use of groundwater includes groundwater used for enhanced recovery (injection) and at gas or petrochemical plants.

The total maximum authorized diversion from the water wells associated with these licences is 8,183,815 m³/day, although actual use could be less. Of the 8,183,815 m³/day, 2,800,546 m³/day (about 34%) is registered for Traditional Agriculture Use, 648,188 m³/day (about 8%) is authorized for agricultural purposes, 2,177,966 (about 27%) is authorized for municipal purposes, 1,174,967 (about 14%) is authorized for industrial purposes, 1,097,440 (about 13%) is authorized for dewatering purposes, and the remaining 284,708 m³/day (about 3%) is allotted for commercial, irrigation, recreation, fish management, wetlands or other use, as shown in Table 1 below. A figure showing the locations of the licensed users and registered Traditional Agriculture Users is in Appendix A (page A-13) and on the CD-ROM. Table 1 also shows a breakdown of the 1,554 licensed and registered groundwater allocations by the aquifer in which the water well is completed. The largest totals of licensed and registered allocations are in the Upper Surficial Aquifer, followed by the Unknown Aquifers, the Foremost and the unspecified Bedrock Aquifers. The Peace River Aquifer has the lowest total of licensed and registered allocations.

<table>
<thead>
<tr>
<th>Aqaurifer**</th>
<th>No. of Diversions</th>
<th>Registration</th>
<th>Municipal</th>
<th>Agriculture</th>
<th>Irrigation</th>
<th>Commercial</th>
<th>Industrial</th>
<th>Dewatering</th>
<th>Fish Mngment</th>
<th>Wetlands</th>
<th>Recreation</th>
<th>Other</th>
<th>Total</th>
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<td>278</td>
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<td>83,870</td>
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<td>38,230</td>
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<td>1,097,440</td>
<td>4,190</td>
<td>8,380</td>
<td>1,831,517</td>
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<tr>
<td>Lower Surficial</td>
<td>47</td>
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<td>-</td>
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<td>-</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>3,910</td>
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<td>Colorado</td>
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<td>8,630</td>
<td>-</td>
<td>27,140</td>
<td>-</td>
<td>-</td>
<td>36,509</td>
<td>0.4%</td>
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<tr>
<td>Cardium</td>
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<td>6,066</td>
<td>-</td>
<td>54,270</td>
<td>-</td>
<td>-</td>
<td>62,914</td>
<td>0.8%</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Kaskapau</td>
<td>27</td>
<td>17,508</td>
<td>204,150</td>
<td>4,930</td>
<td>57,970</td>
<td>27,140</td>
<td>58,000</td>
<td>369,698</td>
<td>4.5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dunvegan</td>
<td>49</td>
<td>31,324</td>
<td>26,670</td>
<td>8,010</td>
<td>-</td>
<td>2,470</td>
<td>-</td>
<td>66,474</td>
<td>0.8%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaftesbury</td>
<td>5</td>
<td>384</td>
<td>1,230</td>
<td>-</td>
<td>6,160</td>
<td>-</td>
<td>-</td>
<td>7,774</td>
<td>0.1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peace River</td>
<td>1</td>
<td>2,470</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2,470</td>
<td>0.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mannville</td>
<td>4</td>
<td>4,694</td>
<td>2,470</td>
<td>1,230</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>8,394</td>
<td>0.1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td>122</td>
<td>1,470,984</td>
<td>18,121</td>
<td>1,000</td>
<td>250</td>
<td>-</td>
<td>-</td>
<td>1,490,455</td>
<td>18.2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>**Total</td>
<td>1554</td>
<td>2,800,546</td>
<td>2,177,966</td>
<td>648,108</td>
<td>2,460</td>
<td>187,010</td>
<td>1,174,967</td>
<td>1,097,440</td>
<td>458</td>
<td>8,183,815</td>
<td>100.0%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Data from Alberta Environment **Aquifer identification by HCL

Table 1. Licensed Groundwater Diversions

Based on the 2001 Agriculture Census (Statistics Canada) for the numbers of various types of livestock in the Study Area and AENV data on the daily quantity of water required for the various types of livestock, the esti-
mated water requirement for the Study Area is in the order of 38,111 m³/day. This value includes intensive livestock use but not domestic animals. A breakdown, based on livestock type, is shown in Table 2 which follows:

AENV has diversions of surface water and groundwater totalling 18,077 m³/day, authorized as Registration of Traditional Agriculture Use and licensed for Agriculture purposes. Agriculture purpose includes water diverted and used for stock watering and feedlot use. Of this total of 18,077 m³/day, 9,448 m³/day (52.3%) is for the diversion of groundwater and 8,629 m³/day (47.7%) is for the diversion of surface water. This assumes the majority of the groundwater and surface water authorized for diversion and use as Traditional Agriculture Use is used for watering livestock. Using this assumption, slightly over 47% of the estimated total water requirement of 38,111 m³/day is accounted for.

The remaining 20,034 m³/day (53%) of the calculated water requirement for livestock use would have to be from other, including unlicensed, sources. The discrepancy may be partially accounted for in several ways. Based on some monitoring and reporting situations, the estimated water requirements for livestock, used by AENV, tend to be somewhat high. Some livestock water requirements would be made up from free-standing water following precipitation events, thus reducing the expected quantity needed. Also, it should be noted that ‘household use’, as defined in the Water Act, can provide sufficient water for about 75 head of cattle, with no need for a licence. It is possible that some such use may have been registered as Traditional Agriculture Use and would therefore be included in the registration quantity. Also, diversions of groundwater and surface water that were eligible for registration as Traditional Agriculture Use can continue to be used for traditional agricultural purposes without the need for authorization.

<table>
<thead>
<tr>
<th>Livestock Type</th>
<th>Number</th>
<th>Estimated Water Requirement (m³/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total hens and chickens</td>
<td>295,189</td>
<td>60</td>
</tr>
<tr>
<td>Turkeys</td>
<td>2775</td>
<td>2</td>
</tr>
<tr>
<td>Other poultry</td>
<td>2,612</td>
<td>1</td>
</tr>
<tr>
<td>Total cattle and calves</td>
<td>392304</td>
<td>21487</td>
</tr>
<tr>
<td>Bulls, 1 year and over</td>
<td>8,221</td>
<td>981</td>
</tr>
<tr>
<td>Total cows</td>
<td>169,761</td>
<td>9263</td>
</tr>
<tr>
<td>Heifers, 1 year and over</td>
<td>46,298</td>
<td>2104</td>
</tr>
<tr>
<td>Calves, under 1 year</td>
<td>148,964</td>
<td>2034</td>
</tr>
<tr>
<td>Total pigs</td>
<td>33,579</td>
<td>611</td>
</tr>
<tr>
<td>Total sheep and lambs</td>
<td>27,303</td>
<td>248</td>
</tr>
<tr>
<td>Horses and ponies</td>
<td>16,901</td>
<td>759</td>
</tr>
<tr>
<td>Goats</td>
<td>7,064</td>
<td>64</td>
</tr>
<tr>
<td>Rabbits</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mink</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fox</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bison (buffalo)</td>
<td>21,675</td>
<td>985</td>
</tr>
<tr>
<td>Deer and elk</td>
<td>205</td>
<td>3</td>
</tr>
<tr>
<td>Llamas and alpacas</td>
<td>1,093</td>
<td>10</td>
</tr>
<tr>
<td>Totals</td>
<td>1,173,944</td>
<td>38,111</td>
</tr>
</tbody>
</table>

Table 2. Estimated Water Requirements for Livestock in Study Area
2.4.6 Groundwater Chemistry and Base of Groundwater Protection

Groundwaters from the surficial deposits can be expected to be chemically hard, with a high dissolved iron content. An analysis of the nitrate + nitrite content was done for 1,215 groundwater samples from water wells completed in the surficial deposits, although most values were indicated as ‘less than’. High nitrate + nitrite (as N) concentrations (> 10 mg/L) were evident in only 34, or approximately 3%, of the analyses; a plot of nitrate + nitrite in surficial deposits is on page B-6 and on the accompanying CD-ROM. The TDS concentrations in the groundwaters from the surficial deposits in the Study Area range from less than 20 to more than 15,000 mg/L (page B-4).

Groundwaters from the bedrock aquifers frequently are chemically soft, with generally low concentrations of dissolved iron. The chemically soft groundwater is high in concentrations of sodium. Approximately 19% of the chemical analyses for bedrock water wells indicate a fluoride concentration above 1.5 mg/L, with most of the exceedances occurring in the southern part of the Study Area in the Horseshoe Canyon, the Oldman, and the Foremost aquifers; a plot of fluoride in the bedrock aquifers is shown on Page C-7 and on the accompanying CD-ROM. The TDS concentrations in the groundwaters from the upper bedrock in the Study Area range from less than ten to more than 24,000 mg/L (page C-4).

In general, AENV defines the Base of Groundwater Protection as the elevation below which the groundwater will have more than 4,000 mg/L of total dissolved solids. By using the ground elevation, formation elevations, and Alberta Energy and Utilities Board (EUB) information indicating the formations containing the deepest usable water for agricultural needs, a value for the depth to the Base of Groundwater Protection can be determined. These values are gridded using the Kriging method to prepare a depth to the Base of Groundwater Protection surface. This depth, for the most part, would be the maximum drilling depth for a water well for agricultural purposes or for a potable water supply. If a water well has groundwater with total dissolved solids exceeding 4,000 mg/L, the groundwater use does not require licensing by AENV.

In the Study Area, the depth to the Base of Groundwater Protection ranges from as little as 25 metres in the Swan River area in the M.D. of Big Lakes in the eastern part of the Study Area to over 400 metres in Saddle Hills County and the County of Grande Prairie in the more western extent of the Study Area, as shown on the adjacent Figure 5 (also see page A-14) and on cross-sections presented in Appendix A (pages A-8 to A-12) and on the CD-ROM. There are

---

6 See glossary
12,099 water wells with completed depth data, of which 527 are completed below the Base of Groundwater Protection.

Proper management of the groundwater resource requires water-level data. These data are often collected from observation water wells. At the present time, there are 33 AENV-operated observation water wells within the Study Area, although not all are being monitored. Details of locations and areas of the AENV monitoring water wells are summarized in the adjacent table.

Additional data can be obtained from some of the licensed groundwater diversions. In the past, the data for licensed diversions have been difficult to obtain from AENV, in part because of the failure of the licensee to provide the data.

Even with the available sources of data, the number of water-level data points relative to the size of the Study Area is too few to provide a reliable groundwater budget (see section 6.0 of this report). The most cost-efficient method to collect additional groundwater monitoring data would be to have the water well owners measuring the water level in their own water well on a regular basis, as has been the case in the Wildrose Country Ground Water Monitoring Association and Flagstaff County.

### 2.5 Terms

Figures 6 and Figure 7, which are on the next page, provide information regarding some of the terminology used in the present report and associated figures, and a list of geological units and some of their equivalents referred to in the report and associated figures.
### Figure 6. Generalized Cross-Section (for terminology only)

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Group</th>
<th>Avg. Thickness (metres)</th>
<th>Designation</th>
<th>Member Designation</th>
<th>Alternate Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>sandstone, shale, coal, bentonite, limestone, sandstone</td>
<td>Edmonton Group</td>
<td>&lt;600</td>
<td>Lower</td>
<td>Wapiti Formation</td>
<td>Upper Wapiti</td>
</tr>
<tr>
<td>sandstone, siltstone, shale, coal</td>
<td>Belly River Group</td>
<td>&lt;180</td>
<td>Lower</td>
<td>Wapiti Formation</td>
<td>Birch Lake Member</td>
</tr>
<tr>
<td>sandstone, shale</td>
<td></td>
<td>&lt;300</td>
<td>Lea Park Formation</td>
<td>Wapiti Formation</td>
<td></td>
</tr>
<tr>
<td>sandstone, siltstone, shale, coal</td>
<td></td>
<td>&lt;250</td>
<td>Milk River Formation</td>
<td>Wapiti Formation</td>
<td></td>
</tr>
<tr>
<td>shale, siltstone</td>
<td></td>
<td>&lt;250</td>
<td>Colorado Shale</td>
<td>First White Specks</td>
<td>Wapiti Formation</td>
</tr>
<tr>
<td>sandstone</td>
<td></td>
<td>&lt;200</td>
<td>Cardium Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>sandstone</td>
<td></td>
<td>&lt;700</td>
<td>Kaskapau Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>sandstone</td>
<td></td>
<td>&lt;400</td>
<td>Dunvegan Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>sandstone</td>
<td></td>
<td>&lt;450</td>
<td>Shalesbury Formation</td>
<td>Base of fish scales</td>
<td></td>
</tr>
<tr>
<td>sandstone</td>
<td></td>
<td>&lt;200</td>
<td>Peace River Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>sandstone, shale</td>
<td></td>
<td>&lt;650</td>
<td>Mannville Group</td>
<td>Spirit River</td>
<td></td>
</tr>
<tr>
<td>limestone</td>
<td></td>
<td>0-400</td>
<td>Jurassic</td>
<td>Nordegg Member</td>
<td>Permo Formation</td>
</tr>
<tr>
<td>siltstone, shale</td>
<td></td>
<td>0-400</td>
<td>Trassic</td>
<td>Dabler Group</td>
<td></td>
</tr>
<tr>
<td>sandstone, chert, carbonates, sandstone</td>
<td></td>
<td>0-200</td>
<td>Belloy Formation</td>
<td>Paleozoic</td>
<td></td>
</tr>
</tbody>
</table>

### Figure 7. Geologic Column
3. Methodology

3.1 Data Collection and Synthesis

The AENV groundwater database is the main source of groundwater data. The database includes the following:

1) water well drilling reports
2) aquifer test results from some water wells
3) location of some springs
4) locations for some water wells determined during water well surveys
5) chemical analyses for some groundwaters
6) location of some flowing shot holes
7) location of some structure test holes
8) a variety of data related to the groundwater resource.

The main disadvantage to the database is the absence of quality control. Very little can be done to overcome this lack of quality control in the data collection, other than to assess the usefulness of control points relative to other data during the interpretation. Another disadvantage to the database is the lack of adequate spatial information. Any duplicate water wells that have been identified within the Study Area have been removed from the database used in this regional groundwater assessment.

The AENV groundwater database uses a land-based system with only a limited number of records having a value for ground elevation. The locations for records usually include a quarter section description; a few records also have a land description that includes a Legal Subdivision (Lsd). For digital processing, a record location requires a horizontal coordinate system. In the absence of an actual location for a record, the record is given the coordinates for the centre of the land description.

The present project uses the 10TM coordinate system based on the NAD27 datum. This means that a record for the NE ¼ of section 19, township 074, range 09, W6M, would have a horizontal coordinate with an Easting of 275990.77 metres and a Northing of 6148484.03 metres, the centre of the quarter section. If the water well has been repositioned by AAFC-PFRA using orthorectified aerial photos, the location will be more accurate, possibly within several tens of metres of the actual location. Once the horizontal coordinates are determined for a record, a ground elevation for that record is obtained from the 1:20,000 Digital Elevation Model (DEM); AltaLis Ltd. provides the DEM.

At many locations within the Study Area, more than one water well is completed at one legal location. Digitally processing this information is difficult. To obtain a better understanding of the completed depths of water wells, a digital surface was prepared representing the minimum depth for water wells and a second digital surface was prepared for the maximum depth. Both of these surfaces are used in the groundwater query on the CD-ROM. When the maximum and minimum water well depths are similar, there is only one aquifer that is being used at a given location.

After assigning spatial control for the ground location for the records in the groundwater database, the data are processed to determine values for hydrogeological parameters. As part of the processing, obvious keying errors in the database are corrected.
Where possible, determinations are made from individual records in order to assign water wells to aquifers and to obtain values for the following:

1) depth to bedrock
2) total thickness of sand and gravel below 15 metres
3) total thickness of saturated sand and gravel
4) depth to the top and bottom of completion intervals.

Also, where sufficient information is available, values for apparent transmissivity\(^7\) and apparent yield\(^8\) are calculated, based on the aquifer test summary data supplied on the water well drilling reports. Where valid detailed aquifer test results exist, the interpreted data provide values for aquifer transmissivity and effective transmissivity. Since the last regional hydrogeological map covering at least a part of the Study Area was published in 1982 (Ozoray, 1982), 2,214 values for apparent transmissivity and apparent yield have been added to the groundwater database. With the addition of the apparent yield values, including a 0.1-m\(^3\)/day value assigned to “dry” water wells and water test holes, a hydrogeological map has been prepared to help illustrate the general groundwater availability across the Study Area (Figure 8 and page A-5). The map is based on groundwater being obtained from all aquifers and has been prepared to allow direct comparison with the results provided on the Alberta Research Council hydrogeological maps.

The EUB well database includes records for wells drilled for the oil and gas industry. The information from this source includes:

1) spatial control for each well site
2) depth to the top of various geologic units
3) type and intervals for various down-hole geophysical logs
4) drill stem test (DST) summaries.

Values for apparent transmissivity and apparent yield are calculated from the DST summaries.

Published and unpublished reports and maps provide the final source of information to be included in the new groundwater database. The reference section of this report lists the available reports. The only digital data from publications are from the Geological Atlas of the Western Canada Sedimentary Basin (Mossop and Shetsen, 1982).
1994). These data are used to support the geological interpretation of geophysical logs but cannot be distributed because of a licensing agreement.

### 3.2 Spatial Distribution of Aquifers

Determination of the spatial distribution of the aquifers is based on:

1. Lithologs provided by the water well drillers
2. Geophysical logs from structure test holes
3. Geophysical logs for wells drilled by the oil and gas industry
4. Data from existing cross-sections.

The aquifers are defined by mapping the tops and bottoms of individual geologic units. The values for the elevation of the top and bottom of individual geologic units at specific locations help to determine the spatial distribution of the individual surfaces. Establishment of a surface distribution digitally requires preparation of a grid. The inconsistent quality of the data necessitates creating a representative sample set obtained from the entire data set. If the data set is large enough, it can be treated as a normal population and the removal of extreme values can be done statistically. When data sets are small, the process of data reduction involves a more direct assessment of the quality of individual points. Because of the uneven distribution of the data, all data sets are gridded using the Kriging method.

The final definition of the individual surfaces becomes an iterative process involving the plotting of the surfaces on cross-sections and the adjusting of control points to fit with the surrounding data.

### 3.3 Hydrogeological Parameters

Water well records that indicate the depths to the top and bottom of their completion interval are compared digitally to the spatial distribution of the various geological surfaces. This procedure allows for the determination of the aquifer in which individual water wells are completed. When the completion interval of a water well cannot be established without making assumptions, the data from that water well are not used in determining the distribution of hydraulic parameters.

After the water wells are assigned to a specific aquifer, the parameters from the water well records are assigned to the individual aquifers. The parameters include non-pumping (static) water level (NPWL), apparent transmissivity, and apparent water well yield. The total dissolved solids, sulfate and chloride concentrations from the chemical analysis of the groundwater are also assigned to applicable aquifers. In addition, chemical parameters of nitrate + nitrite (as N) are assigned to surficial aquifers and fluoride is assigned to upper bedrock aquifer(s). Since 1986, Alberta Health and Wellness has restricted access to chemical analysis data, and hence the database includes only limited amounts of chemical data since 1986.

Once the values for the various parameters of the individual aquifers are established, the spatial distribution of these parameters must be determined. The distribution of individual parameters involves the same process as the distribution of geological surfaces. This means establishing a representative data set and then preparing a grid. The representative data set included using the available data from townships 065 to 107, ranges 05 to 27, W5M and townships 069 to 087, ranges 01 to 13, W6M, plus a buffer area of at least 5,000 metres. Even when only limited data are available, grids are prepared. However, the grids prepared from the limited data must be used with extreme caution because the gridding process can be unreliable; for the maps, the areas with little or no data are identified.
3.4 Maps and Cross-Sections

Once grids for geological surfaces have been prepared, various grids need to be combined to establish the extent and thickness of individual geologic units. For example, the relationship between an upper bedrock unit and the bedrock surface must be determined. This process provides both the outline and the thickness of the geologic unit.

Once the appropriate grids are available, the maps are prepared by contouring the grids. For the upper bedrock aquifer(s) where areas of insufficient data are available from the groundwater database, prepared maps have been masked to indicate these areas. Appendices A to C, produced as a separate volume, include tabloid-size maps from the text, plus additional tabloid-size maps and figures that support the discussion in the text. A list of maps and figures that are included on the CD-ROM is given in Appendix D.

Cross-sections are prepared by first choosing control points from the database along preferred lines of section. Data from these control points are then obtained from the database and placed in an AutoCAD drawing with an appropriate vertical exaggeration. The data placed in the AutoCAD drawing include the geo-referenced lithology, completion intervals and NPWLs. Data from individual geologic units are then transferred to the cross-section from the digitally prepared surfaces.

Once the technical details of a cross-section are correct, the drawing file is moved to the software package CorelDraw! for simplification and presentation in a hard-copy form. Five tabloid-sized cross-sections (A-A’ to E-E’) are presented in Appendix A (pages A-8 to A-12) of the separate appendices report forwarded with this report; only two (A-A’ and C-C’) are included in the text of this report. The cross-sections are also included on the CD-ROM.

3.5 Software

The files on the CD-ROM have been generated from the following software:

- Acrobat 5.0
- ArcView 3.2
- AutoCAD 2002
- CorelDraw! 11
- Microsoft Office XP
- Surfer 8
4. Aquifers

4.1 Background

An aquifer is a permeable rock that is saturated. In this context, rock refers to subsurface materials, such as sand, gravel, sandstone and coal. If the NPWL is above the top of the rock, this type of aquifer is an artesian aquifer. If the rock is not entirely saturated and the water level is below the top of the rock, this type of aquifer is a water-table or unconfined aquifer. These types of aquifers occur in one of two general geological settings in the Study Area. The first geological setting includes the sediments that overlie the bedrock surface. In this report, these sediments are referred to as the surficial deposits. The second geological setting includes aquifers in the upper bedrock. The geological settings, the nature of the deposits making up the aquifers within each setting, the expected yield of water wells completed in aquifer(s) within different geologic units, and the general chemical quality of the groundwater associated with each setting are reviewed separately.

4.1.1 Surficial Aquifers

Surficial deposits in the Study Area are mainly less than 100 metres thick, except in areas of linear bedrock lows where the thickness of the surficial deposits can exceed 100 metres. There are three main linear bedrock lows in the Study Area: the High Prairie Valley, the Shaftesbury Valley and the Notikewin Valley. The High Prairie Valley and the Shaftesbury Valley are present in the southern part of the Study Area. The Notikewin Valley, which is based on few data points, is present in the northern part of the Study Area. The generalized south-north cross-section A-A' shown below (Figure 9 and page A-8) shows the surficial deposits being in excess of 100 metres thick in some areas. Buried bedrock valleys exist in the Study Area, such as the south-trending Berwyn Buried Valley in the Cardinal Lake area, a tributary to the Shaftsbury Buried Valley (Cowen, 1994) and the north-trending Brazeau Buried Valley in the vicinity of Township 077, Range 24, W5M (Hackbarth, 1977), a tributary to the High Prairie Buried Valley. Additional linear bedrock lows, some present in the form of meltwater channels, can be expected throughout the Study Area.

The main aquifers in the surficial materials are sand and gravel deposits. In order for a sand and gravel deposit to be an aquifer, it must be saturated; if not saturated, a sand and gravel deposit is not an aquifer. The top of the surficial aquifers has been determined from the NPWL in water wells that are less than 20 metres deep. The base of the surficial deposits is the bedrock surface.

For a water well with a small-diameter casing to be effective in surficial deposits and to provide sand-free groundwater, the water well must be completed with a water well screen. Some water wells completed in the surficial deposits are completed in low-permeability aquifers and have a large-diameter casing. The large-
diameter water wells may have been hand dug or bored and because they are completed in very low permeability aquifers, most of these water wells would not benefit from water well screens. The groundwater from an aquifer in the surficial deposits usually has a chemical hardness of at least a few hundred mg/L and a dissolved iron concentration such that the groundwater must be treated before being used for domestic needs.

4.1.2 Bedrock Aquifers

In the Study Area, the upper bedrock includes the Horseshoe Canyon, the Oldman, the Foremost, the Lea Park, the Milk River, the Colorado Shale, the Cardium, the Kaskapau, the Dunvegan, the Shaftesbury, and the Peace River formations and the Mannville Group. To be consistent in this report, the Colorado Shale designation applies to the upper shale that contains the distinctive White Specks unit, within the Colorado Group, as opposed to the Colorado Group as a whole. The Colorado Group contains the formations from the Colorado Shale to the Peace River Formation, in the Study Area. Cross-section C-C' in Figure 10 (also on page A-10) shows that the aquifers in which water wells are completed, are mainly within 100 metres of the ground surface. Some of this bedrock contains saturated rocks that are permeable enough to transmit groundwater for a specific need. Water wells completed in bedrock aquifers usually do not require water well screens, although some of the sandstones may be friable\(^\text{10}\) and water well screens are a necessity. The groundwater from the bedrock aquifers is usually chemically soft.

![Figure 10. Cross-Section C - C'](image)

In the Study Area, the Base of Groundwater Protection is variable, extending from a depth of as little as 25 metres to a depth of over 400 metres below ground surface. A map showing the depth to the Base of Groundwater Protection is given on Figure 5 of this report, in Appendix A (page A-14), and on the CD-ROM.

4.2 Aquifers in Surficial Deposits

The surficial deposits are the sediments above the bedrock surface. These include pre-glacial materials, which were deposited before glaciation, and materials deposited directly or indirectly as a result of glaciation. The lower surficial deposits include pre-glacial fluvial\(^\text{11}\) and lacustrine\(^\text{12}\) deposits. The lacustrine deposits include clay, silt and fine-grained sand. Fluvial deposits tend to include coarser sand and gravel. The upper surficial deposits include the more traditional glacial sediments of till\(^\text{13}\) and ice-contact deposits. Pre-glacial materials are expected to be mainly present in association with the buried bedrock valleys. The named major buried bedrock valleys in-
clude the High Prairie, the Shaftesbury and the Notikewin valleys. Tributaries to the major buried bedrock valleys exist in the Study Area. Meltwater channels associated with glaciation can also be expected in the Study Area.

4.2.1 Geological Characteristics of Surficial Deposits

While the surficial deposits are treated as one hydrogeologic unit, they consist of three hydraulic parts. The first unit is the sand and gravel deposits of the lower surficial deposits, when present. These deposits are mainly saturated. The second and third hydraulic units are associated with the sand and gravel deposits in the upper surficial deposits. The sand and gravel deposits in the upper surficial deposits occur mainly as pockets. The second hydraulic unit is the saturated part of these sand and gravel deposits; the third hydraulic unit is the unsaturated part of these deposits. For a graphical depiction of the above description, refer to H, I and J, Figure 6, page 11. While the unsaturated deposits are not technically an aquifer, they are significant as they provide a pathway for liquid contaminants to move downward into the groundwater.

The base of the surficial deposits is the bedrock surface, represented by the bedrock topography as shown on Figure 11 (and on page A-6). The locations of the major buried bedrock valley thalwegs are shown on the map.

Over the majority of the Study Area, the surficial deposits are less than 100 metres thick (see page B-2 and the CD-ROM). The exceptions, representing about 10% of the Study Area, are mainly in association with areas where buried bedrock valleys are present, where the deposits can have a thickness of more than 100 metres. There are three main linear bedrock lows in the Study Area: two are west-east-trending and have been designated as the High Prairie Buried Valley and the Shaftesbury Buried Valley; the other is south-north trending and has been designated the Notikewin Buried Valley. The Brazeau Buried Valley and an unnamed buried bedrock valley are tributaries that join the Buried High Prairie Valley in the southern parts of the Study Area.

The Shaftesbury and Notikewin Buried valleys are present in the western and northern parts of the Study Area, respectively, and are coincidental with the present-day Peace River. The Shaftesbury Buried Valley is in excess of twenty kilometres wide in the area of Fairview and Dunvegan, with local bedrock relief being up to 100 metres. Sand and gravel deposits can be expected in association with this bedrock low. Sand and gravel deposits may be up to 20 metres in thickness but will mainly be less than ten metres thick.

The Brazeau Buried Valley in the south-central part of the Study Area approximates the present-day location of the Smoky River, while an unnamed buried bedrock valley occurring at Sections 068 to 075, Ranges 19 to 21,
W5M follows the location of the present-day Little Smoky River fairly closely. The Brazeau Buried Valley may be in excess of 12 kilometres wide, with local bedrock relief being up to 100 metres. Sand and gravel deposits can be expected in association with this bedrock low, with the sand and gravel deposits expected to be mainly less than ten metres thick.

The High Prairie Buried Valley is coincidental with the present-day location of Lesser Slave Lake. The Valley is in excess of twenty kilometres wide, with local bedrock relief being up to 150 metres. Sand and gravel deposits can be expected in association with this bedrock low, with the sand and gravel deposits expected to be mainly less than ten metres in thickness.

The total thickness of the lower surficial deposits is mainly less than ten metres, but can be more than 30 metres in isolated areas of the buried bedrock valleys (Cowen, 1994). The lowest part of the lower surficial deposits includes pre-glacial sand and gravel deposits. The lower surficial deposits, composed mostly of fluvial and lacustrine deposits, are mainly associated with the linear bedrock lows. Older lower surficial deposits occur on terraces at higher elevations (the Grimshaw Gravels, for example) while younger lower surficial deposits occur on lower valley terraces and as basal channel gravels directly overlying the bedrock surface. The lowest sand and gravel deposits are usually less than five metres thick and may be discontinuous.

In the Study Area, meltwater channels overlying the linear bedrock lows can be expected. The meltwater channels may originally have been tributaries to the buried bedrock valleys.

The upper surficial deposits are either directly or indirectly a result of glacial activity. The deposits include till, with minor sand and gravel deposits of meltwater origin, which are expected to occur mainly as isolated pockets. Because the meltwater channels are mainly an erosional feature, the sand and gravel deposits associated with these features are considered not to be significant aquifers. The thickness of the upper surficial deposits is mainly more than 30 metres, and can be more than 100 metres in the northern and eastern parts of the Study Area.

Outwash plains of sand and gravel occur in the northern part of the Study Area (Fox, 1984). Fox also identified the maximum extent of a large glacial lake that developed in the Study Area during a period of deglaciation.

Sand and gravel deposits as shown in Figure 12 (and also on page B-9) can occur throughout the surficial deposits. The total thickness of sand and gravel deposits is generally less than ten metres but can be more than 20 metres in a few scattered parts of the Study Area. Extensive sand and gravel deposits in the Grimshaw area occur in thicknesses of more than ten metres, with some areas exceeding 30 metres (Cowen, 1994).
Sands and gravels occur in the surficial deposits over approximately 90% of the Study Area. The combined thickness of all sand and gravel deposits has been determined as a function of the total thickness of the surficial deposits. Over approximately 25% of the Study Area where sand and gravel deposits are present, the sand and gravel deposits are more than 10% of the total thickness of the surficial deposits (page B-10). The areas where sand and gravel deposits constitute more than 30% of the total thickness of the surficial deposits are mainly in the areas associated with linear bedrock lows.

### 4.2.2 Sand and Gravel Aquifer(s)

One source of groundwater in the Study Area includes aquifers in the surficial deposits. Since the Sand and Gravel Aquifer(s) are not present everywhere, the actual aquifer that is developed at a given location is usually dictated by the aquifer that is present. In the Study Area, the thickness of the Sand and Gravel Aquifer(s) is generally less than 30 metres, but can be more than 30 metres, especially in areas of linear bedrock lows (page B-11).

From the present hydrogeological analysis, 4,333 water wells are completed in aquifers in the surficial deposits, based on aquifer naming. The determination of which water wells are completed in the surficial deposits is obtained by comparing the elevation of the completed depth is above the elevation of the bedrock surface determined from the gridded bedrock topographic surface at the same location, then the water well is considered to be completed in an aquifer in the surficial deposits.

Water wells completed in the surficial deposits tend to be clustered in two main areas, one in the southwestern and one in the north-central part of the Study Area, as shown in the adjacent Figure 13 (and on page B-12).

#### 4.2.2.1 Apparent Yield

The permeability of the Sand and Gravel Aquifer(s) can be high. The high permeability combined with significant thickness leads to an extrapolation of high yields for water wells; however, because the sand and gravel deposits occur mainly as hydraulically discontinuous pockets, the long-term yields of the water wells are expected to be less than the apparent yields.

**Figure 13. Water Wells Completed in Surficial Deposits**
Apparent yields are available for 749 water wells completed in the Sand and Gravel Aquifer(s) in the Study Area. Twenty-eight (4%) apparent yields exceed 1,000 m$^3$/day, 23 (3%) are between 500 and 1,000 m$^3$/day, 161 (21%) are between 100 and 500 m$^3$/day, 229 (31%) are between 50 and 100 m$^3$/day, and 492 (66%) are less than 50 m$^3$/day. The actual long-term yields for water wells completed through this Aquifer(s) are expected to be mainly less than calculated due to the probable limited areal extent of some of the individual aquifers.

Where yields are low for the Sand and Gravel Aquifer(s), the development of water wells for the domestic needs of single families may not be possible from this Aquifer(s). Construction of a water supply well into the underlying bedrock may be the only alternative to provide the yields and the quality of groundwater that are suitable.

The adjacent map (Figure 14 and page B-13) shows expected yields for water wells completed in the Sand and Gravel Aquifer(s). Over approximately 55% of the Study Area, the sand and gravel deposits are not present, or if present, are not saturated; these areas are designated as grey on the map.

Based on the aquifers that have been developed by existing water wells, these data show that water wells with yields of less than 200 m$^3$/day from the Sand and Gravel Aquifer(s) can be expected in most of the Study Area. The most notable areas where yields of more than 200 m$^3$/day are expected are mainly in association with the buried bedrock valleys. In the Study Area, there are 368 records for surficial water wells with apparent yield data.

There are 359 records for water wells with the designation of Sand and Gravel Aquifer(s) that are indicated as being dry or abandoned with “insufficient water”.

In the Study Area, there are 368 licensed and registered water wells that are completed through the Sand and Gravel Aquifer(s), for a total authorized diversion of 7,795 m$^3$/day. About 995 m$^3$/day (13%) is used for agricultural purposes, and includes both agricultural licences and registrations. Over 38% of the total amount that is allocated for diversion is for a single dewatering project.

Two hundred thirty-two of the 368 licensed water wells completed through the Sand and Gravel Aquifer(s) could be linked to water wells in the AENV groundwater database.
4.2.2.2 Chemical Quality of Groundwater from Surficial Deposits

The chemical analysis results of groundwaters from the surficial deposits indicate the groundwaters are generally chemically hard and high in dissolved iron. In the Peace River Basin Study Area, groundwaters from the surficial aquifers mainly have a chemical hardness of greater than 200 mg/L (see page B-8 and the CD-ROM).

The Piper tri-linear diagram15 (CD-ROM) for surficial deposits shows the groundwaters are either sodium-bicarbonate, sodium-sulfate, calcium-bicarbonate or calcium-sulfate-type waters.

Approximately 66% of the 3,770 TDS values for groundwaters from the surficial deposits have a TDS concentration of more than 500 mg/L. Groundwaters having TDS concentrations of less than 500 mg/L occur mainly in the west-central portion of the Study Area, as shown in Figure 15 (also page B-4).

Two thousand twenty-three out of a total of 3,511 values for iron in the groundwaters from the surficial deposits, representing about 57%, are reported to have dissolved iron concentrations of less than one mg/L; 549 (16%) of the groundwaters have an iron concentration of greater than five mg/L. However, many iron analysis results are questionable due to varying sampling and analytical methodologies.

There are surficial deposit groundwaters with sulfate as the main anion. The groundwaters with elevated levels of sulfate generally occur in areas where there are elevated levels of total dissolved solids. There are very few groundwaters from the surficial deposits with appreciable concentrations of the chloride ion and in nearly 98% of the samples analyzed for surficial deposits in the Study Area, the chloride ion concentration is less than 250 mg/L (see CD-ROM).

In the Study Area, the nitrate + nitrite (as N) concentrations in the groundwaters from the surficial deposits exceed the maximum acceptable concentration (MAC) of ten mg/L in 140 of the 3,024 groundwater samples analyzed.

The minimum, maximum, mean and median concentrations of TDS, sodium, sulfate, chloride and nitrate + nitrite (as N) in the groundwaters from water wells completed in the surficial deposits in the Study Area have been compared to the Summary of Guidelines for Canadian Drinking Water Quality (SGCDWQ) in the following Table 4. Of the five constituents that have been compared to the SGCDWQ, only the mean and median values of TDS concentrations exceed the guidelines.

15 See glossary
4.2.3 The Grimshaw Aquifer

The most widely known lower surficial aquifer in the Study Area is the Grimshaw Gravels or the Grimshaw Aquifer. The Grimshaw Gravels are part of the oldest of the surficial deposits in the area, the Pliocene to Pleistocene Saskatchewan Gravels, and make up the Grimshaw Aquifer. Prior to the formation of the Shaftesbury Buried Valley, gravels were deposited in a fluvial environment that ran somewhat parallel to the Shaftesbury Buried Valley and the Peace River. The earlier deposits are Grimshaw Gravels occupying a broad, approximately 20 km-wide, area (Tokarsky, 1967).

The adjacent Figure 16 shows the extent of the Grimshaw Gravels. The gravels occur in three main bodies: the southwestern body, about 330 km², the central body, about 175 km² and the northeastern body, about 90 km² (Cowen, 1994) for a total area of about 600 km². The Berwyn Channel, tributary to the Shaftesbury Buried Valley, separates the central from the southwestern body.

The Grimshaw Aquifer varies from minimal to over 30 metres in thickness, and occurs in three separate areas, as shown in Figure 16. The southwestern gravel body has a large portion exceeding ten metres in thickness and exceeds 25 metres in thickness in the central region. The central and northeastern gravel bodies have lesser portions that are over ten metres in thickness.

Table 4. Concentrations of Constituents in Groundwaters from Surficial Deposits

<table>
<thead>
<tr>
<th>Constituent</th>
<th>No. of Analyses</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Median</th>
<th>Recommended AO Maximum Concentration SGCDFWQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dissolved Solids</td>
<td>3,770</td>
<td>16</td>
<td>15,712</td>
<td>1,084</td>
<td>728</td>
<td>500</td>
</tr>
<tr>
<td>Sodium</td>
<td>3,108</td>
<td>0.1</td>
<td>4,410</td>
<td>141</td>
<td>46</td>
<td>200</td>
</tr>
<tr>
<td>Sulfate</td>
<td>3,760</td>
<td>0.3</td>
<td>7,625</td>
<td>411</td>
<td>170</td>
<td>500</td>
</tr>
<tr>
<td>Chloride</td>
<td>3,411</td>
<td>0.1</td>
<td>2,178</td>
<td>30</td>
<td>7</td>
<td>250</td>
</tr>
<tr>
<td>Nitrate + Nitrite (as N)</td>
<td>3,024</td>
<td>0.001</td>
<td>513</td>
<td>4.1</td>
<td>0.3</td>
<td>10</td>
</tr>
</tbody>
</table>

AO - Aesthetic Objective  SGCDFWQ - Summary of Guidelines for Canadian Drinking Water Quality

Figure 16. Extent of Grimshaw Aquifer
Apparent yields are available for 128 water wells completed in the Grimshaw Aquifer in the Study Area as shown on the adjacent Figure 17. Eight apparent yields exceed 1,000 m³/day, five are between 500 and 1,000 m³/day, 13 are between 100 and 500 m³/day and 31 are less than 10 m³/day. In general terms, the apparent yields are higher in the western area than in the other two areas.

The Piper tri-linear diagram (CD-ROM) for lower surficial deposits shows the groundwaters are either bicarbonates or sulfates with calcium and magnesium as the predominant cations.

Cardinal Lake exists between the southwestern and central gravel bodies of the Grimshaw Aquifer. The elevation of the water level in the Lake (644.8 metres AMSL) is approximately four metres higher than the water level associated with the Grimshaw Gravels in close proximity to the Lake. This result suggests that Cardinal Lake does not have any impact on the groundwater resources of the Grimshaw Gravels.

The Berwyn Buried Valley tributary extends under Cardinal Lake.
4.3 Bedrock

4.3.1 Geological Characteristics

The upper bedrock in the Study Area includes parts of the Horseshoe Canyon, the Oldman, the Foremost, the Lea Park, the Milk River, the Colorado, the Cardium, the Kaskapau, the Dunvegan, the Shaftesbury, and the Peace River formations and the Mannville Group. A generalized geologic column is illustrated in Figure 7. Bedrock units that outcrop or subcrop in the Study Area are shown on the adjacent Figure 18 (also see page A-7). A non-pumping water-level surface for the upper bedrock is shown on C-10.

The Horseshoe Canyon Formation subcrops in the extreme southern portion of the Study Area and may be up to 700 metres in thickness. The Horseshoe Canyon Formation consists of deltaic and fluvial sandstone, siltstone and shale with interbedded coal seams, bentonite and thin nodular beds of limestone and ironstone (Glass, 1990). Because of the low-energy environment in which deposition occurred, the sandstones, when present, tend to be finer grained. The lower 60 to 70 metres and the upper 30 to 50 metres of the Horseshoe Canyon Formation can include coarser grained sandstone deposits.

The Oldman Formation, which also occurs in the more southern part of the Study Area, underlies the Horseshoe Canyon Formation and is generally less than 50 metres in thickness. The Oldman Formation consists of freshwater sandstone and shales and minor greenish-brown and reddish shale and siltstones. The sandstones are weakly cemented and range from fine- to coarse-grained.

The Foremost Formation subcrops in the southern part of the Study Area and is composed of shales and coal layers. The Formation is divided into four members: the Birch Lake Member, the Ribstone Creek Member, the Victoria Member and the Brosseau Member. Within the Study Area, the maximum thickness of the Foremost Formation is less than 180 metres. Together, the Oldman Formation and the Foremost Formation form the Belly River Group.

The Lea Park Formation underlies the Foremost Formation and is composed mainly of grey shales with minor amounts of silt, and stringers of fine-grained sand and ironstone concretions. The Lea Park Formation has a thickness of approximately 50 metres and occurs mainly in the southeastern part of the Study Area.

\[16\] See glossary

Figure 18. Bedrock Geology
The Milk River Formation underlies the Lea Park Formation and has a maximum thickness of only a few tens of metres in the southern part of the Study Area.

The Colorado (Shale) Formation is composed mainly of shale, including the White Specks unit, with some sandstone, and generally ranges in thickness from 40 to 140 metres.

The Cardium Formation is composed of shale and shaly siltstone with minor sand and conglomerates. The Formation can be up to 60 metres in thickness in the southern part of the Study Area.

The Kaskapau Formation underlies the Cardium Formation, and consists of mainly shale with some sandstone near the base. The Kaskapau Formation can reach a maximum thickness of almost 500 metres in the extreme southwestern part of the Study Area.

The Dunvegan Formation underlies the Kaskapau Formation and has an average thickness of 100 metres, but can range from 70 to 150 metres in the Study Area. The Dunvegan Formation is composed of cross-bedded sandstone, with thin beds of shale, limestone and coal.

The Shaftesbury Formation, which lies beneath the Dunvegan Formation, consists of marine shale with a band of fish scales. The thickness of the Shaftesbury Formation ranges from 150 to 300 metres, with an average thickness of 200 metres.

The Peace River Formation underlies the Shaftesbury Formation. Overall, the Peace River Formation is composed of sandstone, with a shale layer in the middle. The Peace River Formation is generally less than 100 metres in thickness within the Study Area.

The Mannville Group underlies the Peace River Formation and subcrops in the northern part of the Study Area. The Mannville Group consists of interbedded sands and shales. The thickness of the Group ranges from 200 metres in the northern part of the Study Area to over 400 metres in the southern half of the Study Area. The Mannville Group is underlain by bedrock formations from the Jurassic and Triassic periods, which do not subcrop in the Study Area.

The Base of Groundwater Protection varies from less than 50 metres to more than 650 metres below ground surface in the Study Area. The Base of Groundwater Protection tends to cut across formations that dip steeply in the southern part of the Study Area and to more or less coincide with the base of the Dunvegan Formation (or the top of the Shaftesbury Formation) or the base of the surficial deposits for the northern two-thirds of the Study Area where the bedrock units dip more gently. A map showing the depth to the Base of Groundwater Protection is shown in Figure 5, on page A-14, and on the CD-ROM.
4.3.2 Aquifers

Of the 13,032 water wells in the database, 5,295 were defined as being completed below the top of bedrock and 2,256 were completed in surficial aquifers, based on lithologic information and water well completion details. The completion zone could not be determined for 5,481 of the water wells in the database, due to completion detail deficiencies. These 5,481 water wells could be completed in either the bedrock or surficial aquifers.

Assigning a water well to a specific geologic unit is possible only if the completion interval is identified. In order to make use of additional information within the groundwater database, it was assumed that the top of the completion interval was at 80% of the total completed depth of a water well. With this assumption, it has been possible to designate the specific bedrock aquifer of completion for 6,634 water wells. The remaining 1,130 of the total 7,764 bedrock water wells are identified as being completed in more than one bedrock aquifer. The complete breakdown is shown in the adjacent Table 5. The bedrock water wells are mainly completed in the Horseshoe Canyon, the Oldman, and the Foremost aquifers.

There are 2,871 records for bedrock water wells that have apparent yield values, which is 37% of the 7,764 bedrock water wells. In the Study Area, yields for water wells completed in the Upper Bedrock Aquifer(s) are mainly less than 20 m³/day, as shown in Table 6. Some apparent yield values are in the 20 to 75 m³/day category. Most of the water wells with yield data available are in the southern three-quarters of the Study Area, as shown on the adjacent Figure 19 and page C-3. The areas where higher yields are expected may identify locations of increased permeability resulting from the weathering process. In addition to the 7,745 records for bedrock water wells, there are 339 records that indicate that the water well is dry, or abandoned with “insufficient water". In order to depict a more accurate yield map, an apparent yield of 0.1 m³/day was assigned to the 339 dry holes prior to gridding.

Of the 2,871 water well records with apparent yield values, 2,376 have been assigned to aquifers associated with specific geologic units. Forty-three percent (1,018) of the 2,376 water wells completed in the specific bedrock aquifers have apparent yields that are less than 20 m³/day, 46% (1,103) have apparent yield values that range from 20 to 175 m³/day, and 11% (255) have apparent yields that are greater than 175 m³/day, as shown in Table 6.
The majority of the water wells are completed in the upper Horseshoe Canyon, Oldman and Foremost Formations. A significant number of water wells are completed in bedrock aquifers with no specific designation. As a result, 469 apparent yield values, about 16%, could not be assigned to specific bedrock aquifers.

### 4.3.3 Chemical Quality of Groundwater

The Piper tri-linear diagram for bedrock aquifers shows that a variety of chemical types of groundwater occur in bedrock aquifers. However, the majority of the groundwaters are sodium-bicarbonate or sodium-sulfate types, although some have calcium as the dominant ion.

The TDS concentrations in the groundwaters from the Upper Bedrock Aquifer(s) range from less than 500 to more than 28,000 mg/L, with the values that are greater than 2,000 mg/L being mainly in the central and far northern parts of the area, as shown in the figure on Page C-4.

The relationship between TDS and sulfate concentrations shows that when TDS values in the groundwaters from the Upper Bedrock Aquifer(s) exceed 2,000 mg/L, the sulfate concentrations exceed 1,000 mg/L.

In the Study Area, almost 97% of the chloride concentrations in the groundwaters from the Upper Bedrock Aquifer(s) are less than 100 mg/L.

The nitrate + nitrite (as N) concentrations are less than 1.0 mg/L in 86% of the chemical analyses for upper bedrock water wells. Sixty-eight percent of the total hardness values in the groundwaters from the Upper Bedrock Aquifer(s) are less than 200 mg/L.

In the Study Area, approximately 40% of the groundwater samples from Upper Bedrock Aquifer(s) have fluoride concentrations that are too low (less than 0.5 mg/L) to meet the recommended daily needs of people. The fluoride distribution is shown on Figure 20 above and on page C-7. Approximately 34% of the groundwater samples for fluoride from the entire Study Area are between 0.5 and 1.5 mg/L, and approximately 26% exceed the maximum acceptable concentration for fluoride of 1.5 mg/L.

<table>
<thead>
<tr>
<th>Aquifer Name</th>
<th>&lt; 20</th>
<th>20 to 175</th>
<th>&gt; 175</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horseshoe Canyon</td>
<td>473</td>
<td>263</td>
<td>80</td>
</tr>
<tr>
<td>Oldman</td>
<td>202</td>
<td>214</td>
<td>39</td>
</tr>
<tr>
<td>Foremost</td>
<td>306</td>
<td>458</td>
<td>113</td>
</tr>
<tr>
<td>Lea Park</td>
<td>12</td>
<td>24</td>
<td>17</td>
</tr>
<tr>
<td>Milk River</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Colorado</td>
<td>0</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Cardium</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Kaskapau</td>
<td>4</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Dunvegan</td>
<td>15</td>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>Shaftesbury</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Multiple Completions</td>
<td>241</td>
<td>163</td>
<td>27</td>
</tr>
<tr>
<td>Undetermined</td>
<td>28</td>
<td>9</td>
<td>1</td>
</tr>
</tbody>
</table>

Total 2,845 1,287 1,275 283

Table 6. Apparent Yield of Bedrock Aquifers
Figure 21 is a graph showing the relationship between the concentration of fluoride ions and sodium ions in groundwaters from the Peace River district. The original data set included 5,517 values; the values that were reported as less than a specific value were given the specific value. For the preparation of the graph, 12 readings with a sodium concentration of greater than 1,800 mg/L and nine values of fluoride concentration greater than ten mg/L are not shown.

The Figure 21 graph shows that when the sodium concentration is less than 220 mg/L the fluoride concentration is mainly less than 1.0 mg/L. A low sodium ion concentration occurs when the groundwater is chemically hard.

Once the sodium concentration reaches 220 mg/L, the fluoride ion concentration immediately increases to more than six mg/L. As the sodium concentration continues to increase, the maximum value for fluoride ion concentration gradually decreases. Once the sodium concentration reaches 600 mg/L, the fluoride concentration is mainly below 1.4 mg/L.

The higher values of fluoride occur mainly in the southwestern part of the Study Area (see pages C-7 and on the CD-ROM).

A comparison was made of fluoride concentrations in the groundwaters from water wells in the Study Area completed in aquifers in the upper bedrock. The comparison was made to determine if there was a relationship between fluoride concentrations and the aquifer of completion. In addition, the comparisons were extended to compare the trends established within the Study Area to trends throughout Alberta.

The percent of groundwater samples having fluoride exceeding 1.5 mg/L and 2.5 mg/L in the groundwaters from the bedrock aquifers are very similar for the Study Area and for all of Alberta. A higher percentage of the groundwaters from the three main upper bedrock aquifers in the Study Area, the Horseshoe Canyon, the Oldman and the Foremost, contain fluoride than for the whole Province. Groundwaters from the Milk River Aquifer contain less fluoride in the Study Area than in Alberta as a whole; however, there are relatively few groundwater analyses for fluoride in the Study Area compared to the Province.
A summary of the fluoride ion concentration is given in Table 7 which follows:

![Table 7. Fluoride Occurrence in Groundwaters from Various Geological Units](image)

The minimum, maximum, mean, median\(^{17}\) and mode\(^{18}\) concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the upper bedrock in the Study Area have been compared to the Summary of Guidelines for Canadian Drinking Water Quality (SGCDWQ) in the adjacent Table 8. Of the five constituents compared to the SGCDWQ, the mean, median and mode concentrations of TDS and sodium exceed the guidelines; maximum values of all five constituents exceed the guidelines. The distribution of TDS, sulfate, chloride, fluoride and total hardness for groundwaters from water wells completed in the Upper Bedrock Aquifer(s) in the Study Area is shown on pages C-4 to C-8.

\(^{17}\) see glossary

\(^{18}\) see glossary
4.3.4 Horseshoe Canyon Aquifer

The Horseshoe Canyon Aquifer comprises the permeable parts of the Horseshoe Canyon Formation, as defined for the present program. The top of the Horseshoe Canyon Formation is the bedrock surface where the Horseshoe Canyon Formation is present under the extreme southern part of the Study Area. Structure contours have been prepared for the top of the Horseshoe Canyon Formation (page C-12). The structure contours show that the Horseshoe Canyon Formation ranges in elevation from less than 500 to more than 850 metres AMSL and has a thickness of up to 600 metres, generally occurring in the southern part of the Study Area (see north-south cross-section A - A', page A-8). The non-pumping water-level surface (page C-13) for the Horseshoe Canyon Aquifer is a subdued replica of the bedrock surface (also see CD-ROM).

4.3.4.1 Depth to Top

The depth to the top of the Horseshoe Canyon Formation is mainly less than 50 metres and is a reflection of the thickness of the surficial deposits. This information is provided on page C-11 for the Study Area.

4.3.4.2 Apparent Yield

The apparent yields for individual water wells completed through the Horseshoe Canyon Aquifer are mainly less than 20 m³/day, with about 52% of the values being in this category (Table 6). About 40% are in the range of 20 to 175 m³/day; about 9% are greater than 175 m³/day. Figure 22 (also see page C-14) shows the distribution of apparent yields in the Horseshoe Canyon Aquifer.

There are 333 licensed or registered water wells completed through the Horseshoe Canyon Aquifer, for a total authorized diversion of 2,170 m³/day. Forty-three percent of this amount is registered as Traditional Agriculture Use of groundwater. Two hundred fifty-three of the 333 licensed and registered water wells could be linked to specific water wells in the AENV groundwater database.

An extended aquifer test conducted with a water supply well (M35379.120235) completed in the Horseshoe Canyon Aquifer in 13-09-072-09 W6M indicated a long-term yield of 127 m³/day, based on an aquifer transmissivity of 23.5 metres squared per day (m²/day) and an effective transmissivity of 7.5 m²/day after 100 minutes of pumping.

An extended aquifer test was also conducted with a water supply well (M36249.664364) completed in the Horseshoe Canyon Aquifer in 09-16-069-22 W5M, which indicated a long-term yield of 400 m³/day, based on an aquifer transmissivity of 32 m²/day and an effective transmissivity of 8.0 m²/day after 2,059 minutes of pumping (HCL, March 1999).
4.3.4.3 Quality

The groundwaters from the Horseshoe Canyon Aquifer are mainly a bicarbonate-to-sulfate type, with sodium as the main cation (see Piper diagram on CD-ROM), with more than 63% of the groundwater samples having TDS concentrations of greater than 1,000 mg/L. The sulfate concentrations are mainly less than 1,000 mg/L. Chloride concentrations from the Horseshoe Canyon Aquifer are mainly less than 50 mg/L. For example, the groundwater from the water well in 09-16-069-22 W5M (M36249.664364), completed in the Horseshoe Canyon Aquifer, has a bicarbonate concentration of 1,320 mg/L, a sodium concentration of 457 mg/L, a chloride concentration of 5.3 mg/L, and a fluoride concentration of 0.23 mg/L. The total dissolved solids are 1,150 mg/L (HCL, March 1999).

The minimum, maximum, mean, median and mode concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the Horseshoe Canyon Aquifer in the Study Area have been compared to the SGCDWQ in the adjacent Table 9. Of the five constituents that have been compared to the SGCDWQ, the mean, median and mode values of TDS and sodium in the groundwaters from the Horseshoe Canyon Aquifer exceed the guidelines. The median and mode concentrations of TDS in the groundwaters from water wells completed in the Horseshoe Canyon Aquifer are greater than the median and mode concentrations from water wells completed in all Upper Bedrock Aquifer(s); the mean and median concentrations of sodium in the groundwaters from the Horseshoe Canyon Aquifer are greater than the mean and median values from water wells completed in all Upper Bedrock Aquifer(s); and the median concentrations of sulfate and fluoride in the groundwaters from the Horseshoe Canyon Aquifer are greater than the median concentrations from water wells completed in all Upper Bedrock Aquifer(s). The distribution of TDS, sulfate and chloride for groundwaters from water wells completed in the Horseshoe Canyon Aquifer, as well as for fluoride and total hardness, is shown on pages C-15 to C-19.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Number of Analyses</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Median</th>
<th>Mode</th>
<th>SGCDWQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dissolved Solids</td>
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<td>13</td>
<td>5,084</td>
<td>1,227</td>
<td>1,133</td>
<td>1,110</td>
<td>500</td>
</tr>
<tr>
<td>Sodium</td>
<td>794</td>
<td>0.5</td>
<td>2,280</td>
<td>426</td>
<td>417</td>
<td>330</td>
<td>200</td>
</tr>
<tr>
<td>Sulfate</td>
<td>820</td>
<td>0.6</td>
<td>2,440</td>
<td>295</td>
<td>170</td>
<td>10</td>
<td>500</td>
</tr>
<tr>
<td>Chloride</td>
<td>761.0</td>
<td>0.8</td>
<td>586</td>
<td>10.4</td>
<td>7.0</td>
<td>2.0</td>
<td>250</td>
</tr>
<tr>
<td>Fluoride</td>
<td>807</td>
<td>0.05</td>
<td>6.9</td>
<td>0.96</td>
<td>0.63</td>
<td>0.14</td>
<td>1.5</td>
</tr>
</tbody>
</table>

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L (Mar 2001)
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration

Table 9. Apparent Concentrations of Constituents in Groundwaters from Horseshoe Canyon Aquifer
4.3.5 Oldman Aquifer

The Oldman Aquifer comprises the permeable parts of the Oldman Formation that underlie the Horseshoe Canyon Formation, and subcrops under the surficial deposits in the southern part of the Study Area. Structure contours have been prepared for the top of the Oldman Formation. The structure contours show that the Oldman Formation ranges in elevation from less than 300 to more than 900 metres AMSL and has a thickness of in the order of zero to 60 metres, as shown on page C-21. The non-pumping water-level surface of the Oldman Aquifer is downgradient to the south toward the Smoky River and is shown on page C-22.

4.3.5.1 Depth to Top

The depth to the top of the Oldman Formation ranges from less than 50 metres below ground level at the northern extent of its subcrop to more than 450 metres in the southern part of the Study Area (page C-20). The greatest depth is in areas where the Horseshoe Canyon Formation is also present.

4.3.5.2 Apparent Yield

The apparent yields for individual water wells completed through the Oldman Aquifer are less than 20 m³/day for 44% of the water wells for which values are available (Table 6). Forty-seven percent of the apparent yield values range from 20 to 175 m³/day and 9% exceed 175 m³/day. Figure 23 (also see page C-23) shows the distribution of apparent yields in the Oldman Aquifer.

In the Study Area, there are 113 licensed or registered water wells that are completed in the Oldman Aquifer, with a total authorized diversion of 1,358 m³/day. Of the 113 authorizations to divert groundwater, 97 are registrations for Traditional Agriculture use. Eighty-four of the 113 licensed or registered water wells could be linked to specific water wells in the AENV groundwater database.

An extended aquifer test conducted with a water supply well (M35379.120397) completed in the Oldman Aquifer in NE 02-072-10 W6M indicated an apparent yield of 242 m³/day, based on an effective transmissivity of 84.9 m²/day after 4,320 minutes of pumping (HCL, Mar 1976).
4.3.5.3 Quality

The groundwaters from the Oldman Aquifer are mainly a bicarbonate-to-sulfate type, with sodium as the main cation (see Piper diagram on CD-ROM). Ninety-seven percent of the TDS concentrations are between 500 and 2,000 mg/L. The sulfate concentrations are mainly below 500 mg/L and the chloride concentrations are mainly less than 50 mg/L. Thirty-two percent of the fluoride concentrations in the Oldman Aquifer are less than 0.5 mg/L. For example, the groundwater from the water well in NE 02-072-10 W6M (M35379.120397), completed in the Oldman Aquifer, has a bicarbonate concentration of 844 mg/L, a sulfate concentration of 301 mg/L, a sodium concentration of 398 mg/L, a chloride concentration of 81 mg/L, and a fluoride concentration of 0.6 mg/L. The total dissolved solids are 1,190 mg/L (HCL, Dec 1976).

The minimum, maximum, mean, median and mode concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the Oldman Aquifer in the Study Area have been compared to the SGCDWQ in the adjacent Table 10. Of the five constituents that have been compared to the SGCDWQ, the mean, median and mode values of TDS and sodium exceed the guidelines. The median concentrations of TDS and chloride, and the mean, median and mode values of sodium and fluoride in the groundwaters from water wells completed in the Oldman Aquifer are greater than the respective mean, median or mode concentrations from water wells completed in all Upper Bedrock Aquifer(s). The distribution of TDS, sulfate and chloride for groundwaters from water wells completed in the Oldman Aquifer, as well as for fluoride and total hardness, is shown on pages C-24 to C-28.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Number of Analyses</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Median</th>
<th>Mode</th>
<th>SGCDWQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dissolved Solids</td>
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<td>17</td>
<td>4,026</td>
<td>1,125</td>
<td>1,049</td>
<td>850</td>
<td>500</td>
</tr>
<tr>
<td>Sodium</td>
<td>398</td>
<td>9</td>
<td>1,308</td>
<td>413</td>
<td>395</td>
<td>395</td>
<td>200</td>
</tr>
<tr>
<td>Sulfate</td>
<td>395</td>
<td>1.1</td>
<td>2,000</td>
<td>210</td>
<td>90</td>
<td>10</td>
<td>500</td>
</tr>
<tr>
<td>Chloride</td>
<td>405</td>
<td>1</td>
<td>98</td>
<td>16</td>
<td>12</td>
<td>2</td>
<td>250</td>
</tr>
<tr>
<td>Fluoride</td>
<td>407</td>
<td>0.06</td>
<td>7.9</td>
<td>1.3</td>
<td>0.93</td>
<td>0.25</td>
<td>1.5</td>
</tr>
</tbody>
</table>

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration

Table 10. Apparent Concentrations of Constituents in Groundwaters from Oldman Aquifer
4.3.6 Foremost Aquifer

The Foremost Aquifer comprises the permeable parts of the Foremost Formation that underlie the Oldman Formation, and subcrops under the surficial deposits in the southern part of the Study Area. Structure contours have been prepared for the top of the Formation. The structure contours (page C-30) show that the Foremost Formation ranges in elevation from less than 200 to more than 800 metres AMSL and has a thickness of in the order of zero to 180 metres. The non-pumping water-level surface of the Foremost Aquifer (page C-31) slopes mainly toward the Smoky River in the south-central part of the Study Area.

4.3.6.1 Depth to Top

The depth to the top of the Foremost Formation ranges from less than 50 metres below ground level at the northern extent to more than 550 metres in the southern part of the Study Area (see page C-29).

4.3.6.2 Apparent Yield

The apparent yields for individual water wells completed through the Foremost Aquifer are less than 20 m³/day for 35% of the water wells for which values are available (Table 6). Fifty-two percent of the apparent yield values range from 20 to 175 m³/day and 13% exceed 175 m³/day. Figure 24 (also see page C-32) shows the distribution of apparent yields in the Foremost Formation.

In the Study Area, there are 346 licensed and registered water wells that are completed in the Foremost Aquifer, which are authorized to divert a total of 3,097 m³/day. Almost half of the licensed amount, 1,411 m³/day, is for municipal purposes mainly associated with the larger communities using groundwater. Two hundred forty-three of the 346 licensed and registered water wells could be linked to specific water wells in the AENV groundwater database.

An extended aquifer test was conducted in October 1988 with a water supply well located in NE 19-074-09 W6M (M35379.122020) that is completed in the Foremost Aquifer. Analysis of the aquifer test results indicates the water supply well has a long-term yield of 216 m³/day, based on an aquifer transmissivity of 15.9 m²/day and an effective transmissivity of 15.5 m²/day (HCL, Dec 1988).
4.3.6.3 Quality

The groundwaters from the Foremost Aquifer are mainly a bicarbonate-to-sulfate type, with calcium-magnesium and sodium as the main cations (see Piper diagram on CD-ROM). Total dissolved solids concentrations range mainly between 500 and 2,000 mg/L, with more than 93% of the groundwater samples having TDS concentrations of greater than 500 mg/L. Sodium (Na) exceeds 200 mg/L in 85% of the samples. The sulfate concentrations are mainly less than 500 mg/L. Over 98% of the chloride concentrations from the Foremost Aquifer are less than 250 mg/L.

A chemical analysis of a groundwater sample collected in 1988 from the water supply well in NE 19-074-09 W6M (M35379.122020) that is completed in the Foremost Aquifer indicates the groundwater is a sodium-bicarbonate type, with a TDS concentration of 830 mg/L, a sulfate concentration of one mg/L, a chloride concentration of ten mg/L, and a fluoride concentration of 2.45 mg/L (HCL, Dec 1988).

The minimum, maximum, mean, median and mode concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the Foremost Aquifer in the Study Area have been compared to the SGCDWQ in the adjacent table. Of the five constituents that have been compared to the SGCDWQ, the mean, median and mode values of TDS and sodium exceed the guidelines. The mode concentration of sodium, and the mean and median concentrations of fluoride in the groundwaters from water wells completed in the Foremost Aquifer are greater than the respective mode or mean and median concentrations from water wells completed in all Upper Bedrock Aquifer(s). The median concentrations of sodium in groundwaters from water wells completed in the Foremost Aquifer are about the same as the median concentrations from water wells completed in all Upper Bedrock Aquifer(s). The distribution of TDS, sulfate and chloride for groundwaters from water wells completed in the Foremost Aquifer, as well as for fluoride and total hardness, is shown on pages C-33 to C-37.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Number of Analyses</th>
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<th>Maximum</th>
<th>Mean</th>
<th>Median</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDS</td>
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<td>3</td>
<td>4,869</td>
<td>935</td>
<td>870</td>
<td>800</td>
</tr>
<tr>
<td>Sodium</td>
<td>737</td>
<td>1</td>
<td>8,188</td>
<td>350</td>
<td>339</td>
<td>350</td>
</tr>
<tr>
<td>Sulfate</td>
<td>746</td>
<td>1</td>
<td>2,931</td>
<td>168</td>
<td>85</td>
<td>10</td>
</tr>
<tr>
<td>Chloride</td>
<td>727</td>
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<td>1,250</td>
<td>19</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Fluoride</td>
<td>739</td>
<td>0.04</td>
<td>6.78</td>
<td>1.1</td>
<td>0.57</td>
<td>0.18</td>
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</tbody>
</table>

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration

Table 11. Apparent Concentrations of Constituents in Groundwaters from Foremost Aquifer
4.3.7 Lea Park Aquifer

The Lea Park Aquifer comprises the porous and permeable parts of the Lea Park Formation that underlie the Foremost Formation, and subcrops under the surficial deposits in the southern third of the Study Area. Structure contours have been prepared for the top of the Formation. The structure contours (page C-39) show that the Lea Park Formation ranges in elevation from less than 100 to more than 700 metres AMSL and ranges in thickness from zero to 300 metres. The non-pumping water-level surface of the Lea Park Aquifer is downgradient to the north toward the Little Smoky River, as shown on page C-40.

4.3.7.1 Depth to Top

The depth to the top of the Lea Park Formation ranges from less than 100 metres below ground level at the northern extent to more than 600 metres in the southern part of the Study Area (page C-38).

4.3.7.2 Apparent Yield

The apparent yields for individual water wells completed through the Lea Park Aquifer are less than 20 m³/day for 23% of the water wells for which values are available (Table 6). Forty-five percent of the apparent yield values range from 20 to 175 m³/day and 32% exceed 175 m³/day. Figure 25 (also see page C-41) shows the distribution of apparent yields in the Lea Park Aquifer.

Short aquifer tests with four water wells completed in the Lea Park Aquifer, (record numbers M35379.099162, M35379.042995, M35379.034719 and M35379.034721) indicated apparent transmissivities ranging from 2.4 to 33 m³/day. The corresponding apparent yields ranged from 32 to 254 m³/day.

In the Study Area, there are 23 licensed and registered water wells that are completed in the Lea Park Aquifer, for a total authorized diversion of 108 m³/day. Almost two-thirds of the total amount authorized for diversion, 73 m³/day, is registered for Traditional Agriculture Use. Sixteen of the 23 licensed and registered water wells could be linked to water wells in the AENV groundwater database.
4.3.7.3 Quality

The groundwaters from the Lea Park Aquifer are mainly of the sodium-bicarbonate type (see Piper diagram on CD-ROM). Total dissolved solids concentrations range mainly between 500 and 2,000 mg/L, with more than 88% of the groundwater samples having TDS concentrations of greater than 500 mg/L. The sulfate concentrations are mainly less than 500 mg/L, with only 12% of the groundwater samples having sulfate concentrations of greater than 500 mg/L. Nearly 95% of the chloride concentrations from the Lea Park Aquifer are less than 250 mg/L.

The minimum, maximum, mean, median and mode concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the Lea Park Aquifer in the Study Area have been compared to the SGCDWQ in the adjacent table. Of the five constituents that have been compared to the SGCDWQ, the mean, median and mode values of TDS and sodium exceed the guidelines. The median and mode concentrations of TDS and sodium, and the mode concentration of fluoride in the groundwater from water wells completed in the Lea Park Aquifer are greater than the respective median and mode, or mode concentrations from water wells completed in all Upper Bedrock Aquifer(s). The distribution of TDS, sulfate and chloride for groundwaters from water wells completed in the Lea Park Aquifer in the Study Area, as well as for fluoride and total hardness, is shown on pages C-42 to C-46.

<table>
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<th>Constituent</th>
<th>Number of Analyses</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Median</th>
<th>Mode</th>
<th>SGCDWQ</th>
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</thead>
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<tr>
<td>Total Dissolved Solids</td>
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<td>131</td>
<td>3158</td>
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<td>996</td>
<td>1,062</td>
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<td>Sodium</td>
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<td>1184</td>
<td>379</td>
<td>385</td>
<td>346</td>
<td>200</td>
</tr>
<tr>
<td>Sulfate</td>
<td>43</td>
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<td>1550</td>
<td>195</td>
<td>50</td>
<td>10</td>
<td>500</td>
</tr>
<tr>
<td>Chloride</td>
<td>2</td>
<td>1800</td>
<td>74</td>
<td>19.5</td>
<td>6</td>
<td>-</td>
<td>250</td>
</tr>
<tr>
<td>Fluoride</td>
<td>47</td>
<td>0.12</td>
<td>4.4</td>
<td>0.62</td>
<td>0.33</td>
<td>0.27</td>
<td>1.5</td>
</tr>
</tbody>
</table>

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration
"-" Insufficient data

Table 12. Apparent Concentrations of Constituents in Groundwaters from Lea Park Aquifer
4.3.8 Milk River Aquifer

The Milk River Aquifer comprises the permeable parts of the Milk River Formation that underlie the Lea Park Formation and is predominantly sandstone, shale and silty shale of marine and non-marine origin. The Milk River Formation subcrops in a very small portion of the Study Area. Structure contours have been prepared for the top of the Formation and are shown in the figure on page C-48. The structure contours show that the Milk River Formation ranges in elevation from less than zero to 600 metres AMSL and has a thickness of only a few tens of metres. The non-pumping water-level surface for the Milk River Aquifer is shown on page C-49.

4.3.8.1 Depth to Top

The depth to the top of the Milk River Formation is variable, ranging from less than 100 metres at the northern extent to more than 700 metres in the southern part of the Study Area where the Milk River Formation occurs (page C-47).

4.3.8.2 Apparent Yield

There are only three water wells with apparent yield data in the Study Area that are completed in the Milk River Aquifer. There are no apparent yield values that are less than 20 m³/day, two are between 20 and 175 m³/day and one exceeds 175 m³/day (Table 6). Although a minimal number of datapoints for apparent yield are available, an Apparent Yield map has been prepared and is shown in the adjacent Figure 26 and also on page C-50.

In the Study Area, there are only two authorized water wells completed in the Milk River Aquifer, for a total authorized diversion of 11 m³/day. Both authorizations are for Traditional Agriculture Use and are therefore Registrations. One of the two registered water wells could be linked to water wells in the AENV groundwater database.

![Figure 26. Apparent Yield for Water Wells Completed through Milk River Aquifer](image-url)
4.3.8.3 Quality

There are chemical or partial chemical data available for the six water wells completed in the Milk River Aquifer in the Study Area, as shown in the adjacent Table 13. Five chemical analyses were used in the preparation of a Piper tri-linear diagram. The groundwaters tend to be of the sodium bicarbonate-type. Total dissolved solids values range from a low of 539 mg/L to a high of 5,030 mg/L, with two values exceeding 4,000 mg/L. The values for sulfate range from ten to 2,730 mg/L, with two values exceeding 2,000 mg/L. The five sodium values range from 160 to 881 mg/L. The four fluoride values range from 0.16 to 0.55 mg/L. Six chloride values are available and range from 40 to 110 mg/L. Of the five constituents that have been compared to the SGCDWQ, the mean and median values of TDS and sodium exceed the guidelines; the mean value of sulfate also exceeds the guidelines. The mean concentrations of TDS and sulfate, and the median concentration of chloride in the groundwater from water wells completed in the Milk River Aquifer are greater than the respective mean and median concentrations from water wells completed in all Upper Bedrock Aquifer(s). The distribution of TDS, sulfate, chloride, fluoride and total hardness for groundwaters from water wells completed in the Milk River Aquifer in the Study Area, is shown on pages C-51 to C-55.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Number of Analyses</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Median</th>
<th>Mode</th>
<th>SGCDWQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dissolved Solids</td>
<td>6</td>
<td>539</td>
<td>5,030</td>
<td>2,094</td>
<td>807</td>
<td>-</td>
<td>500</td>
</tr>
<tr>
<td>Sodium</td>
<td>5</td>
<td>160</td>
<td>881</td>
<td>339</td>
<td>230</td>
<td>-</td>
<td>200</td>
</tr>
<tr>
<td>Sulfate</td>
<td>6</td>
<td>10</td>
<td>2,730</td>
<td>840</td>
<td>34</td>
<td>-</td>
<td>500</td>
</tr>
<tr>
<td>Chloride</td>
<td>6</td>
<td>40</td>
<td>110</td>
<td>59</td>
<td>49</td>
<td>-</td>
<td>250</td>
</tr>
<tr>
<td>Fluoride</td>
<td>4</td>
<td>0.16</td>
<td>0.55</td>
<td>0.38</td>
<td>0.41</td>
<td>-</td>
<td>1.5</td>
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</tbody>
</table>

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration
"-" Insufficient data

Table 13. Apparent Concentrations of Constituents in Groundwaters from Milk River Aquifer
4.3.9 Colorado Aquifer

The Colorado Aquifer comprises the permeable parts of the Colorado Group that underlie the Milk River Formation and overlies the Cardium Formation and is referred to as the Colorado Shale. This geological unit is predominantly a grey shale to silty shale of marine origin. Structure contours have been prepared for the top of the Formation, which underlies only the southern part of the Study Area. The structure contours, shown on page C-57, indicate that the Colorado Shale ranges in elevation from less than 100 metres below mean sea level (BMSL) to more than 700 metres AMSL. The Colorado Shale thickness ranges from a few tens of metres to a maximum thickness of about 250 metres. The non-pumping water-level surface of the Colorado Aquifer (page C-58) is downgradient to the west toward Kleskun Creek.

4.3.9.1 Depth to Top

The depth to the top of the Colorado Shale is variable, ranging from less than 100 metres at the northern extent to more than 800 metres in the southern part of the Study Area (page C-56).

4.3.9.2 Apparent Yield

There are six apparent yields for individual water wells completed through the Colorado Aquifer shown on the adjacent Figure 27. All six apparent yield values are between 20 and 175 m³/day (Table 6). A map of apparent yields for water wells completed in the Colorado Aquifer is also shown on page C-59.

In the Study Area, there are five licensed and registered water wells completed in the Colorado Aquifer, for a total authorized diversion of 100 m³/day. Three-quarters of the total quantity that is authorized, about 75 m³/day, is for industrial use. Two of the five licensed and registered water wells could be linked to water wells in the AENV groundwater database.
4.3.9.3 Quality

There are chemical or partial chemical data available for eleven water wells completed in the Colorado Aquifer as shown in the adjacent Table 14. Eight of the chemical analyses were used in the preparation of a Piper trilinear diagram (see Piper diagram on CD-ROM). The groundwaters from the Colorado Aquifer tend to be of the bicarbonate and sulfate-type, with sodium and calcium-magnesium being the main cations. The TDS values from eleven analyses range from 102 to 4,554 mg/L. Nine sulfate values range from 17 to 2,024 mg/L. Fluoride values for nine groundwater samples range from 0.09 to 0.71 mg/L. Sodium values, available for eight groundwater samples, range from 5 to 846 mg/L, while ten samples with chloride values range from 8 to 390 mg/L. Of the five constituents that have been compared to the SGCDWQ, the mean and median values of TDS and sodium exceed the guidelines; the mean value of sulfate also exceeds the guidelines. The mean and median concentrations of TDS, sulfate and chloride in the groundwaters from water wells completed in the Colorado Aquifer are greater than the mean and median concentrations from water wells completed in all Upper Bedrock Aquifer(s). The distribution of TDS, sulfate, chloride, fluoride and total hardness for groundwaters from water wells completed in the Colorado Aquifer in the Study Area is shown on pages C-60 to C-64.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Number of Analyses</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Median</th>
<th>Mode</th>
<th>SGCDWQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dissolved Solids</td>
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<td>102</td>
<td>4,554</td>
<td>1,610</td>
<td>1,064</td>
<td>-</td>
<td>500</td>
</tr>
<tr>
<td>Sodium</td>
<td>8</td>
<td>5</td>
<td>846</td>
<td>307</td>
<td>287</td>
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<td>200</td>
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<tr>
<td>Sulfate</td>
<td>9</td>
<td>17</td>
<td>2,024</td>
<td>603</td>
<td>430</td>
<td>-</td>
<td>500</td>
</tr>
<tr>
<td>Chloride</td>
<td>10</td>
<td>8</td>
<td>390</td>
<td>104</td>
<td>38</td>
<td>-</td>
<td>250</td>
</tr>
<tr>
<td>Fluoride</td>
<td>9</td>
<td>0.09</td>
<td>0.71</td>
<td>0.36</td>
<td>0.27</td>
<td>-</td>
<td>1.5</td>
</tr>
</tbody>
</table>

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration
"-" Insufficient data

Table 14. Apparent Concentrations of Constituents in Groundwaters from Colorado Aquifer
4.3.10 Cardium Aquifer

The Cardium Aquifer comprises the permeable parts of the Cardium Formation that underlie the Colorado Shale. Structure contours have been prepared for the top of the Cardium Formation and are shown on page C-66. The structure contours show that the Cardium Formation ranges in elevation from less than 200 metres BMSL to more than 700 metres AMSL, and has a maximum thickness of 200 metres. The non-pumping water-level surface of the Cardium Aquifer is shown on page C-67.

4.3.10.1 Depth to Top

The depth to the top of the Cardium Formation is variable, ranging from less than 100 metres at the northern extent, to more than 900 metres in the southern part of the Study Area (page C-65).

4.3.10.2 Apparent Yield

There are four apparent yield values for water wells completed in the Cardium Aquifer. The apparent yield values are less than 20 m³/day for two water wells and between 20 and 175 m³/day for the remaining two water wells (Table 6). The distribution of apparent yield values, based on minimal data, is shown in the adjacent Figure 28 and on page C-68.

In the Study Area, there are nine licensed and registered water wells completed in the Cardium Aquifer, for a total authorized diversion of 172 m³/day. Of the total of 172 m³/day, 149 m³/day is being diverted for industrial purposes. Eight of the nine licensed and registered water wells could be linked to water wells in the AENV groundwater database.

“Swabbing” aquifer tests are available for a water source well located in SW 29-072-07 W6M (M37147.694220) that is completed in the Cardium Aquifer. The water well is completed in the interval from 495 to 507 metres below ground level. Analysis of the swab-test results indicated the water source well has a long-term yield of 200 m³/day, based on aquifer transmissivity values ranging from 0.12 to 0.56 m²/day (HCL, Feb 1996).
4.3.10.3 Quality

Six chemical analyses are available for groundwaters from the Cardium Aquifer, with sufficient detail to warrant review; a chemical analysis summary is shown in the adjacent Table 15.

The minimum, maximum, mean, median and mode concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the Cardium Aquifer in the Study Area have been compared to the SGCDWQ in the adjacent Table 15. Of the five constituents that have been compared to the SGCDWQ, the mean and median values of TDS, the mean value of sulfate exceed the guidelines. The mean, median and mode concentrations of sulfate, the mean concentration of TDS, the mode concentration of chloride, and the median concentration of fluoride in the groundwaters from water wells completed in the Cardium Aquifer are greater than the respective mean, median or mode concentrations from water wells completed in all Upper Bedrock Aquifer(s). The distribution of TDS, sulfate, chloride and total hardness in the groundwaters from water wells completed in the Cardium Aquifer in the Study Area is shown on pages C-69 to C-72.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Number of Analyses</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Median</th>
<th>Mode</th>
<th>SGCDWQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dissolved Solids</td>
<td>6</td>
<td>420</td>
<td>4,568</td>
<td>1,623</td>
<td>680</td>
<td>606</td>
<td>500</td>
</tr>
<tr>
<td>Sodium</td>
<td>1</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>-</td>
<td>200</td>
</tr>
<tr>
<td>Sulfate</td>
<td>66</td>
<td>4</td>
<td>2,088</td>
<td>699</td>
<td>191</td>
<td>191</td>
<td>500</td>
</tr>
<tr>
<td>Chloride</td>
<td>6</td>
<td>2</td>
<td>85</td>
<td>19</td>
<td>4</td>
<td>4</td>
<td>250</td>
</tr>
<tr>
<td>Fluoride</td>
<td>2</td>
<td>0.32</td>
<td>1.1</td>
<td>0.71</td>
<td>0.71</td>
<td>-</td>
<td>1.5</td>
</tr>
</tbody>
</table>

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration
"-" Insufficient data

Table 15. Apparent Concentrations of Constituents in Groundwaters from Cardium Aquifer
4.3.11 Kaskapau Aquifer

The Kaskapau Aquifer comprises the permeable parts of the Kaskapau Formation that underlie the Cardium Formation, and subcrops under the surficial deposits. Structure contours have been prepared for the top of the Formation and are shown on page C-74. The structure contours show that the Kaskapau Formation ranges in elevation from less than 200 metres BMSL to more than 700 metres AMSL, and has a maximum thickness of 700 metres. The non-pumping water-level surface for the Kaskapau Aquifer is shown on page C-75.

4.3.11.1 Depth to Top

The depth to the top of the Kaskapau Formation is variable, ranging from less than 100 metres at the northern extent, to more than 900 metres in the southern part of the Study Area (page C-73).

4.3.11.2 Apparent Yield

There are 16 apparent yield values for water wells completed through the Kaskapau Aquifer. An apparent yield map is shown on the adjacent Figure 29 and on page C-76. The apparent yields for individual water wells completed through the Kaskapau Aquifer are less than 20 m³/day for 25% of the water wells for which values are available (Table 6). Fifty-six percent of the apparent yield values range from 20 to 175 m³/day, and 19% exceed 175 m³/day.

In the Study Area, there are 27 licensed and registered water wells completed in the Kaskapau Aquifer, for a total authorized diversion of 1,013 m³/day. Fifty-five percent of the total amount authorized for diversion is for municipal purposes. Twenty-two of the 27 licensed and registered water wells could be linked to water wells in the AENV groundwater database.
4.3.11.3 Quality

The groundwaters from the Kaskapau Aquifer are mainly of the bicarbonate and sulfate-type with calcium-magnesium as the main cation (see Piper diagram on CD-ROM). Total dissolved solids concentrations range from 130 to 7,728 mg/L and sulfate concentrations range from ten to 4,900 mg/L. The chloride concentrations range from 0.8 to 283 mg/L and the fluoride concentrations range from a low of 0.05 to a high of 1.34 mg/L.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Number of Analyses</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Median</th>
<th>Mode</th>
<th>SGCDWQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dissolved Solids</td>
<td>230</td>
<td>130</td>
<td>7,728</td>
<td>1,292</td>
<td>845</td>
<td>515</td>
<td>500</td>
</tr>
<tr>
<td>Sodium</td>
<td>191</td>
<td>1</td>
<td>1,486</td>
<td>134</td>
<td>43</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>Sulfate</td>
<td>232</td>
<td>10</td>
<td>4,900</td>
<td>626</td>
<td>326</td>
<td>115</td>
<td>500</td>
</tr>
<tr>
<td>Chloride</td>
<td>155</td>
<td>0.8</td>
<td>283</td>
<td>23</td>
<td>6</td>
<td>2</td>
<td>250</td>
</tr>
<tr>
<td>Fluoride</td>
<td>168</td>
<td>0.05</td>
<td>1.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.19</td>
<td>1.5</td>
</tr>
</tbody>
</table>

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration

Table 16. Apparent Concentrations of Constituents in Groundwaters from Kaskapau Aquifer

The minimum, maximum, mean, median and mode concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the Kaskapau Aquifer in the Study Area have been compared to the SGCDWQ in the adjacent Table 16. Of the five constituents that have been compared to the SGCDWQ, the mean, median and mode values of TDS and the mean value of sulfate exceed the guidelines. The mean concentration of TDS, and the mean, median and mode concentrations of sulfate in the groundwaters from water wells completed in the Kaskapau Aquifer are greater than the respective mean, median or mode concentrations from water wells completed in all Upper Bedrock Aquifer(s). The distribution of TDS, sulfate, chloride, fluoride and total hardness for groundwaters from water wells completed in the Kaskapau Aquifer in the Study Area is shown on pages C-77 to C-81.
4.3.12 Dunvegan Aquifer

The Dunvegan Aquifer comprises the permeable parts of the Dunvegan Formation that underlie the Kaskapau Formation, and subcrops under the surficial deposits. Structure contours have been prepared for the top of the Formation and are shown on page C-83. The structure contours show that the Dunvegan Formation ranges in elevation from less than 700 metres BMSL to more than 400 metres AMSL, and has a maximum thickness of 400 metres. The non-pumping water-level surface for the Dunvegan Aquifer is shown on page C-84.

4.3.12.1 Depth to Top

The depth to the top of the Dunvegan Formation is variable, ranging from less than 100 metres at the northern extent, to more than 1,500 metres in the southern part of the Study Area and is shown on page C-82.

4.3.12.2 Apparent Yield

The apparent yields for individual water wells completed through the Dunvegan Aquifer are shown in the adjacent Figure 30 and on page C-85. The apparent yield values are less than 20 m³/day for 36% of the water wells (Table 6). Fifty-nine percent of the apparent yield values range from 20 to 175 m³/day and 5% exceed 175 m³/day. Figure 30 shows the distribution of apparent yields in the Dunvegan Aquifer.

In the Study Area, there are 49 licensed and registered water wells completed in the Dunvegan Aquifer, for a total authorized diversion of 182 m³/day. Almost half of the total amount, 86 m³/day, is registered for Traditional Agriculture Use. Thirty-eight of the 49 licensed and registered water wells could be linked to water wells in the AENV groundwater database.

Figure 30. Apparent Yield for Water Wells Completed through Dunvegan Aquifer
4.3.12.3 Quality

The groundwaters from the Dunvegan Aquifer are of the bicarbonate and sulfate-type, with calcium and sodium as the main cations (see Piper diagram on CD-ROM). Total dissolved solids concentrations range mainly between 122 and 7,836 mg/L, with 35% of the groundwater samples having TDS concentrations of greater than 1,200 mg/L. The sulfate concentrations are mainly greater than 100 mg/L, with approximately 30% of the groundwater samples having sulfate concentrations of greater than 500 mg/L. Nearly 70% of the chloride concentrations from the Dunvegan Aquifer are less than ten mg/L.

The minimum, maximum, mean, median and mode concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the Dunvegan Aquifer in the Study Area have been compared to the SGCDWQ in the adjacent Table 17. Of the five constituents that have been compared to the SGCDWQ, the mean and median values of TDS exceed the guidelines. The mean, median and mode concentrations of sulfate in the groundwaters from water wells completed in the Dunvegan Aquifer are greater than the respective mean, median and mode concentrations from water wells completed in all Upper Bedrock Aquifer(s). The distribution of TDS, sulfate, chloride, fluoride and total hardness for groundwaters from water wells completed in the Dunvegan Aquifer in the Study Area is shown on pages C-86 to C-90.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Number of Analyses</th>
<th>Range for Study Area (mg/L)</th>
<th>SGCDWQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dissolved Solids</td>
<td>357</td>
<td>122-7,836</td>
<td>1,199</td>
</tr>
<tr>
<td>Sodium</td>
<td>296</td>
<td>3-1,733</td>
<td>183</td>
</tr>
<tr>
<td>Sulfate</td>
<td>356</td>
<td>0.2-4,075</td>
<td>474</td>
</tr>
<tr>
<td>Chloride</td>
<td>266</td>
<td>1-472</td>
<td>36</td>
</tr>
<tr>
<td>Fluoride</td>
<td>248</td>
<td>0.06-1.70</td>
<td>0.36</td>
</tr>
</tbody>
</table>

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration

Table 17. Apparent Concentrations of Constituents in Groundwaters from Dunvegan Aquifer
4.3.13 Shaftesbury Aquifer

The Shaftesbury Aquifer comprises the permeable parts of the Shaftesbury Formation that underlie the Dunvegan Formation, and subcrops under the surficial deposits. Structure contours have been prepared for the top of the Formation and are shown on page C-92. The structure contours show that the Shaftesbury Formation ranges in elevation from less than 1,000 metres BMSL to more than 500 metres AMSL, and has a maximum thickness of 450 metres. The non-pumping water-level surface for the Shaftesbury Aquifer is shown on page C-93.

4.3.13.1 Depth to Top

The depth to the top of the Shaftesbury Formation is variable, ranging from less than 100 metres at the northern extent, to more than 1,700 metres in the southern part of the Study Area (page C-91).

4.3.13.2 Apparent Yield

There are four apparent yield values for water wells completed in the Shaftesbury Aquifer. Four values are less than 20 m³/day (Table 6). Apparent yield values for water wells completed through the Shaftesbury Aquifer were gridded and the results of the gridding are shown in the adjacent Figure 31.

In the Study Area, there are five licensed and registered water wells completed in the Shaftesbury Aquifer, for a total authorization diversion of 21 m³/day. Seventeen cubic metres per day, almost 80% of the total authorized diversion, is for use associated with recreational activities. One of the five licensed and registered water wells could be linked to water wells in the AENV groundwater database.

4.3.13.3 Quality

The chemical analyses available for the Shaftesbury Aquifer do not indicate a groundwater of a specific type, as the groundwaters can be bicarbonate and sulfate types, with sodium, calcium and magnesium as the main cations (see Piper diagram on CD-ROM).

The minimum, maximum, mean, median and mode concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the Shaftesbury Aquifer in the Study Area have been compared to the SGCDWQ in the adjacent Table 18. Of the five constituents that have been compared to the SGCDWQ, the mean, median and mode values of TDS, the mean value of sodium, and the mode value of sulfate exceed the guidelines. The mean, median and mode concentrations of TDS and sulfate in the groundwa-
ters from water wells completed in the Shaftesbury Aquifer are greater than the mean, median and mode concentrations from water wells completed in all Upper Bedrock Aquifer(s). The mean and median concentrations of chloride, and the mode concentration of fluoride in the groundwaters from water wells completed in the Shaftesbury Aquifer are greater than the respective mean and median, or mode concentrations from water wells completed in all Upper Bedrock Aquifer(s) in the Study Area. The distribution of TDS, sulfate, chloride, fluoride and total hardness for groundwaters from water wells completed in the Shaftesbury Aquifer in the Study Area is shown on pages C-95 to C-99.
4.3.14 Peace River Aquifer

The Peace River Aquifer comprises the permeable parts of the Peace River Formation that underlie the Shaftsbury Formation, and subcrops under the surficial deposits. Structure contours have been prepared for the top of the Formation and are shown on page C-101. The structure contours show that the Peace River Formation ranges in elevation from less than 1,200 metres BMSL to more than 200 metres AMSL, and has a maximum thickness of 200 metres. The non-pumping water-level surface for the Peace River Aquifer is shown on page C-102.

4.3.14.1 Depth to Top

The depth to the top of the Peace River Formation is variable, ranging from less than 200 metres at the northern extent, to more than 2,000 metres in the southern part of the Study Area (page C-100).

4.3.14.2 Apparent Yield

There are no values for apparent yield available for the Peace River Aquifer.

In the Study Area, there is one licensed water well completed in the Peace River Aquifer, for a total of seven m³/day. There are no water wells registered for Traditional Agriculture Use. The single licensed water well in the Peace River Aquifer is used for municipal purposes. The licensed diversion could be linked to a water well in the AENV groundwater database.

4.3.14.3 Quality

There are 24 chemical data points available for water wells completed in the Peace River Aquifer. The groundwaters tend to be of the sulfate and chloride-type, with calcium and sodium as the main cations (see Piper diagram on CD-ROM). The minimum, maximum, mean, median and mode concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the Peace River Aquifer in the Study Area have been compared to the SGCDWQ in the adjacent Table 19. Of the five constituents that have been compared to the SGCDWQ, the mean, median and mode values of TDS and sodium exceed the guidelines; the mean value of sulfate, and the mean and mode values of chloride also exceed the guidelines. The mean, median and mode concentrations of TDS, sulfate and chloride, and the mean value of sodium in the groundwaters from water wells completed in the Peace River Aquifer are greater than the respective mean, median and mode, or mean concentrations from water wells completed in all Upper Bedrock Aquifer(s). The distribution of TDS, sulfate, chloride, fluoride and total hardness for groundwaters from water wells completed in the Peace River Aquifer in the Study Area is shown on pages C-103 to C-107.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Number of Analyses</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Median</th>
<th>Mode</th>
<th>SGCDWQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dissolved Solids</td>
<td>20</td>
<td>972</td>
<td>3,409</td>
<td>1,966</td>
<td>1,763</td>
<td>1,579</td>
<td>500</td>
</tr>
<tr>
<td>Sodium</td>
<td>14</td>
<td>68</td>
<td>875</td>
<td>436</td>
<td>321</td>
<td>321</td>
<td>200</td>
</tr>
<tr>
<td>Sulfate</td>
<td>20</td>
<td>46</td>
<td>1,781</td>
<td>593</td>
<td>301</td>
<td>282</td>
<td>500</td>
</tr>
<tr>
<td>Chloride</td>
<td>20</td>
<td>6</td>
<td>1,462</td>
<td>315</td>
<td>35</td>
<td>395</td>
<td>250</td>
</tr>
<tr>
<td>Fluoride</td>
<td>14</td>
<td>0.16</td>
<td>0.60</td>
<td>0.34</td>
<td>0.33</td>
<td>0.16</td>
<td>1.5</td>
</tr>
</tbody>
</table>

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration

Table 19. Apparent Concentrations of Constituents in groundwaters from Peace River Aquifer
4.3.15 Mannville Aquifer

The Mannville Aquifer comprises the permeable parts of the Mannville Group that underlie the Peace River Formation, and subsurfaces under the surficial deposits. Structure contours have been prepared for the top of the Group and are shown on page C-109. The structure contours show that the Mannville Group ranges in elevation from less than 1,300 metres BMSL to 353 metres AMSL, and has a maximum thickness of 650 metres. A non-pumping water-level surface for the Mannville Aquifer is shown on page C-110.

4.3.15.1 Depth to Top

The depth to the top of the Mannville Group is variable, ranging from less than 200 metres at the northern extent, to more than 2,000 metres in the southern part of the Study Area and is shown on page C-108.

4.3.15.2 Apparent Yield

There are no values for apparent yield available for the Mannville Aquifer.

In the Study Area, there are four licensed and registered water wells completed in the Mannville Aquifer, for a total authorized diversion of 23 m³/day. Traditional Agriculture Use accounts for 56%, 13 m³/day, of the total amount allocated for diversion. Three of the four licensed and registered water wells could be linked to water wells in the AENV groundwater database.

4.3.15.3 Quality

There are ten chemical data points available for water wells completed in the Mannville Aquifer. The groundwater chemical analyses indicate chloride-type groundwaters with sodium and magnesium as the main cations (see Piper diagram on CD-ROM). The minimum, maximum, mean, median and mode concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the Mannville Aquifer in the Study Area have been compared to the SGCDWQ in the adjacent Table 20. Of the five constituents that have been compared to the SGCDWQ, the mean, median and mode values of TDS and chloride exceed the guidelines, and the mean and median values of sodium exceed the guidelines. The mean, median and mode concentrations of TDS and chloride in the groundwaters from water wells completed in the Mannville Aquifer are greater than the mean, median and mode concentrations from water wells completed in all Upper Bedrock Aquifer(s). The mean and median concentrations of sodium in the groundwaters from water wells completed in the Mannville Aquifer are greater than the mean and median concentrations from water wells completed in all Upper Bedrock Aquifer(s) in the Study Area. The distribution of TDS, sulfate, chloride, and total hardness for groundwaters from water wells completed in the Mannville Aquifer in the Study Area is shown on pages C-111 to C-114.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Number of Analyses</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Median</th>
<th>Mode</th>
<th>SGCDWQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dissolved Solids</td>
<td>9</td>
<td>478</td>
<td>22,623</td>
<td>9,414</td>
<td>6,612</td>
<td>17,310</td>
<td>500</td>
</tr>
<tr>
<td>Sodium</td>
<td>7</td>
<td>79</td>
<td>8,071</td>
<td>2,222</td>
<td>850</td>
<td>-</td>
<td>200</td>
</tr>
<tr>
<td>Sulfate</td>
<td>7</td>
<td>18</td>
<td>1,031</td>
<td>117</td>
<td>-</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Chloride</td>
<td>9</td>
<td>8</td>
<td>11,000</td>
<td>3,892</td>
<td>923</td>
<td>10,164</td>
<td>250</td>
</tr>
<tr>
<td>Fluoride</td>
<td>3</td>
<td>0.18</td>
<td>0.77</td>
<td>0.41</td>
<td>0.29</td>
<td>-</td>
<td>1.5</td>
</tr>
</tbody>
</table>

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration
*" Insufficient data

Table 20. Apparent Concentrations of Constituents in Groundwaters from Mannville Aquifer
5. Groundwater Budget

5.1 Hydrographs

In the Study Area, there are thirty-three observation water wells that are part of the AENV regional groundwater-monitoring network. The aquifers in which the AENV Observation Water Wells in the Study Area are completed are as follows:

- Surficial Aquifer - 7
- Upper Surficial Aquifer - 11
- Lower Surficial Aquifer - 2
- Bedrock Aquifer - 2
- Horseshoe Canyon Aquifer - 4
- Foremost Aquifer - 1
- Oldman Aquifer - 1
- Lea Park Aquifer - 1
- Kaskapau Aquifer - 1
- Shaftesbury Aquifer - 1

The locations where these observation water levels are being, or have been, measured and recorded as a function of time are shown in the adjacent Table 21. AENV observation water wells exist in eight of the thirteen Municipal Districts and Counties included in the Study Area. Water-level data are not available for the AENV Obs WW UIDs indicated in orange. The seven observation water wells indicated as being in the MD of Greenview were part of a study in the Spring Creek Basin and were monitored for a short period of time in the mid-1990s.

Table 21. Alberta Environment Observation Water Wells in Study Area
AENV Obs WW No. 339 (Grimshaw Kerndale) is located in 04-13-083-25 W5M, southwest of Cardinal Lake and west of Grimshaw. The observation water well is completed in the interval from 27.4 to 33.5 metres below ground level, in a sand and gravel surficial aquifer. The water level in the observation water well tends to fluctuate around a depth of about 17.6 metres below ground level. Groundwater monitoring data for AENV Obs WW No. 339 are available from mid-1965 to the end of 2002.

The adjacent hydrograph generally shows annual cycles of recharge and decline throughout the year, especially since the mid-1970s. In an area where there are no expected seasonal uses of groundwater, the highest water level will usually occur in late spring/early summer and the lowest water level will be in late winter/early spring. The highest water levels in AENV Obs WW No. 339 generally occur in the late fall/early winter and the lowest water levels generally occur in the spring. Overall annual fluctuations in AENV Obs WW No. 339 are mainly about 0.3 metres. From 1997 to 2002, there has been a net decline in the water level of approximately 0.5 metres.

The water-level fluctuations in AENV Obs WW No. 339, located in 04-13-083-25 W5M, have been compared to the precipitation measured at the Peace River A weather station. From 1975 to 2002, the rise in water level in late spring/early summer could be associated with recharge when the frost leaves the ground. The rise is more evident in years of greater rainfall and is suppressed during years of lower precipitation. The rise in the water level in 2000, although evident on the hydrograph, is less than expected and is the result of the two previous consecutive years of lower precipitation.

The nearest authorized diversions of groundwater to AENV Obs WW No. 339 are Registrations in four of the surrounding sections. Since the maximum amount that could be registered is 6,250 m³/year, it is unlikely that this observation water well is being influenced significantly by the authorized diversions in the surrounding area.
AENV Obs WW La Crete 2358E is located in NE 23-106-13 W5M, approximately 20 kilometres east of the community of La Crete. The observation water well is completed in the interval from 19.2 to 20.7 metres below ground level, in the upper surficial aquifer. The water level in the observation water well tends to be at a depth of about 3.4 metres. Groundwater monitoring data for AENV Obs WW La Crete 2358E are available from mid-1986 to the end of 2002, with the exception of mid-1993 to mid-1996, when water levels were not recorded.

Typically, water levels in relatively shallow observation water wells tend to rise during the summer months and begin to decline with the onset of freezing conditions in the fall. This is not the case with AENV Obs WW La Crete 2358E. The adjacent hydrograph shows that the water levels in the observation water well tend to decline from about April to October and then begin to rise, with the highest water levels in AENV Obs WW La Crete 2358E occurring in early spring and the lowest water levels occurring in late summer/early fall.

The water-level fluctuations in AENV Obs WW La Crete 2358E, located in NE 23-106-13 W5M, have been compared to the precipitation measured at the Keg River RS weather station.

The water-level fluctuations in AENV Obs WW La Crete 2358E appear to be related to both the vegetative growing season and the amount of summer precipitation. During the growing season, water levels decline, as any precipitation that is available is consumed by the vegetation. When vegetation begins to mature and water requirements decrease, recharge begins and water levels begin to rise. The overall decline in the water level in this observation water well between 1999 and the end of 2001 corresponds to a decline in the total summer precipitation, indicating that there is also a relationship between the water level in the observation water well and the total precipitation.

The nearest authorized diversions of groundwater to AENV Obs WW La Crete 2358E are Registrations in two of the adjacent sections. Since the maximum amount that could be registered is 6,250 m³/year, it is unlikely that this observation water well is being influenced significantly by the authorized diversions in the surrounding area.

Figure 33. Monthly Precipitation vs Water Levels in AENV Obs WW La Crete 2358E
During the early to mid-1990s, AENV was investigating the influence of clear-cutting logging practices on the water resources of a watershed. The effect of clear-cutting on the shallow groundwater was part of the investigation. The adjacent graph indicates the groundwater level, the precipitation and the mean temperature for a one-year period during the investigation for AENV Obs WW Spring Creek Basin.

AENV Obs WW Spring Creek Basin is located in 15-32-068-25 W5M, about 40 kilometres southwest of the community of Valleyview. The observation water well is completed in the interval from 9.1 to 10.7 metres below ground level, in a bedrock aquifer. The water level in the observation water well tends to be at a depth of about 6.8 metres.

The water-level fluctuations in AENV Obs WW Spring Creek Basin have been compared to the precipitation measured at the Spring Creek Moose weather station. The limited data available, presented in the adjacent hydrograph, show the water level in the observation water well rising near the beginning of April and beginning to decline by the middle of August, after which no further groundwater-level data are available. The water-level fluctuations in AENV Obs WW Spring Creek Basin seem to correlate to the amount of summer precipitation.

There are no authorized diversions of groundwater in the sections adjacent to Section 32, in which AENV Obs WW Spring Creek Basin is located.
AENV Obs WW Watino 2353E is located in 12-31-077-24 W5M, approximately eight kilometres west of the community of Watino. The observation water well is completed in the interval from 6.7 to 8.2 metres below ground level, in the upper surficial aquifer. The water level in the observation water well tends to be at a depth of about 3.8 metres. Groundwater monitoring data for AENV Obs WW Watino 2353E are available from mid-1986 to the end of 2002.

The water-level fluctuations in AENV Obs WW Watino 2353E, located in 12-31-077-24 W5M, have been compared to the precipitation measured at the Watino weather station. Precipitation data are available for the years 1986 to 1996. The data available, presented in the adjacent hydrograph, show the water level in the observation water well rising during the early part of the frost-free period and declining before the end of the frost-free period. The magnitude of the rise does not seem to correlate with the total precipitation received during the period from April to October each year. Overall, there has been a gradual decline in the water level in AENV Obs WW Watino 2353E of 1.25 metres over the 16-year period for which water levels are available.

The nearest authorized diversions of groundwater to AENV Obs WW Watino 2353E are Registrations in three of the adjacent sections. Since the maximum amount that could be registered is 6,250 m³/year, it is unlikely that this observation water well is being influenced significantly by the authorized diversions in the surrounding area.

Figure 35. Monthly Precipitation vs Water Levels in AENV Obs WW Watino 2353E
5.2 Estimated Water Use from Unlicensed Groundwater Users

An estimate of the quantity of groundwater removed from each geologic unit in the Peace River Basin Study Area must include the authorized diversions (licensed and registered) and the unlicensed use. As stated previously on page 8 of this report, the daily water requirement for livestock for the Study Area based on the 2001 census is estimated to be 38,111 cubic metres per day. Of the 38,111 m³/day required for livestock, 18,077 m³/day has been licensed and registered by Alberta Environment, which includes both surface water and groundwater. To obtain an estimate of the quantity of groundwater being diverted from the individual geologic units, it has been assumed that the remaining 20,034 m³/day of water required for livestock watering is obtained from unlicensed groundwater use. However, it should be noted that free-ranging stock may not need a licensed or registered source of water; some surface-water use from dugouts can occur without the need of a licence or registration; and a source of supply that was eligible for registration, but was not registered or licensed, can continue to be legally used for Traditional Agriculture Purposes, but without the protection of the Water Act.

In the groundwater database for the Study Area, there are records for 11,514 water wells that are used for domestic, stock or domestic/stock purposes. These 11,514 water wells include licensed, registered and unlicensed water wells. Of the 11,514 water wells, 988 water wells are used for stock, 2,188 are used for domestic/stock purposes, and 8,338 are for domestic purposes only. There are 3,176 water wells (2,188 + 988) that are used for stock or domestic/stock purposes (Table 22). There are 109 licensed groundwater users for agricultural (stock) purposes and 1,287 registered water wells that are assumed to primarily provide groundwater for livestock, giving 1,780 unlicensed stock water wells. (Please refer to Table 1 on page 8 for the breakdown by aquifer of the licensed stock groundwater users). By dividing the number of unlicensed stock and domestic/stock water wells (1,780) into the quantity of groundwater required for stock purposes that is not licensed (20,034 m³/day), the average unlicensed water well diverts 11.3 m³/day for stock purposes. Because of the limitations of the data, no attempt has been made to compensate for dugouts, springs or inactive water wells, and the average stock use is considered to be 11.3 m³/day per stock water well. It has also been assumed that all water wells indicated as being for stock or domestic/stock purposes are still active and in use. Many of these water wells are old, and may have been reclaimed.

Groundwater for household use, as defined in the Water Act, does not require licensing. Under the Water Act, a residence is protected for up to 3.4 m³/day. However, the more normal groundwater use for household purposes (a family of four) is about 1.1 m³/day. Since there are 8,338 domestic water wells serving a population of 51,888, the domestic use per water well is 1.7 m³/day.

To obtain an estimate of the groundwater from each geologic unit, there are three possibilities for water wells. A summary of the possibilities and the quantity of water for each use is as follows:

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Quantity/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic</td>
<td>1.7 m³/day</td>
</tr>
<tr>
<td>Stock</td>
<td>11.3 m³/day</td>
</tr>
<tr>
<td>Domestic/stock</td>
<td>13.0 m³/day</td>
</tr>
</tbody>
</table>

Based on using all available domestic, domestic/stock, and stock water wells and corresponding calculations, the following table was prepared. Table 22 on the following page shows a breakdown of the 11,514 unlicensed and licensed water wells used for domestic, stock, or domestic/stock purposes by the geologic unit in which each water well is completed. The final column in the table equals the total amount of unlicensed groundwater that is being used for both domestic and stock purposes. The data provided in Table 22 indicate that most of the 44,330 m³/day, estimated to be diverted from unlicensed domestic, stock, or domestic/stock water wells, is from the Horseshoe Canyon, Oldman and Foremost aquifers. In cases where there was domestic, stock or domestic/stock use, but the aquifer designation was indicated as ‘unknown’, there is more licensed than is projected to be used.
By assigning 1.7 m³/day for domestic use, 11.3 m³/day for stock use and 13.0 m³/day for domestic/stock use, and using the total maximum authorized diversion associated with any licensed water well that can be linked to a record in the database, an estimate can be made of the possible groundwater use per section.

There are 17,558 sections in the Study Area. In 76% (13,391) of the sections in the Study Area, there is no domestic, stock, domestic/stock, licensed or registered groundwater user. The range in groundwater use for the remaining 4,167 sections, with groundwater use for the specified purposes, is from 0.1 m³/day, a small registration of groundwater for Traditional Agriculture Use, to more than 1,000 m³/day, the largest authorized groundwater diversion, with an average use per section of 14.7 m³/day (2.2 gpm). The estimated water well use per section can be more than 100 m³/day in 42 of the 4,167 sections. There is more than one licensed groundwater user in 2,429 of the 4,167 sections. The most notable areas where water well use of more than 50 m³/day is expected to occur is mainly in the vicinity of the City of Grande Prairie. Individual maps were prepared and included in the newsletters prepared for each of the 11 individual rural municipalities that make up the study area; a map has not been included for the entire area.

In summary, the estimated total groundwater use within the Study Area is 66,756 m³/day, with the breakdown as shown in the adjacent table. An estimated 2,414 m³/day is being withdrawn from unknown aquifer units. The remaining 64,342 m³/day has been assigned to specific aquifer units. Approximately 34% of the total estimated groundwater use is from licensed and registered water wells.

### Table 22. Licensed, Registered and Unlicensed Groundwater Diversions

<table>
<thead>
<tr>
<th>Aquifer Designation</th>
<th>Unlicensed Domestic, Stock and Domestic/Stock Groundwater Diversions</th>
<th>Licensed Domestic, Stock, Domestic/Stock and Registered Groundwater Diversions</th>
<th>Unlicensed Domestic, Stock and Domestic/Stock Groundwater Diversions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of Daily Use (1.7 m³/day)</td>
<td>Number of Daily Use (11.3 m³/day)</td>
<td>Number of Daily Use (13.0 m³/day)</td>
</tr>
<tr>
<td>Upper Surficial</td>
<td>1,329</td>
<td>543</td>
<td>327</td>
</tr>
<tr>
<td>Lower Surficial</td>
<td>211</td>
<td>29</td>
<td>80</td>
</tr>
<tr>
<td>Multiple Surficial Completions</td>
<td>657</td>
<td>141</td>
<td>244</td>
</tr>
<tr>
<td>Horseshoe Canyon</td>
<td>1,519</td>
<td>80</td>
<td>328</td>
</tr>
<tr>
<td>Oldman</td>
<td>870</td>
<td>30</td>
<td>186</td>
</tr>
<tr>
<td>Foremost</td>
<td>1,538</td>
<td>79</td>
<td>466</td>
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<tr>
<td>Lea Park</td>
<td>66</td>
<td>5</td>
<td>43</td>
</tr>
<tr>
<td>Milk River</td>
<td>7</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Colorado</td>
<td>15</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Cardium</td>
<td>10</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Kaskapau</td>
<td>87</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>Durnvegan</td>
<td>206</td>
<td>29</td>
<td>39</td>
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<tr>
<td>Shafftotesbury</td>
<td>33</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Peace River</td>
<td>13</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Miniville</td>
<td>6</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Multiple Bedrock Completions</td>
<td>755</td>
<td>25</td>
<td>207</td>
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<tr>
<td>Unknown</td>
<td>795</td>
<td>8</td>
<td>33</td>
</tr>
<tr>
<td>Unspecified</td>
<td>221</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td>8,338</td>
<td>988</td>
<td>11,164</td>
</tr>
</tbody>
</table>

Note: The values given in the table have been rounded. Columns and rows may not add up equally.

<table>
<thead>
<tr>
<th>Groundwater Use Within Study Area (m³/day)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic/Stock (registered, licensed and unlicensed)</td>
<td>53,783</td>
</tr>
<tr>
<td>Municipal (licensed)</td>
<td>5,967</td>
</tr>
<tr>
<td>Industrial (licensed)</td>
<td>3,219</td>
</tr>
<tr>
<td>All Other (licensed)</td>
<td>3,787</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>66,756</strong></td>
</tr>
</tbody>
</table>

**Table 23. Total Groundwater Diversions**
5.3 Groundwater Flow

A direct measurement of groundwater recharge or discharge is not possible from the data that are available for the Study Area. One indirect method of measuring recharge is to determine the quantity of groundwater flowing laterally through each individual aquifer. This method assumes that there is sufficient recharge to the aquifer to maintain the flow through the aquifer and the discharge is equal to the recharge. However, even the data that can be used to calculate the quantity of flow through an aquifer must be averaged and estimated. To determine the flow requires a value for the average transmissivity of the aquifer, an average hydraulic gradient and an estimate for the width of the aquifer. For the present program, the flow has been estimated for those parts of the various aquifers within the Study Area.

The flow through each aquifer assumes that by taking a large enough area, an aquifer can be considered as homogeneous, the average gradient can be estimated from the non-pumping water-level surface, and flow takes place through the entire width of the aquifer; flow through the aquifers takes into consideration hydrogeological conditions outside the Study Area border. Based on these assumptions, the estimated lateral groundwater flow through the individual aquifers has been summarized in Table 24, along with the estimated use of groundwater from each aquifer.

Table 24 indicates that there is more groundwater flowing through each aquifer than has been licensed (or registered) to be diverted from the individual aquifers, except for the surficial deposits, where the total estimated usage is more than the estimated flow through the aquifer. However, even where use is less than the calculated aquifer flow, there still could be local impacts on water levels.

<table>
<thead>
<tr>
<th>Aquifer/Area</th>
<th>Trans (m³/day)</th>
<th>Gradient (m/m)</th>
<th>Width (m)</th>
<th>Flow (m³/day)</th>
<th>Aquifer Flow (m³/day)</th>
<th>Licensed Diversion (m³/day)</th>
<th>Unlicensed Diversion (m³/day)</th>
<th>Total (m³/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surficial</td>
<td>6,000</td>
<td>996</td>
<td>19,259</td>
<td>20,255</td>
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<tr>
<td>High Prairie Valley</td>
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<tr>
<td>Grimshaw Gravels</td>
<td>south 200 0.001 15000 1900</td>
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<tr>
<td></td>
<td>southeast 200 0.001 25000 3800</td>
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<td>Horseshoe Canyon</td>
<td>23,400 1,087 9,263 10,350</td>
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<tr>
<td>Wapiti River basin</td>
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<tr>
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<td>east 12.2 0.005 25000 1500</td>
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<td>Little Smoky River basin</td>
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<td></td>
<td>west 12.2 0.005 30000 1800</td>
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<tr>
<td>Sturgeon Lake basin</td>
<td>south 12.2 0.006 30000 2300</td>
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</tr>
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<td>Oldman</td>
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<td></td>
<td>southwest 14 0.005 6000 4200</td>
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<tr>
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<td>Foremost</td>
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<tr>
<td></td>
<td>south 14.4 0.004 10000 6000</td>
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<tr>
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<td>southwest 14.4 0.005 70000 5000</td>
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<tr>
<td>Smoky River Basin</td>
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<tr>
<td>Lea Park</td>
<td>2,700 63 645 728</td>
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<tr>
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<tr>
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</tr>
<tr>
<td></td>
<td>Cardium</td>
<td>200 24 107 131</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
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</tr>
<tr>
<td></td>
<td>Kaskapau</td>
<td>4,900 62 308 370</td>
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</tr>
<tr>
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</tr>
<tr>
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<td>west 12.2 0.001 120000 1500</td>
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<tr>
<td>Dunvegan</td>
<td>4,500 108 1,077 1,185</td>
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<td></td>
</tr>
<tr>
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</tr>
<tr>
<td></td>
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<tr>
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<td></td>
</tr>
<tr>
<td>Peace River</td>
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</tr>
<tr>
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Table 24. Groundwater Budget
The adjacent water-level map has been prepared from water levels associated with water wells completed in aquifers in the surficial deposits. The water levels from these water wells were used for the calculation of the saturated thickness of the surficial deposits. In areas where the elevation of the water-level surface is below the bedrock surface, the surficial deposits are not saturated (indicated by grey areas on Figure 36).

5.3.1 Recharge/Discharge

The hydraulic relationship between the groundwater in the surficial deposits and the groundwater in the bedrock aquifers is given by the non-pumping water-level surface associated with each hydraulic unit. Where the water level in the surficial deposits is at a higher elevation than the water level in the bedrock aquifers, there is the opportunity for groundwater to move from the surficial deposits into the bedrock aquifers. This condition would be considered as an area of recharge to the bedrock aquifers and an area of discharge from the surficial deposits. The amount of groundwater that would move from the surficial deposits to the bedrock aquifers is directly related to the vertical permeability of the sediments separating the two aquifers. In areas where the surficial deposits are unsaturated, the extrapolated water level for the surficial deposits is used.

When the hydraulic gradient is from the bedrock aquifers to the surficial deposits, the condition is a discharge area from the bedrock aquifers, and a recharge area to the surficial deposits.
5.3.1.1 Bedrock Aquifers

Recharge to the bedrock aquifers within the Study Area takes place from the overlying surficial deposits and from flow in the aquifer from outside the Study Area. On a regional basis, calculating the quantity of water involved is not possible because of the complexity of the geological setting, the very large Study Area and the relatively limited amount of data.

In the absence of sufficient water-level data in the surficial deposits, a reasonable hydraulic gradient between the surficial deposits and the Upper Bedrock Aquifer(s) could not be determined. Therefore, the first objective was to determine the location of springs, flowing shot holes and any water wells that had a water level measurement depth of less than 0.1 metres. These locations would reflect where there is an upward hydraulic gradient from the bedrock to the surficial deposits (i.e. discharge). The depth to water level for water wells completed in the Upper Bedrock Aquifer(s) has been determined by subtracting the non-pumping water-level surface associated with all water wells completed in the Upper Bedrock Aquifer(s) from the bedrock surface. This resulting depth to water level grid was contoured to reflect the positioning of springs, flowing shot holes and flowing water wells (i.e. discharge). The recharge classification is used where the water level in the Upper Bedrock Aquifer(s) is more than five metres below the bedrock surface. The discharge areas are where the water level in the Upper Bedrock Aquifer(s) is more than five metres above the bedrock surface. When the depth to water level in the Upper Bedrock Aquifer(s) is between five metres below and five metres above the bedrock surface, the area is classified as a transition, that is, no recharge and no discharge.

Figure 37 shows that, over 38% of the Study Area, the elevation of the water-level surface is no more than five metres above the bedrock surface (interpreted as a recharge condition) and over 62% of the Study Area, the water-level surface is five metres or more above the bedrock surface (interpreted as a discharge condition). Within the Study Area, there are records for 658 flowing water wells and 1,337 flowing shot holes in the database. Of the 1,995 features with the water level above the ground surface, 61% are in the areas designated as discharge areas and 29% are in the areas designated as recharge or transitional flow. In a significant part of the Study Area, there are too few data points to allow for the preparation of representative water-level and bedrock surfaces. The paucity of control is most obvious in the northern parts of the Study Area.

Because of the paucity of data, recharge/discharge maps for the individual bedrock aquifers have not been attempted.

With 38% of the Study Area land area being one of recharge to or transitional flow in the bedrock, and the average precipitation being 395 mm per year, 0.2% of the annual precipitation is sufficient to provide the total calculated quantity of groundwater flowing through the Upper Bedrock Aquifer(s).
6. Recommendations

The present study has been based on information available from the groundwater database. The database has four problems:

1) the quality of the data
2) the coordinate system used for the horizontal control
3) the distribution of the data
4) the number of data points.

The quality of the data in the groundwater database is affected by two factors: a) the technical training of the persons collecting the data, and b) the quality control of the data. The possible options to upgrade the database include the creation of a “super” database, which includes only verified data. The first step would be to field-verify water well records for which a complete water well drilling report is available along with at least a partial chemical analysis. The level of verification would have to include identifying the water well in the field, obtaining meaningful horizontal coordinates for the water well and the verification of certain parameters such as water level and completed depth. There would also be a benefit in measuring a non-pumping water level, collecting a groundwater sample for chemical analysis, and if possible, completion of a short aquifer test. An attempt to update the quality of the entire database is not recommended.

Before an attempt is made to provide a major upgrade to the level of interpretation provided in this report, the accompanying maps and the groundwater query, it is recommended that the field verification of water well records be completed. The data to be collected include the following:

1) The horizontal location of the water well should be determined within ten metres. The coordinates must be in 10TM NAD 27 or some other system that will allow conversion to 10TM NAD 27 coordinates.
2) A four-hour aquifer test (two hours of pumping and two hours of recovery) should be performed with the water well to obtain a realistic estimate for the transmissivity of the aquifer in which the water well is completed.
3) Water samples should be collected for chemical analysis after five and 115 minutes of pumping, and analyzed for major and minor ions.

This additional information would provide a baseline to be used for comparison to either existing chemical analyses or aquifer tests, or to determine if future monitoring would be necessary if significant changes in the aquifer parameters had occurred.

An attempt to link the AENV groundwater and licensing databases was 73% successful in this study (see CD-ROM); twenty-seven percent of licensed water wells do not appear to have corresponding records in the AENV groundwater database. There is a need to improve the quality of the AENV licensing database. It is recommended that attempts be made in a future study to find and add missing drilling records to the AENV groundwater database and to determine the aquifer in which the licensed water wells are completed.
While there are a few areas where water-level data are available at different times, on the overall, there are an insufficient number of water levels to set up a groundwater budget. One method to obtain additional water-level data is to solicit the assistance of the water well owners who are stakeholders in the groundwater resource. In the M.D. of Rocky View and in Flagstaff County, water well owners were being provided with a tax credit if they accurately measured the water level in their water well once per week for a year. A pilot project indicated that approximately five years of records are required to obtain a reasonable data set. The cost of a five-year project involving 50 water wells would be less than the cost of one drilling program that may provide two or three observation water wells. Monitoring of water levels in domestic and stock water wells is a practice that is recommended by AAFC-PFRA in the “Water Wells That Last for Generations” manual and accompanying videos (Buchanan, Bob [editor]. Alberta Agriculture, Food and Rural Development, 1996).

A second approach to obtain water-level data would be to conduct a field survey to identify water wells not in use that could be used as part of an observation water well network. Study Area personnel and/or local residents could measure the water levels in the water wells regularly.

Communities that are concerned about apparent water-level declines in the aquifers in which their water supply wells are completed should implement a conscientious groundwater monitoring program.

There is also a need to provide the water well drillers with feedback on the reports they are submitting to the regulatory agencies. The feedback is necessary to allow for a greater degree of uniformity in the reporting process. This is particularly true when trying to identify the bedrock surface. One method of obtaining uniformity would be to have the water well drilling reports submitted to the AENV Resource Data Division in an electronic form. The money presently being spent by AENV to transpose the paper form to the electronic form should be used to allow for a technical review of the data and follow-up discussions with the drillers.

An effort should be made to form a partnership with the petroleum industry. The industry spends millions of dollars each year collecting information relative to water wells. Proper coordination of this effort could provide significantly better information from which future regional interpretations could be made. This could be accomplished by the Study Area taking an active role in the activities associated with the construction of lease sites for the drilling of hydrocarbon wells and conducting of seismic programs.

In summary, for the next level of study, the database needs updating. The updating of information for existing water wells requires more details designated as being suitable for field verification.

Groundwater is a renewable resource and it must be managed.
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HCL groundwater consulting
environmental sciences


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8. **Conversions**

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9. Glossary

AAFC-PFRA  Prairie Farm Rehabilitation Administration arm of Agriculture and Agri-Food Canada

Aquifer  a formation, group of formations, or part of a formation that contains saturated permeable rocks capable of transmitting groundwater to water wells or springs in economical quantities

Aquitard  a confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer

Available Drawdown  in a confined aquifer, the distance between the non-pumping water level and the top of the aquifer

in an unconfined aquifer (water table aquifer), two thirds of the saturated thickness of the aquifer

Borehole  includes all “work types” except springs

Completion Interval  see diagram

Dewatering  the removal of groundwater from an aquifer for purposes other than use

Dfb  one of the Köppen climate classifications; a Dfb climate consists of warm to cool summers, severe winters, and no dry season. The mean monthly temperature drops below -3° C in the coolest month, and exceeds 10° C in the warmest month.

Evapotranspiration  a combination of evaporation from open bodies of water, evaporation from soil surfaces, and transpiration from the soil by plants (Freeze and Cherry, 1979)

Facies  the aspect or character of the sediment within beds of one and the same age (Pettijohn, 1957)

Fluvial  produced by the action of a stream or river

Friable  poorly cemented

Hydraulic Conductivity  the rate of flow of water through a unit cross-section under a unit hydraulic gradient; units are length/time

km  kilometre

Kriging  a geo-statistical method for gridding irregularly-spaced data (Cressie, 1990)

Lacustrine  fine-grained sedimentary deposits associated with a lake environment and not including shore-line deposits

Lithology  description of rock material

Lsd  Legal Subdivision

m  metres

mm  millimetres

m²/day  metres squared per day

m³  cubic metres
m³/day cubic metres per day
mg/L milligrams per litre
Median the value at the centre of an ordered range of numbers
Mode the most frequently occurring or repetitive, value in an array or range of data.
Obs WW Observation Water Well

Piper tri-linear diagram a method that permits the major cation and anion compositions of single or multiple samples to be represented on a single graph. This presentation allows groupings or trends in the data to be identified. From the Piper tri-linear diagram, it can be seen that the groundwater from this sample water well is a sodium-bicarbonate-type. The chemical type has been determined by graphically calculating the dominant cation and anion. For a more detailed explanation, please refer to Freeze and Cherry, 1979

Rock earth material below the root zone
Surficial Deposits includes all sediments above the bedrock
Thalweg the line connecting the lowest points along a stream bed or valley; longitudinal profile
Till a sediment deposited directly by a glacier that is unsorted and consisting of any grain size ranging from clay to boulders
Transmissivity the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient: a measure of the ease with which groundwater can move through the aquifer

Apparent Transmissivity: the value determined from a summary of aquifer test data, usually involving only two water-level readings
Effective Transmissivity: the value determined from late pumping and/or late recovery water-level data from an aquifer test
Aquifer Transmissivity: the value determined by multiplying the hydraulic conductivity of an aquifer by the thickness of the aquifer

Water Well a hole in the ground for the purpose of obtaining groundwater; “work type” as defined by AENV includes test hole, chemistry, deepened, well inventory, federal well survey, reconditioned, reconstructed, new, old well-test

Yield a regional analysis term referring to the rate a properly completed water well could be pumped, if fully penetrating the aquifer

Apparent Yield: based mainly on apparent transmissivity
Long-Term Yield: based on effective transmissivity
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<tr>
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<td>above mean sea level</td>
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<td>Digital Elevation Model</td>
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<td>drill stem test</td>
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<td>IAAM</td>
<td><em>Infinite Aquifer Artesian Model</em>. The mathematical model is used to calculate water levels at a given location. The model has been used for more than 17 years by HCL for several hundred groundwater monitoring projects. The model aquifer is based on a solution of the well function equation. The simulation calculates drawdown by solving the well function equation using standard approximation methods. The drawdown at any given point at any given time uses the method of superposition.</td>
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<td>non-pumping water level</td>
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<td>Total Dissolved Solids</td>
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<td>WSW</td>
<td>Water Source Well or Water Supply Well</td>
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Surface Topography
Location of Water Wells and Springs

* Water Wells with no Aquifer Designation are not shown on Map
Depth to the Base of Groundwater Protection
PEACE RIVER REGION
Appendix B

Surficial Deposits - Hydrogeological Maps

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<td>Total Dissolved Solids in Groundwater from Surficial Deposits</td>
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<tr>
<td>Apparent Yield for Water Wells Completed in Sand and Gravel Aquifer(s)</td>
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Thickness of Surficial Deposits

[Map showing thickness of surficial deposits in a region of British Columbia and Alberta, with various counties and municipalities such as M.D. 130, M.D. 135, M.D. 136, Saddle Hills County, Northern Sunrise County, and others.]

Legend:
- Green: < 100 m
- Yellow: 100 - 500 m
- Orange: > 500 m

Water consultants ltd.
AAMD&C Northern Zone, Part of the Peace River Basin
Regional Groundwater Assessment, Tp 065 to 107, R 05 to 27, W5M and Tp 069 to 087, R 01 to 13, W6M
Total Dissolved Solids in Groundwater from Surficial Deposits

- **British Columbia**
- **Alberta**
- **Saddle Hills County**
- **Grand Prairie County**
- **Birch Hills County**
- **Northern Sunrise County**
- **M.D. 130**
- **M.D. 135**
- **M.D. 133**
- **M.D. 136**
- **M.D. 16**
- **M.D. 21**
- **M.D. 22**
- **M.D. 23**
- **M.D. 24**
- **M.D. of Big Lakes**
- **Total Dissolved Solids in Groundwater from Surficial Deposits**

*mg/L*
Sulfate in Groundwater from Surficial Deposits
Nitrate + Nitrite (as N) in Groundwater from Surficial Deposits
Total Hardness in Groundwater from Surficial Deposits

[Map showing hardness levels in groundwater from surficial deposits across various regions in Canada]

- British Columbia
- Alberta
- Northern Sunrise County
- County of Birch Hills
- County of Wapiti
- M.D. 16
- M.D. 130
- M.D. 133
- M.D. 135
- M.D. 136
- M.D. 21
- M.D. 22
- M.D. 23
- M.D. 124
- M.D. of Big Lakes
- Saturated Surficial Deposits Absent

Legend:

- 0-100 mg/L
- 100-200 mg/L
- 200-500 mg/L
- 500-1000 mg/L

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groundwater consulting
environmental sciences
Thickness of Sand and Gravel Deposits
Amount of Sand and Gravel in Surficial Deposits
Thickness of Sand and Gravel Aquifer(s)

British Columbia

Alberta

Northern Sunrise County

County of Birch Hills

M.D. 120

M.D. 22

M.D. 23

M.D. 21

M.D. 124

M.D. of Big Lakes

M.D. 16

Eagle Hills County

M.D. 133

M.D. 136

M.D. 135

M.D. 130

M.D. of Big Lakes

Thickness of Sand and Gravel Aquifer(s)
Water Wells Completed in Surficial Deposits
Apparent Yield for Water Wells Completed in Sand and Gravel Aquifer(s)
Apparent Yield for Water Well Completed in Upper Bedrock Aquifer(s)
Total Dissolved Solids in Groundwater from Upper Bedrock Aquifer(s)

- British Columbia
- Alberta

Legend:
- 200 mg/L
- 500 mg/L
- 1000 mg/L
- 1500 mg/L
- 2000 mg/L
- Absent

Hydrogeological Consultants Ltd.

AAMD&C Northern Zone, Part of the Peace River Basin
Regional Groundwater Assessment, Tp 065 to 107, R 05 to 27, W5M and Tp 069 to 087, R 01 to 13, W6M
Chloride in Groundwater from Upper Bedrock Aquifer(s)
Fluoride in Groundwater from Upper Bedrock Aquifer(s)
Recharge/Discharge Areas between Surficial Deposits and Upper Bedrock Aquifer(s)
Non-Pumping Water-Level Surface in Upper Bedrock Aquifer(s)
Depth to Top of Horseshoe Canyon Formation
Structure-Contour Map - Horseshoe Canyon Formation
Non-Pumping Water-Level Surface - Horseshoe Canyon Aquifer
Apparent Yield for Water Well Completed through Horseshoe Canyon Aquifer
Sulfate in Groundwater from Horseshoe Canyon Aquifer
Chloride in Groundwater from Horseshoe Canyon Aquifer
Fluoride in Groundwater from Horseshoe Canyon Aquifer
Total Hardness of Groundwater from Horseshoe Canyon Aquifer
Depth to Top of Oldman Formation
Non-Pumping Water-Level Surface - Oldman Aquifer
Apparent Yield for Water Well Completed through Oldman Aquifer
Total Dissolved Solids in Groundwater from Oldman Aquifer
Sulfate in Groundwater from Oldman Aquifer
Chloride in Groundwater from Olman Aquifer
Fluoride in Groundwater from Oldman Aquifer
Depth to Top of Foremost Formation

Regional Groundwater Assessment, Tp 065 to 107, R 05 to 27, W5M and Tp 069 to 087, R 01 to 13, W6M
Non-Pumping Water-Level Surface - Foremost Aquifer

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Regional Groundwater Assessment, Tp 065 to 107, R 05 to 27, W5M and Tp 069 to 087, R 01 to 13, W6M
Apparent Yield for Water Well Completed through Foremost Aquifer
Total Dissolved Solids in Groundwater from Foremost Aquifer

<table>
<thead>
<tr>
<th>Total Dissolved Solids (mg/L)</th>
<th>Absent</th>
<th>200</th>
<th>500</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
</tr>
</thead>
</table>

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Regional Groundwater Assessment, Tp 065 to 107, R 05 to 27, W5M and Tp 069 to 087, R 01 to 13, W6M

AAMD&C Northern Zone, Part of the Peace River Basin
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Sulfate in Groundwater from Foremost Aquifer
Chloride in Groundwater from Foremost Aquifer
Fluoride in Groundwater from Foremost Aquifer
Depth to Top of Lea Park Formation
Non-Pumping Water-Level Surface - Lea Park Aquifer
Total Dissolved Solids in Groundwater from Lea Park Aquifer
Sulfate in Groundwater from Lea Park Aquifer
Chloride in Groundwater from Lea Park Aquifer
Fluoride in Groundwater from Lea Park Aquifer

Map showing groundwater provinces and regions.
Total Hardness of Groundwater from Lea Park Aquifer
Structure-Contour Map - Milk River Formation
Non-Pumping Water-Level Surface - Milk River Aquifer
Apparent Yield for Water Well Completed through Milk River Aquifer

[Map showing groundwater yield in various regions]
Total Dissolved Solids in Groundwater from Milk River Aquifer

[Map showing dissolved solids in groundwater from the Milk River Aquifer with color-coding for different levels of TDS (mg/L)].

Alberta

British Columbia

Northern Sunrise County

Regional Groundwater Assessment, Tp 065 to 107, R 05 to 27, W5M and Tp 069 to 087, R 01 to 13, W6M
Sulfate in Groundwater from Milk River Aquifer
Chloride in Groundwater from Milk River Aquifer

Regional Groundwater Assessment, Tp 065 to 107, R 05 to 27, W5M and Tp 069 to 087, R 01 to 13, W6M
Fluoride in Groundwater from Milk River Aquifer
Total Hardness of Groundwater from Milk River Aquifer

Regional Groundwater Assessment, Tp 065 to 107, R 05 to 27, W5M and Tp 069 to 087, R 01 to 13, W6M

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Non-Pumping Water-Level Surface - Colorado Aquifer
Apparent Yield for Water Well Completed through Colorado Aquifer
Total Dissolved Solids in Groundwater from Colorado Aquifer
Sulfate in Groundwater from Colorado Aquifer
Chloride in Groundwater from Colorado Aquifer
Fluoride in Groundwater from Colorado Aquifer
Non-Pumping Water-Level Surface - Cardium Aquifer
Apparent Yield for Water Well Completed through Cardium Aquifer
Total Dissolved Solids in Groundwater from Cardium Aquifer
Sulfate in Groundwater from Cardium Aquifer
Total Hardness of Groundwater from Cardium Aquifer

British Columbia
Alberta

M.D. 22
M.D. 23
M.D. 21
M.D. 133
M.D. 135
M.D. 136
M.D. 22
M.D. 23
Northern Sunrise County

Total Hardness of Groundwater from Cardium Aquifer

mg/L

0
500
1000
1500
2000

20
25
30
35
40

200
500
1000
1500
2000

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AAMD&C Northern Zone, Part of the Peace River Basin
Regional Groundwater Assessment, Tp 065 to 107, R 05 to 27, W5M and Tp 069 to 087, R 01 to 13, W6M
Depth to Top of Kaskapau Formation
Non-Pumping Water-Level Surface - Kaskapau Aquifer
Apparent Yield for Water Well Completed through Kaskapau Aquifer

[Map showing the apparent yield for water wells completed through the Kaskapau Aquifer, with different regions and M.D. codes highlighted.]

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AAMD&LC Northern Zone, Part of the Peace River Basin
Regional Groundwater Assessment, Tp 065 to 107, R 05 to 27, W5M and Tp 069 to 087, R 01 to 13, W6M
Total Dissolved Solids in Groundwater from Kaskapau Aquifer
Sulfate in Groundwater from Kaskapau Aquifer
Chloride in Groundwater from Kaskapau Aquifer
Fluoride in Groundwater from Kaskapau Aquifer
Total Hardness of Groundwater from Kaskapau Aquifer
Depth to Top of Dunvegan Formation

[Map of regions in Alberta and British Columbia with color-coded depth levels to the Dunvegan Formation]
Structure-Contour Map - Dunvegan Formation
Non-Pumping Water-Level Surface - Dunvegan Aquifer
Apparent Yield for Water Well Completed through Dunvegan Aquifer

British Columbia

Alberta

M.D. 22

M.D. 23

Northern Sunrise County

Saddle Hills

County

County of Birch Hills

M.D. 130

M.D. 135

M.D. 133

M.D. 136

Birch Hills

Grand Prairie

M.D. 21

M.D. 16

M.D. 13

M.D. of Big Lakes

M.D. 124

M.D. 22

M.D. 23

M.D. 135

M.D. 133

M.D. 136

M.D. 21

M.D. 16

M.D. 13

M.D. of Big Lakes

1.3

75

m³/day

spinf

10.5

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Total Dissolved Solids in Groundwater from Dunvegan Aquifer
Chloride in Groundwater from Dunvegan Aquifer
Fluoride in Groundwater from Dunvegan Aquifer

[Map showing fluoride concentration in groundwater from Dunvegan Aquifer]
Non-Pumping Water-Level Surface - Shaftesbury Aquifer
Apparent Yield for Water Well Completed through Shaftesbury Aquifer
Total Dissolved Solids in Groundwater from Shaftesbury Aquifer
Sulfate in Groundwater from Shaftesbury Aquifer
Chloride in Groundwater from Shaftesbury Aquifer

AAMD&C Northern Zone, Part of the Peace River Basin
Regional Groundwater Assessment, Tp 065 to 107, R 05 to 27, W5M and Tp 069 to 087, R 01 to 13, W6M
Fluoride in Groundwater from Shaftesbury Aquifer

Regional Groundwater Assessment, Tp 065 to 107, R 05 to 27, W5M and Tp 069 to 087, R 01 to 13, W6M
Total Hardness of Groundwater from Shaftesbury Aquifer

[Map showing the distribution of total hardness of groundwater from Shaftesbury Aquifer in various regions of British Columbia and Alberta, including specific areas such as County of Birch Hills, County of M.D. 120, M.D. 16, M.D. 21, M.D. 22, M.D. 23, M.D. 124, M.D. 130, M.D. 135, M.D. 136, County of Northern Sunrise, and others.

Key:
- 200 mg/L
- 500 mg/L
- 1000 mg/L
- 1500 mg/L
- 2000 mg/L

Regional Groundwater Assessment, Tp 065 to 107, R 05 to 27, W5M and Tp 069 to 087, R 01 to 13, W6M]

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Structure-Contour Map - Peace River Formation
Non-Pumping Water-Level Surface - Peace River Aquifer
Total Dissolved Solids in Groundwater from Peace River Aquifer
Sulfate in Groundwater from Peace River Aquifer

Regional Groundwater Assessment, Tp 065 to 107, R 05 to 27, W5M and Tp 069 to 087, R 01 to 13, W6M

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AAMD&C Northern Zone, Part of the Peace River Basin

100 500
Absent
Chloride in groundwater from Peace River Aquifer
Fluoride in Groundwater from Peace River Aquifer
Total Hardness of Groundwater from Peace River Aquifer
Depth to Top of Mannville Formation
Non-Pumping Water-Level Surface - Mannville Aquifer
Total Dissolved Solids in Groundwater from Mannville Aquifer
Sulfate in Groundwater from Mannville Aquifer
Chloride in Groundwater from Mannville Aquifer
Total Hardness of Groundwater from Peace River Aquifer

Total hardness of groundwater from the Peace River Aquifer is represented in the map. The hardness values range from below 200 mg/L to over 2000 mg/L. The map shows the distribution of these values across various regions in British Columbia and Alberta, with specific focus on the Peace River Basin area, covering Township 065 to 107, Range 05 to 27, W5M and Township 069 to 087, Range 01 to 13, W6M.