Hydrogeology Mapping of
NTS Mapsheet Regina 72I

Prepared for:

Water Security Agency

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1.0 INTRODUCTION
This document provides the results of the hydrogeological mapping of the Regina (72I) 1:250,000 NTS mapsheet area completed by MDH Engineered Solutions Corp., a member of the SNC Lavalin Group (MDH), on behalf of the Water Security Agency (WSA) of Saskatchewan. The goal of this project was to map the shallow stratigraphy and groundwater resources of the Regina mapsheet area (Figure 2.1) within a GIS framework as outlined in the procedures manual created for conducting regional hydrogeological mapping in Saskatchewan (MDH, 2010). The GIS data management system has been used to better facilitate groundwater knowledge-building and to improve internal efficiency and timely dissemination of data to the public by the WSA.

1.1 Scope
The general scope of the project was to complete geological, hydrogeological, and hydrostratigraphic mapping of the Regina mapsheet (72I), as well as characterize the groundwater resources on a regional scale. The detailed scope of the project (as outlined in the RFP) was to:

1. Develop new knowledge products, particularly groundwater vulnerability mapping and water availability; and concurrently
2. Map the Regina 72I (1:250,000) NTS mapsheet using the prototype (MDH, 2011a) and standards developed for the province-wide mapping of the Quaternary to Upper Cretaceous aquifers (MDH, 2010; and Schreiner, 2010).

2.0 BACKGROUND
The WSA, previously known as the Saskatchewan Watershed Authority (SWA) is facing demand from the public and government agencies for expert knowledge on groundwater resources. Groundwater mapping forms the fundamental basis for all knowledge development by providing the regional context to any site. This report is meant to be used as an initial step when starting any supplemental environmental, hydrogeological, and geotechnical field investigations for a site. The maps and cross-sections provided will help guide site exploration and development, provide preliminary indications of aquifer vulnerability to surface contaminants, and/or determine potential sources of groundwater. Built from available data, the hydrogeological framework provides the WSA, industry consultants, and the public with fundamental information on the groundwater resources in an area, facilitating development and allowing the WSA staff to effectively manage, sustain, and protect groundwater.
LEGEND

COMMUNITY
APPROXIMATE CLIMATE STATION LOCATION
SWA MONITORING WELL LOCATION
URBAN MUNICIPALITIES
FIRST NATIONS LANDS
RIVER
MAJOR WATERBODY
RAILWAY
HIGHWAY
REGINA 72I NTS BOUNDARY

Notes:
1. COORDINATE SYSTEM: NAD 1983 UTM ZONE 13N
2. CLIMATE STATION DATA OBTAINED FROM SASKATCHEWAN ENVIRONMENT.
3. ELEVATION SCALES FOR PROVINCIAL VIEW DIFFER FROM DETAIL VIEW AS INDICATED ABOVE.

SCALE
AS SHOWN
DATE
DESIGN BY
R. NORMAN, P.Geo.
30-APR-13
DRAWN BY
B. GALIMBERTI, GIS Cert.
30-APR-13
APPROVED BY
30-APR-13

LOCATION OF REGINA 72I AREA

CLIENT
TITLE
PRODUCED BY
PROJECT No.
M2749-1030110
FIG. No.
2.1
DRAW No.
M2749-26-01

SCALE
DETAIL SCALE: 1:650,000
PROVINCE SCALE: 1:6,500,000
ELEVATION (masl)
High : 1388
Low : 206

DETAIL ELEVATION (masl)
Low : 450
High : 850

SCALE DATE
AS SHOWN
DESIGN BY
R. NORMAN, P.Geo.
DATE
30-APR-13
DRAWN BY
B. GALIMBERTI, GIS Cert.
DATE
30-APR-13
APPROVED BY
DATE
30-APR-13

ELEVATION (masl)
High : 1388
Low : 206

ELEVATION (masl)
Low : 450
High : 850

Kilometers
0 30 60 15
0 30 60 15

PATH: L:\SWA\SWA_72I_MXD\M2749-26-01 (Location of Regina 72I Area).mxd
During the late 1960s, the Saskatchewan Research Council (SRC) conducted a groundwater mapping program to delineate potential groundwater resources in the agricultural sector of Saskatchewan based on NTS mapsheets at 1:250,000 scale. This program was funded by the Agriculture and Rural Development Agency (ARDA) and resulted in 20 maps, but was ended in 1980. This program established the foundation for hydrostratigraphic mapping in Saskatchewan and led to what is referred to as the First Generation Groundwater Maps (FGGM). The maps illustrated the spatial extent and distribution of potential bedrock hydrostratigraphic stratified units (HSUs) and each was typically accompanied by four geologic cross-sections.

As the Quaternary geology of Saskatchewan became better understood, it was possible to map groundwater resources within the glacial drift. The Second Generation Groundwater Maps (SGGM) were created by the SRC and the Saskatchewan Watershed Authority (SWA) from 1986 to 2004 to update the FGGM. This mapping program further defined the upper bedrock geology and identified major aquifers within the glacial deposits as well as the near surface bedrock deposits. The second generation mapping program completed 20 NTS mapsheets covering the majority of southern Saskatchewan.

In 2004, the SWA initiated development of the third generation groundwater maps for southern Saskatchewan. These maps provided public information on the groundwater resources and illustrated the spatial extent, distribution, and depth to potential aquifers. Detailed stratigraphic cross-sections illustrating the bedrock and Quaternary stratigraphy were prepared as part of the study. The Cypress Hills (72F), Prelate (72K), Swift Current (72J), and Wood Mountain (72G) mapsheets were completed as the initial stages of this mapping program (Maathuis and Simpson, 2007a, b, c, and d). Maps were produced on the ESRI ArcGIS platform and posted on the SWA website, along with the reports describing the regional geology and hydrogeology.

The WSA presently recognizes the need for better groundwater knowledge and better public access to digital data. The WSA also recognizes that without a current mapping plan, Saskatchewan risks losing key information and expertise in the near future. A new mapping program was therefore initiated by the SWA in 2009 (now the Water Security Agency (WSA)); the Saskatoon 73B (1:250,000) NTS mapsheet was used as the pilot project to establish mapping standards and complete the formal hydrostratigraphic mapping of the 73B area which had not been updated since the FGGM done by SRC. The new mapping program will provide a necessary update to the present understanding of Saskatchewan’s groundwater resources in the area. It will also assist in the development of modern water allocation policies and identify areas susceptible to groundwater contamination.

The hydrogeology of the Regina 72I Mapsheet is the second report to be done for the current generation of hydrogeology mapping projects. This report is an expansion and refinement from the previous SGGM (Simpson, 2004) compiled by the SRC, and all data/information has
been incorporated into an ESRI ArcGIS database to be maintained by the WSA. This will allow public access to the information and data for the Regina mapsheet area.

All the available groundwater mapping products for the province of Saskatchewan are available to the public through the WSA (https://www.wsask.ca).

2.1 Study Area

The 1:250,000 NTS mapsheet Regina 72I encompasses an approximate area of 15,109 km², as shown in Figure 2.1.

2.1.1 Climate

Based on the modified Köppen classification (Köppen, 1936 and Peel et al., 2007), the Regina 72I area has a continental climate characterized by hot summers, cold winters, and little rainfall. While there are more weather stations than shown on Figure 2.1 (http://climate.weatheroffice.gc.ca), only climate stations with averages determined for an approximate history between 1971 and 2000 were used in this report.

The average annual precipitation ranges from 365.1 mm/yr (Moose Jaw) to 459.6 mm/yr (Zehner) with approximately 21% to 27% of that in the form of snowfall. Throughout the year the highest level of precipitation generally occurs during the months from May, June, and July (Figure 2.2).

The annual average temperatures measured at the indicated weather stations ranges between 2.2°C (Cupar) and 4.0°C (Moose Jaw A). The month of January has the coldest temperatures on average, ranging from -13.7°C to -17.0°C, while July is the warmest month with average temperatures ranging between 18.1°C and 19.4°C in the Regina 72I area.

![Figure 2.2 – Climate variable measured at the Moose Jaw A climate station.](image-url)
Evaporation is one of the primary hydrological processes in the semi-arid regions of the Canadian prairies resulting in the uptake of most of the precipitation to the atmosphere. Evapotranspiration is often described as an upward moisture flux from the land and the vegetation (Viessman and Lewis, 1996). In semi-arid regions, most precipitation is stored in the form of soil moisture and is eventually released through evapotranspiration.

Gross evaporation isolines based on a 30-year period from 1971-2000 for the Canadian prairies; created by the Prairie Farm Rehabilitation Administration (PFRA), hydrology division (Martin, 2002) and then updated by SWA recently to show data from 1977-2006 (SWA, 2009) illustrates the level of evaporation from the free water surface of a body of water (Figure 2.3). Based on the isolines, the mean annual gross evaporation for the Regina 72I area is estimated to range from approximately 900 mm to 1,000 mm.

![Figure 2.3 – Modified map of mean annual gross evaporation (mm) in Regina area for small lakes and reservoirs from 1977-2006 (SWA, 2009).](image)

### 2.1.2 Topography and Drainage

Figure 2.4 shows the regional hydrological features and watersheds in the Regina 72I area. The regional drainage basins identified in the study area are: 1) Upper Qu’Appelle River Watershed, 2) Lower Qu’Appelle River Watershed, 3) Moose Jaw River Watershed, 4) Wascana Creek Watershed, 5) Upper Souris River Watershed, and 6) Old Wives Lake Watershed. The Big Muddy Creek Watershed is located just outside the southwest corner of the mapsheet as well. In the Regina 72I area, topographic elevations range from approximately 460 metres above sea level (masl), in Qu’Appelle River Valley near Pasqua Lake, to 874 masl, along the Missouri Couteau in the southwest corner of the mapsheet.
2.1.3 Land Use and Ecoregions

Three ecoregions are present in the study area: the Aspen Parkland, the Moist Mixed Grassland, and the Mixed Grassland (Acton et al., 1998). The Aspen Parkland Ecoregion extends from the southeast corner of the province to the Alberta border near Lloydminster. It covers the east to northeast corner of the mapsheet (Figure 2.5). This region represents the transition zone between forested areas and grassland. The generally hummocky landscape is composed of aspen groves in moist areas and fescue grasslands in drier areas. Trembling aspen forests dominate the northern portion of the ecoregion and grasslands thrive in the southern extent of the area. The dominant land use is agriculture, with 80% of the ecoregion dedicated to cropland, producing cereals and oilseeds or planted to a perennial forage crop. Land that is not suitable for crops is often used as pasture land to support livestock.

The Moist Mixed Grassland Ecoregion cuts through the southern portion of Saskatchewan from Estevan to Saskatoon and west to the Alberta Border. It forms the main ecoregion by area in the Regina mapsheet (Figure 2.5). This area represents the northern most extent of natural open grassland. Wheatgrass and speargrass are the dominant natural grass species in the region with trembling aspen residing in areas around wetlands. The ecoregion supports 55% of Saskatchewan’s population, creating a landscape for a variety of land-uses. Agriculture is the dominant land use in the ecoregion with 80% of the land under cultivation. Crops include spring wheat and other cereal grains, with oilseed becoming an important contributor to total crop production. Areas that are not suitable for cultivation are often used as pasture land for livestock. Potash solution mining is a large industry in this ecoregion.

The Mixed Grassland Ecoregion covers the majority of the southwest corner of the province. It is located in the southwest corner of the Regina mapsheet, around Old Wives Lake and the hills of the Missouri Couteau. It represents the driest area of the province as evidenced by the absence of native trees and scarcity of wetlands and permanent water bodies. Its diverse landscapes include level glacial lake plains; dune-covered sand hill areas; the hilly, pothole country along the Missouri Couteau; and the rolling expanses of native grassland and intermittent "badlands" near the United States border. The native grasslands are characterized mainly by wheat grasses, speargrasses and, to a lesser extent, by blue grama grass which gains prominence on extremely dry soils or under high grazing pressure. About half of the area is cultivated, with the remainder used for extensive grazing of livestock on native or introduced grasses. Cereals are the main crop on cultivated land, although feed grains, forages, and oilseeds are also grown.
LEGEND

- COMMUNITY
- MAJOR HIGHWAY
- RAILWAY
- NATIVE DOMINANT GRASSLAND
- HARDWOOD OPEN
- TALL SHRUB
- WATERBODY
- MARSH
- MUD/SAND/SALINE
- FARMSITE / URBAN MUNICIPALITY
- CULTIVATED LAND
- PASTURE (SEEDED GRASSLAND)
- HAY CROP (FORAGE)

REGINA 72I MAPSHEET AREA
ECOREGION BOUNDARY

Note
1. COORDINATE SYSTEM: NAD 1983 UTM ZONE 13N
2. SASKATCHEWAN SOUTH DIGITAL LAND COVER DATA OBTAINED FROM SASKATCHEWAN INTERACTIVE, SASKATCHEWAN MINISTRY OF ENVIRONMENT.
3. ECOREGION BOUNDARIES OBTAINED THROUGH AGRICULTURE CANADA.
3.0 METHODOLOGY

MDH compiled and examined well, borehole, and hydrogeology related data from a number of sources to complete the hydrogeological mapping of the Regina 72I area. The WSA and the SRC provided the majority of the information necessary to complete the mapping project. Research on the shallow stratigraphy and groundwater resources of the Regina area is fairly extensive and has formed most of the framework for this report. Additional sources were required to provide the full scope of hydrogeological work completed in the study area. Databases and data sources that were compiled for the Mapsheet 72I included:

1. Wells Database
   a. WSA Database
   b. SRC Wells Database

2. Log Data
   a. WSA borehole logs
   b. WSA library report borehole logs
   c. SRC auger borehole logs
   d. SRC borehole logs with geophysics
   e. SRC carbonate data
   f. Saskatchewan Ministry of Highways and Infrastructure (SMHI) historical borehole logs
   g. SMHI Geotechnical Database logs
   h. Saskatchewan Ministry of Energy and Resources (SMER) logs
   i. SMER stratigraphic database
   j. Williston Basin TGI stratigraphic database of deep exploration holes
   k. Selected private industry borehole logs

3. Water Quality Databases
   a. WSA Provincial Water Quality dataset
   b. WSA FoxPro Water Quality dataset
   c. Rural Water Quality Advisory Program (RWQAP) dataset

4. Licensed Groundwater Database

5. Hydrogeological Investigation Reports
   a. WSA Library
   b. Other public reports

6. Observation Well Water Levels

7. Community Water Use Database

The procedures implemented in the collection and processing of these datasets is provided in “Procedures for Regional Hydrogeological Mapping” (MDH, 2010).

3.1 Stratigraphic Data Processing for Mapping

Following data compilation and processing, a total of 3,176 auger borehole logs, professional logs with geophysics, driller’s logs with geophysics, and Williston Basin TGI database records were used to map the stratigraphic units in the Regina 72I area. These records
comprise the Mapping Dataset that contains tabulated boreholes and well information (Mapping Borehole Database) and the associated stratigraphy (Stratigraphic Database). All records are referenced with the WSA Water Well Drilling Record (WWDR) ID. The WWDR ID is a unique identifier for each hole drilled in the area; it has been used to identify the boreholes in this report except for the deep exploration holes which do not have WWDR IDs.

The Williston Basin TGI II Project database provided the stratigraphic interpretation of the deep exploration holes found in the area. This database, undertaken by the governments of Saskatchewan and Manitoba, the Geological Survey of Canada, and the universities of Saskatchewan and Manitoba, covers all of southeastern Saskatchewan to southwestern Manitoba ([http://www.manitoba.ca/iem/mrd/geo/willistontgi/index.html](http://www.manitoba.ca/iem/mrd/geo/willistontgi/index.html)). The interpreted bedrock picks were taken directly from that database to establish a more detailed representation of the Upper Cretaceous bedrock in the area down to the Lea Park Formation. Only deep holes with picks at and above the Judith River Formation were used. None of the deep exploration holes were given a WWDR ID since they are identified through a separate naming convention and are not water wells.

It is noted that the listing of used boreholes is not comprehensive, as not all of the existing boreholes are publicly available. There is a vast amount of information in consulting reports for private industry that were not available. Borehole logs not completed by a professional or without geophysics were not used in the development of the stratigraphic database.

The Canadian Digital Elevation Data (CDED) dataset, available through the National Topographic Data Base (NTDB), was used to provide a consistent reference for all boreholes and maps. This dataset provides a resolution of approximately +/- 10 m for the area with all ground elevations recorded in metres relative to mean sea level and based on the North American Datum 1983 (NAD83) horizontal reference datum. Even when a more accurate surveyed elevation was provided on a borehole log the more general CDED elevation was still used to maintain agreement between the borehole logs and the maps.

All boreholes and water wells used in this project were located to the most accurate geographic location provided on the drillers’ records, electric logs, published reports, or actual GPS survey data. No field verifications were done for the compilation of this report. If a professionally surveyed Universal Transverse Mercator (UTM) location was provided this would be used as the most accurate possible land location providing accuracy to +/-5 m. Otherwise the most accurate legal land description (LLD) which was provided would be used. The LLD provides accuracy from a section in size (640 acres) down to a quarter legal subdivision (LSD) which is 10 acres in size. A complete description of the land survey system is provided at: [https://www.isc.ca/About/History/LandSurveys/Pages/default.aspx](https://www.isc.ca/About/History/LandSurveys/Pages/default.aspx).
As a result of the variability in the level of accuracy provided for borehole locations and elevation it is highly recommended that a proper GPS survey of area wells be conducted to complete a hydrogeological investigation for that area.

3.1.1 Stratigraphic Mapping (Interpretation)

Professional MDH hydrogeologists provided the stratigraphic interpretations for each borehole. The Williston Basin TGI stratigraphic database provided stratigraphic interpretations from deep exploration boreholes. No attempt was made to alter the provided picks in the Williston Basin TGI database, even if they were suspect. Alteration of the deep Williston Basin TGI data was beyond the scope of this study.

Appendix A provides the stratigraphic chart for hydrogeological mapping of the Regina area and southern Saskatchewan. It also provides the stratigraphic chart specific to the Regina 72I area. These charts provide the relative age, stratigraphy, generalized lithology, and a short-form symbol for each hydrostratigraphic unit present. The references used to compile the stratigraphic chart are provided on the chart in Appendix A.

The location and extent of the hydrostratigraphic units involves varying levels of uncertainty. Existing geological and hydrostratigraphic data can be fairly sparse. The majority of water wells in the area are privately drilled to support local farming operations. Many of these wells were not drilled to a stratigraphic marker (e.g. Upper Cretaceous bedrock shale) and/or do not have carbonate data. Stratigraphic interpretations completed without this information can be uncertain. Similarly, the majority of the lithologic descriptions on the boreholes were not created by a professional (i.e. no geologist, engineer, or technologist was on site to provide descriptions of the drill cuttings) and the lithology reported on the logs is based on drillers' descriptions, which, in the experience of MDH, are often unreliable. Only borehole/well records that contained a reliable location, electric log, and cutting description were used in this study. In total 3,073 such records were found in the Regina 72I area, not including the 103 holes used from the Williston Basin TGI database.

An interpretation of the stratigraphy at each borehole (i.e. a strip log) was created using the geophysical signatures supplemented with the driller's or professional's notes, as well as geotechnical soil testing and carbonate content. While this is the most comprehensive interpretation of the stratigraphy and hydrogeology based on the available information, it is and will be subject to error. As a result of this uncertainty, the interpretations provided based on this data should not be used for decisions relating to a development or well installation without verification (i.e. confirmatory drilling). The compiled maps and cross-sections should only be used to provide the stratigraphic framework for the area and to make large-scale general decisions to guide site-specific investigations. All interpretations should be completed by a professional geoscientist.
3.1.2 Stratigraphic Interpretation Methodology

The principles described in the MDH (2010) and the Schreiner (2010) reports were used to interpret the stratigraphy (i.e. make stratigraphic picks) at each borehole in the stratigraphic database. Stratigraphic cross-sections were created as an initial step in the stratigraphic interpretation process. In general, borehole logs with good geophysical signatures, and lithologic description along with supplemental data (especially carbonate contents) were used for the cross-sections. It is noted that there are areas where limited high quality data is available; in these areas, the best information available was used. Appendix B provides a map showing the boreholes used in this study and the locations of cross-sections created for the Regina 72I area. In total twelve cross-sections were created for the Regina 72I area, six running west to east and six running south to north (Appendix C). Professional logs containing geophysical information into the Upper Cretaceous bedrock units (Frenchman, Bearpaw, Judith River, or Lea Park Formation) were preferred for the creation of the stratigraphic cross-sections across the study area. MDH (2010) provides the procedure used to generate the stratigraphic cross-sections.

The interpretation is meant to provide the overall stratigraphic framework for the area, and to provide general information in which to focus more detailed investigations. Site-specific drilling will provide more reliable data for any potential location within the mapsheet. Although the interpretation will be subject to errors, it provides a general hydrostratigraphic framework for the Regina 72I area, and can be used to aid high level decisions that require knowledge of the shallow stratigraphy and hydrogeology. The interpreted stratigraphic picks were input into the Stratigraphic Database, and the borehole and well information was input into the Mapping Borehole Database concurrently during the creation of stratigraphic cross-sections and associated maps.

3.2 Stratigraphic Database and Mapping Borehole Database

A Stratigraphic Database and Mapping Borehole Database were created to map the hydrogeology of the study area, as described in MDH (2010). These databases were then converted to an Arc Hydro compatible database and imported into the Arc Hydro Groundwater Data Model (AHGDM). The AHGDM is based on the ESRI Geodatabase (GDB) format such that the compiled and interpreted information can be accessed via the internet. The “Procedures for Regional Hydrogeological Mapping” (MDH, 2010) provides details on the creation and conversion of these databases into the GIS based AHGDM, such that the information could be used to generate areal limit maps of the mappable stratified deposits, correlate water chemistry and groundwater allocation data to hydrostratigraphic stratified units, and create aquifer vulnerability maps for the Regina 72I study area.

3.3 Areal Limit and Aquifer Vulnerability Index Maps

Areal limit and Aquifer Vulnerability Index (AVI) maps were created for each of the mappable stratified deposits within the Quaternary deposits and the Frenchman and Judith River bedrock formations. Areal limit and thickness maps are an important resource for
groundwater management and siting potential developments. The only defendable way to properly interpret and map complex glacial stratigraphy is to use geologic principals and established formally defined stratigraphic divisions. This means mapping formal stratigraphic units (Formations, Groups, etc.) and not grouped hydrostratigraphic divisions based on material properties. Accordingly, stratified units were mapped with no emphasis on whether they were aquifers or aquitards. This is due to the fact the local variability of these deposits can result in both aquifer and aquitard units being present over short distances. As a result, further subdivision of the stratified deposits could be misleading depending on the sophistication of the user and the purpose for the use of the knowledge product. The GIS based platform should enable users to readily access actual borehole logs during any query to determine what the composition of individual stratified deposits are at any location. The procedures used to create these areal limit and AVI maps is outlined in the MDH (2010) report.

### 3.3.1 Areal Limit Determination

Areal limit determination is the process of analyzing the interpreted stratigraphic picks on borehole logs to determine the 2D (areal) and 3D (extents) of the respective hydrostratigraphic stratified units. This process can be completed manually by “hand contouring” or through an interpolation process using a technique such as natural neighbour to produce a representative surface. This representative surface can then be compared to other horizons (such as the existing topography) to determine overlaps which are removed (clipped) where necessary.

The WSA requested that all contouring be completed using automated computerized methods and that no contouring be completed by hand, such that a web-based Arc Hydro Groundwater Data Model (AHGDM) could be established. It is recognized that computerized determination of the 2D areal limits of mappable stratified deposits will lead to some misrepresentation of the areal extent of these sediments (especially in vicinity of channel features). To limit the automated system from overestimating the extent of hydrostratigraphic stratified units a half-way rule was established whereby the units’ extent is set at the midway point between holes with and without a value for the corresponding unit being mapped.

Contouring by hand provides a significantly better product as geological and geomorphological processes can be used to guide the process. Hand contouring is time consuming and requires re-contouring by hand whenever new data is added. Due to these limitations, a computerized contouring package was considered more desirable for this process. The cross-sections and areal limit maps may not match exactly because the cross-sections were created by hand and the areal limit maps were generated using an automated computerized process. The areal limit maps are provided in Appendix D.

### 3.3.2 Aquifer Vulnerability

Construction and operation of a facility (industrial, agricultural, etc.) can result in significant local effects on the groundwater flow system and subsequently pose a threat to the quality
and quantity of subsurface groundwater. These impacts can be reduced through optimizing the location and/or design of the facility. The vulnerability of subsurface aquifers due to a facility will be a direct function of:

1. the properties of the contaminant(s);
2. the level of natural containment of the sediments (i.e. aquitard thickness); and
3. the design of the waste storage facility.

Protecting the quality of groundwater from contamination is becoming a priority throughout the world as remediation of polluted groundwater and development of clean-up technologies is highly expensive. The risk of pollution to groundwater resources from industrial expansion has resulted in the need to map the vulnerability of these “fresh water” resources on a large scale. Aquifer vulnerability can be defined as follows:

Intrinsic (or natural) vulnerability is the vulnerability solely dependent on the characteristics of an aquifer and the overlying soil and geological materials. It differs from the specific (or integrated) vulnerability in that the latter includes the potential impact(s) of specific land uses or contaminants (Vrba and Zaporozec, 1994).

3.3.2.1 Aquifer Vulnerability Index (AVI) Methodology

Various methods have been used to map aquifer vulnerability, but there is no universally accepted method to date. Consequently, interpretation of vulnerability maps requires an understanding of how they are created. While there are various methods, the ultimate objective of vulnerability mapping is to protect the quality of groundwater by means of the development of land use guidelines or hazardous chemical restrictions. This can involve combinations of: 1) protection of the entire HSU, 2) protection of vulnerable areas, and/or 3) protection of well capture areas (i.e. well head protection). Protection of an entire HSU might be desirable from a point of view of protecting present and future water supplies, but may not be feasible in all cases. Compromises that involve some form of well head protection and protection of the recharge zone are typically required, and the area to be protected may extend beyond the boundaries of the HSU. In many countries this has lead to defining zones around a well head based on travel time considerations.

Regional-scale aquifer vulnerability maps are useful as initial screening tools for land use management. Local and more detailed studies are required to assess the potential impact on a groundwater resource by a specific land use. For this investigation, a modified aquifer vulnerability index (AVI) was used. This AVI was modified from the van Stempvoort et al. (1992, 1993) method that was developed as a tool for regional-scale mapping of the vulnerability of aquifers to contamination from potential sources at or near the ground surface. The method was modified to provide vulnerability maps of multiple stacked HSUs.

The AVI is based on the thickness of the confining aquitard above an HSU and the vertical hydraulic conductivity of that confining aquitard. These two parameters can be combined into a single factor, the hydraulic resistance:
\[ c = \frac{D}{K_v} \]  

where:  
\( c \) = vertical hydraulic resistance (y)  
\( D \) = thickness of confining layer overlying HSU (m)  
\( K_v \) = vertical hydraulic conductivity (m/y)

For a sequence of layers, the total resistance to flow becomes the sum of the \( c \) values of individual aquitard layers. It is assumed that all surficial stratified deposits and intertill deposits are HSUs and have no vertical resistance (this is assumed to keep the calculation conservative). This means only the till and shale units (aquitards) are used in the calculation of the total vertical resistance. The total vertical resistance is calculated as follows:

\[ c_T = \sum_{i=1}^{n} \frac{D_i}{K_{v_i}} \times 3.1688 \times 10^{-8} \]  

where:  
\( c_T \) = Total vertical resistance (y)  
\( D_i \) = Thickness of layer \( i \) (m)  
\( K_{v_i} \) = Vertical hydraulic conductivity of layer \( i \) (m/s)  
\( n \) = Number of layers

note: 3.1688 \( \times 10^{-8} \) provides conversion of \( c_T \) from seconds to years (there are 3.15576 \( \times 10^7 \) seconds per year)

The hydraulic conductivities used for this investigation were based on literature values and engineering judgment, with conservative (high) hydraulic conductivities for the shallow aquitard deposits due to their control over the vulnerability of shallow HSU systems. The assumed hydraulic conductivities for each confining hydrostratigraphic unit are provided in Table 3.1.

To facilitate plotting and contouring of the hydraulic resistance data, the AVI has been defined as:

\[ \text{AVI} = \log_{10}(c) \]
Table 3.1 – Hydraulic conductivities for aquitard units used in AVI calculation.

<table>
<thead>
<tr>
<th>Group</th>
<th>Aquitard Unit</th>
<th>Aquitard Abbreviation</th>
<th>Hydraulic Conductivity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saskatoon Group</td>
<td>Battleford Till</td>
<td>Qb-t</td>
<td>1.0E-07</td>
</tr>
<tr>
<td></td>
<td>Upper Floral Till</td>
<td>Qf-ut</td>
<td>1.0E-08</td>
</tr>
<tr>
<td></td>
<td>Lower Floral Till</td>
<td>Qf-lt</td>
<td>1.0E-09</td>
</tr>
<tr>
<td></td>
<td>Basal Floral Till</td>
<td>Qf-bt</td>
<td>1.0E-09</td>
</tr>
<tr>
<td>Sutherland Group</td>
<td>Warman Till</td>
<td>Qf-wt</td>
<td>1.0E-10</td>
</tr>
<tr>
<td></td>
<td>Upper Dundurn Till</td>
<td>Qd-ut</td>
<td>1.0E-10</td>
</tr>
<tr>
<td></td>
<td>Lower Dundurn Till</td>
<td>Qd-lt</td>
<td>1.0E-10</td>
</tr>
<tr>
<td></td>
<td>Basal Dundurn Till</td>
<td>Qd-bt</td>
<td>1.0E-10</td>
</tr>
<tr>
<td></td>
<td>Upper Mennon Till</td>
<td>Qm-ut</td>
<td>1.0E-10</td>
</tr>
<tr>
<td></td>
<td>Lower Mennon Till</td>
<td>Qm-lt</td>
<td>1.0E-10</td>
</tr>
<tr>
<td>Bearpaw Formation</td>
<td>Aquadell Member Shale</td>
<td>Kbaq</td>
<td>1.0E-11</td>
</tr>
<tr>
<td></td>
<td>Snakebite Member Shale</td>
<td>Kbs</td>
<td>1.0E-11</td>
</tr>
<tr>
<td></td>
<td>Beachy Member Shale</td>
<td>Kbb</td>
<td>1.0E-11</td>
</tr>
<tr>
<td></td>
<td>Sherard Member Shale</td>
<td>Kbsh</td>
<td>1.0E-11</td>
</tr>
<tr>
<td></td>
<td>Broderick Member Shale</td>
<td>Kbbd</td>
<td>1.0E-11</td>
</tr>
<tr>
<td></td>
<td>Unnamed Member Shale</td>
<td>Kbu¹</td>
<td>1.0E-11</td>
</tr>
</tbody>
</table>

The categories for AVI, and their corresponding vulnerability rating and mapping code, are provided in Table 3.2. Table 3.3 provides the values applied to the Regina 72I area. These ratings and codes were used for mapping of the vulnerability of each of the stratified deposits. This assumes that each stratified deposit is composed of aquifer material.

Contouring of AVI values will give the impression of lateral continuity of aquifers and gradation of the index. Neither lateral continuity nor gradation of the AVI values is realistic since hydrogeological settings can change over short distances. The AVI is an averaged property but vulnerability depends on local point values. The aquifer vulnerability mapping should only be considered a guide for the placement of contaminants and has a number of limitations:

- The method assumes that the vulnerability of a mappable stratified deposit is calculated at a point based on overlying deposits at that location. It estimates vulnerability of a hydrostratigraphic unit based on vertical flow at a point source. It does not take into account vulnerability due to:
  a. aquifer connectivity in multiple stacked systems;
  b. lateral flow within the aquifer;
  c. the influence of complex geological structures (e.g. faulting) or unsaturated conditions, etc.; and
  d. anthropogenic influences (i.e. preferential conduits due to improperly grouted boreholes or wells).
### Table 3.2 – AVI ratings and codes.

<table>
<thead>
<tr>
<th>Hydraulic Resistance (years)</th>
<th>Aquifer Vulnerability Index (Log (c))</th>
<th>Aquifer Vulnerability Rating</th>
<th>Aquifer Vulnerability Color Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 10</td>
<td>&lt; 1</td>
<td>very high</td>
<td>very high</td>
</tr>
<tr>
<td>≥ 10 to 100</td>
<td>1 to 2</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>&gt; 1,000 to 1,000</td>
<td>2 to 3</td>
<td>moderate</td>
<td>moderate</td>
</tr>
<tr>
<td>&gt; 10,000 to 10,000</td>
<td>&gt; 4</td>
<td>low</td>
<td>low</td>
</tr>
</tbody>
</table>

### Table 3.3 – AVI applied to the Regina 72I mapsheet.

<table>
<thead>
<tr>
<th>Group</th>
<th>Aquitard Unit</th>
<th>Aquitard Abbreviation</th>
<th>Hydraulic Conductivity (m/s)</th>
<th>Thickness of Aquitard</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 m 2 m 3 m 4 m 5 m 6 m 7 m 8 m 9 m 10 m 15 m 20 m 25 m 30 m 35 m 40 m 45 m 50 m 55 m 60 m 65 m 70 m 75 m 80 m 85 m 90 m 95 m 100 m 120 m 140 m 160 m 180 m 200 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saskatoon Group</td>
<td>Battleford Till</td>
<td>Qb-t</td>
<td>1.0E-07</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Upper Floral Till</td>
<td>Qf-ut</td>
<td>1.0E-08</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower Floral Till</td>
<td>Qf-ft</td>
<td>1.0E-09</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Basal Floral Till</td>
<td>Qf-bt</td>
<td>1.0E-09</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Warman Till</td>
<td>Qf-wt</td>
<td>1.0E-10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Upper Dundurn Till</td>
<td>Qd-ut</td>
<td>1.0E-10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower Dundurn Till</td>
<td>Qd-ft</td>
<td>1.0E-10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Basal Dundurn Till</td>
<td>Qd-bt</td>
<td>1.0E-10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Upper Mennon Till</td>
<td>Qm-ut</td>
<td>1.0E-10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower Mennon Till</td>
<td>Qm-ft</td>
<td>1.0E-10</td>
<td></td>
</tr>
<tr>
<td>Sutherland Group</td>
<td>Bearpaw Formation</td>
<td>Kbaq</td>
<td>1.0E-11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Snakebite Member Shale</td>
<td>Kbs</td>
<td>1.0E-11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Beachy Member Shale</td>
<td>Kiby</td>
<td>1.0E-11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sherard Member Shale</td>
<td>Kbsb</td>
<td>1.0E-11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Broderick Member Shale</td>
<td>Kbbd</td>
<td>1.0E-11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unnamed Member Shale</td>
<td>Kbu1</td>
<td>1.0E-11</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- Aquitard Conductions and Aquitard Units are used in the Regina 72I area.
• The method ignores parameters such as climate, hydraulic gradient, porosity, and water content of the porous media in favour of simple dependence on the two key variables ($D$ and $K_v$).

• The AVI values are determined from information that varies highly in detail and quality (e.g. if using the WSA water well driller’s database without quality control).

• The AVI vulnerability classes have been arbitrarily selected based on engineering judgment and approximated hydraulic conductivities.

• Saturated hydraulic conductivities are used for unsaturated sediments. Since the hydraulic conductivity of unsaturated sediments is less than that of saturated sediments, the calculated resistance is conservative.

• Fracturing is only taken into account in the hydraulic conductivities of the upper Saskatoon Group tills. Fractures can increase hydraulic conductivity by several orders of magnitude.

• A full coverage of the AVI is not possible for the bedrock HSUs of the Bearpaw and Judith River Formations. The stratigraphic data for drill holes in the TGI database do not have interpreted thicknesses of units through the Quaternary deposits. This results in the AVI calculations not being able to calculate because aquitard thicknesses are not available at those drill holes above the bedrock HSUs.

The AVI ratings should only be used as a guide and site-specific data is required to properly assess the presence and vulnerability of any HSU unit (Appendix E).

3.4 Groundwater Quality Data

Three separate water quality datasets were compiled for the Regina 72I area, including:

1. WSA Provincial Water Quality dataset;
2. WSA FoxPro Water Quality dataset; and
3. Rural Water Quality Advisory Program (RWQAP) dataset.

These datasets were combined as discussed in the procedures manual (MDH, 2010). Records without a WWDR ID were cross-referenced with the WSA Wells Database and a WWDR ID was populated where possible. The compiled water quality database was also cross-referenced to the Mapping Borehole Database to assign completion horizons (stratigraphic units) for wells that do have a WWDR ID assigned to them. The compiled water chemistry tables associated with each hydrostratigraphic unit is provided in Appendix F.

To illustrate the different water types from the HSUs identified in the Regina 72I mapsheet area, a trilinear diagram called a Piper Diagram is used (Figure 3.1). This enables multiple samples to be viewed on one diagram to see how samples from different wells installed in the same HSU are chemically similar and/or how the water evolves within an HSU as it moves down gradient. The central diamond shaped field in a Piper Diagram is used to represent the composition of the groundwater with respect to major cations ($Ca^{2+}, Mg^{2+}, Na^+$, and $K^+$) and anions ($Cl^-, CO_3^{2-}, HCO_3^-, and SO_4^{2-}$). The cations and anions are plotted separately on the lower ternary diagrams based on their percent concentrations represented in milliequivalents per litre (meq/L).
3.5 Hydraulic Properties

Definition of the hydraulic properties (hydraulic conductivity, porosity, compressibility, and specific storage) of the hydrostratigraphic units, and their spatial distribution and connectivity, is essential for the understanding of aquifer vulnerability and groundwater availability. These properties are considered in conjunction with the stratigraphy of a study area to delineate the three-dimensional framework of aquifers and aquitards, and to formulate a three-dimensional representation of the natural system.

Gravels and sands represent high hydraulic conductivity units (aquifers) in the study area. Tills, clays, and silts comprise the low hydraulic conductivity units (aquitards). The hydraulic conductivities for the hydrostratigraphic units are expected to fall within the ranges provided in Table 3.4. Pumping test results often report transmissivity, which is the hydraulic conductivity of an aquifer multiplied by its thickness.
Table 3.4 – Typical hydraulic conductivities of hydrostratigraphic units.

<table>
<thead>
<tr>
<th>Hydrostratigraphy</th>
<th>Hydraulic Behavior</th>
<th>Lithology</th>
<th>Hydraulic Conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lower Limit (m/s)</td>
</tr>
<tr>
<td>Surficial Stratified Deposits</td>
<td>Aquifer/Aquitard</td>
<td>Gravel</td>
<td>2x10^{-7} (6)(8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sand</td>
<td>1x10^{-7} (6)(8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Silt</td>
<td>1x10^{-11} (1)(2)(6)(8)</td>
</tr>
<tr>
<td>Oxidized Saskatoon Group Till</td>
<td>Poor Aquitard</td>
<td>Till</td>
<td>1x10^{-10} (1)(3)(8)</td>
</tr>
<tr>
<td>Unoxidized Saskatoon Group Till</td>
<td></td>
<td></td>
<td>1x10^{-11} (1)(3)(8)</td>
</tr>
<tr>
<td>Sutherland Group Till</td>
<td>Aquitard</td>
<td>Till</td>
<td>3x10^{-8} (8)</td>
</tr>
<tr>
<td>Bearpaw Formation Shale</td>
<td></td>
<td>Silt and Clay</td>
<td>3.8x10^{-12} (9)</td>
</tr>
<tr>
<td>Lea Park Formation Shale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saskatoon Group Aquifers</td>
<td>Aquifer</td>
<td>Gravel and Sand</td>
<td>1x10^{-6} (8)(8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gravel, Sand, Silt, Clay</td>
<td>1x10^{-6} (8)</td>
</tr>
<tr>
<td>Sutherland Group Aquifers</td>
<td>Aquifer</td>
<td>Gravel and Sand</td>
<td>1x10^{-6} (8)(8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gravel, Sand, Silt, Clay</td>
<td>1x10^{-6} (8)</td>
</tr>
<tr>
<td>Empress Group Aquifer</td>
<td>Aquifer</td>
<td>Gravel and Sand</td>
<td>1x10^{-5} (8)(9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gravel, Sand, Silt, Clay</td>
<td>1x10^{-5} (8)(9)</td>
</tr>
<tr>
<td>Bearpaw Formation Sands</td>
<td>Aquifer</td>
<td>Sand and Silt</td>
<td>1.2x10^{-5} (11)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sand, Silt, Clay</td>
<td>2x10^{-9} (6)</td>
</tr>
<tr>
<td>Judith River Formation</td>
<td>Aquifer</td>
<td>Sand and Silt</td>
<td>1.9x10^{-6} (10)</td>
</tr>
</tbody>
</table>

2) Domenico and Schwartz (1998)       6) Freeze and Cherry (1979)  12) Estimates based on MDH experience and testing on similar soils
4) Keller et al. (1988)               8) Estimates based on MDH experience and testing on similar soils  14) Kewen and Schnieder (1979)

Unlike hydraulic conductivity (where values range over many orders of magnitude), porosities tend to range from 5% to 50%. Porosity was estimated based on typical ranges for different lithologies as cited in the literature (Table 3.5). Porosity accounts for changes in storage in unconfined aquifers, but for confined aquifers, where the pore-space is fully saturated, changes in pore pressures and surface loads result in an elastic response in both the porous medium and the pore fluid.

Specific storage is the volume of water released from a unit volume of confined media per unit decline in hydraulic head per unit thickness. Porosity and compressibility of both the porewater and the porous medium are related to specific storage as follows:

\[ S_s = (\alpha + n\beta)\gamma_w \]  \[ [4] \]

where:
- \( S_s \) = specific storage (m\(^{-1}\))
- \( \alpha \) = compressibility of the soil matrix (m\(^2\)N\(^{-1}\))
- \( \beta \) = compressibility of water (m\(^2\)N\(^{-1}\))
- \( n \) = porosity (dimensionless ration between 0 and 1)
- \( \gamma_w \) = specific weight of water (Nm\(^{-3}\))
Table 3.5 – Storage properties for hydrostratigraphic units.

<table>
<thead>
<tr>
<th>Hydrostratigraphy</th>
<th>Hydraulic Behavior</th>
<th>Lithology</th>
<th>Porosity Limit (%)</th>
<th>LL</th>
<th>UL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surficial Stratified Deposits</td>
<td>Aquifer</td>
<td>Gravel</td>
<td>25</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aquifer</td>
<td>Sand</td>
<td>25</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aquitard</td>
<td>Silt</td>
<td>30</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aquitard</td>
<td>Clay</td>
<td>40</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Oxidized Saskatoon Group Till</td>
<td>Poor Aquitard</td>
<td>Till</td>
<td>20</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Unoxidized Saskatoon Group Till</td>
<td>Aquitard</td>
<td>Till</td>
<td>20</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Sutherland Group Till</td>
<td>Aquitard</td>
<td>Till</td>
<td>20</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Upper Cretaceous Shale</td>
<td>Aquitard</td>
<td>Silt and Clay</td>
<td>5</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Battleford Aquifer</td>
<td>Aquifer</td>
<td>Gravel and Sand</td>
<td>25</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Floral Formation Aquifers</td>
<td>Aquifer</td>
<td>Gravel and Sand</td>
<td>25</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Sutherland Group Aquifers</td>
<td>Aquifer</td>
<td>Gravel and Sand</td>
<td>25</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Empress Group Aquifer</td>
<td>Aquifer</td>
<td>Gravel and Sand</td>
<td>25</td>
<td>35</td>
<td></td>
</tr>
</tbody>
</table>

LL = Lower Limit
UL = Upper Limit

For unconsolidated sediments, the compressibility of the soil is much greater than that of water so the specific storage is controlled by the compression of the pore skeleton. For rigid bedrock aquifers the opposite is true, with the specific storage controlled by the compressibility of the pore fluid. An increase in head or pore pressure results in a release of fluid from storage and a reduction in storage volume as the skeleton contracts. A reduction in head or pore pressure corresponds to an expansion of the storage volume as the skeleton dilates. The above behaviour is associated only with the elastic deformations.

3.6 Water Level Data

Groundwater flows from areas of high hydraulic head to areas of low hydraulic head. Hydraulic head is a measurement of the energy state of a fluid (in this case groundwater) and is a function of potential energy (elevation head) and porewater pressure (pressure head). Velocity head is also a factor, but it is generally deemed negligible due to the low natural groundwater flow rates.

In central Saskatchewan, natural groundwater originates as infiltration of meteoric water, predominantly through sloughs, lakes, and other surface water bodies within groundwater recharge areas. Once below the water table, groundwater generally migrates vertically downward through the low permeability units (aquitards), and horizontally through the high permeability units (aquifers), until eventually discharging to the surface at a lower elevation relative to the infiltration point.

Water level information was obtained from WWDRs and the WSA observation well network. The water level provided for each WWDR is a single data point and therefore, cannot necessarily be considered “static” or representative of the natural system. This is particularly the case since many of the measurements were acquired by drillers during or following well
installation and testing. As the number of water level readings increase for a single well, the reliability of the dataset also increases and can be used to identify long-term trends and events. Nevertheless, the point-water levels presented in the WWDRs were used to evaluate regional-scale lateral groundwater flow directions, while data from the WSA observation well network was used to provide long-term water level trends in the Regina 72I area.

3.7 Groundwater and Surface Water Withdrawal Data

Groundwater and surface water allocations were obtained from the WSA. Table 3.6 provides the licensed groundwater allocation at the time of writing this report. Table 3.6 was created by assigning WWDR IDs to the records within the Licensed Groundwater Database (as described in MDH, 2010) and cross-referencing records to the stratigraphic interpretation completed as part of this study. Those wells with no WWDR were located on the map and correlated to an aquifer unit based on the depth of the well installed at that location. The table indicates that the majority of the licensed groundwater use is from the Regina and Zehner aquifers which are interpreted to be Floral Formation.

The total annual volume of water (in 2009) used by the communities and industrial users in the Regina 72I area, as reported to the WSA, is provided in Table 3.7. The majority of water use is from surface water sources (primarily Buffalo Pound Lake). But, as is shown in Table 3.6, a large volume of water is also allocated for use from groundwater sources, and this is only from wells that have applied for water use licenses. Many more wells have been installed and are pumping from the area HSUs than are reported, so actual water extraction volumes from groundwater is difficult to accurately determine.

3.8 Groundwater Availability

Groundwater availability is the amount of water available from the subsurface. The determination of groundwater availability is complicated by conflicting factors, including but not limited to:

1. The groundwater quality;
2. The cost to develop a groundwater resource;
3. The interconnectivity of an HSU to the rest of the hydrogeological system (i.e. the three-dimensional framework of the hydrostratigraphic system), the hydrological system, and the ecosystem;
4. Socio-economics; and
5. The regulations and policies governing groundwater and surface water development and use (i.e. effective water and environmental management).
Table 3.6 – Groundwater allocations in the Regina 72I area.

<table>
<thead>
<tr>
<th>Formation</th>
<th>Aquifer Name</th>
<th>Water Use</th>
<th># of Wells</th>
<th>Allocation (dam$^3$/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surficial Stratified Deposits (Qssd)</td>
<td></td>
<td>Domestic</td>
<td>7</td>
<td>17.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Municipal</td>
<td>21</td>
<td>822.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Irrigation</td>
<td>1</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Industrial</td>
<td>5</td>
<td>121.0</td>
</tr>
<tr>
<td>Alluvial Deposits (Qa)</td>
<td></td>
<td>Municipal</td>
<td>12</td>
<td>355.9</td>
</tr>
<tr>
<td>Battleford Aquifer (Q-bs)</td>
<td>Unnamed</td>
<td>Municipal</td>
<td>23</td>
<td>155.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Industrial</td>
<td>1</td>
<td>83.0</td>
</tr>
<tr>
<td></td>
<td>Condie Aquifer</td>
<td>Municipal</td>
<td>11</td>
<td>1,378.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Irrigation</td>
<td>1</td>
<td>130.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Industrial</td>
<td>4</td>
<td>6.0</td>
</tr>
<tr>
<td>Upper Floral Aquifer (Qf-ms)</td>
<td>Unnamed</td>
<td>Domestic</td>
<td>3</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Municipal</td>
<td>64</td>
<td>910.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Irrigation</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multi-Purpose</td>
<td>1</td>
<td>45.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td>Regina Aquifer</td>
<td></td>
<td>Domestic</td>
<td>1</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Municipal</td>
<td>22</td>
<td>1,380.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Irrigation</td>
<td>2</td>
<td>87.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Industrial</td>
<td>11</td>
<td>4,084.3</td>
</tr>
<tr>
<td>Zehner Aquifer</td>
<td></td>
<td>Municipal</td>
<td>7</td>
<td>1,133.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Irrigation</td>
<td>1</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Industrial</td>
<td>1</td>
<td>2.0</td>
</tr>
<tr>
<td>Northern Aquifer</td>
<td>Multi-Purpose</td>
<td>1</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Richardson Aquifer</td>
<td>Industrial</td>
<td>1</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Lower Floral Aquifer (Qf-ls)</td>
<td>Unnamed</td>
<td>Municipal</td>
<td>7</td>
<td>73.1</td>
</tr>
<tr>
<td>Zehner Aquifer</td>
<td>Municipal</td>
<td>6</td>
<td>3,495.0</td>
<td></td>
</tr>
<tr>
<td>Northern Aquifer</td>
<td>Industrial</td>
<td>1</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Upper Dundurn Aquifer (Qd-us)</td>
<td></td>
<td>Domestic</td>
<td>1</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Municipal</td>
<td>21</td>
<td>307.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Industrial</td>
<td>2</td>
<td>12.3</td>
</tr>
<tr>
<td>Lower Dundurn Aquifer (Qd-ls)</td>
<td></td>
<td>Municipal</td>
<td>1</td>
<td>6.2</td>
</tr>
<tr>
<td>Empress Aquifer (QTe)</td>
<td>Unnamed</td>
<td>Municipal</td>
<td>1</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>Buena Vista Aquifer</td>
<td></td>
<td>7</td>
<td>203.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Irrigation</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Hatfield Valley Aquifer</td>
<td></td>
<td>3</td>
<td>278.0</td>
</tr>
<tr>
<td>Judith River Aquifer (Kjr)</td>
<td></td>
<td>Municipal</td>
<td>1</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Industrial</td>
<td>1</td>
<td>123.0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>Domestic</td>
<td>12</td>
<td>23.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Municipal</td>
<td>207</td>
<td>10,509.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Irrigation</td>
<td>7</td>
<td>224.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Industrial</td>
<td>27</td>
<td>4,433.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multi-Purpose</td>
<td>2</td>
<td>47.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>247</td>
<td>15,240.0</td>
</tr>
</tbody>
</table>

*1 cubic decameter (dam$^3$) = 1,000 cubic meters (m$^3$)
Table 3.7 – Volume of recorded water usage in the Regina 72I mapsheet for 2009.

<table>
<thead>
<tr>
<th>Water User</th>
<th>Water Source</th>
<th>Volume Consumed (dam$^3$/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community</td>
<td>Groundwater</td>
<td>1,956.4</td>
</tr>
<tr>
<td></td>
<td>Surface Water</td>
<td>33,951.3</td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
<td>56.6</td>
</tr>
<tr>
<td>Industrial</td>
<td>Groundwater</td>
<td>3,001.9</td>
</tr>
<tr>
<td></td>
<td>Surface Water</td>
<td>13,228.2</td>
</tr>
<tr>
<td>Total</td>
<td>Groundwater</td>
<td>4,958.3</td>
</tr>
<tr>
<td></td>
<td>Surface Water</td>
<td>47,179.5</td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
<td>56.6</td>
</tr>
</tbody>
</table>

For large-scale development projects, hydrogeologists need to study in detail a sufficiently large enough area in order to allow the proponent and the regulatory bodies to make sound decisions on the sustainable development of a groundwater resource. Clearly defined and enforced regulations and policies are required to guide these projects to effectively manage sustainable water use in a potentially affected area. The best way to estimate groundwater availability from a specific HSU is to use a three-dimensional numerical analysis of a hydrogeological system that incorporates recharge, surface water features, topography, water withdrawals, and the influence of (and on) overlying and underlying hydrostratigraphic units. The thickness and areal limits of each unit need to be represented in sufficient detail to accurately simulate the groundwater system. This requires the availability of large borehole datasets often combined with geophysical methods.

A detailed determination of groundwater availability is beyond the scope of this study. However, for non-industrial water users, safe/sustainable yield data from groundwater investigation reports and, to a lesser extent, recommended well yields/pumping rates from WWDRs, provide an indication as to how much water can be reasonably produced from an HSU. Safe yields and well yields are often based on the results of short-term pumping tests, and provide information in the vicinity of the well and/or the observation well network. They should not be considered representative of the groundwater availability from the larger groundwater system. It is also noted that well yields provide a recommended pumping rate at the time of the test and do not necessarily provide an indication of how long water can be produced at the stated rate or that the stated rate is sustainable. Safe yields and well yields do not typically address regional groundwater availability. This report provides only generalized, accessible assessments of water availability.
4.0 STRATIGRAPHY

4.1 Regional Geological Setting

Successive marine transgression and regression in the Upper Cretaceous Period (84 to 65 million years before present) deposited a thick, complex sequence of marine silt and clay deposits across central Saskatchewan. The oldest of these bedrock units mapped is the Lea Park Formation shale and it constitutes the base of “fresh water” exploration associated with the shallow hydrostratigraphy in the study area; the Lea Park Formation is a known marker horizon (i.e. it provides stratigraphic control) for most of southern Saskatchewan. There are no known receptors for contaminants below this formation in the study area.

A marine regression during the Upper Cretaceous Period resulted in the deposition of the Judith River Formation, a calcareous and non-calcareous stratified sand, silt, and clay that overlies the Lea Park Formation shale (McLean, 1971). The Judith River Formation is interpreted to be present across the entire study area, but does pinch out to the east within the Melville 62KL mapsheet (Simpson and Schreiner, 1999). The Bearpaw Formation conformably overlies the Judith River Formation.

The Bearpaw Formation consists predominantly of marine silts and clays deposited during the last major transgression and regression of the Western Interior Seaway, but can be subdivided into a series of alternating silt/clay and sand/silt members. The sand and silt members are used for water supply in some places in southwestern Saskatchewan. The stratigraphic column in Figure 4.1 illustrates the unit divisions of the Bearpaw Formation and all other stratigraphic beds found in the study area down to the Mannville Group. The Bearpaw Formation is found across the mapsheet and is generally the first bedrock unit encountered below the much younger Upper Tertiary and Quaternary (less than 2 million years in age) drift deposits.

The Upper Cretaceous bedrock units are highly faulted across the study area due to the dissolution of the underlying Prairie Evaporite Formation causing the collapse of the overlying beds. This is especially noted in the Regina Low (Christiansen and Sauer, 2002) as well as another large bedrock low to the southwest of Regina. A structure contour map of the top of the Judith River Formation (Figure 4.2) generally identifies the regions with bedrock lows in the study area.

Prior to glaciation (approximately 1.8 million years ago), the Regina 72I area was mature and well integrated with a complex series of water courses and deep valleys. Erosion and subsequent alluvial and colluvial deposition of Tertiary-aged sediments were infilling these valleys.
Figure 4.1 – Stratigraphic column of the Cretaceous and Quaternary deposits in the Regina 72I mapsheet.
The preglacial Swift Current and Hatfield valleys form the dominant bedrock features in the Regina 72I area. These valleys were cut into the bedrock surface primarily before and during the first glaciation (and to a lesser extent during subsequent glaciations) in the early PleistoceneEpoch. These valleys carried melt water, depositing significant accumulations of clastic deposits within the lowlands. The Swift Current Valley begins near the Swift Current area and heads east through south-central Saskatchewan and the Hatfield Valley runs from northwest to southeast Saskatchewan. These valleys have numerous tributaries, mesas, and plateaus and a complex hydrostratigraphy (Figure 4.3, modified from H. Maathuis, SRC).

The stratified preglacial sediments deposited between the bedrock surface and the glacial sediments are formally called the Empress Group (Whitaker and Christiansen, 1972). The Empress Group sediments commonly infilled the large preglacial valley areas, developing into extensive HSUs as shown in Figure 4.3. The sediments from the bedrock surface to the ground surface are collectively called “drift”. They are divided into preglacial and postglacial drift.

Over the past two million years, Saskatchewan has undergone at least eight periods (and possibly ten periods) of significant glacial advance. The final deglaciation occurred in the Pleistocene Epoch between approximately 17,000 and 10,000 years ago (Christiansen, 1979b). Glaciation in the Pleistocene resulted in a complex arrangement of proglacial and glacial sediments interbedded with non-glacial stratified sediments (fluvial, deltaic, lacustrine, aeolian, etc.) that were deposited between glaciations and during interstadial deglaciation. Erosional valleys produced during interglacial periods commonly intersect preglacial valleys, forming complex stratigraphic arrangements. The glaciofluvial, fluvial, alluvial and colluvial sediments that were deposited during preglacial and interglacial periods in the valleys were covered by tills during the final stages of glaciation, forming deep buried valley HSU systems that are often flanked by more regionally extensive blanket HSU systems. The valley systems were buried with deposits from subsequent glacial and non-glacial periods, with limited indication of their presence at depth. They form the most significant “fresh water” HSUs in the province.

The arrangement of glacial, glaciofluvial, and glaciolacustrine deposits within the study area are formally divided into two primary groups: 1) the Sutherland Group; and 2) the Saskatoon Group (Christiansen, 1992). Both the Saskatoon Group and the Sutherland Group are primarily composed of unsorted till formed by glacial erosion and reworking of Precambrian igneous and metamorphic rocks, Paleozoic limestones, and Cretaceous marine shales during glacial advance. Significant intratill and intertill stratified deposits also comprise the Quaternary deposits.
LEGEND

- REGINA 72I MAPSHEET AREA
- TERTIARY AQUIFER
- CUMBERLAND AQUIFER
- QUATERNARY AND/OR TERTIARY AQUIFER
- EASTEND-RAVENSCRAG AQUIFER
- EMPRESS GROUP AQUIFER
- ESTEVAN VALLEY AQUIFER
- MANNVILLE GROUP AQUIFER
- NO MAJOR PREGlacIAL AQUIFER PRESENT

NOTE: MAP MODIFIED FROM ORIGINAL BY H. MAATHIUS, SASKATCHEWAN RESEARCH COUNCIL.
The older till units belonging to the Sutherland Group have a higher clay content as compared to the overlying (younger) Saskatoon Group tills due to a higher percentage of marine shale being incorporated into the matrix of the till. The Saskatoon Group tills have a higher carbonate content due to the incorporation of more Paleozoic limestones and dolomites into the matrix. The stratified deposits between these two groups, and between the individual till formations, represent the major glacial HSUs across the study area.

The current day surface topographic features in the area were largely formed during the melting of the last glacier (between about 17,000 and 10,000 years ago). A wide till plain was deposited over the region and is characterized by a hummocky topography of kettles, moraines, and eskers, covered with glacial, glaciofluvial, glaciolacustrine deposits, and postglacial sediments (Surficial Stratified Deposits).

The Missouri Couteau, a major northeast facing bedrock escarpment in the central plains, runs across the southwest corner of the mapsheet from Claybank to just south of Caronport, SK. The Missouri Couteau is a bedrock high which is covered with ice-thrust sediments that were pushed up during a re-advance of the last glaciation approximately 11,750 years before present (BP) (USGS, 2004). This resulted in a unique depositional and structural environment as the glacier pushed the frozen ground up onto the couteau forming ice thrust ridges. The ice thrust ridges have been clearly identified at the Dirt Hills, Cactus Hills and along the edge of the Missouri Couteau to the northeast. The formation of the hills have been studied in numerous studies (Christiansen, 1961, Kupsch, 1962, Christiansen and Whitaker, 1976, Aber, 1993, and Christiansen and Sauer, 1997).

These ice thrust ridges were formed by a re-advance of a local ice lobe pushing the bedrock and drift deposits against the Missouri Couteau escarpment during the last glaciation. These conditions established a glaciotectonic stress environment for compressive flow resulting in the stacking of bedrock and drift thrust slabs onto the escarpment and formed the Dirt Hills structure and end moraine (Christiansen and Sauer, 1997). A visual representation of this is provided in Figure 4.4.

![Figure 4.4 – Ice-thrust ridges formed through glaciotectonic processes at The Dirt Hills (Christiansen and Sauer, 1997).](image-url)
As a result of this complex stratigraphic situation, interpretation of the drift deposits is difficult and suspect to error. All boreholes installed along the northeast edge of the Missouri Couteau have not been interpreted any further than dividing the Quaternary drift deposits from the bedrock in the area.

The complex stratigraphic arrangement of the Tertiary and Quaternary deposits was further complicated by extensive faulting due to the dissolution of the deep evaporite deposits beneath the area, and subsequent collapse of near-surface sediments (Christiansen and Sauer, 2002). These depressions were infilled, (generally with till) during subsequent glaciations, often resulting in discontinuous and hydraulically isolated accumulations of stratified deposits. Delineation of these collapse structures is important as they are often significant enough to displace HSU units, resulting in lateral connectivity disruptions and significant aquifer boundary effects during water production.

The hydrostratigraphy of interest in the study area (in ascending order) is:

1. Lea Park Formation;
2. Judith River Formation;
3. Bearpaw Formation;
4. Frenchman-Whitemud-Eastend Formation;
5. Empress Group;
6. Sutherland Group:
   a. Mennon Formation;
   b. Dundurn Formation; and
   c. Warman Formation;
7. The Saskatoon Group:
   a. Floral Formation;
   b. Battleford Formation; and
   c. Surficial Stratified Deposits.

The stratigraphic column provided in Figure 4.1 provides the age, stratigraphy, lithology, and corresponding identification symbol used for the identified stratigraphic units in the Regina 72I mapsheet. A brief overview of each unit is provided in the following sections. The complete stratigraphic column for southern Saskatchewan is provided in Appendix A. In this report, depths and thicknesses are often related to a corresponding borehole using the Water Well Drillers Record (WWDR) ID (e.g. 220362 = borehole number (WWDR) 220362). The relative locations of the borehole records and stratigraphic cross-sections are provided in Appendix B. The stratigraphic cross-sections are provided in Appendix C.

4.2 Bedrock Deposits

In the Regina 72I area, thick sequences of sand, silt, and clay of the Lea Park Formation (Lea Park Shale), the Judith River Formation, the Bearpaw Formation (Bearpaw Shale), and the Frenchman-Whitemud-Eastend Formation form the bedrock subcrop in the study area. Figure 4.5 illustrates where the formations subcrop below the overlying drift deposits, as well
as the bedrock topography in metres above sea level (masl) for the top surface of the Cretaceous deposits in the study area. The variability in elevation to the top of bedrock is attributed to preglacial and glacial erosion, and faulting. It is noted that “bedrock” in this geological setting is a misnomer, as the “bedrock” deposits are typically not fully cemented rocks.

The Lea Park Formation is widely considered the base of groundwater exploration in the southern part of the province due to brackish water in deeper horizons. There are generally no perceived receptors for contamination below these horizons. As a result, this formation should be considered the base for drilling and instrumentation in relation to groundwater resource and/or environmental investigations in the study area.

4.2.1 The Lea Park Formation (Klp)

The Lea Park Formation (Klp) is composed of non-calcareous, grey to dark grey, firm to hard, highly plastic, overconsolidated silt and clay. This formation is of marine origin and was deposited in the Western Interior Seaway during the Upper Cretaceous (McNeil and Caldwell, 1981). Concretionary and bentonite-rich beds are common in the Lea Park Formation. The bentonitic horizons can be used as structural marker beds for stratigraphic interpretations, where delineated.

The Lea Park Shale was encountered at depths ranging between 35.4 m at borehole 84042 (cross-section I-I’) in the north-central area of the mapsheet at Last Mountain Lake and 660.0 m (101/11-09-012-24W2/00) below the Dirt Hills at the south-edge of the study area. This unit has been encountered at elevations ranging from 142.5 masl (101/13-16-014-23W2/00) to 455.6 masl (84042) across the study area. In the southern half of the 72I area, bedrock lows are often indicative of collapse due to dissolution of the underlying Prairie Evaporite Formation and subsequent downward faulting of the overlying stratigraphic sequences. The Lea Park Formation subcrops as the uppermost bedrock unit around Last Mountain Lake (Figure 4.5).

4.2.2 The Judith River Formation (Kjr)

The Judith River Formation (Kjr) is an eastward thinning sedimentary wedge found in north central United States, southern Alberta, and Saskatchewan. It is comprised predominantly of clays, silts, and sands deposited in a non-marine deltaic environment formed during a major regression of the marine environment in the Upper Cretaceous Epoch (McLean, 1971). The Judith River Formation can be up to hundreds of meters thick in Alberta. In the Regina 72I area, the Judith River Formation has been encountered up to 85.3 m thick (101/14-11-014-24W2/00), near Briercrest. Average thickness of the formation is 49.2 m. The Judith River Formation has been found at elevations ranging between 189.2 masl (101/13-16-014-23W2/00) to 489.7 masl (101/09-11-023-26W2/00) within the study area.
4.2.3 The Bearpaw Formation (Kb)

The Bearpaw Formation (Kb) consists predominantly of marine silts and clays deposited during the last major transgression and regression of the Western Interior Seaway. Dark grey clays, claystones, silty claystones, shales, silts, and siltstones, comprise the low permeability "clay shales" that form the majority of the formation. Subordinate brownish grey silty sands, sands, and sandstones, and thin beds of bentonite characterize the more permeable units of the Bearpaw Formation according to the Lexicon of Canadian Geology (http://cgkn1.cgkn.net).

Marine transgression and regression in the Upper Cretaceous Epoch deposited a complex sequence of interbedded sand/silt and silt/clay layers. These layers are identifiable on a regional scale and are formally identified as unique members of the Bearpaw Formation. The Bearpaw Formation exists across most of the Regina 72I area. This formation has been subdivided into eleven mappable members (Figure 4.1). In ascending order these are:

1. Unnamed Member (Kbu);
2. Outlook Member (Kbok);
3. Broderick Member (Kbbd);
4. Matador member (Kbm);
5. Sherrard Member (Kbsh);
6. Demaine Member (Kbd);
7. Beechy Member (Kbby);
8. Ardkenneth Member (Kba);
9. Snakebite Member (Kbs);
10. Cruikshank Member (Kbc); and
11. Aquadell Member (Kbaq).

The Bearpaw Formation has been encountered at depths ranging from ground surface on the shores of Last Mountain Lake to 227.1 m (43123 (DOE Regina 509)) in Regina. Where present, the Bearpaw Formation has been found at elevations ranging from 352.9 masl (43193 (DOE Regina 516)) to 691.0 masl (60857, cross-sections E-E' and G-G') across the study area.

4.2.4 The Frenchmen-Whitemud-Eastend Formation (Kfwe)

The undifferentiated Frenchman-Whitemud-Eastend Formation (Kfwe) forms the youngest bedrock unit in the Regina 72I mapsheet area. Its northern extent is just along the southern edge of the study area. The three members of the formation are indistinguishable from each other at the distal edge of the deposit. The formation is composed of coarse to fine-grained, cross-bedded sands interbedded with clays, and thin grey kaolinitic sandstone and lignite beds. Volcanic fragments are common throughout (Misko and Hendry, 1979). The lower contact with the Bearpaw Formation is gradational and occurs over as much as a 16 m thick zone where the lower sandy beds alternate with grey shales of the Bearpaw Formation (Russell, 1943). This formation is only encountered at a handful of locations at the extreme
southern edge of the mapsheet. The unit has been encountered at depths ranging from 7.9 m (11874 (SRC Avonlea), cross-section F-F’) to 214.6 m (14606 (SRC Dirt Hills)) beneath a series of ice-thrust ridges in the area.

4.3 Preglacial Drift Deposits

4.3.1 The Empress Group (QTe)

The Empress Group (Whitaker and Christiansen, 1972) lies between the bedrock and the oldest (stratigraphically lowest) till. The Empress Group (QTe) is composed of preglacial and proglacial stratified sediments. It is characterized by a wide variety of complexly bedded lithologies that were lain down on the bedrock surface as fluvial, lacustrine, and colluvial deposits prior to and during glaciation.

The Empress Group can be divided into an upper (Qe) and lower (Te) unit. However, the two units were not distinguished in this project due to lack of detailed lithology descriptions provided in the majority of borehole logs. A description of the two units is provided in this report for completeness.

The lower unit is generally comprised of complexly stratified valley-fill sediments which consist of quartzite and chert gravels, fine clastic deposits, and organic-rich sediments. This unit is Tertiary in age (preglacial) and is often non-calcareous. The upper unit generally contains clastic sediments derived from igneous, metamorphic, and carbonate rocks that were deposited proglacially during the first glacial advance. The upper unit is often found within the bedrock valley tributaries and along the bedrock uplands. These deposits are generally calcareous due to some of the granular materials being derived from carbonate rocks along the Precambrian margin to the north and from the Manitoba escarpment to the east. The contact between the Empress Group and the overlying glacial deposits is an erosional unconformity to conformable in places with the overlying till.

The Empress Group has been encountered at depths ranging between 6.7 m (87459) and 221.9 m (43123 (DOE Regina 509)) in the Regina 72I area. The Empress Group is variable in thickness, ranging from 0.6 m (93420) to over 72.8 m (226269 (UEM Dilke) cross-section A-A’), with an average thickness of 16 m. The thickest accumulations of Empress Group sediments can be expected in the thalwegs of the preglacial Swift Current and Hatfield valleys.

4.4 Quaternary Drift Deposits (Q)

The successive advance and retreat of continental glaciers deposited the geologic sequences that characterize the regional drift stratigraphy within the Regina 72I area. The accumulation of sediments from the top of the bedrock surface to the ground surface are referred to collectively as drift. The Quaternary drift has been investigated intermittently and a number of papers have been published on the deposits (e.g. Christiansen 1968a; Christiansen 1968b; Christiansen 1990; Christiansen 1992; Christiansen and Sauer 1994;
etc.). The Quaternary deposits (excluding the Empress Group) represent glacial and postglacial sediments and are separated into the Saskatoon Group and the Sutherland Group.

4.4.1 The Sutherland Group (Qsu)

The Sutherland Group (Qsu) lies between the bedrock surface or Empress Group and the Saskatoon Group. Tills of the Sutherland Group can be distinguished from those of the Saskatoon Group based on their carbonate content, Atterberg limits, preconsolidation pressures, jointing, staining, the presence of oxidized zones, their geophysical signatures, and their stratigraphic position. The Sutherland Group is separated into three formal formations, including, in ascending order from oldest to youngest:

1. Mennon Formation (Qm);
2. Dundurn Formation (Qd); and
3. Warman Formation (Qw).

Each of the formations of the Sutherland Group represent at least one distinct glacial period. The Dundurn Formation is comprised of at least two separate glaciations, with three separate glacial periods potentially represented within it. It is also thought that the Mennon Formation may represent two distinct glaciations. Separation of the formations of the Sutherland Group generally requires the use of laboratory testing data in conjunction with visual descriptions, the mapping of intertill (not intratill) deposits, and the presence of paleo-oxidized horizons. Figure 4.6 provides a type log (210624 (SHT Sutherland Overpass No.4)) of drift deposits in Saskatchewan.

4.4.1.1 The Mennon Formation (Qm)

The Mennon Formation (Qm) is divided informally into three mappable units in the study area. In ascending order, these units are:

1. A lower till unit (Qm-lt) overlying the Empress Group or bedrock deposits;
2. An intertill stratified deposit (Qm-s) at the break between the upper and lower till units; and an upper till unit (Qm-ut).

The Mennon Formation is discontinuous and sparse in the study area, and generally exists as erosional remnants along bedrock lows. In the Regina 72I area, the Mennon Formation has been encountered at depths ranging between 9.8 m (114747) and 178.0 m (17549 (SRC Edenwold); cross-section B-B’). The Mennon Formation has been encountered in thicknesses up to 48.8 m (88745 and 89269).
TYPE LOG OF DRIFT DEPOSITS IN SASKATCHEWAN:
SHT SUTHERLAND OVERPASS NO. 4
(210624)
1990
5776286.22 N 392069.32 E
NAD 83 ZONE 13
SE16-25-36-W3

GAMMA RAY (CPS) 10050 SP (mV) 0
0 510m 0 Calibration
Elevation
CALIPER (in)
1 1/4
Graphology
0.75
0
0.5
0.25

SAND, Silt and Clay, interbedded, calcareous gravel

FILL, weak, strongly calcareous, light grey, with clay
FILL, weak, strong calcareous, grey, hard
SAND, fine to medium, grey,贝壳 debris
FILL, strongly calcareous, light yellowish brown
FILL, strongly calcareous, grey
FILL, clayey, strongly calcareous, pale olive and grey, gypseous
FILL, strongly calcareous, grey

FROM 36 m Aban

FILL, slightly calcareous to calcareous, grey
FILL, slightly calcareous, grey

SAND, coarse to very coarse, with gravels, chert and quartzite fraps
SAND, fine to medium, with gravel and fragments (gravels, calcareous, and chert)
CLAY, clayey, non-calcareous, grey

LIMITATION

This drill log is a summary of the conditions estimated by the field personnel at the specific location at the time of drilling. The conditions and properties described above will vary between locations and may vary with time.

SUPERVISION: J. BRIERE
CUTTING SAMPLE INTERVALS: 1.52m (5.0 ft)
COORD. WATER: unknown

LOGGED BY: L. SINCLAIR
TYPE OF DRILL RIG: MDX 1500
COORD. MULTI:

DEPOSIT BY: E.A. CHRISTIENSEN
TYPE OF LOGGER: XLOG 1500
SPEICIFIC GRAVITY:

CONTRACTOR: G.L. MILLAR
ABANDONMENT: POST TV HOE
WATER RATE:

DRAWN BY: A. COLE / E. ONIONA
PROJECT No: M2746-1030110
DATE DRILLED: 18-JUN-90
DATE: 07-MAR-11

CLIENT
PRODUCED BY
Water Security
Tills of the Mennon Formation are generally comprised of a grey, unoxidized, weakly calcareous, low to medium plasticity, clayey silt till with varying accumulations of coarser and finer fractions. The Mennon Formation has a low carbonate content compared to the overlying till formations. The break between the Mennon Formation and the Dundurn Formation is also determined by the presence of an intertill (not intratill) stratified unit (Qd-Is) and/or the presence of an oxidized contact.

4.4.1.2 The Dundurn Formation (Qd)

The Dundurn Formation (Qd) is divided informally into five mappable units in the study area. In ascending order, these units are:

1. A basal till unit (Qd-bt);
2. A lower stratified unit (Qd-ls);
3. A lower till unit (Qd-lt);
4. An intertill stratified deposit (Qd-us) at the break between the upper and lower till units; and
5. An upper till unit (Qd-ut).

Differentiation of these units is based on carbonate content and the presence of paleo-oxidized horizons and/or intertill stratified deposits (Qw-s, Qd-us, and Qd-ls). The carbonate content of the upper unit of the Dundurn Formation (Qd-ut) is higher than that of the Warman or Mennon formations, but typically lower than that of the Floral Formation (Figure 4.6). The carbonate content commonly decreases with depth in the lower unit of the Dundurn Formation (Qd-lt). It should be noted that differentiation of the Mennon, Dundurn, and Warman formations is difficult without carbonate content data and/or the presence of intertill stratified deposits.

Tills of the Dundurn Formation are generally comprised of grey, unoxidized, calcareous, silt and clay till with varying accumulations of coarser and finer fractions. It is found in large part across the northern half of the Regina 72I area, but is still considered discontinuous due to post-depositional erosion. The Dundurn Formation has been interpreted to exist in thicknesses up to 105.4 m (11987 (SRC Rocky Lake); cross-section C-C’) in the area. This formation has been encountered at depths ranging from 0.0 m to 176.2 m (43123 (DOE Regina 509)).

4.4.1.3 The Warman Formation (Qw)

The Warman Formation (Qw) lies between the Dundurn Formation and the Floral Formation where present. The Warman Formation is differentiated from the overlying and underlying formations based on the presence of a paleo-oxidized contact, carbonate content, geophysical signatures, Atterberg limits, and the presence of mappable stratified deposits (Qf-ls and Qw-s, respectively). It is noted that mappable stratified deposits are verified intertill units (not intratill deposits). The Warman Formation has a relatively low carbonate content and high clay content, making it readily identifiable from the overlying Saskatoon Group tills and the underlying upper till unit of the Dundurn Formation.
Tills of the Warman Formation are generally comprised of grey, medium to highly plastic, calcareous, silty clay till. The Warman Formation has been encountered in thicknesses up to 36.6 m (88128) in the Regina 72I area. The depth to this unit ranges from 0.0 m to 163.4 m (43123 (DOE Regina 513)), where encountered across the study area.

4.4.2 The Saskatoon Group (Qsk)

The Saskatoon Group (Qsk) was first proposed by Christiansen (1968a) as the portion of drift lying between the Sutherland Group and the topographic surface. The Saskatoon Group is differentiated from the underlying Sutherland Group on the basis of carbonate content, resistivity signatures, lithologic characteristics, Atterberg limits, and preconsolidation pressures. The Saskatoon Group tills have a higher carbonate content and resistivity signature, and are generally coarser in lithology, as compared to the underlying Sutherland Group tills (i.e. the Sutherland Group tills generally have significantly higher clay contents). The higher clay content of the Sutherland Group tills is also reflected by Atterberg limits (when available) with a higher plasticity index relative to Saskatoon Group tills.

The Saskatoon Group is separated into three formal formations, including (in ascending order):

1. Floral Formation (Qf);
2. Battleford Formation (Qb); and
3. Surficial Stratified Deposits (Qssd).

4.4.2.1 The Floral Formation (Qf)

In the study area, the Floral Formation (Qf) is divided informally into five units. In ascending order, these units are:

1. A basal till unit (Qf-bt);
2. A lower intertill stratified deposit (Qf-Is);
3. A lower till unit (Qf-Lt);
4. An middle intertill stratified deposit (Qf-ms); and
5. An upper till unit (Qf-ut).

Delineation of these units is based on the presence of paleo-oxidized horizons and/or intertill stratified deposits (Qb-s, Qf-ms, and Qf-Is), and, to a lesser extent, on carbonate content. Tills of the Floral Formation are predominantly firm to hard, low to high plasticity, silt till with varying accumulations of coarser and finer fractions. The Floral Formation has been encountered at depths of 0.0 m to 54.3 m (77128) in the Regina 72I area, and in thicknesses up to 144.5 m (43123 (DOE Regina 513)).

The upper till unit of the Floral Formation is identified by iron and manganese stained fractures and strong oxidization. The firm to hard consistency and fractured nature of this upper till unit make it readily identifiable from the Battleford Formation till, which is generally much softer than the Floral Formation. The Floral Formation tills have a preconsolidation
pressure of 1,800 ± 200 kPa, whereas till of the Battleford Formation has a preconsolidation pressure of 400-750 kPa (Sauer et al., 1993). The contact between the Floral Formation and the overlying Battleford Formation is non-conformable.

4.4.2.2 The Battleford Formation (Qb)

In the study area, the Battleford Formation (Qb) is divided informally into three units. In ascending order, these units are:

1. A lower till unit (Qb-lt);
2. An intertill stratified deposit (Qb-s) at the break between the upper and lower till units; and
3. An upper till unit (Qb-ut).

The Battleford Formation (Qb) was first described by Christiansen (1968b) and is typically composed of soft, massive, oxidized tills. It is the youngest formation of the Saskatoon Group containing till deposits. The Battleford Formation tills were deposited during the last glaciage period and have not been overridden by any subsequent glaciers. As a result, this formation is readily separated from the underlying Floral Formation based on its soft consistency. The lower Battleford till unit is unique to the Regina area and is found only in the vicinity of the Condie Moraine underlying the stratified deposits of the Condie Aquifer. In the study area, the Battleford Formation has been encountered in thicknesses up to 48.2 m (77128 (SRC Echo Lake No.5)), immediately northwest of Regina on the Condie Moraine.

4.4.2.3 The Surficial Stratified Deposits (Qssd)

The Surficial Stratified Deposits (Qssd) are the top unit of the Saskatoon Group. These postglacial sediments include fluvial, lacustrine, aeolian, and topsoil deposits. The Surficial Stratified Deposits are divided into Haultain and alluvium. The clays, silts, sands, and gravels of the Haultain unit are found at the ground surface across the study area. Lacustrine clays from Glacial Lake Regina form the most significant surficial stratified deposits in the area. The lacustrine clays blanket a large portion of the mapsheet along with the deltaic sands and gravels deposited on the lake edge during the recession of the last ice sheet 14,000 years ago (Christiansen, 1979b). Accumulations of these sediments are up to 30.5 m thick (43434 (DOE Baildon 12)).

Alluvial deposits in the area river valleys are comprised of silts, sands, and gravel from current day fluvial activity along the river channels and valley side alluvial fans as well as from glacially influenced spillway deposits. The Qu’Appelle Spillway eroded down through the Quaternary and Upper Cretaceous bedrock deposits down into the Judith River Formation (cross-section L-L’). Accumulations of these sediments are up to 97.5 m (17570 (SRC Muskowpetung)) west of Pasqua Lake.
5.0 HYDROGEOLOGY

Deposits of silts, sands, gravels, and cobbles are relatively high hydraulic conductivity units that form the paths of least resistance for groundwater flow and solute transport (aquifers). An aquifer is defined as a saturated geologic unit that is permeable enough to transmit significant quantities of water under ordinary hydraulic gradients; or as the term is commonly used in the water-well industry, an aquifer is a saturated geologic unit that is permeable enough to yield economic quantities of water to wells (e.g. Freeze and Cherry, 1979; Kruseman and de Ridder, 1990). Aquifers can be part of a geological formation, the entire formation, or a group of formations. Conversely, silt and clay rich deposits form low hydraulic conductivity units that impede groundwater flow and solute transport (aquitard). An aquitard is a saturated geologic unit that is permeable enough to transmit water in significant quantities when viewed over large areas and long periods of time, but does not yield economic quantities of water to wells (Kruseman and de Ridder, 1990). Aquitards generally have hydraulic conductivities of less than $1\times10^{-7}$ m/s. The expected hydraulic conductivities of the aquifers and aquitards in the Regina 72I area is shown in Table 3.4.

The spatial arrangement of aquifers and aquitards in three dimensions form the hydrostratigraphy of a site. When combined with the physical characteristics of the hydrostratigraphic units, an overall view of the hydrogeology can be determined. For this reason the Regina mapsheet has been mapped by identifying the hydrostratigraphic units as a whole as opposed to individual aquifers. Limited reference to named aquifers has been provided for those with significant importance and high usage such as the Regina Aquifer, Condie Aquifer, and Zehner Aquifer.

Gravel, sand, silt, and/or clay predominantly comprise the Surficial Stratified Deposits (Qssd), the intertill stratified deposits (Qb-s, Qf-ms, Qf-I, Qw-s, Qd-us, Qd-I, and Qm-s), the Empress Group (QTe) sediments, and the Upper Cretaceous sand/silt stratified units (Kfwe, Kbc, Kba, Kbd, Kbm, Kbo, and Kjr), in the study area. These stratified deposits can vary significantly over short distances and be aquifers or aquitards depending on lithology, hydraulic connectivity, potential well yields, etc. For simplicity, these mappable stratified deposits are described as hydrostratigraphic stratified units (HSUs) in the report. Although none of these horizons are composed solely of laterally continuous gravels and sands, the complexities of the mappable stratified deposits do not preclude the potential of finding lithologies capable of supplying small quantities of water. The actual amount of water available will be based on the site-specific hydraulic properties of the sediments, and the thickness and lateral continuity of the higher permeability sediments.

The interpretations provided should not be used for decisions relating to a development or well installation without verification (i.e. confirmatory drilling). The compiled maps and cross-sections should only be used to provide the framework for the area and to make large-scale general decisions to guide site specific investigations.
Bedrock silts, sands, gravels, and preglacial valley fill sediments form major “fresh water” HSUs across Saskatchewan. Figure 4.3 shows the approximate location of the major shallow bedrock and buried valley aquifer systems across Saskatchewan. The preglacial Hatfield and Swift Current valleys are the major buried valley HSU systems in the area.

In addition to the major buried valley HSUs incised into the marine shales, the overlying Quaternary aged stratum contains both blanket and channel deposits of sand and gravel that were deposited by retreating and/or advancing glaciers. These deposits are found between the major till units and are called intertill stratified deposits. These intertill stratified deposits can form broad, laterally extensive HSUs and/or a small channel aquifer, depending on their depositional setting and subsequent erosion. Although intratill deposits are abundant, they generally form only isolated, discontinuous pockets, and are therefore not significant with respect to groundwater sourcing.

In the Regina 72I area, there are 16 major mappable HSU horizons above the Lea Park Formation that may contain aquifer sediments. Known, named aquifer units are also listed under the corresponding stratigraphic unit they belong to (in ascending order):

1. Judith River Formation (Kjr);
2. Outlook Member (Kbok);
3. Matador Member (Kbm);
4. Demaine Member (Kbd);
5. Ard kenneth Member (Kba);
6. Cruikshank Member (Kbc);
7. Frenchman-Whitemud-Eastend Formation (Kfwe)
8. Empress Group (QTe);
   a. Hatfield Valley Aquifer;
   b. Swift Current Valley Aquifer; and
   c. Buena Vista Aquifer (includes the Lumsden Valley Aquifer)
9. Mennon Formation Stratified Deposits (Qm-s);
10. Lower Dundurn Formation Stratified Deposits (Qd-ls);
11. Upper Dundurn Formation Stratified Deposits (Qd-us);
12. Warman Formation Stratified Deposits (Qw-s);
13. Lower Floral Formation Stratified Deposits (Qf-ls);
   a. Zehner Aquifer; and
   b. Northern Aquifer;
14. Upper Floral Formation Stratified Deposits (Qf-ms);
   a. Regina Aquifer;
   b. Richardson Aquifer;
   c. Zehner Aquifer; and
   d. Northern Aquifer;
15. Battleford Formation Stratified Deposits (Qb-s);
   a. Condie Aquifer;
b. Moose Jaw Moraine; and
16. Surficial Stratified Deposits (Qssd).

5.1 Judith River Formation (Kjr)

The Judith River Formation is comprised of Upper Cretaceous clays, silts, and sands deposited in a non-marine shoreline environment typical of deltaic deposits (McLean, 1971). The Judith River Formation is encountered across the entire Regina 72I area, except for an area at the north end of Last Mountain Lake where the unit subcrops and pinches out (Figure 4.5 and Figure D1, Appendix D). The sediments of the Judith River Formation form a major HSU in Saskatchewan, referred to as the Judith River Aquifer. This HSU is not commonly accessed for use as a “fresh water” resource due to its waters being highly mineralized and the presence of shallower, more accessible aquifers. The Judith River Formation is laterally discontinuous in the Regina 72I area due to large vertical changes that has been interpreted as extensive faulting, such that only low volume users could potentially use it as a resource. This is best seen in the south to north running cross-sections G-G’ to L-L’ (Appendix C).

5.1.1 Hydraulic Properties

There are limited available hydraulic conductivity measurements for the Judith River Aquifer in the Regina 72I area, although third party measurements are known to exist. Kewen and Schneider (1979) reported hydraulic conductivities ranging from $1.9 \times 10^{-6}$ m/s to $1.7 \times 10^{-5}$ m/s, with an average of $7.1 \times 10^{-6}$ m/s. These values can be considered representative of bulk hydraulic conductivities in this unit. Based on the experience of MDH, values of less than $1.9 \times 10^{-6}$ m/s can be found locally. The transmissivity and storativity reported from a 48-hour constant-rate pumping test was $17.8 \text{ m}^2/\text{d}$ and $2.3 \times 10^{-4}$, respectively (Golder Associates, 2006).

5.1.2 Groundwater Flow

Generally, the Judith River Formation is recharged by the infiltration of meteoric water and the inflow of connate water from the overlying and underlying shales. The hydraulic head distribution within this HSU is expected to be complex in the area due to extensive faulting attributed to salt dissolution collapse. From the few wells installed in the HSU, the water level data suggest lateral groundwater flow is east to northeast in direction toward the Qu’Appelle River and the preglacial Hatfield Valley where the it is incised into and connected to the alluvial deposits of the river or sediments of the Hatfield Valley Aquifer (cross-sections A-A’, B-B’, I-I’, K-K’, and L-L’, Appendix C). Groundwater flow in this aquifer is also strongly influenced by flow (and water development) within the deep Empress Group sediments (e.g. Swift Current and Hatfield Valley aquifers), where they have incised into and are hydraulically connected to the Judith River Formation.
5.1.3 **Groundwater Availability**

One third party report was available from the Aylesbury area in the northwest corner of the mapsheet where a maximum safe or sustainable yield from the Judith River Formation was calculated to be 439 m³/d (Golder Associates, 2006). This is a high yield for a Judith River well, compared to the average recommended pumping rate (124 m³/d) from 26 drillers' records of wells installed with short-term pumping test data in the Judith River Formation. While this says nothing of the groundwater availability, it does provide some indication of expected well yields from the Judith River Formation. This formation is not recommended as a groundwater source if production rates of >200 m³/d are required. It is noted that multiple wells may be required to obtain even this quantity of water and will depend on the local hydraulic properties and use. The depth to the Judith River Formation is much less over the northern half of the mapsheet (about 140 m depth on average) and even forms the bedrock surface in places (Figure 4.2 and Figure 4.5); as compared to the approximate 300 m average depth south of Township 18. The groundwater users of the Judith River Formation and any of the other bedrock aquifers are generally located across the northern half of the Regina 72I area for this reason.

5.1.4 **Groundwater Quality**

A Piper Diagram of groundwater samples from the Judith River Formation and the other bedrock HSUs in the study area is provided in Figure 5.1. Water from the Judith River Formation is predominantly characterized as sodium-sulfate (Na-SO₄) to sodium-chloride (Na-Cl) type water (i.e. similar to seawater).
In the majority of samples, the Canadian Council of Ministers of the Environment (CCME) drinking water objective for TDS (500 mg/L), sodium (200 mg/L), and sulfate (500 mg/L) is exceeded. The objective for pH (6.5-8.5), iron (0.3 mg/L), manganese (0.05 mg/L), chloride (250 mg/L) is also exceeded in one or more samples. The TDS concentration of groundwater from the Judith River Formation ranged from 2,200 mg/L (122506) to 4,620 mg/L (65349) (Table F1 – Appendix F). Water from this unit is generally not suitable for human consumption, irrigation, or livestock watering without treatment.

5.1.5 Groundwater Vulnerability

Figure E1 (Appendix E) shows the vulnerability of the Judith River Formation to contamination from the surface, in the Regina 72I area. The aquifer vulnerability index (AVI) is predominantly low to very low. The exception is along the Qu’Appelle river valley where the alluvium deposits are deep enough to be connected to the Judith River Formation resulting in a high AVI rating at those locations (e.g. cross-section K-K’). Since the AVI map is based on calculations at borehole locations, the AVI index should be very high at all locations where any of the mappable aquifer units are interpreted to outcrop. The AVI map only covers the northern half of the mapsheet due the lack of sufficient data regarding the overlying deposits over the Judith River Formation in the southern portion of the mapsheet.
5.2 The Outlook Member (Kbok)

The Outlook Member of the Bearpaw Formation is a thick bedded to massive sand and poorly indurated sandstone, fine to medium grained, silty, with a variety of bedded calcareous concretions (Caldwell, 1968, 1975). This unit has been interpreted to exist across the majority of the area (Figure D2, Appendix D) and grades down into the upper Judith River Formation sediments or a thin unnamed member of the Bearpaw Formation. The thickness of the Outlook Member is variable across the Regina 72I area, ranging from 4.3 m (17570) to 97.7 m (101/09-27-016-20W2/00), where present, with an average thickness of 45.1 m. This unit thins northward with the thickest accumulations identified through the south and central portions of the mapsheet. The thin unnamed clay shale member of the Bearpaw Formation which separates the Outlook Member and Judith River Formation has been identified in a few locations (cross-sections A-A’, B-B’, H-H’, and I-I’). It is confined at the top by the Broderick Member (Kbbd) of the Bearpaw Formation.

No wells were interpreted to be installed in the Outlook Member. Where it is connected to the Judith River Aquifer there is likely some hydraulic connectivity between the two units resulting in waters from the Outlook Member to be chemically similar to those of the Judith River Formation. In places, it is also connected to the Empress Group sediments in the preglacial Swift Current and Hatfield Valleys, as well as the alluvium in the Qu’Appelle Valley.

5.2.1 Groundwater Flow

Groundwater flow within the Outlook Member is likely similar to that of the Judith River Aquifer due to the high connectivity between these units. This is illustrated on area cross-sections (Appendix C) from the interpretation of the Outlook Member and Judith River Formation having no hydraulic barrier (i.e. shale unit) identified between them at most locations. Lateral groundwater flow will be east to northeast in direction toward the Qu’Appelle River and the preglacial Hatfield Valley. Groundwater flow will also be toward rivers where alluvial deposits are incised into the Outlook Member (cross-sections K-K’ and L-L’).

5.2.2 Groundwater Quality

Figure 5.1 provides a Piper Diagram of groundwater samples from a small number of wells installed in the Bearpaw Formation (Kb). The member that these wells are completed in is unknown. These samples are predominantly characterized as sodium-sulfate (Na-SO₄) to sodium-chloride (Na-Cl) type water, similar to that from the Judith River Formation.

The TDS concentration of groundwater from the Bearpaw Formation ranges from 2,500 mg/L to 6,380 mg/L (Table F1 – Appendix F). In the majority of samples, the Canadian Council of Ministers of the Environment (CCME) drinking water objective for TDS (500 mg/L), sodium (200 mg/L), sulfate (500 mg/L), and chloride (250 mg/L) is exceeded. The objective for iron (0.3 mg/L) is also exceeded in one sample. In the Regina 72I area, water from the bedrock
HSUs in the Bearpaw Formation are generally not suitable for human consumption, irrigation, or livestock watering without treatment.

5.2.3 **Groundwater Vulnerability**

Figure E2 (Appendix E) shows the vulnerability of the Bearpaw HSUs to contamination from the surface in the Regina 72I area. The aquifer vulnerability index (AVI) is predominantly low to very low, except where this formation is encountered near surface (e.g. cross-section D-D’), or where thick overlying HSUs are present. Direct hydraulic connectivity to the Qu’Appelle Valley alluvium and the Outlook Member does occur between the Craven area and Pasqua Lake resulting in a high to very high AVI (cross-sections B-B’ and K-K’, Appendix C). Since the AVI map is based on calculations at borehole locations, the AVI index should be very high at all locations where any of the mappable aquifer units are interpreted to outcrop. Similar to the Judith River Formation AVI, insufficient information about the overlying materials in the southwest and southeast corners of the mapsheet results in the cropping of the AVI in these areas.

5.3 **The Matador (Kbm) and Demaine (Kbd) Members**

The Matador and Demaine Members of the Bearpaw Formation are fine to medium-grained sand and silt, non-calcareous, unconsolidated units. The two aquifers are divided by the Sherrard Member. The aquifers are discontinuous in the area due to either erosion or pinching out due to local facies changes. The areal extent of the Matador and Demaine Members are shown in Figure D3 and Figure D4, respectively (Appendix D). The Matador and Demaine Members are found in thicknesses up to 17.6 m (101/03-18-020-01W3/00) and 20.0 m (101/10-33-012-29W2/00), respectively, but are on average 10.1 m to 11.0 m thick, where present. No wells were interpreted to be installed in either the Matador or Demaine Members.

5.4 **The Ardkenneth Member (Kba)**

The Ardkenneth Member of the Bearpaw Formation is composed predominantly of unoxidized, silty, very fine to fine-grained sand with lesser amounts of interbedded silts and clays. The Ardkenneth Member is limited in areal extent and discontinuous in the area, as shown in Figure D5 (Appendix D). The Ardkenneth Member has been encountered at depths ranging from 40.8 m (115105), in the northwest corner of the mapsheet area, to 370.0 m (101/11-09-012-24W2/00), below the Dirt Hills at the southern edge of the study area. This unit is generally about 16 m thick within in the Regina 72I area.

5.4.1 **Hydraulic Properties**

Hydraulic properties were not available for the Ardkenneth Member in the study area. A hydraulic conductivity range of 1x10⁻⁶ m/s to 1x10⁻⁴ m/s has been estimated for this unit. Maathuis and Simpson (2007) estimated the hydraulic conductivity of Bearpaw Formation sands members to be 1.2x10⁻⁵ m/s to 5.8x10⁻⁵ m/s.
5.4.2 Groundwater Flow

There is limited information on water levels in this hydrostratigraphic unit within the Regina 72I area. Groundwater flow in the Ardkenneth Member appears to be toward the Qu'Appelle River system. Cross-sections G-G' and H-H' show where this unit is interpreted to daylight along the valley walls of Buffalo Pound Lake. Groundwater flow in this unit will likely be complex due to faulting of the bedrock.

5.4.3 Groundwater Availability

The Ardkenneth Member is used as a water source in numerous locations in southwestern Saskatchewan and may be possible as a water supply in the western edge of the Regina 72I area. However, only two water wells, both on the western edge of the mapsheet, are interpreted to be installed in the Ardkenneth Member in the study area. A recommended pumping rate of 19.6 m³/d and 130.9 m³/d was provided for these wells. Yields greater than this should not be expected from this unit.

5.4.4 Groundwater Quality

No water chemistry data is available specifically for the Ardkenneth Member. Table F1 (Appendix F) provides water chemistry from undifferentiated Bearpaw Formation aquifers. Figure 5.1 provides a Piper Diagram of these results and water from the Ardkenneth Member is expected to be Na-SO₄ to Na-Cl type water. Generally, this water is not considered suitable for human consumption, irrigation, or livestock watering without treatment.

5.5 The Cruikshank Member (Kbc)

The Cruikshank Member of the Bearpaw Formation is composed predominantly of unoxidized, silty, very fine- to fine-grained sand with lesser amounts of interbedded silts and clays. The Cruikshank Aquifer is limited in areal extent and is discontinuous in the study area, as shown in Figure D6 (Appendix D). It is only present where preserved due to the down faulting associated with salt dissolution collapse structures found in the south central region of the mapsheet.

The Cruikshank Aquifer has been encountered at only seven boreholes in the area at depths ranging between 10.4 m (43229 (DOE Regina 522), cross-section D-D’) and 280.4 m (101/11-09-012-24W2/00) below the Dirt Hills. The thickness of this unit ranged from 9.1 m (66665, cross-section H-H’) to 17.9 m (101/11-09-012-24W2/00), where encountered.

Hydraulic properties, groundwater flow, and chemistry were not available for the Cruikshank Aquifer in the study area, but are expected to be similar to those of the other Bearpaw Formation aquifers. In the Regina 72I area, the Cruikshank Aquifer is limited in areal extent and should not be targeted for water supply.
5.5.1 Groundwater Vulnerability

Figure E2 (Appendix E) shows the vulnerability of the Bearpaw Formation HSUs to contamination from the surface in the Regina 72I area. The high AVI rating west of Regina is due to thin drift deposits over the Cruikshank Member in a local bedrock high. The aquifer vulnerability index (AVI) is predominantly low to very low.

5.6 The Frenchman-Whitemud-Eastend Formations (Kfw e)

Fine to coarse-grained interbedded sand and silt comprise the Frenchman Whitemud Eastend Formations. These Formations are discontinuous in the Regina 72I area due to either erosion or pinching out because of local facies changes, as shown in Figure D7 (Appendix D). It has been identified up to 58.0 m thick (116926 (SHT Eagle No.177 Spring Valley) in the Dirt Hills area, south of the Regina 72I mapsheet boundary. The HSU is likely hydraulically connected to the Empress Group south of Old Wives Lake where the formation forms the bedrock surface (87998, cross-section G-G'). Only one well was interpreted to be installed in the Frenchman Whitemud Eastend Formations just south from the edge of the Regina 72I mapsheet; water sampled from this well is a sodium-sulfate type (Na-SO₄), with a TDS concentration of 3,990 mg/L. This water is not considered suitable for human consumption, irrigation, or livestock watering without treatment.

5.7 The Empress Group (QTe)

Sands, gravels, silts and clays of the Empress Group are found primarily infilling portions of the pre-glacial Hatfield and Swift Current valleys. Other small pockets of the Empress Group sediments are found over the remaining Regina 72I area, as can be seen on Figure D8 (Appendix D). The Empress Group is interpreted to be hydraulically connected to the Mennon, Outlook, and Judith River, as well as the Matador, Demaine, Ardkenneth, Frenchman Whitemud Eastend, Upper Dundurn, and alluvium HSUs (Appendix C). The Hatfield Valley and Swift Current Valley aquifers form two of the most significant aquifers in the Regina 72I area.

**Hatfield Valley Aquifer:**

The stratified deposits of the Hatfield Valley Aquifer comprise one of the largest “fresh water” aquifer systems in the province, extending from within Alberta, crossing the border near Cold Lake, AB and continuing across Saskatchewan to the southeast where it goes into Manitoba (Figure 4.3). In the Regina 72I area, the Hatfield Valley crosses the northern section of mapsheet from Last Mountain Lake to Pasqua Lake.

The Hatfield Valley was formed from fluvial erosion, which cut down into the bedrock during the advance of the first continental ice sheets. The stratified deposits of the Empress Group were deposited within the Hatfield Valley during that first glacial advance (Whitaker and Christiansen, 1972). The Empress Group sediments within the Hatfield Valley in the study area has an average depth of approximately 100 m, and range from 1.8 m thick (84042,
cross-section I-I’) to >56.1 m (8133, cross-section L-L’). The main thalweg of the Hatfield Valley is located north of the Regina 72I mapsheet.

**Swift Current Valley Aquifer:**
The Swift Current Valley Aquifer was likely a preglacial channel that drained to the northeast and was later truncated by the Hatfield Valley which drained to the northwest (Maathuis and Schreiner, 1982). The aquifer originates around the Swift Current area (Twp15-Rng15-W3) and heads east into the Regina 72I mapsheet, terminating west of Last Mountain Lake near Dilke. It is unclear whether the Swift Current Valley Aquifer is hydraulically connected to the Hatfield Valley Aquifer, but this may be a possibility. The Swift Current Valley Aquifer is found at an average depth of roughly 80 m and in thicknesses up to 39.6 m (90658, cross-section C-C’), but is generally around 16 m thick in the area.

**Buena Vista Aquifer:**
The Buena Vista Aquifer (which includes the Lumsden Valley Aquifer) is a small isolated region of Empress Group sediments that are accessed by the town of Buena Vista and have been studied extensively by the local municipality. The Lumsden Valley Aquifer is a local channel aquifer that is connected to the Buena Vista Aquifer but has a regional extent too small to illustrate on the area maps. It has been incorporated into the extent of the Buena Vista Aquifer for the purposes of this report. The two aquifers were divided based on water quality in the groundwater studies in the area but were determined to be hydraulically connected based on results from a 32-day pump test (Beckie Hydrogeologists Ltd., 1995). This aquifer has a limited areal extent around the Buena Vista and Lumsden Beach areas. It is found at an average depth of 81 m and in thicknesses up to >42.7 m (83716), but on average is 24.7 m thick.

### 5.7.1 Hydraulic Properties

The hydraulic properties of the Empress Group have been explored in many investigations across Saskatchewan, as it is readily exploited for industrial, municipal, and domestic water use.

**Hatfield Valley Aquifer:**
A hydraulic conductivity and transmissivity of 2.0\times10^{-4} m/s and 522 m²/d was determined by Keith Consulting Engineers Ltd. (1970), for the Town of Cupar. This corresponds to a large study of the Hatfield Valley Aquifer by Maathuis and Schreiner (1982) across the Wynyard region south to the Qu’Appelle River Valley. They provided a range of hydraulic conductivity for the aquifer from 1.7\times10^{-4} m/s to 2.9\times10^{-4} m/s, a transmissivity between 200 m²/d and 2,500 m²/d, and a storage coefficient around 2.0\times10^{-4} as typical for this aquifer. This is considered representative of the Empress Group sands.

**Buena Vista Aquifer:**
The hydraulic conductivity and transmissivity was determined, from pumping tests on the Buena Vista Aquifer, to range from 2.9\times10^{-4} m/s to 3.8\times10^{-4} m/s and 44 m²/d to 596 m²/d,
respectively (Beckie Hydrogeologists Ltd., 1988a, 1988b, and 1995). A storage coefficient of 1.0x10^-4 was estimated.

**Empress Group:**
One pump test has been completed in the Empress Group in the Craven area. Clifton and Associates (1997) estimates the hydraulic conductivity between 1.0x10^-4 m/s and 5.1x10^-4 m/s, the transmissivity from 127 m^2/d to 618 m^2/d, and a storage coefficient of 0.0455.

### 5.7.2 Groundwater Flow
Groundwater within the Empress Group is recharged by downward flow through overlying strata and lateral flow from interconnected HSUs, including, but not limited to, the Judith River, Outlook, Demaine, Matador, Ardkenneth, and some Sutherland Group HSUs, as well as alluvium, at certain locations in the mapsheet. In general, the lateral boundaries of the Empress Group are formed by the Upper Cretaceous marine deposits (in which it is incised) and the overlying till. Vertical recharge to the Empress Group is slow due to the thick, low permeability confining units (overlying till and underlying marine shales).

**Hatfield Valley Aquifer:**
Lateral groundwater flow within the Hatfield Valley Aquifer is in a southeasterly direction, toward the Qu’Appelle River, where it discharges in the Fort Qu’Appelle area, near Pasqua Lake (Maathuis and Schreiner, 1982). This is confirmed by the measured water levels from wells installed in the aquifer which decline toward the Qu’Appelle Valley. Water level data also suggest that groundwater is discharging at Last Mountain Lake, north of Glen Harbour.

**Swift Current Valley Aquifer:**
Within the mapsheet, lateral groundwater flow in the Swift Current Valley Aquifer is toward Buffalo Pound Lake. There is also a potential for some groundwater flow to continue northeast toward Last Mountain Lake, but this cannot be confirmed as there is limited potentiometric data in that area. While Figure D8 (Appendix D) shows the Hatfield Valley and Swift Current Valley aquifers as nearly connected in this area, there is not enough information to definitely indicate that a connection exists.

**Buena Vista Aquifer:**
Due to the small aerial extent of this aquifer, the groundwater flow gradient is not apparent and therefore is likely consistent across the aquifer. A large-scale pump test was used to determine that the aquifer is not hydraulically connected to any overlying aquifers (Beckie Hydrogeologists Ltd., 1995). The water level data from the WSA observation well 226588 installed in the Buena Vista Aquifer (Figure 5.2) and observation well 226401 installed in the Lumsden Valley Aquifer (Figure 5.3) show that the groundwater level is higher in elevation than the lake level (approximately 490 masl), suggesting that the aquifer is not directly
Figure 5.2 – WSA Observation well hydrograph for Buena Vista 09 (226588) installed in the Buena Vista Aquifer.

Figure 5.3 – WSA Observation well hydrograph for Buena Vista 18 (226401) installed in the Lumsden Valley Aquifer.
connected to the Qu'Appelle system at this location. The hydrographs also show the seasonal variability coupled with the higher water usage during the summer months, resulting in up to a 2.0 m change in water level over a one-year period.

5.7.3 Groundwater Availability

In the Regina 72I area, licensed groundwater allocation from the Empress Group sediments was 487.5 dam$^3$/y. There is a 203.3 dam$^3$/y allocation from the Buena Vista Aquifer for municipal use by Buena Vista, Regina Beach, Silton and area. The Town of Cupar is allocated for 278.0 dam$^3$/y from the Hatfield Valley Aquifer for municipal use. The town of Craven extracts water from the Empress Group for an area subdivision at an allocation of 6.0 dam$^3$/y. The recommended pumping rate from the 149 WWDRs installed in the Empress Group collectively ranged from 13 m$^3$/d to 982 m$^3$/d (106441, Town of Cupar). Since the Empress Group often discharges to the river valleys, the available drawdown is typically reduced toward the Qu’Appelle River. The depth to water from WWDRs ranged from near surface to 125 m. The Empress Group is generally capable of producing large volumes of water (i.e. >200 m$^3$/d).

Hatfield Valley Aquifer:

Based on estimates from previous work done on the Hatfield Valley Aquifer by Maathuis and Schreiner (1982) a net groundwater yield was calculated for the aquifer. The net groundwater yield for the Hatfield Valley Aquifer ranging from the Humboldt area south to the Pasqua Lake area was determined to be 1.0x10$^8$ m$^3$/y. For a single well yield, the maximum production rate that could be withdrawn for a short period of time without causing unconfined conditions was 22,000 m$^3$/d, assuming average aquifer characteristics.

For any development considering extracting at these high volumes, an extensive pumping test, coupled with analytical or numerical modelling, is typically required to quantify groundwater availability, as it is highly dependent on aquifer discontinuities and the three-dimensional configuration of the entire groundwater system. It is recommended the water withdrawal by all users in the potentially affected area is considered in any analysis for the assessment of high volume production.

Swift Current Valley Aquifer:

No large aquifer characterization studies have been done in the Swift Current Valley Aquifer in the Regina area. The recommended pumping rates, from the 29 wells installed in the aquifer in the area with short-term pumping test data, ranged from 13 m$^3$/d to 164 m$^3$/d (106220). The average depth of a well installed in the Swift Current Valley Aquifer is 99.6 m.

Buena Vista Aquifer:

A large 32-day pump test was completed in the Buena Vista Aquifer (Beckie Hydrogeologists Ltd., 1995) which characterized the aquifer for the area. A maximum sustainable well yield was determined to be 979 m$^3$/d for the aquifer, but a safe continuous pumping rate of 327 m$^3$/d was established with a maximum annual extraction of 50 dam$^3$. At these rates it
was determined that extraction at the pump well would not have any impact on the production capacity of neighbouring wells. For the 14 known wells installed in the aquifer, the recommended pumping rates ranged from 45 m$^3$/d to 131 m$^3$/d (70718), not including the well used in the pump test. The average depth for a well installed in the Buena Vista Aquifer is 103.0 m.

### 5.7.4 Water Quality

Groundwater in deep buried valley aquifers can be variable, and in most cases, is highly mineralized, hard, and sulphate rich. Groundwater entering a deep aquifer from the overlying glacial deposits has undergone considerable chemical evolution and some of the groundwater may represent water trapped during deposition of the tills. A Piper Diagram of the groundwater samples obtained from the Empress Group is provided in Figure 5.4.

The water from the general Empress Group, Hatfield Valley and Swift Current Valley aquifers is primarily characterized as sodium-sulphate (Na-SO$_4$) type water, (89% of samples), showing some similarities to the water sampled from the Bearpaw and Judith River HSUs. This indicates that the water is generally derived from the overlying till sequences and connate water from the Upper Cretaceous sediments in which it is incised. This is typical of the Empress Group in most areas of Saskatchewan. The Buena Vista Aquifer was unique from the other aquifers in that it is a sodium-bicarbonate (Na-HCO$_3$) type water (Figure 5.4). This suggests that the Buena Vista Aquifer is influenced more by meteoric water, compared to the other Empress Group sediments in the mapsheet. This is corroborated by generally lower TDS concentrations in the Buena Vista Aquifer.

Groundwater samples from the Empress Group in the Regina 72I area indicate that it is generally not potable without treatment. In the majority of samples, the CCME objectives for TDS, sodium, iron, manganese, and sulfate are exceeded (Table F2 – Appendix F). The aesthetic objective for chloride is also exceeded in several samples. The TDS concentration ranges for the different aquifers are from 476 mg/L to 3,020 mg/L, with an average of 1,848 mg/L, making the aquifers a poor source of water for irrigation due to soil salinization concerns. However, water from the Empress Group is often used for domestic purposes (when treated) and as a direct water supply for livestock. The Buena Vista Aquifer has a lower TDS concentration ranging from 476 mg/L (BHL15-94PZ) to 752 mg/L (226563 (BHL20-95PZ)), with an approximate average of 619 mg/L.
5.7.5 **Groundwater Vulnerability**

Figure E3 (Appendix E) shows the vulnerability of the Empress Group to contamination from the surface in the Regina 72I area. The aquifer vulnerability index (AVI) is low to very low for the main body of the Empress HSU over the mapsheet. For locations where there is a moderate or greater rating it is due to either the HSU being near surface or other thick HSUs with thin aquitard layers are situated above the Empress Group (e.g. along the western edge of Regina, as shown in cross-section C-C’).

5.8 **The Mennon HSU (Qm-s)**

The Mennon HSU generally overlies the lower till unit of the Mennon Formation (where it is not eroded) or lies directly on the bedrock surface. A complex arrangement of gravel, sand, silt, and clay comprises this unit. The Mennon HSU is discontinuous in the Regina 72I area and is generally found as isolated aquifers where the sediments have not been eroded (Figure D9 (Appendix D)). It has been encountered in the study area in thicknesses between 1.22 m and 29.0 m (17431 (SRC Cupar); cross-sections A-A’ and L-L’) and at depths ranging from 24.4 m (114747) to 141.1 m (10824 (CorR TH15-H62), cross-section C-C’). The Mennon HSU is commonly hydraulically connected with the Empress Group where it has eroded down into Empress Group sediments during deposition. This is illustrated at hole 17431 (SRC Cupar) on cross-sections A-A’ and L-L’ in the Hatfield Valley.
5.8.1 Hydraulic Properties

Hydraulic properties were not available for the Mennon HSU in the Regina 72I area. A hydraulic conductivity range of $1 \times 10^{-6}$ m/s to $5 \times 10^{-4}$ m/s can be expected for the sands and gravels. Significantly lower hydraulic conductivities can be expected for the silt and clay units within this unit.

5.8.2 Groundwater Flow

There are a limited number of wells and water levels available from the Mennon HSU in the mapsheet area. Lateral groundwater flow within this unit is expected to be similar to that of the Empress Group, toward the Qu'Appelle River Valley and Buffalo Pound Lake.

5.8.3 Groundwater Availability

No licensed groundwater wells extract water from the Mennon HSU. The Mennon HSU is hydraulically connected to the Empress Group in some places and is likely part of both the Swift Current Valley and Hatfield Valley aquifer systems in the Regina 72I area. A large-scale pumping test with observation wells installed in multiple-aquifer horizons, coupled with three-dimensional groundwater flow modelling, would likely be required to better determine hydraulic connectivity and groundwater availability for this system.

5.8.4 Groundwater Quality

No water samples have been analyzed from the Mennon HSU in the Regina 72I area. Due to the hydraulic connectivity of the Mennon HSU with the Empress Group HSU it can be assumed that groundwater quality will be similar to that of the Empress Group.

5.8.5 Groundwater Vulnerability

Figure E4 (Appendix E) shows the vulnerability of the Mennon HSU to contamination from the surface in the Regina 72I area. The aquifer vulnerability index (AVI) is low to very low, except for a small section with a moderate rating along the Qu'Appelle River west of Pasqua Lake where the unit is hydraulically connected to the alluvial deposits of the river.

5.9 The Lower Dundurn HSU (Qd-I_s)

The Lower Dundurn HSU is generally composed of a complex arrangement of gravel, sand, silt, and clay. Figure D10 (Appendix D) shows the interpreted areal limits of this unit. The Lower Dundurn HSU is discontinuous in the Regina 72I area. It is interpreted to be encountered in thicknesses up to 55.5 m (43190 (DOE Regina 512)) and depths of 5.5 m (114747) to 161.5 m (17549 (SRC Edenwold, cross-section B-B')).

The Lower Dundurn HSU is not found as a large regionally extensive unit but is rather characterized as a generally thin (6.0 m thick on average) laterally discontinuous HSU with limited connectivity to other HSUs.
5.9.1 Hydraulic Properties
Hydraulic properties were not available for the Lower Dundurn HSU in the Regina 72I area. A hydraulic conductivity range of $1 \times 10^{-6}$ m/s to $5 \times 10^{-4}$ m/s can be expected for the sands and gravels. Significantly lower hydraulic conductivities can be expected for the silt and clay units within this unit.

5.9.2 Groundwater Flow
The lateral groundwater flow direction in the Lower Dundurn HSU could not be determined due to the discontinuous and isolated nature of this unit. However, lateral groundwater flow will likely be toward the river and lake valleys in the mapsheet area.

5.9.3 Groundwater Availability
Third party well reports and associated safe or sustainable yields were unavailable for the Lower Dundurn HSU in the Regina 72I area. Thirty-seven driller's records show a range in recommended pumping rates from 20 m$^3$/d to 327 m$^3$/d, with an average of 74 m$^3$/d. While this says nothing of the groundwater availability, it does provide some indication on expected well yields from this unit. The sustainable yield from the Lower Dundurn HSU is expected to be low given the discontinuous nature and variable lithology of this unit. The Town of McLean has a licensed allocation for this unit of 6.2 dam$^3$/y for use at the municipal campground.

5.9.4 Groundwater Quality
A Piper Diagram of the groundwater sampled from the Lower Dundurn HSU is provided in Figure 5.5. Two samples from the Lower Dundurn HSU that are hydraulically connected to the Empress Group or a bedrock HSU are characterized as a sodium-sulphate type water. The other two samples, which are isolated from other water bearing units, are calcium/magnesium-sulfate type. The CCME objective is exceeded for these four samples for a number of the analytes tested (Table F3 – Appendix F). Without treatment, this water is generally not suitable for human consumption, irrigation, or for livestock water supply.

5.9.5 Groundwater Vulnerability
Figure E5 (Appendix E) shows the vulnerability of the Lower Dundurn HSU to contamination from the surface in the Regina 72I area. Due to this unit's depth, the aquifer vulnerability index (AVI) is generally low to very low. There are several small sections rated as moderate which are in close proximity to the Qu’Appelle River valley.
5.10 The Upper Dundurn HSU (Qd-us)

The Upper Dundurn HSU is generally comprised of a complex arrangement of gravels, sands, silts, and clays. Figure D11 (Appendix D) shows the interpreted thickness and areal extent of the Upper Dundurn HSU in the 72I area. The Upper Dundurn HSU is much more prevalent in the northern half of the mapsheet area, compared to the southern half. The thickness of this unit is variable as a result of both post-depositional erosion and/or non-deposition. The Upper Dundurn HSU was encountered in thicknesses up to 39.9 m (43192 (DOE Regina 517), cross-section J-J’) in the Regina 72I area. The interpreted depth of this unit ranges from ground surface to 143.3 m (65697, cross-section L-L’) in the study area. Similar to the Lower Dundurn and Mennon HSUs, potential hydraulic connectivity with the Empress Group sediments exists in the study area, as can be seen in cross-sections C-C’, H-H’, J-J’, and L-L’ (Appendix C).

5.10.1 Hydraulic Properties

Hydraulic properties of the Upper Dundurn HSU have been assessed for the Village of Chamberlain in the Regina 72I area. The transmissivity determined during the constant-rate pumping test of Well No.3 for Chamberlain was estimated at 216 m²/d with a storage coefficient of 0.0003 (PFRA, 1990). The hydraulic conductivity of the Upper Dundurn HSU ranged between $1 \times 10^{-6}$ m/s and $1 \times 10^{-3}$ m/s. Significantly lower hydraulic conductivities can be expected for wells completed in silts or clays within this HSU.
5.10.2 Groundwater Flow
Groundwater flow in the Upper Dundurn HSU is generally toward the nearest river valley or lake in the Regina 72I area. This is based on 186 point water level readings from wells in the area. The main focus of groundwater flow is toward the Qu’Appelle River system, Last Mountain Lake, and Buffalo Pound Lake. The Upper Dundurn HSU is recharged by the downward migration of meteoric water through the overlying sediments.

5.10.3 Groundwater Availability
In the Regina 72I area, licensed groundwater allocation from the Upper Dundurn HSU is approximately 322.3 dam$^3$/y (Table 3.6) with the three primary users being the towns of Southey (112 dam$^3$/y), Earl Grey (50 dam$^3$/y), and Vibank (49.2 dam$^3$/y). Less than 4% of the licensed allocation is for industrial agriculture, commercial users, and tankload facilities. The recommended pumping rate from WWDRs ranged from <7 m$^3$/d to 655 m$^3$/d, with an average of 100 m$^3$/d, for wells installed in this HSU within the 72I area. The 655 m$^3$/d rate can likely be regarded as an upper limit to sustainable groundwater production from this HSU in the area. The sustainable yield for the No. 3 Well at Chamberlain was calculated to be 328.3 m$^3$/d. An extensive pumping test, coupled with numerical modelling, is typically required to quantify groundwater availability, as it is highly dependent on HSU discontinuities, the three-dimensional configuration of the entire groundwater system, and multiple groundwater users.

5.10.4 Groundwater Quality
Groundwater within large intertill blanket HSUs (such as the Upper Dundurn HSU) has typically undergone chemical evolution, similar to the deeper buried channel HSUs (e.g. Empress Group. Water chemistry from the Upper Dundurn HSU is provided in Table F3 (Appendix F). A Piper Diagram of this chemistry data is provided in Figure 5.5. The groundwater is characterized as calcium-magnesium-bicarbonate to sodium-sulphate type water.

Groundwater from the Upper Dundurn HSU is generally not potable (without treatment) and is very hard and sulphate rich. It typically exceeds several CCME drinking water quality objectives, including (but not limited) to TDS, iron, manganese, and sulfate. The TDS concentration is 1,724 mg/L on average and ranges from 995 mg/L to 2,757 mg/L in sampled groundwater available for this project.

5.10.5 Groundwater Vulnerability
Figure E6 (Appendix E) shows the vulnerability of the Upper Dundurn HSU to contamination from the surface in the Regina 72I area. The aquifer vulnerability index is generally low to very low due to this unit’s depth. However, there are several areas rated moderate mainly along river valley edges or topography changes where the HSU outcrops or comes near to surface. One location has a rating of high to very high west of Pasqua Lake along the Qu’Appelle Valley at hole 114743 where the HSU outcrops on the valleyside.
5.11 The Warman HSU (Qw-s)

The Warman HSU is comprised of a complex arrangement of gravels, sands, silts, and clays, typically at the contact between the Warman Formation and the underlying Dundurn Formation. Figure D12 (Appendix D) shows the interpreted areal extent and thickness of the Warman HSU. This HSU is highly discontinuous across the study area and generally occurs as isolated intertill stratified deposits. This HSU has been encountered in thicknesses up to 28.3.0 m (219599) in the Regina 72I area and at an average depth of 32.5 m where present.

5.11.1 Hydraulic Properties

In the Regina 72I area, hydraulic conductivity was not available for the Warman HSU but can be expected to range between $1 \times 10^{-6} \text{ m/s}$ to $5 \times 10^{-4} \text{ m/s}$ in the sand and gravel units. The hydraulic conductivity will be significantly less in silt and clay units within this HSU.

5.11.2 Groundwater Flow

Lateral groundwater flow will likely be toward the river valleys within the Warman HSU.

5.11.3 Groundwater Availability

There were no third party reports available to provide an idea of safe or sustainable yield from the Warman HSU in the study area. No licensed groundwater wells are installed in the Warman HSU. Ten driller's records show a range in recommended pumping rates from 16 $\text{m}^3/\text{d}$ to 164 $\text{m}^3/\text{d}$, with an average of 92 $\text{m}^3/\text{d}$ within the study area. While this says nothing of the groundwater availability, it does provide some indication on expected well yields from this HSU. Given the discontinuous nature and depth of this unit, the sustainable yield from this HSU is expected to be low for the Regina 72I area.

5.11.4 Groundwater Quality

The groundwater chemistry is available from two sampled wells installed in the Warman HSU (11694 (Hall Albatross) and 85388) is provided in Table F3 (Appendix F). A Piper Plot of the groundwater samples obtained from the wells is provided in Figure 5.6. The groundwater is characterized as sodium-sulfate type water. The TDS, sulphate, sodium, iron, and manganese concentration exceeds the CCME objective in both samples. The water sampled from 13407 also exceeds the objective for sodium. They are both considered hard water and are high in TDS as well. This water chemistry may not be representative of the Warman HSU in the study area, since water chemistry data was only available for two locations.
5.11.5 Groundwater Vulnerability

Figure E7 (Appendix E) shows the vulnerability of the Warman HSU to contamination from the surface in the Regina 72I area. The AVI ranges from low to moderate where the HSU is found due to the depth of this unit in the study area.

5.12 The Lower Floral HSU (Qf-ls)

Interbedded stratified deposits often occur at the contact between the Sutherland Group and the Saskatoon Group, where the basal Floral Formation till is not present. This unit has been informally called the Lower Floral HSU. The Lower Floral HSU is interpreted to be discontinuous in the study area, as shown in Figure D13 (Appendix D). The Lower Floral HSU has been encountered in thicknesses up to 71.3 m (43123 (DOE Regina 513)) and at depths from ground surface to 110.2 m (123893), with an average depth and thickness of 44.9 m and 8.1 m, respectively, in the Regina 72I area.

The Lower Floral HSU may be hydraulically connected to the Upper Floral HSU at several locations within the study area. It is also noted that sediments interpreted as belonging to the Upper Floral HSU may be part of the Lower Floral HSU, since these two units are lithologically similar. Where they are directly connected it is very difficult, if not impossible, to differentiate these units, based on available information. For the majority of locations interpreted, the Lower Floral Formation till unit is found to separate the Upper and Lower Floral HSUs. The Zehner Aquifer and Northern Aquifer are comprised of both the Upper and
Lower Floral HSUs, and are interpreted to be interconnected in some places (e.g. cross-sections B-B’ and K-K’).

The Lower Floral portion of the Zehner aquifer is interpreted to extend from the northeast corner of Regina to the Frank’s Lake area. The Northern Aquifer is located north of Franks Lake and Edenwold to the edge of the Qu’Appelle River Valley (Figure D13, Appendix D). The two aquifers are distinguished based on the difference in hydraulic head (Maathuis and van der Kamp, 1988). A thinning at the northern edge of the Zehner Aquifer provides some evidence that there is a hydrogeological barrier between the two aquifers.

5.12.1 Hydraulic Properties

Hydraulic properties were obtained from available reports on the Zehner and Northern aquifers and were found to be within the expected range. The hydraulic conductivity of this aquifer throughout the Regina 72I area is expected to be within the 1x10⁻⁶ m/s to 1x10⁻³ m/s range. Groundwater investigations in the area (Maathuis and van der Kamp, 1985, Beckie Hydrogeologists Ltd., 1986, 1995, and 2004, Watermark, 2006, MLM Ground-Water Engineering, 1982, and Saskmont Engineering Ltd., 1991) estimated the transmissivity and storativity to range between 51 m²/d to 2,540 m²/d and 1.1x10⁻⁴ to 2.5x10⁻³, respectively. A range of hydraulic conductivities from 1.1x10⁻³ m/s to 1.4x10⁻⁴ m/s was determined from the HSU testing done in the Lower Floral HSU.

5.12.2 Groundwater Flow

Infiltration of meteoric water through the Saskatoon Group sediments generally recharges the Lower Floral HSU. Lateral groundwater flow in the Lower Floral HSU is generally toward the nearest river valleys where these units discharge as springs along the valley walls. The groundwater level data suggests that flow in the Zehner Aquifer is southwest toward Boggy Creek. A number of flowing artesian wells exist in the vicinity of Boggy Creek, forming a groundwater discharge zone for the Zehner Aquifer. The groundwater level readings for the lower Floral sediments in the Northern Aquifer indicate that the groundwater flow is northward to the Qu’Appelle River. Flowing conditions have also been noted in the Mound Springs area, connected to the Northern Aquifer, since the decommissioning of the city of Regina wells in the late 1990s.

Figure 5.7 shows a hydrograph for WSA observation well Buena Vista 21, installed in the Lower Floral HSU, near Last Mountain Lake. This hydrograph shows >2 m change in water levels through the summer months at this location. This suggests the HSU is affected by groundwater withdrawal by local users through the summer, followed by recharge through the winter months.
5.12.3 Groundwater Availability

In the Regina 72I area, total licensed groundwater water allocation from wells installed in the Lower Floral HSU is 3,569.1 dam$^3$/y (Table 3.6), with the majority (98%) being allocated for withdrawal from the Zehner Aquifer. Virtually all of the water allocated for withdrawal from the Lower Floral HSU is for municipal use. Due to the connection of the Lower and Upper Floral HSUs at the Zehner and Northern Aquifers, there is likely some water being withdrawn from the Upper Floral HSU at certain wells and vice versa.

Water allocated to users of the Lower Floral HSU, not including the Zehner or Northern aquifers, is 73.1 dam$^3$/y across the Regina 72I area. The towns of Vibank, Cupar and the RM of South Qu’Appelle are the primary users of this allocation. The recommended pumping rate from the 140 WWDRs with short-term pumping test information known to be installed in the Lower Floral HSU ranges from 13 m$^3$/d to 655 m$^3$/d, with an average recommended pumping rate of 90 m$^3$/d.

The Zehner Aquifer is one of the most utilized aquifers in the 72I area, with a 3,495.1 dam$^3$/y allocation. The Towns of White City and Emerald Park and the City of Regina account for 72% of that allocation. Actual water use by the City of Regina is generally much lower than allocated, since the city will only withdraw groundwater as a backup to their surface water supply.
Sustainable well yields of 3,273 m$^3$/d (Beckie Hydrogeologists Ltd., 1986) to 3,676 m$^3$/d (Beckie Hydrogeologists Ltd., 2004) have been calculated for a well installed in the lower unit of the Zehner Aquifer. This can likely be regarded as an upper limit for sustainable yield for the aquifer. The recommended pumping rate from the 37 WWDRs known to be installed in the Lower Floral stratified sediments of the Zehner Aquifer was from 20 m$^3$/d to 982 m$^3$/d, with an average of 98 m$^3$/d. It is noted that higher individual well yields could be possible, but the allocation from this aquifer appears to be at or exceeding the sustainable yield of the system.

The lower Floral sediments of the Northern Aquifer is not utilized much by licensed groundwater users as only 1 dam$^3$/y for use in a livestock operation is allocated. A sustainable well yield of 45.8 m$^3$/d (Watermark, 2006) was calculated for a well installed in the lower unit of the Northern Aquifer. The recommended pumping rate from the 60 WWDRs interpreted to be installed in lower Floral portion of the Northern Aquifer ranged from 13 m$^3$/d to 327 m$^3$/d, with an average rate of 81 m$^3$/d.

The impact on overlying HSU units due to pumping of the Lower Floral HSU should be evaluated to determine impact on other water users in the area and assist in the determination of safe yields. An evaluation of existing pumping tests (and possibly additional pumping tests), coupled with numerical modelling of all historic, existing and proposed groundwater production, would be required to better quantify groundwater availability within the Floral Formation HSUs in the vicinity of Regina, as it is highly dependent on the three-dimensional configuration of the groundwater flow system and the rate of groundwater production from wells and well fields.

### 5.12.4 Groundwater Quality

A Piper Diagram of the groundwater chemistry for the Lower Floral HSU is provided in Figure 5.8. Table F4 (Appendix F) provides the chemistry of the major ions and indicators of water quality for the Lower Floral HSU. The groundwater is predominantly characterized as calcium/magnesium-bicarbonate type to calcium-sulfate type. The TDS concentration in sampled groundwater ranged from 404 mg/L (OBS#6 – Zehner Aquifer) to 3,020 mg/L (17761 – Northern Aquifer). The TDS, iron and manganese concentrations generally exceed the respective CCME drinking water quality objectives.

**Zehner Aquifer:**

Water from this aquifer is dominantly calcium-bicarbonate type water, with a lower hardness and alkalinity concentration than that found in the Northern Aquifer. The average TDS concentration is 1,181 mg/L.

**Northern Aquifer:**

Water from this aquifer is dominantly calcium-bicarbonate to magnesium-sulfate type water with an average TDS concentration of 1,595 mg/L.
5.12.5 Groundwater Vulnerability

The Lower Floral HSU has been impacted by several anthropogenic developments at surface in Saskatchewan and is a concern for potential contamination from surface. Figure E8 (Appendix E) shows the vulnerability of this HSU unit to contaminants from the surface. The AVI is predominantly moderate, but ranges from low to very high in the Regina 72I area.

5.13 The Upper Floral HSU (Qf-ms)

Interbedded stratified deposits occur at the contact between the upper and lower till units of the Floral Formation (i.e. the Riddell Member). This unit has been informally called the Upper Floral HSU. The Upper Floral HSU is often complexly stratified and can include significant till horizons due to interstadial glacial retreat and advance. This is a common occurrence within the Floral Formation HSUs across the province. The Upper Floral HSU is interpreted to be discontinuous in the study area, as shown in Figure D14 (Appendix D). The Upper Floral HSU has been encountered in thicknesses up to 69.8 m (43122 (DOE Regina 511)) and at depths from ground surface to 84.7 m (209631), with an average depth and thickness of 22.8 m and 9.9 m respectively, in the Regina 72I area.

The Upper Floral HSU is hydraulically connected to the Lower Floral HSU at several locations within the study area. It is also noted that sediments interpreted as belonging to the Upper Floral HSU may be part of the Lower Floral HSU, since these two units are lithologically similar. Where they are directly connected it is very difficult, if not impossible, to
differentiate these units. For the majority of locations the Lower Floral till unit separates the Upper and Lower Floral HSUs.

There are four named aquifers in the Regina 72I area in close proximity to the City of Regina that are within the Upper Floral HSU. These are called the Regina, Richardson, Zehner, and Northern aquifers.

**Regina Aquifer:**
The Regina Aquifer is found from approximately 12 km northeast of the town of Rouleau then north under the western and northern half of the City of Regina and continues north to the number 11 highway just east of Lumsden. The Regina Aquifer borders the Zehner Aquifer on its eastern edge under the northeast corner of the City of Regina (cross-section C-C’). A difference in water levels and the thinning of the aquifer on its eastern edge provides evidence of a hydrogeological barrier between the Regina and Zehner Aquifers.

**Richardson Aquifer:**
The Richardson Aquifer is located southeast of Regina and continues to the Town of Richardson covering a relatively small area. Flowing conditions are common in the Richardson Aquifer, as illustrated on cross-section K-K’, in the vicinity of Wascana Creek.

**Zehner Aquifer:**
The upper Floral portion of the Zehner Aquifer extends from the northeast corner of Regina to the Town of Zehner, east to the Balgonie area, and south to the Mallory Springs area near Pilot Butte. There is likely some hydraulic connection between the Zehner and Northern aquifers where they are in close proximity. A difference in water levels and the thinning of the Zehner Aquifer along its northern limits provides some evidence that there is a hydrogeological barrier between the two aquifers. Connectivity between the Upper and Lower Floral HSUs has been identified (e.g. cross-section K-K’). The lower Floral Formation till is found at most locations dividing the two Floral HSUs.

**Northern Aquifer:**
The upper Floral Formation portion of the Northern Aquifer is located north from the Town of Zehner and Franks Lake to the edge of the Qu’Appelle River Valley. Hydraulic connection of the Upper and Lower Floral HSUs has been identified on the western edge of the Northern Aquifer at the Mound Springs area, as can be seen at borehole 43131 (DOE Regina 507, cross-section B-B’).

### 5.13.1 Hydraulic Properties
The Upper Floral HSU has been explored in many investigations, as it is readily exploited for industrial, municipal, and domestic water use in the Regina 72I area; however, publically available pumping test results are not available for all the Upper Floral HSUs in the 72I area. The general Upper Floral HSU has been studied in the Baildon area as a research site for SIAST. A transmissivity and storativity were determined to be 88.8 m²/d and 0.0015,
respectively. The following provides a summary of hydraulic properties for named aquifers comprised of Riddell Member stratified sediments.

**Regina Aquifer:**
Pumping tests have been conducted on a number of wells installed in the Regina Aquifer by the City of Regina, the Town of Lumsden, and some industrial facilities in the area (Beckie Hydrogeologists Ltd., 1991, 1992, 1994, 1999, Clifton and Associates, 1993, 1994, 1999, 2000, 2003, and Saskmont Engineering, 1991). The minimum, mean, and maximum hydraulic properties of the Regina Aquifer from the collected reports done in the area is:

1. Transmissivity – 235 m²/d, 3,546 m²/d, and 13,100 m²/d, respectively;
2. Storage coefficient – 9.2x10⁻⁶, 0.02, and 0.2, respectively; and
3. Hydraulic conductivity – 4.7x10⁻⁴ m/s, 3.1x10⁻³ m/s, and 2.0x10⁻² m/s, respectively.

The high transmissivity and hydraulic conductivity values provided were determined from an industrial pump well installed by Clifton and Associates (2000). The values are quite high for the Regina Aquifer and should not be expected without a professional well design and extended well development time.

**Richardson Aquifer:**
While there were no available reports where aquifer properties were determined for the Richardson Aquifer, the expected values for the hydraulic conductivity are between 1.0x10⁻⁶ m/s and 1.0x10⁻³ m/s.

**Zehner Aquifer:**
The City of Regina and the Town of Balgonie have conducted a number of studies on the upper Floral portion of the Zehner Aquifer. Pumping test data from the associated reports (Beckie Hydrogeologists Ltd., 1996, Saskmont Engineering, 1991, and Mollard and Associates, 1975) provide a minimum, mean, and maximum hydraulic properties of the Zehner Aquifer:

1. Transmissivity – 248 m²/d, 880 m²/d, and 2,520 m²/d, respectively;
2. Storage coefficient – 1.1x10⁻⁴, 0.06, and 0.12, respectively; and
3. Hydraulic conductivity – 1.9x10⁻⁴ m/s, 4.0x10⁻⁴ m/s, and 7.2x10⁻⁴ m/s, respectively.

**Northern Aquifer:**
Hydraulic properties for the upper portion of the Northern Aquifer were not found in available reports, but will be similar to those found for the Upper and Lower Floral aquifers in the area.

### 5.13.2 Groundwater Flow
Infiltration of meteoric water through upper Saskatoon Group sediments (Surficial Stratified Deposits, Battleford Formation, and Upper Floral Formation), in areas with a downward vertical gradient, recharge the Upper Floral HSU; this is predominantly achieved through depression focused recharge. In the study area, the vertical component of groundwater flow is generally downward to and from this HSU toward respective underlying formations. In areas with an upward vertical groundwater gradient, such as the Richardson Aquifer, Mound Springs area (Northern Aquifer) or the Regina East area around the Pilot Butte observation
wells (Zehner Aquifer), the groundwater is either discharging into area springs or creek or adding to the groundwater in overlying aquifers such as the Condie Aquifer. The upward vertical groundwater flow is noted from this HSU in the vicinity of some creeks, valleys, and other topographically low points in the study area.

Lateral groundwater flow in the Upper Floral HSU is effectively the same as that of the Lower Floral HSU, typically toward the nearest river valleys. The HSUs will possibly discharge as springs along the valley walls or feed directly or indirectly to the river or creek. On the west side of the mapsheet, groundwater in the Upper Floral HSU typically flows toward Buffalo Pound Lake, Arm River Valley, or the Moose Jaw River. On the northeast quarter of the mapsheet, the main direction of lateral groundwater flow in this unit will be toward the Qu’Appelle River.

In general, the water level of the Upper Floral Aquifer has been rising over the past decades as can be seen in the Riceton observation well (114726). This observation well has little to no influence from surrounding area wells on the recorded water levels (Figure 5.9). Since 1970 the water level has risen by approximately 0.25 m at the Riceton well. The Riceton observation well was originally interpreted as belonging to the Empress Group but through the reinterpretation of the area it was determined that it belongs to the Upper Floral HSU due to the presence of an underlying till unit.

![Figure 5.9 – Hydrograph for WSA observation well Riceton (114726) installed in the Upper Floral HSU.](image-url)
**Regina Aquifer:**
The groundwater level data suggests that flow in the Regina Aquifer is relatively flat around the Regina area but does have a northerly gradient toward Wascana Creek, Boggy Creek and the Qu’Appelle River. Aquifer discontinuities have been identified in the Regina Aquifer near the Regina sewage treatment plant (Beckie Hydrogeologists Ltd., 1993), resulting in irregular hydraulic gradients and complicated flow paths in those areas. South of Regina the gradient is very gradual but there is a slight southward gradient toward Rouleau and the Moose Jaw River.

Two observation wells are installed in the Regina Aquifer and are shown in Figure 5.10 and Figure 5.11. Water levels have been steadily rising in the Regina Aquifer since the middle to late 1990s and show much less influence due to pumping at both observation wells. This is due to the decommissioning and reduction in pumping from wells installed in this aquifer by the City of Regina in the late 1990s.

![Figure 5.10 – Hydrograph for WSA observation well Regina 530 (56992) installed in the Regina Aquifer.](image-url)
Figure 5.11 – Hydrograph for WSA observation well Regina Firehall (87410) installed in the Regina Aquifer.

Richardson Aquifer:
Groundwater flow from the Richardson Aquifer is toward Wascana Creek. There is upward vertical groundwater flow into Wascana Creek from this aquifer. Local springs and seeps in the vicinity of the creek evidence a groundwater discharge zone.

Zehner Aquifer:
The groundwater level data suggests that flow in the Zehner Aquifer is southwest toward Boggy Creek. A number of flowing artesian wells are located in the vicinity of Boggy Creek, where a groundwater discharge zone for the Zehner Aquifer is interpreted. The WSA observation well installed near Pilot Butte (Figure 5.12) shows a consistent pattern of seasonal groundwater usage with an up to one metre decline in water level through the summer months and then rebounding every winter. This pattern occurs up to 2010. Since 2010, seasonal fluctuation is not apparent and the potentiometric surface has risen by over one metre above the previous levels. The City of Regina - Boggy Creek well field (supplying water for the City of Regina) was partially decommissioned in 2008 (Beckie Hydrogeologists Ltd., 2008), which may have some impact on water levels.
The groundwater level readings for the Riddell Member of the Northern Aquifer indicate that the groundwater flow is northward to the Qu’Appelle River. The Mound Springs well field used as a water supply for the City of Regina located in the southwest corner of the Northern Aquifer has also been decommissioned. Water levels in this area have likely followed a similar pattern of rebound following the decommissioning of pump wells in 1993 and 2010. No WSA observation well is installed in the Northern Aquifer to confirm this.

5.13.3 Groundwater Availability
The total allocation for licensed wells installed in the Upper Floral HSU is 7,656.8 dam$^3$/y; of this 45% is used by municipalities and 53% by industrial users (Table 3.6). The allocation to meet municipal water demand used to be much higher from the Upper Floral HSU. Since the early 1990s a number of municipal wells have been decommissioned as surface water sources have become more dependable and the groundwater sources are only accessed during periods of high demand. As recently as 2010, the West Regina well field installed in the Regina Aquifer, the Boggy Creek well field installed in the Zehner Aquifer, and the Mound Springs well field installed in the Northern Aquifer, have been decommissioned with only a few of the wells at each location still operational for emergency purposes. The high rainfalls in 2010 and resulting flooding have likely increased the recharge of the Upper Floral in recent years. These events have resulted in observed water levels rising in recent years (Figure 5.10, Figure 5.11, and Figure 5.12).
Water allocated from users of the Upper Floral HSU not including the Regina, Richardson, Zehner, or Northern aquifers is 960.7 dam$^3$/y, in the Regina 72I area. The Towns of Regina Beach, Milestone, McLean, Holdfast, Sedley, and Wilcox are the primary users of this HSU. The recommended pumping rate from the 165 WWDRs with short-term pumping test information known to be installed in the Upper Floral HSU ranges from 10 m$^3$/d to 655 m$^3$/d with an average recommended pumping rate of 86 m$^3$/d.

**Regina Aquifer:**
The Regina Aquifer has been a highly utilized aquifer in the area for both municipal and industrial users. Current groundwater allocation is 5,551.8 dam$^3$/y from all licensed users. Industrial users, primarily the Consumers Co-Op Refinery Ltd. (CCRL) facility, receive 74% of this allocation. Actual water usage by CCRL for the last year on record was 1,436.7 dam$^3$/y which amounts to only 39% of their actual allocation of 3,900 dam$^3$/y.

Sustainable well yields determined in hydrogeological reports on the aquifer range from a minimum of 491 m$^3$/d (Clifton and Associates, 1996) to 13,840 m$^3$/d (Beckie Hydrogeologists Ltd., 1992). On average the sustainable well yield for the Regina Aquifer is 4,689 m$^3$/d. These high yields are from professionally designed wells that have been carefully installed and developed to achieve these high extraction volumes, either for the City of Regina or CCRL. A proper hydrogeological investigation should be undertaken prior to installing any wells capable of pumping such high volumes. It is noted that sustainable well yields may not reflect the sustainable yield of the aquifer.

The recommended pumping rate from the 58 WWDRs known to be installed in the Regina Aquifer ranged from 13 m$^3$/d to 3,927 m$^3$/d, with an average of 584 m$^3$/d. It is noted that higher individual well yields could be possible but water requirements at these rates would likely require extensive testing, multi-well arrays, and could have large scale impacts.

**Richardson Aquifer:**
Only one industrial user is noted from the Richardson Aquifer with an annual allocation of 1 dam$^3$/y. The recommended pumping rate from the one reported well installed in the aquifer was 164 m$^3$/d. This rate was achievable by allowing the well to flow naturally by its flowing artesian conditions.

**Zehner Aquifer:**
The upper Floral portion of the Zehner Aquifer is not as utilized by licensed groundwater users as the lower Floral zone of the aquifer. The licensed wells extracting water from the upper Zehner Aquifer have an annual allocation of 1,141 dam$^3$/y. The Town of Balgonie and the City of Regina account for 28% and 71% of that allocation, respectively. Actual water use by the City of Regina is generally much lower than this since the city will only withdraw groundwater as a backup to their surface water supply during periods of high demand. Allocation from licensed wells in the Lower Floral Formation zone of the aquifer is 3,495.1 dam$^3$/y for a total allocation of 4,636.3 dam$^3$/y for the entire Zehner Aquifer.
A sustainable well yield of 655 m³/d (Mollard and Associates, 1975) was determined for the Balgonie pump well. The recommended pumping rate from the 45 WWDRs known to be installed in the upper Floral stratified sediments of the Zehner Aquifer with short-term pumping tests performed on the well was from 13 m³/d to 655 m³/d, with an average of 84 m³/d. It is noted that higher individual well yields could be possible but water requirements at these rates would likely require extensive testing, multi-well arrays, and could have large scale impacts.

**Northern Aquifer:**
The upper Floral sediments of the Northern Aquifer is not utilized much by licensed groundwater users as only 2 dam³/y for use in a poultry operation are allocated. A sustainable well yield of 864 m³/d and 1,296 m³/y (SRC, 1985) was calculated for two of the pump wells installed in the Mound Springs well field in the upper Northern Aquifer. The recommended pumping rate from the 18 WWDRs installed in the upper unit of the Northern Aquifer ranged from 20 m³/d to 1,257 m³/d, with an average rate of 279 m³/d.

**5.13.4 Groundwater Quality**
A Piper Diagram of the groundwater sampled from the Upper Floral HSU is provided in Figure 5.13. The Piper Diagram illustrates that the groundwater chemistry from the Upper Floral HSU is very similar to that of the Lower Floral HSU. The water from the Upper Floral HSU is primarily characterized as a calcium-sulfate, sodium-sulfate, and/or magnesium-sulfate type water in 74% of the water samples. It is also common for the water to be classified as a calcium-bicarbonate or magnesium-bicarbonate type water (Table F5 – Appendix F). Sulfate rich groundwater is typical for waters that have migrated through glacial deposits, whereas bicarbonate type water is typically caused by the dissolution of carbonates and dolomites by carbonic acid (H₂CO₃) in the shallow surface. Bicarbonate type water is more typical in recharge areas and younger, less chemically evolved groundwater.

The TDS concentration in sampled groundwater ranged from 368 mg/L (77180 – Zehner Aquifer) to 7,120 mg/L (114726 (SRC Riceton) – Qf-ms) with an average concentration of 1,560 mg/L. The CCME drinking water objective for sulphate is exceeded in 43% of samples. The TDS, iron and manganese concentrations generally exceed the respective CCME drinking water quality objectives.
Water from the Regina Aquifer is dominantly calcium-sulfate type water with a higher hardness concentration than that found in the other Upper Floral HSUs of 795 mg/L, just below the SDWQSO aesthetic objective of 800 mg/L. The average TDS concentration is 1,473 mg/L.

Richardson Aquifer:
Only two water samples collected from the Richardson Aquifer. Both are sodium-sulfate type water with a lower hardness and alkalinity concentration than found in the other aquifers. The average TDS concentration is 2,167 mg/L.

Zehner Aquifer:
Is dominantly calcium-sulfate to calcium-bicarbonate type water with a high hardness concentration of 766 mg/L and a lower iron concentration than in the other Upper Floral HSUs. Average TDS concentration of the Northern Aquifer is 1,311 mg/L.

**5.13.5 Groundwater Vulnerability**

Figure E9 (Appendix E) shows the vulnerability of Upper Floral HSU to contamination from a surficial source in the Regina 72I area. The AVI is predominantly high due to the proximity of
these stratified deposits to the surface. There are some moderate to very high to rated patches in the study area.

5.14 The Battleford HSU (Qb-s)

Stratified sediments at the contact between the Battleford and Floral Formation are informally named the Battleford HSU in this report. Figure D15 (Appendix D) shows the thickness and the areal limits of this unit in the Regina 72I area. The Battleford HSU is highly discontinuous across the Regina mapsheet and generally found as thin stratified deposits that are rarely used as a water resource. Two notable exceptions to this are the laterally continuous stratified deposits of the Condie Moraine, called the Condie Aquifer and the Moose Jaw Moraine which are both utilized as a water resource. The Battleford HSU over the Regina 72I area has been interpreted to occur at depths of 0.0 m to 21.3 m (43443 (DOE Baildon 7)), but on average has been encountered at depths of 5.8 m. The average thickness of the HSU is 10.8 m with a maximum encountered thickness 45.4 m (14782 (SRC Moose Jaw), cross-section H-H') in the study area. Due to their relatively shallow depth, the Battleford HSU is highly influenced by seasonal runoff and precipitation.

Condie Aquifer:
The east-west trending Condie Moraine, is located across the northern half of Regina and out past the city limits on either side. The moraine forms one of the most noticeable landforms in the area rising more than 30 m above the surrounding area. The moraine was deposited during the last glaciation when the glacial margin stood just north of Regina. Large quantities of stratified deposits were deposited at the toe of the glacier which were subsequently covered by till as the glacier re-advanced over the moraine (Christiansen, 1961, 1979a, and 1979b). The stratified deposits found within the Condie moraine and in the sand and silt aprons south of the moraine have been identified as the Armour Member by Christiansen and Sauer (2002). The sediments at the base of the Armour Member are course sands and gravels which fine upward. As the sediments of the Armour Member became saturated within the moraine they formed what is now the Condie Aquifer. At the IPSCO site, just north of Regina, the coarse sands and gravels are well defined (Maathuis and Campbell, 1998b). The Condie Aquifer is found at ground surface to depths up to 20.1 m (114993). The aquifer has an average thickness of 13.5 m, with a maximum thickness of 40.5 m (77128).

Moose Jaw Moraine:
The Moose Jaw Moraine forms a northwest to southeast trending ridge of fluvial sand and gravels which was deposited on the lower reaches of the Thunder Spillway upstream of glacial Lake Regina as the glacier was retreating at the end of the last glaciation (Christiansen, 1961, 1979a, and 1979b). During deposition the moraine was situated in an ice-walled channel cut between a wall of stagnant ice to the south, wedged up against the Missouri Couteau, and the retreating active glacier to the north (Meneley, 1975). Following deposition of the moraine the glacier continued to retreat to the north and glacial Lake Regina grew in extent covering the moraine. Lacustrine silts and clays from glacial Lake
Regina drape over the southeastern region of the moraine which can be seen in cross-section E-E' (Appendix C). A laterally continuous aquitard unit of silt and clay is prevalent through the Moose Jaw Moraine and appears to the more permeable sands into an upper and lower zone as shown by water level data. An extensive network of monitoring wells have been installed in the Moose Jaw Moraine around the Baildon area to gather water quality and ground water level data in support of the Baildon Moose Jaw effluent irrigation study with the monitoring wells installed in 1975 (Meneley, 1975) and the initiation of the effluent irrigation program in 1982 (Hogg et al., 1997).

The Moose Jaw Moraine is included as a Battleford aged deposit as evidence of till is found within and overlying the moraine in places and deposition of the sediments was within the glacial environment. The Moose Jaw Moraine sediments are found at ground surface to depths up to 21.3 m (43443). The stratified deposits have an average thickness of 14.1 m, with a maximum thickness of 45.4 m (14782 (SRC Moose Jaw), cross-section H-H').

### 5.14.1 Hydraulic Properties

Hydraulic properties for the Battleford HSU in the Regina 72I area were obtained from an available groundwater investigation report from a feedlot located approximately 15 km east of Craven. The transmissivity and storativity was estimated to range from 655 m$^2$/d to 1,440 m$^2$/d and 3.6x10$^{-4}$ to 1.3x10$^{-3}$, respectively. The hydraulic conductivity of the Battleford HSU is expected to be within the typical range for an HSU (1x10$^{-3}$ m/s to 1x10$^{-6}$ m/s).

**Condie Aquifer:**

A number of studies conducted by the City of Regina, the Town of Pilot Butte and some industrial facilities in the area have conducted pumping tests on wells installed in the Condie Aquifer (Beckie Hydrogeologists Ltd., 1984, 1986, and 2003, Clifton and Associates, 2003, Saskmont Engineering, 1991, and Maathuis, et al., 1992). The minimum, mean, and maximum hydraulic properties of the Condie Aquifer from these reports are:

1. Transmissivity – 298 m$^2$/d, 1,832 m$^2$/d, and 4,474 m$^2$/d, respectively;
2. Storage coefficient – 1.0x10$^{-4}$, 0.2, and 0.3, respectively; and
3. Hydraulic conductivity – 2.5x10$^{-4}$ m/s, 1.4x10$^{-3}$ m/s, and 3.1x10$^{-3}$ m/s, respectively.

**Moose Jaw Moraine:**

A project area run by SIAST was used to conduct pump tests in the Moose Jaw Moraine as a training project for students in the Baildon area (SIAST, 2000, 2008, and 2010). They evaluated the transmissivity and storativity to range from 29.1 m$^2$/d to 88.9 m$^2$/d and 7.3x10$^{-4}$ to 1.5x10$^{-3}$, respectively. Only one value for hydraulic conductivity was provided of 2.0x10$^{-4}$ m/s.

### 5.14.2 Groundwater Flow

Lateral groundwater flow within the Battleford HSU will be strongly topographically focused. The groundwater flow pattern within this unit will be generally focused towards local sloughs and depressions. This HSU is generally recharged by infiltrating meteoric water.
**Condie Aquifer:**
The groundwater flow in the Condie Aquifer has been examined in depth in a couple of reports (Maathuis *et al.*, 1992, Maathuis and Campbell 1996 and 1998b, and Ballagh, 1997). Generally, the groundwater flows from east to west. The aquifer is recharged on its eastern side where the sands are not covered by much if any till at surface. The Battleford Formation till is thicker through the central and western side of the Condie Aquifer, and forms an aquitard above the aquifer. Groundwater also flows out to the north and south away from the thick core of the moraine. The groundwater moves at a nearly constant rate along the core of the moraine as indicated by a nearly constant rate of groundwater level change over distance (Maathuis *et al.*, 1992). Lateral groundwater flow was estimated at a rate of 380 m/y by Maathuis et al. (1992).

In the west-central region of the Condie Aquifer a strong vertical gradient was identified between the Condie Aquifer and the underlying Regina Aquifer (Maathuis and van der Kamp, 1988 and Maathuis *et al.*, 1992). In the IPSCO site the Condie Aquifer has a water level around 569 masl to 572 masl and the Regina Aquifer's water level is from 557 masl to 558 masl resulting in a 12 m to 15 m head difference (Maathuis and Campbell, 1998b). The main zone of water loss from the Condie to the Regina Aquifer is not known exactly, but is likely to be located west of the IPSCO site based on the noted reduction in lateral hydraulic conductivity moving west from that location in the Condie Aquifer. Prediction for the amount of vertical groundwater flow from the Condie down to the Regina Aquifer is difficult due to the change in both the aquitard thickness between the aquifers over distance and the variability in vertical hydraulic conductivity. In general, vertical flow from the Condie Aquifer down to the Regina Aquifer is likely, but at a much slower rate than the lateral groundwater flow.

Two observation wells are installed in the Condie Aquifer and are shown in Figure 5.14 and Figure 5.15. The observation well at Pilot Butte (87403) located at the east end of the aquifer has a much higher water level (~610 masl) as compared to that at the Regina Winnipeg observation well (~577.4 masl) located at the western half of the aquifer. This supports the groundwater flow direction of east to west. Similar to the Regina Aquifer, the water levels in the Condie Aquifer have increased over the past couple years which may be attributed to the reduction in pumping from the aquifer along with a potentially higher recharge rate.
Figure 5.14 – Hydrograph for WSA observation well Pilot Butte North (87403) installed in the Condie Aquifer.

Figure 5.15 – Hydrograph for WSA observation well Regina Winnipeg (87411) installed in the Condie Aquifer.
Moose Jaw Moraine:
Groundwater flow in the Moose Jaw Moraine is topographically focussed and as such the dominant groundwater flow direction is to the northeast to east toward the Moose Jaw River. The groundwater level has been influenced since the start of the effluent irrigation project in 1982 showing a marked rise since that time as seen in Figure 5.16 and Figure 5.17. Since the water used for irrigation in the area is from the effluent at the Moose Jaw water treatment facility none of the water is extracted from the Moose Jaw Moraine resulting in a net increase of water added to the area. Each year a rapid increase in water level is noted through the spring and early summer and then a similar drop after irrigation is completed for the year. The water level in a well installed in the upper zone has shown an increase of approximately 4 m since irrigation began and up to 5 m increase has been noted from a well installed in the lower zone (Hogg et.al. 1997). The trend for the deep wells showing an increase suggests there is a direct response to the irrigation in the area.

Figure 5.16 – Hydrograph for WSA observation well Baildon 59 (43453) installed in the Moose Jaw Moraine.
5.14.3 Groundwater Availability

The Battleford HSU is generally not used for water supply due to its discontinuous nature and shallow depth. In the study area, the licensed groundwater water allocation from the Battleford HSU, not including the Condie Aquifer, is 238.3 dam$^3$/y. The largest allocation (83 dam$^3$/y) is for irrigation purposes east of Craven and the second largest allocation (43.4 dam$^3$/y) is for recreational purposes. A sustainable yield was determined for the irrigation well east of Craven at 229 m$^3$/d (Watermark, 2006). From the 7 WWDRs installed in the Battleford HSU, the range of recommended pumping rates are 10 m$^3$/d to 262 m$^3$/d, with an average of 74 m$^3$/d. Due to the high variability of the Battleford HSU in regards to its areal extent and composition, potential yields may be very different from site to site.

Condie Aquifer:

The licensed wells extracting water from the Condie Aquifer have an annual allocation of 1,515 dam$^3$/y. A subdivision east of Regina, the City of Regina and a local golf course account for 66%, 20% and 8% of that allocation, respectively. Sustainable well yields of the Condie Aquifer have been determined from a number of reports and aquifer characterizations studies completed on this aquifer (Beckie Hydrogeologists Ltd., 1984, 1986, Clifton and Associates, 2003, Maathuis, et.al., 1992, and Saskmont Engineering, 1991). A minimum, mean, and maximum sustainable well yield was determined as 294 m$^3$/d, 1,495 m$^3$/d, and 2,160 m$^3$/d, respectively. For data where a short-term pumping test had been performed, the recommended pumping rate from the 43 WWDR records interpreted to
be installed in the Condie Aquifer ranged from 13 m³/d to 196 m³/d, with an average rate of 68 m³/d.

**Moose Jaw Moraine:**
There are five licensed wells extracting water from the Moose Jaw Moraine with an annual allocation of 144 dam³/y. A livestock operation and the RM of Baildon account for 83% and 17% of the allocation respectively. Seventeen WWDRs have been identified as installed in the Moose Jaw Moraine, they have a range of recommended pumping rates from 20 m³/d to 393 m³/d, with an average rate of 95 m³/d.

### 5.14.4 Groundwater Quality

A Piper Diagram of the analyzed groundwater from the Battleford HSU (available for the study area) is provided in Figure 5.18. Water from the Battleford HSU is characterized as calcium-bicarbonate type water, typical of water in a recharge zone. A TDS of 927 mg/L was determined from the one Battleford HSU sample collected outside of the Condie Aquifer and Moose Jaw Moraine (Table F6; Appendix F).

**Condie Aquifer:**
The Condie Aquifer had the highest number of available water chemistry data in the area. Water from the Condie Aquifer is dominantly a calcium-sulphate type with some samples identified as calcium-bicarbonate type water (Figure 5.18). The TDS concentration in sampled groundwater ranged from 456 mg/L (115236) to 4,216 mg/L (226211 (IPSCO 96-05)), with an average concentration of 1,560 mg/L. Water in the Condie Aquifer is rich in sulfate, with the CCME drinking water objective being exceeded in 63% of samples. A number of those samples have sulphate concentrations above 1,000 mg/L and are associated with some of the industrial sites in the area. The TDS and manganese concentrations generally exceed the respective CCME drinking water quality objectives.

Historical and ongoing affects on the groundwater chemistry of the Condie Aquifer has occurred due to its proximity to surface, with elevated TDS, sulphate, and chloride concentrations identified in the vicinity of several facilities. The chloride concentrations only exceed the CCME guideline for drinking water (250 mg/L) at a few locations. Those samples with chloride concentrations over 100 mg/L in the Condie Aquifer are noted on the Piper Diagram to illustrate its affect on the water chemistry (Figure 5.18).

**Moose Jaw Moraine:**
The Moose Jaw Moraine has available water chemistry data from the mid 1970’s when the series of monitoring wells were installed and multiple sample dates collected from the two dedicated WSA observation wells (43423 (Baildon 60) and 43453 (Baildon 59)) in the area. Water from the Moose Jaw Moraine is dominantly a calcium-bicarbonate type with some samples identified as calcium-sulfate type water and one sample of magnesium-bicarbonate type (Figure 5.18). The TDS concentration in sampled groundwater ranged from 251 mg/L (43433 (Baildon 33)) to 3,170 mg/L (43464 (Baildon 56)), with an average concentration of 1,003 mg/L. From an analysis of groundwater samples collected up to 1995 within the
effluent irrigation project site there has been an increased concentration of sodium, chloride, sulfate and bicarbonate noted in the shallow piezometer samples (Hogg, et al. 1997). Samples collected from the deeper horizons (i.e. >15 m depth) appear to be unaffected. The Battleford HSU is vulnerable to contamination from the surface.

5.14.5 *Groundwater Vulnerability*

Figure E10 (Appendix E) shows the very high vulnerability of the Battleford HSU in the Regina 72I area. The AVI is very high for this mappable stratified unit and highly susceptible to contamination from the surface, because there is little to no confining aquitard layer above the sediments of the Battleford HSU. A well documented 7,700 m long chloride contaminant plume has been identified in the Condie Aquifer. It was caused by the use of water softener salt at the Provincial Correctional Centre increasing the concentration of chloride in its effluent discharged into the sewage reservoir from 1964 to 1991 (Maathuis et al., 1992). This is just one example of contamination in the Condie Aquifer from discharge of contaminants on the surface without proper containment.

![Image](image.png)

*Figure 5.18 – Piper Diagram of groundwater chemistry for the Battleford HSU (Qb-s).*

5.15 *The Surficial Stratified Deposits*

A complex arrangement of stratified post-glacial sediments comprise the Surficial Stratified Deposits. These deposits have been encountered in thicknesses up to 27.1 m (226228) found north of the town of Zehner; the average thickness of this unit is 6.5 m. Figure D16 (Appendix D) shows the interpreted lateral extent and thickness of the Surficial Stratified Deposits.
The most extensive surficial deposit in the area is the Regina Clay lacustrine deposits found over most of the central and southern region of the mapsheet. While the Regina Clay is the most extensive unit it acts as an aquitard in the area and is not used as a water source. The depth, thickness, and extent of individual gravels, sands, silts, and clays are highly variable and the hydraulic connectivity between these units is highly complex. Due to the complexity of these deposits, a simplified interpretation is presented herein as they may form a relatively continuous “aquifer” in some areas.

Alluvial sand, silt, and gravel deposits situated in river valleys and streams are accessed as a water resource in the area. They have been encountered in thicknesses up to 97.5 m (17570 (SRC Muskowpetung)) in the Qu’Appelle River Valley, east of Pasqua Lake. The average thickness of alluvium encountered in the Regina 72I area is 20.3 m.

5.15.1 Hydraulic Properties

Many towns and RMs use the Surficial Stratified Deposits for water supply. One pump test was conducted on these deposits for the Town of Qu’Appelle (112476 (Qu’Appelle PW4)). A range for transmissivity was determined to be 211 m²/d to 497 m²/d, with a specific storage of 0.2. Hydraulic conductivity for the Surficial Stratified Deposits can be expected to be within a wide range from 1.0x10⁻¹¹ m/s to 1.0x10⁻³ m/s.

The alluvium has been assessed as a groundwater resource along the Qu’Appelle River at Lumsden and Fairy Hill, and in local alluvial deposits at Mossbank, just outside the southwest corner of the mapsheet. Transmissivity for the Qu’Appelle Valley alluvium ranged from 600 m²/d to 745 m²/d, with a storativity of 6.4x10⁻¹⁴. At Mossbank, the transmissivity of the alluvium was between 75 m²/d and 225 m²/d.

5.15.2 Groundwater Flow

Groundwater flow within the Surficial Stratified Deposits will be strongly topographically focused. The groundwater flow pattern within this unit will be focused towards sloughs and depressions on a local scale and toward the river valleys on a regional scale. The infiltration of meteoric water predominantly recharges these deposits in the study area.

Groundwater flow in the alluvium can be fairly complex due to the stratified nature of the deposit along with the high number of hydraulic connections with other units. Lateral groundwater flow in the alluvium will generally follow the direction of surface water flow. For the most part, vertical groundwater flow will be dependent on river or lake stage within alluvial deposits beneath the surface water courses.

5.15.3 Groundwater Availability

The sustainable yield from a surficial sand and/or gravel unit will depend largely on the thickness, areal extent, recharge rate, available drawdown, extraction rate, and continuity of these sediments. In the Regina 72I area, licensed groundwater water allocation from the surficial deposits is 817 dam³/y, with the majority being used for municipal purposes. The primary users of that allocation are in the Caronport area and Regina Beach.
yield of a well installed in a surficial aquifer near the Town of Qu’Appelle was 982 m$^3$/d
112476 (Qu’Appelle TH5(PW4)) (Beckie Hydrogeologists Ltd., 1980). The recommended
pumping rate ranged from 20 m$^3$/d to 131 m$^3$/d, with an average of 71 m$^3$/d, from the 4
WWDRs installed in the Surficial Stratified Deposits.

Licensed wells located in the alluvial deposits in the study area are given an annual
allocation of 356 dam$^3$/y all for municipal uses. The primary users are the Towns of
Lumsden and Craven in the Qu’Appelle River Valley. A sustainable yield of 1,636 m$^3$/d was
determined for the pump well in the Lumsden area (69173 (Lumsden TH4-81 (PW3-81))
(Beckie Hydrogeologists Ltd., 1981d), whereas a sustainable yield of 281 m$^3$/d was
evaluated for the well at Fairy Hill (103881) (Lebedin, 1992). A recommended pumping rate
of 20 m$^3$/d to 524 m$^3$/d, with an average rate of 167 m$^3$/d, was provided for the 13 WWDRs
installed in alluvium in the Regina 72I area.

5.15.4 Water Chemistry

Groundwater chemistry in shallow subsurface can be quite variable depending on residence
time in the ground. A Piper Diagram of the groundwater chemistry for the Surficial Stratified
Deposits is provided in Figure 5.19. Predominantly, water is a calcium or magnesium-sulfate
type with one calcium-bicarbonate type sample collected. Bicarbonate type water is caused
by the dissolution of carbonates and dolomites by carbonic acid ($\text{H}_2\text{CO}_3$). Carbonic acid is
formed when infiltrating rainwater reacts with CO$_2$ generated in the soil. In recharge zones,
the groundwater will be relatively fresh due to the limited residence time of the groundwater
in the near surface deposits. Higher TDS concentration groundwater can be expected in
local shallow discharge zones and can be highly mineralized. The available groundwater
chemistry is provided in Table F7 (Appendix F). Four of the samples show elevated sulphate
and TDS values and suggest a groundwater discharge zone or impact from anthropogenic
sources, with from the Moose Jaw Moraine and the other two from the IPSCO site. TDS
concentrations measured in the Surficial Stratified Deposits ranged from 739 mg/L (85861
(CofR Mt. Pleasant MP-1AL) to 4,143 mg/L (85800 (IPSCO CAL507). Water sampled from
wells installed in the alluvium had a lower TDS of 1,381 mg/L than that found in the Haultain,
likely due to less residence time or impact from surface sources.
5.15.5 Groundwater Vulnerability

The vulnerability of the Surficial Stratified Deposits is very high since they are at surface. Where these sediments are present it is susceptible to contamination from a surface source. Waste containment facilities and operations with the potential to release contaminants at surface should be designed accordingly.

6.0 ACKNOWLEDGEMENTS

This project was commissioned by the Water Security Agency, who recognized the need to update the mapping of groundwater resources in Saskatchewan and the Regina area. The WSA provided the majority of available water well and borehole data for the Regina area along with water quality databases, numerous reports, and historical studies. The Saskatchewan Research Council aided in the efforts through providing the data from their stratigraphic holes and interpretations along with carbonate data for the area. The previous large scale studies conducted by the SRC of the Regina area provided the framework upon which this report is built. Finally, to the team who helped put this project together, interpreting the thousands of logs, compiling all the data, development of the GIS framework, and creation of the cross-sections. Thank you.
7.0 CLOSURE

The hydrogeological mapping of the Regina 72I NTS Mapsheet was completed as authorized by the Water Security Agency. This report was prepared for the Water Security Agency in accordance to generally accepted geo-environmental engineering practice, no other warranty, expressed or implied is made.

We trust that this report meets your needs. Please contact the undersigned if you have any question or concerns, or if we can be of further assistance.

Respectfully submitted,

MDH Engineered Solutions Corp., a member of the SNC Lavalin Group

Association of Professional Engineers and Geoscientists of Saskatchewan
Certificate of Authorization Number 662

Water Security Agency – Hydrogeological Mapping of NTS Mapsheet Regina 72I.
(608886_M2749-1030111) 30 May 2013

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9.0 GLOSSARY OF TERMS

Aeolian – Pertaining to the wind; erosion and deposition of sediment accomplished by the wind.

Alluvial deposition – Material deposited by a stream or running water.

Analyte – A substance or chemical constituent that is determined in an analytical procedure.

Anthropogenic – of, relating to, or resulting from the influence of human beings on nature.

Atterberg limits – Basic measure of the nature of a fine-grained soil. Depending on the water content of the soil, it may appear in four states: solid, semi-solid, plastic and liquid. In each state the consistency and behavior of a soil is different and thus so are its engineering properties. Thus, the boundary between each state can be defined based on a change in the soil’s behaviour. The Atterberg limits can be used to distinguish between silt and clay, and it can distinguish between different types of silts and clays.

Aquifer – An underground layer of permeable rock, sediment (usually sand or gravel), or soil that yields water. The pore spaces in an aquifer is filled with water and is interconnected, so that water flows through it. Sandstones, unconsolidated gravels and sands, and porous limestones make the best aquifers. They can range from a few square kilometres to thousands of square kilometres in size.

Aquitard – A geologic formation that inhibits the flow of groundwater.

Baseline conditions – Data that depicts conditions prior to development or disturbances.

Bedrock – The native consolidated rock underlying glacial deposits.

Borehole – An exploratory drill hole used for the classification and sampling of geological layers and aquifers.

Boulder – A detached rock mass having a diameter greater than 256 mm being somewhat rounded or otherwise distinctively shaped by abrasion in the course of transport.

Brine – Water saturated or nearly saturated with salts and other soluble minerals.

Bulk hydraulic conductivity – An average hydraulic conductivity accounting for soil variability.

Calcareous – Containing calcium carbonate; when it applies to a rock name, it implies that as much as 50% of the rock is calcium carbonate.

Canadian Shield – A large region of exposed basement rocks on the North American continent.

Carbonate – A mineral compound characterized by a fundamental anionic structure of CO3.

Carbonate content – A laboratory measure of carbonate content of a soil generally expressed in ml/CO2/g

Cenozoic Era – The latest of the four eras into which geologic time is divided; it extends from the close of the Mesozoic Era, about 65 million years ago, to the present.

Clastic – Pertaining to a rock or sediment composed principally of fragments derived from pre-existing rocks or minerals and transported some distance from their places of origin.

Clay – Soil particles smaller than 0.002 mm (ISO 14688). These materials also have plasticity properties.

Cobble – A rock fragment between 64 and 256 mm in diameter, rounded or otherwise abraded in the course of aqueous, aeolian, or glacial transport.

Colluvial deposit – A general term applied to loose and incoherent deposits, usually at the foot of a slope or cliff and brought there chiefly by gravity.

Concretionary – Characterized by, consisting of, or producing a hard, compact aggregate of mineral matter, subspherical to irregular in shape, formed by precipitation from water solution around a nucleus, such as a shell or bone, in a sedimentary or pyroclastic rock. Concretions are generally different in composition from the rock in which they occur and represent a concentration of some minor constituent of that rock.

Connate water – Water entrapped in the interstices of a sedimentary rock at the time the rock was deposited.

Consolidation – Any process whereby loose or soft earth materials become firm and coherent.

Contamination – To make impure or unclean by contact or mixture.

Decommission – To withdraw from active service.
Deep evaporite deposit – Sediments which are deposited from aqueous solution as a result of extensive or total evaporation.

Deltaic deposit – Assemblage of sediments accumulated where a stream flows into a body of standing water, its velocity and transporting power suddenly reduced.

Dolomites – A common rock-forming mineral, CaMg(CO\textsubscript{3})\textsubscript{2}; it is white to light coloured and has perfect rhombohedral cleavage.

Drawdown cones – Reduction of the pressure head as a result of the withdrawal of water from a well.

Drift – A general term for all rock material transported by glaciers and deposited directly from the ice or through the agency of meltwater.

Effective stress – The average normal force per unit area transmitted directly from particle to particle of a soil or rock mass; it is the stress that is effective in mobilizing internal friction.

Eskers – A serpentine ridge of roughly stratified gravel and sand that was deposited by a stream flowing or beneath the ice of a stagnant or retreating glacier and was left behind when the ice melted.

Faulting – The process of fracturing and displacement that produces a fracture or fracture zone along which there has been displacement of the sides relative to one another parallel to the fracture.

Fluvial – Of or pertaining to rivers.

Geomorphology – The study of the classification, description, nature, origin, and development of landforms and their relationships to underlying structures and the history of geologic changes as recorded by these surface features.

Geophysical – Of or concerned with the physics of the earth and its environment.

Glaciation – The formation, movement, and recession of glaciers or ice sheets. Any of several minor parts of geological time during which glaciers were more extensive than at present; a glacial epoch, or a glacial stage.

Grain size distribution – The variation in the diameter of individual grains of sediment.

Gravel – Any loose rock that is larger than 2 millimetres and no more than 63 millimetres.

Groundwater – Water located beneath the ground surface in soil pore spaces and in the fractures of lithologic formations.

Groundwater recharge – A process involving in the addition of groundwater to a zone of saturation.

Gypsiferous – Comprised of gypsum (a widely distributed mineral consisting of hydrous calcium sulfate:CaSO\textsubscript{4} \cdot 2H\textsubscript{2}O).

Hard water – Water high in ions of calcium and magnesium.

Head – The elevation to which water rises at a given point as a result of reservoir pressure.

Horizons – An interface that indicates a particular position in a stratigraphic sequence.

Hummocky topography – Variable topography with numerous knobs and kettles, they have a round broad shape and are formed by ice deposited below the surface that thaws and freezes to form an undulating surface.

Hydration – The chemical combination of water with another substance.

Hydraulic barrier – A general term that refers to a groundwater flow boundary, usually induced by groundwater pumping, that significantly impedes the movement of dissolved contaminants.

Hydraulic conductivity – Ease with which water can move through pore spaces or fractures in a medium.

Hydraulic gradient – In an aquifer, the rate of change of total head per unit of distance of flow at a given point and in a given direction.

Hydraulic head – A specific measurement of water pressure or total energy per unit weight above a geodetic datum.

Hydrocarbon – Any organic compound, gaseous, liquid, or solid consisting solely of carbon and hydrogen.

Hydrostratigraphic unit – A geologic framework consisting of a body of sediment and/or rock characterized by groundwater flow having considerable lateral extent and composing a reasonably distinct hydrologic system, and
is distinguishable from flow in other hydrostratigraphic units. A hydrostratigraphic unit may contain more than one aquifer within it as long as they show a similar stratigraphic correlation and hydraulic connectivity.

**Ice Thrust** – The structural deformation of glacial and non-glacial sediments caused by the thrust of an overriding glacier moving the sediment in a cohesive slab forming distinctive ridges that are parallel to the glacier front which formed them.

**Igneous** – Of a rock or material that solidified from molten of partly molten material.

**Incised** – Cut into.

**In-situ** – Within a structure/feature (e.g. within the ground).

**Interstadial** – A warmer sub-stage of glaciation, marked by a temporary retreat of ice.

**Intertill deposits** – Material placed down between glaciations.

**Intratill deposits** – Material placed down during glaciation.

**Isopach** – A line drawn on a map through points of equal thickness of a designated stratigraphic unit or group stratigraphic units.

**Kame** – A moundlike hill of poorly sorted drift, mostly sand and gravel, deposited on the edge or near the terminus of a glacier. A kame may be produced either as a delta of a meltwater stream or as an accumulation of debris let down onto the ground surface by the melting glacier. In small areas, kames may form the terminal moraine.

**Lacustrine** – Pertaining to, produced by, or inhabiting a lake or lakes.

**Limestone** – Sedimentary rock consisting chiefly of mineral calcite (calcium carbonate, CaCO₃), with or without magnesium carbonate.

**Liquid limit** – The water content boundary between the semi-liquid and the plastic states of a sediment.

**Lithology** – The description of rocks on the basis of such characteristics as color, mineralogical composition, and grain size.

**Marine regression** – Coastal advance due to falling sea level.

**Marine transgression** – An event during which sea level rises relative to the land, resulting in coastal flooding, the opposite of marine regression.

**masl** – Meters above sea level.

**Mesa** – An isolated, nearly level landmass standing distinctly above the surrounding country with steeply dipping sloping sides.

**Metamorphic** – Of a rock or material derived from pre-existing rocks by mineralogical, chemical, and/or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the earth’s crust.

**Meteoric water** – Water that occurs in or is derived from the atmosphere.

**Moisture content** – The amount of moisture in a given soil mass, expressed as weight of water divided by weight if oven-dried soil, multiplied by 100 to give a percentage.

**Moraine** – A mass of till (boulders, pebbles, sand, and mud) deposited by a glacier, often in the form of a long ridge. Moraines typically form from the ploughing effect of a moving glacier pushing the entrained material to the lateral edges or terminus of the glacier and deposited during the periodic melting of the ice in warmer intervals. A moraine deposited in front of a glacier is a terminal moraine. A moraine deposited along the side of a glacier is a lateral moraine.

**Non-conformable** – An unconformity between rock/soil units representing a break in geological time.

**Organic** – Pertaining or relating to a compound containing carbon, especially as an essential component; organic compounds usually have hydrogen bonded to the carbon atom.

**Overconsolidated** – Consolidated to a greater extent than that due to the overburden.

**Oxidization** – The process of becoming oxidized (the portion of soil that has been previously exposed to air; reacted with oxygen).

**Paleo-oxidized horizons** – Old or ancient horizons that have been exposed to weathering.
Paleozoic Era – The earliest of three geologic eras of the Phanerozoic eon. The Paleozoic spanned from roughly 542 to 251 million years ago and is subdivided into six geologic periods; from oldest to youngest they are: the Cambrian, Ordovician, Silurian, Devonian, Carboniferous, and Permian.

Permeability – The capacity of a porous rock, sediment, or soil for transmitting a fluid; it is a measure of the relative ease of fluid flow under unequal pressure.

Piezometer – Small diameter water well used to measure the hydraulic head of groundwater in aquifers; allows access for sample collection and monitoring of contaminant transport through aquifers.

Piper Diagram – A trilinear plot that visually describes differences in major ion chemistry in groundwater flow systems and permitting a reference to water compositions by identifiable groups and categories.

Plastic limit – The water content boundary of a sediment where it move from a plastic to a brittle state.

Plasticity index – The percent difference between moisture content of soil at the liquid and plastic limits.

Plateau – A relatively elevated area of comparatively flat land which is commonly limited on at least one side by an abrupt descent to lower ground.

Porewater pressures – Pressures developed in the micro and macro pores of soils due to hydraulic heads and overlying material.

Potable – Water that is safe and palatable for human use.

Potash – An impure form of potassium carbonate used primarily as a fertilizer.

Potentiometric surface – A hypothetical surface representing the level to which groundwater would rise if not trapped in a confined aquifer (an aquifer in which the water is under pressure because of an impermeable layer above it that keeps it from seeking its level). The potentiometric surface is equivalent to the water table in an unconfined aquifer.

Precambrian – An informal name for the supereon comprising the eons of the geologic timescale that came before the current Phanerozoic eon. It spans from the formation of Earth around 4500 million years ago (Mya) to the evolution of abundant macroscopic hard-shelled animals, which marked the beginning of the Cambrian, the first period of the first era of the Phanerozoic eon, some 542 Mya.

Preconsolidation pressure – Pressure exerted on unconsolidated sediment by overlying material that resulted in compaction; the overburden may have been removed later by erosion.

Preglacial – Pertaining to the time preceding a period of glaciation.

Proglacial – Immediately in front of or just beyond the outer limits of a glacier or ice sheet, generally at or near its lower end.

Quaternary age – The second period of the Cenozoic Era, following the Tertiary; it began two to three million years ago and extends to the present.

Recharge rate – The rate of addition of water to the zone of saturation.

Response testing (Hydraulic) – A method of determining in-situ hydraulic conductivities of geologic layers, typically in aquifers.

Sand – Soil particles larger than silts, with diameters greater than 0.063 mm and less than 2 mm in diameter.

Sediment load – The solid material transports by a stream, expressed as the dry weight of all sediment that passes a given point in a given period of time.

Shale – A fine-grained sedimentary rock whose original constituents were clay minerals or muds. Characterized by its thin laminate breaking with an irregular curving fracture, often splintery and usually parallel to the often-indistinguishable bedding plane.

Silt – Soil particles larger than clay but smaller than sand particles. Defined by ISO14688 as particles between 0.002 and 0.063 mm in diameter.

Stacked piezometers – The installation of several piezometers in the same hole.

Standpipe piezometers – A piezometer with a tip that has a slotted PVC screen protected by a filter material.

Static conditions – Conditions that exhibit little or no change.

Storage coefficients – The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.
**Strandline** – The level at which a body of standing water meets the land.

**Storativity** – The volume of water released from storage per unit decline in hydraulic head in the aquifer, per unit area of the aquifer.

**Stratified** – Formed, arranged, or laid down in layers or strata.

**Stratigraphic** – A field of geology that studies rock and soil layers and layering.

**Stratigraphic control** – The degree of understanding of the stratigraphy of an area.

**Stratigraphic drilling** – A detailed method of drilling and classifying geological layers for the purposes of exploration, classification and/or monitoring.

**Subaerial** – Situated, formed, or occurring on or immediately adjacent to the surface of the earth.

**Subcrop** – Ancient erosional surface of bedrock that is now buried.

**Subsurface receptor** – Any underground structure which, on receiving environmental stimuli, produces a response.

**Surface casing** – A large diameter pipe that is assembled and inserted into a recently drilled section of a borehole and typically cemented into place; used to isolate freshwater zones from contamination during drilling and borehole completion or to prevent sloughing of poorly consolidated surficial deposits.

**Tertiary Period** – The first period of the Cenozoic era (after the Cretaceous of the Mesozoic era and before the Quaternary) thought to have covered the span of time between 65 million and 2 million years ago.

**Thalweg** – The centerline or deepest portion of a channel.

**Till** – Unstratified drift, deposited directly by a glacier without reworking by meltwater and consisting of a mixture of clay, silt, sand, gravel, and Youngs ranging widely in size and shape.

**Transmissivity** – The rate at which water of the prevailing kinematic viscosity is transmitted through a unit of hydraulic gradient; spoken as a property of an aquifer, embodies the saturated thickness and the properties of the contained liquid; is equal to the hydraulic conductivity multiplied by the thickness of the aquifer.

**Tributaries** – Any stream that contributes water to another stream.

**Unconfined conditions** – A situation where there is no confining layer between features (i.e. water table and the ground surface).

**Unconformity** – A break or gap in the geologic record, such as an interruption in the normal sequence of deposition of sedimentary rocks.

**Unoxidized** – Not oxidized (reacted with oxygen).

**Upper Cretaceous Period** – Refers to the second half of the Cretaceous Period (100 – 65 million years ago).

**UTM** – Universal Transverse Mercator, a projection used in mapping.

**Water content** – Water contained in porous sediment or sedimentary rock, generally expressed as a ratio of water weight to dry sediment weight.
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