CROWSNEST RIVER WATERSHED AQUIFER MAPPING AND GROUNDWATER MANAGEMENT PLANNING STUDY
TWPS 006 TO 009, RGES 01 TO 06 W5 ALBERTA

Submitted To:

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EXECUTIVE SUMMARY

The Oldman Watershed Council (OWC)has identified groundwater as a priority to address in the Integrated Watershed Management Plan for the Oldman River basin, located in south western Alberta. The objective of the study is to compile existing groundwater information to paint a picture of what is currently known and to set the stage for what needs to be done in the near future. Recommendations are included in this report that will assist in understanding the resource and managing it for long term sustainable use.

The OWC released *Priorities for the Oldman Watershed: Promoting action to maintain and improve our watershed* in January 2012 which outlines eight goals including one for groundwater. The OWC is developing an Integrated Watershed Management Plan for the Oldman River basin which will achieve the eight goals in the *Priorities* document. Goal five is “understand groundwater and how it interacts with surface water” which is followed by three objectives including one that states “research the availability and quality of groundwater and its interaction with surface water”. This study is a step towards meeting that objective.

This study also fulfills one of many outcomes of the Land Use Framework initiative for groundwater in the South Saskatchewan Regional Plan. The Government of Alberta is working on an integrated approach to land management that includes a new cumulative effects management system. Land use impacts on groundwater will have to be an integral part of that system but groundwater information is lacking.

The Oldman River drains into the larger South Saskatchewan River basin and Alberta Environment and Sustainable Resource Development has placed a moratorium on surface water diversion and use because it is fully allocated. The Crowsnest River watershed drains into the Oldman River east of Lundbreck, Alberta and therefore is also under moratorium with respect to surface water diversion. Groundwater resources beneath Crowsnest River form part of the water budget in the basin; the Oldman Watershed Council have come to recognize that a conceptual understanding of the subsurface hydrogeology is required. Waterline Resources Inc. was retained to develop the conceptual hydrogeological model within the Crowsnest River Watershed as it relates to water supply aquifers and interactions with surface water in Crowsnest River as well as to develop a groundwater monitoring plan for key aquifers within the watershed.

Average precipitation in the fall and winter (October to February) is generally between 20 mm and 32 mm between 1911 and 1958. The most rain, approximately 88 mm, falls in June.
Annual precipitation in the Crowsnest River Watershed, averaging 530 mm annually in the west and 453 in the east, ranges from 88 mm in June to 20 mm fall and winter.

Overburden deposits in the Crowsnest River watershed consist of pre-glacial, glacial, and recent alluvial deposits. Bedrock geology consists of highly complex, thrust faulted and folded geological sequences west of Highway 22. The following key groups of aquifers were identified:

- Surficial unconsolidated sediments such as
  - Pre-glacial buried valley aquifer (e.g, Middlefork Valley aquifer);
  - Glacial and recent alluvial aquifers in the vicinity of creeks and rivers such as Crowsnest River;
- Bedrock consisting of
  - Karstic carbonates consisting of solution cavities in limestone (e.g., Banff and Palliser formations and Rundle Group); and
  - Porous/fractured bedrock such as sandstone (Belly River Formation and Blairmore Group).

Springs within the Crowsnest watershed provide much of the volume of flow within the Crowsnest River. Three main types of springs were noted within the Crowsnest River watershed:

- Karst-related springs hosted by limestone in the western portion of the watershed with discharge rates as high as 189,216 m^3/d. These consist of Crowsnest Lake spring, Ptolemy Spring and sub-lacustrine springs in Crowsnest, Island and Emerald lakes in the Crowsnest Pass area.
- Fault-related springs flowing along the numerous thrust faults in the watershed. The best known example is Turtle Mountain Spring near the site of the 1903 Frank Slide. The spring water contains sulphur and flows at less than 1,000 m^3/d.
- Other springs that tend to form along breaks in slope, more evenly distributed across the watershed. They tend to have a more local water source and generally flow at lower rates than the other types of springs.

Coal has been mined in the Crowsnest River watershed since 1900 resulting in as many as 68 coal mines although there are no currently operating coal mines within the watershed. The location of historical coal mining operations show no correlation to the location of springs, suggesting coal mining areas do not contribute to the baseflow in the watershed. There is potential for impact to water quality from coal mining operations within the watershed.

Precipitation recharges into either the karstic carbonate bedrock and through dissolution channels and caverns into the lakes at the headwaters of the Crowsnest River, or into the sandstone/shale bedrock then flowing from higher elevations into the tributary creek valleys, discharging into the Crowsnest River and from west to east in the vicinity of the Crowsnest River. Groundwater flow enters the unconsolidated alluvial aquifers from the bedrock, and in places with downward directed hydraulic gradients from the Crowsnest River. The alluvial aquifer is split into two aquifers west of Coleman with a clay till aquitard confining the lower alluvial aquifer between Blairmore and Frank. This lower alluvial aquifer likely forms part of the Middlefork pre-glacial valley.

At present, alluvial aquifers are the most important in the watershed from a groundwater use perspective, although buried valley aquifers such as the Middlefork Valley aquifer can yield high volumes of groundwater. Alluvial deposits within the Crowsnest River valley form an unconfined aquifer which is likely in direct connection with surface water. The Crowsnest River alluvial aquifer is of importance from a water use perspective and is also highly vulnerable to contamination from surface activities. The greatest number of water wells in the watershed is completed in the alluvial aquifer.

The groundwater in wells screened deeper than 10 m in unconsolidated materials have greater sodium and potassium concentrations indicating longer travel distances. Groundwater within the unconsolidated materials overlying the Belly River Formation in the east is more evolved, having travelled further. Most TDS concentrations were less than 500 mg/L (drinking water criteria); those with greater concentrations tended to occur in the upper 100 m of the subsurface.

The volume of recharge to groundwater systems over the watershed is estimated to be between 19,186,000 m^3/yr to 57,558,000 m^3/yr based on an estimated 5% to 15% infiltration from precipitation. The 250 groundwater diversion licenses existing within the watershed account for a groundwater diversion volume of 6,007,385 m^3/yr. Groundwater diversion and use for domestic purposes is estimated to be 3,750,000 m^3/yr based on 3,000 households within the watershed. This suggests that there may be a groundwater surplus of 9,428,615 m^3/yr to 48,129,385 m^3/yr. This also suggests that anywhere from 17-51% of the estimated recharge to aquifers may be currently in use.

Forty wells and springs were visited as part of the field verification survey conducted by Waterline. Less than half could be linked to records in the Alberta Water Well Information database. The GPS location of these wells is an improvement on the accuracy of the well location within the database. In addition, to providing accurate well location and water data, the field verified survey was beneficial in terms of providing information to the public regarding groundwater protection initiatives being undertaken by OWC. Development of strong community relations and education programs regarding groundwater development and protection is critical to the successful implementation of groundwater management plans.

A fundamental knowledge/data gap, results from the inability to reconcile water wells in the field with Alberta Environment and Water's water well database. The problem arises as a result of the fact that wells are not generally tagged in the field and there is no requirement to record an accurate well location. In most instances, the well location is estimated to the nearest quarter section by the driller which is only accurate to +/- 400 m, making it difficult to reconcile with well ID's in ESRD's water well database, ESRD's well license approval database, and with water chemistry records. In Waterline's opinion, drillers should be required to apply for ESRD well ID number before wells are drilled. In this manner ESRD can issue tags which can be affixed to the well casing by the driller so that a tracking system can be established. Although this is a provincial responsibility, the Oldman Watershed Council should promote this practice to drillers operating in the region or to the landowner after the well is drilled, as every well drilled in the watershed is a potential groundwater monitoring point that can help resolve data gaps in developing our understanding of groundwater systems within the watershed.

The large majority of water use in the watershed is through groundwater distributed by the Municipality of Crowsnest Pass. The Municipality of Crowsnest Pass tracks their water use, however, they do not track water levels in their wells. If there is no knowledge of whether water levels are declining, static, or increasing with time then there is no understanding of the groundwater supply. The collection of water level data throughout the watershed is a critical step in increasing the understanding and awareness of groundwater conditions in the watershed. It is the only way of knowing whether the water supply is diminishing, or whether the area can support an increased population

There is also an immediate need to establish a groundwater monitoring network in key areas. The intent of such a network is to have a series of control points in key aquifers so that the current groundwater conditions can be determined and a long-term water level record can be established. A critical question is whether aquifers in the watershed are being over-exploited and if water levels are stable, increasing or more importantly in decline. Declining water levels in wells would indicate that groundwater diversion may be exceeding aquifer recharge and that corrective action may be required to ensure sustainable use of groundwater resources in the region.

Waterline has identified critical areas based on aquifer characteristics, population density, the number of wells completed in aquifers which have been identified, vulnerability of areas, areas where insufficient hydrogeological data exist, and future development areas. The following locations are recommended for establishing an observation well network within the watershed:

- Near Crowsnest spring located in the western portion of the watershed. The alluvial aquifer, Banff Formation and Alberta Group should be monitored at this location;
- Crowsnest Lake outlet to Crowsnest River to monitor discharge from sub-lacustrine springs and the Belly River St. Mary River Succession;
- Downstream of Coleman to monitor water quality in the alluvial aquifer and in the bedrock;
- Downstream of Blarimore to monitor water quality in the alluvial aquifer and in pre-glacial valley aquifer; and
- Near Lundbreck to monitor the downstream eastern edge of the watershed as well as the buried valley aquifer.

Continuous long-term, water level and water quality monitoring of aquifer response to natural phenomena such as precipitation events, or human activities such as groundwater pumping and diversion, and contamination is fundamental to developing an understanding of groundwater flow systems and interactions. Such an approach provides an early-warning system for aquifer management and the needed information for future land use planning. Waterline recommends the use of existing wells, or drilling new wells as required, and continuous monitoring of water levels using pressure transducer-data loggers.

Aquifer mapping, and particularly aquifer vulnerability mapping, should be updated once baseline groundwater data are available. Land development and land use planning can then be addressed with some consideration of existing cumulative groundwater impacts. In addition, sustainable development strategies can be established to reduce impacts in sensitive areas through low impact development practices, water conservation, water capture and infiltration measures, establishing communal well systems, and through other measures. Community outreach programs can also be developed in an effort to clarify roles and responsibilities of all users who reside in the watershed.

Managing groundwater resources within the Crowsnest River watershed will undoubtedly present challenges but also presents a unique opportunity for innovation and setting the template for the future approach to aquifer management in Alberta. Waterline has developed an approach that we believe will maximize the understanding of aquifers within the Crowsnest River watershed so that the data can be integrated into a future groundwater management framework.

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1.0 INTRODUCTION

1.1 Report Terminology

The reader is advised that some of the terms used in the enclosed report are of a technical nature, and some may be described in the glossary of terms (**Section 8.0**). A superscript "g" ([g]) is at the end of the first occurrence of words that are in the glossary. In addition, a brief description of groundwater and groundwater theory is in Appendix A.

1.2 Project Background

Waterline Resources Inc. (Waterline) was retained by the Oldman Watershed Council (OWC) to complete an aquifer mapping and groundwater management planning study within the Crowsnest River watershed. The study was completed using publicly available information and by completing a field verification survey of major groundwater supply areas. The study area is located in Southern Alberta within Townships 006 to 009, Ranges 1 to 6 W5 (**Figure 1** and **Figure 2**). The Crowsnest River watershed lies with the Oldman River sub-basin, which is part of the South Saskatchewan River basin. The inset map on **Figure 2** and other map figures shows the location of the Crowsnest River watershed (pink line) within the Mountain sub-basins (sub-basin number: 05AA; blue line) within the Oldman River sub-basin (red line).

The Crowsnest River watershed encompasses approximately 724 km^2 comprising all the area drained by the Crowsnest River and its tributaries. Approximately 54 percent of the watershed is in the Municipal District of Pincher Creek (No. 9). The remaining area is divided between the M.D. of Ranchland (No. 66) (36 percent) and Municipality of Crowsnest Pass (10 percent).

Aquifers within the watershed are contained within unconsolidated deposits (e.g., sand and gravel) and consolidated bedrock (e.g., sandstone). Groundwater is extracted from these aquifers for local domestic, municipal, agricultural, and commercial/industrial water supplies. An alluvial[g] aquifer exists in the vicinity of the Crowsnest River, and consists of shallow unconfined fluvial[g] sand, silt and gravel. These alluvial deposits represent approximately 13 percent of the land area of the watershed (95 km^2). These alluvial materials are thought to be in direct connection with the Crowsnest River. Therefore, groundwater withdrawals from these deposits may be considered groundwater directly connected to surface water and would generally be licensed as surface water sources by Alberta Environment and Sustainable resources Development (ESRD) under the Water Act (Alberta Environment, 2006). Other water wells[g] in the watershed withdraw groundwater from the underlying bedrock, which is a heterogeneous structurally complex system dominated by sandstone, siltstone and mudstone.

Numerous factors such as climate, population growth, agricultural practices, and industrial activities are placing pressure on groundwater quantity and quality in the South Saskatchewan River Region (**Figure 1**). Demand for water in the watershed includes:

- Agriculture – raising of crops and livestock;
- Golf Courses – one exists within the Crowsnest River watershed at Blairmore;
- Oil and Gas activity – mainly in the eastern half of the watershed;

- Recreation (Island Lake and Chinook Provincial Parks and Lundbreck Falls Recreational Area); and
- Residential – Municipality of Crowsnest Pass.

In addition, timber harvesting will influence hydrologic processes and will influence recharge to the groundwater. Groundwater flow is not well understood in the Crowsnest River watershed. Although there have been past initiatives to map groundwater resources in this region, mapping is incomplete. Within this region, areas with high population density have been identified as vulnerable to groundwater overuse. Long-term monitoring is required to demonstrate whether water levels are declining and overuse is indicated.

Figure 1 Location map

The Crowsnest River watershed has been identified by the OWC as an area of groundwater vulnerability within the South Saskatchewan River Region (**Figure 1**). The OWC has identified a need to compile, evaluate and present existing information regarding groundwater resources and identify any knowledge gaps in order to initiate the process of groundwater management planning in the region. The OWC has identified groundwater as a priority item in their process for the development of an Integrated Watershed Management Plan for the Oldman River sub-basin (OWC, 2011a). As part of the development of the South Saskatchewan (River) Regional Plan (Government of Alberta (GOA), 2010e), the Government of Alberta, with recognition of the pressures on water within the region and identification of the need to better understand groundwater, is working toward establishing a land-use change model which includes groundwater and geotechnical data. Municipalities, health agencies and many other stakeholders also have an interest in understanding groundwater and ensuring it is managed for long-term sustainable use.

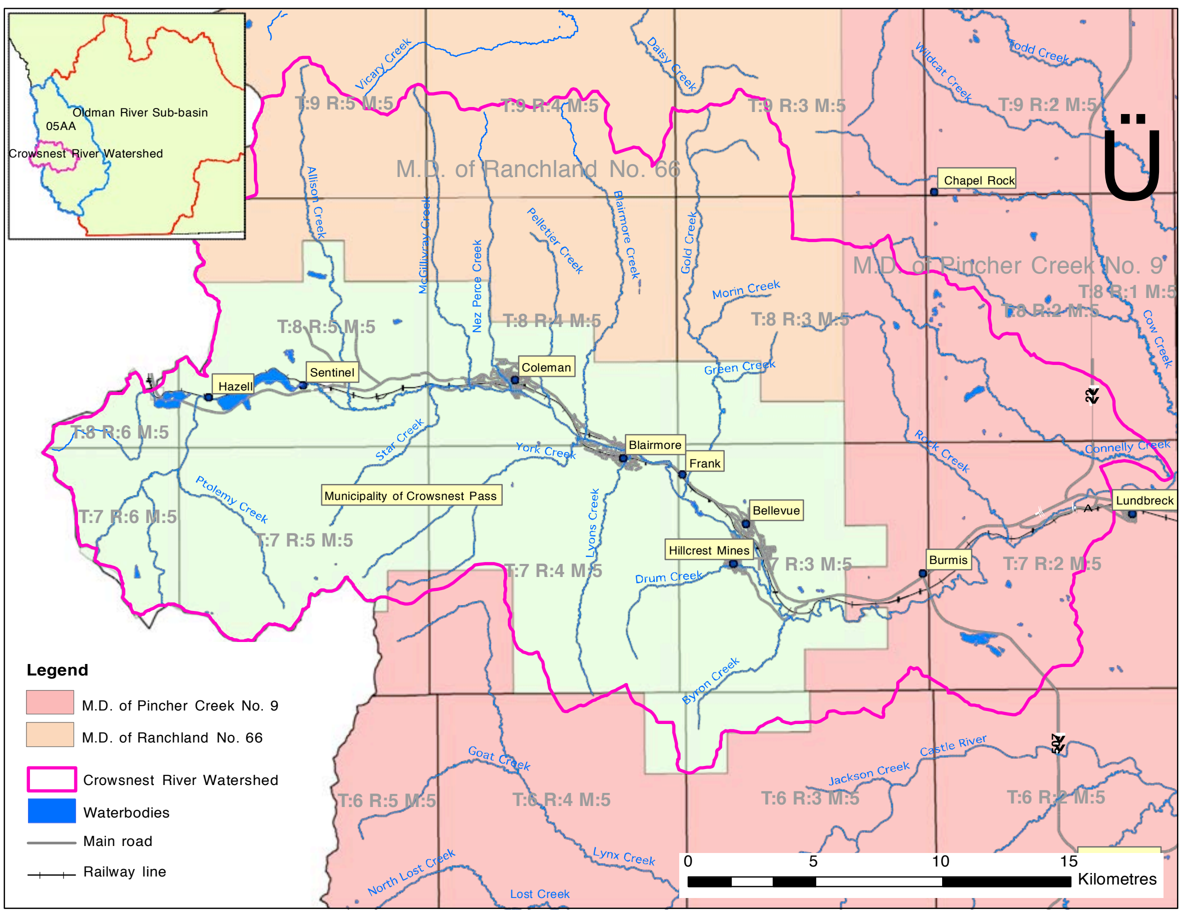


Figure 2 Crowsnest River watershed

1.3 Political and Regulatory Environment

1.3.1 Political Jurisdictions and Competing Interests

The Crowsnest River watershed falls within a number of different political jurisdictions (**Figure 2**). The watershed includes the Municipality of Crowsnest Pass, an amalgamation as of 1979 that includes the towns/villages of Bellevue, Blairmore, Coleman, Frank and Cowley, and the hamlets of Hillcrest, Burmis and Lundbreck. Municipal government bodies, including the Municipality of Crowsnest Pass, the MD of Pincher Creek and the MD of Ranchland, all have land-use decision making authority for their communities. The largest portion is within the Municipality of Crowsnest Pass (**Table 1**).

Table 1 Crowsnest River watershed Political Jurisdictions

Entity	Jurisdiction	Watershed Area (km^2)	Watershed Area (percent)
Crowsnest River watershed	Municipality of Crowsnest Pass	371.1	51
	MD Ranchland No.66	196.6	27
	MD Pincher Creek No. 9	157.0	22
	Total	**724.7**	**100**

1.3.2 Water Management and Land-Use Frameworks

Water management and land-use in the province of Alberta are overseen through policy and legislation, including most recently, development of regional plans. Documents outlining strategies and background for the Oldman River sub-basin include:

- *Water for Life: Alberta's Strategy for Sustainability (GOA, 2008).* Its goals include: safe, secure drinking water supply; healthy aquatic ecosystems; and reliable, quality water supplies for a sustainable economy. It requires the formation of Watershed Planning and Advisory Councils (WPACs) in each major river basin of the province; the Oldman Watershed Council (OWC) oversees initiatives in the Oldman River sub-basin.

- Alberta's *Land-use Framework* (LUF) (GOA, 2008) and the *Alberta Land Stewardship Act* (GOA, 2009) divide the province into seven regions and commits land and resource managers in those regions to taking a cumulative effects approach to land-planning and related management activities. The LUF identified the South Saskatchewan Regional Plan as an immediate priority (GOA, 2010a). Groundwater Management Frameworks as part of LUF have been developed for other regions (e.g., Lower Athabasca Region) to integrate the principles of the groundwater protection framework established in the Water for Life Strategy (GOA, 2008). The development of a Groundwater Management Framework for the sustainable management of groundwater in the Crowsnest River watershed is desirable.

- *Alberta Water Act* (GOA, 2000) governs the diversion of water from surface and groundwater sources. Under the Act, households have a statutory right to divert up to 1,250 m^3/year without a requirement for a Water Act license. Although no longer issued, traditional agricultural uses were managed under registration, allowing diversion and use of 6,250 m^3/year.

- *Approved Water Management Plan for the South Saskatchewan River Basin* (Alberta Environment, 2006) Announced Alberta Environment would no longer accept new surface water license applications for the Bow, Oldman, and South Saskatchewan sub-basins. Within the SSRB, the closure of the basin to new surface water applications includes those applications where groundwater is shown to have a proven connection with surface water.

- Other provincial documents of relevance include the Eastern Slopes Policy (GOA, 1984), Public Lands Act (GOA, 2010f) and the Municipal Government Act (2010g).

- *Oldman River: State of the Watershed Report* (OWC, 2010a and 2010b) which contains a recommendation to monitor groundwater as an indicator of the health of water resources within the watershed.

- *Priorities for the Oldman Watershed: "Promoting action to maintain and improve our watershed"* (OWC, 2011b). Identified a lack of knowledge and understanding of groundwater and its interaction with surface water

The availability of water within the South Saskatchewan Region will likely become one of the limiting factors to future population and economic growth. The region faces challenges in meeting future water demand because of a combination of history, climate, geographic factors, and patterns of settlement. In dry years, demand for water can exceed the volume of water available from some rivers for extended periods (GOA, 2010a).

The present study aims to provide the background information and conceptual model in order to help ESRD and the OWC evaluate whether a groundwater management plan is necessary. **Figure 3** (next page) shows how a groundwater management plan fits within the overall planning and management policies of the province with respect to water (i.e. Land-Use Framework and Water for Life Strategy).

1.3.3 Population and Water Supply Demand

Almost half of the population of Alberta (45 percent) resides in southern Alberta; the majority in Calgary and Lethbridge. Population projections indicate that the population of Alberta will increase considerably during the next 65 years from 3.3 million (2006 Census) to four million by 2076.

The population of the region (M.D.s of Ranchland and Pincher Creek and Municipality of Crowsnest Pass in their entirety), based on the 2006 population census, is 9,144. This number includes the urban dwellers in the Municipality of Crowsnest Pass and the rural population (**Table 2**).

Table 2 Summary Population Statistics (2006 census data)

Type	Total Population	Total Private Dwellings
Urban	1,830	929
Rural (outside cities)	5,695	3,073

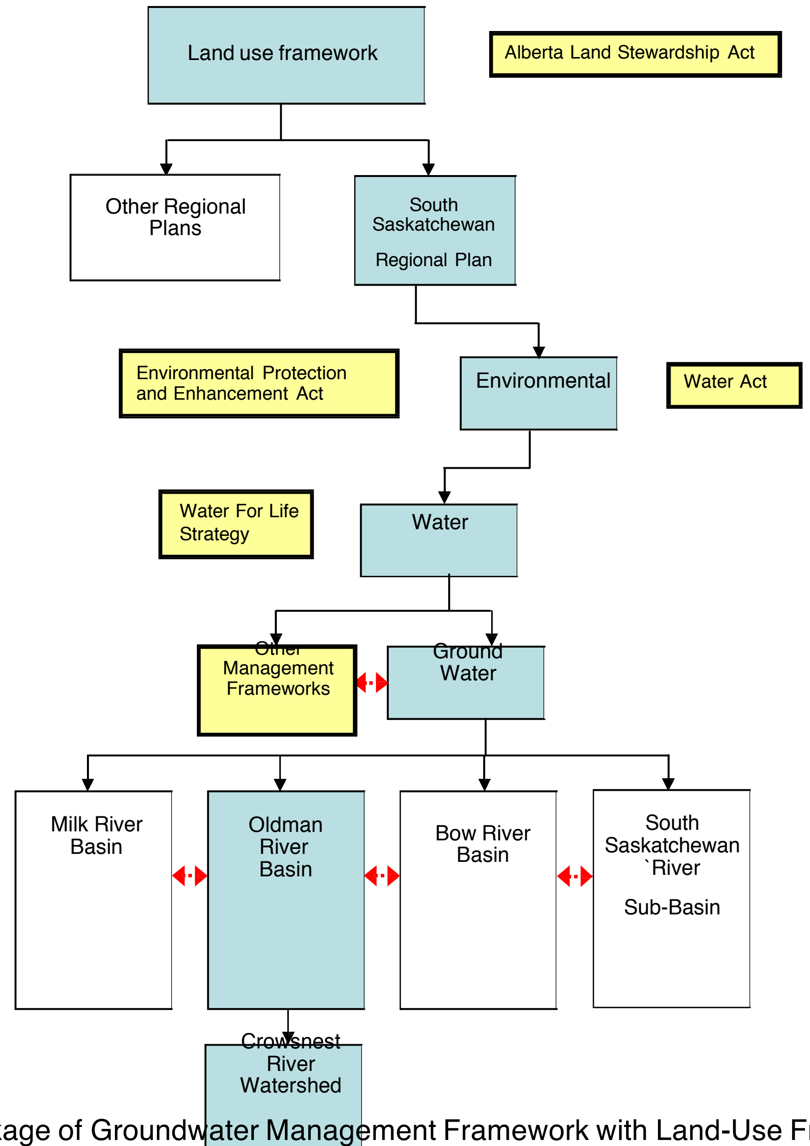


Figure 3 Linkage of Groundwater Management Framework with Land-Use Framework and alignment with overall planning and management policies of the province of

The breakdown of population by district is shown in **Table 3** (OWC, 2010 and Statistics Canada, 2007). The total population in the three areas has decreased by five percent from 9,636 people (2000) to 9,144 people (2006) (Statistics Canada, 2007b). This suggests that groundwater use for domestic purposes may not have increased greatly, although other uses may have increased. The M.D. of Ranchland is home to 86 people (Statistics Canada, 2007). Note that the data for the M.D. of Pincher Creek and Ranchland are for the entire Municipal District in each case as it was not possible to extract the data on a watershed basis.

Table 3 Population Comparison (2000, 2006 and 2011 census data)

District	2000 Population	2006 Population	2011 Population	% Change (2000 to 2011)
Municipality of Crowsnest Pass	6,356	6,262	5,749	-10
MD Pincher Creek No.9	3,172	3,197	3,309	+4
MD Ranchland No.66	108	96	86	-20

Note: the data for 2000 were collected in 1996, for 2006 in 2001 and for 2011 in 2006

The vast majority of the population in the Crowsnest River watershed resides in the Crowsnest Valley along Highway 3 which runs along the Crowsnest River (**Figure 4**). The population circles in **Figure 4** are for dissemination blocks developed by Statistics Canada for the census. The circle size is dependent on the number of people within the dissemination block.

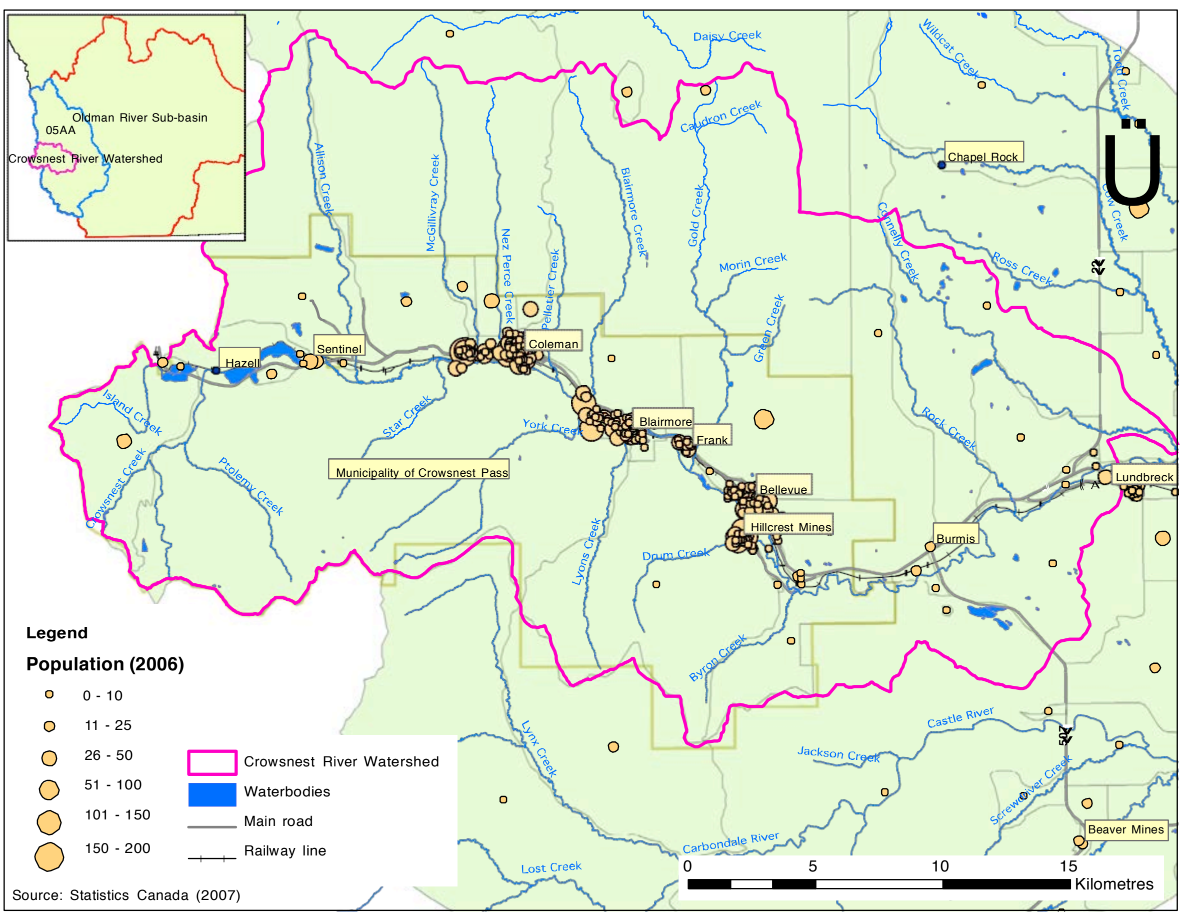


Figure 4 Population distribution

The distribution of water supply wells is consistent with the population distribution (**Figure 5**).

The Municipality of Crowsnest Pass operates water supply wells in Coleman (2 wells), Hillcrest Mines (4 wells), Blairmore (4 wells) and Bellevue (1 well).

As will be discussed, there are 912 water wells within the Crowsnest River watershed listed in the ESRD water well database (July 2012). Based on population statistics (rural population of 5,695 and 912 well records), this results in a ratio of approximately 6.2 people per water well record.

Given the ESRD-imposed moratorium on new surface water licences (and groundwater with a proven to surface water) in the South Saskatchewan River basin, the demand for groundwater resources in the Crowsnest River watershed is expected to increase in the future.

1.4 Objectives and Scope of Work

The objective of the study is to compile existing groundwater information and develop a conceptual understanding of key aquifers, groundwater flow, and groundwater-surface water interactions within the Crowsnest River watershed. The intent is to build a conceptual model which will form the framework and basis for future groundwater management plans being contemplated by OWC.

The OWC released a document in January 2011 entitled: "*Priorities for the Oldman Watershed: Promoting action to maintain and improve our watershed"* which outlines eight goals; including one for groundwater (OWC, 2011). The OWC is developing an Integrated Watershed Management Plan for the Oldman River sub-basin in response to the eight goals identified in the *Priorities* document. Goal Five states that there is a need to: "research the availability and quality of groundwater and its interaction with surface water". The present study undertaken by Waterline is the first step in meeting the objectives in Goal Five.

This study also fulfills one of many outcomes of the Land-Use Framework initiative for groundwater in the South Saskatchewan Regional Plan. The Government of Alberta is working on an integrated approach to land management that includes a new cumulative effects[9] management system. The evaluation of land-use impacts on groundwater resources will be an integral part of that system. However, it is recognized that groundwater information is lacking in many of the areas under study.

The scope of work for the present study is to identify and review available information relating to groundwater supply and quality within the Crowsnest River watershed (**Figure 2**). In addition, the present study was intended to provide a description of the hydrologic, geologic, hydrogeological and hydrogeochemical setting which allows for the development of a conceptual hydrogeological model for the region. An attempt was made to develop a groundwater budget (groundwater availability versus use) based on the limited data available. The OWC recognized at the outset of the project that data and knowledge gaps were likely to exist and therefore recommendations for groundwater monitoring sites are required so that long-term data can be collected from key aquifers within the watershed. These data should allow for improved groundwater assessment and evaluation; and provide the required information for planning, and sustainable development of the groundwater resources within the watershed.

2.0 METHODOLOGY AND STUDY APPROACH

2.1 Identification of Project Area Boundaries

Two boundaries were identified for this project: the watershed boundary, and a 10-km buffer zone outside the watershed boundary. The buffer zone boundary was selected in order to incorporate information from geological units and aquifers that extend beyond the watershed boundary. Maps presented in the enclosed document were scaled to show the Crowsnest River watershed and only a portion of the data within the 10 km buffer zone were considered.

The Crowsnest River watershed is defined by the height of land surrounding the Crowsnest River and included all tributary streams and creeks above the full supply level of the Oldman River arm of the Oldman Reservoir. Aquifers within the watershed are bounded by differences in permeability[g] which is generally controlled by differences in lithology, and structural properties of bedrock units (fractures, faults[g], folds, etc.). In the case of the Crowsnest River watershed, the topography generally slopes from west to east, extending from the Rocky Mountain Front Ranges to the Foothills and the western edge of the Plains. The western boundary of the watershed coincides with the Alberta-British Columbia border and the continental divide.

2.2 Data Sources

Data collection and compilation for the present study consisted of gathering the available data from a variety of sources that included public domain databases as well as subscribed databases. All data sources are provided in the extended bibliography in **Section 9.0**. The major sources include the following:

- Alberta Environment and Sustainable Resources Development (ESRD) – Environment management System
    - Groundwater Information Centre - Alberta Water Well Information Database;
    - ESRD Approval database;
    - Snow data;
    - Geographic Information System (GIS) base data (roads, water bodies, digital elevation model data); and
- Alberta Research Council (ARC; now Alberta Innovates Technology Futures) - Reports and maps
- Alberta Geological Survey (AGS), and Energy Resources and Conservation Board (ERCB)
    - Reports and Maps;
    - Depth to Base of Groundwater Protection Database,
    - GIS datasets (bedrock geology, aggregate), and
    - Land-use data interpretation
- Environment Canada

- Weather data (precipitation); and
- Stream flow data.

- Geological Survey of Canada (GSC) - Reports and publications
- Oldman Watershed Council (OWC)
  - Reports; and
  - Personal communications
- University of Calgary, McMaster University - Unpublished university theses (maps and cross-sections)
- Municipal Districts (M.D.) of Pincher Creek (No. 9) and Ranchland (No. 66)
  - County maps; and
  - Data regarding gravel pits and community wells
- Statistics Canada - Census 2006 population data
- Information Handling Services (IHS) Accumap database - Energy well information (lithology and geophysical logs)

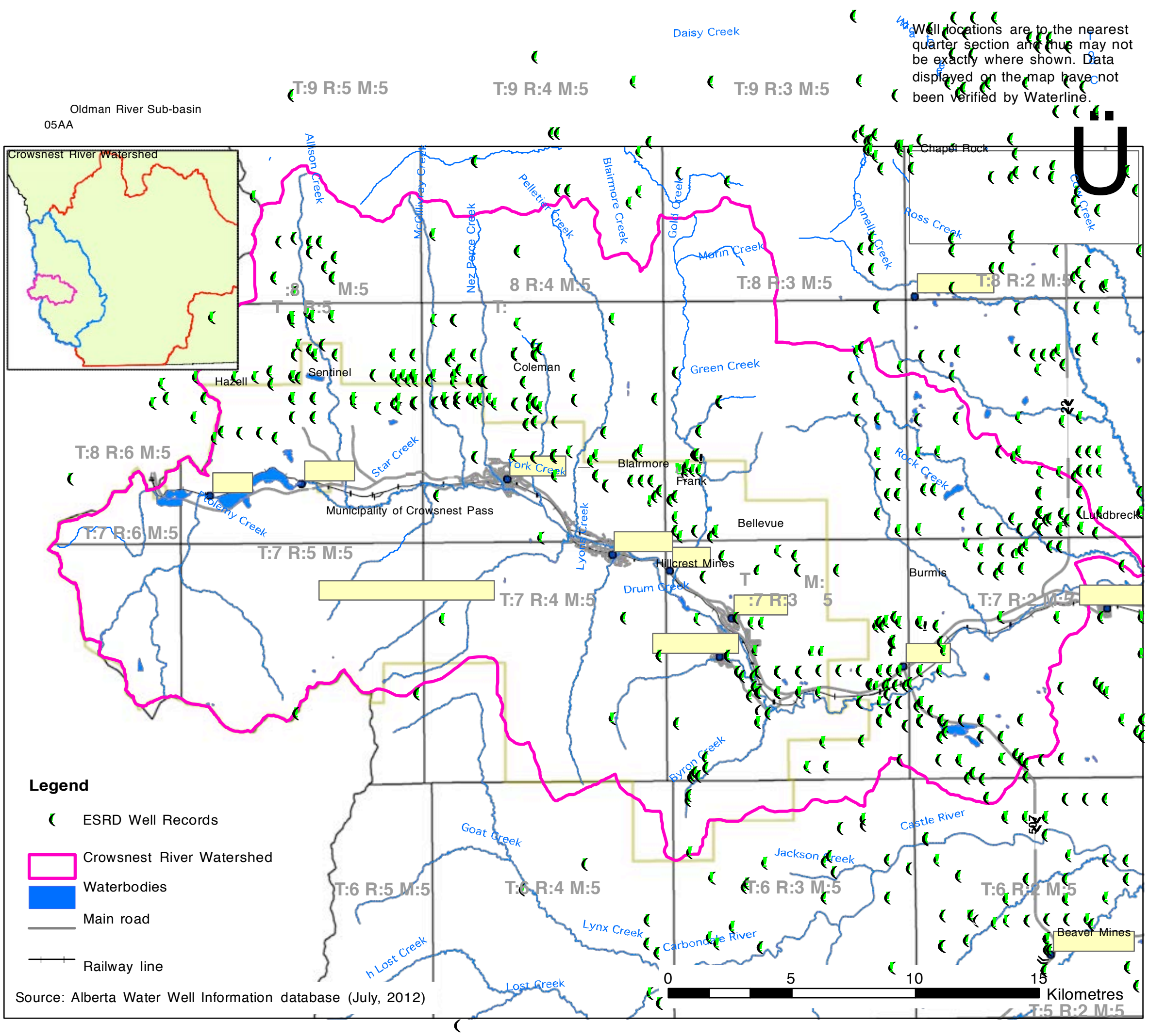


Figure 5 Water well locations

The most important source of data pertaining to the present groundwater resource evaluation is the Alberta Water Well Information Database (ESRD, 2012a). The Alberta Water Well

Information Database contains data submitted by water well drillers associated with water wells drilled throughout the province of Alberta. Based on Waterline's review of the database (July 2012 version) there are 1,642 water well records within the Crowsnest River watershed and the 10-km buffer zone (**Figure 5**). Of these, 912 water well records lie entirely within the Crowsnest River watershed.

Oil and gas well information was also an important source of geological and hydrogeological information used in the development of the conceptual hydrogeological model for the area. The IHS Accumap database (IHS, 2012) contains information for oil and gas wells drilled by industry and submitted to the Alberta ERCB. Various private companies make these data available (e.g., IHS Accumap and Geoscout). The IHS Accumap database contained 186 oil and gas well records within the Crowsnest River watershed and the 10-km buffer zone (as of Aug 2012) (**Figure 6**). This information was used in the development of the conceptual hydrogeological model for the watershed to supplement the water well database information where deeper geological information is limited or unavailable.

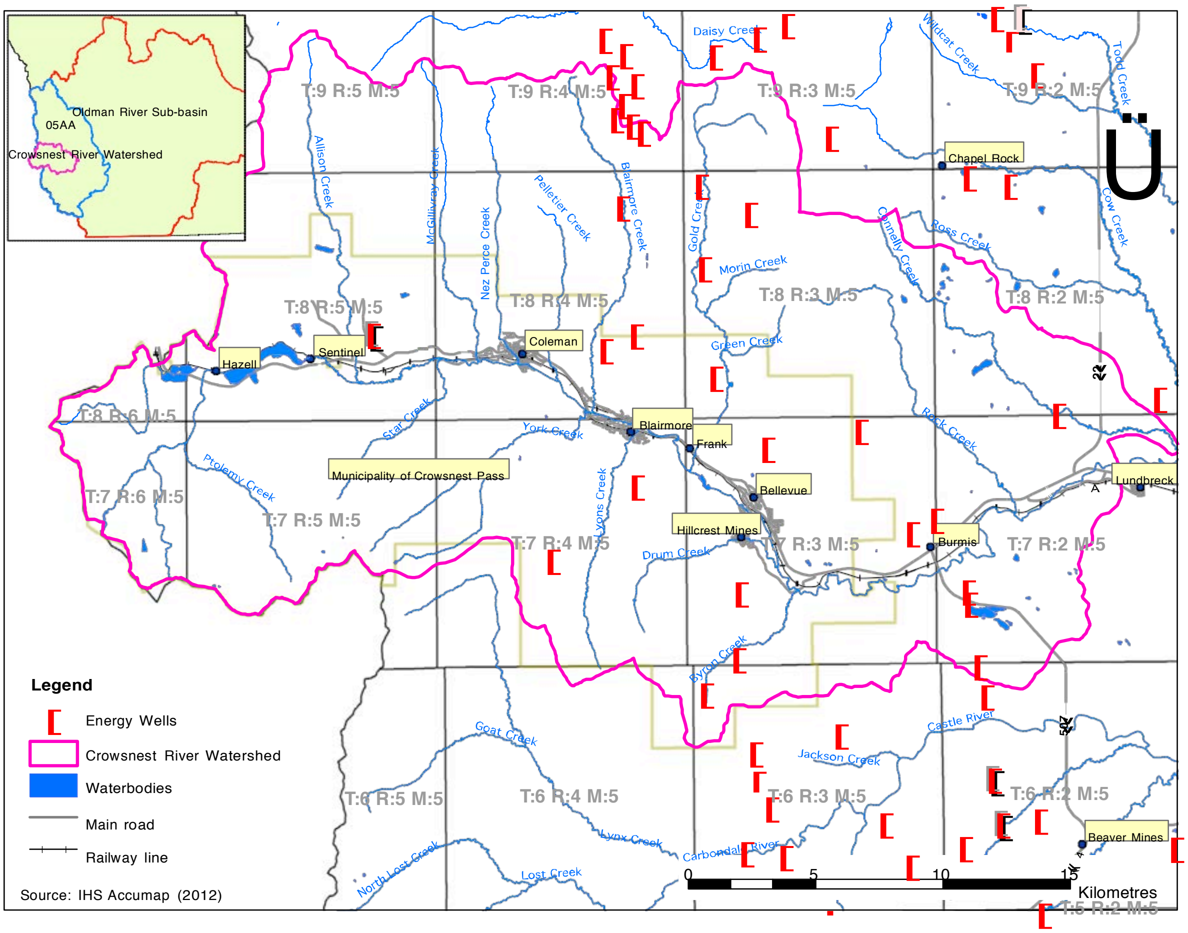


Figure 6 Oil and gas well locations

2.3 Field Verification Survey

As part of this study, Waterline conducted field work in order to verify the locations and other characteristics of selected water wells and springs in critical areas. The field work was conducted from September 17 to 21, 2012 and concentrated in three areas within the Crowsnest River watershed (West of Coleman, area of Blairmore, and near Burmis). The work included the following:

- Locate as many wells as possible along each transect and for each well determine:
  - Location (longitude, latitude and ground elevation);
  - Depth to the water level in the well;
  - If possible, collect a water sample for analysis; and
  - Any other relevant information of potential use in identifying the well with regard to the data in the Alberta Water Well Information Database.
- Locate the following major springs in the watershed:
  - Crowsnest Spring
  - Ptolemy Spring
  - Turtle Mountain Spring; and
  - Any other accessible springs, time permitting

Insufficient budget for the project and time in the field were available to assess the historical coal mines in relation to the groundwater flow regime.

2.4 Data Compilation

The development of a conceptual model to assess groundwater flow requires a detailed understanding of the inter-connections or "plumbing system" across the watershed. A physical understanding of the structural geology and lithology in the disturbed zone is the foundation for the development of a representative conceptual model. Specifically, geology and hydrogeology information are required and need to be synthesized and integrated so that key aquifers across the Crowsnest River watershed can be evaluated. The following information was used to complete the conceptual model:

- Structural geology and stratigraphy across the watershed and extending to the base of groundwater protection;
- Aquifer and aquitard properties (e.g., composition, thickness, transmissivity, storativity, hydraulic conductivity, water or piezometric level, hydraulic gradients);
- Aquifer type (e.g., unconfined or confined);
- Delineation of recharge and discharge areas;
- Groundwater geochemistry; and
- Information about active wells (number of wells, location, depth, production interval, water levels, pumping rates, etc).

The methods used in compiling geological and hydrogeological data from various databases and sources are described in detail in Appendix A and summarized below.

Developing conceptual hydrogeological models of aquifers within the Crowsnest River watershed involved the integration of numerous key datasets described above. All of the datasets were processed electronically so they could be entered into geodatabases and processed. These data were then used to develop other maps and to profile the subsurface geology in an attempt to develop an understanding of how surface features interact with the subsurface geology.

Borehole information was compiled and assessed using software developed by Mount Pleasant Software (2012). The information was entered into a database to enable the development of a conceptual hydrogeological model for the subsurface geology and hydrogeology. The data were evaluated and integrated with other geology and survey data within an Arc-GIS platform consistent with OWC's and ESRD's GIS format. Numerous other licensed software packages were used in the preparation of the report, tables, figures, maps and cross-sections.

It should be noted that any data received and compiled by Waterline as part of the present study were assumed to be correct. The data have not otherwise been verified by Waterline for quality or accuracy, other than what could be assessed by cross-referencing datasets and confirmed as part of the field verified survey. For instance, where exact location information was not available, water well and chemistry data were assigned to the center of the nearest quarter section. For the purposes of the enclosed study, maps showing data points may be offset by as much as 400 m. It is cautioned that there may be a need for further verification of the data used to develop the conceptual model if interpretations and analysis conflict with other information. In addition, as new data become available and a more comprehensive understanding of groundwater flow systems is developed within the Crowsnest River watershed, the conceptual model presented herein should be updated accordingly.

3.0 CONCEPTUAL MODEL DEVELOPMENT

3.1 Topography and Physiography and Natural Regions

The terrain in the Crowsnest River watershed consists of gently undulating to gently rolling uplands, level to gently undulating lowlands, moderately sloping to very steeply sloping escarpments and gullies and level terraces and flats along the Crowsnest River. The Crowsnest River valley was shaped by Quaternary glaciers forming a U-shaped valley following the pre-glacial drainage (OWC, 2010a). The process of converting 'V'-shaped alluvial valleys to U-shaped glacier-formed valleys within the Crowsnest River watershed resulted in a steepening of the valley walls. This, coupled with the structural nature of fractured and faulted rock in the region created the unstable conditions that resulted in the Frank Slide which buried the small mining Hamlet of Frank in 1903 (OWC, 2010a).

The ground elevation in the watershed ranges from 1136 metres above mean sea level (mASL) at the confluence of the Crowsnest River and Connelly Creek near Lundbreck, to 2,740 mASL at Mount Ptolemy on the western boundary of the watershed (**Figure 7**). The area is well drained by numerous streams, flowing into Crowsnest River moving surface water and discharged groundwater east toward the Oldman River and ultimately toward Hudson's Bay.

The west boundary of the Crowsnest River watershed coincides with the continental divide and surface water west of the boundary flows toward the Pacific Ocean.

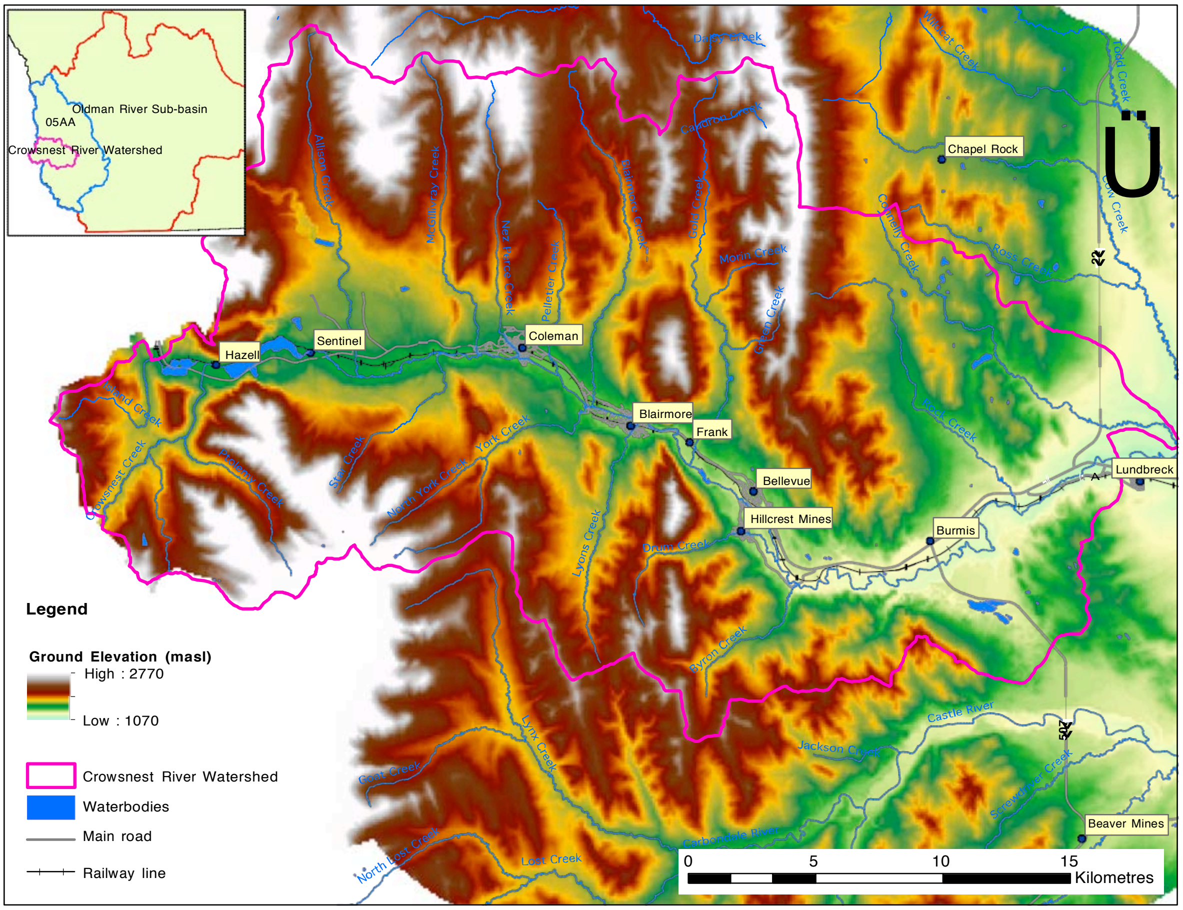


Figure 7 Topography in the Crowsnest River watershed

The Crowsnest River watershed is in the Foothills Fescue Grassland Natural Region in the easternmost area of the watershed, the Montane region in lower parts of the Crowsnest River valley, and to the Subalpine and Alpine Natural Regions at higher elevations to the north and south of the Crowsnest River valley (Natural Regions Committee, 2006)(**Figure 8**). This classification is based in part on elevation, local climate and growing season characteristics.

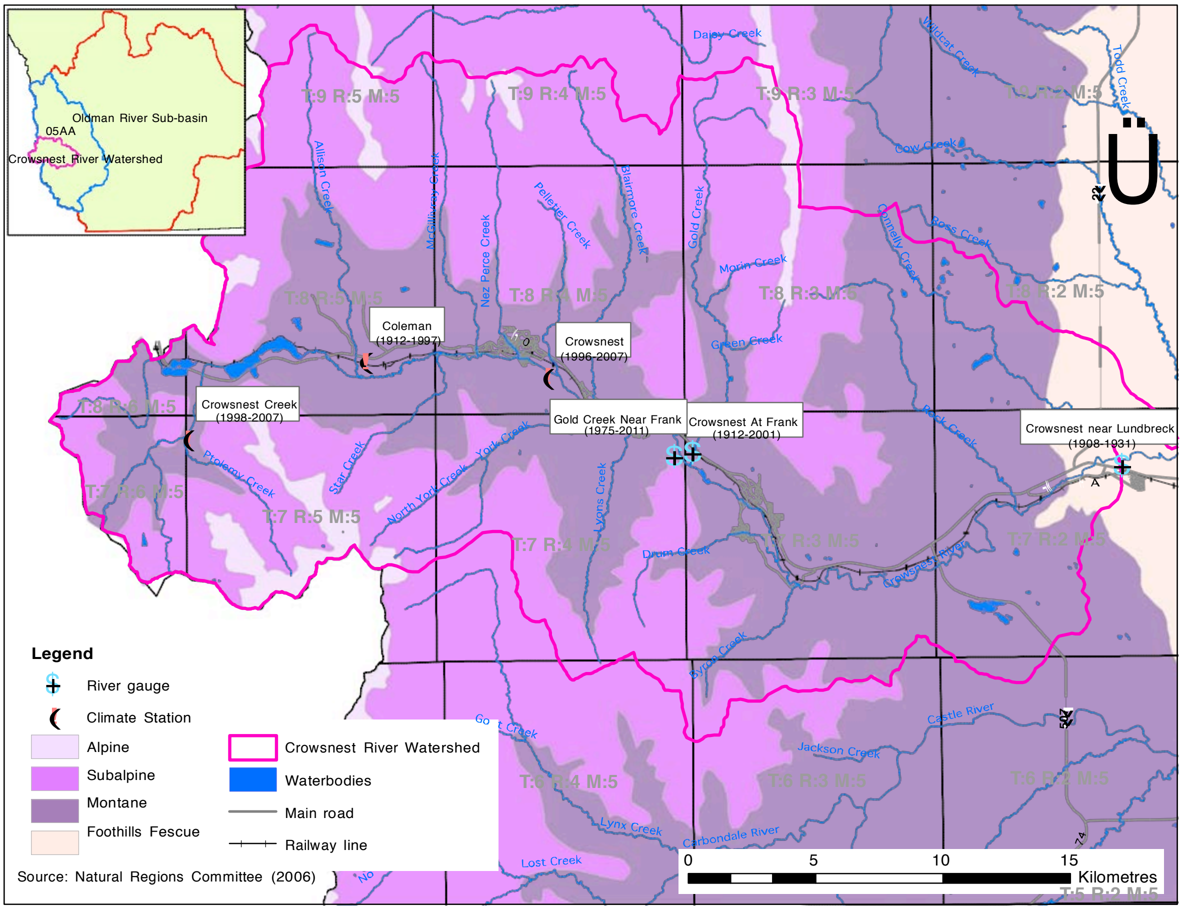


Figure 8 Natural Regions and Creeks in the Crowsnest River watershed

3.2 Land Cover and Use

The classification of land vegetation cover and land-use within the Crowsnest River watershed was completed by Agriculture and Agri-Food Canada (2009) and is shown in **Figure 9**. This information indicates that agricultural lands (annually cropped or seeded pasture) within the Crowsnest River watershed are primarily located east of Highway 22. West of Highway 22, the land cover consists of shrub land and grass land with minor agriculture. Further west, into the mountains the land cover consists of primarily coniferous forests and is largely undeveloped. In the Crowsnest River valley, land cover consists of wetlands, deciduous forest and some minor agriculture.

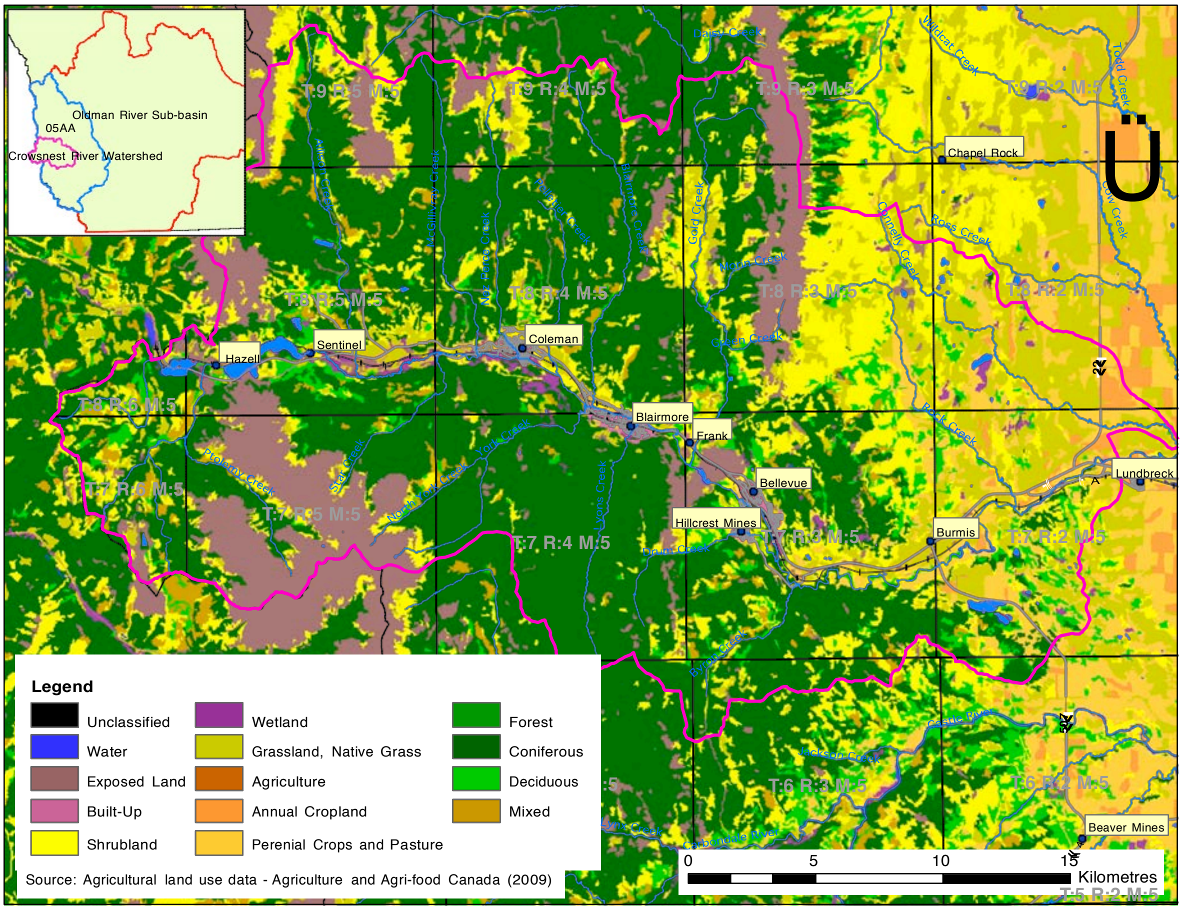


Figure 9 Interpreted land cover (2000)

3.3 Local Climate and Indicators of Variability

3.3.1 Climate Zone

Climate zones are typically defined using the Köppen classification system (e.g., Strahler and Strahler, 2006). The Köppen classification is based on annual temperature and distribution of precipitation throughout the year. The Crowsnest River watershed lies within a subarctic (Köppen climate classification Dfc[9]) zone characterized by long, cool summers, severe winters and no dry season.

The long-term climate record collected at the Coleman weather station (Climate Station ID: 3051720), which lies in the Crowsnest Valley central to the watershed, are available from 1912 to 1997 (Environment Canada, 2012).The climate in the region is characterized as follows:

- Daily average temperatures range from -8.3 °C in January, to 14.5 °C in July;
- Non-freezing (i.e. >0 °C) daily average temperatures occur from April to October; and
- An average annual precipitation of 483.7 mm of which approximately 72 percent occurs during the non-freezing months of the year.

Climate variability and/or change have the potential to drastically alter the surface water and groundwater flow regimes in the Crowsnest River watershed. Chen et al. (2006) showed that during the past century, the annual mean minimum and maximum temperatures in southern Alberta increased, albeit at different rates of 1.5 °C and 0.45 °C, respectively. Although Chen et al. (2006) stated that these differing rates are likely the result of different climate mechanisms, they did not speculate on the nature of those mechanisms.

Chen et al. (2006) also noted an increasing number of days with rain and a decreasing precipitation variance. The impact of warming on circulation may explain the increased number of annual precipitation days.

3.3.2 Pacific Decadal Oscillation

The Pacific Decadal Oscillation[9] (PDO) is a long-lived El Nino-like pattern of Pacific climate variability. It is a measure of the variability of the sea surface temperature (SST). Combined with an understanding of atmospheric circulation patterns, it has been used to assess the regional/global effects of weather patterns along the coast of western North America and may also affect climate patterns east of the Rocky Mountains. A typical warm phase (red along the coast; purple arrow) and cool phase (green along the coast; purple arrow) are shown in **Figure 10**.

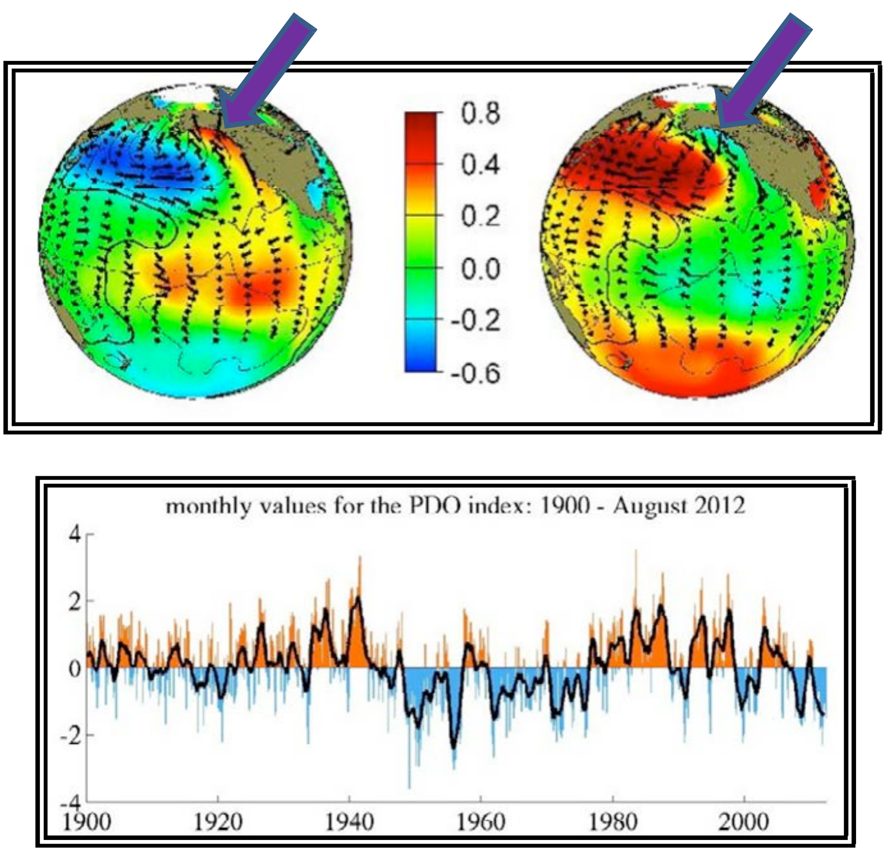


Figure 10 Pacific Decadal Oscillation Map and Temporal Variation Graph

It has been recognized by researchers at the University of Washington (Mantua and Hare, 1997) that the SST oscillation causes warming and cooling trends with periods ranging from 15 to 25 years (Minobe, 1997) that can dramatically affect regional weather patterns. The current PDO trend during the past 35 years appears to be in a warm phase, which generally means drier climate along the coast resulting in less water available to recharge aquifers.

The causes of PDO are not entirely understood and the predictability of climate oscillation is uncertain. However, long-term climate variability will need to be considered as part of land-use planning strategies and water budget analysis within the Crowsnest Pass Watershed.

3.3.3 Precipitation

The total annual precipitation as measured at Coleman (Station ID# 3051720; the weather station with the longest term record in the watershed), for the period from 1912 to 1997, is presented in **Figure 11**. A 12-month moving average was applied to the precipitation data and is displayed as a red line on the graph. This indicates that annual precipitation has a roughly 20-year cycle with lows in precipitation in 1947, 1967 and 1988. The PDO Index is also plotted on this graph and shows that until roughly 1955, the annual total precipitation follows the PDO curve.

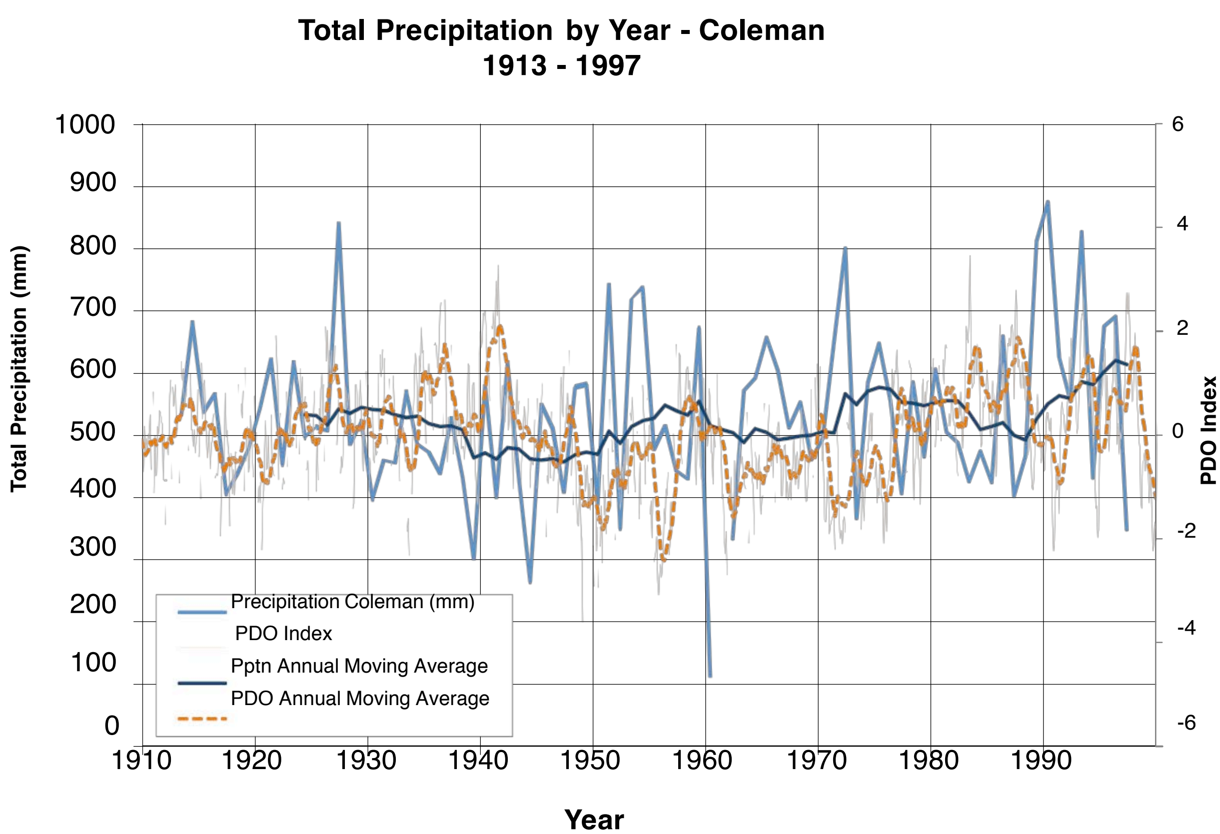


Figure 11 Precipitation graph

After that time, the pattern appears to be offset from the local precipitation trend and this may imply there are other mechanisms controlling the timing of the precipitation cycle. From about 1988 to the end of the data set (1997) the annual moving average of precipitation increased from 500 to 612 mm/year.

Annual precipitation of 530 mm/yr was determined in the central portion of the watershed (Coleman; Station ID# 3051720; years 1912 to 1997) and 453 mm/yr (Lundbreck; Station ID# 3054080; years 1911-1958) in the eastern portion of the watershed. Average precipitation in the fall and winter (October to February) ranged from 19.9 mm (January) to 31.6 mm (October) from 1911 to1958 at Lundbreck. The highest rainfall, averaging 88 mm over the same time period, occurs in the month of June. In the western portion of the watershed, precipitation data are available from 1998 to 2007 (Crowsnest Creek; Station ID# 05AA812). There is no period of overlap between this station and that at Coleman so comparisons of rainfall at different elevations could not be made.

According to Tokarsky (1974) the potential evaporation is 635 mm in the mountain areas in the watershed where total precipitation is the highest. This suggests that the Crowsnest River watershed is in a moisture-surplus area which is expected to significantly affect recharge to subsurface aquifers. In the eastern area of the watershed, Chinook winds ablate some of the snow cover by sublimation[g] indicating that winter evaporation is still significant (Tokarsky, 1974). This easternmost area is likely in a moisture-deficit.

Generally warmer temperatures as a result of global warming are expected to lead to warmer and longer summers which may result in:

- Increasing evapotranspiration[g];
- Less recharge to subsurface aquifers; and
- Lowering of the water table as supply wells continue to be pumped and new wells are brought on line as the population expands.

Changes in temperature and precipitation will likely alter recharge to groundwater aquifers, causing shifts in water table levels in unconfined aquifers. In addition, if there is an overall increase in temperature, there will be increased lake evaporation, which will lower lake levels and streamflow. Although an increase in precipitation could increase recharge to aquifers, actual recharge will depend on timing of precipitation events. Since a significant volume of groundwater recharge is derived from snowmelt released for several months, increasing temperatures and winter precipitation for a shorter period will undoubtedly increase surface runoff and may reduce aquifer recharge in the long-term. Our understanding of climate variability/change and potential impacts on groundwater resources remains limited.

The projected population growth in the region will likely cause an increase in groundwater demand as surface water is currently fully allocated and licensing is under a moratorium. Anticipated increase in groundwater diversion and use for domestic purposes which does not have to be licensed under the Water Act, may cause lowering of groundwater levels and has the potential to reduce groundwater discharge into streams and rivers if not properly managed.

In the absence of long-term groundwater monitoring, it is difficult to accurately predict the cumulative effects of climate change and on-going development in the region. Surface water features respond quickly to climate variability and the response may be on the order of hours or days. Groundwater systems may have longer response times extending from years to millennia depending on the hydraulic connection to surface water and, therefore can be more difficult to manage in the absence of a regional monitoring well network.

In Canada, most research on the potential impacts of climate change on the hydrologic cycle has been directed at forecasting the potential impacts on surface water, specifically the links between glacier runoff and river flows. Relatively little research has been undertaken to determine the sensitivity of aquifers to changes in the key climate change variables including but not limited to, precipitation and temperature (van Everdingen, 2006).

3.3.4 Natural Regions

Six Natural Regions based on geography, vegetation, soils and physiographic features combined with climate, are defined in the province of Alberta (Natural Regions Committee, 2006). Within the Crownest River watershed, two of the regions are represented, Rocky Mountain and Grassland. The Rocky Mountain Region consists of three Subregions: Alpine; Subalpine and Montane, all three of which are present in the watershed. The Grassland Region within the watershed consists of only the Subregion of Foothills Fescue.

Table 4 Climate Characteristics of Natural Subregions

Subregion	**Elevation of Upper Limit** (mASL)	**Mean Annual Temperature** (ºC)	**Average Annual Precipitation** (mm)	**Growing Season Precipitation** (mm)	**Percent of Annual Precip. Falling in Growing Season** (%)
Alpine	-	-2.4	989	472	48 (Jul-Aug)
Subalpine	2000	-0.1	755	419	56 (Jun-Aug)
Montane	1550	2.3	589	382	65 (Jun-Aug)
Foothills Fescue	1300	3.9	470	333	71 (Jun-Sep)

Note: mASL mean metres above sea level, mm means millimetres

In general, the Alpine and Subalpine Subregions have mean annual temperatures lower than 0 ºC (**Table 4**). The average annual precipitation in these two Subregions is greater than 755 mm of which more than 44 percent falls in the winter as snow. In the Montane Subregion the mean annual temperature is higher than 0 ºC and the average annual precipitation is approximately 60 percent of that in the Alpine Subregion, but only 35 percent falls during the winter. The Foothills Fescue Subregion has generally warmer temperatures and lower precipitation than does the Montane Subregion.

In the Montane Subregion the average annual precipitation of 589 mm is slightly greater than that noted at Coleman (530 mm for the period 1912 to 1997). According to data presented by the Natural Regions Committee (2006) the precipitation in the Subalpine and Montane Subregions is 75 percent and 60 percent, respectively, of that in the Alpine Subregion.

3.4 Surface Water Hydrology and Drainage

There are numerous tributary creeks that flow into the Crowsnest River as it flows from west to east for about 52 km and discharges into the Oldman Reservoir. The majority of creeks and headwater lakes originate from surface runoff generated from precipitation and snowmelt. Notable exceptions include Ptolemy Creek, Crownest Lake, Emerald Lake and Island Lake which are all fed by groundwater springs. The constant flow of groundwater from these springs (possibly exception Ptolemy Spring) indicates a deep-seated and regional groundwater system is connected to the surface environment in these areas.

There are no dams constructed on the Crowsnest River, although the river does empty into the reservoir created by the Oldman dam, east of the watershed. Therefore, the flow in the Crowsnest River is considered to approximate natural flow conditions. Flow gauging along the Crownest River was conducted at Frank (Station ID# 05AA008) and at Lundbreck (Station ID# 05AA003). Data at Frank was collected from 1910 to 1920 and again from 1949 to 2011 (Water Survey of Canada, 2013). The Lundbreck record is from 1908-1931 (ESRD later extended this through modelling to 2010). Surface water use is low in the upper reaches of the Crowsnest River. As a result, the recorded flows at Frank (Station ID# 05AA008) are considered to be approximately equal to natural flows. Refer to **Figure 8** for station locations.

Table 5 Crowsnest River Gauging Stations

Station Name	WSC Station Number	Date Range (yyyy-yyyy)	Minimum Discharge (m^3/s (month))	Maximum Discharge (m^3/s (month))	Drainage Area (km^2)
Crowsnest River at Frank	05AA008	1912-2011	0.82 (Dec)	33.8 (Jun)	402.7
Crowsnest River near Lundbreck	05AA003	1908-1931	1.2 (Jan)	51.4 (Jun)	676.0
Gold Creek near Frank	05AA030	1975-2011	0.23 (Apr)*	0.47 (Jun)	63.3

Note: WSC Means Water Survey of Canada, * - no measurements collected during winter months

The total discharge from Crowsnest River varies from year to year. The mean annual discharge as modelled by ESRD for the period from 1912 to 2001 (OWC, 2010a), is approximately 4.6 m^3/s at Frank, and 6.64 m^3/s at Lundbreck. The maximum recorded monthly flow was noted at Frank in June 2002 (33.8 m^3/sec), and at Lundbreck in June 1923 (51.4 m^3/s).

Mean monthly discharges in Crowsnest River reported at the Frank and Lundbreck gauging stations are plotted on **Figure 12** over the period from 1950 to 2010 for comparison. The drainage areas extending above each of the stations are noted in **Table 5**. These data were obtained from the Water Survey of Canada website (Water Survey of Canada, 2013).

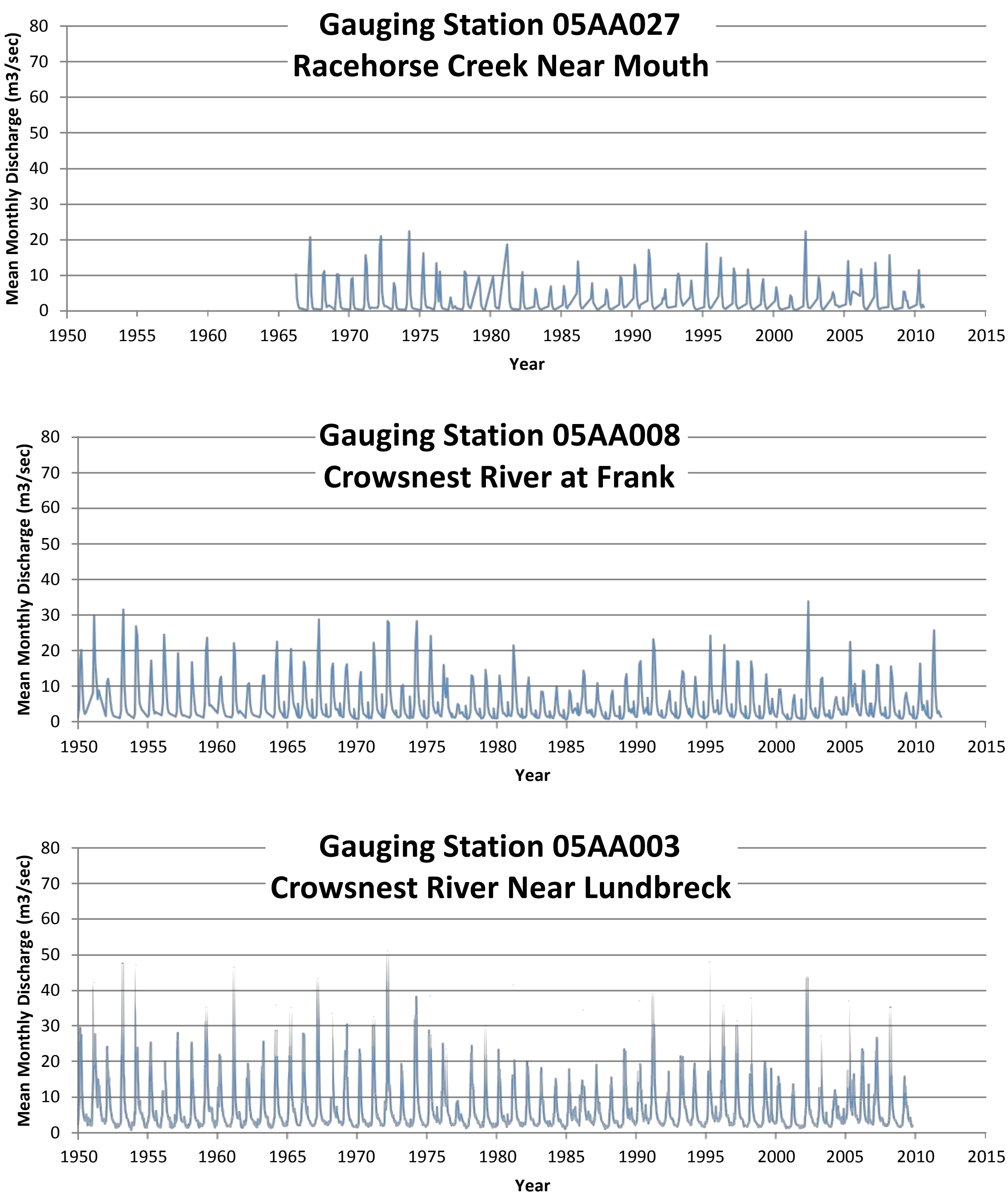


Figure 12 Crowsnest River discharge

The mean, minimum and maximum annual discharge for the period 1986 to 2010, which is the overlap period for the three gauging stations. This shows that peak flow in Crowsnest River occurs in early June (**Figure 13**). This peak roughly coincides with the period of spring snowmelt.

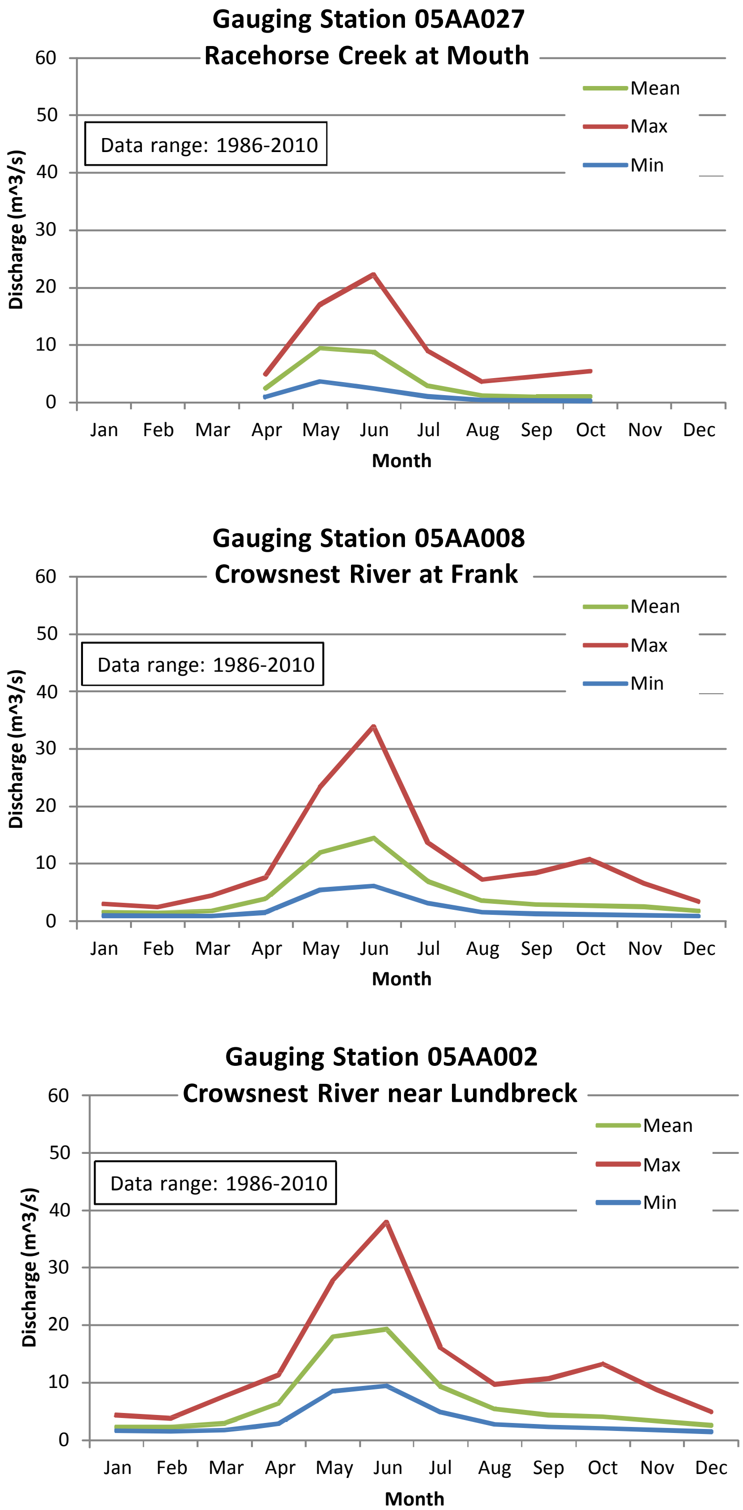


Figure 13 Crowsnest River mean discharge

Based on estimated naturalized flows from 1965 to 1995, trend lines constructed by the OWC (2010a) showed that the Crowsnest River flows are decreasing by 0.3% per year near Frank and by 0.5% near Lundbreck. However, the OWC (2010a) reported that these decreases were not statistically significant.

The Frank gauge was not monitored after 1931 so comparison of actual recent data was not possible. However, comparison of mean annual discharge for the period 1910 to 1920, at the Frank and Lundbreck stations show little difference in flow and only increase slightly from Frank to Lundbreck. This indicates that there is not much additional flow into the surface water in this stretch of the river that is approximately 20 km long (**Figure 14**).

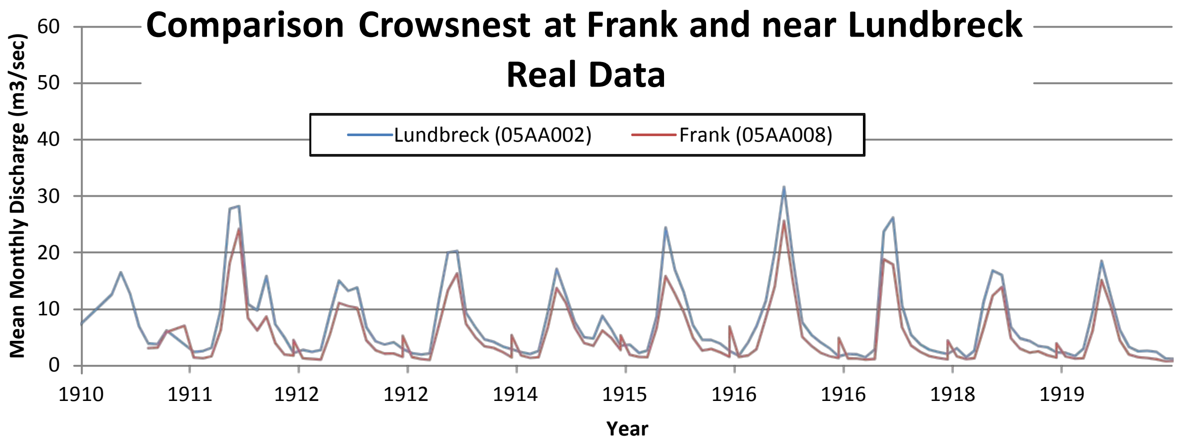


Figure 14 Crowsnest River Real Data Comparison Between Frank and Lundbreck

3.5 Bedrock and Surficial Geology

The regional stratigraphy in southern Alberta is summarized in a stratigraphic column on **Figure 15** modified from Core laboratories (2002) and based on work by Gordy et al. (1977) and Hiebert (1992). The stratigraphy includes the following from oldest to youngest:

- Devonian Palliser Formation (limestone and dolomitic limestone);
- Unconformably overlain by the Mississippian Exshaw (shale), Banff Formation (carbonates), Rundle Group (carbonates) and Pennsylvanian and Permian Rocky Mountain Group (carbonates, shales);
- Unconformably overlain by the Jurassic Fernie Group (shale) and Kootenay Group (sandstone and shale);
- Overlain by the Lower Cretaceous Blairmore Group (sandstone) and the Crowsnest Formation (volcanic breccia);
- Unconformably overlain by Upper Cretaceous Alberta Group (predominately shales); and
- Upper Cretaceous Belly River (sandstone), Bearpaw (shale) and St. Mary River (sandstone) Formations.

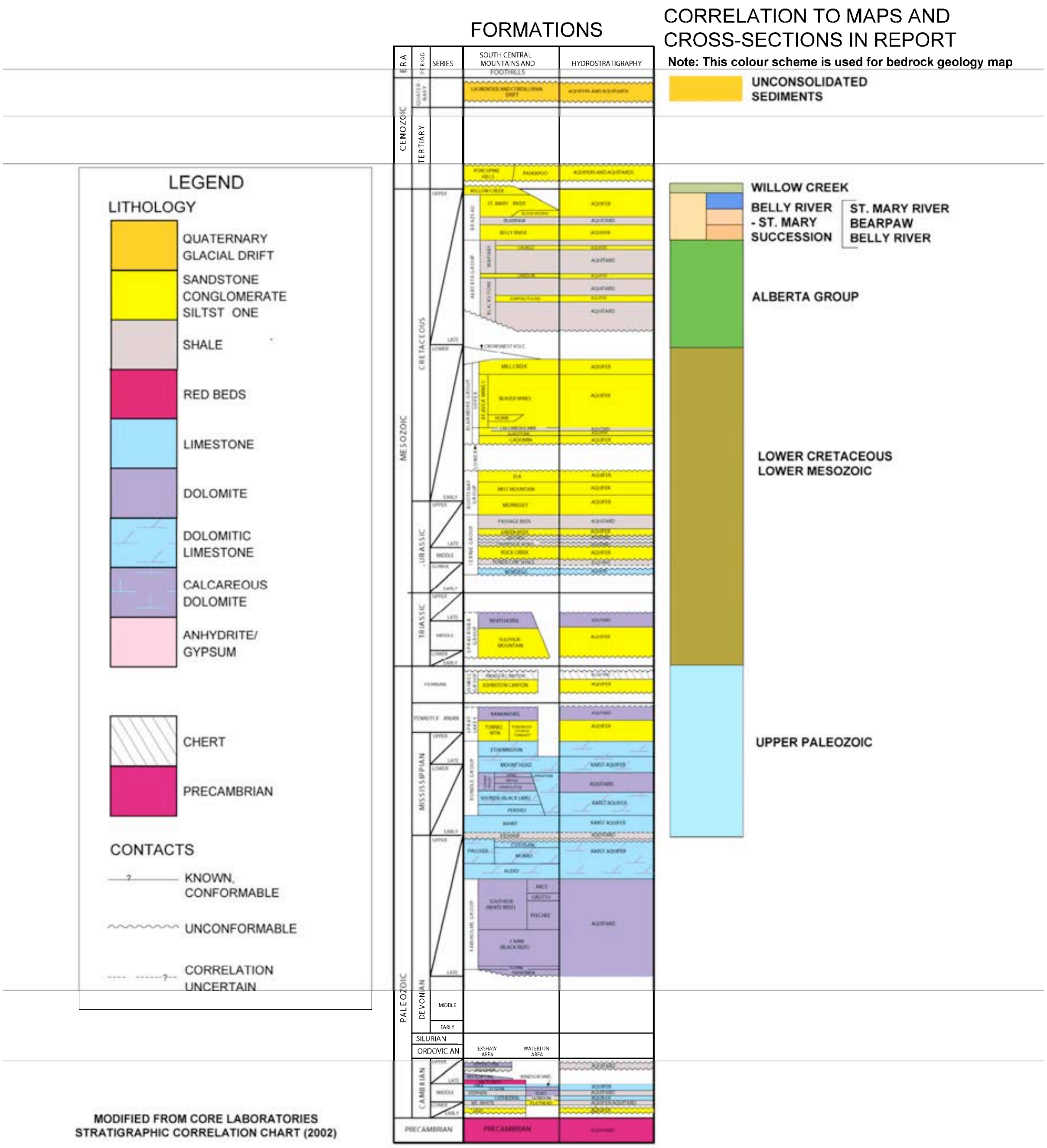


Figure 15 Stratigraphic Column

The bedrock geology was previously compiled by Hamilton et al. (1998) and is also presented in Gadd (2008). The bedrock geology map of the Crowsnest River watershed, based on data from the Alberta Geological Survey, is shown on **Figure 16**. Note that the bedrock geology on the AGS map is subdivided based on lithologic and temporal nomenclature; although this is an inconsistency, and this was done in order to group various units to make them easier to display on large scale maps.

The Crowsnest River watershed lies within the western slopes of what is known as the disturbed belt (Nielsen, 1965; Gadd, 2008). The disturbed belt is found at the leading edge of the Rocky Mountain chain and comprises a northwesterly trending zone of closely spaced and westerly dipping thrust faults and intensely folded bedrock. The zone was formed as part of the mountain building process. Thrust faults subdivide the disturbed belt into long, narrow structural units, which also results in the emplacement of older rocks over younger rocks (Nielsen, 1965). Older bedrock formations appear to be less erosive or more resistant and therefore are prominent features of the front ranges in the Rocky Mountains.

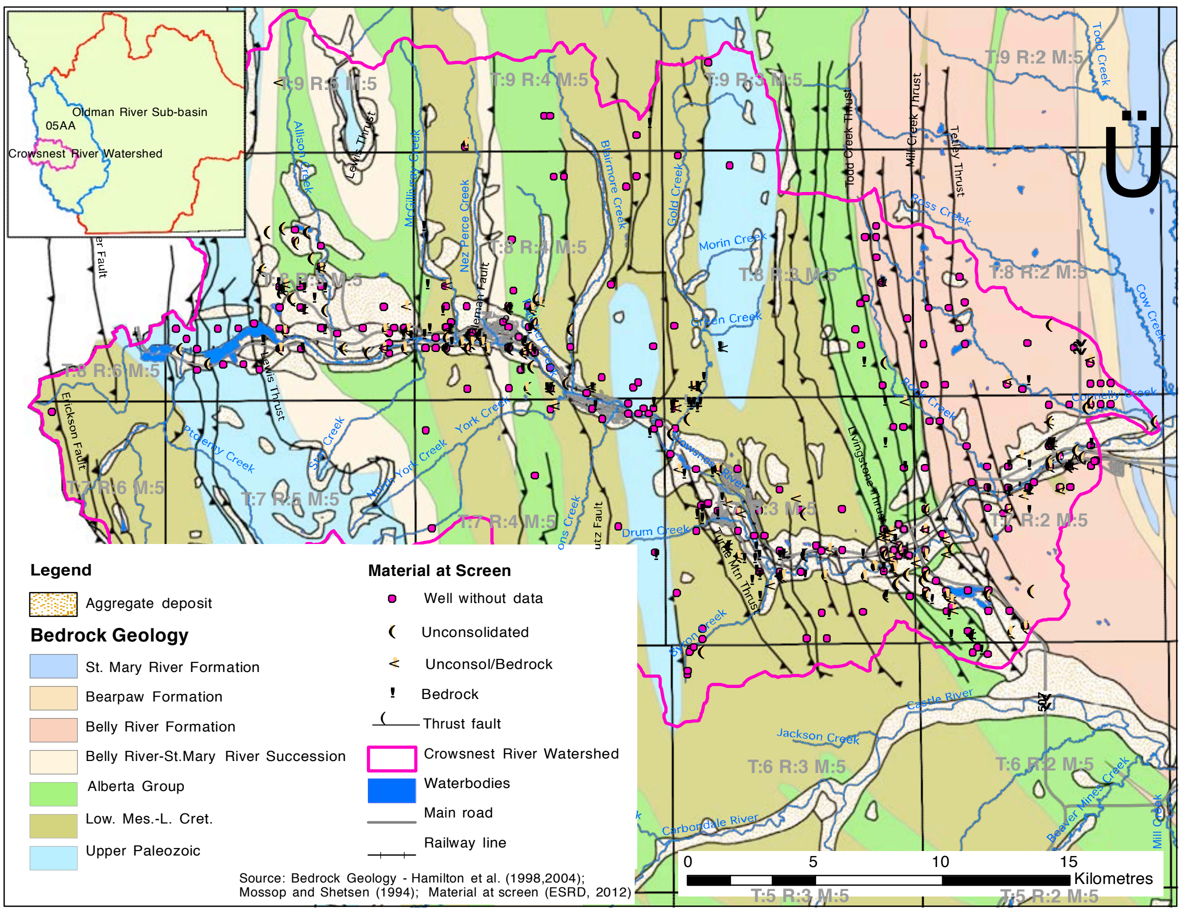


Figure 16 Bedrock geology map

3.5.1 Paleozoic Bedrock

Paleozoic bedrock in the western part of the watershed (**Figure 16**) consists of Cambrian carbonate, shale and sandstone, Devonian limestone and dolomite and Mississippian shale and carbonate. Thrust faulting and folding within the watershed is common and may have created permeable condition needed for water supply development. However, the permeability of these rocks has not been extensively tested since very few wells are completed in this area. It is anticipated that sandstone and limestone units would likely have greater permeability/transmissivity[g] because of the greater fracture porosity, karstic[g] features and fractures relating to faulting and folding.

3.5.2 Lower Mesozoic and Lower Cretaceous

3.5.2.1 Jurassic Fernie Group and Kootenay Group

The Fernie Group is composed of brown and dark gray and black shale which may be fractured. Most of its primary sedimentary rock types that make up the group originated to the east (Canadian Geoscience Knowledge Network, 2013). The Fernie Group typically has a thickness of 70 to 150m.

The Kootenay Group consists predominantly of formations composed of sandstone (Morrissey, Mist Mountain and Elk formations) with some interbedded siltstone, mudstone and shale. The Kootenay Group hosts the coal that was historically mined within the Crowsnest River Watershed (Campbell, 1967). Coal seams up to 60 m thick have been noted.

3.5.2.2 Blairmore Group and the Crowsnest Formation

The Blairmore Group consists of four formations, including: Cadomin, Gladstone, Beaver Mines and Mill Creek. The basal Cadomin consists of a pebble conglomerate which can form a significant aquifer. The Gladstone Formation consists of grey mudstone and sandstone. The Beaver Mines and Mill Creek formations consist of mudstone and fine-grained sandstone.

The Crowsnest Formation consists of volcanic breccias; they are the eroded remnants of an alkaline volcanic centre that erupted in a fluvial environment predating the Rocky Mountains

3.5.3 Upper Cretaceous Alberta Group

The Alberta Group consists mainly of silty mudstone (the Blackstone Formation in its lower part and the Wapiabi Formation in its upper part). The two formations are separated by a prominent sandstone unit in the middle (Cardium Formation).

3.5.4 Upper Cretaceous Belly River, Bearpaw St. Mary River Succession

The Belly River Formation consists of grey thick-bedded sandstone, clayey siltstone and mudstone.

The Bearpaw Formation consists of dark gray blocky silty shale and grey clayey sandstone.

The St. Mary River Formation consists of non-marine sandstone (coarse to fine-grained, pale brown, massive to well-bedded) interbedded with grey carbonaceous shale. It grades into the Edmonton Group to the north. The lower part consists of sandstone, shale and coal; whereas; the upper portion is composed of sandstone, shale and limestone (Veilleux, 1993). The upper and basal contacts are gradational. The Belly River – St. Mary River succession is noted in the vicinity of Crowsnest Lake.

3.5.5 Unconsolidated Surficial Deposits

Surficial geology of the area was compiled by Bayrock and Reimchen (1975) and is shown on **Figure 17**. Mountains and steeply sloping terrain were generally mapped as having thin colluvium and till horizons. Within the Crowsnest River valley, pre-glacial, alluvial sand and gravel underlying glacial and post-glacial deposits exist or were interpreted to exist within the majority of this river valley (EBA, 2006). The surficial geology of the Crowsnest River valley and sub-valleys is generally mapped as silty sand till generally less than three m in thickness and coarse grained alluvium, kames, kame terraces and glacial moraines.

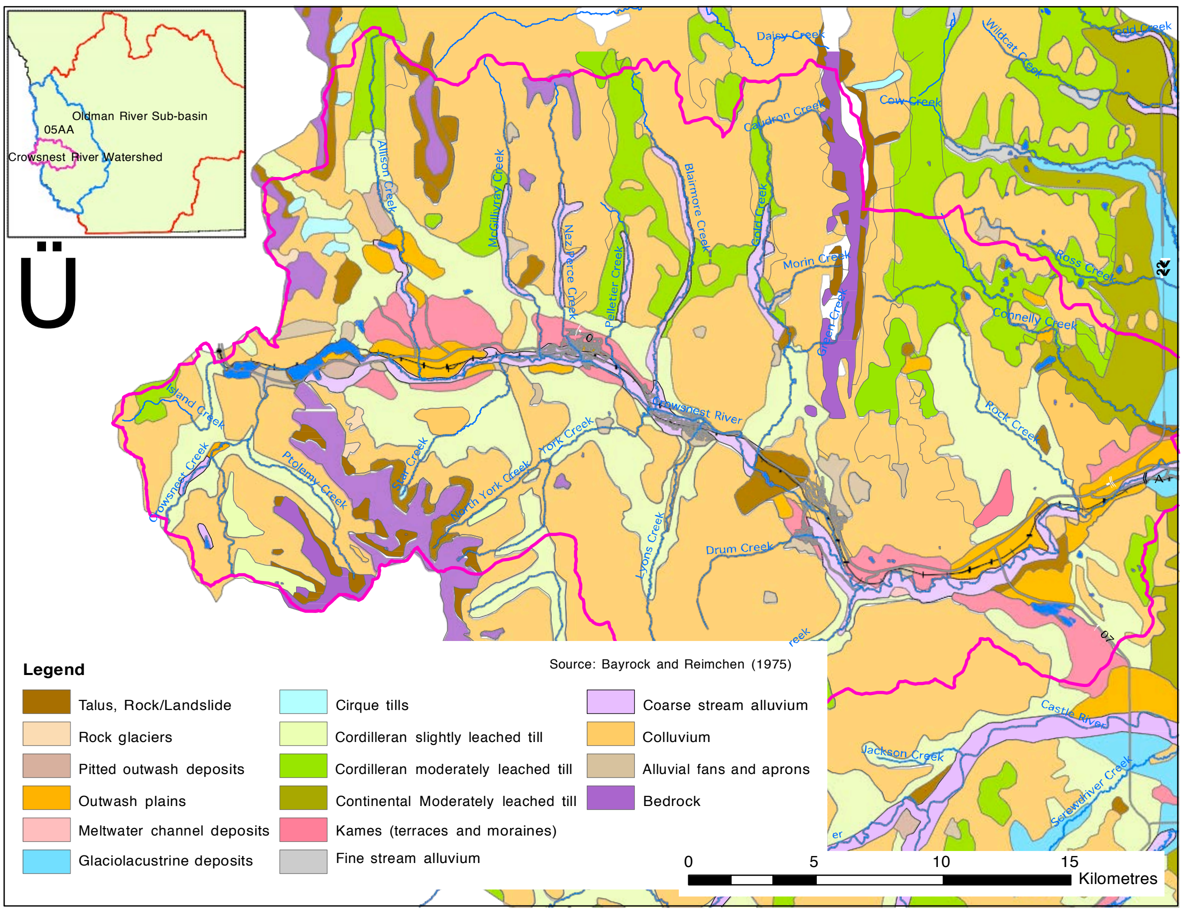


Figure 17 Surficial Geology (Bayrock and Reimchen. 1975)

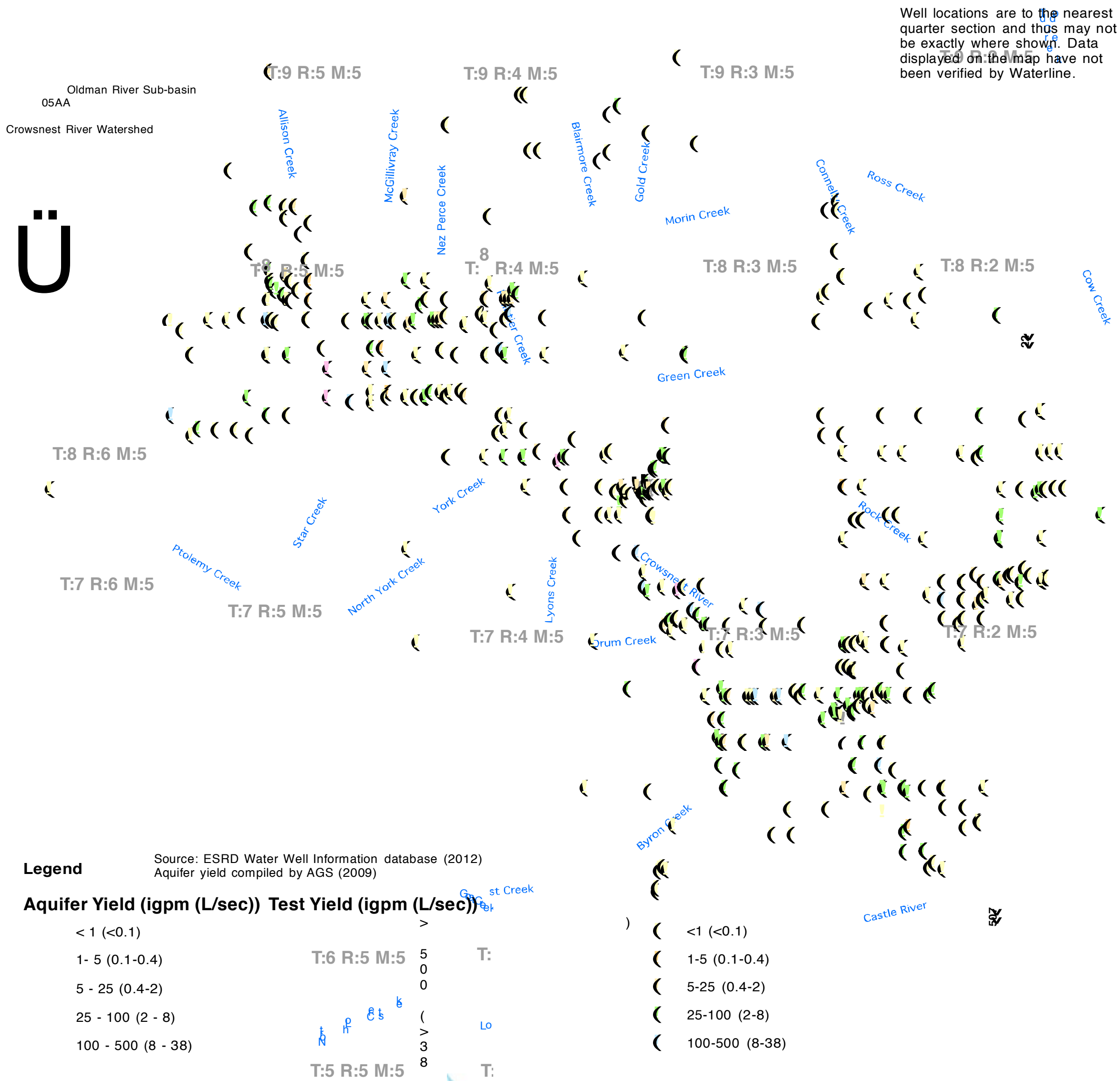
Local surficial geology features and depositional processes of particular importance from a hydrogeological/aquifer development perspective include:

- Crowsnest Lake was formed by late Wisconsinan glaciers from side valleys creating a large depression (Gadd, 2008);

- After glaciation, on-going erosion and deposition by Crowsnest Creek resulted in a large alluvial fan, which separates Crowsnest Lake from Island Lake to the west (the approximate location of the continental divide);
- Several glacio-fluvial gravel deposits (i.e., kame deposits with locally large proportions of fine-grained material and/or outwash plains) exist just east of Crowsnest Lake in the vicinity of Sentinel, north of Sentinel along Allison Creek, and east and south of the intersection of Highway 3 and Highway 507 (shown on **Figure 2**); and
- In the vicinity of Highway 3 and Highway 507, the Crowsnest River has cut into glaciofluvial deposits and created terraces that extent almost 4 km in length (Gadd, 2008).

3.6 Hydrogeology and Groundwater Flow

The regional hydrogeology in the Crowsnest River area has been described in Tokarsky (1974). Aquifer yields vary greatly within the area. The highest aquifer yields are observed in the present-day alluvial gravels adjacent to the Crowsnest River and major creeks (**Figure 18**).



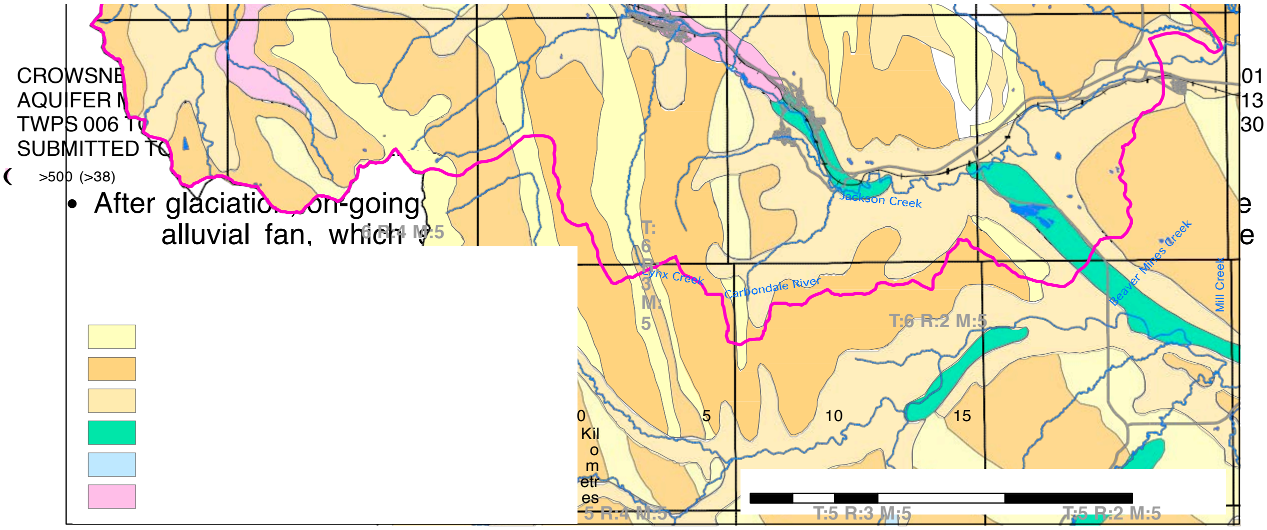


Figure 18 Aquifer yield and Well Yield (based on ARC reports)

In addition, sand and gravel beds which occur in pre-glacial and glacial buried valleys mapped in the region are described in the following sections. Bedrock formations are expected to produce generally very low to moderate yields. Exceptions may be fractured and locally karstic, limestone formations in the western portion of the Crowsnest River watershed.

Well and/or aquifer yield in the bedrock is proportional to the intensity of fracture development. In contrast, aquifer yield in alluvial or glacio-fluvial aquifers is a function of the grain-size distribution and saturated thickness is generally higher where coarse sand and gravel deposits are present. Other factors such as structural and depositional features that determine the areal extent of aquifers, and topographic location and recharge/discharge conditions within the watershed also play a significant role in determining the long-term productivity or yield of aquifers or wells.

3.6.1 Water Well Completion

There is a total of 912 water well records in the Alberta Water Well Information Database within the Crowsnest River watershed. A total of 1,642 water well records are indicated within the watershed plus the 10-km buffer zone. The distribution of well records based on the geology encountered at the well screen interval or perforated interval is shown in **Table 6**. This table is based on all well records that contain information on well production (well screen) intervals and lithology.

Table 6 Distribution of Well Records by Material at Production Interval within the Watershed

Geology Across Screen	Number of Well Records
Unconsolidated	172
Unconsolidated/Bedrock	97
Bedrock	249
No Lithology/Unknown	394

The distribution of water well records by material encountered at the well screen is shown in **Figure 16**. Of the 419 water well records in alluvial materials, 90 are actually screened in the bedrock below the alluvial materials.

Of the 912 well records in the watershed, 11 were dry and 109 were abandoned. A dry well is one that does not produce enough water for the intended use. As dry wells appear to be evenly distributed throughout the watershed, it suggests that there are no large areas within the watershed in which there is no available groundwater supply. That is to say, if a dry well is encountered in one area, a move of 10’s to 100’s of metres away may prove more successful. This is common in areas of fractured bedrock where the productivity or yield of a well depends on whether it intercepts fractures that are hydraulically connected to the regional fracture network.

In the past, property development in the region focused on utilizing near-surface sand and gravel aquifers adjacent to the major rivers and railway lines. Groundwater supply from bedrock aquifers has generally been under-utilized, in part because development has been within the larger valleys where alluvial aquifers are most common. As the desire of people to live in more rural settings increases, so does the demand for groundwater supply. Often, rural lots can be several hectares in size and the demand for groundwater is greater if irrigation systems are required to maintain large landscaped areas. In addition, developments with scenic views are typically located at higher elevations where individual groundwater supplies likely must come from bedrock aquifers near the top of the watershed. As groundwater recharge and flow is gravity driven, smaller catchment areas at higher elevations can result in lower aquifer recharge resulting in lower groundwater yield.

Using water well data from the Crowsnest Pass and Waterton Lakes regions, for example, Nielsen (2009) tabulated the main bedrock formations versus well yield (**Table 7**). This shows that the success rate for drilling a useable supply well is less than 50 percent in the Alberta Group, and in the Kootenay Group and Fernie Group whose lithologies largely consist of mudstone and shale. The largest average yields were noted in sandstone of the Blairmore Group, the Belly River Formation, and in Mississippian limestone, which are likely karstic in nature.

Table 7 Distribution of Well Yield by Lithology (from Nielsen, 2009)

Formation	Geologic Period	Time Range (Ma)	Lithology	No. of Wells (>2.27 L/min)	No. of Dry Wells (<2.27 L/min)	Avg Yield (m^3/d)
Belly River Gp.	Upper Cretaceous	70-83	Deltaic plain and semi-arid alluvial plain deposits, sandstone, shale, siltstone, continental	41	13	40
Blairmore Gp.	Early Cretaceous	100-145	Very fine to fine sandstone, mudstone, coal, greenish color, continental	87	16	67
Alberta Gp.	Middle Cretaceous	70-112	Dark grey silty mudstone to thick massive shale, sandstone unit in the middle, marine.	57	60	15
Crowsnest Fm.	Lower Cretaceous	100-109	Pyroclastic ash to brecchia, volcanic	11	1	20
Kootenay Gp.	Late Jurassic to early Cretaceous	65 –161	Massive sandstone, siltstone, mudstone, shale, coal, continental	0	1	0
Fernie Gp.	Jurassic	146-200	Brown, grey and black shale, marine	0	3	0
Other Units	Mississippian	325-360	Limestone, dolostone, shale, marine	5	0	45

Notes: Gp means Group, Ma means million annum/years, gpm means gallons per minute, m^3/d means cubic metres per day, avg means average. 2.27 L/min converted to metric from 0.5 Imperial gallons/min

3.6.2 Results of Field Verification Survey

Approximately 40 wells were verified in the field as part of the Waterline study. Fifteen of these could be linked to a water well record in the Alberta Water Well Information Database. The well verification is of great value as GPS coordinates provided well location data to the nearest 10 m allowing more accurate construction of cross sections and maps. The locations of field verified water wells and springs are shown on **Figure 19**.

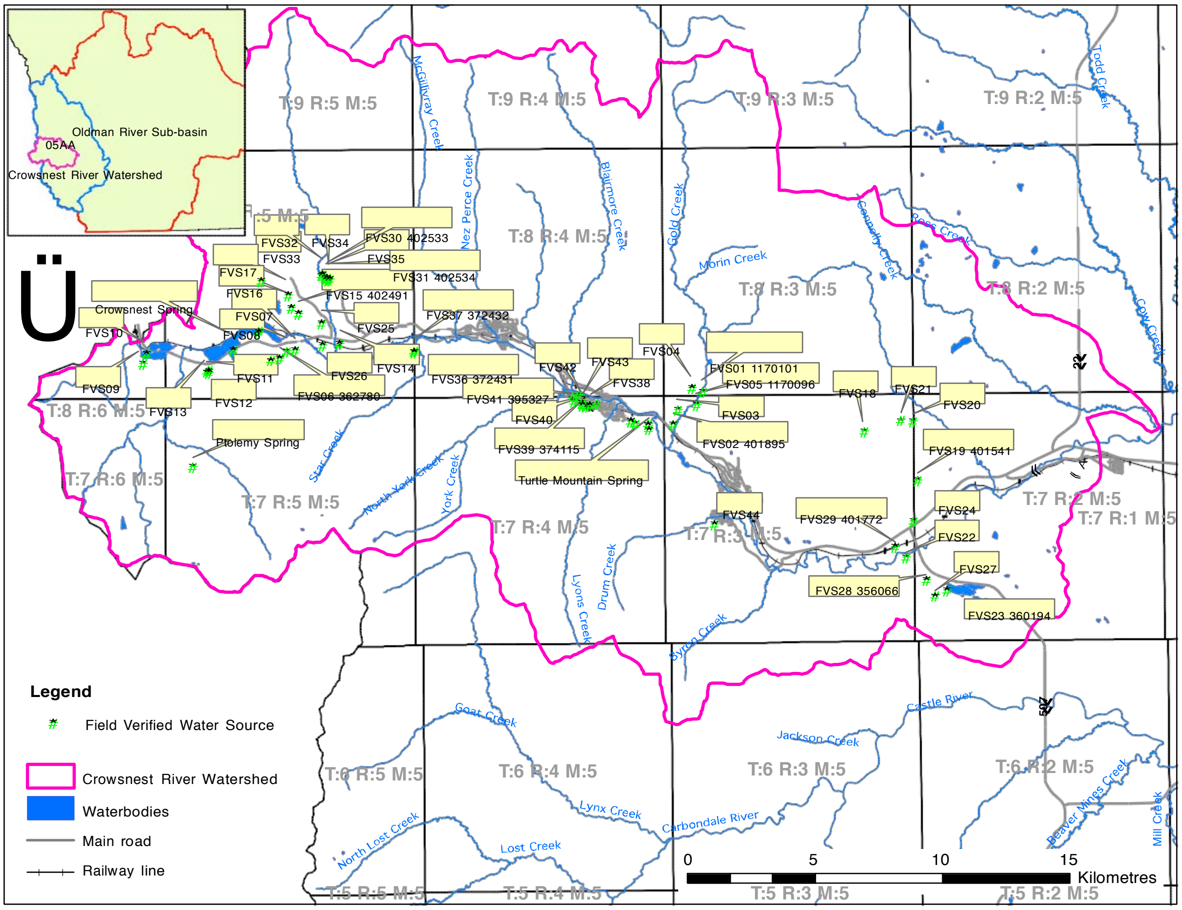


Figure 19 Field Verified Water Supply Locations

The field verification study was able to link 15 of the water wells in the field to ESRD water well records (**Table 8**). It is important to note that the difference in locations between field-verified location and those in the ESRD water well database differ by as much as 500 m. In a high relief terrain such as the Crowsnest River watershed, this change in location means the well elevation changes by as much as 36 m which can be significant when assessing aquifer geometry and groundwater flow. Piezometric surfaces which are dependent on the elevation of the water level are thus greatly impacted by inaccuracies in the elevation. Also, in the case of FVS37 (this refers to the field verified survey (FVS) identification number assigned by Waterline) which had a change in location of 500 m, this meant that the bedrock formation underlying the well is actually Alberta Group rather than Lower Mesozoic-lower Cretaceous. Field notes related to the survey work are presented in Appendix B.

In addition, to providing accurate well location and water data, the field verified survey was beneficial in terms of providing information to the public regarding groundwater protection initiatives being undertaken by OWC. Development of strong community relations and education programs regarding groundwater development and protection is critical to the successful implementation of groundwater management plans. Waterline learned that landowners with water wells tended to be more aware of groundwater issues than those who were serviced by a municipal system.

Table 8 Linkage Between Field Verified Wells and ESRD Water Well Records

FVS ID	ESRD ID	Original Northing	Original Easting	FVS Northing	FVS Easting	Distance Difference (m)	FVS Ground Elevation	Original Ground Elevation	Elevation Difference (m)
FVS01	1170101	5499118	688457	5499317	688725	334	1408	1421.30	13.3
FVS02	401895	5498273	687695	5497989	687635	290	1342	1354.30	12.3
FVS05	1170096	5499118	688457	5498784	688497	336	1385	1421.30	36.3
FVS06	362780	5500184	672109	5500184	672109	0	1374	1362.68	11.3
FVS15	402491	5502035	672676	5502008	672804	131	1419	1418.19	0.8
FVS19	401541	5496198	697579	5495892	697311	407	1336	1312.56	23.4
FVS23	360194	5491370	698556	5491561	698556	191	1229	1249.90	20.9
FVS28	356066	5492145	697723	5491916	697742	230	1253	1255.70	2.7
FVS29	401772	5493129	696652	5493188	696487	175	1227	1221.84	5.2
FVS30	402533	5503474	673634	5503565	673884	266	1456	1435.76	20.2
FVS31	402534	5503474	673634	5503499	673836	204	1447	1435.76	11.2
FVS37	372432	5500342	677002	5500654	677394	501	1336	1338.15	2.1
FVS39	374115	5498982	684400	5498594	684262	412	1300	1325.00	25.0
FVS41	395327	5498774	684206	5498658	684075	175	1303	1301.05	2.0

Note: All Easting and Northing values are NAD 83 Grid zone 11; FVS means field verified survey

3.6.3 Well Yield and Aquifer Transmissivity

Mapped aquifer yield, based on data presented by Tokarsky (1974) and compiled by the AGS, is presented in **Figure 18**. The highest well yields are found in Quaternary (alluvial) sand and gravel beds in the vicinity of the Crowsnest River. In some cases well yield appears to exceed 38 L/s (3,283 m^3/day). Individual wells ranged from less than 0.01 L/s (0.9 m^3/day) to more than 128 L/s (7,717 m^3/day) (**Figure 18**).

It should be noted that well yield values in the ESRD water well database are based only on measured pumping rate, determined during short-term air-lift and pumping tests performed in the well during or immediately after drilling. These values may not represent an accurate measure of the long-term sustainable rate or safe yield for the well. Nevertheless, the test data can be used to determine the apparent aquifer transmissivity, which is an indicator of the ability of the geologic material to transmit groundwater.

Apparent aquifer transmissivity is determined by an iterative calculation that relates the pumping rate during the test to the water level response of the well. The apparent aquifer transmissivity is therefore more representative of the potential long-term productivity of an aquifer than the pumping rate during a test. Appendix A provides the methodology for determining the apparent transmissivity based on individual well tests. Using the location of the water well production interval with respect to the mapped geology (unconsolidated and bedrock materials), the apparent transmissivity values were grouped by formation (**Table 9**).

Table 9 Apparent Transmissivity by Formation

Formation	Apparent Transmissivity (m^2/day)			No. of Tests
	Minimum	Maximum	Geometric Mean[g]	
Unconsolidated	0.10	99.5	45.2	140
Belly River Formation	0.02	6.9	1.9	21
Belly River-St.Mary River Succession	0.16	5.2	1.1	9
Alberta Group	0.06	9.2	3.4	34
Lower Mes. -Lower Cret.	0.12	994.1	3.5	115
Upper Paleozoic	13.45	13.5	13.5	1

Notes: m^2/day means metres squared per day, No. means number, Mes. means Mesosoic Era, Cret. Means Cretaceous Period; Lower Mesozoic-Lower Cretaceous not differentiated into formations

The data indicate that the highest mean apparent transmissivity values occur in water wells with production intervals completed in the unconsolidated surficial materials. This agrees with the regional hydrogeology interpretation by Tokarsky (1974). The next highest transmissivity values occur in wells with production intervals in the Lower Mesozoic-Lower Cretaceous and Alberta Group. These wells tend to be in the eastern portion of the watershed.

3.6.4 Piezometric Surfaces and Horizontal Flow

The scarcity of water level data made it impossible to create piezometric surface contour maps with any degree of accuracy. In its stead water level elevations using coloured dots were plotted for water wells completed from 0-25 m below ground and wells completed from 25-50 m below ground (**Figure 20** and **Figure 21,** respectively). Water wells in the ESRD water well database generally do not include ground elevation data. These data were determined from a digital elevation model provided by ESRD for this study. **Figure 20** presents water level elevation values within the Crowsnest River watershed. The water levels were measured in wells at the time of well construction or testing (source: ESRD water well database, July 2012). The data can be interpreted to provide a general interpretation of groundwater flow in the watershed. It should be cautioned that these maps comprise water level data collected at different times and from different hydrostratigraphic zones and therefore may not reflect local conditions. However, they were plotted to give an impression of the water level elevations across the watershed; and also to highlight gaps in the data. For simplicity, the well water level data were grouped according to well depth to give a regional sense of the groundwater flow direction. The maps depict groundwater elevation at the following depth intervals:

- 0-25 mbGL – includes wells completed in unconsolidated materials; and
- 25-50 mbGL, shallow bedrock water wells.

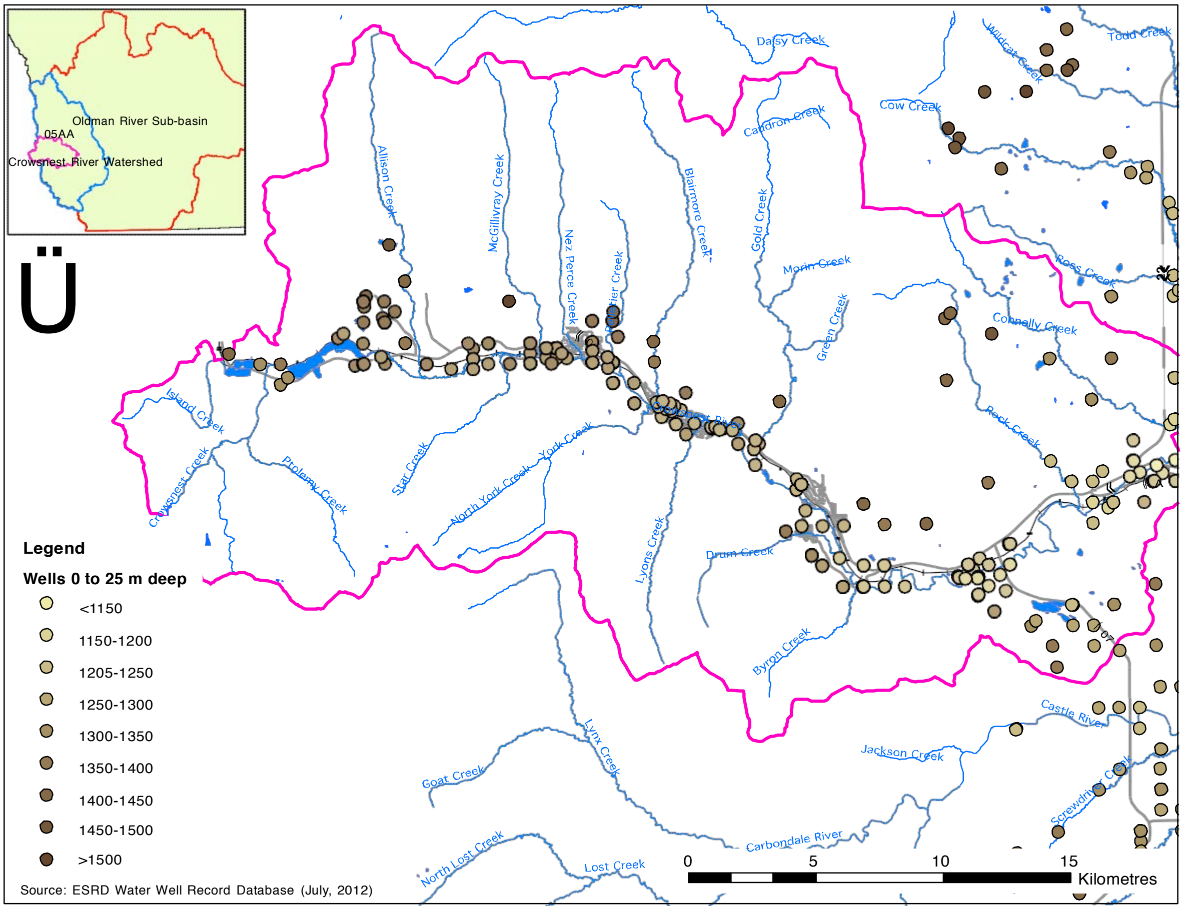


Figure 20 Water level elevations for wells 0 – 25 m Deep

In general, the groundwater flow direction is locally toward the Crowsnest River, and regionally from west to east paralleling the Crowsnest River. The data indicate that groundwater flow across formational boundaries is fault and fracture controlled and this is approximately perpendicular to the axis of the Crowsnest River. Groundwater flow follows this path of least resistance, which essentially short circuits the groundwater from individually stacked formation to the centre of the valley and then east toward the Oldman River.

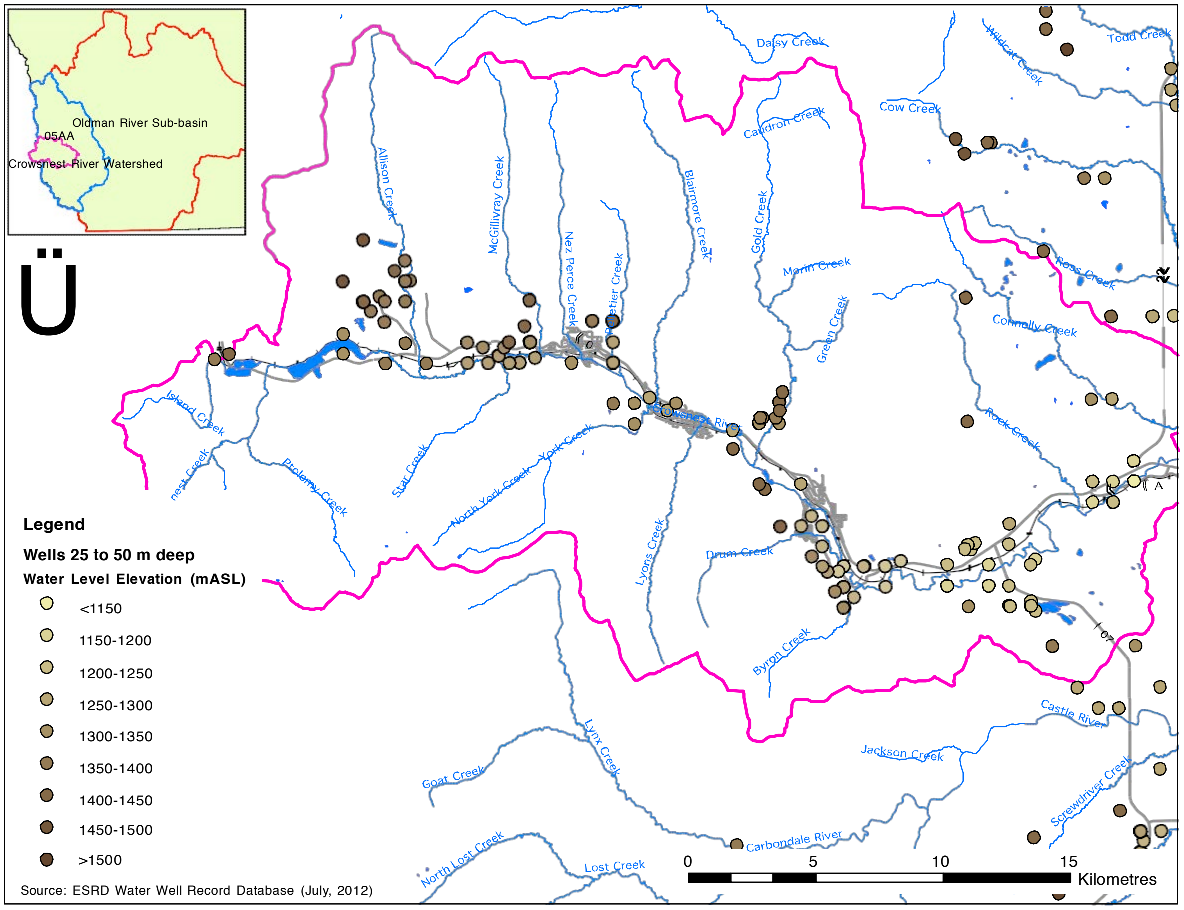


Figure 21 Water level elevations for wells 25 – 50 m Deep

3.6.5 Assessment of Vertical Groundwater Flow

In general, based on the preceding figures (**Figure 20** and **Figure 21**), the data indicate that the shallow wells exhibit higher water levels (or higher groundwater elevation) in comparison to deeper wells across the watershed. This suggests that groundwater predominantly moves downward (recharging). The exception occurs in the vicinity of the Crowsnest River valley where gradients appear to be upwards and groundwater moves from deeper to shallow zones and discharges to the surface environment. This pattern of flow is consistent with the known bedrock structure where geologic formations in the disturbed zone tilted to the west and strike north-south.

Six nested piezometers were installed in the Crowsnest River Valley to assess the vertical component of groundwater flow (Grisak, 1976). The piezometer locations are plotted on **Figure 22**. The water level data collected from those piezometers indicated the following:

- Downward gradients are indicated between Blairmore and Coleman suggesting recharge conditions dominate in this area;

- Neutral gradients are indicated to the east of Blairmore suggesting that horizontal groundwater flow dominates in this area with generally no vertical component;
- Upward gradients are indicated approximately 200 m further downstream of Blairmore suggesting discharging conditions; and
- The water levels in two wells completed in the basal sand and gravel unit just to the east and west of the Turtle Mountain thrust (piezometers 8 and P9; **Figure 22**) indicate artesian (discharging) conditions with a strong upward vertical gradient.

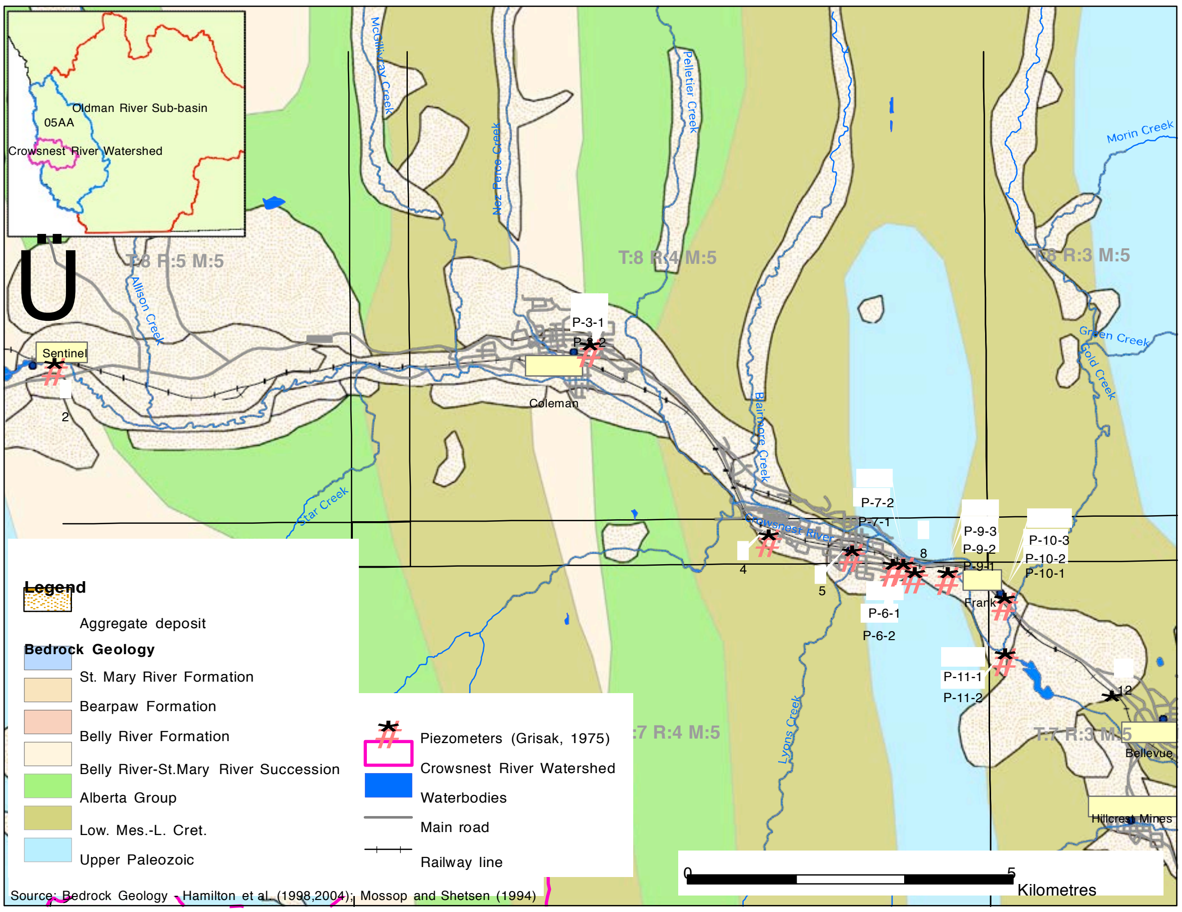


Figure 22 Nested Piezometer Locations (Grisak, 1976)

3.6.6 Water Level Monitoring

3.6.6.1 ESRD Groundwater Observation Well Network (GOWN)

There are no ESRD observation wells within the Crowsnest River watershed. The only groundwater monitoring point for the entire watershed is the one well located at the Allison Creek Trout Hatchery described below.

3.6.6.2 Allison Creek Trout Hatchery

The only long-term monitoring of groundwater levels in the Crowsnest River watershed was performed during the 10-year period 1986-1996 at the Allison Creek Trout Hatchery north of Crowsnest Lake. The hydrograph (water levels plotted versus time; **Figure 23**) shows only depth to water levels since the elevation of the well is not known with any accuracy. The hydrograph does show that the water levels in the well follow the PDO Index curve very closely, suggesting that the global climate especially that of the Pacific Ocean strongly affects precipitation and consequently groundwater recharge amount at this location.

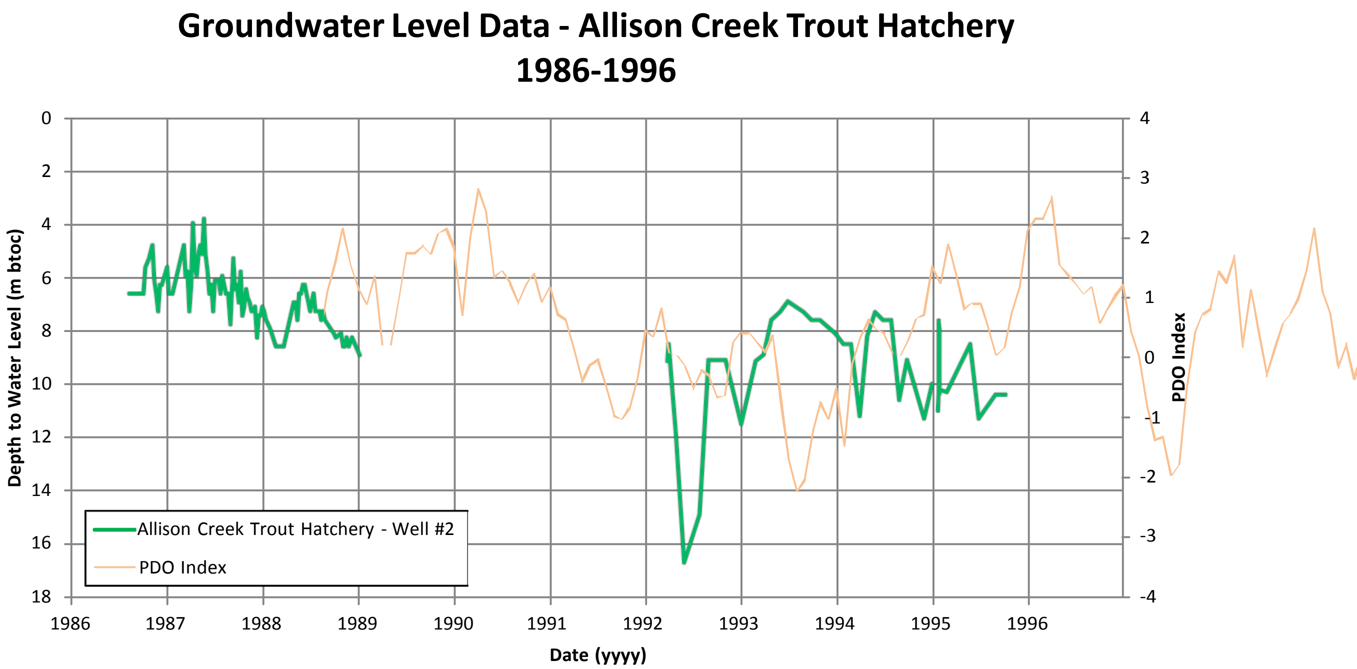


Figure 23 Allison Creek Trout Hatchery Hydrograph

The only other method to get a crude assessment of whether there might be declining water levels with time in the watershed is by plotting water levels measured in all wells at the time of well drilling and construction. **Figure 24** shows depths to water level encountered in wells plotted against the time that the wells were drilled.

The intent is to assess whether the overall trend in the watershed is one of declining water levels, which might be an indicator of drought conditions, groundwater mining or over-use. The data show a declining water level trend during the 60 year record (based on a moving average) in wells completed in unconsolidated and bedrock materials, although the declining trend is less pronounced in the wells completed in unconsolidated materials.

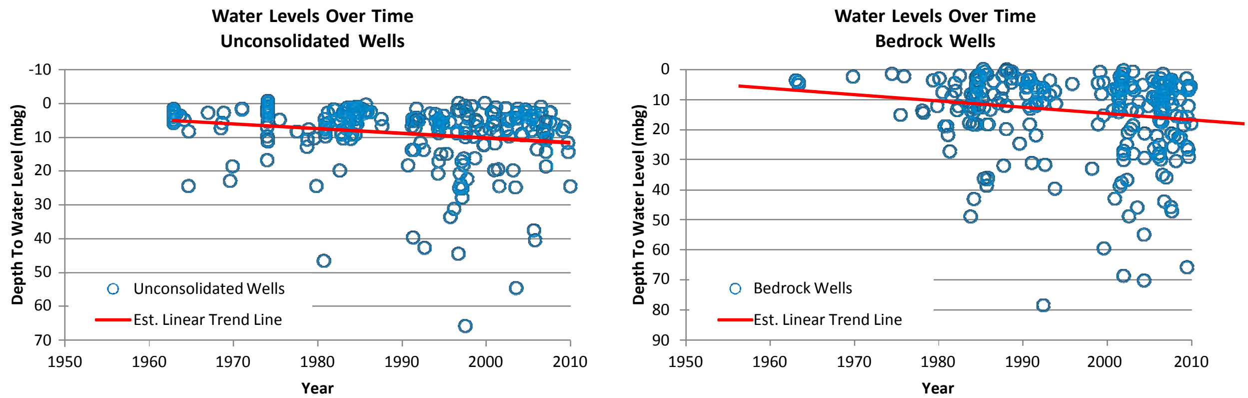


Figure 24 Water levels over time

3.6.7 Springs and Groundwater Discharge

Springs represent areas of groundwater discharge at the ground surface and are generally associated with upward hydraulic gradients or where flow paths intercept the ground surface in steep terrain.

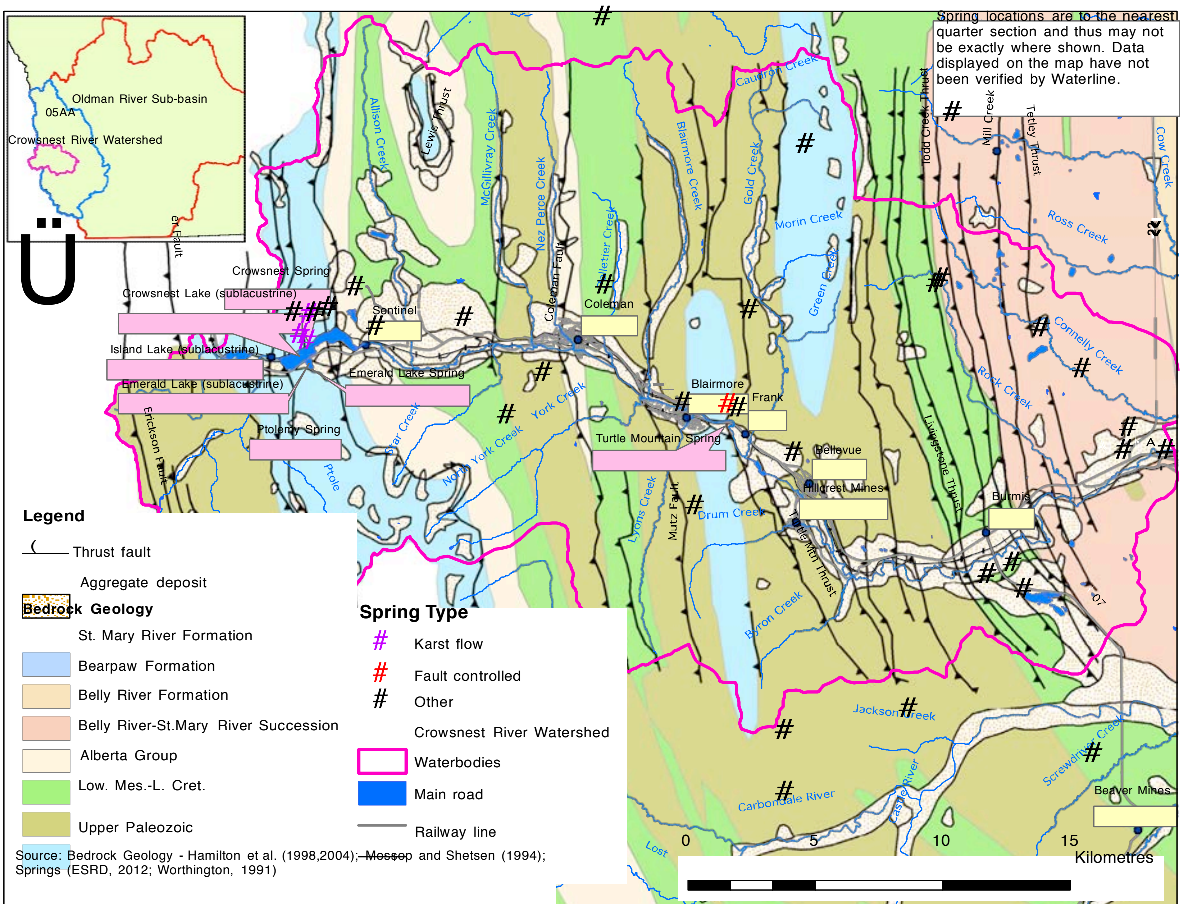


Figure 25 Springs in the Crowsnest River watershed

The Alberta Water Well Information Database indicates that within the Crowsnest River watershed there are records for 33 springs (**Figure 25**). The springs appear to be of three types:

- Karst-related Springs;
- Fault-related Springs; and
- Other springs.

Photographs of the Turtle Mountain, Crowsnest Lake and Ptolemy Springs are presented in Appendix B.

A detailed description of each spring type is provided below.

Karst Springs

These springs are in the limestone and dolostone formations situated in the western portion of the watershed. They include the Ptolemy, Crowsnest and the sub-lacustrine springs in Crowsnest, Emerald and Island Lakes (**Figure 26**). These springs discharge groundwater from karstic terrain and related caverns that formed through dissolution in the limestone and dolostone rocks of the Palliser, Banff and Rundle formations in the High Rock and Flathead Ranges, north and south of the Crowsnest Pass. Dissolution features can store and release a large amount of groundwater. The karstic bedrock is recharged by rain and snowmelt in the mountains and follows the north-south strike of the formations toward the Crowsnest River Valley where the large springs form the points of discharge.

The Crowsnest Pass is the lowest point in the Rocky Mountain Front Ranges between the border to the United States located 70 km to the south and the Bow River 160 km to the north (**Figure 7** shows the topography within the watershed). Its location within the Crowsnest River watershed has the potential to drain much of the limestone outcrop of the Flathead and High Rock ranges, an area of 400 km^2. Based on water balance calculations, measured spring flows of two m^3/s (172,800 m^3/d) at Crowsnest Pass drains an area of about 150 km^2 (Worthington, 1991).

Sub-lacustrine springs are also related to Karst Springs but discharge at the bottom of Crowsnest, Emerald and Island Lakes in the Crowsnest Pass (Worthington, 1991). These springs are difficult to identify and measure but have been inferred indirectly by assessing the difference between inflow and outflow of surface water from respective lakes.

The Ptolemy, Crowsnest, and the sub-lacustrine springs have the highest flow rates of all spring types found within the Crowsnest River watershed. For instance, from August 1985 to September 1986, the Ptolemy Spring, Crowsnest Spring and the sub-lacustrine springs had measured discharge rates as high as 127,872 m^3/d, 158,112 m^3/d and 189,216 m^3/d, respectively in June 1986 (Worthington, 1991).

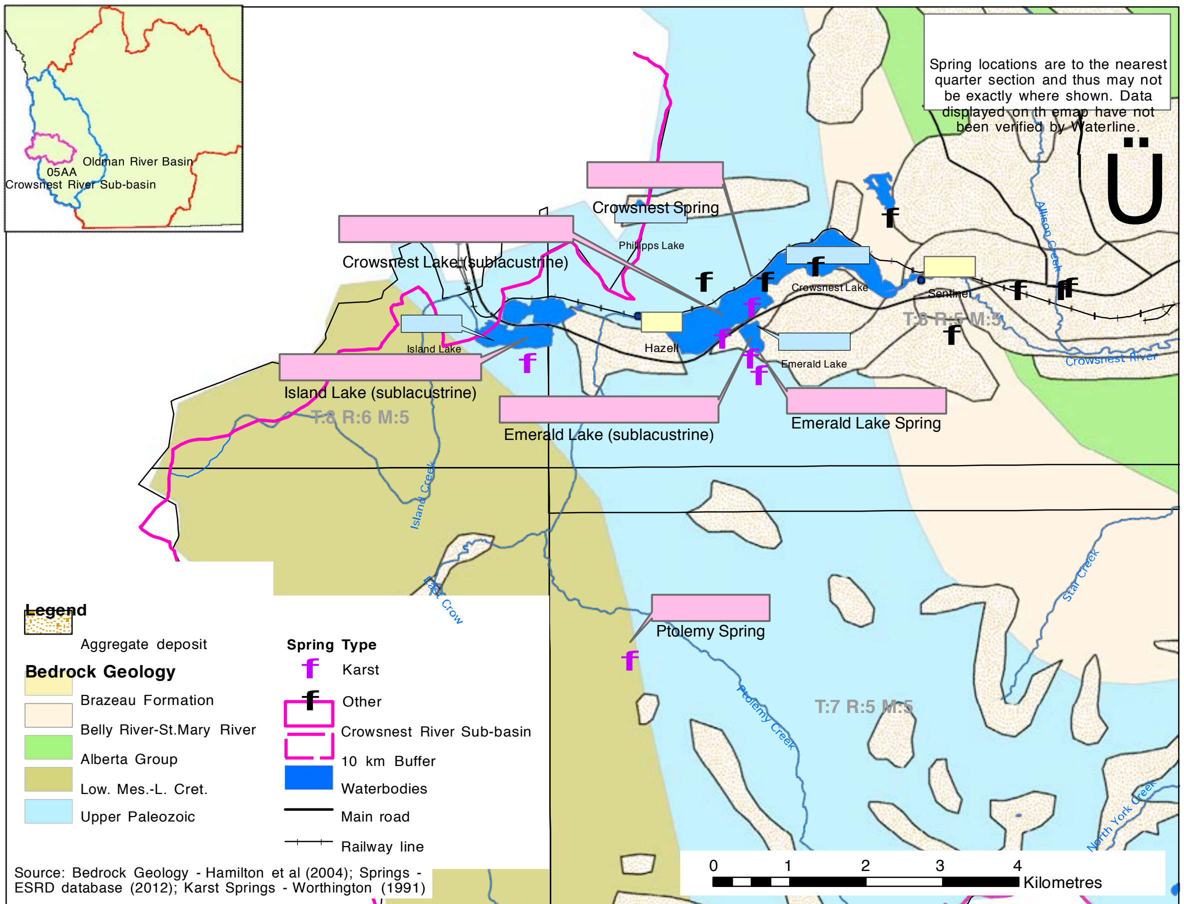


Figure 26 High Volume Discharge Springs

Crowsnest Spring discharges from the base of the Palliser Formation limestone at two locations; one situated approximately one metre above the lake surface and is perennial with a maximum discharge of 400 L/s (34,560 m^3/d; ESRD database, 2012) and a second is located four metres higher and discharges the bulk of the groundwater flow during early summer. A dye test completed by Worthington (1991) from the north cirque of Mt. Phillips showed that groundwater flows through the Banff and Rundle Formation strata.

Six springs were mapped by Worthington (1991) at Emerald Lake on the south side of the Crowsnest Pass, and these springs discharge from the Palliser Formation approximately 44 m above the lake level. The maximum combined discharge of these springs measured in 1986, was 50 L/sec (4,320 m^3/day) (Worthington, 1991).

The Ptolemy Spring is on the slopes of Mt Ptolemy at an elevation of 1,560 mASL, and discharges from the Rundle Formation, about four km south of Crowsnest Pass. The water likely flows along a thrust fault in the Rundle Group (Worthington, 1991). It exhibits low dissolved solids concentrations (93 mg/L) suggesting a high altitude source and a short residence time from recharge to discharge.

A summary of flow volumes measured from the various springs in 1985-1986 is presented in **Table 10**. Flow measurements as part of the present (2012) study are also shown.

Table 10 Karst Spring Flow Volumes

Date		Monthly Spring Discharge (m^3/d)		
		Ptolemy Spring	Crowsnest Spring	Sub-lacustrine Springs
Elevation Æ		(1550 mASL)	(1348 mASL)	(<1347 mASL)
Year	Month			
1985	Aug	40,176	42,682	68,083
1985	Sep	39,917	58,666	71,194
1985	Oct	17,107	51,494	70,070
1985	Nov	12,269	40,781	76,896
1985	Dec	7,171	27,216	43,978
1986	Jan	3,715	21,082	38,448
1986	Feb	2,160	23,155	31,709
1986	Mar	3,370	27,302	27,821
1986	Apr	11,146	46,224	57,888
1986	May	90,720	127,872	148,608
1986	Jun	127,872	158,112	189,216
1986	Jul	52,618	71,798	93,312
1986	Aug	30,499	37,238	83,722
1986	Sep	26,525	29,894	43,546
Total Mean Annual Flow (Sep-1985 to Aug-1986)		**12,159,936 m^3/yr**	**21,069,072 m^3/yr**	**28,460,074 m^3/yr**
1988	Oct*	11,521		
2012	Sep**	1,142	34,037	-

Data source: Worthington, 1991, * - R. Stein, pers. comm., ** – this study

These flow rates show that the sub-lacustrine springs exhibit the highest flows of the three sets of springs. Because of their location at the bottom of the various lakes, only indirect measurements based on surface flow are possible. A graphical assessment of spring flows is presented in **Figure 27.**

The monthly cumulative flows from all karst springs and the monthly flow measured at the outlet at Crowsnest Lake are also shown on **Figure 27**. The data indicate that the springs provide as much as 90 percent of the baseflow in the Crowsnest River in August (1985), and as little as 60 precent of the baseflow in March (1986). Given the large contribution to surface water baseflow, these springs serve a critical function in the upper reaches of the Crowsnest River. As will also be discussed, the geochemistry of these karst springs indicates low total dissolved solids suggesting that the residence time from recharge to discharge is relatively short.

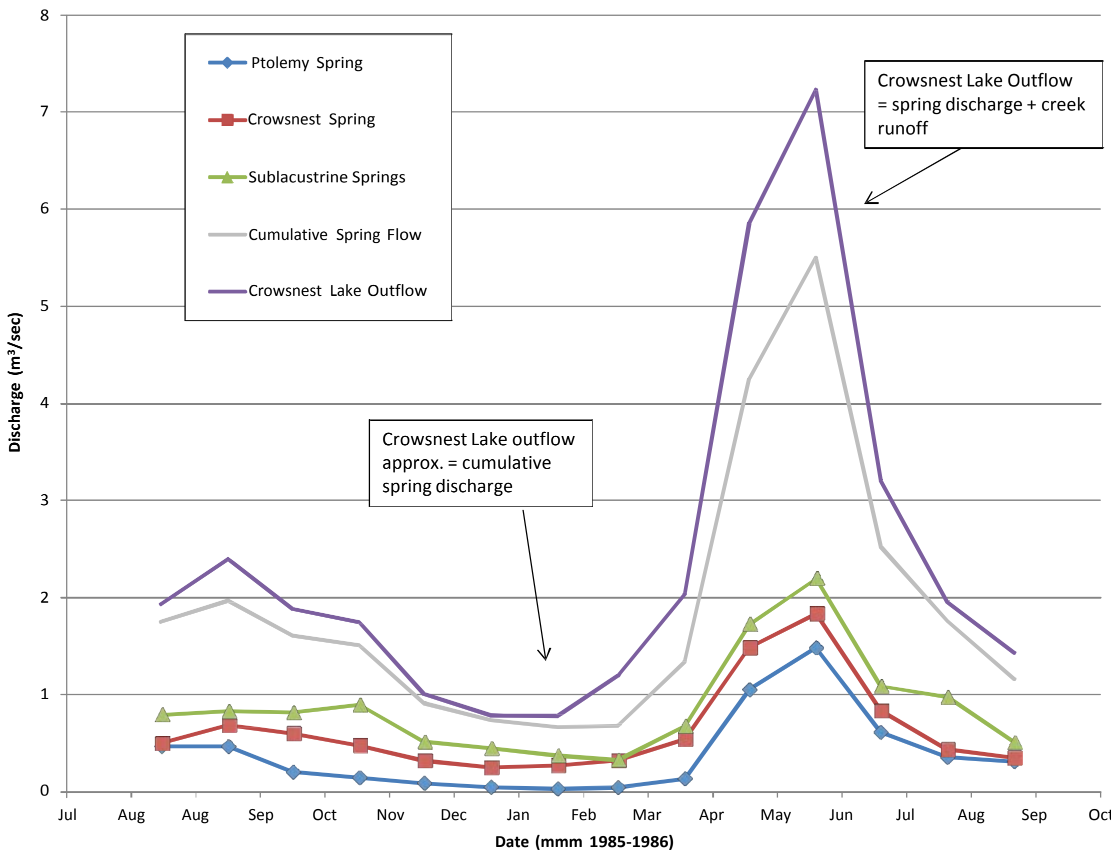


Figure 27 Karst Springs Discharge Rates

Fault-Controlled Springs

These springs flow along faults parallel to bedding or formational boundaries. These springs tend to be deep-seated, and groundwater appears to be sourced for a large area. This is consistent with observed groundwater geochemistry which exhibits higher total dissolved solids concentration as compared to other spring water, indicating a longer residence time or contact with the bedrock.

The Turtle Mountain Spring is situated near the base of Turtle Mountain just east of the Hamlet of Frank (**Figure 25**). It is likely fault controlled as its location coincides with the lowest exposure of the Turtle Mountain Thrust Fault and this places the older Banff Formation over younger rocks of the Fernie Formation. The groundwater is chemically different from other springs in that it contains a high concentration of sulphate (258 mg/L).

The ESRD database indicates that the Turtle Mountain spring has historically exhibited a flow rate of up to 7,855 m^3/d. The flow rate of this spring was estimated by Waterline in September of 2012 at 654 m^3/d which is significantly lower than what was reported in the ESRD database. According to van Everdingen (1972), the spring flows year-round. The discharge rate has tended to increases somewhat during May and early June, and this is likely related to spring snowmelt and increased precipitation. The groundwater discharging from the spring flows into the Crowsnest River 275 m east of the point of discharge.

Other Springs

Other springs include local discharge points occurring at breaks in slope, likely resulting from the intersection of the water table with the ground surface. These springs are somewhat evenly distributed throughout the watershed (**Figure 25**). They tend to be locally sourced, exhibit lower flow, and are commonly seasonal in nature compared to the karst springs. The other springs exhibiting greater flows in the spring and possibly drying up in the fall and winter. The records indicate that fourteen springs have been identified and exhibit flow rates ranging from 6.5 to 1,309 m^3/d.

3.7 Aquifers and Hydrogeologic Boundaries

An aquifer is defined as a "saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients" (Freeze and Cherry, 1979). If the geologic unit or material is in contact with the atmosphere then it is known as an unconfined or water-table aquifer. Aquifers bounded at the top and bottom by lower permeability layers (clay or shale) are referred to as confined aquifers and water levels referred to as the piezometric surface. In the case of fractured bedrock, aquifers may only be related to fracture zones rather than lithological units.

Aquifers beneath the Crowsnest River watershed occur in two general settings:

- Surficial unconsolidated sediments (e.g., sand and gravel deposits); and
- Bedrock consisting of:
    - Karstic carbonates consisting of solution cavities in limestone (including Banff and Palliser formations and Rundle Group);
    - Porous bedrock such as sandstone (e.g., Belly River Formation and Blairmore Group); and
    - Fractured bedrock including all bedrock lithologic units (i.e., limestone, sandstone, siltstone and shale)

The hydrogeologic boundaries within the Crowsnest River watershed consist of the following:

- Surface water boundaries are coincident with topographic highs which direct surface water toward creeks and the Crowsnest River;
- The groundwater boundaries are related to:
    - Lithological contacts between the various formations identified in the watershed (e.g., alluvial aquifer, Belly River and St. Mary's River formations);
    - The formations can then be further subdivided into discrete units based on intervening confining materials such as shale and other low permeability

materials that separate conglomerate, sandstone, siltstone and coal which define aquifers within the watershed; and
- Intensely fractured, faulted, or karstic features.

It should be noted that watershed boundaries for surface water do not necessarily coincide with the boundaries of aquifers that occur in the subsurface. As indicated above, aquifer boundaries are controlled by the material and structural properties, and observed hydraulics in the system. Within the project area, the following regional aquifers have been identified:

- Pre-glacial buried valley aquifer (**Figure 29**);
- Unconsolidated glacial overburden aquifers (**Figure 29**);
- Crowsnest River alluvial aquifer (**Figure 30**);
- Belly River Formation aquifers (multiple sandstone units with depth) (**Figure 16**); and
- Karstic Upper Paleozoic carbonates, in the western portion of the watershed (**Figure 16**).

3.7.1 Unconsolidated Deposits and Aquifers

The near-surface deposits consist of alluvial sediments deposited by ancient (post-glacial) and present-day rivers and streams, and those deposited prior to or during glaciation. Geologic materials exposed at the ground surface north and south of the Crowsnest River valley consist of bedrock and glacial materials (**Figure 17**) (Bayrock and Reimchen, 1975). Further east, the surficial geology consists dominantly of glacial till. Along the Crowsnest River valley, recent sand and gravel deposits form the alluvial aquifer (**Figure 17**).

Based on lithologic information presented on well logs, the thickness of surficial deposits across the watershed is generally less than 50 m, with an average of approximately 7 m (**Figure 28**). One pre-glacial valley, the Middlefork Valley, has been mapped by Geiger (1965) within the Crowsnest River watershed (**Figure 29**). The Middlefork Valley is a tributary of the Lethbridge pre-glacial river valley. This bedrock valley was initially formed in pre-glacial times by fluvial activity and then altered during glaciation.

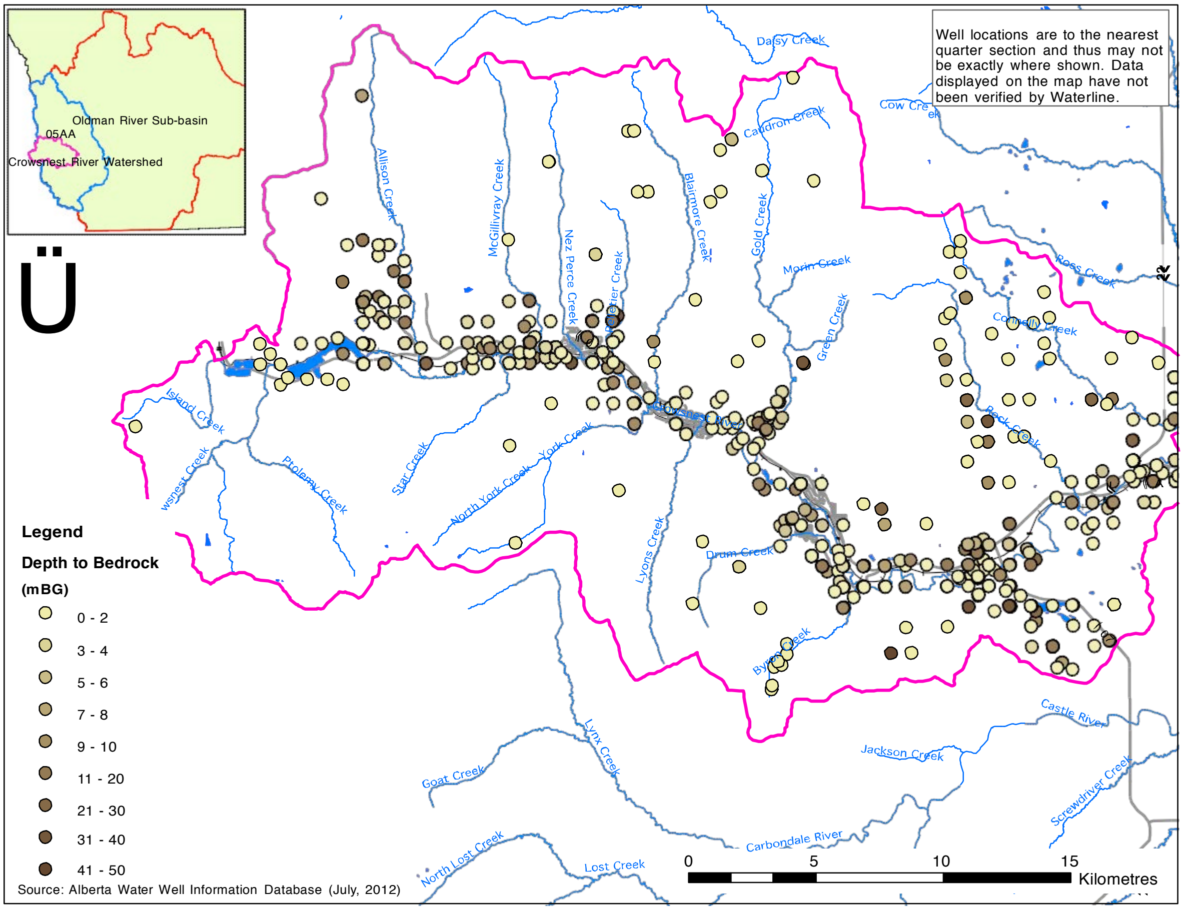


Figure 28 Depth to Bedrock

The alluvial sand and gravel materials in the Crowsnest River watershed are generally found on the flood plains and terraces of the Crowsnest River and tributary creeks. The largest sand and gravel deposits occur at several locations including east of Crowsnest Lake near Allison Creek, east of Blairmore and Frank, east of Lundbreck, and south of the watershed along the Castle River (**Figure 29**). Large deposits are also indicated by remote sensing between the Crowsnest River and the Castle River south of Burmis, suggesting that the Crowsnest River may have once connected to the Castle River. The remote sensing data does not appear to correlate to the observed water well log information and therefore field verification would be required.

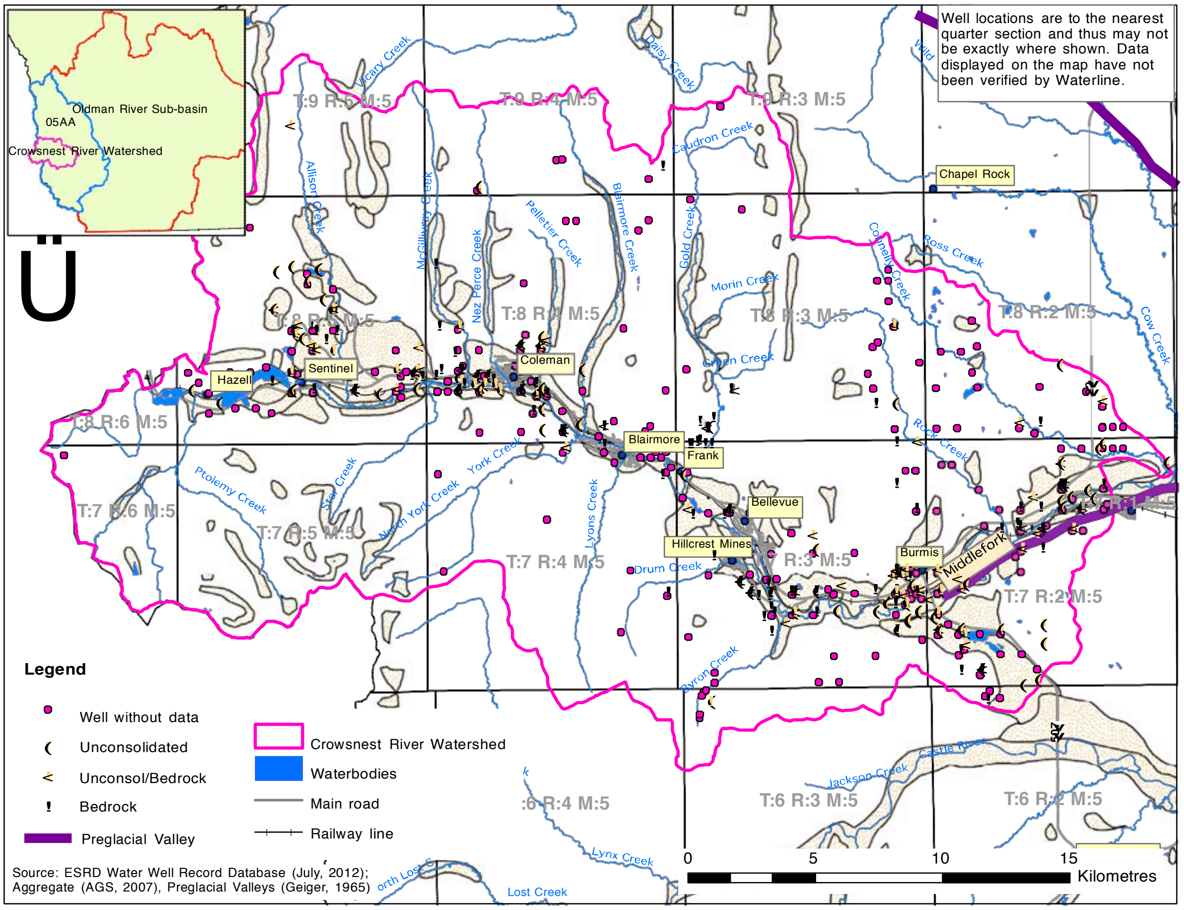


Figure 29 Aggregate Deposits and Preglacial Valley

The main alluvial aquifer within the Crowsnest River watershed is associated with sand and gravel deposited along and within the Crowsnest River valley. Other smaller deposits related to glacial deposition of sand and gravel materials may be locally important for supplying individual lots or livestock watering but are not expected to be significant in terms of the overall groundwater supply in the watershed.

The alluvial materials extend for more than 30 km from the Crowsnest Lake outlet to the eastern edge of the watershed at the confluence with the Oldman Reservoir (**Figure 29)**. The alluvial materials are highly permeable and are thought to be hydraulically connected to Crowsnest River. Approximately 478 water well records are present within the area of the Crowsnest River Alluvial Aquifer. Of these, 190 wells appear to be completed within alluvial sand and gravel, and 98 wells completed in the underlying bedrock. The remaining well records did not have any associated lithology data.

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The horizontal extent of the alluvial aquifer adjacent to the Crowsnest River was determined from remote sensing for desk-based aggregate mapping data by the Alberta government (Edwards and Budney, 2004) and then refined by Waterline using the lithologic records from the

ESRD water well database. Based on this information, it is apparent that the aggregate mapping performed based on remote sensing data was not field verified nor cross-referenced to borehole lithology data and therefore are not completely reliable for use in aquifer mapping. Based on information compiled during the present Waterline study, alluvial aquifers are shown on **Figure 30**.

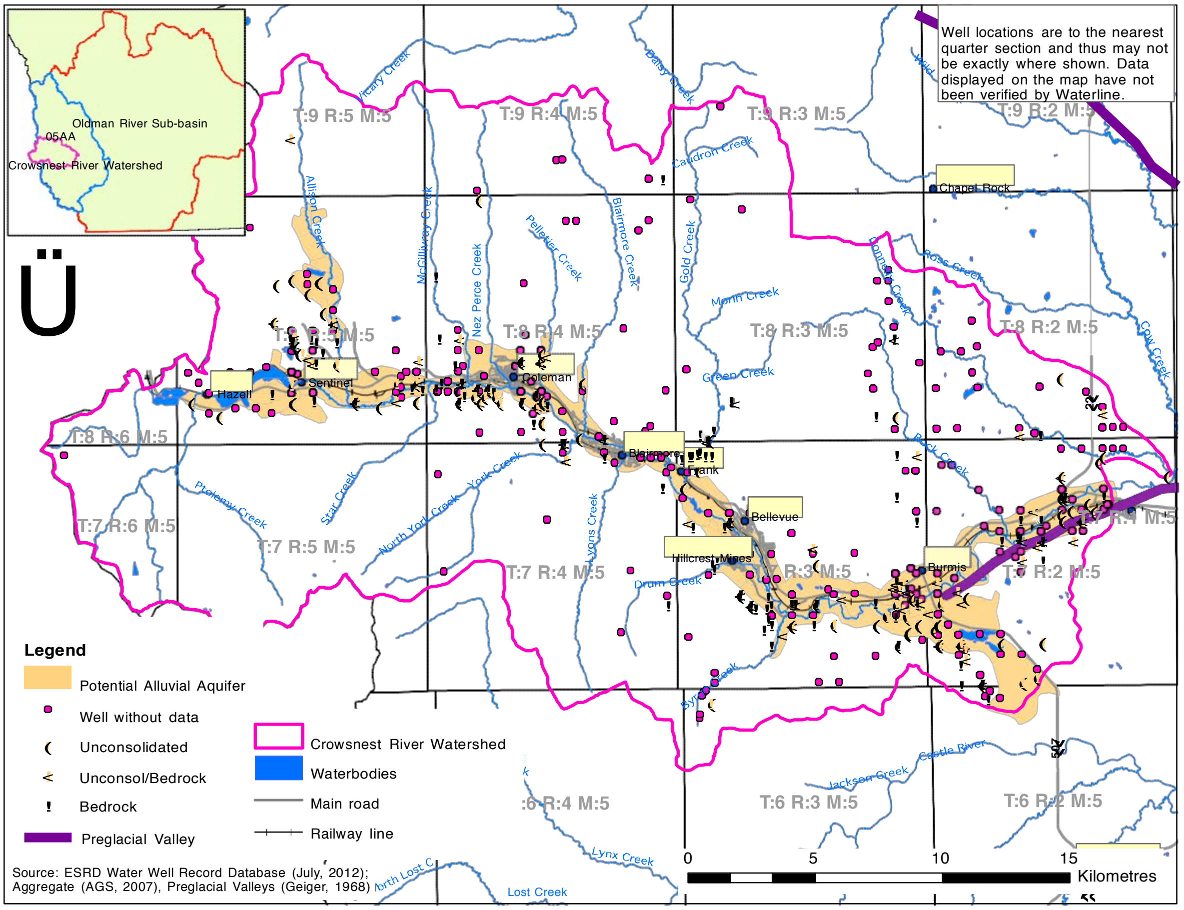


Figure 30 Crowsnest River Alluvial Aquifer

3.7.2 Bedrock Aquifers

Bedrock aquifers are not well developed within the Crowsnest River watershed (**Figure 31**). Many of the bedrock wells were completed within the Crowsnest River valley and formations extend to the top of the watershed (and beyond) on either side of the Crowsnest River, however, few wells exist in those areas. Major bedrock aquifers are expected within the Paleozoic carbonates in the west part of the watershed and form part of the spring discharges in that region. These include the Banff, Palliser, and Rundle formations but again only a few water supply wells exist in the valley and this is insufficient to extend aquifer boundaries beyond where wells exist. Other lightly developed bedrock aquifers include the following bedrock lithology types which have been mapped from west to east within the watershed:

- Upper Paleozoic bedrock;
- Alberta Group bedrock;
- Belly River-St. Mary River formations; and
- Lower Mesozoic and Late Cretaceous bedrock

Developed bedrock aquifers mapped as part of the present study were delineated on the basis of water well locations within each formation; areas where groundwater-use was developed to some degree (**Figure 31**). From a water management perspective, this method of aquifer delineation provides an indication of where the greatest groundwater use is and thus areas that may require groundwater management to ensure sustainable use of the resource. This does not mean that the delineated boundaries are the physical boundaries of the aquifers which may extend further. The delineated boundaries show areas of the bedrock from which groundwater is being extracted.

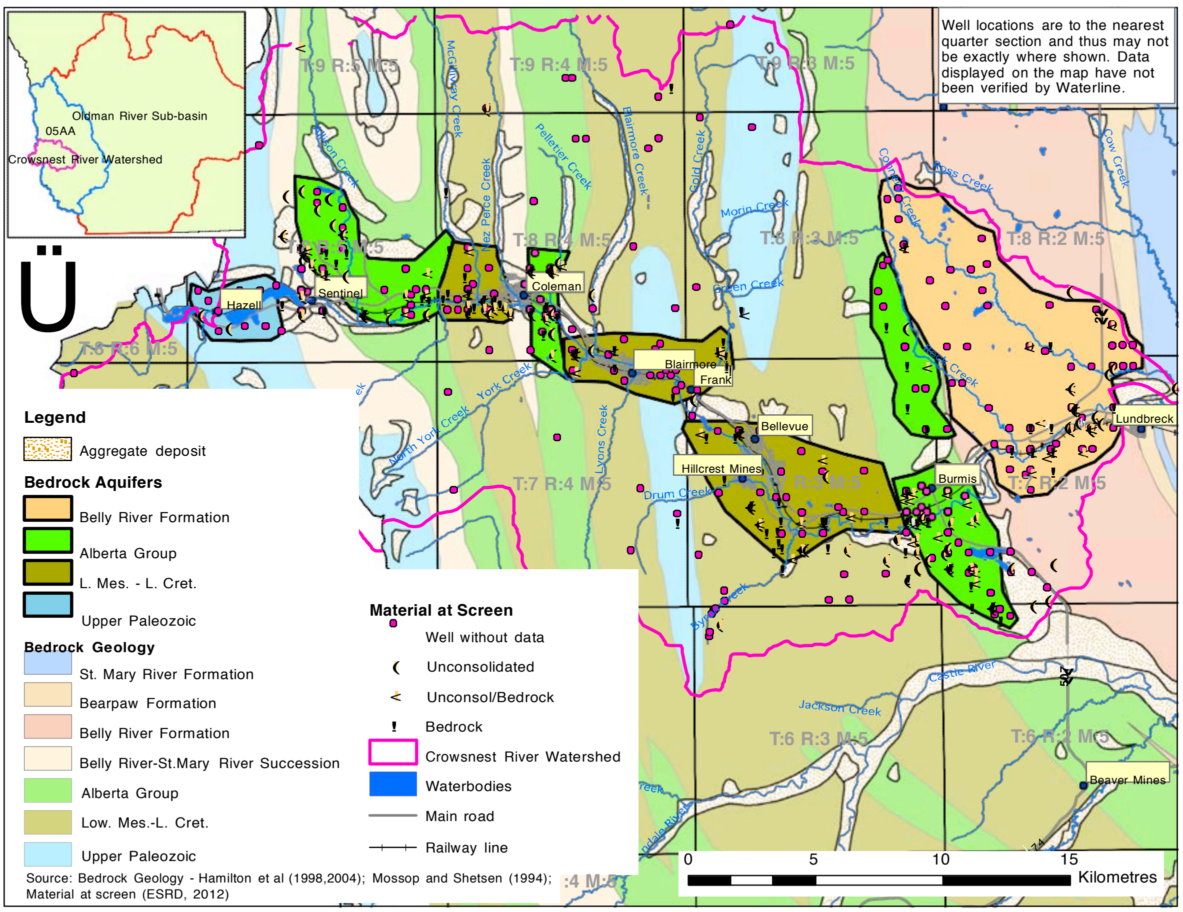


Figure 31 Bedrock Aquifers

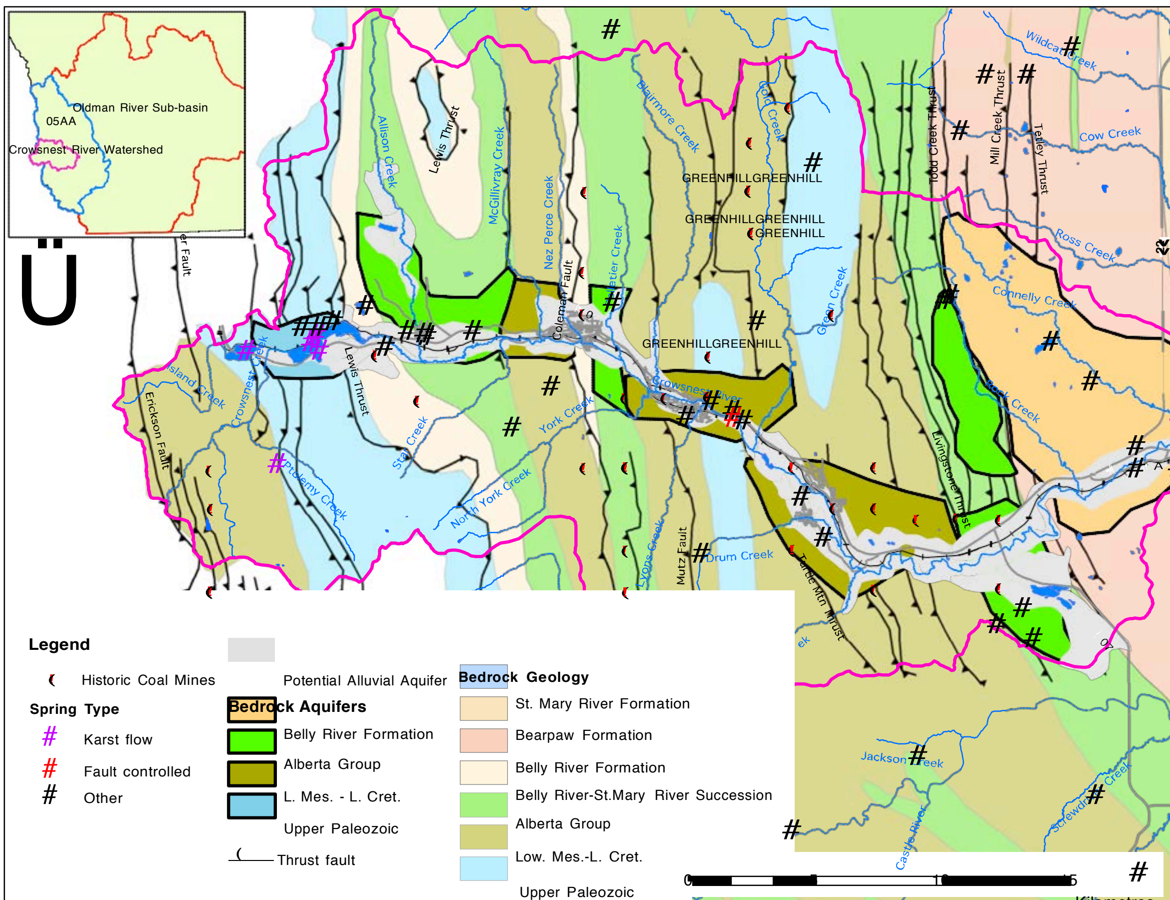
The bedrock aquifers were mostly delineated within the Crowsnest River valley because that is where development of the groundwater resource has been concentrated. The exception is the Belly River aquifer, which covers a greater area, in the eastern portion of the watershed at the edge of the Foothills where more agricultural activity occurs.

Alberta Group aquifers occur in three places throughout the watershed because of the repetition of bedrock sequences caused by thrust faulting.

The potential Upper Paleozoic aquifer, in the western portion of the watershed is inferred from the locations of wells, however, these wells, as can be seen on the map (**Figure 31**), do not have accompanying lithology to directly assign them to Upper Paleozoic materials.

3.8 Coal Mining in the Crowsnest River Watershed

Coal has been mined in the Crowsnest River watershed since 1900 resulting in as many as 68 coal mines (ERCB coal database, accessed April 2013) (**Figure 32**).



Source: Bedrock geology - Hamilton (1998, 2004); Mossop and Shetsen (1994); Coal Mines - ERCB (2013).

Figure 32 Historical Coal Mines in the Crowsnest River watershed

Many of the towns in the Crowsnest River watershed originated as a result of the presence of mineable coal including, for example, Coleman, Blairmore, Frank, Hillcrest, Bellevue. None are currently operating in the watershed although Riversdale Resources, an Australian coal mining company submitted an application for an open-pit mine near Blarimore and Coleman (Lethbridge News, 2013).

Of the 68 historical coal mines, twelve fall within the aquifer areas identified in the Crowsnest River Watershed (**Section 3.7**). Of those, eight fall within the area of the alluvial aquifer. Since the principal groundwater water supply aquifer is alluvial aquifer, water quality issues could be of concern.

Comparison of the locations of springs and those of historical coal mining operations indicates there is no correlation between the two, suggesting that the mined areas do not provide major contributions to baseflow through from these areas. Waterline only reviewed publically available information sources and further fieldwork is recommended but was outside the scope of this study

3.9 Water Quality Assessment

3.9.1 Surface Water Chemistry

A surface water quality study was conducted to provide an assessment of the Oldman River and its tributaries (Saffran, 2005). The results of this study noted the following regarding water quality in the Crowsnest River:

- The concentration of the pesticide, 2,4-D (2,4-Dichlorophenoxyacetic Acid), ranged from less than detect to 0.007 µg/L which is orders of magnitude lower than the drinking water criteria
- Sodium concentrations were lowest in the study upstream of Connelly Creek - about 10 times less than in the Oldman River main stem;
- Total Dissolved Solids (TDS) concentration ranged from 157 to 306 mg/L; and
- Chloride concentration ranged from 0.9 to 6.9 mg/L.

Saffron (2005) concluded that the water quality of the Crowsnest River is considered good.

3.9.2 Spring and Well Water Geochemistry

Piper tri-linear diagrams were used to display the major ion chemistry of spring and well water samples in an attempt to classify water sources and assess interactions. The following sub-sections discuss the analysis in the context of the physical environments from which samples were collected including surface water, springs and groundwater samples collected from wells. The spring and groundwater data are presented on **Figure 33** and the sample locations of the water quality data (source: ESRD, 2012) are shown in **Figure 34**.

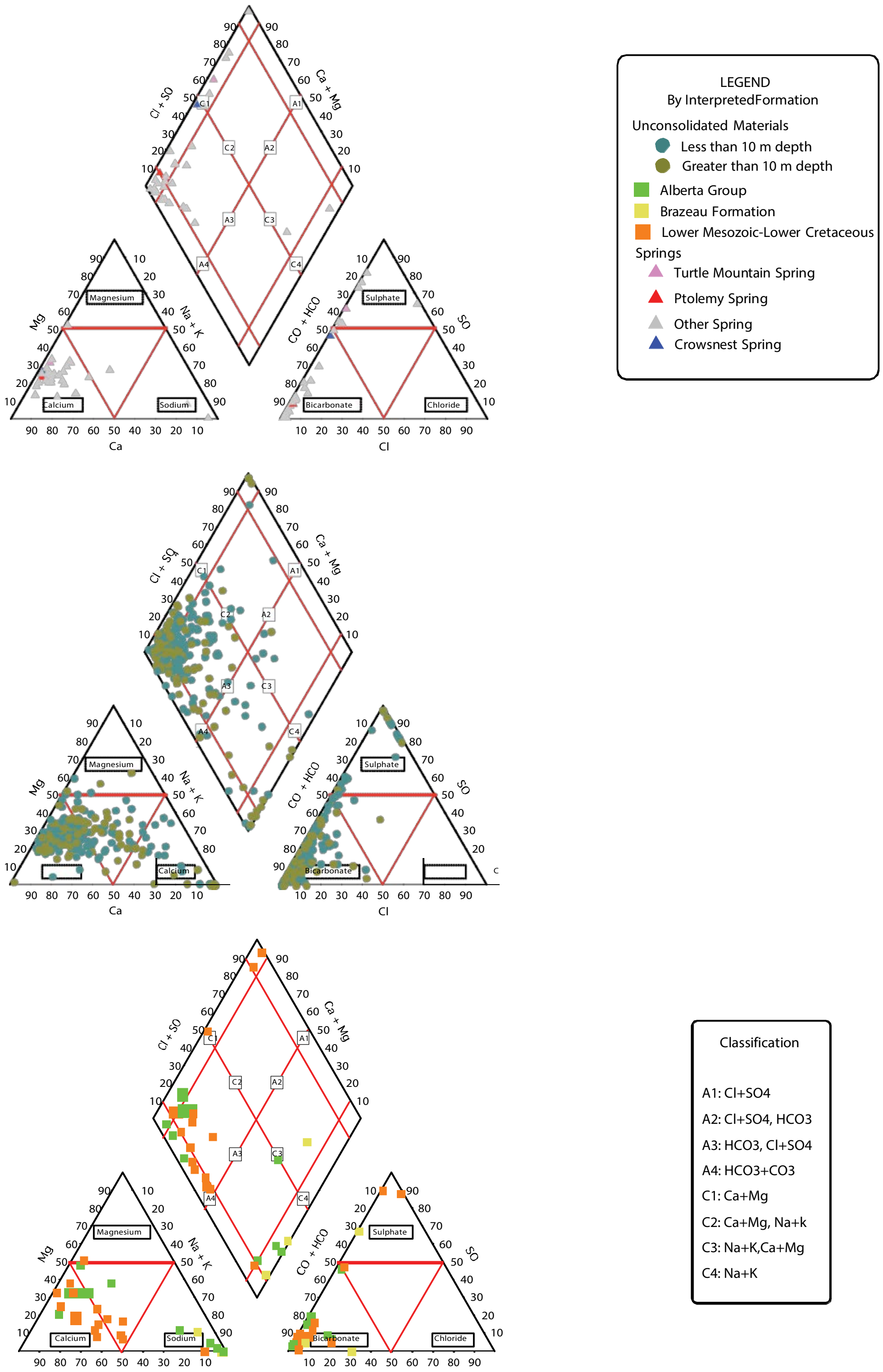


Figure 33 Groundwater quality – Piper Diagram

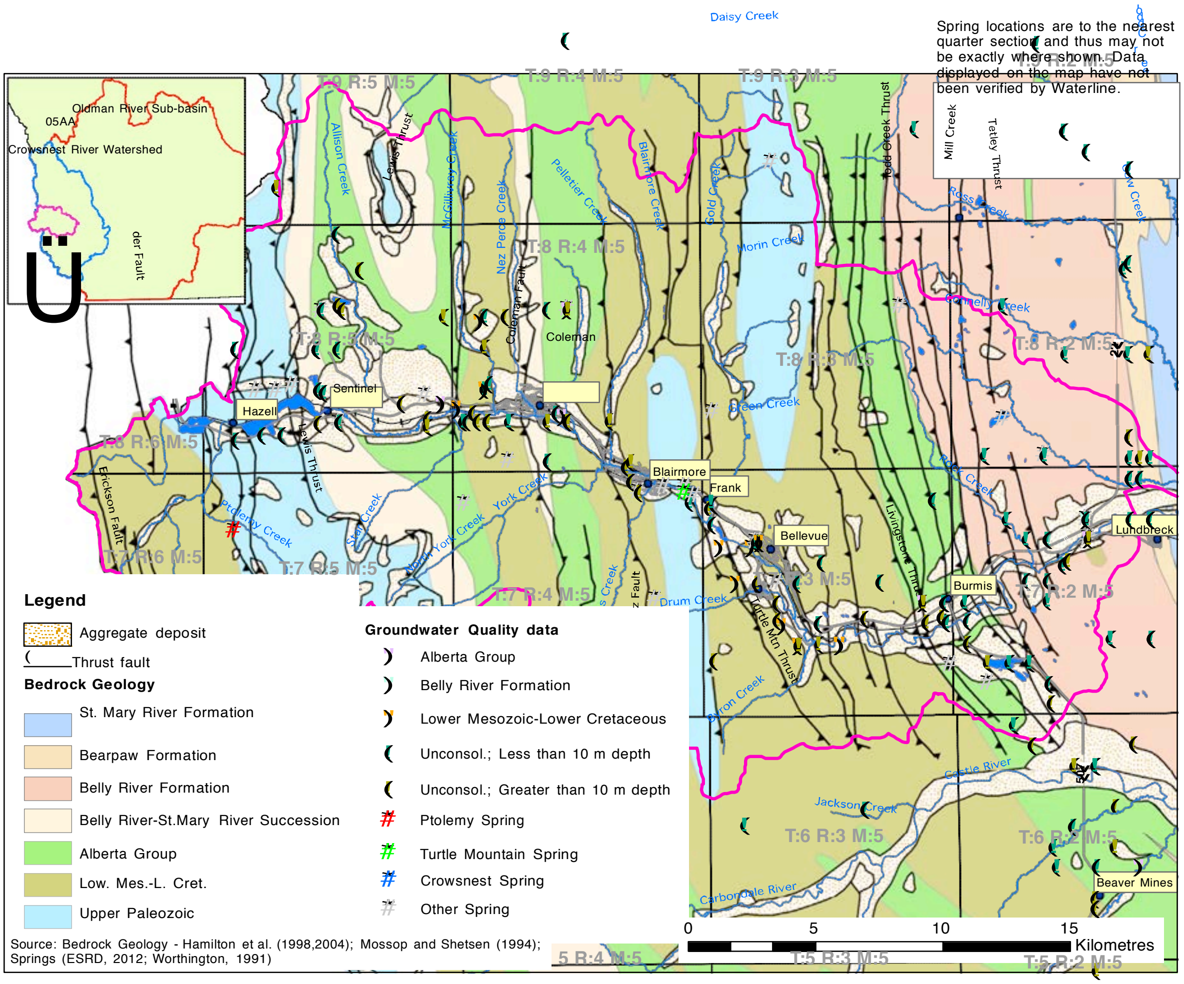


Figure 34 Groundwater quality – Sample Locations

3.9.2.1 Karst-Related Springs

Crowsnest Spring

Crowsnest Spring water chemistry changes from low TDS (e.g., 200 mg/L) and sulphate (e.g., 46 mg/L) during periods of high flow (summer months) to higher TDS (e.g., 341 mg/L) and higher sulphate (e.g., 137 mg/L) during periods of lower flow (Stein, R., pers. comm.). Worthington (1991) described the two outlets of the spring one at 1 metre above lake level and the other four metres higher.

The water in the spring is very fresh and is slightly alkaline. The sulphate concentration in this spring's water is 119 mg/L (September, 2012). The temperature is relatively high (5.5 to 6 °C). This spring may have two sources; (1) fed by rainfall and snowmelt and (2) deep seated source potentially related to a regional thrust fault (Stein, R., pers. comm.).

Ptolemy Spring

The water in the spring is slightly alkaline. The sulphate concentration in this spring's water is 11 mg/L (September, 2012). This spring has the lowest TDS concentration of the three karst springs again suggesting a high altitude water source with a short travel time (Ford, 1971). The temperature varies from 2.9 to 3.6 °C (Stein, R., pers. comm.).

3.9.2.2 Fault-Related Springs

Turtle Mountain Spring

The dissolved solids content (484 mg/L) of Turtle Mountain Spring suggests a short circulation path. Its average annual temperature of 5 °C and a thermal gradient of 1 °C/100 m gives a depth of circulation of approximately 120 m (van Everdingen, 1972). This suggests a local source for the water, likely precipitation infiltrating the Turtle Mountain area between the Turtle Mountain and Mutz thrust faults. The water in the spring is slightly alkaline. The concentration of sulphate in the spring water is 258 mg/L (sampled by Waterline September, 2012). At the discharge point there is a hydrogen sulphide odour and suspended sulphur imparts the water with a milky white hue (van Everdingen, 1972).

3.9.2.3 Topography-Related Springs

The ESRD Alberta Water Well Information Database contains analytical data from springs sampled throughout the watershed. Thirty-one of the spring records had associated chemical analyses dating from the late 1960's to the mid 1980's. The locations of springs are shown on **Figure 25**. The water chemistry data indicate the TDS concentration ranged from 83 to 4,280 mg/L.

The Piper plot of the spring water major-ion chemistry (**Figure 33**) does not indicate any separation between samples although there may be some influence of depth of circulation. They are typically of the $Ca+Mg/HCO_3+CO_3$ to $Ca+Mg/HCO_3, Cl+SO_4$ type.

In addition, the springs with low TDS concentrations are likely sourced locally; whereas, the groundwater in spring samples exhibiting high TDS concentrations originates either from a deeper, more regional source or potentially from contamination.

3.9.3 Groundwater Geochemistry

Some groundwater water quality data are available in the ESRD water well database. Based on these data, the TDS of groundwater ranges from four to more than 4,270 mg/L.

The Piper plot (**Figure 33**) shows that the greatest number of groundwater samples was collected within the unconsolidated materials, and likely from alluvial aquifer(s). Of these, 247 samples or roughly two-thirds are from wells that are less than 10 m deep. In general, HCO_3 and SO_4 are the dominant anions, whereas Ca+Mg and Na are the dominant cations and are sometimes replaced by Mg.

Table 11 Summary of Groundwater Geochemistry Data by Formation

Unit	Number of Samples	TDS Range (mg/L)	Dominant Groundwater Type
Unconsolidated <10 m	247	83 – 4,270	$Ca+Mg/ HCO_3-SO_4$
Unconsolidated >10 m deep	85	4 – 2,568	$Ca+Mg/HCO_3-Cl-SO_4$
Belly River Formation	4	1,027-2,884	$Na+K /HCO_3-Cl-SO_4$
Low Mes. – Low Cret.	17	194 – 389	$Ca-Na/ HCO_3-Cl-SO_4$
Alberta Group	11	244-825	$Ca+Mg/HCO_3-Cl-SO_4$

Note: Ca means Calcium, Na means Sodium, Mg means Magnesium, K means Potassium, HCO_3 means Bicarbonate, CO_3 means Carbonate, SO_4 means Sulphate, Cl means Chloride, Low Mes. – Low Cret. Means Lower Mesozoic to Lower Cretaceous

Comparison of the water chemistry for samples collected from wells screened in unconsolidated materials indicates that the samples from wells greater than 10 m deep tend to have greater sodium and potassium concentrations indicating longer travel distances or passage through clayey sediments and cation exchange has occurred, than those from wells less than 10 m deep. The samples collected from the unconsolidated materials in the western (up to Sentinel) and central portions of the watershed (Sentinel to Frank) suggest that these waters are similar, generally having greater Ca and Mg concentrations when compared to samples from the eastern portion of the watershed (i.e., east of Frank). Overall this suggests that the groundwater in the unconsolidated materials overlying the Belly River Formation is more evolved, having travelled farther.

There appears to be a distinction between groundwater originating in different formations and that in the unconsolidated materials; this implies that the water has a short residence time in the system leading to less dissolution of ions from the rock to the groundwater.

Figure 35 is a plot showing relative TDS concentration throughout the watershed. Of the 380 samples with a measured TDS concentration from the Crowsnest River Formation (data from the ESRD water well database), only 73 had TDS concentrations greater than 500 mg/L (drinking water criteria for TDS; Health Canada, 2010); all occur in the upper 100 m of the subsurface and there does not seem to be any correlation with depth.

Although time series plots and contouring of major anions and cations were considered as part of this project, insufficient data exist to provide a meaningful assessment of water quality beyond what was completed using Piper plots.

3.9.3.1 Groundwater Quality in Historical Coal Mine Areas

On the north side of the Crowsnest River, in Blairmore within the alluvial aquifer, an area proposed for land development is the site of a former coal waste area filled with up to 10 m of coal waste. Groundwater in monitoring wells installed at the site indicates the presence of selenium (exceeding guidelines), petroleum hydrocarbons and polycyclic aromatic hydrocarbons (WA Environmental Services Ltd., 2008). This suggests the groundwater is impacted. North of this site lies the former Greenhill coal mine. A study by Golder Associates (2011) concluded that the primary groundwater contaminants of concern are metals and polycyclic aromatic hydrocarbons. Golder Associates did not rule out the possibility that the impacted groundwater is flowing into the Crowsnest River.

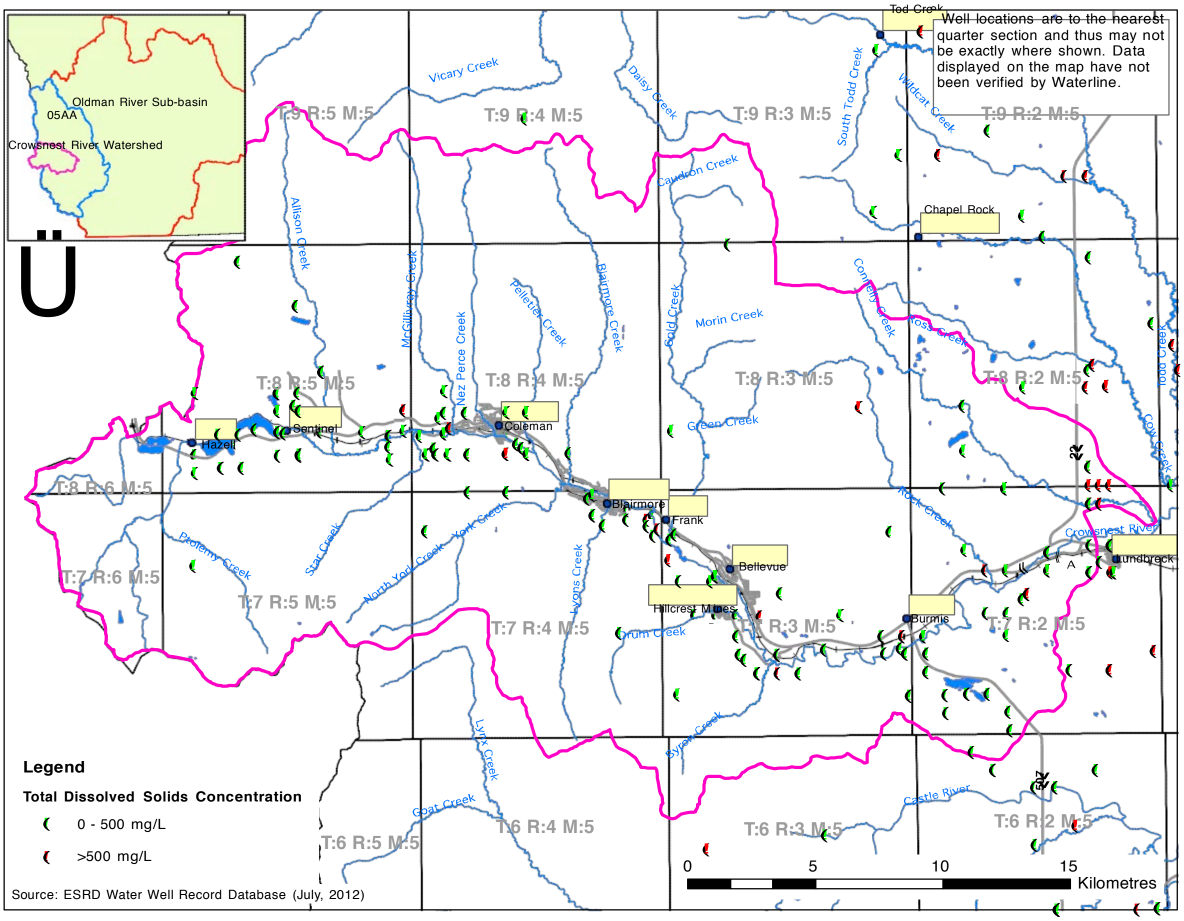


Figure 35 Total Dissolved Solids in the Crowsnest River

3.10 Conceptual Hydrogeological Model

A conceptual model and understanding of the subsurface geology and hydrogeology of the bedrock has been developed for the Crowsnest River watershed using a series of cross sections that integrate numerous datasets. The cross-sections were developed using lithological descriptions and hydrogeological data provided in water well records (Alberta Water Well Information Database, July 2012) and oil and gas well logs (IHS Accumap, December 2012), as well as structural geological studies (e.g., Hamilton et al., 1998). The oil and gas data are based on lithological descriptions and geophysical data (often natural gamma logs), which helps identify formation contacts.

The method of geological interpretation and construction of cross-sections is further discussed in Appendix A. Full-page versions of the cross-sections can be found in Appendix C. A vertical exaggeration of 75:1 was selected to enable cross-section A-A' to fit on a standard page and also to enhance the appearance of the geologic structure.

The hydrogeology in the disturbed belt is complex and is difficult to assess accurately because of the lack of available information. Groundwater flow is controlled by the lithology (e.g., carbonate formations exhibit karstic dissolution features and tend to be more permeable) and the numerous thrust faults that further increase the secondary porosity and permeability of bedrock (Hamilton et al. 1998, Stockmal, 2004 and Stockmal et al. 2001).

Recharge to groundwater systems and defined aquifers within the disturbed belt is also strongly influenced by lithology at the surface and faulting. As shown on **Figure 16,** major thrust faults are parallel to bedding and generally perpendicular to the axis of the Crowsnest River. This creates a flow pattern that locally directs groundwater to the Crowsnest River Valley, which flows to the east portion of the watershed.

In order to differentiate between the formations in the cross-sections, estimated lithologic boundaries were drawn as orange dotted lines. The base of groundwater protection (BGP) was arbitrarily set by the ERCB to 600 m beneath ground surface in this region. As such, the BGP is below the maximum depth of the cross-section where no water quality information exists to confirm the non-saline and saline groundwater boundary.

As indicated, the structural history in the disturbed zone is complex because of the mountain building process in the Rockies. The stress regime imposed on bedrock formations in this area has resulted in various fracture patterns. Some fractures are oriented along bedding planes, which are sometimes folded, and secondary vertical to sub-vertical fractures related to thrust faulting. The structural dip of thrust faults is oriented to the west with angles varying from horizontal to 70 degrees (the thrust faults may themselves be folded) in the western portion of the section, which thrust older rock over younger rock causing repetition of the stratigraphy. In the bedrock, fractures that are oriented parallel to bedding are thought to be a major control mechanism for lateral groundwater flow (south on the north side of the valley, and north on the south side of the valley) within stratigraphic bedrock units in the watershed. These structural features are important in terms of understanding the aquifer recharge mechanism and the flow of groundwater throughout the watershed.

Figure 36 shows the approximate location of three cross-section traces, used to develop the conceptual geological model in the watershed. Note that the vertical exaggeration of cross-sections B-B' and C-C' is 10:1.

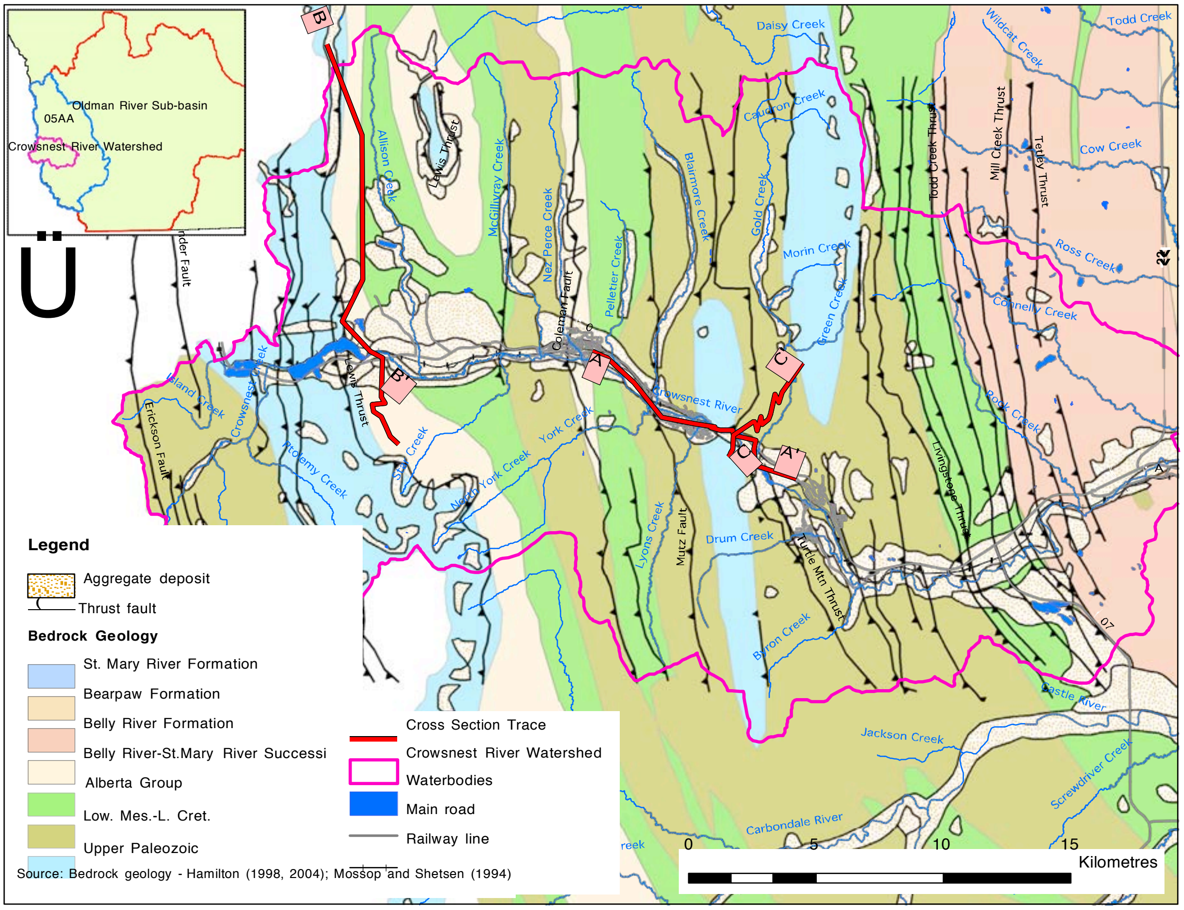


Figure 36 Cross-section location map

In order to provide a better understanding of the relief and complexity of the area the surface traces of the cross-section lines discussed below, are plotted on a Google Earth (Google, 2012) map of the watershed with a third dimension perspective. **Figure 37** shows the surface trace of cross-section A-A' (vertical exaggeration 75:1) within the Crowsnest River valley starting from near Coleman through Blairmore toward the hamlet of Frank in the east. Turtle Mountain lies to the south of the cross-section trace.

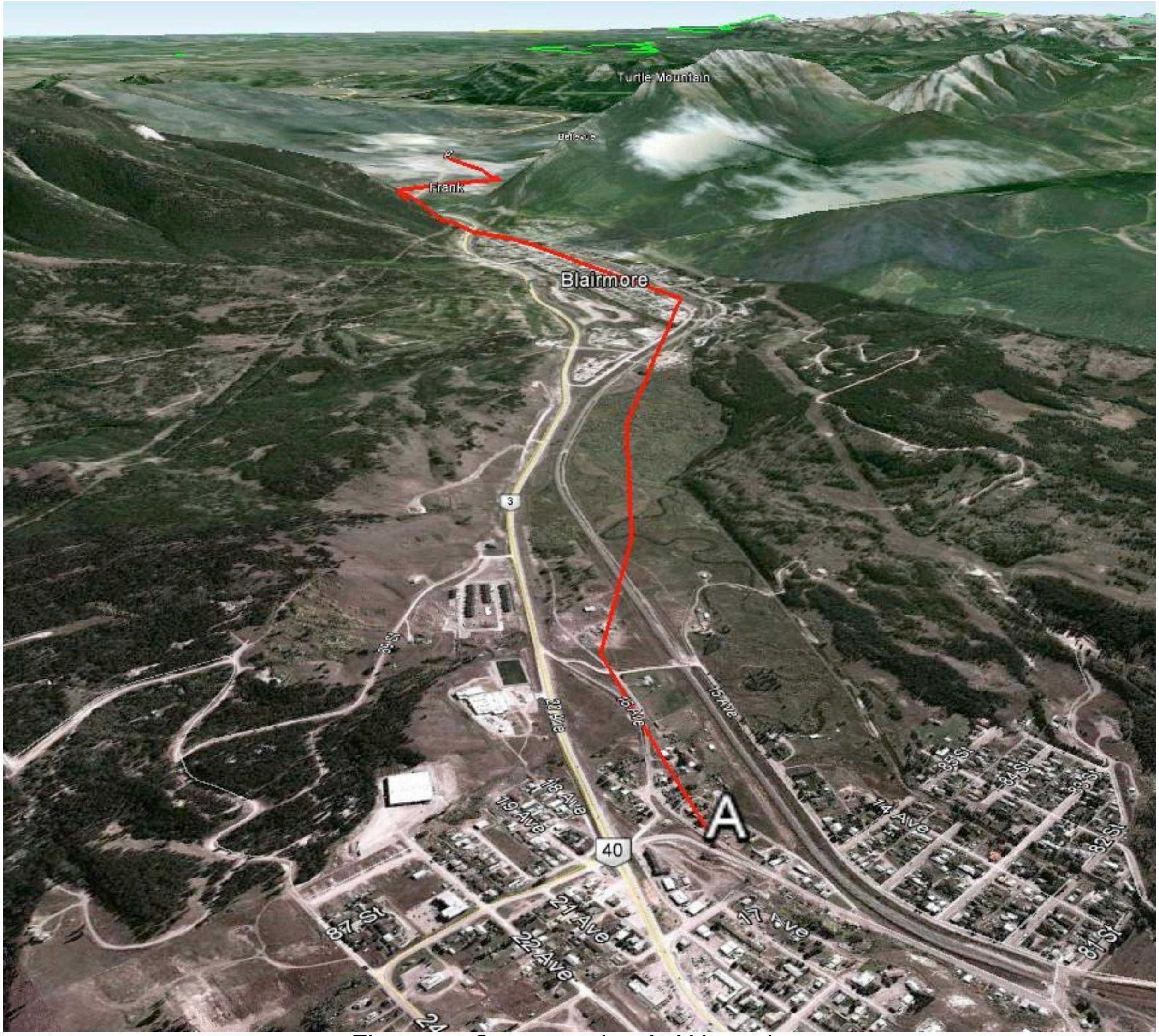


Figure 37 Cross-section A-A' Location

The cross-section (**Figure 38**; trace A-A' on **Figure 36**) is drawn perpendicular to the strike of the bedrock bedding and thrust faults. The western boundary of the cross section was terminated at the eastern edge of Coleman townsite because of the sparseness of data to the west of Coleman along the Crowsnest River. This western portion of the watershed will be described further in cross section B-B'.

The cross-sections display anticipated groundwater flow direction arrows (blue) and yield of the well during pumping tests, portrayed by arrows above the wells showing the pumping test rates. The unconsolidated materials, where present, consist of glacial till and include more permeable sand and gravel deposits forming aquifer zones, and less permeable clay deposits that form aquitards or barriers to groundwater flow.

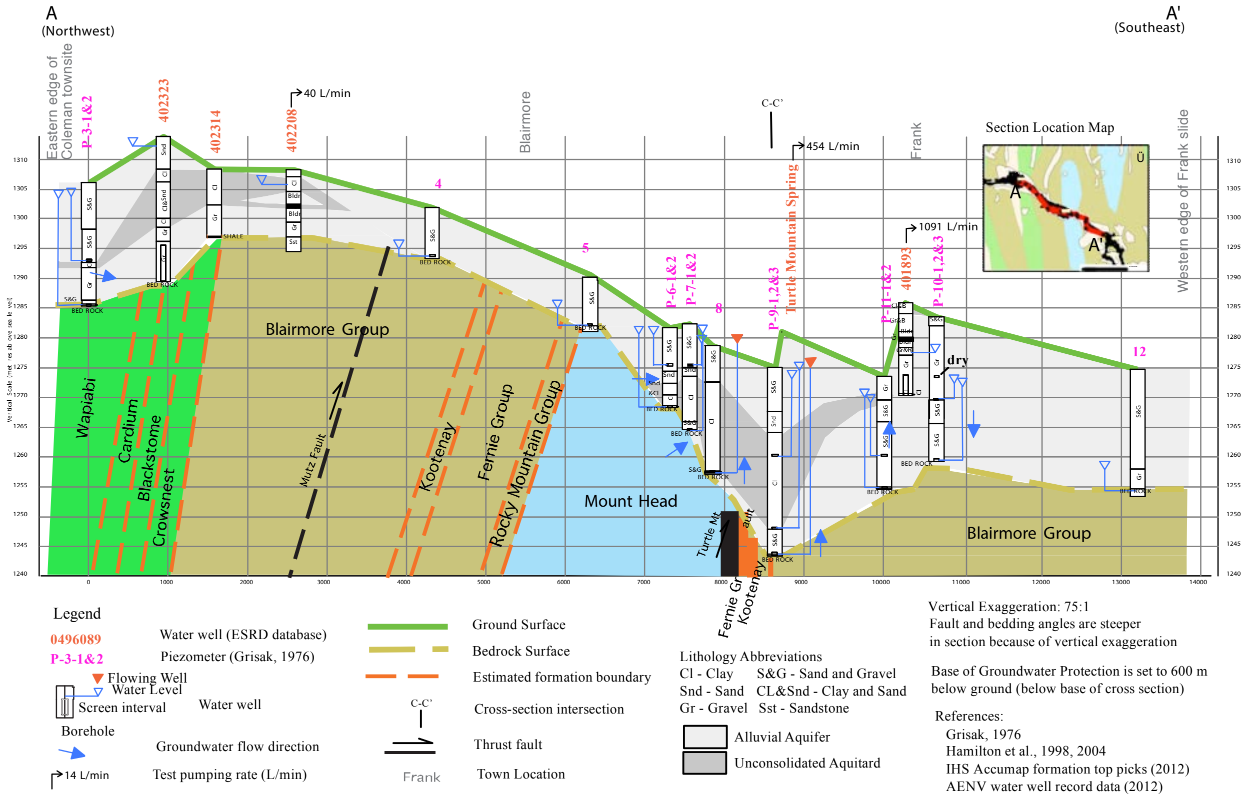


Figure 38 Cross-section A-A'

In general, the bedding within the bedrock formations dips perpendicular to the thrust faults at 40-50 degrees toward the west. Note that the vertical exaggeration in the section increases the angle of the faults and formation contacts and gives the appearance that beds and thrust faults may be steeply dipping at greater than 60 degrees. There are numerous thrust faults placing older materials on younger materials in the watershed. The Mutz and Turtle Mountain thrust faults are shown on this section between the towns of Blairmore and Frank.

As can be seen from the section, water supply wells in the area are typically completed within 25 m of ground surface and mostly within the unconsolidated alluvial materials. Pumping test yield rates are shown where available on the cross-section over the well.

The unconsolidated materials shown in the upper part of cross-section A-A' form part of the Crowsnest River alluvial aquifer. In addition, the Middlefork pre-glacial valley was mapped in the eastern portion of the watershed by Geiger (1968) (**Figure 29**). This pre-glacial valley is the western extension of the Lethbridge pre-glacial channel and represents a major buried channel aquifer east of this area. It is possible that this pre-glacial valley extends further to the west than it was initially mapped. The Middlefork valley was filled with sand and gravel deposits prior to glaciation and subsequently infilled with approximately 10 m of clay over the basal gravel (shown as unconsolidated aquitard on cross-section A-A'). The basal sand and gravel deposit forms the only mapped buried channel aquifer in the watershed. Upon glacier retreat, sand and gravel was once again deposited in the glacial valley which forms the present day alluvial aquifer in that area.

The available water level data in wells 8 and P9 on cross-section A-A' indicate that there are upward hydraulic gradients (discharge condition) in the basal sand and gravel to the extent that water levels in these piezometers are above ground level. This implies that the basal unit is confined by the overlying clay till. Well 401983 is listed as a municipal supply well.

As discussed earlier, the Turtle Mountain Spring discharges near the Crowsnest River at the base of Turtle Mountain flowing along the Turtle Mountain Thrust Fault.

Two north-south cross-section have been developed in selected "type areas"; one in the Allison Creek Valley in the western portion of the watershed (B-B') and one between Blairmore and Frank in the east central portion of the watershed (C-C'). They are discussed below.

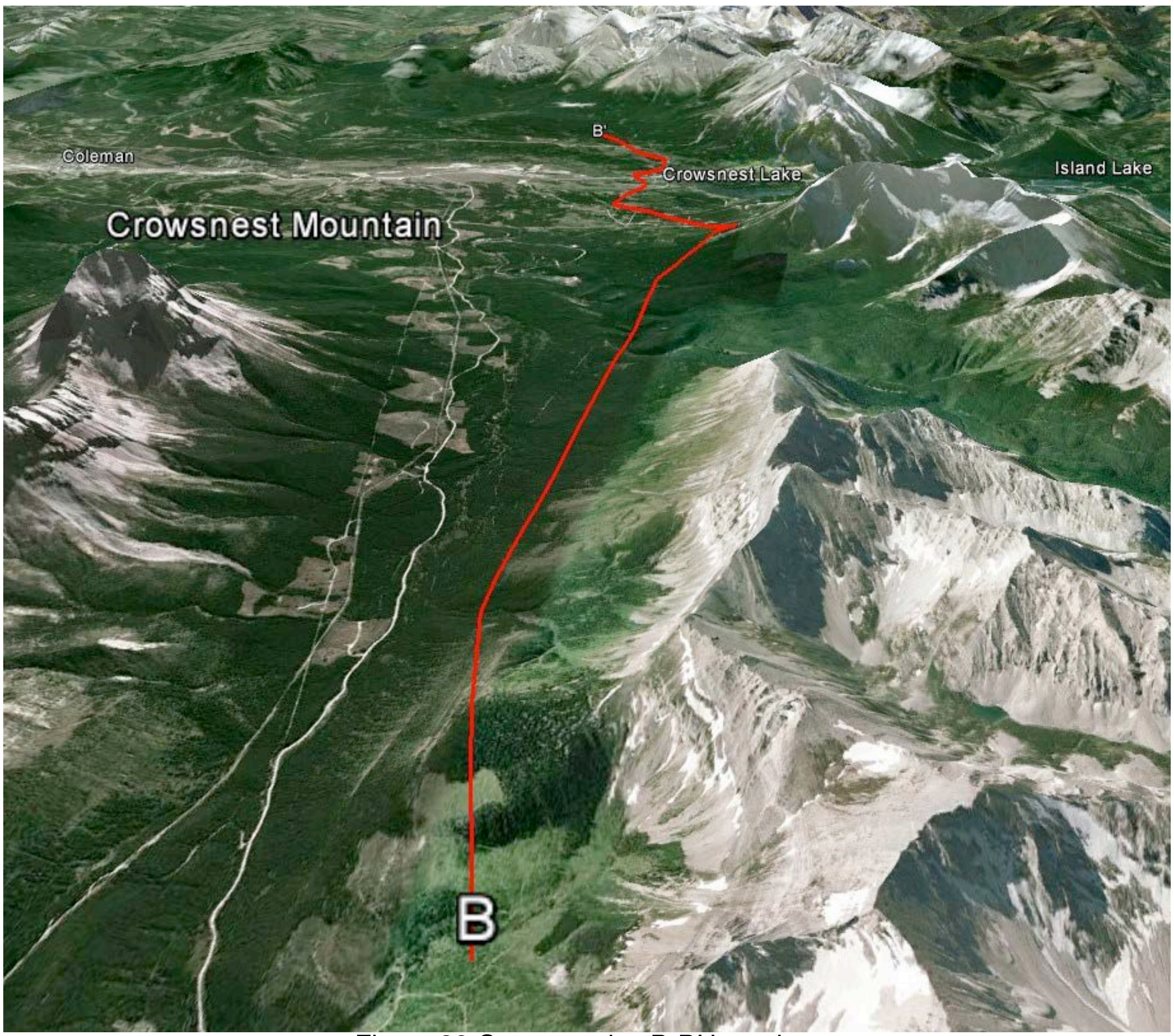


Figure 39 Cross-section B-B' Location

Figure 39 shows the surface trace of cross-section B-B' along the Allison Creek valley toward Crowsnest Lake and across the Crowsnest River. The location of well records dictated the less than ideal location of this cross-section, which is oblique to the strike of the bedrock geology in places (**Figure 36**).

North-south trending cross-section B-B' (**Figure 40**; trace B-B' on **Figure 36**) is drawn approximately parallel to the strike of the bedrock bedding and thrust faults looking toward the east. The Upper Paleozoic bedrock in the northern portion of the cross-section is steeply inclined to the west (remember the section is oblique to the strike off the bedding and faults). It is thrust over the Belly-River-St. Mary River succession by the Lewis thrust fault.

As noted previously in the discussion in **Sections 3.6.4** and **3.6.5**, groundwater flow, in the Allison Creek valley is most likely toward the valley floor and then along Allison Creek into the Crowsnest River. The flow of groundwater through the Upper Paleozoic karstic carbonates is possibly prevented by the thrust fault from flowing to the adjacent sandstone of the Belly-River-St. Mary River succession. Water use is concentrated in the Crowsnest River valley.

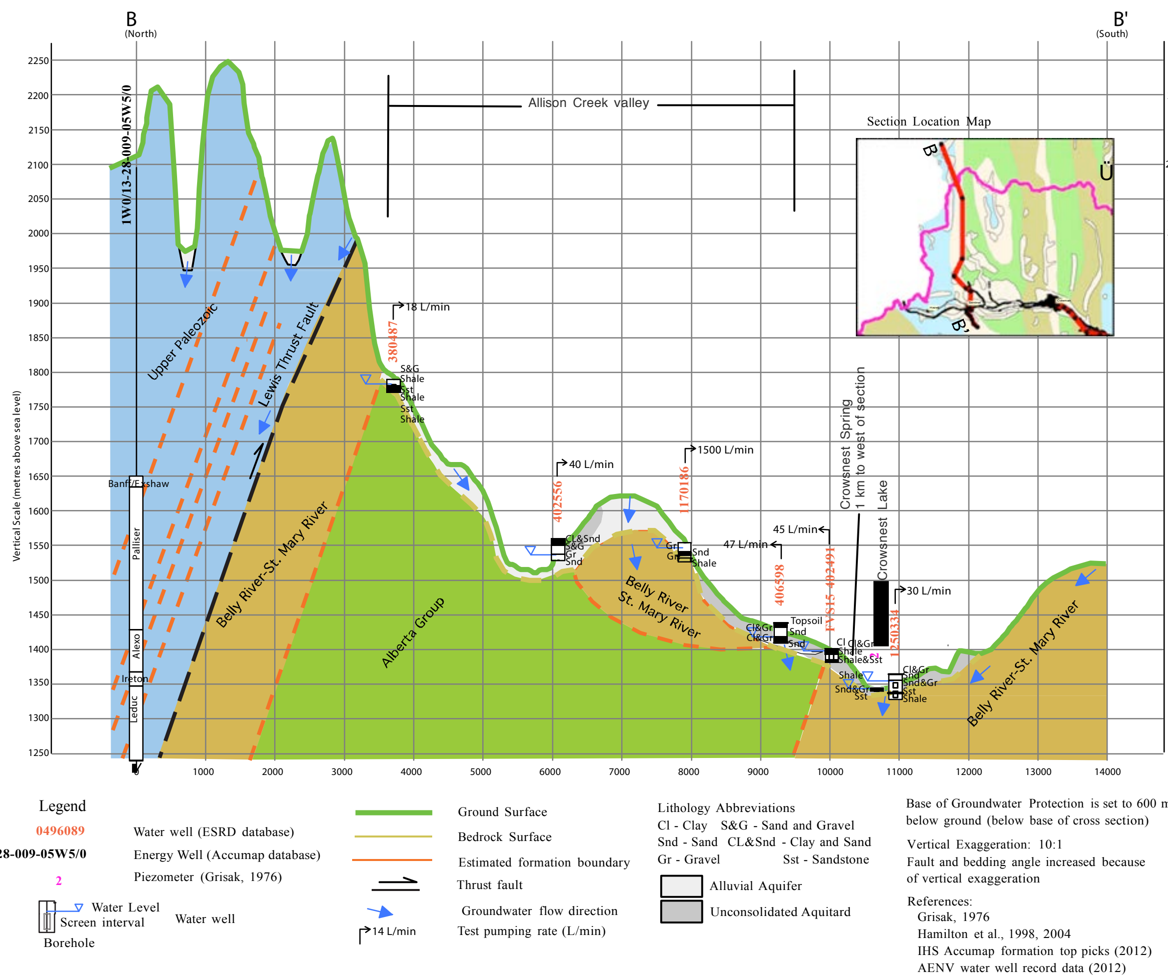


Figure 40 Cross-section B-B'

The Crowsnest Spring discharges into Crowsnest Lake approximately one km to the west of the cross-section trace.

Although not easily shown on cross-section B-B', the work by Worthington (1991) suggests that precipitation infiltrates over the limestone bedrock for an area of more than 100 km^2. Rainwater and snowmelt percolate through the soil and bedrock and migrate along fractures, dissolution channels, and caverns from areas of high elevation to lower elevations surrounding Crowsnest Lake (i.e., the "plumbing system"). The high natural flows occurring from the springs indicate that pathways may be confined and the volume of spring discharge is related to the pressure in the system and proportional to the recharge elevation (the water moves under the force of gravity; water flows downhill). The flow measurements indicate that a large system of interconnected fractures and caverns likely exist within the carbonate bedrock but at present this cannot be mapped.

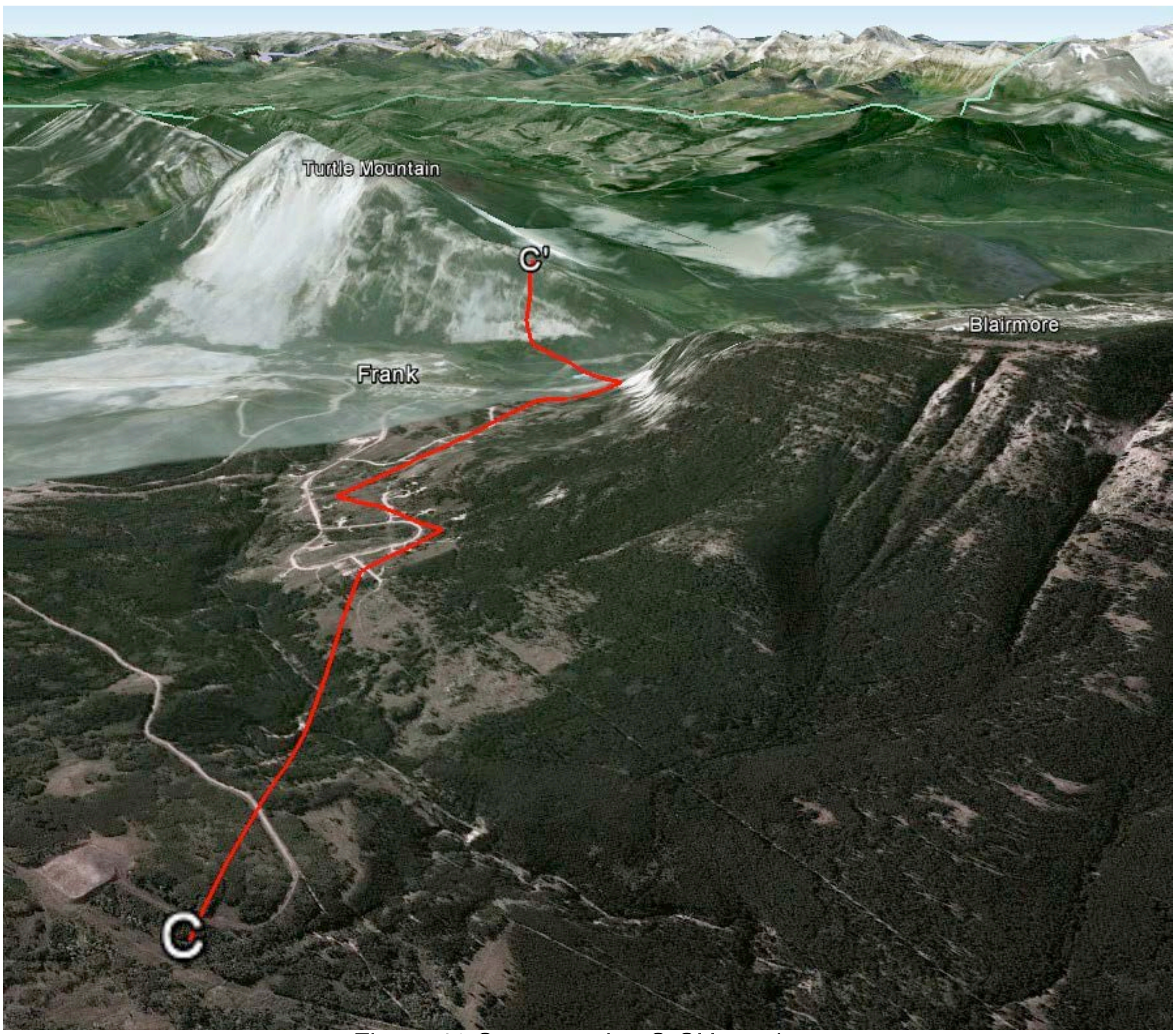


Figure 41 Cross-section C-C' Location

Figure 41 shows the surface trace of cross-section C-C' from north of the Hamlet of Frank through a subdivision development (Stantec, 2007), to Frank and then across the Crowsnest River toward Turtle Mountain.

North-south trending cross-section C-C' (**Figure 42**; trace C-C' on **Figure 36**) is drawn approximately parallel to the bedding and thrust fault strike looking toward the west.

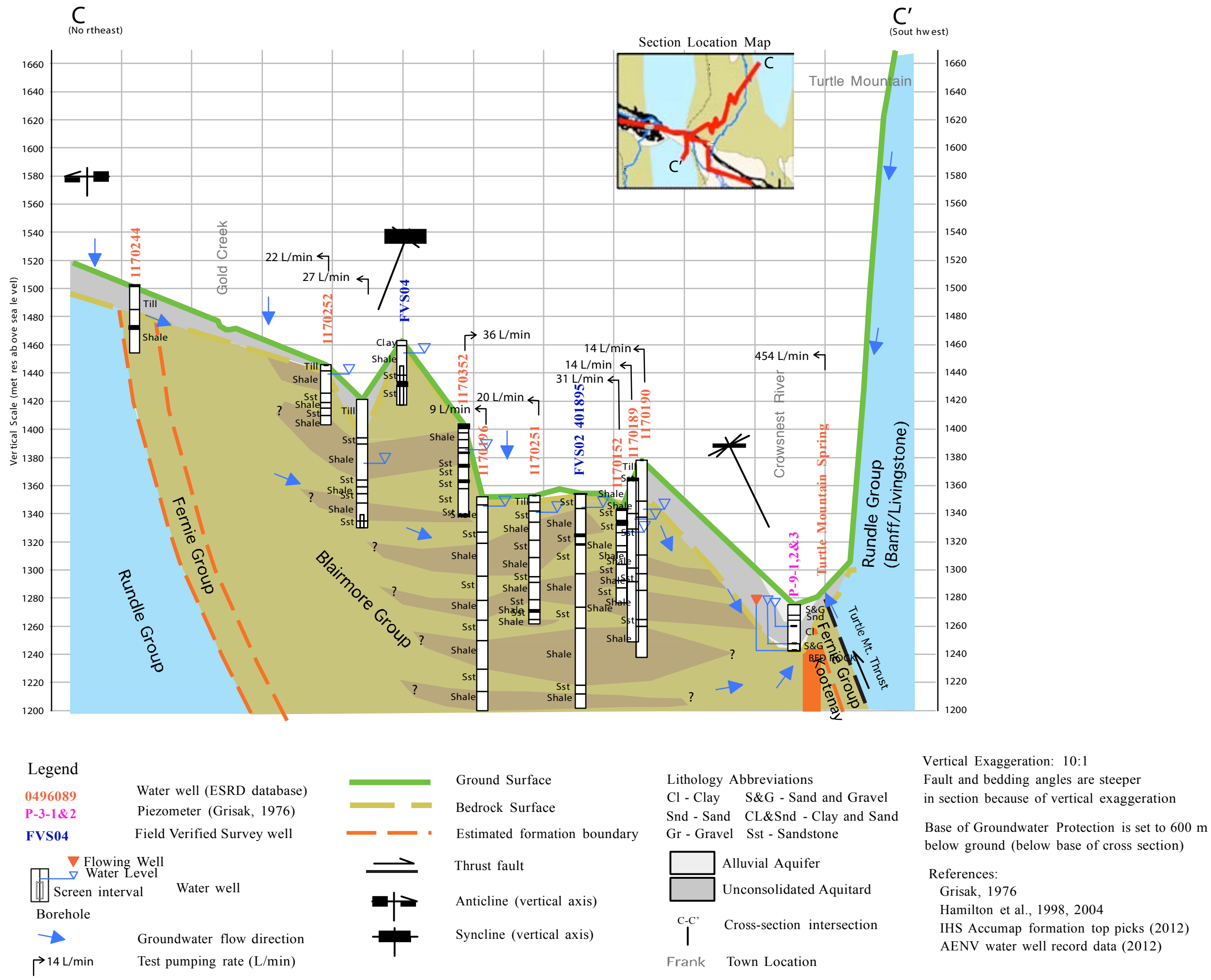


Figure 42 Cross-section C-C'

Groundwater flow shown in the alluvial materials of the northern portion of the section is likely not as significant because of the low permeability clay till that appears to be present throughout much of the area. As a consequence there is much greater development of groundwater resources from the bedrock to depths of 150 m.

The Blairmore Group based on the well lithology logs, consists of interbedded sandstone and shale units that do not appear to be extensive.

Groundwater flow is directed downward (recharge condition), in the northern portion of the cross-section, toward the Crowsnest River. As indicated earlier (Section A-A'), groundwater gradients in the alluvial materials of the Crowsnest alluvial aquifer are directed upward (discharge condition). This is also supported by the qualitative assessment of water levels in shallow and deep water wells across the watershed (**Section 3.6.5**).

The Turtle Mountain thrust which emplaced Upper Paleozoic Banff and Livingstone formations on top of the Blairmore Group sedimentary rocks acts as a conduit for groundwater flowing through the carbonates (potentially karstic) of Turtle Mountain to discharge near the Crowsnest River from Turtle Mountain Spring.

Based on these cross-sections the precipitation recharges into either the karstic carbonate bedrock and through dissolution channels and caverns into the lakes at the headwaters of the Crowsnest River, or into the sandstone/shale bedrock flowing from higher elevations into the tributary creek valleys, discharging into the Crowsnest River and then from west to east in the vicinity of the Crowsnest River. Flow enters the unconsolidated alluvial aquifers from the bedrock, and in places with downward directed hydraulic gradients from the Crowsnest River. The alluvial aquifer is split into two aquifers west of Coleman with a clay till aquitard confining the lower alluvial aquifer between Blairmore and Frank. This lower alluvial aquifer likely forms part of the Middlefork pre-glacial valley.

3.10.1 Groundwater/Surface Water Interaction

Understanding groundwater-surface water interactions is of utmost importance to allow for the proper management of surface water and groundwater resources within the Crowsnest River watershed. The circulation of water within the watershed is best explained in terms of the water cycle.

Figure 43 provides a schematic showing a generalized flow path of groundwater in the subsurface. Unconfined sand and gravel aquifers that are in direct connection to the surface (e.g., Crowsnest River Alluvial Aquifer) can provide short flow paths on the order of 10 to 100's of metres in length, with travel times of days to a few years. As water moves down through the strata from above, deeper flow-paths to underlying confined aquifers may be kilometres to 10's of kilometres in length and have travel times of decades to millennia.

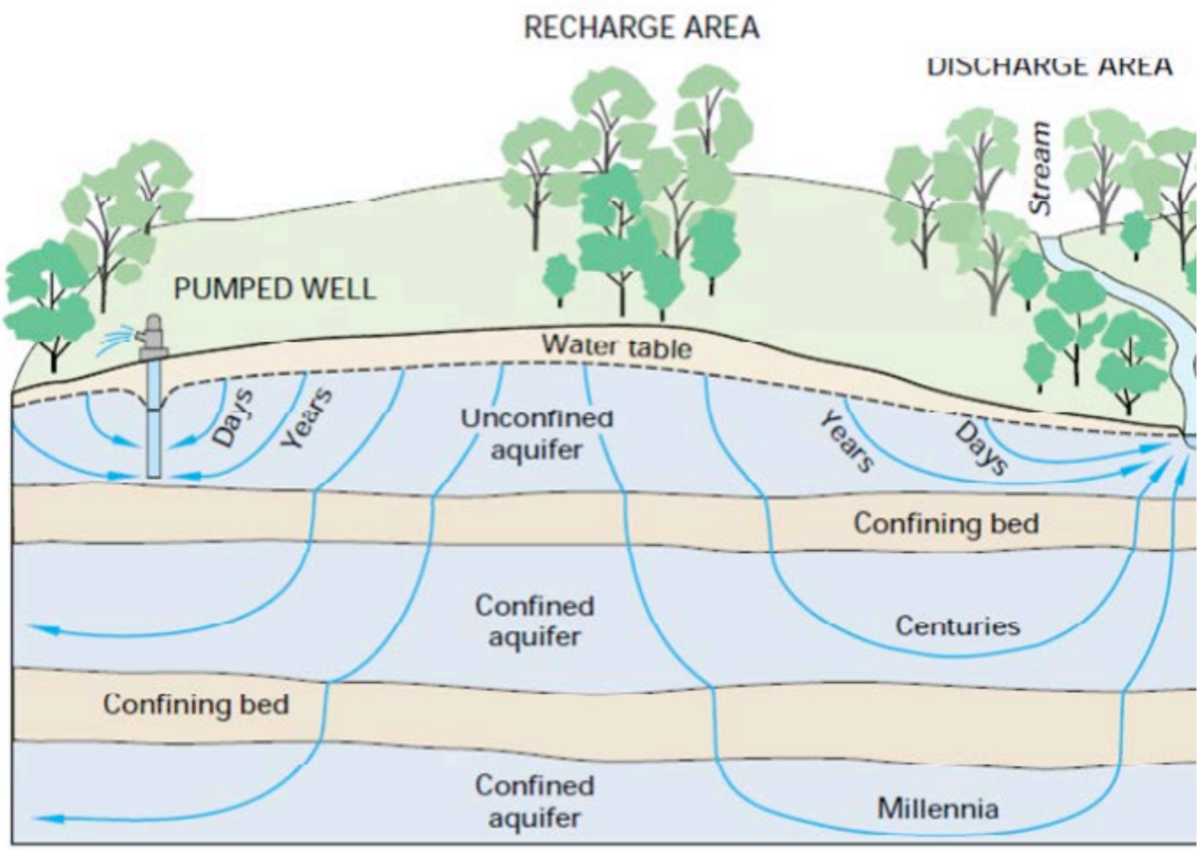


Figure 43 Conceptual groundwater flow paths (from Winter et al., 1998)

Throughout the watershed upward hydraulic gradients or discharging conditions dominate within the carbonate bedrock and along the Crowsnest River Valley and this is consistent with the physical model. As indicated in **Section** 3.6.5, the discharging groundwater contributes significantly to the baseflow of the Crowsnest River and should be identified as a critical area in any water management plan.

The Belly River to St. Mary succession sandstone and Alberta Group shale subcrop east of the Paleozoic limestone formations (**Figure 16**). Downward hydraulic gradients (recharge conditions) and/or neutral gradients prevail along the slopes on either side of the Crowsnest valley. The stratigraphy/bedding and fracture orientation suggests that recharge from snowmelt and precipitation will tend to follow topography and flow north or south along the tributary creeks and valleys and then east along the Crowsnest River. Although a significant amount of runoff contributes to creek flow, groundwater discharge to the alluvial aquifers in this area from adjacent bedrock aquifers may also be significant and needs to be further investigated.

4.0 WATER BUDGET ASSESSMENT

4.1 Water Budget Approach

A water budget is used to assess the stress on surface and groundwater resources within watersheds by comparing water availability with water demand. The surface water budget needs to consider inflows and discharges from the surface water component of the water cycle including rainfall and snowmelt as inflow; evaporation and evapotranspiration, canopy storage and human consumption as losses; transfer to and from soil moisture storage, surface storage in lakes and reservoirs; and ground water recharge and exfiltration. It should be noted that some of the amount of water extracted for human consumption can be returned to the surface water or ground water components of the water cycle either through treated waste-water effluent, septic fields or irrigation runoff.

A generalized surface water budget is shown below (**Figure 44**). Although this is not part of the scope of the present work, the linkages between groundwater and surface water within the Crowsnest River watershed will require a comprehensive surface water assessment in order to fully reconcile the groundwater budget. A detailed description of the recommended surface water assessment is provided in Section **6.2** of this report.

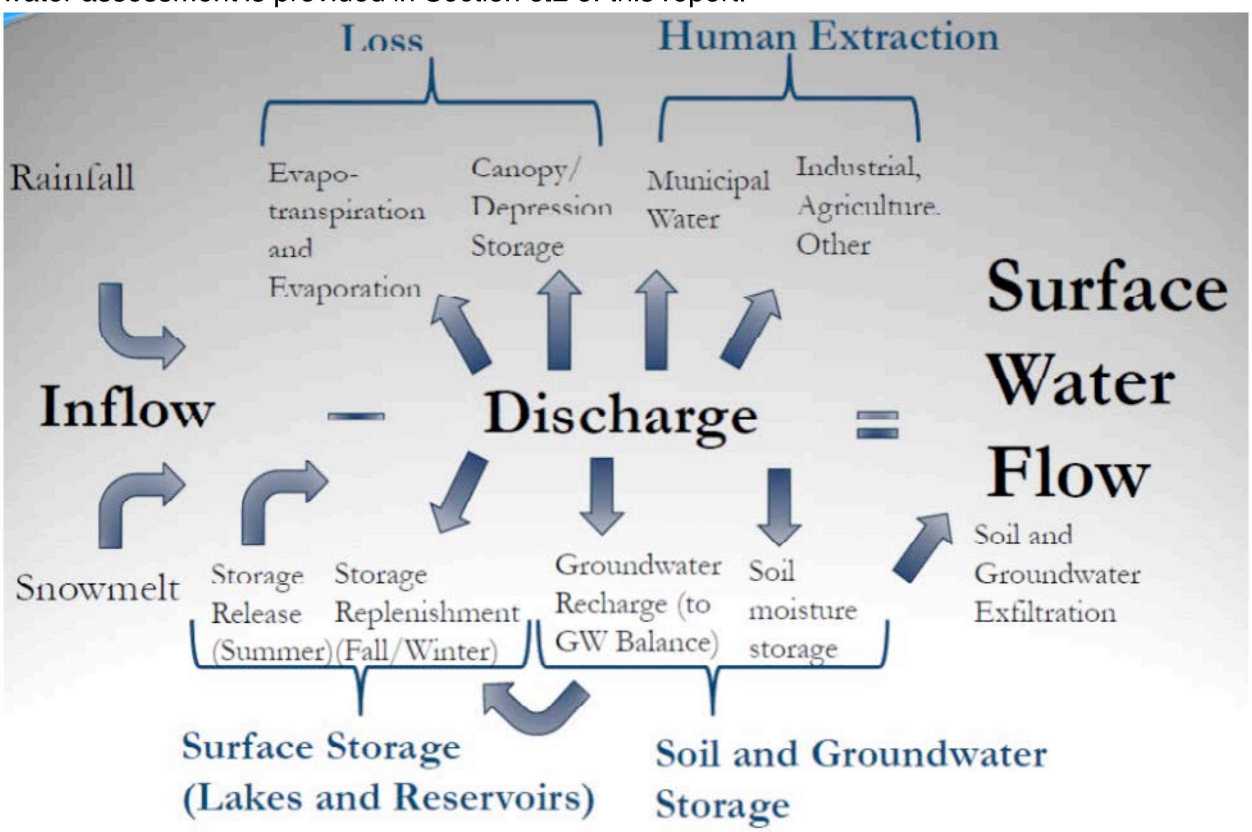


Figure 44 Generalized Surface Water Budget

The main parameter of interest to assess groundwater resources is the groundwater recharge which is identified as discharge parameter in the surface water budget in **Figure 44**. Once the recharge has been estimated, the following groundwater budget equation can be applied:

$$Rp + Rr + Rf + Rt + Si + Ig = Et + Tp + Se + Og + \Delta S$$

Where;
Rp = recharge from precipitation;
Rr = recharge from reservoir seepage;
Rf = recharge from field irrigation;
Rt = recharge from tanks (if available);
Si = influent seepage from rivers;
Ig = inflow from other basins (if any);
Et = evapotranspiration;
Tp = draft from ground water;
Se = effluent seepage to rivers (springs);
Og = outflow to other basins; and
ΔS = change in ground water storage.

The equation presented above considers only one aquifer or watershed system and does not account for the interflows between aquifers in a multi-aquifer system. However, if sufficient data related to water table and/or piezometric head fluctuations, and hydraulic parameters of intervening layers are available, additional terms can be included to account for these interflows in the governing equation. Computations of water budget parameters will invariably involve errors, due to insufficient or poor quality input data. The water budget equation, therefore, may not balance. In such cases, the discrepancy of the water balance will produce a residual term which will then be compared against the surface water balance in the region until calibration of the entire system is achieved (water inputs = water outputs + change in storage).

The water budget may be computed for any time interval. However, the complexity of the computation of the water balance increases as the time interval decreases. Surface water budgets should be developed based on water balances on a monthly time interval, which will allow for the analysis of seasonal effects without the complexity required for modeling at shorter time intervals. Groundwater or aquifer water budgets can initially be completed on an annual basis using analytical methods. However, shorter time steps are possible if more complex numerical computer simulations are completed. This is a common approach to water balance modeling for water supply and storage assessments.

The following sections attempt to reconcile groundwater use and availability based on a very rudimentary estimate of potential aquifer recharge throughout the entire watershed and all aquifers. Since the assessment is at the watershed scale, it does not provide sufficient detail to deal with any issues at the local scale such as local depletion/dewatering of individual aquifers. The assessment presented herein is very much conceptual in nature and is a first attempt to determine if collectively all aquifers in the watershed can meet the demand for water or are under stress.

4.2 Regulatory Requirements for Groundwater Diversion

Under Alberta's Water Act (GOA, 2010a), the commercial/industrial use of surface water and groundwater is regulated through a system of water licences issued by ESRD. Approvals or licensing under the Water Act limits the user to a specific annual water volume based on their specific requirement. In order to comply with the terms and conditions in the license, the user is obligated to report water volumes used and water levels on an annual basis through ESRD's on-line Water Use Reporting (WUR) System. Water Act licences are subject to a priority system based on the principal of first in time, first in right.

The Water Act also provides statutory rights to a person who owns or occupies land that adjoins a water body, or a person who owns or occupies land under which groundwater exists to divert water for household purposes as defined in the Act. Rural landowners have a right to divert and use up to 1,250 m^3/yr of surface water or groundwater for household purposes. In addition, registered traditional agricultural users (restricted to raising animals or applying pesticides to crops) have the right to divert and use up to 6,250 m^3/yr of surface water or groundwater.

The Municipality of Crowsnest Pass has groundwater (Coleman, Blairmore, Bellevue and Hillcrest) and surface water allocations at 4,055,000 m^3/yr and 1,026,000 m^3/yr, respectively. In the M.D. of Pincher Creek (within the Crowsnest River watershed), the hamlet of Lundbreck uses surface water. The M.D. of Ranchland has no municipal facilities that use groundwater.

4.2.1 Water Use Reporting (WUR) Database

Alberta Environment and Sustainable resource Development operates an on-line reporting system for approval holders to enter water level and groundwater usage data. Of 250 approvals for groundwater use shown in the WUR database, only 11 approval holders have submitted data from 2005 to 2010. Of these 11 submissions, no water level data have been reported. The 250 approvals in the region allocate a total of 6,007,385 m^3/yr. The total amount reported (use minus returns) increased from 474 m^3 in 2005 to 3,141,650 m^3 in 2007.

The Municipality of Crowsnest Pass has 15 licenses for the extraction of groundwater for a total annual volume of 4,055,274 m^3. They have reported on three of the approvals in the WUR database. They have records for 11 wells located at Coleman (two wells; 627,981 m^3 in 2010), Hillcrest (four wells; 302,924 m^3 in 2010), Blairmore (four wells; 2,036,178 m^3 in 2010) and Bellevue (one well; 360,023 m^3 in 2010) for a total of 3,327,106 m^3 in 2010.

4.2.2 Surface Water Diversion – Crowsnest River

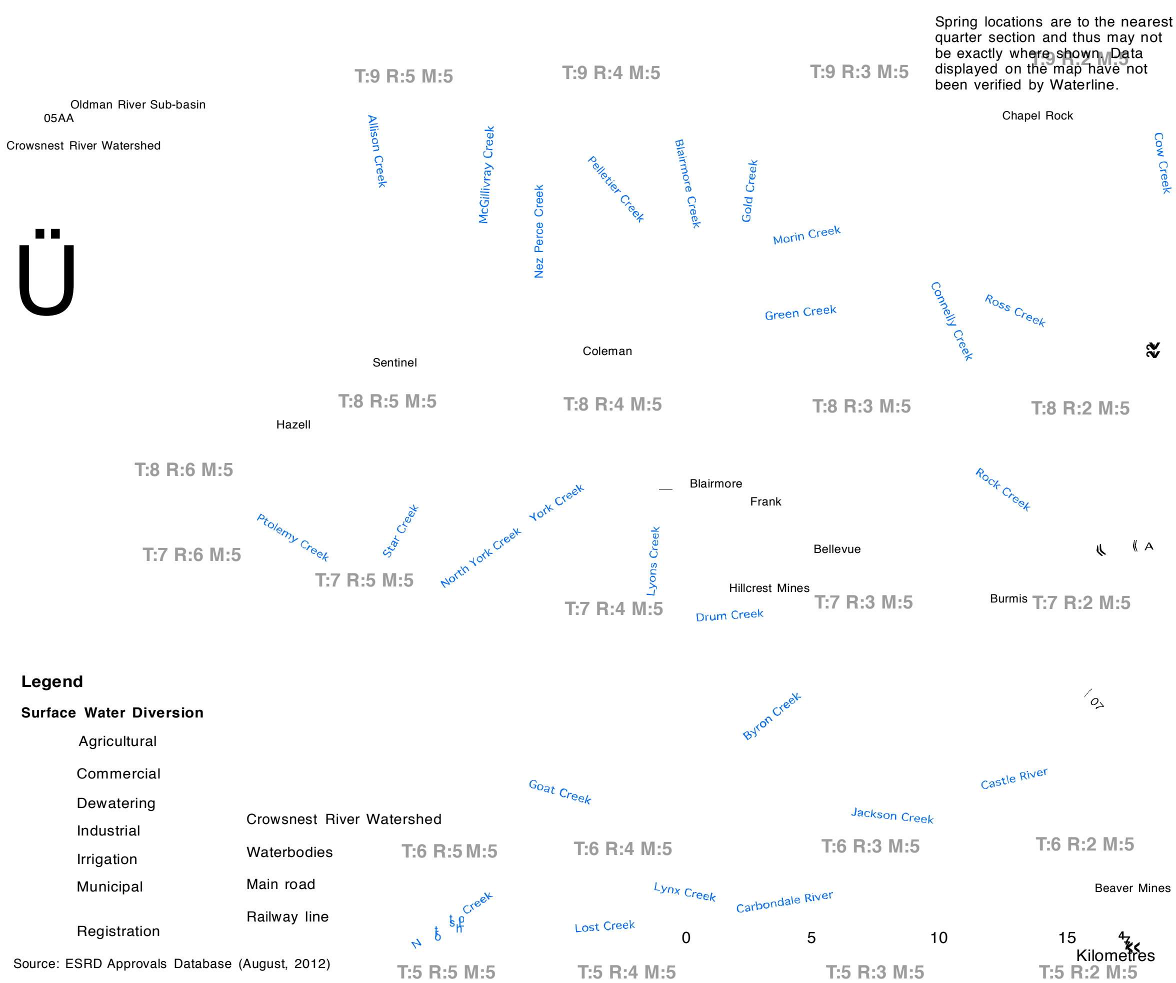
The most common use of surface water in the watershed is for commercial and municipal use **(Table 12**).

Surface water license locations plotted on **Figure 45** show that most of the surface water use is in the eastern portion of the watershed where agricultural land-use is the most common, although registrations appear to be more evenly distributed throughout the watershed.

Table 12 Surface Water Diversion

Type of Surface Water Diversion	Maximum Annual Diversion (m^3/year)	# of Authorizations
Agricultural	451,880	19
Commercial	19,248,114	229
Dewatering	0 (no amounts provided)	9
Disturbance	6,175	2
Irrigation	1,127,402	25
Management of Fish	1,036	1
Municipal	14,463,590	20
Other Purpose (Director specified)	1,020	1
Recreation	198,617	6
Registrations	56,988	538
Unknown	299	2
Total Licensed Allocation	35,555,120	852

The Municipality of Crowsnest Pass holds seven surface water diversion licenses for a total annual volume of 1,506,100 m^3. Of these; 103,610 m^3 is from the Crowsnest River, and the remainder is taken from tributaries including Gold, Drum and York Creeks.



Waterline Resources Inc.

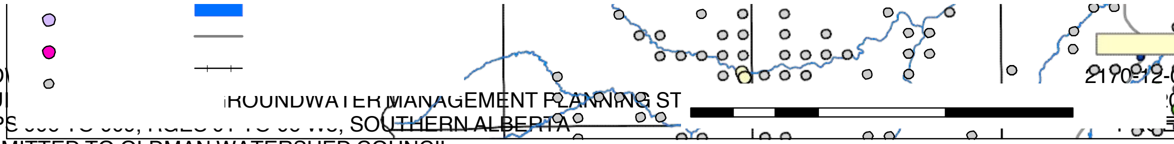


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Figure 45 Surface water diversion

4.2.3 Types of Groundwater Use and Licensed Diversion

Table 13 summarizes the well information based on proposed use indicated on well logs.

Table 13 Proposed Uses For Water Wells Within the Watershed

Water Well Use	# of Well Records
Domestic	621
Domestic and Stock	20
Domestic and Industrial	1
Industrial	51
Commercial	1
Investigation	11
Irrigation	1
Dewatering	1
Municipal	41
Municipal and Observation	1
Observation	63
Other	6
Standby	----
Stock	2
Unknown	89
Total	**912**

Groundwater diversion licenses (**Figure 46**) indicate that the most common use of groundwater in the watershed is for municipal purposes followed by management of fish (**Table 14**).

Table 14 Licensed Groundwater Diversion

Type of Groundwater Diversion	Maximum Annual Diversion (m^3/year)	# of Authorizations
Agricultural	1,926	2
Commercial	1,230	1
Exploration	19,893	1
Management of Fish	829,640	3
Municipal	4,923,747	24
Other Purpose specified by the Director	300	1
Recreation	1,230	1
Registrations	16,452	35
Total Licensed Allocation	5,794,418	68

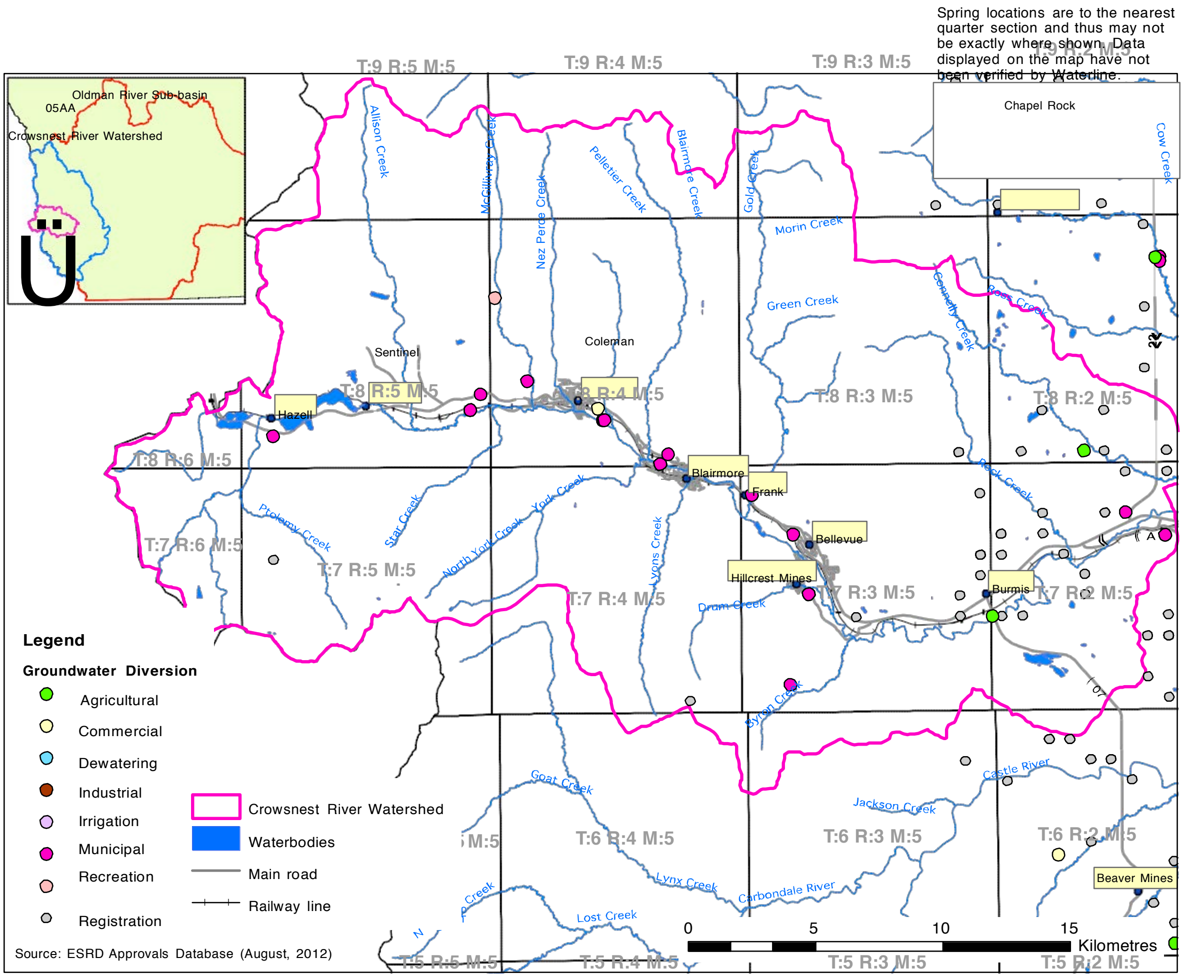


Figure 46 Groundwater diversion

The maximum approved groundwater diversions are shown in **Table 15** and have been subdivided by formation. It should be noted that the information included in the license approval often does not include the associated water well (e.g., by ESRD Well ID) or formation/aquifer name.

Waterline was able to cross-reference the license approval location to the nearest water well(s) and assign a formation into which the well was most likely completed. However, it was not possible to assign the diversion volume to unconsolidated aquifers because depths were usually not provided in the approval. Based on this assessment, the most commonly used aquifers are situated in the Lower Mesozoic to Lower Cretaceous followed by the Alberta Group aquifer(s).

The Municipality of Crowsnest Pass obtains its water from groundwater, which for the most part, is extracted from the alluvial sand and gravel in the vicinity of the Crownest River. The municipality holds 15 diversion licenses that allow a diversion of 4,055,274 m^3/yr. The reported diversions from 2009 to 2011 were 3,534,801 m^3/yr, 3,327,106 m^3/yr and 3,038,546 m^3/yr respectively. Although the municipality uses approximately 74% (2011) to 87% (2009) percent of its total approved groundwater diversion volume; this amount is decreasing.

Table 15 Groundwater Diversion by Formation

Formation	**Alberta Group**	**Belly River Formation**	**Lower Mesozoic-Lower Cretaceous**	**Upper Paleozoic**
Type of Diversion	Maximum Diversion Allowed (m^3/year)			
Agricultural	1,230	696	-	-
Commercial	1,230	-	-	-
Exploration	-	-	19,893	-
Management of Fish	829,640	-	-	-
Municipal	1,677,299	56,122	3,186,235	4,091
Other Director specified purpose	-	-	300	-
Recreation	1,230	-	-	-
Registrations	7,786	7,094	1,572	-
Total	2,518,415	63,912	3,208,000	4,091
# Diversion Licenses	29	19	19	1

Note: # means number

The municipality wishes to replace a large number of domestic wells with poor quality water in the area with a single production well installed by Stantec (2007) near Sentinel on the north-shore of Crowsnest Lake. Approval from ESRD has not been granted to date because the well has been proven to be connected to the surface water in Crowsnest Lake (pers. comm. J. Gutsell, ESRD). Groundwater that is connected to surface water falls under the moratorium in the South Saskatchewan River basin and ESRD would not allow its development unless the volume extracted falls within the current surface water license amount.

4.3 Aquifer Recharge Estimate

Recharge to bedrock aquifers within the Crowsnest River watershed is not known with certainty at this time.

Establishing an actual value for aquifer recharge is currently of secondary importance, as there are insufficient data to allow for an accurate assessment. It is more important to confirm that recharge is in fact occurring. Water level monitoring occurred in only one well within the watershed; this was located at the Allison Creek Trout Hatchery. Note that the monitoring time period extended only until 1996. Therefore, it is not possible to determine whether aquifers are currently being sufficiently recharged or over-exploited.

In terms of estimating potential recharge throughout the entire watershed, some approximations can be made. The average annual precipitation for the watershed, based on the last 90 yr of record is approximately 530 mm in the Montane zone. Note that this amount does not take into account the higher rainfall in the Sub-alpine and Alpine areas which make up approximately 50 percent of the watershed area (**Figure 8**). A more accurate assessment should be completed using the USGS distributed runoff model described above.

Based on this assessment, an average of 383,720,000 m^3/yr precipitation in the form of rain and snow falls onto the 724 km^2 area of the Crowsnest River watershed each year. Assuming 5 percent to 15 percent infiltrates into the subsurface soils and bedrock in the form of recharge to underlying aquifers, this means that 19,186,000 m^3/yr to 57,558,000 m^3/yr of water may recharge the underlying aquifers in an average year.

4.4 Groundwater Pumping Estimate

Groundwater pumping and use from the aquifers within the Crowsnest River watershed includes the following:

- Licensed groundwater diversion. A total 250 licenses with approved groundwater diversion of 6,007,385 m^3/yr. As shown in the previous section it is not known whether the full licence allocation is being diverted.
- Although the actual groundwater that is being diverted for household use in the watershed is not being measured, under the Water Act a landowner has the statutory right to divert and used up to 1,250 m^3/year. Therefore, for the purposes of the present calculation, groundwater diverted for domestic use within the Crowsnest River watershed is estimated to be approximately 3,750,000 m^3/yr (3,000 households x 1,250 m^3/year).

Therefore, the total amount of groundwater extraction estimated for the Crownest River watershed is 9,757,385 m^3/yr.

4.5 Groundwater Budget Estimate

In order to achieve sustainable groundwater use, aquifer recharge should be greater than, or equal to, groundwater discharge (human extraction activities as well as areas of discharge to rivers and creek to maintain a healthy ecosystem). That is to say, that the total diversion of groundwater should not exceed aquifer recharge, otherwise aquifer mining or dewatering will occur.

Based on the above assessment, the difference between the estimated recharge of 19,186,000 m^3/yr to 57,558,000 m^3/yr, and the estimated groundwater extraction of 9,757,385 m^3/yr suggests a surplus of groundwater of 9,428,615 m^3/yr to 48,129,385 m^3/yr. This indicates that 17 to 51 percent of groundwater recharge may currently be used for water supply. This assessment does not consider groundwater discharge to creeks and rivers and this is believed to be significant in the western part of the watershed where spring discharge alone has been estimated at more than 2,000,000 m^3/yr based on measurements by Worthington (1991) in 1985-1986.

It should be cautioned that this is a very crude estimate for all groundwater systems within the watershed and should not be used for development planning purposes. A more detailed assessment is required of specific aquifers within localized areas where a higher density of groundwater diversion is occurring. Future studies need to focus on monitoring of groundwater water levels, surface water flow, and water quality in order to assess if water use practices are balanced or possibly over-exploiting aquifers, or if water quality is being degraded.

Waterline recommends the distributed drainage model approach as a next step to further refine water budget estimates and move to watershed management planning. Additional data will be needed and is described in the following sections on aquifer vulnerability and data/knowledge gaps.

5.0 KNOWLEDGE AND DATA GAPS

There is a considerable amount of hydrogeologic-related data collected each year within the Crowsnest River watershed. However, this information is not necessarily being submitted or compiled in a way that is useful to hydrogeologists conducting local or regional scale assessments such as the present Crowsnest River watershed study.

5.1 Water Well ID's, GPS Location and Tagging System

Knowledge/Data Gap:

Water well drillers continue to drill wells for private landowners and others, and based on Waterline's extensive experience in Alberta, they may or may not submit their driller report and associated test data to ESRD for compilation into the water well database. Furthermore, well records are often submitted with the location of water wells estimated to the nearest quarter section, which is insufficient in Waterline's view. Drillers should be required to use a handheld Global Positioning System (GPS) to obtain well coordinates to at least 10 m accuracy. Some drillers have started to do this. Finally, a water well tagging system is required so that the ESRD Identification Number (ID) is clearly shown on the well and it can be reconciled at any future date with the well record in the ESRD database. This will also enable reconciliation with ESRD licence approval database and WUR system, when further testing or assessment is completed. The following recommendations are presented for consideration by ESRD to address this critical issue.

Recommendation:

There is an opportunity to capture very important groundwater data at a minimal cost but some changes need to be made to direct landowners, drillers, and groundwater professionals in this regard. In Waterline's opinion, a self-policing system is possible with minor changes to existing ESRD guidelines and regulations. For instance, drillers should be required to apply for an ESRD well ID number before any water well is drilled. This could be done electronically, allowing the tracking of a well even before it is drilled. The system should be universally applied to water wells but consideration should also be given to other types of monitoring wells that are drilled above the base of groundwater protection (e.g., environmental monitoring wells, wells used for remediation, seismic holes, etc.). The rationale for this is that any activity occurring in the subsurface that has the potential to affect the quality or quantity of non-saline groundwater resources needs to be controlled or regulated. It also provides hydrogeologists with the needed data to assess and properly manage the groundwater resources. Waterline understands that extending the requirements beyond water wells would create some challenges. However, it should be noted that what is at stake is the protection of groundwater resources for future Albertans.

Well tags should be made mandatory with well ID's and GPS location inscribed on the tag and firmly affixed to the well. In addition, an electronic photo can be taken by the driller and submitted to ESRD as a permanent record and proof that the well was tagged. In this manner, any further work, such as testing of or sampling from a particular well, can be tracked with the well ID (or to a known GPS location if the tag is damaged) and a database of historical water levels and water chemistry data can be established with time.

Enforcement occurs if the driller fails to submit a well log with appropriate information because the well ID has been linked to the driller from the outset. Self-policing by the Alberta Water Well Driller's Association is therefore possible and disciplinary action can be initiated, which could involve revocation of a driller's license if he/she fails to comply. In Waterline's view, this proactive approach is required immediately, as every well completed in the Crowsnest River watershed is a potential monitoring point from which conceptual hydrogeological models can be developed and sustainable groundwater management can be accomplished. Although the present Groundwater Observation Well Network (GOWN) system in Alberta is useful, there is potentially an abundance of essentially free, and very valuable, groundwater data that is not being captured in any way that is useful. Although this is a provincial responsibility, the Oldman Watershed Council should promote this practice to drillers operating in the region or to the landowner after the well is drilled, as every well drilled in the watershed is a potential groundwater monitoring point that can help resolve data gaps in developing our understanding of groundwater systems within the watershed.

5.2 Reconciliation of Water Act Approval Records to ESRD Water Well Database

Knowledge/Data Gap:

Approximately 68 Water Act licenses have been issued for diversion of groundwater within the Crowsnest River watershed (ESRD, 2012). Upon inspection of the licensing data provided by ESRD, well licenses cannot always be reconciled to a specific ESRD well ID. This is a result of timing because ESRD well ID's are only issued after the Driller's report has been entered into the ESRD Water Well database. By the time drilling and testing have been completed, application under the Water Act has often already been made to ESRD and the cross-referencing is lost.

Recommendation:

The solution to this problem has already been addressed in the recommendation for Data Gap #1. If drillers are issued an ESRD Well ID prior to drilling a well, all paper work including reports and applications made by groundwater professionals on behalf of their clients should include the proper ESRD Well ID, so that they are then directly linked to the water well record.

5.3 Capturing Municipal Water Level Data

Knowledge/Data Gap:

The large majority of water use in the watershed is through groundwater distributed by the Municipality of Crowsnest Pass. The Municipality of Crowsnest Pass tracks their water use, however, they do not track water levels in their wells. If there is no knowledge of whether water levels are declining, static, or increasing with time then there is no understanding of the groundwater supply.

Recommendation:

Waterline recommends that the Municipality collects and analyses water level data from all of their supply and observation wells. The collection of water level data throughout the watershed is a critical step in increasing the understanding and awareness of groundwater conditions in the watershed. It is the only way of knowing whether the water supply is diminishing, or whether the area can support an increased population.

5.4 Capturing Landowner Water Level and Water Quality Data

Knowledge/Data Gap:

Energy companies building pipelines, drilling conventional oil and gas wells, conducting seismic programs, or undertaking other oil and gas related activities often complete pre- and post-testing of domestic wells. This is also the case for land developers proposing large residential or commercial developments where there would be a public concern relating to potential impacts to existing water wells. Water well testing is done as part of stakeholder engagement or community relations work, which in the case of energy companies, may be required under directive from the ERCB. At this time, the only regulatory requirement for such test work to be submitted to ESRD is under ERCB Directive 35 relating to coal bed methane (CBM) development in the province of Alberta. However, energy companies conducting activities other than CBM development (e.g., seismic programs), or land development companies are under no obligation to submit the data to ERCB or ESRD.

Since about 2005, Waterline has completed several thousands of domestic well tests for energy companies and land developers throughout Alberta, and only those tests that relate to CBM activities are being captured by ESRD. Based on this experience, Waterline has identified numerous problems in attempting to reconcile field-verified water wells with those listed in the ESRD database. If a property has been sold to a new owner and the wells are not tagged it is often impossible to reconcile the groundwater data being collected with the information provided in the ESRD database. If a well test was commissioned by an oil company, a report will be issued to the landowner and also remains in company files, but it is not accessible for consideration as part of regional groundwater management initiatives such as the present study.

Recommendation:

The purpose of the present study and ESRD's philosophy and mandate is clearly stated in the Water for Life Strategy, Land-Use Framework, and SSRP. It is therefore imperative that any groundwater data collected by private or public companies and individuals be submitted to ESRD for consideration so that it can be used to aid in the protection of groundwater resources belonging to all Albertans. Waterline understands that legal issues surrounding the Privacy Act may come into play when dealing with privately owned water wells. However, the protection of a public resource is at stake and therefore serious consideration needs to be given to requiring that any new test work completed on water wells be submitted to ESRD as part of its mandate to protect groundwater resources in Alberta.

5.5 Capturing Subdivision Approval Well Testing Data

Knowledge/Data Gap:

It was not possible to obtain reports prepared in support of subdivision approvals within the Crowsnest River watershed. The subdivision process is administered by the Oldman River Regional Services Commission (ORRSC).

The Alberta Water Act, Section 23 (3) (a) indicates the following for household diversions:

"If, on or after January 1, 1999, a subdivision of land of a type or class of subdivision specified in the regulations is approved under the Municipal Government Act, a person residing within that subdivision on a parcel of land that adjoins or is above a source of water described in section 21 has the right to commence and continue the diversion of water under section 21 only if (a) a report certified by a professional engineer or professional geoscientist, as defined in the Engineering and Geoscience Professions Act, was submitted to the subdivision authority as part of the application for the subdivision under the Municipal Government Act, and the report states that the diversion of 1250 cubic metres of water per year for household purposes under section 21 for each of the households within the subdivision will not interfere with any household users, licensees, or traditional agriculture users who exist when the subdivision is approved."

Recommendation:

Make groundwater evaluation reports available to the public (on-line). For example, Lacombe County posts subdivision approval support documents on their web site, because it is important that the general public has access to these documents as per the public's right to be consulted, informed, and to raise concerns with respect to any proposed development. For the same reason, the Oldman River Regional Services Commission should make any development approval support documents available for review by the general public, if the approval has gone to public hearing. Ultimately it is the municipal approval process that is public in nature, and includes the release of supporting documents at public hearings.

5.6 Chemical Analysis by Local Health Units

Knowledge/Data Gap:

Another disconnect exists in the database between the well ID and water quality samples collected by landowners or local health units without attempting to reconcile each sample with a water well listed in the ESRD Water Well database. If the well cannot be reconciled to an ESRD Well ID, then another ID is created and the chemistry is logged into the water well database giving the appearance that another well may exist. Since the early 1990's, these data have been collected but not entered into the water well database because of privacy issues.

Recommendation:

Again, if all water wells were tagged and GPS coordinates measured, it should be possible to exactly reconcile the wells listed in the ESRD database with those found in the field.

5.7 Conceptual Model Development and the Need for Groundwater Monitoring

Knowledge/Data Gap:

The development of an accurate conceptual model is contingent on available geological and hydrogeological data. The geology within the Crowsnest River watershed is relatively well understood owing to the considerable amount of historical mapping that has been completed, the presence of numerous wells and boreholes, and a number of energy well logs. However, there is a lack of readily accessible groundwater monitoring data. These include the following:

- Water level monitoring throughout the watershed as indicated above
- No GOWN wells exist within the watershed;
- Transmissivity and storativity/specific yield data are needed to understand groundwater flow in various aquifers across the watershed; and
- Quantitative studies of groundwater/surface-water interaction are needed to better understand the interconnections between the shallow bedrock and the alluvial aquifers.

As stated previously, the actual measure of recharge is made difficult as a result of the variability of physical parameters that affect infiltration of rainwater and snowmelt (vegetation cover, soil cover, bedrock type, slope of the land, precipitation, snow pack, temperature, etc.). Empirical estimates can be made but monitoring of groundwater level fluctuations on a seasonal basis and with many years, is the best method to verify whether our estimates are correct.

Recommendation:

As stated above, there is an opportunity to obtain high quality groundwater monitoring data from existing and new wells being drilled, if ESRD provides a clear directive and guidance to water well drilling contractors, municipal planning departments involved in approving new developments, oil companies involved in conducting tests for oil and gas activities other than CBM, landowners, and groundwater professionals. This alone could capture a significant amount of groundwater data with very little added expense and without the need for drilling and testing new wells by ESRD as part of the GOWN system. Notwithstanding the success of such an initiative, in the short term, expansion of the Alberta Groundwater Observation Well Network is recommended for key areas within the Crowsnest River watershed. Specific well locations are presented in **Section 6.4.3** of this report.

5.8 Impact of Historical Coal Mining

Knowledge Gap:

Very little environmental information is available concerning the 68 historical coal mining locations within the Crowsnest River watershed. The potential impacts from coal mining activities to the environment and groundwater include: groundwater quality, mine-water discharge into rivers, recharge/discharge of surface water into/from mine adits. In addition, subsidence as a result of settlement over adits and tunnels is a potential hazard to land development.

Recommendation:

Waterline recommends that adits, tunnels and other mine workings be mapped and made available to municipalities as an aid to subdivision development. In addition sampling of discharging groundwater from historical mine areas and groundwater flowing through coal waste is critical to determiner the potential effects to surface water as well as groundwater.

5.9 Promoting Groundwater Stewardship

Knowledge Gap:

Based on Waterline's experience in conducting thousands of field verification surveys, interviews with landowners, and testing and sampling of domestic water wells, there is a fundamental misunderstanding about groundwater and its interrelationship with the land. The Alberta Water Act protects water being used for household purposes by providing a statutory right to divert and use up to 1,250 m^3/yr for household purposes (Water Act, Section 21, GOA, 2000), with no monitoring requirements. A "right" to divert and use groundwater can only be realized if the water exists. Therefore, common sense dictates that all water users need to consider practices that help to conserve groundwater resources and promotes sustainable groundwater use. Although licensed users are more likely to cause adverse impact because larger volumes are being pumped, cumulative diversion by smaller unlicensed users can also have a negative impact.

Despite the large volume of literature that is available through the internet or through the various publications issued by special interest groups, municipal, provincial, and federal regulatory agencies, there still remains a fundamental misunderstanding regarding individual responsibilities with respect to the management of groundwater resources in Alberta (Summer, 2010).

Recommendation:

Waterline has observed that community outreach and public education programs are useful to encourage groundwater stewardship and participation in groundwater protection by all groundwater users in the watershed. Waterline has been involved in the development of effective strategies for promoting groundwater stewardship at the landowner level. These programs can be as simple as posting message boards along major highways or in sensitive areas where people can take the opportunity to learn more about their drinking water and the flow of groundwater in aquifers. To this end, ESRD initiated the Working Well program in 2006 to promote stewardship and better understanding of wells and groundwater (refer to: http://environment.alberta.ca/01317.html). Some consideration should be given to implementing such a strategy tailored specifically to the Crowsnest River watershed.

6.0 PROPOSED WATERSHED MANAGEMENT ACTION PLAN

6.1 Geo-database Development

The first task for OWC is to assemble existing surface water and groundwater data into a single, centralized repository for data. The recommended geo-database structure is intended to serve as a data repository for use by the OWC to store and update future water and environmental related information. It is important to have these data available electronically as the OWC moves toward fully integrated watershed planning and management. Waterline has customized our in-house geodatabase to accommodate datasets for completion of the present study. A similar approach is recommended in order to construct such a database for the Crowsnest River watershed.

The idea is to compile environmental data into a consistent format that would allow OWC and water managers to complete water budget assessments on a consistent basis (annually). In this manner, a “state of the watershed” report could be issued on a regular basis so that the public and regulatory officials would remain informed. The intent is also to develop a “living system” whereby the state of knowledge on surface water and groundwater systems within the Crowsnest River watershed could be expanded with every new study that is completed. This could involve the compilation of groundwater, surface water, geotechnical, environmental, fisheries, and any other information that needs to be considered in a fully-integrated watershed management plan.

The database described above could be used to develop a tool that would ultimately be made available to the public through a user friendly interface. Data would be served up as maps and tables where landowners, drillers, and environmental practitioners could access up-to-date information, and would also be required to use this information in any new studies. Water management guidelines could be developed by OWC or regulatory officials to address the unique features and specific needs within the Crowsnest River watershed. New data could be uploaded to the system so it can be considered in any future studies. This ultimately would allow for cumulative effects analysis to be completed and help to elevate the accuracy of water budget estimates. All of this information will be needed by OWC to manage water resources and to make informed land-use decisions into the future.

As a web-interface is developed, it should also be possible for users to upload electronic groundwater and surface water data on-line from various sources through a single portal and then integrate this with other on-line databases (WUR, water wells, approvals, etc.). The data could include monthly/annual water use, water levels, water chemistry, aquifer properties interpreted from pumping test analysis, cross-sections, time-series data, hyperlinks to raw data (ESRD Water Well database, approvals database, WSC time series data, etc.), and a geo-referenced copy of any final reports that are publicly available. Guidelines, policies, and templates for data collection and submission as part of their planning and watershed management initiatives will obviously be required in order to maintain a consistent format.

The database can (and should) be expanded to accommodate other forms of environmental and infrastructure data (e.g. fisheries, geotechnical, air, soil, LIDAR, land-use, etc.). Waterline does not recommend separating the water-related datasets from other datasets. Access to multi-disciplinary data allows scientists and engineers to consider human-environment interactions. It also provides a basis for assessing cause-and-effect response in surface water or groundwater systems.

Waterline's custom geodatabase can also be used to construct two- and three-dimensional hydrological and hydrogeological images so that scientific and non-scientific readers can visualize and understand how surface features and activities relate to subsurface aquifers. The compiled data, in conjunction with water use and demand data can then be used to assess the level of stress on the watershed and aquifer. The models developed could be scaled down to assess subwatershed or local issues as required. Such a database would form the foundation for understanding the present and future availability and demand for fresh water in the watershed. The outcome allows OWC to plan for future development in a way that contributes to protection and management of groundwater and surface water resources not previously available.

6.2 Surface Water Budget Assessment

A monthly water balance model developed by the United States Geological Survey (McCabe and Markstrom, 2007) can be used to assess surface water balance and estimate contributions to groundwater. The model uses physical parameters of the watersheds to calculate runoff for each one square kilometre grid cell. The physical parameters considered in the water balance for each square kilometre include:

1. Average ground elevation (slope to assess runoff characteristics);
2. Surficial soil types (assess infiltration versus runoff);

information, and would also be required to use this information in any new studies. Water and

4. Leaf area index (Parameter based on remote sensing data. If available would allow for an assessment of evapotranspiration and help estimate infiltration and aquifer recharge).

Once calculated at a grid-scale, the surface runoff in the model is then routed to watercourses using a flow accumulation routine to estimate surface water discharges for the entire watershed. The model is then calibrated to actual hydrometric monitoring data. The inputs to the model include gridded average monthly precipitation and temperature data that allow the model to calculate average monthly streamflow at any point in the watershed. The model is relatively simple to run and can be easily adjusted to site conditions.

Through the surface water balance process, the model also estimates groundwater recharge on one-square kilometre grid-cells throughout the region. This parameter is needed to assess groundwater budgets for each aquifer.

6.3 Aquifer Protection and Vulnerability

Protection of the Crowsnest River watershed groundwater supply is critical to maintaining a safe and reliable water supply and the general health of the ecosystem in this region. Aquifer protection strategies need to incorporate a thorough understanding of the interactions of the aquifer with potential sources of contamination at the surface and in the subsurface. Although not part of the present scope of work, an inventory of all potential sources of contamination should be conducted and become part of the Crowsnest River watershed aquifer management plan.

Potential contaminants[9] can originate from a variety of sources including, but not limited to, the following:

- Domestic or industrial use of fertilizers and pesticides;
- Fuel-supply dispensing facilities (underground and above-ground storage tanks);
- Landfill operations;
- Confined feeding operations;
- Runoff from agricultural operations (stables, composting);
- Upstream oil and gas operations;
- Storm-water management;
- Septic fields; and
- Industrial operations.

Government of Alberta (2010b,c) list water quality concerns in the South Saskatchewan River basin as including contamination from agricultural runoff (especially manure) and impacts from oil and gas activity on groundwater quality. Various participants called for action to conserve and provide stewardship in the region's water resources by:

- Developing a consistent definition of headwaters or source waters and their locations;

- Protecting watersheds;
- Conducting an inventory of groundwater supply, quality and demand;
- Transferring information from the mapping of aquifers currently underway into the South Saskatchewan Regional Plan as soon as possible;
- Developing an overall water conservation plan;
- Designating some areas of the region as no-growth zones or delimiting the type of development in order to protect water sources; and
- Determining flood risk and limiting development in flood zones.

In terms of vulnerability, unconfined aquifers occurring near ground surface are much more susceptible to surface sources of contamination than are confined aquifers overlain by low permeability (aquitard) material. However, if the overlying deposits are fractured, then aquifer contamination can result more easily. The slow movement of groundwater means that aquifer contamination often takes many years or even decades to be recognized, and many more years and great expense to remediate once contamination is apparent (Cherry 1987). The prevention of groundwater contamination is therefore crucial to preserve the quality of this valuable finite groundwater resource. The most effective solution to groundwater contamination problems is prevention (Cherry 1987).

Waterline recommends that an aquifer vulnerability assessment be completed where the results of the enclosed study are integrated into the vulnerability assessment.

6.3.1 Assessment of Historical Coal Mining Areas

Water quality concerns with regard to coal mining in the Crowsnest River watershed (**Section 3.9.3.1**) include the potential discharge of impacted groundwater into the Crowsnest River. In addition to groundwater quality issues, Waterline recommends that abandoned mine shafts, adits and workings be mapped (if not already done) as these potentially represent hydrogeological conduits (sources and sinks), geotechnical and hydrogeological hazards.

6.4 Recommended Monitoring Program

6.4.1 Monitoring Objectives

The establishment of a groundwater monitoring network is necessary in order to better understand the interconnections between aquifers and surface water resources and to provide an early warning system in the event of adverse impact. If negative impacts are realized, then mitigation can quickly be implemented and groundwater resources managed in a sustainable manner for future generations.

The objectives of a groundwater monitoring plan/program are to:

- Identify any long-term geochemical trends and potential cumulative effects from current and future development in the Crowsnest River watershed;
- Increase our understanding of background conditions;

- Detect any potential large-scale groundwater quality and quantity effects;
- Provide appropriate baseline coverage (in areas of no anthropogenic effects) in each of the key aquifers for use in future development planning;
- Gain a better understanding of the background variability in the region;
- Gain further understanding of aquifer interactions and how the groundwater system is connected to surface environments;
- Verify and refine the regional conceptual hydrogeologic model;
- Identify high-risk areas that may require additional monitoring;
- Provide information to better understand the natural groundwater discharge and constituent flux to the rivers and local tributaries (i.e., loading to the system);
- Verify and refine local and regional conceptual hydrogeologic models which will serve as input data to numerical groundwater flow and transport models;
- Calibrate/verify predictive surface water and groundwater flow and contaminant transport models; and,
- Refine targets for indicator parameters for key aquifers in the Crowsnest River watershed region through an adaptive management process.

The development of a monitoring plan is driven by pressures on the Crowsnest River watershed in terms of sustainability of water quality and quantity. Population growth and increasing development in the region likely place the greatest pressures on the Crowsnest River watershed.

It is likely that the data resulting from implementing the monitoring plan will be used by all stakeholders identified in **Section 1.3.1**. Monitoring goals must be discussed with ESRD and the OWC and other stakeholders in order to gain agreement that will lead to the development of an appropriate groundwater management plan that will lead in turn to sustainable use of the water resources in the watershed.

The first steps toward a monitoring plan were taken in the preparation of this report.

The recommended groundwater monitoring plan will help to establish present conditions in the watershed in terms of groundwater quantity and quality and serve as a baseline for future work. It should be noted that the monitoring system will undoubtedly answer some questions raised herein but will also likely reveal other questions. The intent is to establish a baseline of groundwater information that is available to future users in the watershed to help guide the use of groundwater (and surface water) resources.

6.4.2 Past and Current Initiatives

Alberta Environment and Sustainable Resources Development established the Groundwater Observation Well Network in 1991. It currently encompasses more than 400 wells of which approximately 250 are actively monitored for quality or water levels (the remainder are inactive). Currently there are no active GOWN wells within the Crowsnest River watershed buffer zone; the nearest are at the Oldman Reservoir (**Figure 47**).

A large portion of the Crowsnest River watershed, west of Highway 22 and north of Highway 3, is largely uninhabited with very few water wells. Alberta Environment and Sustainable Resources Development monitors snow pack thickness at two locations (Allison Pass and South Racehorse Creek) outside the watershed and monitors river stage at several locations along Crowsnest River and this is important for assessing recharge.

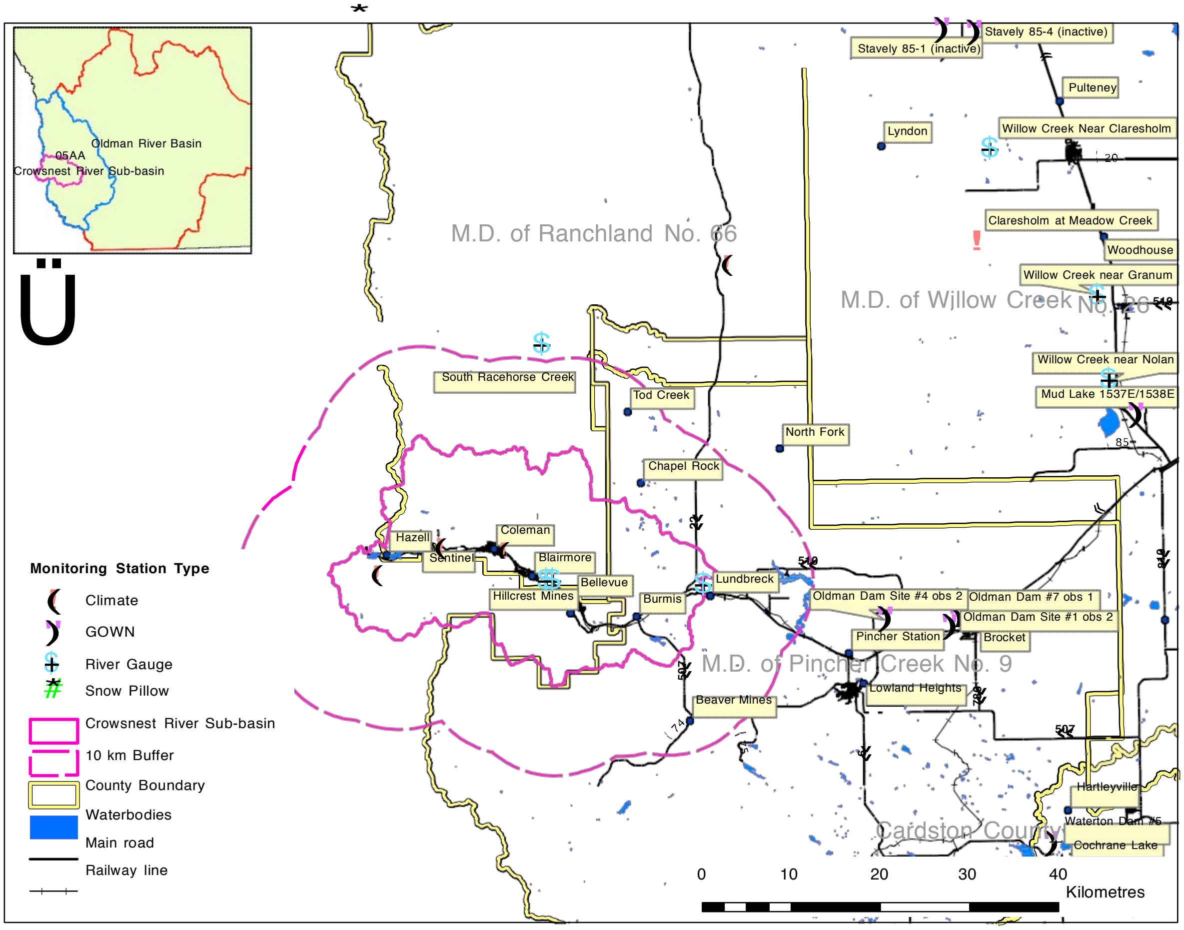


Figure 47 Current ESRD monitoring

6.4.3 Proposed Monitoring Locations

Identification of monitoring well locations should consider the following criteria:

- Identified aquifers within the watershed (e.g., alluvial aquifer, buried valley aquifer, bedrock aquifer(s), etc.);
- Population density and number of existing users (Crownest River valley towns such as Coleman and Blairmore areas);
- Vulnerable areas where the combination of environmental factors and land-use are not quite aligned. Industrial or commercial operations have the potential to impact water quality or perhaps unique aquifer conditions (e.g., unconfined aquifer) increase the

sensitivity or risk to protecting groundwater quantity or quality and therefore consideration should be given to monitoring these existing areas.

- Areas where insufficient data are available to fully characterize the geology or hydrogeology. A good example is in the western part of the watershed where no baseline information exists and recreational and industrial (timber harvesting – this is in part addressed by Silins et al., 2009) use can potentially impact recharge characteristics and groundwater quality/quantity; and
- Areas where future development is being proposed. The OWC will have to work closely with the subdivision authority or perhaps the ERCB and other regulatory authorities in Alberta to understand future plans within the watershed. Collecting baseline data prior to development will help determine whether additional measures are require to protect groundwater resources in advance of approving such developments.

Based on the above criteria, Waterline has selected five locations within the Crowsnest River watershed (**Table 16**).

Table 16 Proposed Monitoring Locations

Location		Status	Reason	Comments
1	Near Crowsnest Spring	No existing well(s)	Water supply to Crowsnest River	Alluvial materials; Banff Formation, Alberta Group; Future recreational use
2	Crowsnest Lake outlet to Crowsnest River	No existing wells; Possible wells at Trout Hatchery	Monitor sub-lacustrine spring discharge	Belly River-St. Mary River Succession and Alberta Group
3	Downstream of Coleman	No existing monitoring well(s)	Monitor quality and quantity alluvial aquifer and bedrock	Alluvial aquifer, bedrock
4	Downstream of Blairmore	No monitoring existing well(s)	Monitor quality and quantity alluvial aquifer and bedrock	Alluvial aquifer, pre-glacial valley aquifer
5	Near Lundbreck	No existing monitoring wells	Monitor quality and quantity near outflow from watershed	Buried pre-glacial valley materials

There is a need to initially focus on key areas of municipal groundwater use that are under pressure of development. It is critical to know whether the municipal groundwater use is impacting the water supply in terms of over use. At present, with no water level monitoring it is not possible to know whether over use is occurring. In addition, monitoring wells in the upper watershed are unlikely to help quantify recharge to the system whereas water levels in areas of groundwater extraction are based on the cumulative recharge and discharge from the system at that location. Thus declines in water levels with time are indicative of discharge exceeding recharge. Proposed monitoring locations are shown on **Figure 48**. The red circles are the locations for the first five proposed monitoring locations. Note that these are locations for monitoring which means that multiple wells could be installed at these locations in order to monitor groundwater at various depths and in various units (e.g., unconsolidated or bedrock aquifers).

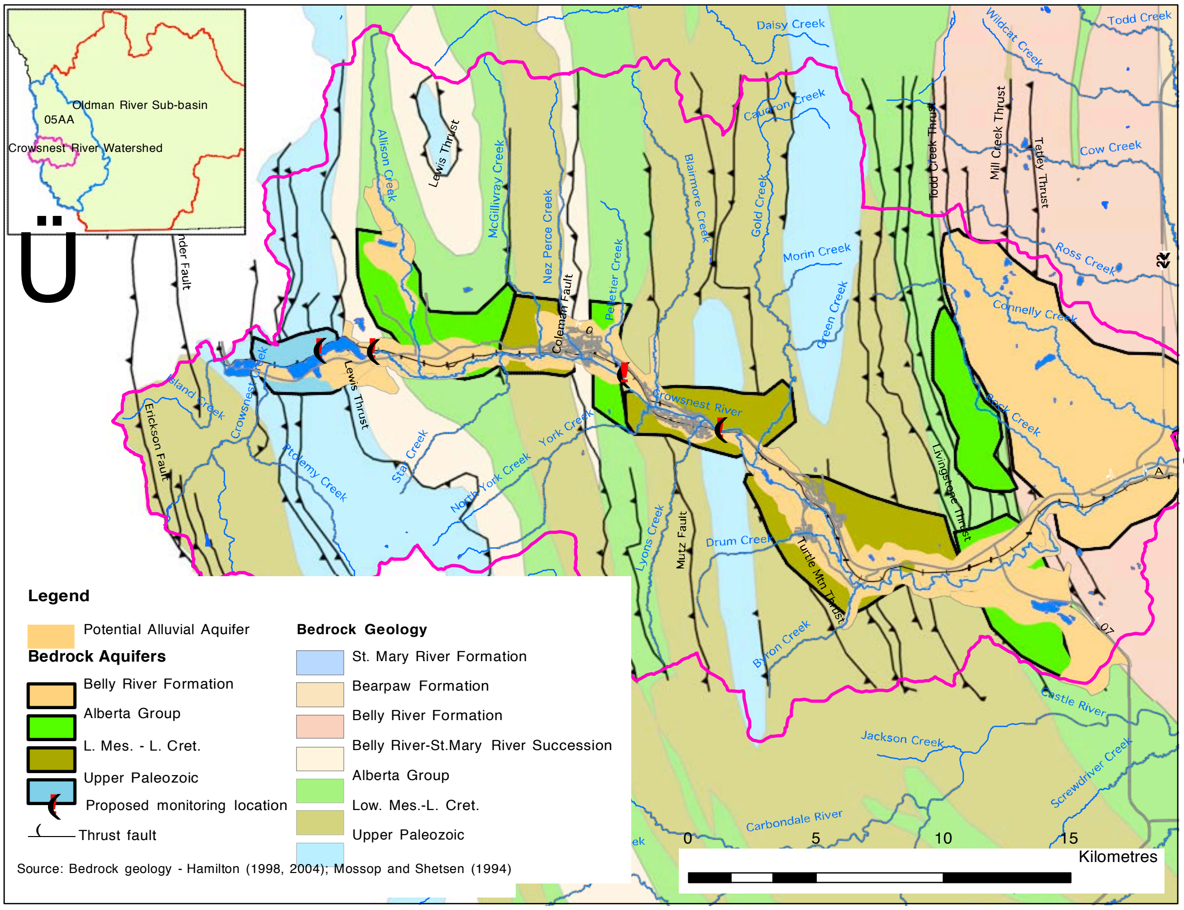


Figure 48 Proposed Monitoring Locations

To reiterate the previous discussion, there is an opportunity to collect significantly more groundwater-related data than is otherwise possible by installing a few observation wells in the watershed. The monitoring wells and locations being recommended in **Table 16** are presented for discussion purposes at this time. A considerable amount of data exist that could not be obtained as part of the present Waterline study because of timing and budgetary constraints. For instance, land-use data should be better integrated into the existing GIS database constructed as part of the present study, as it could assist to refine monitoring well locations based on water quality concerns. Once these data are obtained and integrated into the present study, a final decision on the location of the monitoring well network can be made.

6.4.4 Process for Determining Water Quality Indicator Parameters

Indicator parameters are commonly used to measure the cause and effect relationship between human activities on the landscape and the environmental response to those activities (ESRD, 2008). With respect to groundwater, measurement and tracking of indicator trends helps to ensure that quality and quantity conditions are maintained for human and ecosystem needs into the future. Suitable indicators include those that are:

- commonly present in the environment;
- relatively easy and inexpensive to measure;
- sensitive to environmental change; and
- specific to disturbance impacts.

Indicators can be grouped as “condition” and “development” indicators. Condition indicators relate to the physical, chemical and biological aspects of the ecosystem, while development indicators relate to anthropogenic activities in a certain area. The indicators would be selected based on land-use information.

Primary indicators should ultimately be selected to address development issues as well as other human activities. Secondary indicators are intended to support any follow-up investigation required following the exceedance of an established target or identification of an unacceptable trend. If required, a tertiary level of assessment may be required. As such, the tertiary indicators tend to be more expensive and assess conditions from a very high level of refinement and should only be used if required.

A preliminary list of indicator parameters should enable assessment of whether there are contaminant sources within the Crowsnest River watershed and whether there is deterioration of groundwater quality. These parameters must act as sentinels to assess changes in the water quality on a regional basis. Other parameters may be more useful on a local scale where contamination is suspected.

Possible parameters for providing regional water quality information could include:

- Total dissolved solids;
- Nutrients such as nitrate, nitrite;
- All major anions (e.g., bicarbonate, carbonate, chloride (salt impacts) and sulfate;
- All major cations (e.g., calcium, magnesium, potassium and sodium); and
- Field measurements such as oxidation/reduction potential and pH.

A parameter such as total coliforms would indicate if there was bacteriological activity but this does not necessarily present a health risk. To determine the presence of health risks, a better parameter would be E. Coli or fecal coliforms. It can also be used as guidance to well owners for determining a schedule for shock chlorination and well maintenance.

Parameters to be measured as a follow-up action when a problem is suspected could include

- Mercury;
- Trace metals such Arsenic; and
- Other indicators indicative of anthropological activity such as herbicides/pesticides or pharmaceutical compounds.

6.4.5 Monitoring Frequency

The frequency at which monitoring should be completed is dependent on establishing long-term baseline trends, thus there should be sufficient data for this purpose. Typically, baseline data are collected seasonally (two to four times per year) in order to assess which parameters should be used as indicators. In order to be able to establish a statistical trend, a minimum of eight data points are preferred (Gibbons, 1994). Once a baseline is establish, sampling frequency could be reduced. It should be noted that depending on the trends observed, confirmatory sampling may be needed to verify the results. Land development has occurred within the Crowsnest River watershed for more than one hundred years. As such it may be difficult to assess natural baseline conditions. The purpose of the monitoring is to aid in assessing changes with time in the condition of the groundwater in the watershed. Therefore, groundwater monitoring should be initiated early. This is best assessed through monitoring of water levels in water wells on a regular or continuous basis either by hand measurements or, preferably, through the use of pressure transducers-data loggers.

The monitoring process for each location must also be defined in order to estimate cost and time commitments with regard to:

- Who will do the monitoring (e.g., well owners, government, consulting company);
- What is to be monitored and/or sampled (e.g., water levels, water quality);
- Knowledge of aquifer parameters (e.g., transmissivity);
- How is the monitoring to be done (e.g., data loggers/pressure transducers, hand measurements, types of pumps and sampling equipment required);
- Requested laboratory analytical tests (e.g., major ion chemistry);
- Well development and maintenance (e.g., camera surveys of well casing, cleaning, surface casing repairs, pumping test); and
- Data interpretation and reporting.

6.4.6 Establishing Target Water Quality Values

A brief description of the system components used in groundwater management frameworks in the province of Alberta is provided below.

Target: A target is a numerically-defined desired condition for a given indicator, and a management tool, which is somewhere defined through the integrated process to identify a place between natural conditions (or variability) and an established threshold.

Threshold: Value not to be exceeded, such that groundwater quality may be maintained including resources with which the groundwater interacts (i.e. an exceedance of established or agreed-upon management criterion).

As more data become available for individual monitoring wells, statistical control charting may be used for each selected indicator parameter measured at a regional monitoring well to assess natural variability, and to track quality and quantity (i.e., water levels) conditions at each designated location. This technique is being promoted by ESRD in their draft Groundwater Monitoring Directive (ESRD, 2012b). The control chart technique is used to determine whether or not an observed value is significantly different from historical values (Gibbons 1994). Once a statistically meaningful set of water quality data is available, an upper concentration limit or a lower water level limit is established for each indicator parameter and water level. These limits represent the range of natural variability.

A data point that exceeds the upper concentration limit for a given parameter is an indication that something unusual may be occurring with respect to natural variability in the data. This knowledge should trigger confirmatory sampling followed by mitigative action if the result is verified. Confirmatory sampling is done to ensure that the criteria exceedance is not the result of lab or sampling error. Mitigative actions start with determining the source of contamination or cause of water level decline, and are followed by an assessment of available options.

Analyses of long-term trends in the data may be done using the Mann Kendall[g] test. This is a non-parametric statistical test that assesses the data for an upward or a downward trend. This works well with small data sets containing less than 48 data points that do not show seasonal trends.

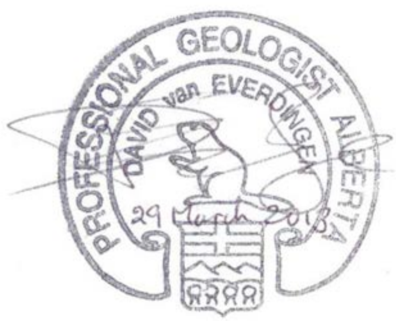
Other statistical methods are available; however, the use of any statistical test must be preceded by an assessment of the method for its application and appropriateness to this context.

7.0 CLOSURE

This report and the information included were compiled exclusively for the Oldman Watershed Council and present results of the groundwater data evaluation and monitoring plan development. This work was carried out in accordance with the scope of work for this project and accepted hydrogeological practices. No other warranty, expressed or implied, is made as to the professional services provided to the client. Any use which a third party makes of this report, or any reliance on or decisions to be made based upon it, are the responsibility of such third parties. Waterline accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

Respectfully submitted,

Waterline Resources Inc.
APEGGA Permit To Practice No. P07329



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8.0 GLOSSARY OF TERMS

Acre-foot	The amount of water that will cover an acre of land one-foot deep. A flow of one cubic meter per second will, in a day, equal seventy acre-feet
Alluvial	Applying to the environments, actions, and products of rivers or streams.
Aquifer	Any water-saturated body of geological material from which enough water can be drawn at a reasonable cost for the purpose required. An aquifer is only a relative term determined largely by economics and is best illustrated by extreme examples. An aquifer in an arid prairie area required to supply water to a single farm may be adequate if it can supply 1 m^3/day. This would not be considered an aquifer by any industry looking for cooling water on the order of 10,000 m^3/day. A common usage of the term aquifer is to indicate the water-bearing material in any area from which water is most easily extracted.
Activity	(working within a water body or work that may affect a water body (e.g. drainage)) by definition;" placing constructing, operating, maintaining, removing or disturbing works, maintaining, removing or disturbing ground, vegetation or other material, carrying out any undertaking, including but not limited to groundwater exploration, in or on any land, water or water body". Any disturbance requires an Authorization for the Activity under the Act. Authorizations for activities may include Approvals, authorization under a Code of Practice and Permits under the predecessor Act (Water Resources Act)
Activity Application	Application received by the department and may still be under process or withdrawn, not required or rejected.
Activity Authorization	Activity has been authorized under the Act and the current status might be Issued, Expired, Cancelled, etc.
Aquifer management unit	A hydraulically-connected groundwater system that is defined to facilitate management of the groundwater resources (quality and quantity) at an appropriate scale.
Aquitard	A water-saturated sediment or rock whose permeability is so low it cannot transmit any useful amount of water. An aquitard allows some measure of leakage between the aquifer intervals it separates.
Baseline concentration	The baseline concentration of a substance in groundwater is the natural concentration of that substance in a particular groundwater

zone in the absence of any input from anthropogenic activities and sources.

Bedrock — The solid rock that underlies unconsolidated surficial sediments.

Block-Faulted — High-angle faulting in which blocks of the crust move vertically up or down relative to each other. Often occurs in areas undergoing horizontal extension.

BSk — One of the Köppen climate classifications; a BSk climate usually features hot and dry (often exceptionally hot) summers, cold winters and major temperature swings between day and night. The mean monthly temperature for the warmest month ranges from 0.1 to 9.9° C. B = dry (arid and semi-arid) climates. The second letter can be either W: desert - dry winter where the driest winter month has at most 1/10 of the precipitation found in the wettest summer month, or S: Steppe - dry summer where the driest summer month has at most 30 mm of rainfall and has at most 1/3 the precipitation of the wettest winter month. The third letter h: low latitude climate with average annual temperature greater than 18 °C or k: middle latitude with average annual temperature less than 18 °C.

Bedrock aquifer — A bedrock unit that has the ability to transmit significant volumes of water to a well completed within it. Typical examples include sandstone and siltstone or significantly fractured intervals.

Buried valley — An eroded depression in the unconsolidated sediment or bedrock within which sediments with significant permeability (e.g. sand) or low permeability (e.g. till, clay) have accumulated.

Channel — An eroded depression in the soil or bedrock surface within which alluvial deposits accumulate (i.e. gravel, sands, silt, clay).

Contaminant — A substance that is present in an environmental medium in excess of natural baseline concentration.

Contemporaneous — Formed or existing at the same time

Cretaceous — A period of the Mesozoic era thought to have covered the span of time between 140 and 65 million years ago; also, the corresponding system of rocks.

Cumulative Effects — The changes to the environment caused by all past, present, and reasonably foreseeable future human activities.

Dfc — One of the Köppen climate classifications; a Dfc climate consists of warm to cool summers, severe winters, and no dry season. The mean monthly temperature drops below -3° C in the coolest month, and exceeds 10° C in the warmest month. D = continental/microthermal climate. The second letter can be either w: a dry winter where the driest winter month has at most 1/10 of the precipitation found in the wettest summer month, or s: a dry summer where the driest summer month has at most 30 mm of rainfall and has at most 1/3 the precipitation of the wettest winter month, or f: Does not meet either of the above specifications. The third letter a: warmest month averages above 22 °C or b: does not meet the requirements for a, but there still are at least four months averaging above 10 °C; c means 3 or fewer months with mean temperatures above 10 °C.

Diversion — By definition;" the impoundment, storage, consumption, taking or removal of water for any purpose, except the taking or removal for the sole purpose of removing an ice jam, drainage, flood control, erosion control or channel realignment". A Diversion requires a Licence. Authorizations for Diversions may include Licences (Water Act Licence, Water Resources Act Licence), Registrations under the Water Act, Interim Licence, Preliminary Certificates (construction phase and may not divert water until a licence issued), Temporary Diversion Licence and Temporary Diversion of Water under a Code of Practice for Hydrostatic Testing. Note those records without a Maximum Annual Quantity of Water Allocated and a Rate of Diversion are considered Approvals and were issued under the predecessor Act.

Diversion Application — Application received by the department and may still be under process or withdrawn, not required or rejected.

Diversion Authorization — Diversion has been authorized under the Act and the current status might be Issued, Expired, Cancelled etc.

Evapotranspiration — The process by which water is discharged to the atmosphere as a result of evaporation from the soil and surface-water bodies and transpiration by plants. Transpiration is the process by which water passes through living organisms, primarily plants, into the atmosphere.

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

Fault — A break in material in which material on one side of the break has moved relative to that on the other side. In the Foothills and Rocky Mountain Front Ranges Thrust faulting is the most common type of fault present. Thrust faults are low angle faults in which older material may be ‘thrust over’ younger material.

Fluvial	Produced by the action of a stream, river or other flowing water
Geometric mean	A geometric mean, unlike an arithmetic mean, tends to dampen the effect of very high or low values, which might bias the mean if a straight average (arithmetic mean) were calculated. This is helpful when analyzing transmissivity estimates, which may vary over 10 orders of magnitude. A geometric mean is a log (base 10) transformation of data to enable meaningful statistical evaluations.
Groundwater	All water beneath the surface of the ground whether in liquid or solid state.
Hydraulic Conductivity	The rate of flow of water through a unit cross-section under a unit hydraulic gradient; units are length/time.
Hydraulic Gradient	In an aquifer, the rate of change of total head per unit distance of flow at a given location and direction. It has both horizontal and vertical components.
Hydrogeology	The science that relates geology, fluid movement (i.e. water) and geochemistry to understand water residing under the earth's surface. Groundwater as used here includes all water in the zone of saturation beneath the earth's surface, except water chemically combined in minerals.
Hyporheic	Region beneath and lateral to a stream bed, where there is mixing of shallow groundwater and surface water.
Imbricated	Overlap in a regular pattern, like scales or roof-tiles
Infiltration	The flow or movement of precipitation or surface water through the ground surface into the subsurface. Infiltration is the main factor in recharge of groundwater reserves.
Instream Flow Needs	The amount of water required in a river to sustain a healthy aquatic ecosystem, and/or meet human needs such as recreation, navigation, waste assimilation or aesthetics.
Karst	Landscape underlain by soluble rocks (e.g., halite, gypsum, anhydrite and limestone) that has been eroded by dissolution, producing ridges, towers, fissures, sinkholes and underground caverns
km	kilometres
Lacustrine	Fine-grained sedimentary deposits associated with a lake environment and not including shore-line deposits

License	Legal document granting permission to divert water and use water.
m	metres
mm	millimetres
m^2/day	metres squared per day
m^3	cubic metres
m^3/day	cubic metres per day
mg/L	milligrams per litre
Mann Kendall test for trend	The Mann-Kendall, non-parametric statistical test is routinely used to assess trends in groundwater concentration data.
Monitoring Well	A constructed controlled point of access to an aquifer which allows groundwater observations. Small diameter observation wells are often called piezometers.
Overburden	Any loose material which overlies bedrock (often used as a synonym for Quaternary sediments and/or surficial deposits) or any barren material, consolidated or loose, that overlies an ore body.
Pacific Decadal Oscillation	Long-lived El Nino-like pattern of Pacific climate variability. It is a measure of the variability of the sea surface temperature
Permeability	A physical property of the porous medium providing an indication of how easily water will flow through the material. Has dimensions Length^2. When measured in cm^2, the value of permeability is very small, therefore more practical units are commonly used - darcy (D) or millidarcy (mD). One darcy is equivalent to 9.86923×10^{-9} cm^2.
pH	The logarithm of the reciprocal of hydrogen-ion concentration in gram atoms per litre; provides a measure on a scale from 0 to 14 of the acidity or alkalinity of a solution (where 7 is neutral and greater than 7 is more basic and less than 7 is more acidic).
Piper tri-linear diagram	A method that permits the major cation and anion compositions of single or multiple samples to be represented on a single graph. This presentation allows groupings or trends in the data to be identified. For a more detailed explanation, please refer to Freeze and Cherry (1979)
Receptor	Components within an ecosystem that react to, or are influenced by, stressors.

Recharge	The infiltration of water into the soil zone, unsaturated zone and ultimately the saturated zone. This term is commonly combined with other terms to indicate some specific mode of recharge such as recharge well, recharge area, or artificial recharge.
Registration	One time opportunity for agricultural water users who used water prior to January 1, 1999, to register their use and receive a priority number dating back to the first time of use. Protects right to divert and use water. Only applicable for the diversion and use of water for animals and/or applying pesticides to crops. Maximum 6,250 cubic metres.
Significant Aquifer	A permeable water-bearing horizon of sufficient thickness and lateral extent that can yield useable quantities of water. An aquifer in excess of 5 m thick, 100 m or more in width and extending a lateral distance of 500 m or more may be considered a significant aquifer.
Stratigraphy	The geological science concerned with the study of sedimentary rocks in terms of time and space.
Stressor	Physical, chemical and biological factors that are either unnatural events or activities, or natural to the system but applied at an excessive or deficient level, which adversely affect the receiving ecosystem. Stressors cause significant changes in the ecological components, patterns and processes in natural systems.
Strike	The strike line of a bed, fault, or other planar feature is a line representing the intersection of that feature with a horizontal plane.
Subcrop	An occurrence of the strata directly beneath an unconformity (e.g., base of unconsolidated materials constituting a weathering surface).
Sublimination	A change directly from the solid to the gaseous state without becoming liquid. For example, snow converted to water vapour by warm Chinook winds
Surficial Deposits	See Overburden.
Sustainable	A characteristic of an ecosystem that allows it to maintain its structure, functions and integrity over time and/or recover from disasters without human intervention.
Target	A management tool, which is somewhere defined through the integrated process to identify a place between natural conditions or variability and a threshold. A target is a numerically defined desired condition for a given indicator.

Thalweg	The line defining the lowest points along the length of a river bed or valley. Also the line defining the central (long) axis of a buried channel or valley.
Threshold	Value not to be exceeded, such that resource health may be maintained including resources with which the resource interacts (i.e. an exceedance of established natural variability at a given location or an agreed-upon published criterion).
Thrust Faulting	A shallow dipping fault in which the hanging wall moves up relative to the footwall. It is caused by horizontal compression. This results in placing older rock over younger rock.
Till	A sediment deposited directly by a glacier that is unsorted and consisting of any grain size ranging from clay to boulders.
Total Dissolved Solids	Concentration of all substances dissolved in water (solids remaining after evaporation of a water sample).
Transmissivity	The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient; a measure of the ease with which groundwater can move through the aquifer. **Apparent Transmissivity**: the value determined from a summary of aquifer test data, usually involving only two water-level readings; **Effective Transmissivity**: the value determined from late pumping and/or late recovery water-level data from an aquifer test; and **Aquifer Transmissivity**: the value determined by multiplying the hydraulic conductivity of an aquifer by the thickness of the aquifer.
Trend	The relationship between a series of data points (e.g. Mann Kendall test for trend).
Water Management Framework	A framework to enable water planning, allocation and management of water resources.
Water Management Plan	A plan that provides guidance for water management and sets out clear and strategic directions for how water should be managed.
Watershed	The geographic area of land that drains water to a shared destination. The boundary is determined topographically by ridges, or high elevation points. Water flows downhill, so mountains and ridge tops define watershed boundaries.
Water Well	A hole in the ground for the purpose of obtaining groundwater; "work type" as defined by AEW includes test hole, chemistry, deepened,

	well inventory, federal well survey, reconditioned, reconstructed, new, old well-test.
Yield	A regional analysis term referring to the rate a properly completed water well could be pumped, if fully penetrating the aquifer: **Apparent Yield**: based mainly on apparent transmissivity, and **Long-Term Yield**: based on effective transmissivity.

Abbreviations

AENV	Alberta Environment (prior to late-2011)
AEW	Alberta Environment and Water (prior to mid-2012)
ESRD	Alberta Environment and Sustainable resources Development
amsl	above mean sea level
BGP	Base of Groundwater Protection
DEM	Digital Elevation Model
GCDWQ	Guidelines for Canadian Drinking Water Quality
NPWL	non-pumping water level also often referred to as static water level
OWC	Oldman Watershed Council
TDS	Total Dissolved Solids

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By the end of 2005, Alberta had allocated more than 9.5 billion m³ of water for various uses throughout the province. The majority (97%) of this was from surface water sources. Although we rely less on groundwater than on surface water, groundwater is typically a much more important source for individual domestic water supplies in rural areas. Many smaller communities may rely on groundwater as well as some industrial and commercial operations where surface water supplies are not sufficient.

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Statistics Canada, 2007, Crowsnest Pass, Alberta (Code4815007) (table). 2006 Community Profiles. 2006 Census. Statistics Canada Catalogue no. 92-591-XWE. Ottawa., Last viewed: 2012-Nov-05, Website: http://www12.statcan.ca/census-recensement/2006/dp-pd/prof/92-591/index.cfm?Lang=E. Released March 13, 2007

Stockmal, G.S., 1998, Geology Langford Creek (East Half), Alberta (preliminary), Geological Survey of Canada, Open File 3568, Scale 1:50,000.

*Stockmal, G.S., 2004, A pop-up structure exposed in the outer foothills Crowsnest Pass area, Alberta, Bulletin of Canadian Petroleum Geology v52, n2, June 2004, p139-155.

Stockmal, G.S. and Lebel, D., 2003, Geology Blairmore (East Half - 82G/9E), Geological Survey of Canada, Map 1653, Scale 1:50,000.

Stockmal, G.S. and Lebel, D., 2003, Blairmore (East Half - 82G/9E), Geological Survey of Canada, Open File 1653, Scale 1:50,000, Website: http://apps1.gdr.nrcan.gc.ca/mirage/full_result_e.php?id=214510.

Located in 082G/09. Regional and structural geology

*Stockmal, G.S., Lebel, D., McMechan, M.E., and MacKay, P.A., 2001, Structural style and evolution of the triangle zone and external Foothills, southwestern Alberta: Implications for thin-skinned thrust-and-fold belt mechanics, Bulletin of Canadian Petroleum Geology, 49, p472-496.

*Strahler, A.H. and Strahler, A.N., 2006, Introducing physical geography, Wiley Interscience, Fourth Edition, 728p.

Discussion of climate classification (Koppen) systems

Strong, W. L., and K. R. Legatt, 1981, Ecoregions of Alberta, Alta. En. Nat. Resour., Resour. Eval. Plan Div., Edmonton as cited in Mitchell, Patricia and Ellie Prepas (eds.). 1990. Atlas of Alberta Lakes. The University of Alberta Press., 12p.

*Summer, R.J., 2010, Alberta Water Well Survey, A report prepared for Alberta Environment. (University of Alberta: Edmonton, Canada), 116p.

A study based on approximately 1000 survey questionnaires suggesting that: Survey respondents demonstrated a low level of participation in well maintenance and stewardship practices; most respondents demonstrated a low level of knowledge with regard to the source of

their well water and the functioning of their well; Most survey respondents have a false sense of security regarding the risks posed by their well and unjustified confidence in their knowledge of their water supplies.

* Theis, C.V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage, Am. Geophys. Union Trans., 16, p519-524.

Thornthwaite, C. W., and J. R. Mather, 1957, Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance, Drexel Institute of Technology. Laboratory of Climatology. Publications in Climatology, v 10 n 3, p181-289.

*Tokarsky, O., 1974, Hydrogeology of the Lethbridge Fernie Area, Alberta Research Counil, Report 74-1, 22p, Website: http://www.ags.gov.ab.ca/publications/abstracts/ESR_1974_01.html.

Clastic rocks, largely non-marine, of Upper Cretaceous age and some of Tertiary age underlie the plains in the Lethbridge-Fernie map area. The regional dip is westward, ranging from 20 to 200 feet per mile. Closely spaced, high-angle thrust faulting has deformed the Upper and Lower Cretaceous clastics of the foothills belt. Mesozoic clastics, Paleozoic carbonates, and Precambrian clastic and carbonate rocks in the mountain areas have been affected by low to moderate angle thrusting. The interpretation of the hydrogeology has certain limitations due to the low reliability of data over large areas, thus yield values are based on a number of assumptions related to geology and topography. The highest expected well yields are to be found in present-day alluvial gravels and in sands and gravels of buried river valleys. Bedrock formations are expected to give generally very low to moderate yields, although there are some major exceptions. Groundwater of over 1 000 ppm in total dissolved solids of either sodium sulfate or mixed cation sulfate-bicarbonate type is common over much of the plains part of the area, while better quality potable water of the calcium-magnesium bicarbonate type predominates in the foothills and mountain areas.

UMA Engineering Ltd., 1985, Crowsnest Pass Municipality Application For License to Extract Water in Blairmore Townsite, UMA Engineering Ltd., Microfiche from ESRD.

Pumping test results for Blairmore townsite well

Underwood McLellan Ltd., 1978, Water Use in the Oldman River Basin, Alberta Environment, Environmental Engineering Support Services, Oldman River Basin Study Management Committee (Alta.), 21p.

This report provides, the water use estimates for the Oldman River Watershed. At that time, the two major water uses indicated in the report are irrigation and flows for river maintenance.

van der Kamp, G. and Maathuis, H., 2011, The Unusual and Large Drawdown Response of Buried-Valley Aquifers to Pumping, Groundwater, doi: 10.1111/j.1745-6584.2011.00833.x, 9p, Website: http://ngwa.org.

The buried-valley aquifers that are common in the glacial deposits of the northern hemisphere are a typical case of the strip aquifers that occur in many parts of the world. Pumping from a narrow strip aquifer leads to much greater drawdown and much more distant drawdown effects then would occur in a sheet aquifer with a similar transmissivity and storage coefficient. Widely used theories for radial flow to wells, such as the Theis equation, are not appropriate for narrow strip aquifers. Previously published theory for flow to wells in semiconfined strip aquifers is reviewed and a practical format of the type curves for pumping-test analysis is described. The drawdown response of strip aquifers to pumping tests is distinctive, especially for observation wells near the pumped well. A case study is presented, based on extensive pumping test experience for the Estevan Valley Aquifer in southern Saskatchewan, Canada. Evaluation of groundwater resources in such buried-valley aquifers needs to take into account the unusually large drawdowns in response to pumping.

*van Everdingen, R.O., 1972, Thermal and Mineral Springs in the Southern Canadian Rocky Mountains of Canada, Environment Canada, EN36-415/1972, 151p (p132-136).

*van Everdingen, D.A., 2006, Potential Effects Of Climate Change On Groundwater Systems, Climate Change and Water Management, Edmonton,Alberta, 24 slides, April 2-4 2006.

General discussion on the effects of climate change on groundwater with some specific examples in the prairies and the City of Calgary

*van Everdingen, D.A., Bergeron, L.E. and Mellor, A., 2009, Alluvial Aquifers of the Bow And Elbow Rivers, Alberta, Alberta Research Council for City of Calgary, 99p.

*van Everdingen, R.O., 1963, Groundwater flow-diagrams in sections with exaggerated vertical scale, Geological Survey of Canada, Paper 63-27, 22p.

Provides methods for the determination of the distorted angle of bedding and flow directions in a cross-section with a vertical exaggeration

*Veilleux, B., 1993, Structural geology of the triangle zone at Langford Creek, S.W. Alberta, Unpublished M.Sc. Thesis, University of Alberta, 85p.

9 large fold-out enclosures. H.A.K. Charlesworth, supervisor

WA Environmental Services Ltd., 2008, Phase II Environmantal Sitre Assessment River Run Development, Blairmore Alberta, Bridgecreek Development Corporation, WA-07-09-506, 172p, February 25, 2008.

Contains monitoring well borehole logs and some water level data for the site

*Water Survey of Canada, 2013, Hydrometric Data, Environment Canada, last viewed February, 2013, Website: http://www.wsc.ec.gc.ca/applications/H2)/index-en.cfm.

Archived hydrometric data

Winter, T.C., Harvey, J.W., Franke, O.L. and Alley, W.M., 1998, Ground Water and Surface Water A Single Resource, U.S. Geological Survey, Circular 1139, 87p.

General information about the interaction of groundwater and surface water resources

*Worthington, S.R.H., 1991, Karst Hydrogeology of the Canadian Rocky Mountains Unpublished Ph.D. thesis McMaster University, Unpublished Ph.D. thesis McMaster University, 406p.

Excellent overview of karst based springs in the Crowsnest River watershed

Zhang, C and Wijesekara, N., 2010, Land Use maps 1985 to 2010 Elbow River Watershed, University of Calgary, Dept of Geomatics Engineering.

These maps were created using a cellular automata model run on Landsat Thematic Mapper (TM) data. The analysis was done for the years 1985, 1991, 1996, 2001, 2006 and 2010 resulting in 6 spatial datasets (grids).

APPENDIX A

BACKGROUND INFORMATION

Methodology

Waterline Resources Inc.

METHODOLOGY

This section of the report provides details on the methodology used in preparation of the various datasets used in this report:

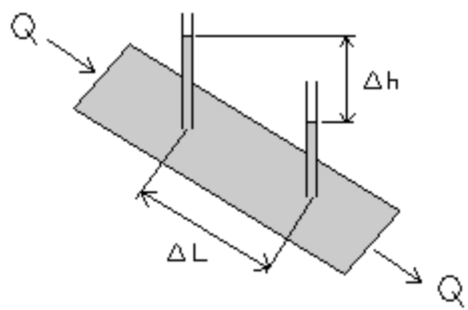
1. Introduction to basic groundwater theory
2. Classification of water-well records by lithology at completion interval
3. Determination of apparent transmissivity from pumping test data in the Alberta Water Well Information Database
4. Construction of cross-sections
5. Vertical exaggeration in cross-sections
6. Recognition of alluvial aquifers
7. Determination of hydraulic gradient based on data in the Alberta Water Well Information Database
8. Field Work Methodology

GENERAL THEORY OF GROUNDWATER MOVEMENT

Groundwater is water that has entered (recharged) the ground after falling as precipitation on the ground. Groundwater flows through pore spaces and fractures in unconsolidated and consolidated materials. This flow is driven by physical gradients, such as pressure, gravity, density and temperature. The rate of flow is dependent on the material properties (e.g., permeability) through which the fluid flows.

1.1. Darcy's Law

Darcy's law is an empirical law based on experimental observation of flow through a porous medium (i.e., sand). This law relates the rate of flow through a unit cross-sectional area under a unit gradient multiplied by a constant of proportionality (hydraulic conductivity).



The fluid in the figure above flows from the upper left to the lower right driven by gravity as a result of the difference in elevation between the ends of the sand filled tube. The flow rate is denoted by Q and has units of L^3/T. The magnitude of the potential gradient, i, is the difference in head, h, between the two manometers divided by the distance, L between the two manometers.

$$i = \frac{dh}{dL}$$

The specific discharge, $\upsilon = \frac{Q}{A}$ (where, Q is the flow rate and A is the cross-sectional area through which the fluid flows) is directly proportional to the negative of the change in head, Δh and inversely proportional to the distance between monitoring points, ΔL (refer to the figure above).

Based on the above relationships, the French engineer, Darcy, came up with the following empirical formula,

$$Q = -KiA\,,$$

where K, the constant of proportionality, referred to as the hydraulic conductivity, is related to both the material properties and the fluid properties.

1.2. Hydraulic Conductivity

Hydraulic conductivity, K, provides a measure of the relative ease with which a fluid passes through a material. It incorporates the properties of the fluid and those of the porous medium through which the fluid passes,

$$K = \frac{k\rho \vec{g}}{\mu},$$

where g is acceleration due to gravity, k is the intrinsic permeability, a property of the medium through which the fluid passes and based on the square of the particle diameter and the grain size distribution for porous media. In fractured media the permeability is proportional to the square of the fracture aperture (it has units of length squared).

The fluid properties that are part of the constant, K, include the fluid viscosity, μ, and the fluid density, ρ.

The hydraulic conductivity of an aquifer may be different in different directions – it is expressed mathematically as a three dimensional tensor. It depends on the variation of the material properties throughout the porous medium.

Table 1 Ranges of Hydraulic Conductivity Values for Various Materials (from Freeze and Cherry, 1979)

Material	Type	K (m^2/s)
Gravel	Unconsolidated	10^{-3} to 1
Sand	Unconsolidated	10^{-5} to 10^{-2}
Silt	Unconsolidated	10^{-9} to 10^{-5}
Clay (glacial till)	Unconsolidated	10^{-12} to 10^{-6}
Sandstone	Consolidated	10^{-10} to 10^{-6}
Shale	Consolidated	10^{-13} to 10^{-7}
Limestone	Consolidated	10^{-9} to 10^{-6}

The hydraulic conductivity is generally estimated in monitoring wells through a slug test. The slug test involves the instantaneous addition or removal of a slug. The slug may be the removal of a volume of water (not the addition of water since that brings up potential external contamination issues) or the removal/addition of a metal or other material bar of known volume.

The test duration is typically of the order of seconds to minutes, although it can last hours in materials with very low hydraulic conductivity. Because the volume of water displaced in the well is quite small (a few litres or so), the radius of influence of the test is also small.

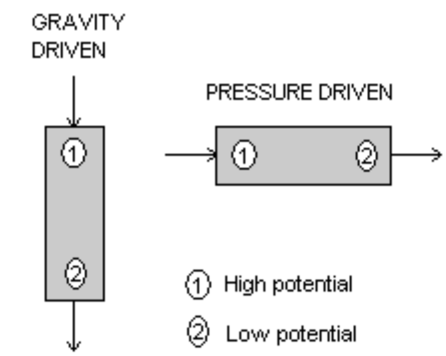
To get an idea of the conductivity of materials over a larger area or volume of formation, a pumping test would be more appropriate. The results of the pumping test are then evaluated to determine the transmissivity, T of the aquifer in which the well is screened. The transmissivity is related to the hydraulic conductivity through the following equation,

$$T = K\,b,$$

where b is the thickness of the aquifer. Thus, a thick aquifer with a low hydraulic conductivity can have the same transmissivity as a thin aquifer with a high hydraulic conductivity.

1.3. Fluid Potential

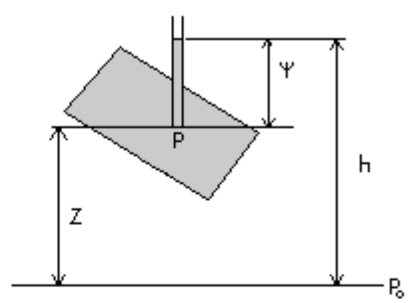
Groundwater flows from areas of high potential to areas of low potential. The potential consists of, elevation and fluid pressure. Refer to the figure below – flow is in the direction of the arrows.



The level to which fluid will rise in a manometer or piezometer is a measure of the total head at the open end, point P (refer to figure below) of the manometer or piezometer. At this point P, the fluid pressure is defined as,

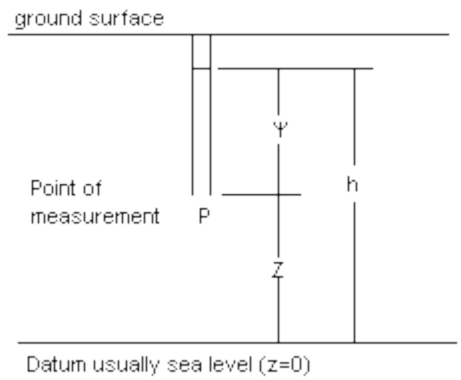
$$p = \rho g(h - Z) + P_0$$

where P_0 is the pressure at the datum point (reference elevation, e.g. mean sea level).



The total potential, h or head, at the measurement point, P, which is the open end of the piezometer or the screened interval of the well, consists of Ψ, the pressure head plus Z, the elevation head,

$$h = z + \psi$$

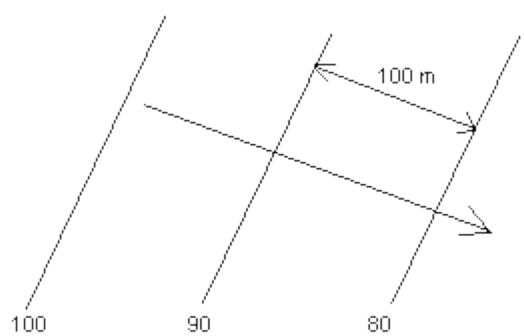


It should be noted that the point to which these data apply is the mid-point of the screen – thus if the well has a long screen the data are an integration over the length of the screen. Thus longer screens give less specific hydraulic information than shorter screens.

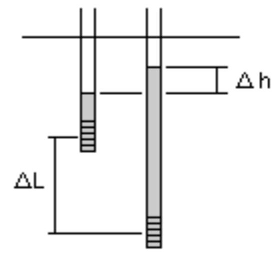
1.4. Hydraulic Gradients

Flow direction in porous media is determined by the hydraulic gradient. There is a tendency for environmental investigations to focus only on the horizontal component of flow. In fact, the hydraulic gradient consists of both horizontal and vertical components.

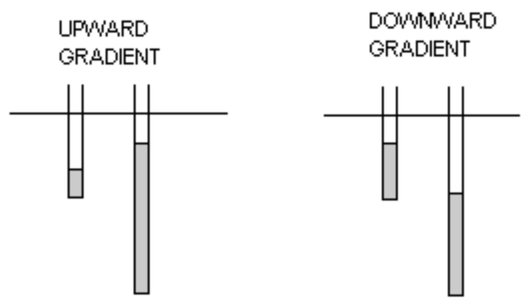
The hydraulic gradient is given by the ratio of the change in head over the distance between two points. The horizontal component of the gradient is usually determined in a direction perpendicular to the equi-potential lines drawn on a map. The map below contains three equi-potential or piezometric contour lines (labeled from left to right 100, 90, 80). These values are the heads along the contour lines. The flow direction is perpendicular to those equi-potential lines and is to the southeast. To determine the horizontal hydraulic gradient take the difference in equi-potential between two of the lines (90-80) and divide that by the distance between those lines (100 metres) to give a horizontal gradient of 0.1.



The vertical gradient is calculated the same way, only now it is the head difference between the centre points of two well screens (∆h) situated as close as possible to each other (horizontally) – such as in a well nest. This is divided by the distance between the centre points of the well screens (∆L - refer to figure below).



The direction of the vertical gradient (up or down) indicates whether there are local discharge or recharge conditions. The figure below (on the left) shows a water level in the deeper well that is higher than that in the shallow well, indicating an upward gradient exists, this suggests that discharge conditions could exist locally.

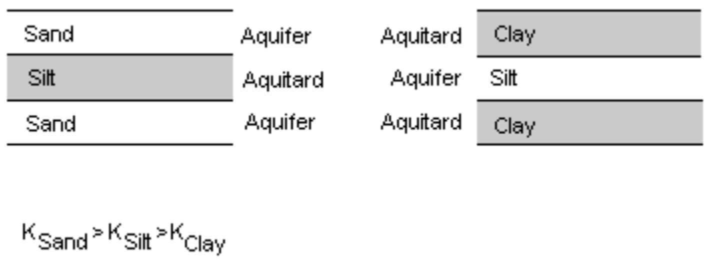


An upward gradient would be expected in areas such as valley floors, at the base of hills or near bodies of water. Downward gradients (the level in the deeper well is deeper than that in the shallow well) are indicative of recharge conditions. These conditions generally exist on topographically high areas.

1.5. Aquifer versus Aquitard

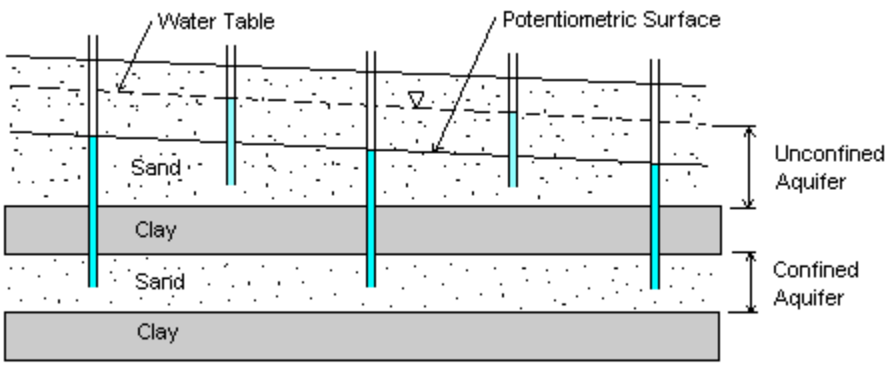
There are numerous definitions of an aquifer. In general, though aquifers are defined as materials that yield economic quantities of water; aquitards on the other hand do not. Alberta Environment and Sustainable Resource Development in their Standards For Landfills states that an "exceptional underlying aquifer" means a hydrostratigraphic unit with a transmissivity of greater than 2.5×10^{-3} m^2/s yielding water with a total dissolved solids (TDS) concentration not exceeding 4,000 mg/L. They also use the concept of Domestic Use Aquifer that is defined as a water-bearing unit capable of a sustained yield of 0.76 L/min and currently used for domestic purposes and/or a total dissolved solids concentration of 4,000 mg/L or less. It can also be defined as an aquifer that is determined by ESRD to be capable of domestic use. From a contamination viewpoint an investigation should look for the presence of an aquitard capable of protecting the groundwater beneath a contaminated aquifer.

A material does not define an aquifer; it is the contrast between different adjacent materials that determines which will be the aquifer and which the aquitard, as demonstrated in the following figure.



1.6. Confined versus Unconfined Aquifers

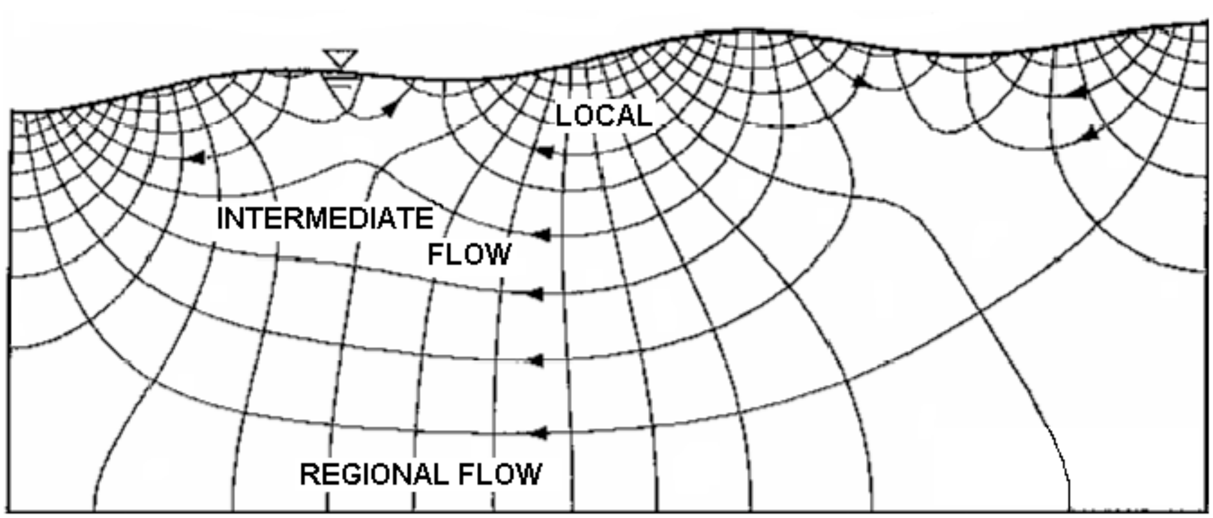
A confined aquifer is one that underlies materials of lower permeability. Generally speaking, in the previous figure on the right-hand side the silt unit would be classed as a confined aquifer because it is confined by the overlying clay layer. An unconfined aquifer lies near the ground surface and generally contains an unsaturated zone near the top.



The water table is a potentiometric surface with zero pressure head; the total head consists of elevation head. To be sure that you are monitoring the water table level – the fluid level in the well must be in the screened interval. For a confined aquifer the head may lie within the aquifer or above it – this is not the same as the water table.

1.7. Regional and Local Flow

Groundwater flow occurs wherever that there are hydraulic gradients. The flow is controlled in the near surface by the local topography. Deeper groundwater flow is controlled by more regional topographic changes. For example, local depressions on a hill slope may act as local discharge (springs or seepage) areas, whereas local topographically higher points act as recharge areas. Regional flow is driven by regional topography - in Alberta this flow is driven by the higher mountains to the west and the lower Plains to the east. The figure below demonstrates these relationships.



1.8. Porous Media versus Fractured Media

Consolidated and unconsolidated materials contain porosity. This porosity is termed either primary or secondary porosity. The primary porosity is the porosity preserved from deposition through lithification and consists of the original pore spaces.

This type of material can typically be treated as a porous medium implying homogeneous distribution of hydraulic conductivity. From a hydrogeological perspective a porous medium is simpler to deal with.

Secondary porosity is the porosity created through alteration of rock, commonly by processes such as dolomitization, dissolution and fracturing.

Fracture porosity is a type of secondary porosity produced by the tectonic deformation of rock. Fractures themselves typically do not have much volume, but by joining preexisting pores, they enhance permeability significantly. This material is termed a fractured medium.

Fluids will preferentially flow along fractures rather than flowing through the matrix pore spaces. Both consolidated and unconsolidated materials can contain fractures. Fracture development is quite common in the glacial tills in Alberta. The fluid flow is still driven by hydraulic head gradients but the direction of flow is controlled to a greater degree by the orientation, continuity and connectivity of the fractures.

CLASSIFICATION OF WATER WELL RECORDS BY LITHOLOGY AT COMPLETION INTERVAL

In order to objectively evaluate the aquifer properties in the surficial deposits and consolidated bedrock aquifers, it is first necessary to select the water well records that have data indicating they were completed in the overburden or in the bedrock. This information is not directly stored in the ESRD water-well-record database. These water well records were assigned to unconsolidated or bedrock aquifers by assessing where the completion interval is situated with respect to the lithology as follows:

- Water well records with information of completion interval above the bedrock or total depth less than that of the bedrock were classified as completed in the unconsolidated deposits, whereas those with completion intervals below the top of bedrock were designated as bedrock wells.
- Water well records that had a completion interval extending from above the top of bedrock and into the bedrock were classified as completed in unconsolidated/bedrock.
- Water well records without either lithology information or completion interval were marked as indeterminate since no determination could be made.

DETERMINATION OF APPARENT TRANSMISSIVITY FROM PUMPING TEST-DATA IN THE ALBERTA ENVIRONMENT WATER WELL INFORMATION DATABASE

Transmissivity is generally defined as the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It is a measure of the ease with which groundwater can move through the aquifer. The following are further definitions:

- Apparent transmissivity is determined from a summary of aquifer test data using only two water-level readings;
- Effective transmissivity is determined from late pumping and/or late recovery water-level data from an aquifer test; and
- Aquifer transmissivity is determined by multiplying the hydraulic conductivity of an aquifer by the thickness of the aquifer.

Note that hydraulic conductivity of a material is the volume of water that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

The Alberta Environment Groundwater Information Centre Water Well Database contains records sent in by drillers at the time of the well installation. Some of the records contain pumping test data. These data can be used to estimate apparent transmissivity value (e.g., Farvolden, 1959 and Ozoray, 1970). The apparent transmissivity can be calculated assuming the assumptions of the Theis (1935) pumping test analysis are valid and values for the following parameters: discharge rate, discharge time, casing diameter and drawdown at the end of the discharge interval. The apparent transmissivity can be determined through iterative solution of the following equations:

For short-term pumping tests (typically tests of 2-hour duration), and with information available for the pumping rate, length of test, drawdown at end of test and radius of well casing, the following approach is used in calculating the apparent transmissivity, T.

To calculate the apparent transmissivity, a value is required for discharge rate, discharge time, casing diameter and drawdown at the end of the discharge interval. The equations used in the solution are (Hydrogeological Consultants Inc., 1998):

$$u = \frac{r^2 S}{4tT}$$

$$T = \frac{Q\left(-0.5772 - \ln u + u - \frac{u^2}{4} + \frac{u^3}{18}\right)}{4\pi \Delta h}$$

where,

u - well function
r - radius of casing (m)
S – Storativity (taken as 0.0001)
T – Apparent transmissivity (m^2/day)
Q - pumping rate (m^3/day)
Δh - drawdown per log cycle (m)
t - time (min)

The apparent transmissivity is calculated by the iterative solution of two equations, since T occurs in both equations.

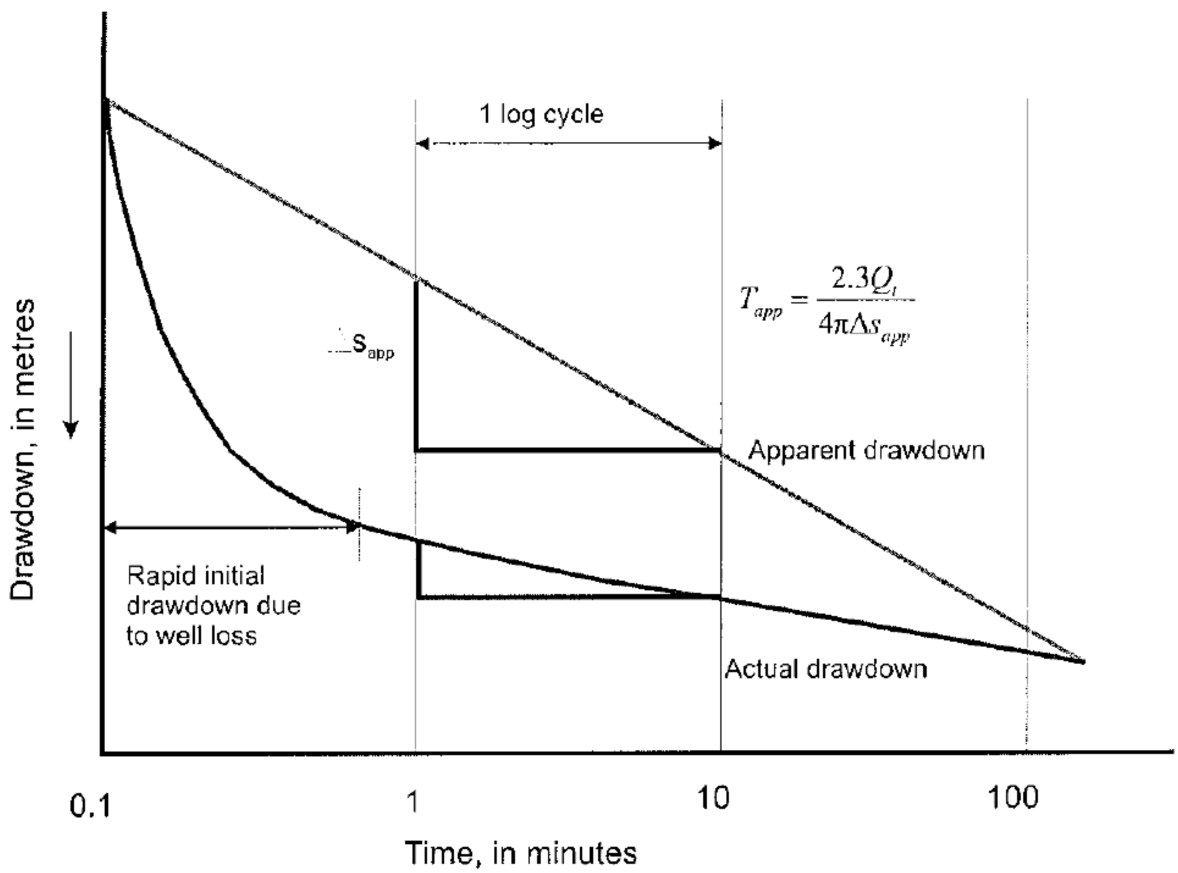


Illustration of Farvolden's apparent transmissivity concept (source: Figure 6 in Maathuis and van der Kamp, 2006).

It should be noted that the pumping tests from which these data come are rarely of more than 2 hours duration which means that the volume of the aquifer that the pumping test influences is quite small, especially in highly permeable materials. Thus these data provide apparent transmissivity estimates that are likely higher than the true transmissivity of the aquifer. Comparison with pumping test analyses for which there is more than just the start and end point data available shows that the apparent transmissivity can over- or underestimate the transmissivity by an order of 3 times. They do however provide a first estimate of the transmissivity for the area. These estimates should not be relied upon for specific sites. In such cases, it is always preferable to conduct a long-term pumping test (e.g., 24 to 48 hours duration) in order to obtain data that give an estimated transmissivity that is more representative of the aquifer.

CONSTRUCTION OF CROSS-SECTIONS

The cross-sections prepared for this study (**Figure 38**, **Figure 40** and **Figure 42**) were constructed as follows:

1. Using ESRI's ArcMap, select the water well records within the Crowsnest River watershed buffer zone (10km beyond the edge of the watershed boundary). Save the selected water well records to a shapefile.
2. Using the BH_Log borehole data management program and the shapefile produced in the first step, extract the associated borehole data from the ESRD water-well-record database (this includes the lithology, well location production intervals, etc).
3. Using IHS Accumap and their database to select oil and gas well records within the 10 km buffer zone. These data are generally exported to an MS Excel file.
4. Import the oil and gas well data into the BH_Log program database.
5. Using the BH_Log program, select those wells with lithology data present and prepare cross-sections. These sections display the lithology at the wells. Note, however that these wells were drilled and logged by different people and thus the descriptions are comparable only with difficulty. For these reason the lithologic descriptions were standardized using a common terminology so that boreholes and their lithology could be more easily compared.
6. Using Adobe Illustrator connect the lithologies in the various wells to provide an interpretation of the subsurface lithology/formations. Other information used in the construction of the cross-sections included the Alberta Geological Survey geology maps (Hamilton et al., 2004), University of Calgary structural geology theses (e.g., Hiebert, 1992) and Geological Survey of Canada reports (e.g., Stockmal et al., 2001).

VERTICAL EXAGGERATION IN CROSS-SECTIONS

It is important to note that cross-sections in this report exhibit a large degree of vertical exaggeration. This is a distortion applied to the cross-section in order to view long sections (covering long stretches of land) while still being able to view the changes in lithology with depth. In a cross section with no vertical exaggeration a unit distance horizontally is the same as a unit distance vertically. In a cross-section with vertical exaggeration of 10 to one (noted as 10:1) a unit distance vertically translates into 10 units horizontally. So, on paper, for a cross section with a 10:1 vertical exaggeration, one cm in the vertical direction may equate to one m whereas in the horizontal direction that one cm would equate to 10 m.

It is important to note that in cross-sections with vertical exaggeration angles are not preserved. This means that if a lithologic unit or a fault dips at 10 degrees in the ground, on the section, depending on the amount of vertical exaggeration that dip will be much steeper, following this equation:

$$\text{Tan(angle on section)} = \text{Tan(angle in ground)} * \text{(vertical exaggeration)}$$

So for our 10:1 example above, the fault dipping at 10 degrees in the ground would dip at 60 degrees on the cross section. The same applies to lithologic boundaries and groundwater flow directions. Keep this in mind when viewing cross-sections with vertical exaggeration. A more complete treatment of the subject can be found in van Everdingen (1963).

RECOGNITION OF ALLUVIAL AQUIFERS

(taken from van Everdingen et al. 2009)

Rivers and their alluvial aquifer systems are dynamic and constantly changing. The alluvial aquifer systems provide a valuable source of groundwater to surrounding communities, while the surface alluvial features provide excellent soils for agricultural purposes.

Alluvial aquifers are those that were deposited by a stream or other body of running water in a streambed, on a flood plain, on a delta, or at the base of a mountain. They are usually located under and on at least one side of the river and can be highly permeable.

An aquifer is an underground unit or layer that yields water. By this definition the unsaturated portion of the layer above the water table is not part of the aquifer. Alluvial materials were deposited by a river at some time in the past; since that time the river channel may have moved or may have cut down further into the alluvial materials. Thus there may (will) be portions of the alluvial material that are not saturated and thus are not part of the alluvial aquifer. The distinction can only be determined through invasive investigations, such as through drilling boreholes and installing monitoring wells.

This distinction can not generally be made on the basis of remotely sensed data (aerial photographs or satellite imagery). If one makes the assumption that (from a vulnerability viewpoint) contaminants dumped onto the alluvial materials will eventually make their way into the river, even if dumped on unsaturated portion of the alluvium, then a definition of an alluvial aquifer could encompass all those alluvial materials of high permeability that are adjacent to or beneath a body of running water (i.e., including the unsaturated portions). This includes materials both in the flood plain and the older terraces.

Alluvial aquifers are also recognized by topographic breaks (i.e., alluvial materials fill a river valley and are bounded by outcroppings of material that existed prior to the river (e.g., bedrock).

FIELD WORK METHODOLOGY

This field program was conducted from September 17 to 21, 2012 by Waterline Resources Inc. (Waterline), with the assistance of volunteer(s) and involved conducting a field verified survey of water supplies and springs in the Crowsnest River watershed.

Primary objectives of the field verified survey of water supplies included establishing the location, elevation, groundwater elevation, and water quality of these water supply systems. Water supply systems were field verified along three north-south transects that were considered representative of the watershed. The location and approximate elevations of water supplies were measured with a handheld GPS and all vertical and horizontal location measurements were accurate to ±10 m.

If permission was given by the landowner and the well was easily accessible, a water level was measured with a water level tape or acoustic sounder. If an acoustic sounder was used, three reading were collected and averaged. Downhole equipment, such as a water level tape, was cleaned with bleach between each well. If a water level was collected, landowners were asked about their recent water usage to establish whether water levels were representative of non-pumping conditions.

Field readings were measured with a multi-parameter field meter for pH, specific conductivity, and temperature at water supplies. If permission was given by landowners, water samples were collected in lab-supplied bottles, suited to the required analyses. Water supply samples were submitted for analysis of general chemistry parameters to the Alberta Centre for Toxicology under standard Chain-of-Custody procedures.

An Alberta Health Services representative provided landowners with water quality results data and, if applicable, a letter informing landowners about parameters that exceeded the Guidelines for Canadian Drinking Water Quality (Health Canada, 2010).

Landowners were also asked to qualitatively describe water quantity and/or quality of their water supplies and provide information, such as the driller's name, total depth, date drilled, etc., to potentially allow Waterline to match their wells to publically available water well records from Alberta Environment and Sustainable Resources Development (ESRD). An example of the form used to collect the data is provided at the end of this section of the Appendix A. If a water supply was a spring, a rough estimate of a discharge rate was measured, if possible.

Springs that were considered to be significant groundwater sources to the watershed, including Turtle Mountain, Crowsnest, and Ptolemy springs, were field verified to determine their discharge volumes, locations, and water quality on September 18 to 19, 2012.

A discharge measurement was not collected at Turtle Mountain spring, because the spring outlet bubbled directly into a pond. Discharge rate measurements were collected at Crowsnest Spring at the culvert under the railway tracks and approximately 30 m and approximately one km downstream of the Ptolemy Spring outlet.

Discharge rates were measured with a Global Water FP-111 flow meter. Average velocity measurements were collected every 0.1 or 0.2 m perpendicular to flow; depending on the width of the spring outflow. The average velocity was measured for more than 40 seconds at 0.6 of the total depth of the stream at each measurement point. The total depth at each measurement point was also collected. Using the cross-sectional area and the average velocity, discharge rates were calculated.

Flow was laminar at Crowsnest spring and the downstream measurement location at Ptolemy spring. However, there was minor turbulence at the upstream measurement point at Ptolemy spring.

Water samples from Turtle Mountain, Crowsnest, and Ptolemy springs were collected at the spring outlets and field parameters were measured using a multi-parameter field meter for pH, specific conductivity and temperature. Water samples were collected into lab-supplied bottles, suited to the required analyses. Samples were placed in ice-packed coolers to maintain cool but not freezing temperatures for the storage and shipment to AGAT Laboratories of Calgary, Alberta. Locations and elevations of spring outlets and discharge measurement locations were measured with a handheld GPS.

APPENDIX B

FIELD DATA

Field Verified Survey
Spring Photos

OLDMAN WATERSHED COUNCIL FIELD VERIFIED SURVEY FOR CROWSNEST RIVER WATERSHED GROUNDWATER STUDY

A field verified water well survey is being undertaken as part a groundwater assessment of the Crowsnest River Watershed for the Oldman Watershed Council.

Survey Period: Sept 15-30, 2012

In the case the surveyor did not find the owner at home, please provide any information listed below which may be available for your well(s) or other groundwater sources, and mail or fax the information to the address listed above. If you should have any questions, please contact the undersigned at your convenience.

Current Owner:

Original Owner:

LSD or 1/4:
Section:
Township:
Range:
Meridian:

Plot approx. location on section block below

NW	NE
SW	SE

1 mile

Latitude:
Longitude:
GPS Easting:
GPS Northing:
Grid zone:
Ground Elevation:

Gov't Well ID:
Well use:
Well depth:

Construction date:
Depth to aquifer top:

Drilling Contractor:
Estimated yield (pumping rate):
Estimated daily use:

Well completion details:

Non pumping water level (Original/Current):

Pumping water level:

Type/Status of water source:

Water Quality (owners' general assessment):

Water Quantity (history of water shortages, well drying up in summer, etc.):

General Knowledge (local groundwater conditions such as location of springs, artesian wells, etc.):

Other Comments:

Thank you for your cooperation.

Brent Lennox, M.Sc., P.Geol.
Intermediate Hydrogeologist

Email: blennox@waterlineresources.com
Phone: (403) 880-8543
Fax: (403)-243-5613

Waterline Resources Inc.

OLDMAN WATERSHED COUNCIL
watershed management – watershed health

Appendix B - Well and Spring Survey

Transect	Central	Central	Central	Central	Central
Location Identification	FVS1	FVS2	FVS3	FVS4	FVS5
Legal Land Description	SE-06-08-03 W5M	NW-31-07-03 W5M	NW-31-07-03 W5M	SE-06-08-03 W5M	SE-06-08-03 W5M
Current Owner's Name	Karen and Dale Paton	Richard and Kathy Koentges	Lindon Appleby	Bulloch	Kari Lehr and Dave Rothlin
Original Owner's Name	Eric Scott	Kotas	Lindon Appleby	None	Kari Lehr and Dave Rothlin
Easting	688725	687635	687760	688288	688497
Northing	5499317	5497989	5498539	5499452	5498784
Surface Elevation (m)	1426	-	1384	1448	1393
Date Field Verified	17-Sep-12	17-Sep-12	17-Sep-12	17-Sep-12	17-Sep-12
Water Source (e.g., well, creek, dugout, spring, etc.)	Well	Dug well	Well in pit	Drilled well	Drilled well
Description of Location (e.g., 25 m NE of house)	10 m W and 10 m S of house	50 m N and 40 m W of house	15 m S and 10 m E of SE corner of house	10 m east of NE corner of house	-
Date Constructed/Created	-	1962/1964	2008	2003	Spring 2004
Drilling Company	Camfield Drilling Services	Unknown	Camfield Drilling Services	Camfield Drilling Services	Camfield Drilling Services
Well Depth (m)	-	3.6	30	46	38
AENV Well Record ID	1170101	401895 (Chemistry)	N/A	N/A	1170096
Status (e.g., producing, standby, abandoned, etc.)	Active	Active	Active	Active	Active
Current Use (e.g. domestic, livestock, etc.)	Domestic	Domestic	Domestic	Domestic	Domestic
Estimated Yield (m^3/day)	40-50	98	20	46	79
Transmissivity (m^2/day)	-	-	-	-	-
Stickup (m)	0.43	1.05	-	0.67	0.56
Water Level (mbtoc)	56.64	2.38	-	9.05	21.07
Water Level Measurement Point (m)	1426.43	-	-	1448.67	1393.56
Water Level Measurement Date	17-Sep-12	17-Sep-12	-	17-Sep-12	17-Sep-12
Static Water Level Measurement? (Y/N)	N, washing machine on for 4.5 loads prior to measurement	Y	-	Y	N, pump on for hours prior to test
Water Sample Prior to Treatment and/or Pressure Tank? (Y/N)	Y	Y	N, post-pressure tank	Y	N, post-pressure tank
Pump Intake Depth (m)	-	3.6	-	30	-
Well Completion Details	-	Cement Culvert	In pit	Open from 18 to 46 m	-
Measured Flow Rate (m^3/day)	-	-	-	-	-
Flow Rate Date	-	-	-	-	-
Additional Comments (e.g., hard water, high sulphur, never dry, etc.)	Sulphur odour, hard, iron smell. Issues with pressure.	Recently more sediment in water. Reinstalled new well due to potential problems with pipeline. Dug to shale bedrock. Not pumped prior to water level measurement.	Good quality water, hard, never runs dry. No softener or other treatment. Sampled collected outside, on west side of building.	Good quality and taste. Softener used due to iron in water. Well doesn't go dry. Seasonal spring west of the house. Water well drilling report available.	Good quality; water softener for hot water; drilling record available but not in water well database

Notes

This appendix documents information about domestic wells that was provided by landowners and may not be comparable to water well records. If discrepancies existed, water well records were considered more accurate.

Appendix B - Well and Spring Survey

Transect	West	West	West	West	West
Location Identification	FVS6	FVS7	FVS8	FVS9	FVS10
Legal Land Description	SE-09-08-05 W5M	SW-10-08-05-05	SW-12-08-06 W5M	SW-12-08-06 W5M	SW-12-08-06 W5M
Current Owner's Name	Lloyd and Carol Hendrickson	Mona and Alan Mundy	Terrance and Adele Heisler	Island Lake Conference Center	Betty Harker
Original Owner's Name	-	Mona and Alan Mundy	-	-	-
Easting	672483	672711	672376	666567	666762
Northing	5500551	5500537	5500554	5499864	5500221
Surface Elevation (m)	1384	1382	1327	1393	1371
Date Field Verified	18-Sep-12	18-Sep-12	18-Sep-12	18-Sep-12	18-Sep-12
Water Source (e.g., well, creek, dugout, spring, etc.)	Drilled well	Drilled well	Dug well	Drilled well	Dug well
Description of Location (e.g., 25 m NE of house)	10 m S of SE corner of house	30 m N of NW corner of house	Well in basement	Well 1 m south of building.	Well in basement
Date Constructed/Created	~1985	1985	~1982	1991	<1982
Drilling Company	Dollman's Water Well Drilling	Dollman's Water Well Drilling	-	-	-
Well Depth (m)	14.6	9.2	6.1	17	1.2
AENV Well Record ID	362780	N/A	N/A	N/A	N/A
Status (e.g., producing, standby, abandoned, etc.)	Active	Active	Active	Active	Active
Current Use (e.g. domestic, livestock, etc.)	Domestic	Domestic	Domestic	Commercial/Domestic	Domestic
Estimated Yield (m^3/day)	98	196	-	Up to 120 beds, unknown	-
Transmissivity (m^2/day)	-	-	-	-	-
Stickup (m)	0.51	-	-	0.1	-
Water Level (mbtoc)	7.94	-	3	16.09	-
Water Level Measurement Point (m)	1384.51	-	-	1393.10	-
Water Level Measurement Date	18-Sep-12	-	18-Sep-12	18-Sep-12	-
Static Water Level Measurement? (Y/N)	Y	-	-	-	-
Water Sample Prior to Treatment and/or Pressure Tank? (Y/N)	N, post-pressure tank	N, post-pressure tank	N, post-pressure tank	N, post-chlorine treatment, pressure tank, and cistern	-
Pump Intake Depth (m)	-	-	-	-	-
Well Completion Details	-	Well in pit	-	-	-
Measured Flow Rate (m^3/day)	-	-	-	-	-
Flow Rate Date	-	-	-	-	-
Additional Comments (e.g., hard water, high sulphur, never dry, etc.)	Good quality, hard water. Never has gone dry. Previously had dug well in basement to 6.4 m but it went dry in the winter. Ok with being tested again in future.	Good quality hard water. Only has gone dry once. No water softener.	Good quality water. Enough for two people, goes dry if too much laundry. Replenishes quickly in winter. Caved in old well repaired 30 years ago.	Very hard (207 ppm), chlorine treatment, no softener. Water quantity issues; 10,000 L cistern.	Good quality water. Only has run dry once, generally a good producer. House is 50 m north of Island Lake conference Center, on or near continental divide. When first moved in, mud at bottom of well, dug deeper and installed plastic blue barrel.

Notes

This appendix documents information about domestic wells that was

Appendix B - Well and Spring Survey

Transect	West	West	West	West	West
Location Identification	FVS11	FVS12	FVS13	FVS14	FVS15
Legal Land Description	NE-06-08-05 W5M	NE-06-08-05 W5M	NE-06-08-05 W5M	NW-11-08-05 W5M	SW-15-08-05 W5M
Current Owner's Name	Crowsnest Lake Bible Camp	Crowsnest Lake Bible Camp	Crowsnest Lake Bible Camp	Nature Conservancy (Brenda Clarke is the resident)	Fred Bradley
Original Owner's Name	CSSM Camp	CSSM Camp	CSSM Camp	Jean Kerr	John Kerr
Easting	669237	669231	669162	674443	672804
Northing	5499535	5499637	5499577	5500900	5502008
Surface Elevation (m)	1365	1376	1379	1377	1305
Date Field Verified	18-Sep-12	18-Sep-12	18-Sep-12	18-Sep-12	19-Sep-12
Water Source (e.g., well, creek, dugout, spring, etc.)	Dug well	Dug well	Drilled well	Spring	Drilled Well
Description of Location (e.g., 25 m NE of house)	West of Crowsnest Lake	North of motel dug well.	West of Crowsnest Lake and motel and old camp well.	-	-
Date Constructed/Created	1960	1962	Not Operational	-	~1980
Drilling Company	-	-	Camfield Drilling Services	-	-
Well Depth (m)	3.7	2.4	18.3	1.47	-
AENV Well Record ID	N/A	N/A	1170337	N/A	402491
Status (e.g., producing, standby, abandoned, etc.)	Active	Active	Not Operational	Active	Active
Current Use (e.g. domestic, livestock, etc.)	Domestic	Domestic	Domestic	Domestic	Domestic
Estimated Yield (m^3/day)	-	216	100000	-	-
Transmissivity (m^2/day)	-	-	-	-	-
Stickup (m)	0.16	-	0.645	0.21	0.5
Water Level (mbtoc)	3.04	-	3.84	0.38	3.46
Water Level Measurement Point (m)	1365.16	-	1379.65	1377.21	1305.5
Water Level Measurement Date	18-Sep-12	-	18-Sep-12	18-Sep-12	19-Sep-12
Static Water Level Measurement? (Y/N)	Y?	-	Y?	Y	Y
Water Sample Prior to Treatment and/or Pressure Tank? (Y/N)	-	-	-	Y	N, post-pressure tank
Pump Intake Depth (m)	-	-	-	-	-
Well Completion Details	-	-	-	Culvert installed in spring outlet	-
Measured Flow Rate (m^3/day)	-	-	-	2.5	-
Flow Rate Date	-	-	-	18-09-12	-
Additional Comments (e.g., hard water, high sulphur, never dry, etc.)	Water supply for motel. Good quality water. Never runs dry.	Old well for Crowsnest Lake Bible Camp. Good quality water, never runs dry.	New well for Crowsnest Lake Bible Camp.	Very good taste, hard water. Flows year round, no previous quantity issues.	Well never goes dry. Iron filter. Water level comparable to creek elevation to west. Creek was diverted at one point but people complained that wells had gone dry. Creek was diverted back to original location.

Notes

This appendix documents information about domestic wells that was

Appendix B - Well and Spring Survey

Transect	West	West	East	East	East
Location Identification	FVS16	FVS17	FVS18	FVS19	FVS20
Legal Land Description	NE-16-08-05 W5M	NE-16-08-05 W5M	NW-36-07-03 W5M	SW-30-07-02 W5M	36-07-3 W5M
Current Owner's Name	George VanderVeen	Janice Wilkes	Laine Ripley	Garth Michalsky	Lynn Harker
Original Owner's Name	John Slupsky, Gaston Auben	Janice Wilkes	-	-	-
Easting	672383	672257	-	697311	697057
Northing	5502326	5502846	-	5495892	5498237
Surface Elevation (m)	1291	1296	-	1333	1334
Date Field Verified	19-Sep-12	19-Sep-12	20-Sep-12	20-Sep-12	20-Sep-12
Water Source (e.g., well, creek, dugout, spring, etc.)	Dug well	Drilled well	Drilled well	Spring with culvert	Dug well
Description of Location (e.g., 25 m NE of house)	15 m N and 5 m W of NW corner of house	30m W of NW corner of house	-	-	-
Date Constructed/Created	~1980	2007	-	1987	-
Drilling Company	-	Camfield Drilling Services	Dollman's Water Well Drilling	-	-
Well Depth (m)	11.3	24.3		6.1	>2.4
AENV Well Record ID	N/A	N/A	499263	401541 (Chemistry)	N/A
Status (e.g., producing, standby, abandoned, etc.)	Active	Active	Active	Active	Active
Current Use (e.g. domestic, livestock, etc.)	Domestic	Domestic	Domestic	Domestic	Domestic
Estimated Yield (m^3/day)	-	19.6	-	33	-
Transmissivity (m^2/day)	-	-	-	-	-
Stickup (m)	0.5	-	-	0.86	0.43
Water Level (mbtoc)	2.65	-	-	3.61	-
Water Level Measurement Point (m)	1291.5	-	-	1333.86	1334.43
Water Level Measurement Date	19-Sep-12	-	-	20-Sep-12	-
Static Water Level Measurement? (Y/N)	N, hose run 1.5 hours prior to measurement	-	-	Y	Y
Water Sample Prior to Treatment and/or Pressure Tank? (Y/N)	Y	N, post-cistern and pressure tank	-	N, post-pressure tank	Y
Pump Intake Depth (m)	-	-	-	-	-
Well Completion Details	-	-	-	-	-
Measured Flow Rate (m^3/day)	-	-	-	-	-
Flow Rate Date	-	-	-	-	-
Additional Comments (e.g., hard water, high sulphur, never dry, etc.)	Owner uses softener and sand filter. Well close to creek. Will go dry if two sprinklers are used. Water sample collected with bailer.	Good quality water. Well doesn't go dry. Water is pumped into cistern every four hours to remove silt. The depth to water was approximately 6 mbgl in 2010 and 2011. Dug well with total depth of 4.5 mbgl went dry and is not in use. Bedrock is at ~4.5 mbgl.	Sulphur odour; not used for potable water; only used for watering plants.	Good quality water; water quantity seasonal; well dug at seepage location; local seeps are seasonal	Used as a backup well for watering garden in summer.

Notes
This appendix documents information about domestic wells that was

Appendix B - Well and Spring Survey

Transect	East	East	East	East	West
Location Identification	FVS21	FVS22	FVS23	FVS24	FVS25
Legal Land Description	36-07-3 W5M	SE-13-07-03 W5M	SE-07-07-02 W5M	SW-29-7-2 W5M	SE-15-08-05 W5M
Current Owner's Name	Lynn Harker	Gerry Nichol	John Schuster	Beau Wallace	Terry Ostrom
Original Owner's Name	-	-	-	-	Jean Kerr
Easting	696587	696934	698556	697187	673716
Northing	5498243	5492766	5491561	5494217	5501675
Surface Elevation (m)	1330	1234	1233	1237	1363
Date Field Verified	20-Sep-12	20-Sep-12	20-Sep-12	20-Sep-12	21-Sep-12
Water Source (e.g., well, creek, dugout, spring, etc.)	Spring with culvert	Dug well	Drilled well	Dug well	Drilled well
Description of Location (e.g., 25 m NE of house)	0.4 km from house	75 m E and 20 m S of SE corner of house	0 m S and 10 m W of SW corner of house	40 m N and 20 m E of NE corner of house	20 m E and 15 m S of SE corner of house
Date Constructed/Created	1992	1977	July 1983	Prior to 1983	2005
Drilling Company	-	-	Camfield Drilling Services	-	Dollman's Water Well Drilling
Well Depth (m)	4.6	4.6	29.7	2.4	62.5
AENV Well Record ID	N/A	N/A	360194	N/A	1250066
Status (e.g., producing, standby, abandoned, etc.)	Active	Active	Active	Active	Active
Current Use (e.g. domestic, livestock, etc.)	Domestic	Domestic	Domestic	Domestic	Domestic
Estimated Yield (m^3/day)	-	-	137	-	9.8
Transmissivity (m^2/day)	-	-	-	-	-
Stickup (m)	-	-	0.6	-	0.54
Water Level (mbtoc)	-	-	17.64	-	28.87
Water Level Measurement Point (m)	-	-	1233.6	-	1363.54
Water Level Measurement Date	-	-	20-Sep-12	-	21-Sep-12
Static Water Level Measurement? (Y/N)	-	-	Y	Y	N?
Water Sample Prior to Treatment and/or Pressure Tank? (Y/N)	Y?, gravity drainage	N, post-UV, carbon filter, and pressure tank	-	Y	N, post-cistern and pressure tank
Pump Intake Depth (m)	-	-	-	-	-
Well Completion Details	Dug well with culvert, in middle of spring	Culvert	-	-	Perforations from 15 to 24 m, completed in black shale and water bearing clay
Measured Flow Rate (m^3/day)	-	-	-	-	-
Flow Rate Date	-	-	-	-	-
Additional Comments (e.g., hard water, high sulphur, never dry, etc.)	Mineralized, brown staining on bathroom and kitchen sinks and toilets. No problems with water quantity. Water level usually 2 m below ground level and constant throughout year. Uses bottled water for potable water.	Good quality, not hard, no discolored appliances. Well never goes dry. Water softener, UV and carbon filters are used.	Well never goes dry. Treatment system installed.	Water quality is good, hard. Never has run dry, this includes when running on water all day to water lawn. Tried to dig well on slope to north without success. Went west by 50 m and had success, well has comparable specs. Iron precipitate in sample.	Sulphur smell to water. Rarely goes dry unless los of people are using water. 1000 gallon cistern present. Not used for potable water. Camfield drilled another well but it was dry.

Notes
This appendix documents information about domestic wells that was

Appendix B - Well and Spring Survey

Transect	West	East	East	East	West
Location Identification	FVS26	FVS27	FVS28	FVS29	FVS30
Legal Land Description	NE-10-08-05 W5M	SW-07-07-02 W5M	NW-07-07-02 W5M	13-07-03 W5M	SE-22-08-05 W5M
Current Owner's Name	Jean Kerr	Dan Larson	John and Susanna MacGarva	Elizabeth Pyper	Allison Trout Hatchery
Original Owner's Name	Harry Boulton	-	Gerry Rinaldi	Elizabeth Pyper (Claire Ellison-Anclet)	-
Easting	673775	698110	697742	696487	673884
Northing	5500846	5491301	5491916	5493188	5503565
Surface Elevation (m)	1229	1242	1230	1197	1402
Date Field Verified	21-Sep-12	21-Sep-12	21-Sep-12	21-Sep-12	20-Sep-12
Water Source (e.g., well, creek, dugout, spring, etc.)	Spring	Drilled well	Drilled well	Drilled well	Drilled well
Description of Location (e.g., 25 m NE of house)	-	-	-	15 m E and 10 m S of SE corner of house	-
Date Constructed/Created	1940	1995	1983	-	26-Oct-83
Drilling Company	-	Dollman's Water Well Drilling	Camfield Drilling Services	-	Camfield Drilling Services
Well Depth (m)	-	30.5	50.3	16.7	29.8
AENV Well Record ID	N/A	N/A	356066	401772	402533
Status (e.g., producing, standby, abandoned, etc.)	Active	Active	Active	Active	Inactive
Current Use (e.g. domestic, livestock, etc.)	Domestic	Domestic	Domestic	Domestic	Industrial
Estimated Yield (m^3/day)	-	98	-	-	2415
Transmissivity (m^2/day)	-	-	-	-	129,000 to 219,120 Gal/Day/ft
Stickup (m)	-	0	-	-	0.91
Water Level (mbtoc)	-	26.32	-	-	-
Water Level Measurement Point (m)	-	1242	-	-	-
Water Level Measurement Date	-	21-Sep-12	-	-	-
Static Water Level Measurement? (Y/N)	-	Y	-	-	-
Water Sample Prior to Treatment and/or Pressure Tank? (Y/N)	Y	Y, hand pump	N, post-pressure tank	Y	-
Pump Intake Depth (m)	-	29.6	-	-	-
Well Completion Details	Spring pumped into line	Well in pit. Screened from 27.3 to 30.4 m in pebbles and cobbles with water.	-	-	Screened from 25.9 m to 29.8 m in coarse gravel.
Measured Flow Rate (m^3/day)	7.7	-	-	-	-
Flow Rate Date	21-09-12	-	-	-	-
Additional Comments (e.g., hard water, high sulphur, never dry, etc.)	Spring never runs dry. Some sediment issues. Spring is piped into line to a cistern and then to a pressure tank in the house.	Good quality water. Well went dry November 2000 but had water again in May 2001. Otherwise, no issues with water quantity. Water well drilling report available. Dugout just northeast of well.	Excellent water quality, hard. Well has never gone dy.	Good water quality, some iron issues. Never has run dry	Process Well #1. Well not used recently, siltation problems.

Notes

This appendix documents information about domestic wells that was

Appendix B - Well and Spring Survey

Transect	West	West	West	West	West
Location Identification	FVS31	FVS32	FVS33	FVS34	FVS35
Legal Land Description	SE-22-08-05 W5M	SE-22-08-05 W5M	SE-22-08-05 W5M	SE-22-08-05 W5M	SE-22-08-05 W5M
Current Owner's Name	Allison Trout Hatchery	Allison Trout Hatchery	Allison Trout Hatchery	Allison Trout Hatchery	Allison Trout Hatchery
Original Owner's Name	-	-		-	-
Easting	673836	673697	-	673928	673998
Northing	5503499	5503665	-	5503473	5503534
Surface Elevation (m)	1401	1391	-	1402	1403
Date Field Verified	20-Sep-12	20-Sep-12	20-Sep-12	20-Sep-12	20-Sep-12
Water Source (e.g., well, creek, dugout, spring, etc.)	Drilled well	Drilled well	Drilled well	Drilled well	Drilled well
Description of Location (e.g., 25 m NE of house)	-	-	S of FVS32	-	-
Date Constructed/Created	24-Feb-86	2008	2008	-	-
Drilling Company	Camfield Drilling Services	-	-	-	-
Well Depth (m)	30.5	30.92	-	-	-
AENV Well Record ID	402534	1170208	1170209	N/A	N/A
Status (e.g., producing, standby, abandoned, etc.)	Active	Inactive	Active	-	-
Current Use (e.g. domestic, livestock, etc.)	Industrial	Observation	Industrial	Domestic	Domestic
Estimated Yield (m^3/day)	-	-	1728	-	-
Transmissivity (m^2/day)	-	-	-	-	-
Stickup (m)	-	0.8	-	-	-
Water Level (mbtoc)	-	11.75	-	-	-
Water Level Measurement Point (m)	-	1391.8	-	-	-
Water Level Measurement Date	-	20-Sep-12	-	-	-
Static Water Level Measurement? (Y/N)	-	-	-	Y	-
Water Sample Prior to Treatment and/or Pressure Tank? (Y/N)	-	-	Y	-	-
Pump Intake Depth (m)	-	-	-	-	-
Well Completion Details	-	-	-	-	-
Measured Flow Rate (m^3/day)	-	-	-	-	-
Flow Rate Date	-	-	-	-	-
Additional Comments (e.g., hard water, high sulphur, never dry, etc.)	Process Well #2	2007 well not in use	South Well; in use on 20-Sept-12; estimated yield is actually measured yield; 1,728 m^3/day discharged to river; automatic water level recorder installed but data not downloaded regularly	-	-

Notes

This appendix documents information about domestic wells that was

Appendix B - Well and Spring Survey

Transect	-	-	-	-	-
Location Identification	FVS36	FVS37	FVS38	FVS39	FVS40
Legal Land Description	SE-12-8-5 W5M	SE-12-8-5 W5M	SW-02-08-04 W5M	SW-02-08-04 W5M	SW-02-08-04 W5M
Current Owner's Name	Municipality of Crowsnest Pass (Coleman Pumping Well #1)	Municipality of Crowsnest Pass (Coleman Pumping Well #2)	Municipality of Crowsnest Pass (Blairmore Observation Well #1)	Municipality of Crowsnest Pass (Blairmore Pumping Well #1)	Municipality of Crowsnest Pass (Blairmore Observation Well #2)
Original Owner's Name	-	-	-	-	-
Easting	677406	677394	684363	684262	684198
Northing	5500644	5500654	5498662	5498594	5498616
Surface Elevation (m)	1391	1366	1239	1227	1234
Date Field Verified	21-Sep-12	21-Sep-12	21-Sep-12	21-Sep-12	21-Sep-12
Water Source (e.g., well, creek, dugout, spring, etc.)	Drilled well	Drilled well	Drilled well	Drilled well	Drilled well
Description of Location (e.g., 25 m NE of house)	-	-	130 m N of 22 Ave and 121 Street on 22 Ave, 15m S of Crowsnest Road; adjacent to bike pathway	60 m W of Observation Well #1	75 m N of Observation Well #2
Date Constructed/Created	-	-	-	-	-
Drilling Company	-	-	-	-	-
Well Depth (m)	-	-	-	-	-
AENV Well Record ID	372431	372432	N/A	374115	N/A
Status (e.g., producing, standby, abandoned, etc.)	-	-	-	-	-
Current Use (e.g. domestic, livestock, etc.)	-	-	-	-	-
Estimated Yield (m^3/day)	-	-	-	-	-
Transmissivity (m^2/day)	-	-	-	-	-
Stickup (m)	-	-	-	-	-
Water Level (mbtoc)	-	-	-	-	-
Water Level Measurement Point (m)	-	-	-	-	-
Water Level Measurement Date	-	-	-	-	-
Static Water Level Measurement? (Y/N)	-	-	-	-	-
Water Sample Prior to Treatment and/or Pressure Tank? (Y/N)	-	-	-	-	-
Pump Intake Depth (m)	-	-	-	-	-
Well Completion Details	-	-	-	-	-
Measured Flow Rate (m^3/day)	-	-	-	-	-
Flow Rate Date	-	-	-	-	-
Additional Comments (e.g., hard water, high sulphur, never dry, etc.)	Municipality of Crowsnest Well located in Coleman, AB. Possibly corresponds to approval record 00034273 with a production interval between 27.3 and 33.3 m and a maximum pump rate of 1000 IGal/min.	Municipality of Crowsnest Well located in Coleman, AB. Pumping Well #2? Located 11 m North and 9 m West of Pumping Well #1. Possibly corresponds to approval record 00034273 with a producion interval between 27.3 and 33.3 m and a maximum pump rate of 1,000 Igpm.	Municipality of Crowsnest observation well located in Blairmore, AB.	Municipality of Crowsnest pumping well located in Blairmore, AB. Possibly related to approval records 00034620, 0034621, or 00034622. Wells have a production interval between 27.3 and 33.3 m and a maximum pump rate between 500 and 1,770 IGal/min	Municipality of Crowsnest observation well located in Blairmore, AB.

Notes

This appendix documents information about domestic wells that was

Appendix B - Well and Spring Survey

Transect	-	-			Central
Location Identification	FVS41	FVS42	FVS43	FVS44	Turtle Mountain Spring
Legal Land Description	SW-02-08-04 W5M	SW-02-08-04 W5M	SW-02-08-04 W5M	15-17-7-3 W5M	-
Current Owner's Name	Municipality of Crowsnest Pass (Blairmore Pumping Well #2)	Municipality of Crowsnest Pass (Blairmore Observation Well #3)	Municipality of Crowsnest Pass (Blairmore Observation Well #3)	Municipality of Crowsnest Pass (Hillcrest)	Turtle Mountain Spring
Original Owner's Name	-	-			-
Easting	684075	684052	684052	-	686696
Northing	5498658	5498664	5498664	-	5497779
Surface Elevation (m)	1231	1231	1231	-	1238
Date Field Verified	21-Sep-12	21-Sep-12	21-Sep-12	17-Sep-12	18-Sep-12
Water Source (e.g., well, creek, dugout, spring, etc.)	Drilled well	Drilled well	Drilled well	-	Spring
Description of Location (e.g., 25 m NE of house)	100 m N of Observation Well #1	22 m N of pumping well 2, 20 m S of 22 Ave and 117 Street	20 m S of 22 Ave and 117 St intersection	-	-
Date Constructed/Created	-	-	-	-	-
Drilling Company	-	-	-	-	-
Well Depth (m)	-	-	-	-	-
AENV Well Record ID	395327	N/A	-	-	-
Status (e.g., producing, standby, abandoned, etc.)	-	-	-	-	-
Current Use (e.g. domestic, livestock, etc.)	-	-	-	-	-
Estimated Yield (m^3/day)	-	-	-	-	-
Transmissivity (m^2/day)	-	-	-	-	-
Stickup (m)	-	-	-	-	-
Water Level (mbtoc)	-	-	-	-	-
Water Level Measurement Point (m)	-	-	-	-	-
Water Level Measurement Date	-	-	-	-	-
Static Water Level Measurement? (Y/N)	-	-	-	-	-
Water Sample Prior to Treatment and/or Pressure Tank? (Y/N)	-	-	-	-	-
Pump Intake Depth (m)	-	-	-	-	-
Well Completion Details	-	-	-	-	-
Measured Flow Rate (m^3/day)	-	-	-	-	-
Flow Rate Date	-	-	-	-	-
Additional Comments (e.g., hard water, high sulphur, never dry, etc.)	Municipality of Crowsnest pumping well located in Blairmore, AB. Possibly related to approval records 00034620, 0034621, or 00034622. Wells have a production interval between 27.3 and 33.3 m and a maximum pump rate between 500 and 1,770 IGal/min	Municipality of Crowsnest observation well located in Blairmore, AB.	Municipality of Crowsnest observation well located in Blairmore, AB.	Municipality of Crowsnest pumping well located in Hillcrest, AB. Possibly related to approval records 00029000 and 00029001. Wells has a production interval between 20.0 to 24.5 mbgl and 18.2 to 22.7 mbgl; maximum pump rates of 360 IGal/min and 370 IGal/min	Flow measurement not able to be collected; water bubbling out of pond; rotten egg smell, cloudy, white precipitates.

Notes

This appendix documents information about domestic wells that was

Appendix B - Well and Spring Survey

Transect	West	West
Location Identification	Crowsnest Spring	Ptolemy Spring
Legal Land Description	-	-
Current Owner's Name	Crowsnest Spring	Ptolemy Spring
Original Owner's Name	-	-
Easting	670260	668807
Northing	5500603	5495756
Surface Elevation (m)	1432	1555
Date Field Verified	19-Sep-12	19-Sep-12
Water Source (e.g., well, creek, dugout, spring, etc.)	Spring	Spring
Description of Location (e.g., 25 m NE of house)	-	-
Date Constructed/Created	-	-
Drilling Company	-	-
Well Depth (m)	-	-
AENV Well Record ID	-	-
Status (e.g., producing, standby, abandoned, etc.)	-	-
Current Use (e.g. domestic, livestock, etc.)	-	-
Estimated Yield (m^3/day)	-	-
Transmissivity (m^2/day)	-	-
Stickup (m)	-	-
Water Level (mbtoc)	-	-
Water Level Measurement Point (m)	-	-
Water Level Measurement Date	-	-
Static Water Level Measurement? (Y/N)	-	-
Water Sample Prior to Treatment and/or Pressure Tank? (Y/N)	-	-
Pump Intake Depth (m)	-	-
Well Completion Details	-	-
Measured Flow Rate (m^3/day)	341037.28	4983.84 to 6125.76
Flow Rate Date	19-Sep-12	19-Sep-12
Additional Comments (e.g., hard water, high sulphur, never dry, etc.)		

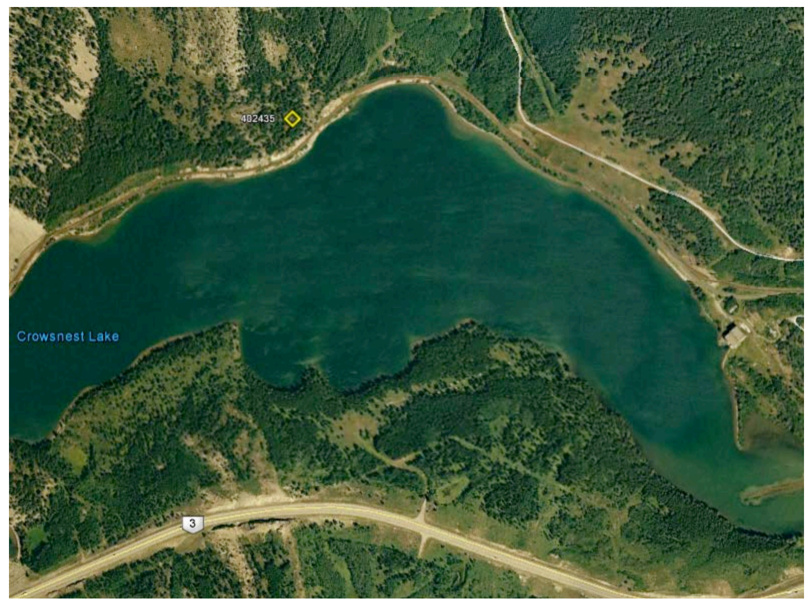
Notes

This appendix documents information about domestic wells that was

Crowsnest spring cave outlet north side of Crowsnest Lake

Crowsnest spring flow. Crowsnest Lake in background

Crowsnest spring outlet under train tracks into Crowsnest Lake



Location Crowsnest spring north side of Crowsnest Lake

Ptolemy Spring outlet

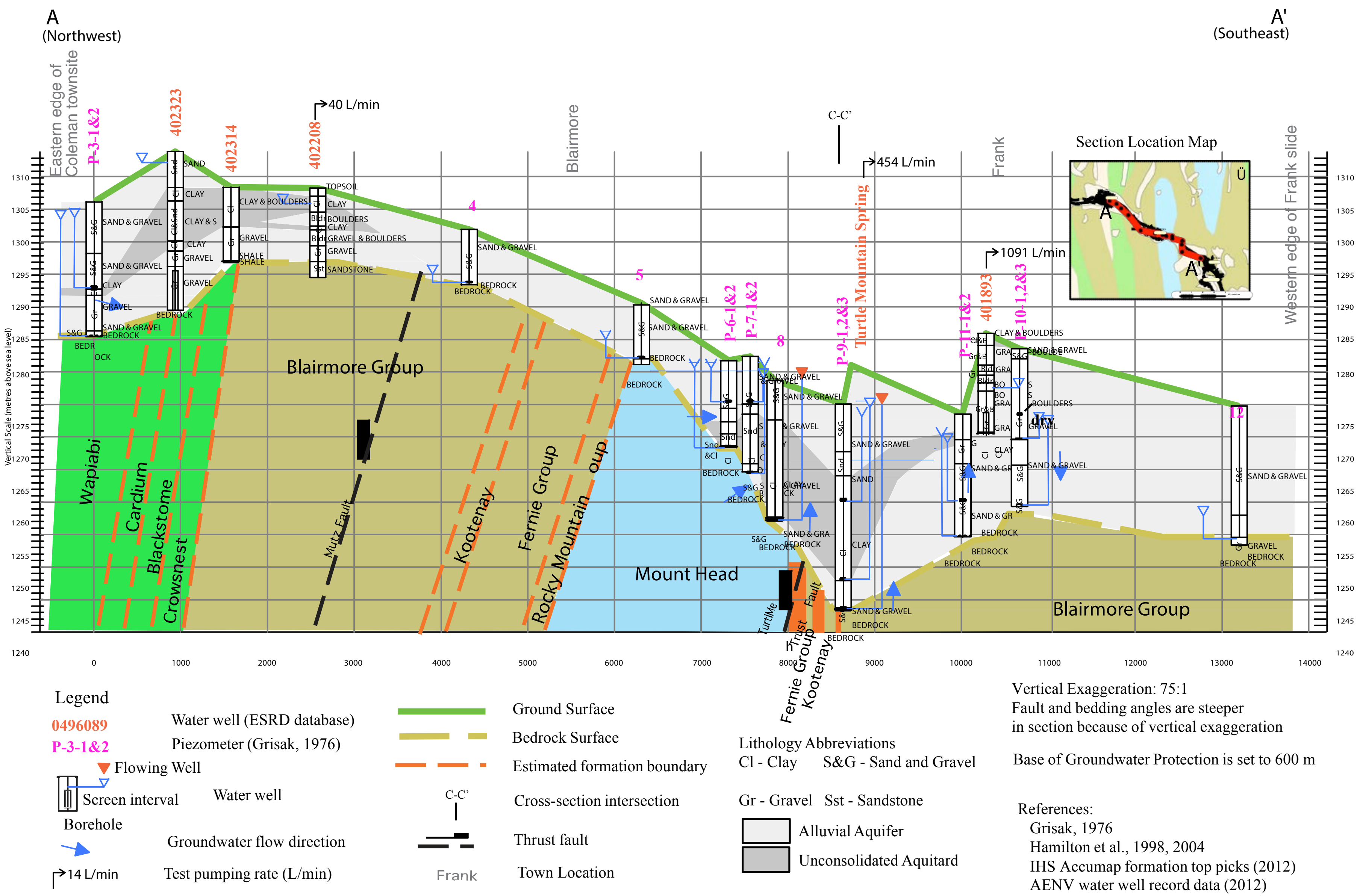
Turtle Mountain Spring outlet. Note milky colour.

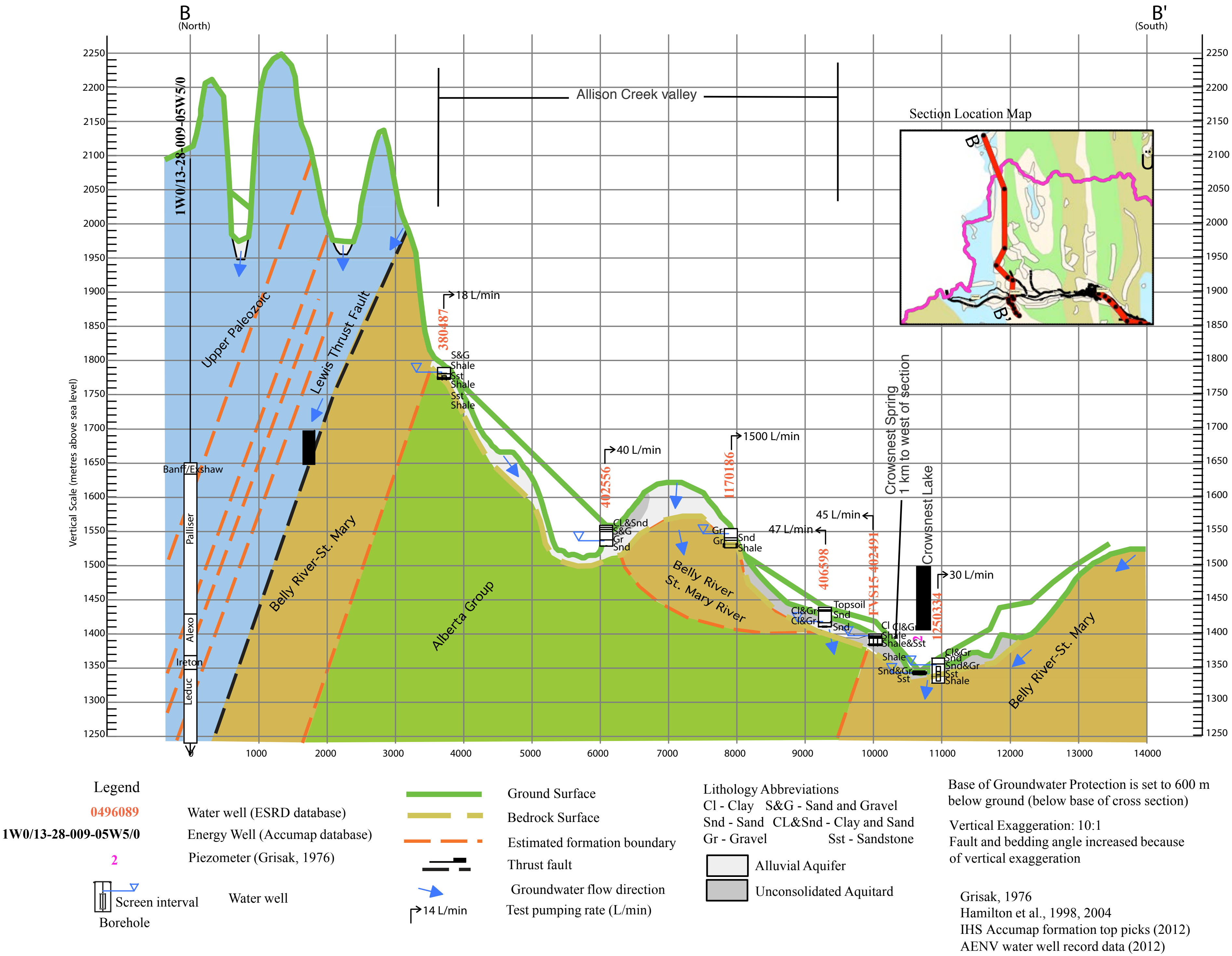
Location of Ptolemy Spring

Location of Turtle Mountain Spring

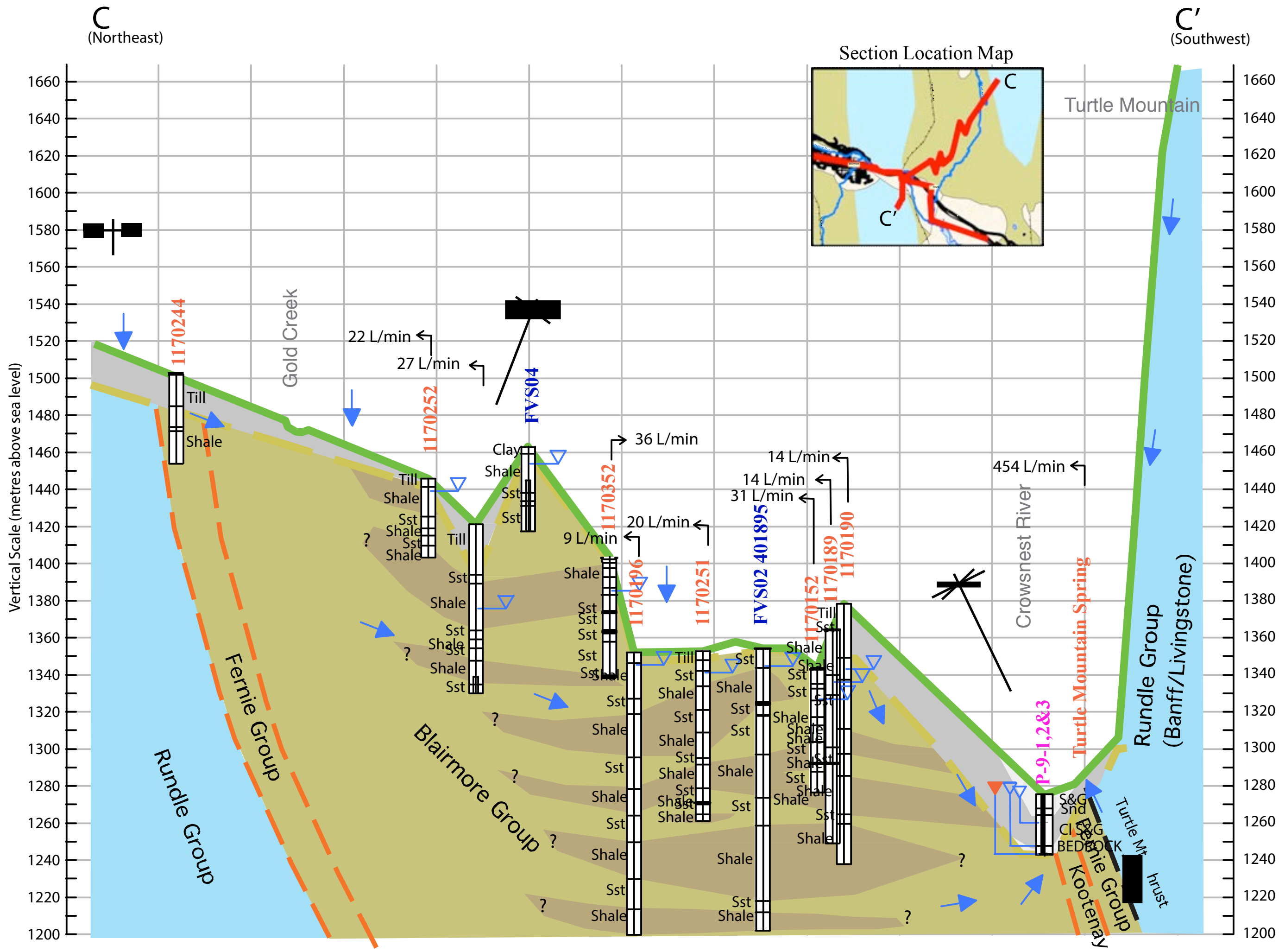
APPENDIX C

CROSS-SECTIONS


A
(Northwest)
A'
(Southeast)
Eastern edge of Coleman townsite
P-3-1&2
402323
402314
402208
40 L/min
Blairmore
C-C'
454 L/min
Turtle Mountain Spring
Frank
1091 L/min
401893
P-11-1&2
P-10-1,2&3
P-9-1,2&3
P-6-1&2
P-7-1&2
4
5
8
12
Western edge of Frank slide
Section Location Map
Vertical Scale (metres above sea level)
SAND & GRAVEL
CLAY
GRAVEL
BEDROCK
SAND
CLAY & BOULDERS
SHALE
TOPSOIL
BOULDERS
GRAVEL & BOULDERS
SANDSTONE
dry
Wapiabi
Cardium
Blackstome
Crowsnest
Blairmore Group
Mutz Fault
Kootenay
Fernie Group
Rocky Mountain Group
Mount Head
Turtle Mountain Thrust Fault
Fernie Group
Kootenay
Blairmore Group
1310
1305
1300
1295
1290
1285
1280
1275
1270
1265
1260
1255
1250
1245
1240
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
Legend
0496089 Water well (ESRD database)
P-3-1&2 Piezometer (Grisak, 1976)
Flowing Well
Screen interval
Water well
Borehole
Groundwater flow direction
14 L/min Test pumping rate (L/min)
Ground Surface
Bedrock Surface
Estimated formation boundary
C-C' Cross-section intersection
Thrust fault
Frank Town Location
Lithology Abbreviations
Cl - Clay
S&G - Sand and Gravel
Gr - Gravel
Sst - Sandstone
Alluvial Aquifer
Unconsolidated Aquitard
Vertical Exaggeration: 75:1
Fault and bedding angles are steeper in section because of vertical exaggeration
Base of Groundwater Protection is set to 600 m
References:
Grisak, 1976
Hamilton et al., 1998, 2004
IHS Accumap formation top picks (2012)
AENV water well record data (2012)



B
(North)
B'
(South)
Allison Creek valley
Section Location Map
Vertical Scale (metres above sea level)
2250
2200
2150
2100
2050
2000
1950
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
1400
1350
1300
1250
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
1W0/13-28-009-05W5/0
Upper Paleozoic
Lewis Thrust Fault
Banff/Exshaw
Palliser
Alexo
Ireton
Leduc
Belly River-St. Mary
Alberta Group
Belly River
St. Mary River
Belly River-St. Mary
18 L/min
380487
S&G
Shale
Sst
Shale
Sst
Shale
40 L/min
402556
CL&Snd
S&G
Gr
Snd
1500 L/min
1170186
Gr
Gr
Snd
Shale
45 L/min
47 L/min
406598
Topsoil
Cl&Gr
Cl&Gr
Snd
Snd
FVS15-402491
Cl
Cl&Gr
Shale
Shale&Sst
Crowsnest Spring
1 km to west of section
Crowsnest Lake
30 L/min
1250334
2
Shale
Snd&Gr
Sst
Cl&Gr
Snd
Snd&Gr
Sst
Shale
Legend
0496089
Water well (ESRD database)
1W0/13-28-009-05W5/0
Energy Well (Accumap database)
2
Piezometer (Grisak, 1976)
Screen interval
Borehole
Water well
Ground Surface
Bedrock Surface
Estimated formation boundary
Thrust fault
Groundwater flow direction
14 L/min
Test pumping rate (L/min)
Lithology Abbreviations
Cl - Clay S&G - Sand and Gravel
Snd - Sand CL&Snd - Clay and Sand
Gr - Gravel Sst - Sandstone
Alluvial Aquifer
Unconsolidated Aquitard
Base of Groundwater Protection is set to 600 m below ground (below base of cross section)
Vertical Exaggeration: 10:1
Fault and bedding angle increased because of vertical exaggeration
Grisak, 1976
Hamilton et al., 1998, 2004
IHS Accumap formation top picks (2012)
AENV water well record data (2012)



Legend

0496089 Water well (ESRD database)
P-3-1&2 Piezometer (Grisak, 1976)
FVS04 Field Verified Survey well

Flowing Well
Screen interval
Water well
Borehole
Groundwater flow direction
14 L/min Test pumping rate (L/min)

Ground Surface
Bedrock Surface
Estimated formation boundary
Anticline (vertical axis)
Syncline (vertical axis)

Lithology Abbreviations
Cl - Clay
Snd - Sand
Gr - Gravel
S&G - Sand and Gravel
CL&Snd - Clay and Sand
Sst - Sandstone

Unconsolidated Aquitard
C-C' Cross-section intersection
Frank Town Location

Vertical Exaggeration: 10:1
Fault and bedding angles are steeper in section because of vertical exaggeration

Base of Groundwater Protection is set to 600 m below ground (below base of cross section)

Grisak, 1976
Hamilton et al., 1998, 2004
IHS Accumap formation top picks (2012)
AENV water well record data (2012)