

# **DRAFT Background Technical Report: Surface Water Quantity and Groundwater Resources**

## **Prepared for the Red Deer River Integrated Watershed Management Plan**

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Prepared by: O2 Planning + Design Inc. (O2)



in association with Integrated Sustainability Consultants Ltd. and LimnoLogic Solutions Ltd.

Prepared for: The Red Deer River Watershed Alliance, in association with Alan Dolan and Associates



## EXECUTIVE SUMMARY

Watershed management requires an effective process to integrate science, policy, and stakeholder and public participation in a flexible manner. The Red Deer River Watershed Alliance and its project manager and facilitator, Alan Dolan, commissioned O2 Planning + Design Inc. (O2) to prepare background technical reports to support the development of an Integrated Watershed Management Plan (IWMP). This report focuses on providing draft outcomes, indicators, and targets for the Red Deer River Watershed for: (i) surface water quantity and (ii) groundwater resources (including groundwater quantity and groundwater quality).

Extensive literature review, data assembly, and Geographic Information Systems (GIS) mapping were applied to summarize information and help formulate appropriate indicators and targets. In addition, a multidisciplinary technical review process was undertaken to incorporate advice and feedback from provincial subject matter experts in government, industry, and consulting.

Recommended outcomes, indicators, and targets for each of the topics are summarized below. The report also outlines, for each topic, priorities for improved monitoring and data acquisition, research needs, and key Beneficial Management Practices (BMPs) recommended for implementation.

### Surface Water Quantity

Surface water resources in the watershed vary considerably in response to seasonal influences, as well as drought and deluge cycles. Runoff volumes tend to peak in June and July along the Red Deer River, while flow decline usually begins in early to mid July and continues until the winter. Water yields in August and September – a period of high demand – are more modest. Minimum flows occurring in winter are augmented by the operations of the Dickson Dam along the Red Deer River. For many of the tributaries, April snowmelt often dominates the hydrograph, and summer and fall are characterized by very low flows.

Paleo-records indicate that severe, extended droughts are not uncommon in the region, which pose a threat to the reliability of water supplies. The risk of floods, such as those that occurred in 1915, 1954, 2005, and 2013, are a concern recently heightened by the severe June 2013 floods in southern Alberta. Research indicates that ongoing climate change could amplify and heighten the risks of both seasonal flooding and long-term droughts.

Surface water resources also vary considerably across different parts of the watershed. Over 50% of the total water yield in the Red Deer River originates from snow and rain in the Rocky Mountains and Upper Foothills. In contrast, in the Dry Grasslands, less than 1% of all precipitation typically becomes stream flow, and the reliability of water supplies from year to year is very low. For example, Alkali Creek has a 30% chance of running virtually dry for the vast majority of any given year. Areas upstream from the confluence of the Blindman River and the Red Deer River near Red Deer contribute over 87% of the total yield in the entire basin. By the time the Red Deer River reaches the confluence with the Rosebud River just downstream from Drumheller, over 99% of all “blue” stream water in the watershed has already been generated.

Over 16,000 surface water licences occur in the watershed. Total water allocations are currently 335,000 cubic decameters (dam<sup>3</sup>) per year – a volume that could fill Pine Lake more than 16 times or Gleniffer Lake almost 2 times. These volumes do not represent actual use, which is typically lower. In addition, documented return flows to rivers and streams represent almost 60,000 dam<sup>3</sup> / year, or close to 20% of the total volume diverted.

Statistics for estimated total consumptive demand (licensed allocations – return flows) were calculated and mapped for both user types and specific reaches of the Red Deer River. Overall, irrigation is the largest single user group in the watershed (26% of total demand). Municipal, industrial, and commercial uses are also important consumers in the watershed. Near the border with Saskatchewan, total demand currently represents about 18% of average annual flow, and 29% of the estimated 1-in-10 dry year annual flow. In contrast, upstream from Dickson Dam in the headwaters, total water demand is minor, representing less than 1% of the total available volume, even for relatively dry years. Despite these relatively encouraging statistics, there is the potential that future increased water consumption could impact water quality and environmental values, although impacts would be concentrated more within downstream reaches of the river basin. In addition, finer-scaled analyses indicate that water security and environmental issues for many of the prairie sub-watersheds, tributaries, and non-contributing areas dominated by wetlands are of much higher concern than impacts and supply/demand issues along the mainstem river.

More widespread water conservation could be the key to enabling both additional long-term economic growth and water allocations, while also potentially enhancing natural instream flows.

A variety of plans and policies govern and affect surface water in the watershed. The Master Agreement on Apportionment of the Prairie Provinces Water Board and the South Saskatchewan River Basin Water Management Plan are very important considerations. Currently, the Red Deer River watershed has a target allocation limit of 600,000 dam<sup>3</sup> and a specified temporary closure of new licences at 550,000 dam<sup>3</sup>. Water Conservation Objectives (WCOs) specifying minimum flow rates for the Red Deer River were established in 2007 under the *Water Act*. Various Instream Flow Needs (IFN) studies have been conducted to determine environmental requirements for water quality, fish habitat, riparian vegetation, and channel maintenance, both on the main stem and in tributaries.

Recommended draft goals and outcomes for surface water quantity, as well as indicators and targets for surface water quantity for consideration in the IWMP are provided below.

### Draft Goals and Outcomes for Surface Water Quantity in the Red Deer Watershed

DRAFT MANAGEMENT GOALS FOR SURFACE WATER QUANTITY	DRAFT OUTCOMES FOR SURFACE WATER QUANTITY
1. Balance water demand with water supplies for all users, including the environment, through seasonal and extreme conditions	1. Safe, secure water supplies are available for municipal and domestic water users
	2. Water flow regimes in the Red Deer River maintain healthy aquatic and riparian ecosystems
	3. Water flow regimes in tributaries minimize impacts on aquatic ecosystems
	4. Surface water supplies for sustainable industrial, commercial, and agricultural uses are available and reliable
	5. Surface and groundwater supply and demand are integrated to optimize options (e.g., where suitable, use groundwater to leave more surface water flow)
	6. All industries apply water conservation techniques and technologies to reduce water use and to minimize the potential for impacts on water resources and future conflicts
2. Flooding events are anticipated proactively and mitigated	7. Land uses in the basin aim to conserve pre-development hydrology and minimize the risk of increased peak flows (e.g., forestry, urbanization, etc.)
	8. Restrict new development in flood-prone areas
	9. Build flood control infrastructure in select locations if absolutely necessary to protect human life and existing property
3. Knowledge of surface water resources continually improves	10. Knowledge of surface water resources at multiple scales is enhanced, as well as Beneficial Management Practices to mitigate impacts

**Draft Indicators and Targets for Surface Water Quantity**

Indicator	Scale of Analysis	Targets	Notes
Total Surface Water Licence Allocations	Red Deer River Watershed	335,000 – 600,000 dam <sup>3</sup>	Lower end of range represents current volumes; higher end represents established new licence closure limits
Total Water Demand (Licences – Return Flows) as a Proportion of the 90% POE Water Yield (Dry Conditions)	Red Deer River reaches  (nested contributing area analysis)	A: Upstream from Dickson Dam: 0.5 to 1%	Expressed as cumulative demand divided by the 90% POE yield for each contributing area
		B: Upstream from Red Deer: 5% to 8%	Lower end of range represents current conditions. Higher end of range would allow approximately 64% expansion of licensed allocations consistent with established government policy.
		C: Upstream from Drumheller: 16% to 25%	
		D: Upstream from Saskatchewan: 29% to 48%	The optimal value may not be near the upper range specified due to ecological impacts
Total water diversion during low flow periods as a proportion of natural flow	Unregulated tributaries	No diversions when flows are in the lowest 20 <sup>th</sup> percentile based on a weekly / monthly time step  If flows are above the 20 <sup>th</sup> percentile, no more than 15% of the natural flow can be taken	From: Locke and Paul (2011)
Number of New Licences in Local Areas with Supply Shortages	Specific areas determined to be water-short (e.g., Rosebud or Buffalo sub-watershed)	No more new surface water licences in these areas	Groundwater licensing or licensing from the Red Deer River main stem (where feasible) are alternatives for these areas  More detailed work may be needed to identify all local water supply shortage areas (e.g., Rosebud, Buffalo, Kneehills, Threehills, Michichi sub-watersheds)
Deviation of recorded flows from Water Conservation Objectives	All areas	No deviations from established WCOs (e.g., 16 m <sup>3</sup> /s – See Table 9 for additional details)  Maintain junior licence deficit frequency	Based on discussions and review of the WRMM data  Calculate junior licence deficit volume and frequency under historical and future climate change scenarios
Municipalities with water conservation management plans	Programmatic	100%	AUMA (Water Conservation for Life, 2013) has more specific targets:  -100% of municipalities with >10,000 population -75% of municipalities with 2500 to 10,000 people - 50% of municipalities with population < 2500
Industries with water conservation plans	Programmatic	All industries aim for a 30% increase in water productivity and efficiency	The Alberta Water Council recently established formal plans for a 30% improvement in water productivity and efficiency by 2015 for seven industrial sectors

In general, more widespread water conservation could be key to enabling both additional long-term economic growth and water allocations, while also potentially enhancing natural instream flows.



## Groundwater Resources

Groundwater is a significant water supply source in the watershed, and is used for a variety of purposes. There are three different types of aquifers beneath the Red Deer River Watershed, all of which can exist in unconfined (i.e., water table) or confined states. These include:

- Near surface sand and gravel deposits (sometimes referred to as “alluvial aquifers”)
- Buried channels and/or inter-till sands and gravels (of pre-glacial or glacial origin, respectively)
- Bedrock aquifers (sandstone, siltstone and/or fractured bedrock)

Estimates of groundwater quantity are presented for the various aquifer types residing beneath the Red Deer River watershed and are in the billions of cubic meters.

Groundwater can be considered a renewable resource, because each year some snowmelt and precipitation infiltrates the subsurface. As such, recharge is very much a function of precipitation received and the types of soil and near-surface rock materials. As this water infiltrates, it adds to the water stored beneath the ground — causing water levels to rise in wells.

Groundwater interacts with the surface environment in many different ways. For example, the flow of rivers and streams throughout the year is not only sustained by drainage of water from the landscape, but also by groundwater discharge during certain periods of the year (i.e., winter). Similar interactions occur for lakes and wetlands.

Licensed groundwater use in the Red Deer River Watershed amounts to 37 million m<sup>3</sup> per year. Licensed surface water use is almost ten times that of groundwater use (335 million m<sup>3</sup> per year). The agricultural sector is the largest user of groundwater, at 65%, followed by the oil and gas sector (16%), other uses (8.5%), municipal sector (7.1%), and commercial (3.3%) and industrial (0.2%) sectors.

The estimated amount of water used for household purposes from groundwater wells is 365 m<sup>3</sup> per year (or about 250 L per person per day). Based on the total number of well records for all aquifer types and intervals, and assuming each well record is associated with a particular household, the total estimated volume of unlicensed groundwater use is approximately 14 million m<sup>3</sup> per year. This should be considered a conservative, high-end estimate.

A number of risks to groundwater quantity and quality exist in the Red Deer River Watershed, from large groundwater diversions to support agricultural and industrial activities to leaks and spills of materials either on or below the surface that may degrade local groundwater quality conditions. Those of particular relevance to groundwater resources beneath the basin are presented along with a description of potential implications for various sectors, including oil and gas, mining, agriculture, urban and rural development, forestry, and recreation and tourism. A recent new activity in the watershed is hydraulic fracturing activity, which is concentrated primarily in the Lower Headwaters and Central Urbanizing regions. The depth at which hydraulic fracturing is typically between 1,000 to 2,500 m depth or greater, whereas depths of most domestic and livestock water wells are less than 100 m.

Taken individually, activities in certain parts of a basin may not necessarily represent a threat to groundwater quantity or quality conditions. However, when the density, or intensity, of activities increases, resulting additive or cumulative effects on groundwater resources can be significant.

Groundwater resources are not only affected by human activity, but also by variations in climate that occur naturally, and the impact humans may be having on a global scale. Reduced precipitation and increased evaporation and evapotranspiration can lead to water level declines in aquifers.

A number of key issues and challenges related to groundwater resources exist in the Red Deer River Watershed. These include:

- Lack of a refined understanding regarding distribution of aquifers, related groundwater volumes, amounts of recharge, sustainable yields, and groundwater-surface water interaction
- Potential for over-development in certain areas

- Potential effects of unconventional oil and gas development
- Effect of fertilizer, pesticide, and manure applications to the land
- Impacts to groundwater dependent ecosystems from sand and gravel mining for aggregate production
- Placement of hazardous infrastructure (e.g., landfills, oil and gas facilities) in vulnerable and sensitive locations
- Limited knowledge of risks related to aging pipeline infrastructure
- Lack of integrated system for monitoring and evaluating water levels and changes in groundwater storage for heavily used aquifers
- Lack of integrated system for monitoring, evaluating, and reporting groundwater quality changes across the basin
- Impacts of climate variability and climate change on water security of basin communities

Recommended draft goals and outcomes for groundwater, as well as indicators and targets for consideration in the IWMP, are provided below.

### Draft Management Goals and Outcomes for Groundwater

DRAFT MANAGEMENT GOALS FOR GROUNDWATER	DRAFT OUTCOMES FOR GROUNDWATER
1. Maintain and protect groundwater quantity of non-saline sources for human consumption and other uses	1. Adequate knowledge of groundwater resources is obtained through refined assessment
	2. Groundwater withdrawals for licensed diversions are allocated and operated sustainably
	3. Robust groundwater level monitoring in higher risk areas is implemented to identify changes outside historic variability
	4. Assistance is provided to AESRD and AGS with respect to provincial groundwater mapping and inventory initiative
	5. Alternative storage and management approaches (e.g., conjunctive use) are assessed for applicability on a sub-basin scale
	6. Sensitive areas (i.e., recharge zones; groundwater- surface water interaction areas) are identified and land-based activities are managed accordingly
2. Maintain and protect groundwater quality of non-saline sources for human consumption and other uses	7. Select locations in the basin are monitored to document groundwater quality and assess changes outside historic variability (i.e., TDS and major ions outside established control limits or exhibiting unacceptable trend), and managed accordingly.
	8. Groundwater quality in important GW-SW interaction areas (e.g., streams, lakes) is assessed for key nutrients (N, P), pathogens (fecal coliforms), major ions, TDS, trace elements (e.g., As), and other relevant organic and inorganic contaminants, and managed accordingly.

	9. Risks to groundwater from oil and gas development, nutrient loading, and pesticide use (i.e., transport and fate characteristics) are understood and monitored sufficiently.
	10. Activities in the upper headwaters are restricted in areas where GW-SW interaction is important to the health of the tributaries and related streams.
3. Protect and maintain groundwater-dependent ecosystems	11. Groundwater contributions to surface water bodies are not to be adversely affected, particularly 1 <sup>st</sup> and 2 <sup>nd</sup> order streams, sensitive lakes and important wetlands.
	12. Risks associated with gravel extraction from river-connected deposits are understood and managed to ensure against adverse impacts to connected aquatic systems or nearby groundwater users.
4. Understand saline aquifer water volumes and how this fossil resource is being managed	13. Volumes of saline groundwater used to support various development activities (e.g., oil and gas development) are properly allocated and sufficiently monitored to ensure sustainable use.
	14. Potential impacts effects (quantity or quality) stated in project applications compare well to actual monitoring results.
5. Understand the role the climate variability and change play on the balance of groundwater storage	15. Dynamic water storage due to changes in precipitation and recharge is understood, and higher-risk basins are identified.
	16. Mitigation strategies are identified in advance of upset events, including options to ensure water security for all uses.

### Draft Indicators and Targets for Groundwater

Indicator	Scale of Analysis	Targets	Notes
Water levels	Areas with large diversions and risk of cumulative effects (i.e., overlapping drawdown cones)	Drawdown in major aquifers to be ≤50% of available head near the pumping centre (i.e., 150 m radius).	Consistent with Water Conservation and Allocation Guideline (2006)
Water flows	Sensitive reaches of streams and rivers	No more than a 10% reduction in baseflow contribution to 1 <sup>st</sup> and 2 <sup>nd</sup> order streams	
		No more than a 15% reduction in baseflow contribution to 3 <sup>rd</sup> order streams and higher	
Nutrients (N and P) and trace elements	High loading areas; sensitive aquifers	No change in shallow groundwater (e.g., <30m depth) outside established statistical control limits (e.g., see Section 4.16.2)	Trace element scans to include Arsenic, Mercury, Selenium, and Uranium
Pesticides and pathogens	Local to sensitive aquifers	If detected, concentrations should be stabilized and reversed back towards natural conditions, if practical	

Indicator	Scale of Analysis	Targets	Notes
Dissolved gases	Basin-wide; high risk areas	Increased knowledge of presence in aquifers and related source(s)	Expand on current baseline monitoring related to CBM
Sectoral water use	Basin-wide	30% increase in water productivity and efficiency over next 5 years	Consistent with Alberta's <i>Water for Life</i> goal and recent Alberta Water Council sectoral plans
		Monitoring of key source aquifers (non-saline and saline) to ensure management within sustainable supplies (e.g., no more than a 50% reduction in available head)	
Monitoring programs	Basin-wide; high risk areas	Establishment of an adaptive, groundwater monitoring system	Should be consistent with regional planning initiatives (i.e., SSRP) and degree of data volume and quality (GOWN wells plus others)
		At least 12 sites commissioned by end of 2014	
Evaluation process	Basin-wide; major aquifers utilized	Evaluate existing GW quality data and initiate evaluation process by end of 2014	
		Knowledge of water level variability and implications of climate change acquired by 2017	A provincial-scale study has been commissioned by Alberta Innovates and will be completed by 2016
Communication	Basin-wide	Established website and fact sheet to communicate state of groundwater and surface water conditions (inventory & dynamics)	
		Secure regular media coverage	

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## 1. INTRODUCTION AND CONTEXT

The Red Deer River Watershed Alliance (RDRWA) was formed to promote watershed health and guide water resource management in the Red Deer River watershed. It was designated as the Watershed Planning and Advisory Council (WPAC) for the Red Deer River watershed in September 2005 under the Government of Alberta's Water for Life Strategy. The fundamental goal of the Water for Life Strategy (GOA, 2003; GOA, 2008a) is to ensure sustainable management of the province's water resources so Albertans are assured of:

- Safe and secure drinking water supply
- Healthy aquatic ecosystems
- Reliable quality water supplies for a sustainable economy

As indicated in Alberta's Water for Life Strategy, WPACs are responsible for *“leading watershed planning, developing best management practices, fostering stewardship activities within the watershed, reporting on the state of the watershed, and educating users of the water resource.”*

In 2009, the RDRWA released its State of the Watershed Report (SOW) (Aquality, 2009). Currently, the RDRWA is in the process of developing an Integrated Watershed Management Plan (IWMP) for the Red Deer River basin that transforms the information in the SOW report into a planning process that will establish desired outcomes, indicators, and targets. The terms of reference as approved by the RDRWA Board of Directors state that the objectives of the IWMP are:

- To set targets and thresholds for water quality, land use, biological, and water quantity indicators as reported in the State of the Watershed Report
- Through the process of identifying targets and thresholds, stakeholders can work out mutually acceptable solutions for the protection, restoration, and/or maintenance of the health of the individual sub-watersheds as well as the Red Deer River watershed as a whole
- To make recommendations such as Beneficial Management Practices, market-based instruments, monitoring strategies, and future research priorities that may eventually be reflected in policies
- To provide information and guidance to stakeholders in developing their action plans to implement the recommendations of the IWMP
- To provide decision makers with the relevant information specific to the Red Deer River watershed essential for its effective protection, restoration, and/or maintenance as a healthy watershed

### 1.2 Study Scope and Objectives

The RDRWA's vision is that the IWMP will help to achieve or exceed requirements under government regulations. Moreover, management efforts will be directed towards maintaining current conditions where they are good, and improving conditions where they have deteriorated because of human activities. The RDRWA has commissioned three background reports to date to support the development of the IWMP that collectively aim to provide a solid scientific basis for the IWMP, which ultimately will help meet the RDRWA's vision:

***“The Red Deer River Watershed will be healthy, dynamic and sustainable through the efforts of the entire community.”***

The first Background Technical Report for the IWMP focused on surface water quality, and was completed in early 2012 (Anderson, 2012). The second Background Technical Report summarized information on land use, riparian areas, and wetlands (O2, 2013). This study constitutes the third Background Technical Report, and addresses the topics of (i) groundwater quantity and quality and (ii) surface water quantity. All IWMP components are intimately related, and consistent links and interrelationships between the different topic areas will be critical for crafting a successful IWMP.

This document aims to:

- Ensure groundwater and surface water resources are comprehensively described and mapped using the best available information and data
- Define outcomes and propose indicators and potential quantitative targets for managing groundwater and surface water resources in the basin at multiple scales
- Build on and complement the information in the State of the Watershed Report (Aquality, 2009) as well as the first and second Background Technical Reports

### 1.3 Technical Team Input

The RDRWA expanded its Technical Advisory Committee (TAC) by assembling additional Technical Team members who were consulted for their expertise in groundwater and surface water resources and familiarity with the Red Deer River basin.

Engagement and input from the Technical Teams took the form of a survey, distributed in May 2013, some follow-up conversations by phone with selected Technical Team members, and circulation of the draft document for comments. A web conference in early September 2013 provided opportunities for discussion, commenting, and feedback prior to releasing the report to the public and stakeholders.

### 1.4 Report Structure

This report is structured as a series of chapters. Chapter 1 provides an introduction to the context and scope. Chapter 2 provides some additional background information on outcomes, indicators, targets, and risk management in a watershed planning process. Chapter 3 focuses on hydrology and surface water quantity. Chapter 4 focuses on groundwater resources. Both Chapter 3 and 4 include background information, baseline data, draft outcomes and targets for indicators, and recommendations related to monitoring and data acquisition, research needs, and suggested Beneficial Management Practices for different stakeholder and industry groups. Chapter 5 provides a brief conclusion and summary of the study's findings.

Three appendices complement the main report. Appendix A illustrates the estimated effects of river flows on the Red Deer River's aquatic environment (Goater et al. 2007) (formatted as an 11" x 17" sheet for legibility). Appendix B lists existing Groundwater Observation Monitoring Wells (GOWN) in the Red Deer River watershed and related attribute data. Appendix C provides comprehensive maps of surface and groundwater resources, which are referred to throughout the main body of the report and provide visualization of watershed conditions.



## 2. OUTCOMES, INDICATORS, AND TARGETS

Outcomes, indicators, and targets are important to synthesize information on watersheds, which contain many complex, interrelated variables. Indicators are also important to craft feasible monitoring and management programs. For a WPAC, indicators are critical to measure an organization's progress towards meeting its vision, as well as specified outcomes and goals. This contributes to a performance management system that gauges success through time.

Throughout the watershed planning and implementation process, indicators and targets should be selected, refined, and modified to reflect changing conditions and priorities. As the watershed planning process proceeds, a measureable target is set for each indicator, which allows for measuring progress and ultimately reaching the target (USEPA, 2008).

Watershed management plans should aim to provide a set of environmental, programmatic, and social indicators, as defined below. In addition, indicators selected must be influenced by several considerations including validity, clarity, and practicality of the selected indicators.

### Definitions

**Outcomes** are the desired future conditions that guide the development and implementation of an organization's recommendations.

**Indicators** are measurable surrogates for end points of value to the public. Indicators measure progress towards achieving the desired outcomes.

**Targets** are specific, quantitative values assigned to indicators that reflect a desired outcome.

### Factors to consider when selecting watershed indicators

(USEPA, 2008; Davenport, 2003)

#### Validity:

- Is the indicator related to your goals and objectives?
- Is the indicator appropriate in terms of geographic and temporal scales?

#### Clarity:

- Is the indicator simple and direct?
- Are the methodologies consistent over time?

#### Practicality:

- Are adequate data available for immediate use?
- Are there any constraints on data collection (e.g., costs, available technology)?

#### Clear Direction:

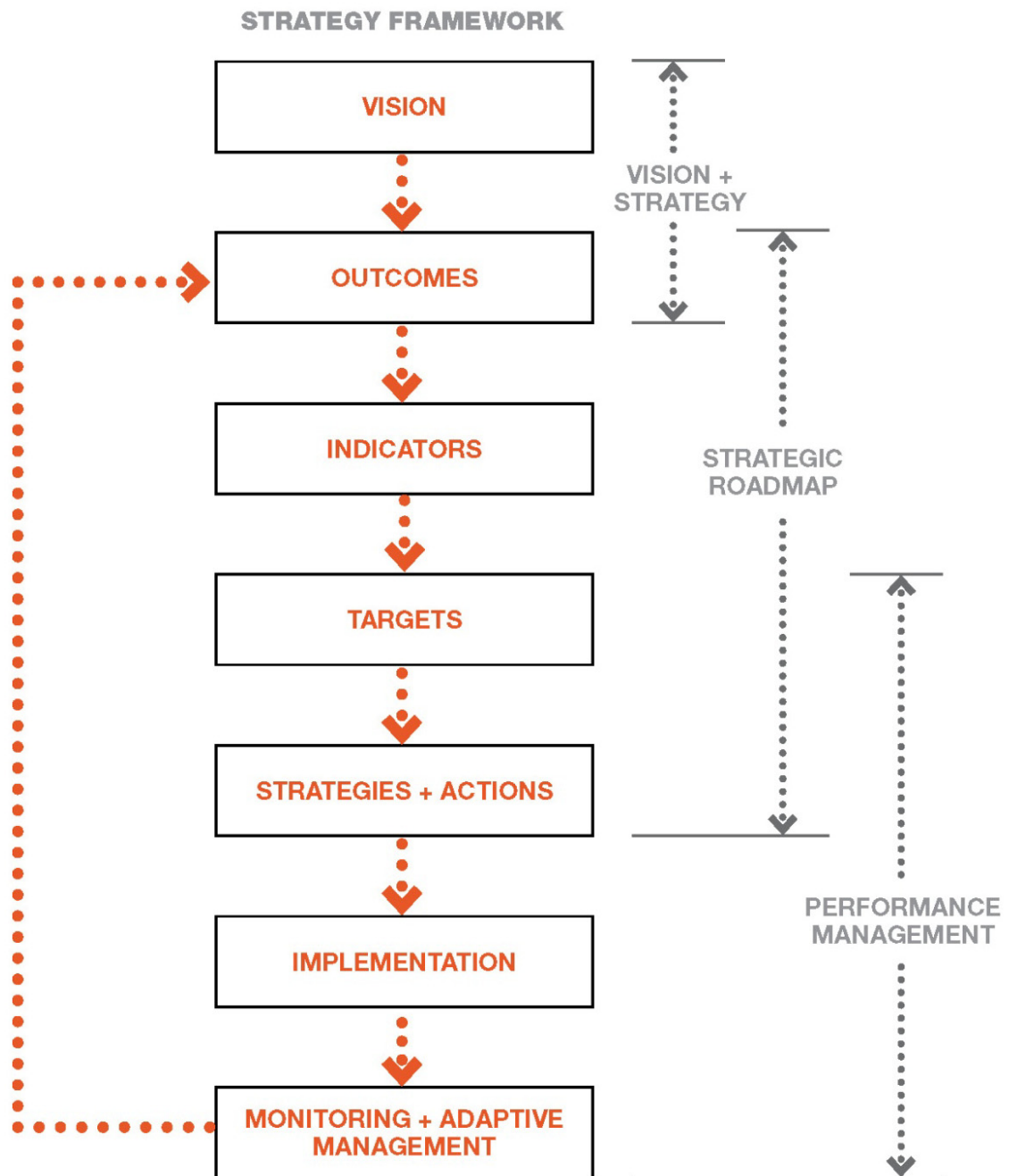
- Does the indicator have clear action implications depending on whether change is good or bad?

### 2.1.1 Environmental Indicators

Environmental indicators are based on observed variables of concern in the watershed as well as sources of degradation that contribute to impacts on the aquatic environment. For example, reach-specific water flow conditions that support instream flow needs during average and extreme hydrological conditions are important. Equally important are the water use and land use factors that can potentially influence observed water flows.

Previous work in the watershed listed 20 recommended indicators in four major categories, including indicators and metrics related to groundwater and surface water quantity (Aquality, 2008). The *"Guide to Reporting on Common Indicators Used in State of the Watershed Reports"* (AESRD, 2012) was also consulted for ideas on


indicators. Both of these sources of initial information on environmental indicators for groundwater and surface water are summarized in Table 1<sup>1</sup>.



**Figure 1. A Strategic Framework to Link Outcomes, Indicators, Targets, and Strategies in an Adaptive Management Process** (Source: O2)

<sup>1</sup> The Technical Advisory Committee (TAC)'s review of *Data Gaps in Watershed Health Indicators* (RDRWA, 2011) was also reviewed as a source of information to determine potential indicators for groundwater resources and surface water quantity.

**Table 1. Examples of *Potential* Environmental Indicators for Groundwater and Surface Water**  
(as recommended by AESRD (2012) and/or Aquality (2008))

Indicator <sup>2</sup>	Metrics
<b>Surface Water</b>	
Licensed Allocations	Millions of m <sup>3</sup> per year
Licensed Allocations as a Proportion of Mean Annual Flow	% of mean annual flow
AESRD Historical Lake Level Index (for the 27 lakes listed on AESRD's <i>State of the Environment – Status of Alberta Lake Levels</i> )	“Much below normal” to “much above normal”
Alberta River Flow Quantity Index (ARFQI) <sup>3</sup>	 <p>Seasonal flow exceeded outside of natural range ] Increased Outside of Natural  Seasonal flow above normal natural ] Above Normal  Seasonal flow within normal natural ] Normal  Seasonal flow below normal natural ] Below Normal  Seasonal flow much below normal natural ] Stressed  Seasonal flow diminished outside of natural range ] Reduced Outside of Natural</p>
Deviation of recorded flows from Water Conservation Objectives (WCO)	m <sup>3</sup> /s (minimum flows) % of the natural flow rate
Deviation of recorded flows from Instream Flow Needs (IFNs)	m <sup>3</sup> /s (minimum flows)
<b>Groundwater</b>	
Licensed Groundwater Allocations	m <sup>3</sup> /year (e.g., mapped for each Section)
Unlicensed Allocations and Withdrawals	Known number of domestic wells (Alberta's water well database) multiplied by an estimated usage of approximately 365 m <sup>3</sup> /household/year
Groundwater Well Density	Total # of water wells (mapped spatially for, e.g., each township)

### 2.1.2 Programmatic and Social Indicators

Technical watershed reports often neglect or overlook “softer” *programmatic and social indicators* that are important to establish and track in addition to environmental indicators (Davenport, 2003).

*Programmatic indicators* measure actions taken that are intended to achieve a goal. Examples include:

- Number of municipalities adopting water conservation bylaws or policies
- Number of groundwater monitoring wells present in vulnerable areas

*Social indicators* measure changes in social or cultural practices, such as increased awareness of watershed issues, and behavioural changes that lead to implementation of management measures, increased stewardship, and lower risks of impacts. Examples of social indicators include:

<sup>2</sup> See glossary for definitions of WCO, IFN, and ARFQI.

<sup>3</sup> In the Red Deer River basin, AESRD only calculates the ARFQI for the City of Red Deer gauge. Technical reviewers of this document recommended that AESRD consider expanding this to measure the indicator at Empress/Bindloss as well.

- Rates of citizen participation in watershed restoration activities
- Knowledge / attitudes among resource industries and/or field staff

### 2.1.3 Indicators, Targets, Scale, and Geography

Watershed Planning and Advisory Councils (WPACs) should select a number of assessment techniques for watershed indicators at several spatial scales (AENV, 2008a). In addition, targets and management objectives should ideally differ in a watershed in response to spatial patterns driven by natural, hydrological, geological, and anthropogenic factors. The selection of planning units and scales for indicators and targets must be easy to communicate so they can be understood and applied broadly. The planning units selected for analysis in this report included four defined reaches for the Red Deer main stem, as well as 16 sub-watersheds, as shown on **Map 1: Reaches and Sub-watersheds**. A detailed justification for the selection of these areas is provided below.

For surface water and hydrology, specific contributing areas upstream from long-term, water-gauging stations are the most logical units for assessment and planning purposes. In addition, for the Red Deer River mainstem, specific reaches have been defined and tied to Water Conservation Objectives (WCOs) (AENV, 2007) and Instream Flow Needs (IFNs) (Clipperton et al., 2003). These reaches are associated with specific upstream contributing areas that form logical units for indicators and targets. However, the State of the Watershed report (Aquality, 2009) assessed issues based on 14 defined sub-watershed boundaries. The Phase 2 *Background Technical Report on Wetlands, Riparian Areas and Land Use* for the IWMP maintained consistency with these sub-watershed boundaries for data analysis (O2, 2013). Yet complications arise in situations where contributing areas for flow-gauging stations do not match the delineated sub-watersheds. In some cases (e.g., Threehills sub-watershed), multiple gauging stations are present, whereas in others (e.g., Raven sub-watershed), the gauging station near Raven is far from the mouth of the river and cannot be used to assign values to the sub-watershed as a whole (See **Map 2: Red Deer Watershed Surface Water Monitoring**). To deal with mismatches present between gauging stations and the sub-watersheds as described above, weighted averages for some data sets (e.g., water yield) were used to assign values to specific sub-watershed polygons.

Another identified reporting unit issue was that the defined sub-watersheds (Aquality, 2009) grouped many smaller tributaries with larger tributaries. In many cases the smaller tributaries are hydrographically separate and stream-gauging stations may capture flow records of these grouped small and large tributaries at different locations. The most prominent example of this is where Fallentimber Creek is grouped together with the Little Red Deer River sub-watershed. Fallentimber Creek enters the Red Deer River near Sundre and has its own hydrometric gauging station, whereas the Little Red Deer River enters the Red Deer River downstream from the Dickson Dam, in a separate reach as defined by the province. Another example includes a small area north of Red Deer including Blackfalds Lake that was grouped with the Waskasoo sub-watershed, which is separate hydrographically and only occurs south of the Red Deer River. Many other small coulee systems adjacent to the Red Deer River Valley were also grouped together with larger adjacent sub-watersheds.

With these factors in mind, this project aimed to:

- Define a set of planning units at different scales to help frame indicators and targets in a simple yet relevant manner for surface water and hydrology
- Achieve a realistic level of accuracy without requiring a large amount of additional GIS processing

The solution was to first conduct an analysis for specific reaches on the Red Deer River mainstem, followed by a more detailed analysis of tributaries based on the sub-watershed boundaries. For the Red Deer River mainstem, four separate reaches and associated upstream contributing areas were defined (Table 2). Fallentimber Creek was defined as a new sub-watershed, but other minor inconsistencies within the sub-watersheds were considered acceptable at this scale of analysis and were therefore left to be as consistent as possible with the State of the Watershed (SOW) sub-watershed boundaries. For analyses of tributaries, sub-watersheds from the SOW report were generally used to maintain consistency, although an additional sub-watershed for Fallentimber Creek was defined and reported on separately due to the issues described above.

In the case of groundwater, the location and interrelationships between groundwater aquifers exhibit complex 3-dimensional subsurface patterns. Consequently, there is a large number of potential spatial groundwater

reporting units. For the purpose of consistency and ease of interpretation, reporting units for groundwater were kept consistent with the major regions and sub-watersheds used to describe the surface water resources. However, in the future, a more detailed analysis of the groundwater system and related issues may be in order, which would examine specific bedrock, buried channels, and near-surface sand and gravel aquifers, potentially setting targets for the areas corresponding to each individual aquifer, or portions thereof.

**Table 2. Sub-watersheds and Grouped Reaches**

Grouped Reach for the Main Stem	Water Survey of Canada Gauging Station	Coordination with WCO Objectives (AENV 2007)	Coordination with IFN Reaches (Clipperton et al. 2003)	Queried Upstream Drainage Area (km <sup>2</sup> )	Sub-Watersheds	Comparison to Landscape Units (Phase 2 Background Technical Report)	Comparison to Water Quality Reaches (Phase 1 Background Technical Report)
1. Upper Headwaters to Dickson Dam	Dickson Dam Tunnel Outlet (05CB007)	No specific WCO objectives for this reach	No IFN studies have been done for this reach	5,591	Includes the Panther, James, Raven, Fallentimber sub-watersheds	All of the Upper Headwaters region + Raven and Fallentimber sub-watersheds	Reach 1 - Headwaters to Hwy 22 (Sundre) Reach 2 - Hwy 22 to upstream of Gleniffer Lake
2. Dickson Dam to Red Deer upstream of the Blindman River confluence	Red Deer River at Red Deer (05CC002)	Consistent with established WCO for "Dickson Dam to Blindman River confluence"	Includes IFN Reaches RD6 (a very short segment) and RD7	6,410 (12,001 cumulative upstream drainage)	Includes the Medicine, Little Red, and Waskasoo sub-watersheds	Most of the Lower Headwaters region + Waskasoo sub-watershed; does not include Raven or Fallentimber sub-watersheds	Reach 3 - Gleniffer Lake to Hwy 2 (Red Deer)
3. Red Deer to Drumheller	Red Deer River at Drumheller (05CE001)	Encompasses reaches with a WCO established for "Blindman River to the Saskatchewan Border"	Includes IFN Reaches RD 4 and RD5, which were also grouped together in Clipperton et al. (2003)	16,015 (28,016 cumulative upstream drainage)	Includes the Blindman, Buffalo, Threehills, Kneehills, and Michichi sub-watersheds	Most of Central Agricultural region + Blindman sub-watershed; does not include the Rosebud sub-watershed	Reach 4 - Hwy 2 to Nevis  Reach 5 - Nevis to Morrin (upstream of Drumheller)
4. Drumheller to Saskatchewan border	Red Deer River near Bindloss (05CK004)		Includes IFN Reaches RD1, RD2, and RD3, which were also grouped together in Clipperton et al. (2003)	22,193 (50,209 cumulative upstream drainage)	Includes the Rosebud, Matzhwin, Berry, and Alkali sub-watersheds	Most of the Dry Grasslands region; also includes the Rosebud sub-watershed	Reach 6a - Morrin to Jenner  Reach 6b - Jenner to Bindloss

Note: As upstream contributing areas are nested and cumulative, nested reaches of A=1, B=1+2, C=1+2+3, and D=1+2+3+4 were also defined and used for some analyses

### 2.1.4 Targets, Risk, and Cumulative Effects Management

Cumulative effects are the result of multiple activities occurring through time and space. The federal practitioners' guide defines cumulative effects as "*changes to the environment that are caused by an action in combination with other past, present and future human actions*" (Hegmann et al., 1999). Cumulative effects tend to occur because of mismatches in the scale at which impacts accumulate and the scale at which decisions are made. The consequences of human activities often appear insignificant on an individual project-by-project basis, but accumulate to levels of significance when broader or different scales of time and space are considered (Kingsley, 1997).

Cumulative impacts are rarely linear, and are more typically characterized by sudden non-linear shifts, critical thresholds, and surprises (Folke et al. 2004). Ecosystems are complex, dynamic, and adaptive systems, and rarely follow simple, predictable, linear changes through time. Long periods of stability, punctuated by abrupt, rapid, non-linear change to an alternative state are characteristic features of most ecosystems. These "surprises" are caused by complex interactions between ecosystem resilience and the cumulative effects of multiple stressors. Often, ecosystems are resilient to a certain level of stress and will show little change. However, if multiple stressors are crowded in space and time, a sudden "trigger" or critical threshold can be surpassed, causing the ecosystem to "flip" into an alternative state. Well-documented examples of these "non-linear" changes include shifts from clear water to turbid water conditions in temperate lakes (Carpenter et al., 1999)<sup>4</sup> and shifts from hard corals to macro algae in coral reef ecosystems (Hughes, 1994).

The concept of cumulative effects also applies to groundwater systems, where multiple activities can lead to additive effects, such as overlapping drawdown cones or non-point source contamination of a shallow aquifer. The difference between the surface water environment and the groundwater environment relates to the amount of time it takes for the effect to occur, and how and when that effect may result in an adverse condition. Groundwater quality or quantity effects can take from several years to decades to manifest themselves. This needs to be considered when developing monitoring and evaluation programs for the subsurface environment.

It can be very difficult to predict what combination of cumulative effects will cause unacceptable change. However, once a system has "flipped" into a degraded state, it can be difficult and sometimes even impossible to restore it back to its former condition.

### 2.1.5 Targets and Management Responses

Management responses need to be driven by, and linked to, established indicators and targets specifying the desired level, or range, an indicator must achieve or maintain through time. The aim is to be proactive to help avoid reaching potential critical thresholds where undesirable conditions and unacceptable environmental, social, or economic impacts occur. Determining the appropriate target value for an indicator often requires a blend of science, planning, and social values. This is because *ecological* thresholds, defined as a critical value at which sudden, non-linear and often irreversible change occurs (Folke et al., 2004), are notoriously difficult to quantify and predict. Data gaps and incomplete information are also a challenge when formulating targets. The natural range of variability in environmental conditions must also be considered carefully.

**However, in the absence of perfect scientific knowledge, planning exercises still require management targets.** Targets must be set by integrating existing knowledge and data, expert analysis, and socioeconomic considerations. Adaptive management frameworks are also useful. Effective adaptive management requires testing of assumptions, and iterative analysis through time to refine or change targets as necessary in response to new data and information.

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<sup>4</sup> However, in cold boreal lake environments, natural oscillations between clear and turbid regimes can also occur (Bayley et al., 2007).



### 3. Surface Water Quantity

This chapter focuses on hydrology and surface water quantity. Included are sections on hydrology and surface water supplies (3.1), surface water use and demand (3.2), a synthesis of current policy and management issues (3.3), a list of key issues for surface water quantity (3.4), draft goals and outcome statements for surface water quantity (3.5), draft indicators and targets for surface water (3.6). The section concludes with a description of management implications and recommendations (3.7).

#### 3.1 Hydrology and Surface Water Supplies

The Red Deer River watershed is the largest of the four sub-basins in the South Saskatchewan River watershed. However, it is the smallest by flow volume, contributing an average of 20% to the annual flow of the South Saskatchewan River. The river originates in Banff National Park, located in the Rocky Mountains, and flows through foothills, parkland, and prairie landscapes to join the South Saskatchewan River about 8 km east of the Alberta-Saskatchewan border (**Map 1**). The topography and landscape of the basin influences the climate, soils, vegetation and settlement patterns, as well as water quantity and quality.

##### Cumulative Effects and the Land Use Framework

Cumulative effects management frameworks, including those related to surface water and groundwater, are being included in the regional plans under development for the provincial *Land-use Framework*. Each regional plan will identify specific triggers and limits for selected indicators. **The RDRWA could contribute to this process by developing a set of watershed-based cumulative effects indicators for further consideration in the Red Deer Regional Plan.**

##### 3.1.1 Hydrologic Cycle

The hydrologic cycle describes the continuous movement of water on, above, and below the surface of the earth. It represents a continuous cycle where water is transferred from the oceans and the land surface into the atmosphere by evaporation and transpiration, dropped on the land as precipitation (leading to groundwater recharge), and transferred back to the sea by rivers and groundwater (Figure 2).

The traditional focus for water resources management and planning is on the liquid water component of the hydrologic cycle, i.e., precipitation, water in lakes, rivers, wetlands, and aquifers (Falkenmark & Rockstrom, 2006). The approach proposed by Falkenmark and Rockstrom (2006), allows the partitioning of precipitation into blue water and green water resources (Figure 3). Blue water is derived from rainfall that enters lakes, rivers and groundwater. Green water includes all precipitation that is either intercepted by vegetation, or enters the soil and is evapotranspired back to the atmosphere. Two complementary flows result: the liquid “blue” water flow through rivers and aquifers, and the “green” water vapour flow back to the atmosphere. Only about 30-35% of all water in the global hydrological cycle is blue water, and even lower amounts occur in many parts of southern and central Alberta. The blue water component is, however, the main source of water used for industrial, domestic and irrigation purposes (Schreier & Pang, 2012).

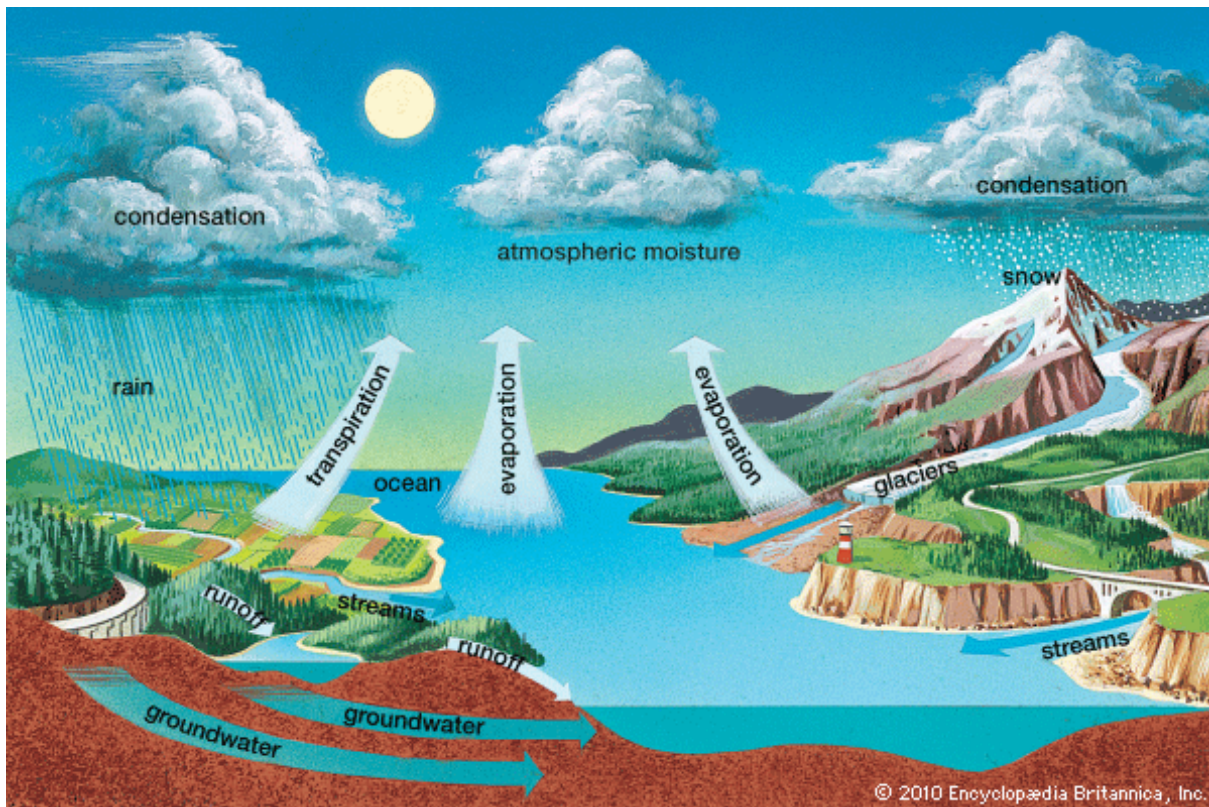


Figure 2. The Hydrologic Cycle (Encyclopædia Britannica, 2010)

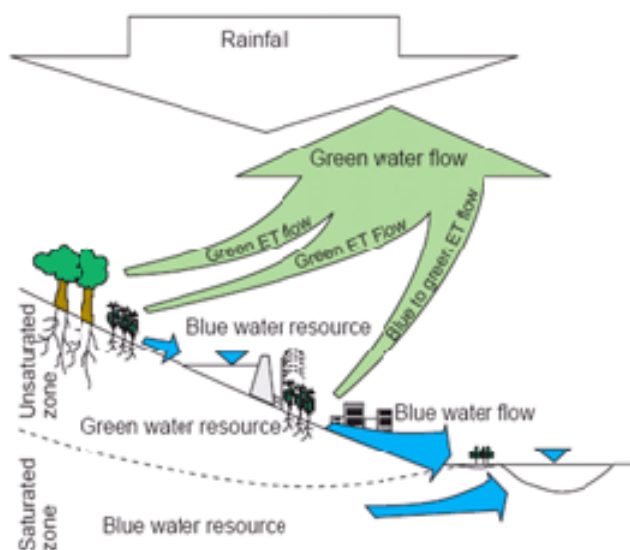


Figure 3. Blue/Green Water Cycle (Falkenmark & Rockstrom, 2006)

Note: ET = evapotranspiration

#### New Gauging Stations in the Watershed

The HYDROMET committee recently installed the following new hydrometric gauging stations (**Map 2**):

- Red Deer River near Nevis (re-activation of discontinued station 05CD004)
- Ghostpine Creek
- Medicine River near the Mouth
- Rosebud River near the Mouth
- Bullpound Creek upstream from Coleman Lake

### 3.1.2 Climate and Precipitation

Climate and precipitation in the Red Deer River watershed are monitored by a network of 35 meteorological stations as shown in **Map 2**. Average climate and precipitation vary in the watershed in a general west to east

pattern as shown in Table 3. Some general trends in climate and precipitation can be identified based on Natural Regions (AMEC, 2009)<sup>5</sup>.

- The Rocky Mountain area has lower average temperatures and higher precipitation than areas to the east. Average precipitation is about 780 mm, with a large proportion occurring as snowfall. The mountainous areas in Alberta are sometimes referred to as the “water towers” of the prairies due to the large contribution of runoff in relation to their size. Local precipitation patterns in the area are variable due to orographic effects on prevailing westerly winds.
- The median temperature in the Foothills area is somewhat above the temperature in the mountains and slightly below areas to the east. The average precipitation in the Foothills area is about 495 mm. Most of the precipitation occurs in the summer months where July is the wettest month of the year.
- The climate in the Boreal Forest natural region is continental, with large differences between summer and winter temperatures. On average, temperatures are similar to the Foothills region. Average annual precipitation is about 380 mm, about two-thirds of which occurs in summer. July is the wettest month.
- Median temperatures in the Parkland region are slightly higher than the Boreal region and slightly less than the Grassland region further to the east. Average annual precipitation is about 405 mm, with the majority of precipitation falling in the summer months.
- The climate of the Grassland region is continental, with long cold winters, short summers and generally low precipitation. Average precipitation is about 350 mm, with the majority falling in the summer months.

**Table 3. Median Average Annual Precipitation by Natural Sub-region**

<b>Natural Region and Nested Sub-regions</b>	<b>Average Annual Precipitation (mm)</b>
<b>Rocky Mountains Natural Region</b>	<b>780</b>
Alpine	650
Sub-alpine	930
Montane	600
<b>Foothills Natural Region</b>	<b>495</b>
Upper Foothills	540
Lower Foothills	465
<b>Boreal Forest Natural Region</b>	<b>380</b>
Central Mixedwood	380
Dry Mixedwood	380
<b>Parkland Natural Region</b>	<b>405</b>
Central Parkland	400
Foothills Parkland	575
<b>Grassland Natural Region</b>	<b>350</b>
Northern Fescue	400
Foothills Fescue	575
Mixed Grass	340
Dry Mixed Grass	270

<sup>5</sup> The AgroClimatic Information Service of Alberta Agriculture provides a set of Alberta climate and atlas maps that are updated regularly and include informative maps, information and data: <http://www.agric.gov.ab.ca/acis/climate-maps.jsp>, while the weather data viewer enables download of station-specific information: <http://www.agric.gov.ab.ca/acis/alberta-weather-data-viewer.jsp>

### 3.1.3 Hydrology

The Red Deer River originates in the Rocky Mountains and flows east for over 800 km through foothills, parkland, and prairie landscapes. The gross drainage area of the Red Deer River is over 49,000 km<sup>2</sup>. The effective drainage area of the watershed is about 32,400 km<sup>2</sup> due to large tracts of non-contributing area<sup>6</sup> in the lower watershed. The non-contributing areas make up about 31% of the overall drainage area and are characterized by flat slopes and poorly developed drainage (AMEC, 2009). A map of non-contributing areas is shown in **Map 3: Non-Contributing Drainage Areas**. Elevation in the watershed ranges from a high of about 3350 m in the Rocky Mountains to a low of about 300 m near the border with Saskatchewan.

There are two glaciers in the upper watershed: the Drummond and the Bonnet. Glacial melt contributes very little to the overall flow of the river (Gill et al., 2008). The Water Survey Canada (WSC) monitors stream flows at over 50 locations and AESRD monitors snow pack depths at two locations in the Red Deer River watershed (See **Map 2**). Based on analysis of the WSC records, most of the flow in the river at the Saskatchewan border (Bindloss) has been accumulated by the time the river reaches the City of Red Deer. Runoff originating in the headwaters from the mountain and foothills zones contributes about 80 % of the natural river flow at Bindloss, despite only accounting for 20 % of the overall watershed area. Since discharge is largely governed by runoff from the headwaters, lower reaches of the river can be vulnerable reduced flows and drought events, particularly during late summer (Gill et al., 2008).

Flows in the Red Deer River generally follow a seasonal pattern (Figure 4) and are highly variable from year to year depending on annual snowmelt and precipitation patterns (Figure 5). Typically, flows begin to rise in March and April as runoff from snowmelt at lower elevations in the headwaters reaches the river. Flows decrease as snowmelt at lower elevations becomes depleted. As temperatures increase in May and June, snowmelt from higher elevations causes stream flows to increase again. If heavy precipitation events coincide with periods of high snowmelt, flooding may occur. Flow decline usually begins in early to mid July and continues until the winter. During the remainder of the year, flows are usually low.

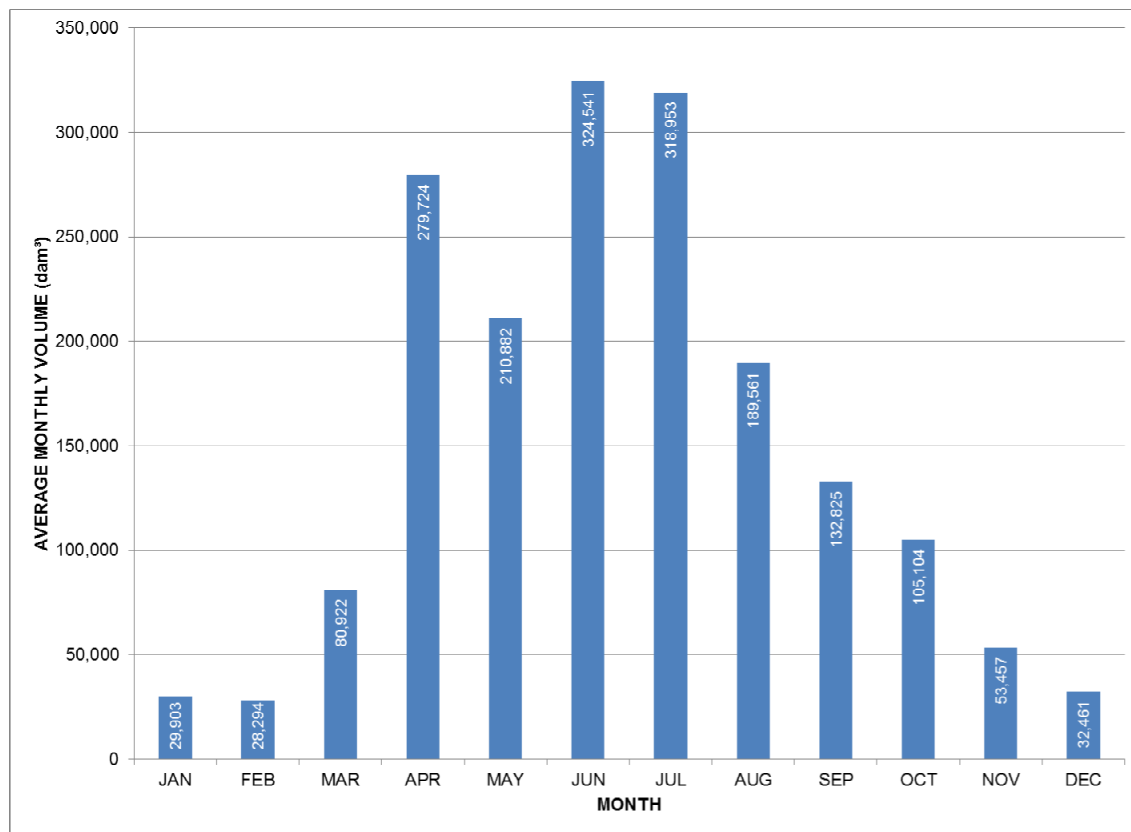
Flows in the Red Deer River have been regulated by the Dickson Dam since 1983. The Dickson Dam impounds the river to create the Glenniffer Reservoir, located about 40 km southwest of the City of Red Deer, and 35 km northeast of the Town of Sundre. Its primary purpose is to provide a reliable supply of high quality water downstream, including high water quality during winter (also see Section 3.1.6). According to AESRD (2004), the dam has little impact on annual flow volumes. However, it does increase the summer low flows by a small amount, and winter low flows have substantially increased (AMEC, 2009).

The **gross drainage area** of a stream at a specified location is that plane area, enclosed by its drainage divide, which might be expected to entirely contribute runoff to that specified location under extremely wet conditions. The gross drainage boundary is the drainage divide (i.e. the height of land between adjoining watersheds).

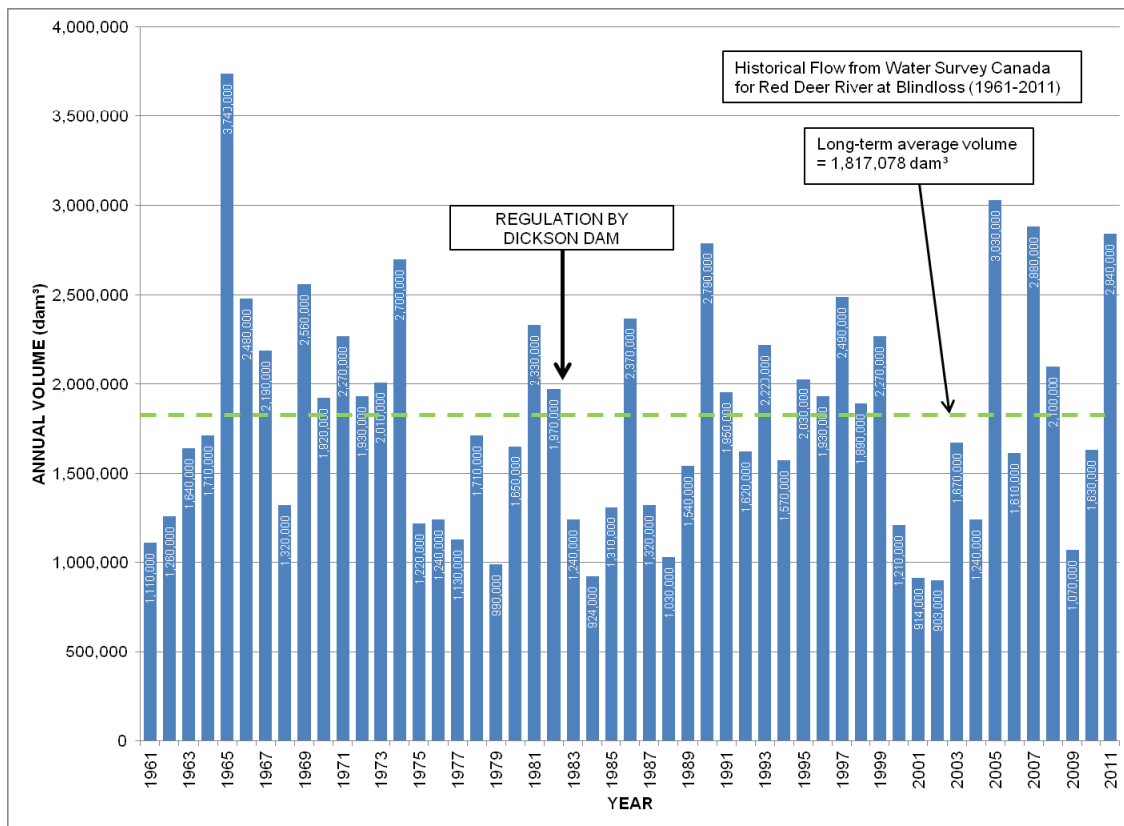
The **effective drainage area** is that portion of a drainage basin which might be expected to entirely contribute runoff to the main stream during a flood with a return period of two years. This area excludes marsh and slough areas and other natural storage areas which would prevent runoff from reaching the main stream in a year of 'average runoff'.

The **non-contributing area** is the area between the effective and gross drainage delineations. The portion of the non-contributing area that contributes to runoff in a particular event varies with the frequency of that event. Typically, under normal circumstances (1:2 year events) these areas contribute no surface flow downstream (PFRA, 2008).

<sup>6</sup> Non-contributing areas do not contribute surface flow to creeks and streams for a median (1:2) annual runoff, but they can become contributing areas by fill and spill processes during extremely wet periods



**Figure 4. Average monthly runoff volumes in cubic decameters (1 decameter = 1000 m³) for the Red Deer River at Bindloss (WSC Station 05CK004)**



**Figure 5. Average annual runoff volume in cubic decameters (1 decameter = 1000 m³) for the Red Deer River at Bindloss (WSC Station 05CK004)**



### 3.1.4 Glacier and Snowmelt Patterns

When glaciers make up a significant percentage of a watershed, meltwater contribution to river discharge can be a significant fraction of total annual discharge (Marshall & White, 2010). The fraction of the discharge becomes most important in late summer, since glacier melting and subsequent runoff peak around that time, while runoff from precipitation events and snowmelt are generally lower in Alberta. In some years this effect can also extend into the early fall. This delay in glacier melt until after spring/early summer precipitation and snowmelt subsides dampens inter-annual runoff variability and buffers against drought. For watersheds with high glacier cover, groundwater recharge and glacier meltwater can be dominant contributors to streamflow during summer droughts (e.g., Bow River at Banff) (Marshall & White, 2010).

Glacier cover in the Red Deer River Basin is fairly limited compared to other watersheds in Alberta. Glacier coverage accounts for only 16.6 km<sup>2</sup>, or 0.03% of the Red Deer River watershed area. For comparison, glacier cover accounts for 0.2% of the Bow River watershed area (Marshall & White, 2010). There are 22 glaciers identified in the Red Deer River headwaters of which the Drummond<sup>7</sup> and the Bonnet are the two main glaciers (Marshall & White, 2010). Glacier volume in the watershed is currently estimated at  $0.9 \pm 0.2$  km<sup>3</sup> and the estimated associated water volume in glaciers is approximately 0.63 to 0.99 billion m<sup>3</sup>.

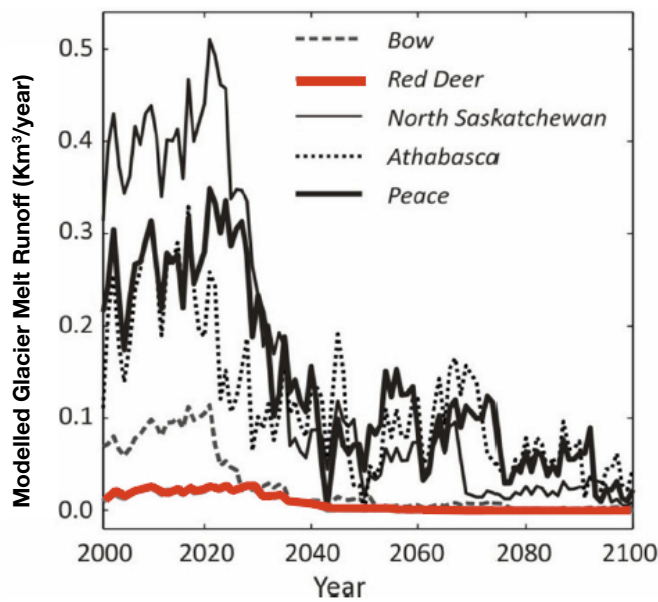
Meltwater from headwater glaciers contributes very little to the overall flow of the Red Deer River as the majority of river discharge is generated from rainfall and snowmelt from forested Rocky Mountain and Foothills natural regions (Gill et al., 2008). Since the influence of glaciers is proportional to the percentage of the catchment with glaciers (Marshall & White, 2010), the benefits of glacier meltwater mentioned above only have a minor influence on the Red Deer River, leaving the lower reaches of the river particularly vulnerable to possible declines in late summer flow (Gill et al., 2008). The annual contribution of glacial meltwater to streamflow in the Red Deer River is only approximately 0.6%, and accounts for about 1.8% during the summer months (July/August/September). Future climate predictions show a moderate decrease in glacial meltwater contributions to streamflow for the Red Deer River (Figure 6) (Marshall & White, 2010). Expected changes are fairly minor and not expected to have a major influence overall on flows in the Red Deer River, although there is uncertainty over whether this might upset the delicate balance of water supply for fall spawning species in tributaries of the Upper Headwaters, particularly during drought years.

Snowmelt is an important contributor to the annual runoff for the Red Deer River. Snow pillow data, collected at two locations in the Red Deer River Watershed, Skoki Lodge (05CA805) and Limestone Ridge (05DB802), show that snow depth (shown in snow water equivalent) is at a maximum at the end of April (Figure 7). The majority of the melting typically occurs throughout the month of May.

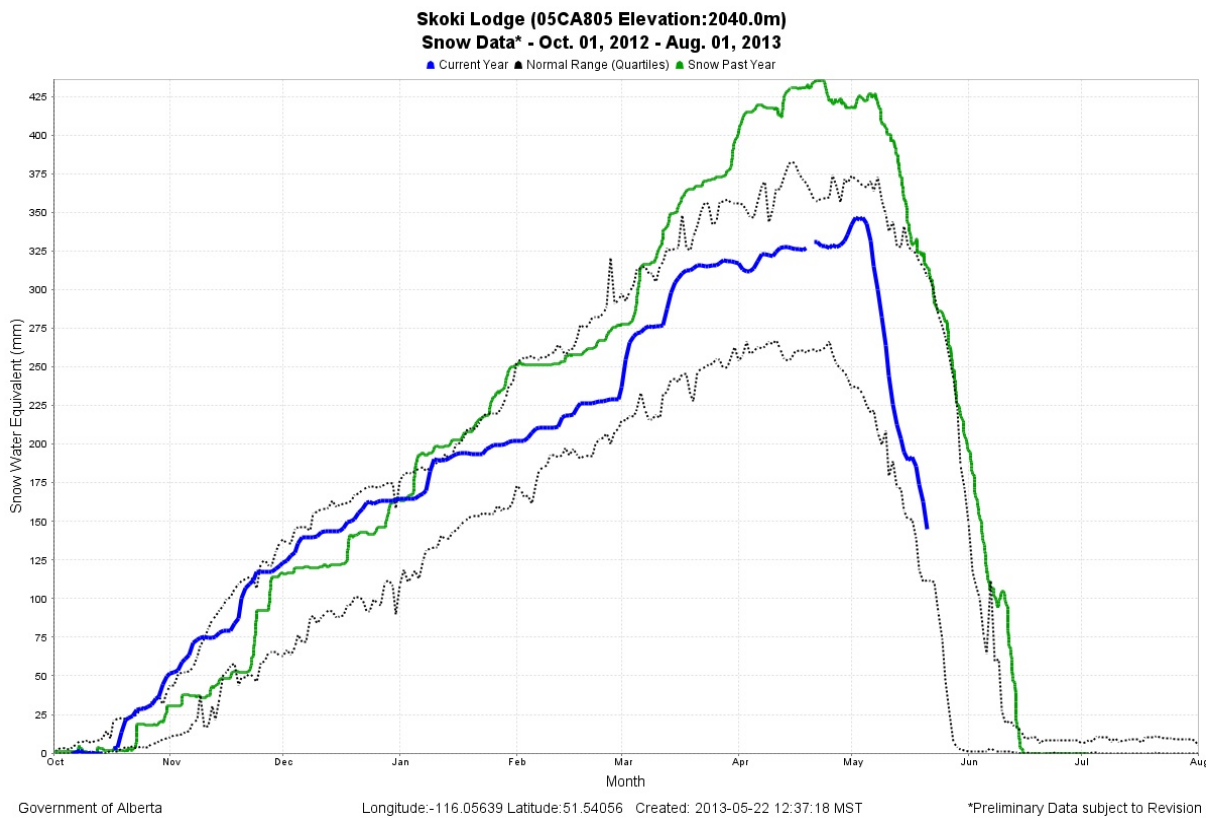
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<sup>7</sup> The Drummond Glacier has receded considerably since the late 1880s (Nelson et al., 1966), and recent estimates are that glaciers on Alberta's eastern slopes have lost 25% of their mass since 1985 (Marshall & White, 2010)





**Figure 6.** Projected Changes to Glacial Contributions to Stream Flow in the 21<sup>st</sup> Century  
Source: Marshall and White (2010)



**Figure 7.** Snow Pillow Monitoring Data for Skoki Lodge (Station No. 05CA805)

### 3.1.5 Water Yield

Water yield can be defined simply as the measured runoff from the drainage basin, and includes the groundwater contribution that appears in the stream (USGS, 2013). Water yield values are useful to summarize the “blue water” component of the hydrological cycle, or in other words, how much total water flows past a given point each year. Water yield statistics can be calculated at multiple scales and for many different time periods, including long-term averages, or can be used to examine variability across years or months. Water yield is a very integrative, informative way to look at how much water is present in different parts of the watershed under different conditions. It is a potentially useful way to examine and compare water supply to demand. Units for water yield can be expressed in several interchangeable ways, including:

- **mm:** representing the water depth converted to blue water flows from a particular drainage area (e.g., 150 mm = 0.15 m spread out over the entire area upstream from that point), usually associated with a particular unit of time (month, year)
- **dam<sup>3</sup>/km<sup>2</sup>:** cubic decameters per square kilometer (dam<sup>3</sup>/km<sup>2</sup>) is a volume unit per area for a particular drainage area, which is interchangeable with mm (mm depth across a watershed = dam<sup>3</sup>/km<sup>2</sup>), usually associated with an annual time unit
- **dam<sup>3</sup>:** (equivalent to 1,000 m<sup>3</sup> or 1 ML), this is a common unit used by hydrologists to assign a total volume to a particular drainage usually associated with an annual time unit (note: volume can also easily be calculated as: dam<sup>3</sup> = (dam<sup>3</sup>/km<sup>2</sup>) x (km<sup>2</sup> of area))
- **acre-feet:** another unit commonly used, particularly among irrigators, is the “acre-feet” unit, which is a unit of volume equal to the volume of one foot covering an area of one acre (one acre foot is equivalent to 43,560 cubic feet or 1,233.5 cubic metres, or alternatively, 1.2335 dam<sup>3</sup>)

For this study, water yield statistics conducted at various scales and probability frequencies for the Red Deer Watershed were pulled together and synthesized. These included<sup>8</sup>:

- **Alberta Innovates Water Yield Study** (Kienzle & Mueller, 2010): A province-wide study, conducted out of the University of Lethbridge, calculated water yields (mm) for polygons upstream from Water Survey of Canada stations with long-term monitoring records. A total of 34 stations in the Red Deer Watershed were assessed. The record lengths used in the analysis varied slightly but were generally from 1971-2000. Results for the Red Deer River Watershed, expressed as dam<sup>3</sup>/km<sup>2</sup> or mm for each polygon are shown in **Map 4: Mean Annual Water Yield (mm)**. In addition, **Map 5: Mean Annual Water Yield (%)** depicts the proportion of the total basin yield assigned to each polygon for the entire watershed. Table 3 also summarizes and compares the results of this study to the results obtained by Golder (2008).
- **Water Supply Assessment for Alberta** (Golder, 2008): This study included calculated water yields (mm) for the Red Deer River Basin both on an annual and a monthly basis. The record lengths used in the analysis varied depending on the station but generally were from the earliest times available at the station up to 2006. Table 4 also summarizes the results of this analysis for the purposes of the current study, and compares the annual values to the results obtained by Kienzle (2010).
- **Agriculture and Agri-Food Canada Water Yield Study** (AAFC, 2013): This recent national study calculated water yields for selected hydrometric stations (1,184 stations nation-wide, including 18 stations in the Red Deer Watershed). The targeted period of record was 1950-2006, and the shortest period used in Alberta for the analysis was 1950-1975. Sophisticated statistical and mapping methods were applied to hydrometric gauging stations, and the following probabilities of exceedance (POE) were calculated: 10%, 25%, 50%, 70%, 75%, 80%, and 90%. This study generated isopleths interpolated across the landscape for each POE calculated. The results of this study are summarized in Table 5 as well as in the following three maps showing isopleths of water yield across the Red Deer Watershed:
  - **Map 6: 10% POE (Wet) Annual Water Yield (mm)**
  - **Map 7: 50% POE Annual Water Yield (mm)**

<sup>8</sup> All studies were based on gross drainage area of watersheds, not effective drainage area

○ **Map 8: 90% POE (Dry) Annual Water Yield)**

- **O2 Reach-Specific Contributing Area Water Yields:** O2 compiled specific water yield statistics representing contributing areas of the four defined reaches (Table 2). This information was not readily available from the above studies. Annual volumes derived from the AESRD Water Resources Management Model (WRMM)<sup>9</sup> were used to calculate the statistics. These inputs are based on the Red Deer River naturalized flows<sup>10</sup> at Water Survey of Canada stations (reconstructed for 1928-2001). Table 6 summarizes the results of the analysis.

The results of the Kienzle (2010) study (**Map 4 and Map 5**) indicate that much of the water flow is generated in the headwaters, where snowfall and rainfall are much higher and evapotranspiration is much lower than in the rest of the watershed. In fact, over 50 % of the total water yield in the Red Deer River originates from the Rocky Mountains and Upper Foothills, which represent only a small fraction of the watershed. Areas upstream from the confluence of the Blindman River and the Red Deer River near Red Deer contribute over 87% of the total yield in the entire basin. By the time the Red Deer River reaches the confluence with the Rosebud River just downstream from Drumheller, over 99% of all “blue” stream water has already been generated (**Map 5**).

The monthly statistics compiled for the stations show some interesting results (Table 4), including:

- In April, the largest yields originate in the Blindman River sub-watershed, largely driven by snowmelt
- Threehills Creek contributes a fairly large snowmelt pulse in April, particularly compared to yields from this sub-watershed later in the year
- Other prairie watersheds show characteristic spring peak runoff, followed by very low streamflow during the summer and fall seasons (e.g., Michichi Creek, Bullpound Creek, Blood Indian Creek)
- In May and June, yields from upper headwater sub-watersheds (e.g., Panther River, James River) in the mountains and foothills increase sharply, and in July these sub-watersheds contribute a large portion of the total basin yield
- In August and September, yields for most sub-watersheds have dropped considerably, although the Panther River (57 mm for August) and the upper Red Deer River in the vicinity of Burnt Timber Creek (41 mm for August) continue to produce substantial amounts of water. These areas are critical for maintaining water supplies in late summer when downstream irrigation demands are high.

### Probability of Exceedance

Probability of Exceedance (POE) refers to the chance that a unit runoff value will be equaled or exceeded in one year based on past records. For example, an annual unit runoff of 50 mm (or 50 dam<sup>3</sup>/km<sup>2</sup>) at a 70% probability of exceedance means that, in any given year, there is a 70% probability that the annual unit runoff will be at least 50 dam<sup>3</sup>/km<sup>2</sup>.

### Water Yield as a Proportion of Precipitation

Water yield numbers can be understood as a proportion of annual precipitation. For example, in the Foothills, approximately 30-60% of total rainfall will become flowing “blue” water in the Red Deer River. In contrast, in the Dry Mixed Grasslands, the majority of precipitation remains as “green” water in the landscape and is evapotranspired by plants and crops, with typically less than 1% of all precipitation becoming “blue” stream water flow.

<sup>9</sup> Obtained from Kent Berg, Water Resources Modeller, AESRD, Calgary Office

<sup>10</sup> See glossary for definition of “naturalized flows”

Water yields for various probabilities of exceedance (Table 5 also show very interesting trends. In particular, ratios between the 10% POE (wet) and 90% POE (dry) water yields for specific sub-watersheds included in the analysis are illustrative. Key trends include:

- Blood Indian Creek and Alkali Creek in the Dry Mixed Grasslands have values of 0 for the 70% or higher POE values, meaning that in any given year, there is a 30% chance that these creeks will be virtually dry most of the year.
- Bullpound Creek and Berry Creek show similar trends, with only 2 mm per year of water yield calculated for the 70% POE, and 0 mm (dry) for 90% POE, meaning that in any given year there is a 10% chance that these creeks will be virtually dry.
- For the Kneehills, Rosebud, and Three Hills creeks in the Central Agricultural area of the watershed, water yields are extremely low at the 90% POE event (1-2 mm), although they do not run dry. The ratio between the 10% POE and 90% POE water yields is very high with ratios of 16:1 to as high as 28:1 for the upper Rosebud River. This highlights that these areas have very low reliability of water supplies from year to year.
- The Blindman and upper Little Red Deer River sub-watersheds have ratios of about 5:1 or 6:1 between the 10% POE and 90% POE water yields. Sub-watersheds in these lower headwater regions of the watershed have intermediate levels of variability, although water yields are still reasonable at the >90% POE event frequencies (e.g., 33 mm for the Blindman River near Bluffton, 41 mm for the Little Red Deer River near Water Valley).
- Ratios of 3:1 occur for the James River near Sundre and the lower portion of the Little Red Deer River, indicating some variability but generally more reliable year-to-year supplies.
- Ratios of less than 2:1 occur for the Raven River near Raven and the Red Deer River below Burnt Timber Creek, indicating relatively high reliability of supply for these watersheds.

Maps 6, 7, and 8 are very interesting to compare. For example:

- The 2 mm annual isoline is absent completely from the 10% POE (wet conditions) map, and shifts from its location in the Alkali sub-watershed in the 50% POE map to over 150 km to the west in the vicinity of the Town of Three Hills in the 90% POE (dry conditions) map.
- The 10 mm annual isoline shifts from the vicinity of the City of Red Deer in the 90% POE (dry conditions) to the very easternmost portions of the watershed in the 10% (wet conditions).
- The 50 mm annual isoline shifts from a north-south orientation running through the Little Red Deer sub-watershed, Glennifer Lake, and the Medicine sub-watershed in the 50% POE (median) conditions, while including a much wider swath in the north portion of the watershed for the 10% POE (wet) conditions, while for the 90% POE (dry) conditions, it loops far to the west of Sundre.
- The 500 mm annual isoline includes only a very small mountainous portion of the watershed for the 50% POE (median) values, then shifts only about 10 km to the west for the 10% POE (wet) values, and is completely absent from the 10% POE (dry) annual values, replaced by the 250 mm isoline value (only half as much yield).

**Table 4. Water Yield Statistics (mm or dam<sup>3</sup>/km<sup>2</sup>) for Gauging Stations in the Red Deer River basin (Annual and Monthly)***Sources: (Kienzle 2010 and Golder 2008) (note: blank cell indicates missing data)*

Station #	Station Name	Mean Annual* (mm)		Mean Monthly Yield (mm)											
		Golder 2008	Kienzle 2011	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec
05CA004	Red Deer River above Panther River	364	359				9.2	38.5	86.4	78.0	57.2	32.7	19.9		
05CA002	James River near Sundre	175	162			4.1	12.4	27.5	38.0	31.2	19.1	15.4	10.1		
05CA009	Red Deer River bel. Burnt Timber Creek	292	300	6.1	5.5	5.9	8.5	34.3	70.9	58.8	41.3	26.9	17.6	9.4	7.2
05CAD12	Fallen Timber Creek near Sundre	195	N/A				13.1	25.7	34.8	29.4	17.2	14.0	9.15		
05CB004	Raven River Near Raven	110	109	4.6	4.5	8.5	16.0	12.3	12.5	12.9	9.9	9.6	8.4	5.9	4.9
05CB001	Little Red Deer River near the Mouth	57	52	0.5	0.5	4.0	11.0	8.8	10.1	8.9	4.6	3.8	2.9	1.47	0.69
05CB002	Little Red Deer River Near Water Valley	155	136			3.0	13.1	23.5	31.6	25.6	13.9	10.1	6.9		
05CC007	Medicine River Near Eckville	68	71	0.5	0.4	4.9	17.8	9.2	7.9	14.1	5.1	3.4	2.5	1.3	0.7
05CC010	Block Creek Near Leedale	81	79			8.2	17.7	9.9	9.2	16.1	5.8	5.5	5.0		
05CC008	Blindman River Near Bluffton	109	121			5.3	33.1	16.6	14.0	22.9	6.7	2.9	2.2		
05CC009	Lloyd Creek Near Bluffton	79	87			3.8	23.7	11.2	9.2	15.7	5.7	3.0	2.9		
05CC001	Blindman River Near Blackfalds	60	55	0.5	0.5	4.50	20.1	7.3	5.6	11.9	3.9	1.7	1.7	1.2	0.7
05CC002	Red Deer River at Red Deer	121	118	1.9	2.0	4.0	14.4	17.6	25.7	22.6	12.9	8.1	6.0	3.3	2.0
05CC011	Waskasoo Creek at Red Deer	41	23			6.3	13.0	4.2	4.7	5.6	2.1	1.2	0.8		
05CD006	Haynes Creek near Haynes	11	11			2.1	6.5	0.7	0.5	0.6	0.1	0.06	0.05		
05CD007	Parlby Creek at Alix	22	20			3.5	10.0	2.2	1.3	1.8	0.7	0.2	0.5		
05CE002	Kneehills Creek near Drumheller	17	10			3.3	7.3	1.2	0.7	0.5	0.16	0.15	0.12		
05CE006	Rosebud River below Carstairs River	15	12			4.1	5.9	1.5	1.2	0.8	0.2	0.3	0.2		
05CE007	Three Hills Creek near Carbon	30	16			4.6	18.3	1.7	1.4	1.3	0.3	0.2	0.2		
05CE018	Three Hills Creek below Ray Creek	28	21			4.2	14.7	2.9	2.6	1.5	0.4	0.2	0.3		
05CE010	Ray Creek near Innisfail	25	21			5.4	10.5	2.2	1.9	1.8	0.7	0.5	0.5		
05CE011	Renwick Creek near Three Hills	12	11			5.1	3.6	0.9	1.0	0.8	0.2	0.2	0.05		
05CE001	Red Deer River at Drumheller	82	65	1.7	1.6	4.2	12.7	9.8	14.6	14.7	8.3	5.8	4.4	2.4	1.8
05CE020	Michichi Creek at Drumheller	11	7			4.6	4.4	0.4	0.3	0.4	0.2	0.1	0.04		
05CG006	Fish Creek above Little Fish Lake	9	8			3.0	3.9	0.5	0.1	0.4	0.02	0.03	0.05		
05CG004	Bullpound Creek near Watts	7	6			2.7	1.8	0.5	0.2	0.8	0.3	0.05	0.02		
05CK007	Blood Indian Creek near Cabin Lake	4	2			1.4	1.7	0.06	0.03	0.12	0.02	0.02	0.03		
05CK001	Blood Indian Creek near the Mouth	5	0.9			0.7	2.8	0.4	0.09	0.05	0.05	0.04	0.04		
05CK005	Alkali Creek near the Mouth	5	1.6			0.92	3.2	0.07	0.02	0.01					

\*Annual yield numbers of Golder (2008) and Kienzle (2011) for some stations differ due to use of different periods of record; two gauge stations were assessed by Kienzle (2011) but not Golder (2008) and are not shown (i.e., the Rosebud River at Redland — 18 mm/year annual average — and Berry Creek near Rose Lynn — 3.3 mm/year. Mean monthly yield from Golder (2008).

\*\*Blank cells indicate missing / unreported data.

**Table 5. Annual Water Yield (mm) Probabilities of Exceedance for the Red Deer River Watershed (AAFC 2013)**

Station #	Station Name	Effective Drainage Area (km <sup>2</sup> )	Water Yield Values (mm) for Various Annual Probabilities of Exceedance (%)							Approximate Ratio of 10% (wet) to 90% (dry) POE values	Notes
			10%	25%	50%	70%	75%	80%	90%		
05CA002	James River near Sundre	821.2	241	194	147	117	110	101	82	3:1	
05CA003	Deer Creek (main stem) Near Sundre	5.6	204	148	98	68	61	54	38	5:1	Not included as a polygon in Kienzie (2010)
05CA009	Red Deer River below Burnt Timber Creek	2245.7	384	340	296	266	259	250	229	<2:1	
05CB001	Little Red Deer River near the Mouth	2439.2	72	57	43	34	31	28	22	3:1	Adjusted for nested stations upstream
05CB002	Little Red Deer River Near Water Valley	451.3	216	170	118	81	72	62	41	5:1	
05CB004	Raven River Near Raven	634.1	145	129	112	100	97	94	85	<2:1	
05CC001	Blindman River Near Blackfalds	1458.1	83	58	38	27	25	23	18	5:1	Adjusted for nested stations upstream
05CC007	Medicine River Near Eckville	1857.3	122	88	61	46	42	38	30	4:1	
05CC008	Blindman River Near Bluffton	353.1	183	123	79	56	50	45	33	6:1	
05CC009	Lloyd Creek Near Bluffton	238.8	129	88	58	43	40	36	28	5:1	
05CE002	Kneehills Creek near Drumheller	1965.0	32	17	8	4	4	3	2	16:1	
05CE005	Rosebud River at Redland	2198.5	22	11	5	2	2	2	1	22:1	
05CE006	Rosebud River below Carstairs River	641.6	28	14	6	3	3	2	1	28:1	
05CE007	Three Hills Creek near Carbon	955.8	32	17	8	5	4	3	2	16:1	
05CG004	Bullpound Creek near Watts	169.2	21	10	4	2	1	1	0	>100:1	
05CH008	Berry Creek near Rose Lynn	780.7	33	13	4	2	1	1	0	>100:1	
05CK001	Blood Indian Creek near the Mouth	383.7	8	3	1	0	0	0	0	>100:1	
05CK005	Alkali Creek near the Mouth	308.8	8	3	1	0	0	0	0	>100:1	

Source: AAFC. 2013. *Annual Unit Runoff in Canada*. By: Anna Cole. Agriculture and Agri-Food Canada.

**Table 6. Annual Water Yield (mm and dam<sup>3</sup>) for the Nested Reaches**

Reach	Station #	Description	Gross Drainage Area (km <sup>2</sup> )**	Average Annual Yield	Water Yield Probability of Exceedances in dam <sup>3</sup>		
					90% (Dry)	50%	10% (Wet)
<b>A</b>	<b>05CB007</b>	Red Deer River At Dickson Dam (Tunnel Outlet)	5,594	188.7 mm (1,055,600 dam <sup>3</sup> )	723,000	1,010,000	1,450,000
<b>B</b>	<b>05CC002</b>	Red Deer River at Red Deer	11,609	120.4 mm (1,397,723 dam <sup>3</sup> )	854,000	1,300,000	2,060,000
<b>C</b>	<b>05CE001</b>	Red Deer River at Drumheller	24,865	65.5 mm (1,628,657 dam <sup>3</sup> )	968,000	1,500,000	2,440,000
<b>D</b>	<b>05CK004</b>	Red Deer River at Bindloss	47,850	35.8 mm (1,713,030 dam <sup>3</sup> )	967,000	1,560,000	2,640,000

\*Annual volumes are derived from the AESRD Water Resources Management Model (WRMM) inputs for the Red Deer River naturalized flows at the specified Water Survey of Canada stations (reconstructed for 1928-2001); statistical fit for probability of exceedance is LP3 and method applied is SAM as per AAFC (2013)

\*\*Based on Water Survey of Canada reported gross drainage areas in km<sup>2</sup>.

### 3.1.6 Dams, Reservoirs, Canals and Irrigation Infrastructure

Water infrastructure in the Red Deer River Watershed is shown in **Map 9: Provincially Owned Water Infrastructure**, including dams, flood control structures, and infrastructure related to the Buffalo Lake/Mirror Lake/Alix Lake system.

The largest water management infrastructure in the basin is the **Dickson Dam**, which was completed in 1983. The main earthfill dam is 40 m high and 650 m in length (AENV, 2006). Related structures include two main diversion tunnels and a service spillway that were originally designed to pass a 1 in 10,000 year event. Gleniffer Lake, the reservoir created by Dickson Dam, has a flooded area of 1735 ha, and can store 202,900 dam<sup>3</sup> with a full storage elevation located at 948.01 m. There are 3 km of containment dyking on either side of the reservoir and two fuse plugs originally designed to pass the probable maximum flood. Additional engineering details can be found in AENV (2006).

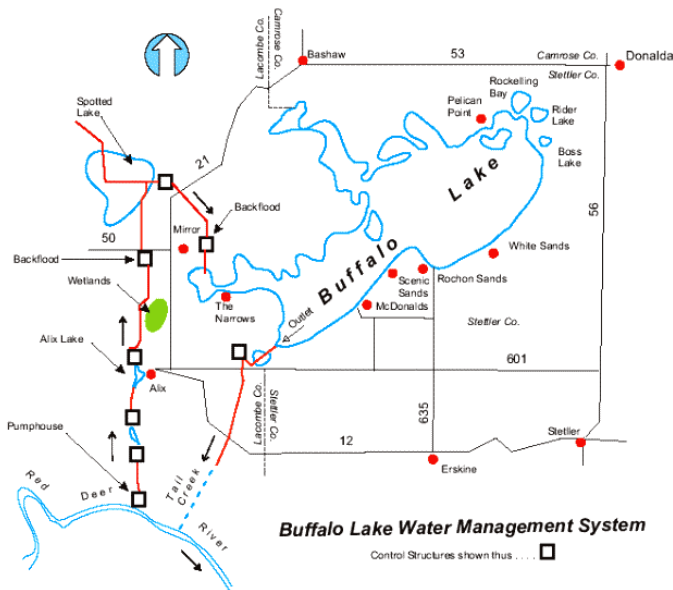
Dickson Dam was constructed primarily to assure high quality water supplies during periods of winter low flow for downstream municipal, industrial, and agricultural users. Before the dam was built, observed low flows threatened downstream water quantity and quality for these three sectors. Historic low flows also impacted fish and fish habitat due to low dissolved oxygen concentrations during the winter months (Shaw & Anderson, 1994). The operation of the dam now provides adequate stable minimum flows with a minimum release rate of 16 m<sup>3</sup>/s, as well as improved instream water quality for the environment and water users (AENV, 2006; Shaw & Anderson, 1994). Other benefits of the project include some flood attenuation, ice jam flood reduction, hydroelectric power generation, flexibility to meet apportionment commitments, wildlife habitat, and provision of recreational opportunities and facilities.

A variety of other water infrastructure exists in the basin. Key developments are highlighted below:

- **Western Irrigation District (WID) and Eastern Irrigation District (EID):** Considerable amounts of irrigation infrastructure exist in both the Western Irrigation District (WID) and the Eastern Irrigation District (EID), which overlap the watershed, as shown in **Map 2**. Both the irrigation districts own and operate a complex network of irrigation canals, control structures, dams, and monitoring equipment. For example, the Crawling Valley Reservoir and dam is owned and operated by the EID. The districts are owned and operated by elected boards.
- **Sheerness / Deadfish System:** The Sheerness / Deadfish system provides irrigation, stock and domestic water to 9,000 acres of irrigated land southeast of Hanna as well as water for municipal use to the Henry Kroeger water system. Through an agreement with ATCO's Sheerness Power station, water is pumped from the Red Deer River to the ATCO cooling pond, then pumped down a canal to the Carolside reservoir (18,000 acre-feet). From there, it is distributed downstream in Berry Creek to irrigators. The provincial government operates its own pump station from the Red Deer River that supplies irrigators along Deadfish Creek with water from the Red Deer River through a series of smaller reservoirs. Deadfish eventually merges with Berry Creek, and several irrigators take water downstream of the confluence, while return flows go to the Red Deer River. The system is operated by the Special Areas through contract with AESRD offices in Medicine Hat and Calgary.
- **Parlby Creek – Buffalo Lake Water Management System** (Figure 8): This project was designed to provide agricultural flood control, fish and wildlife habitat enhancement, municipal water supplies, and stabilization of lake levels in Buffalo Lake. Water is pumped from the Red Deer River into Parlby Creek and flows into Buffalo Lake through a conveyance system. Return flows to the Red Deer River are from the southwest corner of Buffalo Lake through Tail Creek. Construction began in 1985 and now includes the following (from downstream to upstream) (BLMT, 2010):
  - 3.8 kilometer (km) channel and backflood structure from Buffalo Lake to Highway 21
  - 1.9 km channel and backflood structure from Highway 21 to Spotted Lake
  - 4.1 km channel through Spotted Lake to Highway 50 near Mirror



- Channel from Highway 50 to Alix Lake, a backflood structure and dyke near Mirror, and a wildlife conservation wetland and private backflood system east of Mirror between Spotted Lake and Buffalo Lake
  - Private backflood system east of Mirror between Spotted Lake and Buffalo Lake
  - Series of open channels, underground concrete conduits, and wetland ponds from Alix Lake upstream to the outlet from the pump station
- **Blood Indian Creek Reservoir Dam:** Owned and operated by the Special Areas Board, this structure impounds the Blood Indian Creek Reservoir. It was originally built in 1965 to provide water for livestock watering downstream as well as for the irrigation of small plots adjacent to the creek. The reservoir now contains an important stocked rainbow trout fishery.



**Figure 8. Schematic of the Buffalo Lake Water Management System**

### 3.1.6.1 Potential Environmental Impacts of Dams and Water Infrastructure in the Red Deer River Watershed

Physical structures such as dams typically alter the natural hydrologic regime of the river. This can lead to many undesirable and unanticipated environmental impacts caused by changes to the annual hydrograph, including less frequent floods and lower peak flows (Postel & Richter, 2003). While downstream impacts are initially subtle, progressive change over years or decades often produces major cumulative ecological impacts (Rood et al., 2005). Some studies in Alberta have shown that recruitment sites for riparian trees such as balsam poplar (*Populus balsamifera*) and sandbar willow (*Salix exigua*) decrease in response to dams due to reduced flooding and associated changes to geomorphic and ecological processes (Rood et al., 1999). Dams can also affect a range of other biological processes, for example some research has highlighted the possibility that dams may favour the development of mats of the algae *Didymosphenia geminata*.

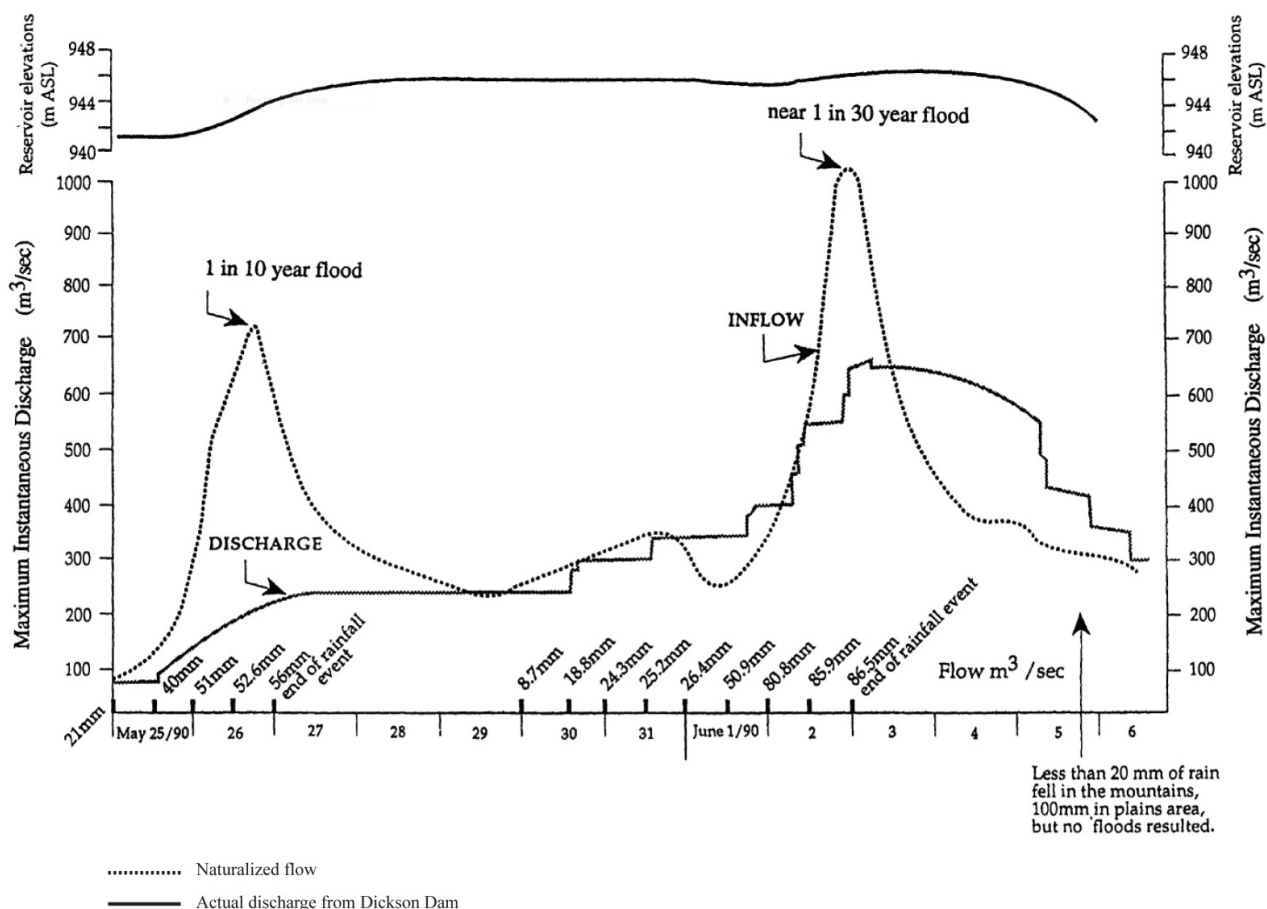
Most riparian species in the prairie rivers of western North America have strong seasonal needs for particular amounts of water and habitat creation associated with flooding. Sediment deposition creates sites suitable for regeneration and establishment, as well as community succession. In reaches of meandering or confined-meandering rivers, suitable sites are created by 1 in 10 year floods. However, in braided reaches, significant floodplain development only occurs under much higher flows. High flow patterns play a key role in maintaining sandbar willow communities and, therefore, indirectly aiding cottonwood establishment (Cordes et al., 1997).

A 1 in 10 year event (approximately 918 m<sup>3</sup>/s at Red Deer) will flood all the colonizing willow, mature willow, most stands of young cottonwoods and some areas of mature cottonwood. This is the minimum level of flooding required to cover a significant portion of all sites where fringe replenishment of cottonwoods occurs.

These higher floods lead to higher sedimentation that in turn promotes lower densities of willow colonization and improved opportunities for cottonwood establishment.

The construction of the Dickson Dam above the City of Red Deer in 1983 led to at least some attenuation of floods and a reduced likelihood that extensive flooding and poplar regeneration will occur again (Cordes et al. 1997). However, in contrast to other basins, overall impacts of the Dickson Dam on flows in the Red Deer River have been minimal and perhaps even beneficial to the environment, due to mitigation of low flow events and related low dissolved oxygen concentrations in winter months, which can be harmful to many aquatic organisms, including fish (AENV, 2004; Shaw & Anderson, 1994). A recent study confirmed that the Dickson Dam has had some influence on flood peaks but has not resulted in major changes to the overall hydrologic regime of the Red Deer River (Gill et al. 2008). According to the results from Gill et al. (2008), there were three years (1984, 1988, and 2001) where the dam clearly attenuated the flood peak, but these years were very dry and the river would not have experienced a large flood peak anyway. In recent years, the dam has provided significant attenuation during large flood events. AESRD estimated that the dam reduced peak flows by about 33 and 30 per cent for the 2005 and 2013 floods respectively (Rick Friedl, Head, Central / Northern Operations Branch, AESRD, personal communication). However, differences in the pre-dam to post-dam flood peaks are typically minor in comparison to other dam-affected watersheds (Gill et al., 2008). This is likely due to the small size of Gleniffer Lake in relation to the upstream drainage basin. In addition, planned release events from the Dickson Dam help mitigate at least some of these impacts by attempting to mimic natural hydrograph patterns more closely (Aquality, 2009). Operational rules at the dam do not currently include gradual “ramping” of flows post-flooding, which has been implemented at the Oldman Dam to promote cottonwood seedling establishment with a gradual river recession (Rood et al., 2005). Current operational rules for the Dickson Dam call for returning the reservoir back to its seasonal operational level as soon as possible post-flood; cottonwood seedling establishment is not a factor in post-flood decision making (Rick Friedl, Head, Central / Northern Operations Branch, AESRD, personal communication).

Water infrastructure such as groynes or other flood control structures may do a very good job of protecting development on the floodplain. However, these structures inevitably have local environmental impacts as floodwaters are restricted from certain areas of the floodplain and ecological processes are prevented from occurring. Flood control infrastructure, excluding dams, may create a “slingshot” effect where downstream areas experience more severe flooding, which should be a consideration for any investments in additional flood control. It also underscores the need to prevent human development on floodplains as much as possible to mitigate the magnitude of flood disasters and address environmental issues.



**Figure 9. Alterations in Red Deer River flows resulting from flood attenuations at the Dickson Dam: May 25 to June 6, 1990 (Source: Cordes et al. 1997)**

### 3.1.7 Lakes

There are several sizeable lakes in the Red Deer Watershed. Some of the larger lakes and reservoirs are described below (Mitchell & Prepas, 1990):

- Gleniffer Lake** – Gleniffer Lake was created in 1983 when the Red Deer River was impounded by Dickson Dam. The reservoir provides an assured year-round water supply, improved water quality in the Red Deer River and some level of flood control. The lake is located about 20 km west of Innisfail and is about 17.6  $\text{km}^2$  in size with a mean depth of 11.6 m. The drainage area of the lake is 5,610  $\text{km}^2$ .
- Gull Lake** – Gull Lake is a large, shallow natural lake located about 15 km west of Lacombe. There are no permanently flowing inlet streams, and the lake's natural outlet in the southwest corner has been dry for many years. Lake levels are stabilized by pumping water from the Blindman River. The lake surface area is 80.6  $\text{km}^2$ , mean depth is 5.4 m and drainage area is 206  $\text{km}^2$ . The lake is used extensively for recreation.
- Buffalo Lake** - Buffalo Lake is a large, shallow natural lake in central Alberta, located 60 km northeast of Red Deer. The lake is the main hydrological feature of the Buffalo sub-watershed and is fed by several small tributaries including Clive Creek and Spotted Creek. Lake levels are stabilized by pumping water from the Red Deer River through the Buffalo Lake Water Management System (Section 3.1.6). The outlet channel, Tail Creek, connects directly to the Red Deer River about 50 km east of Red Deer. The lake surface area is 93.5  $\text{km}^2$ , mean depth is 2.8 m, and drainage area is 1440  $\text{km}^2$ . The lake is primarily used for recreation.

- **Pine Lake** – Pine Lake is a long, narrow natural lake set in a wooded valley about 35 km southwest of the City of Red Deer. Inflows to the lake are from small intermittent tributaries. Outflows from the lake are to Ghostpine Creek, a tributary of Threehills Creek. The surface area of the lake is 3.89 km<sup>2</sup>, mean depth is 5.3 m and drainage area is 150 km<sup>2</sup>. The lake is extensively used for recreation.
- **Sylvan Lake** – Sylvan Lake is a large, shallow natural lake located about 20 km west of the City of Red Deer. Inflows to the lake are from intermittent streams and numerous submerged springs. Outflows from the lake are to a small creek that enters Cygnet Lake downstream. Outflows from the lake are sporadic and intermittent. The surface area of the lake is 42.8 km<sup>2</sup>, mean depth is 9.6 m and drainage area is 102 km<sup>2</sup>. The lake is extensively used for recreation.
- **Crawling Valley Reservoir** – Matzhiwin Creek was impounded in 1985 to create Crawling Valley Reservoir, a 25.1 km<sup>2</sup>, 18 km long reservoir about 10 km northeast of Bassano. Crawling Valley makes up part of the Eastern Irrigation District's North Branch Canal system. The drainage area contributing to the reservoir is about 802 km<sup>2</sup>, however the majority of inflows are from the irrigation canal system. Mean depth of the reservoir is 5.2 m.
- **Blood Indian Creek Reservoir** – Blood Indian Creek is impounded to create a long, narrow reservoir about 70 km southeast of Hanna. The reservoir has a surface area of 1.06 km<sup>2</sup>, and a mean depth of 4.6 m. The drainage area to the reservoir is 116 km<sup>2</sup>. The reservoir was built by PFRA in 1965 to provide water for livestock downstream and for future irrigation of small plots adjacent to the creek. Carolside (Berry Creek) Reservoir occurs in the same area.
- **Bigelow Reservoir** – This is a small reservoir located along Ghost Pine Creek.
- **Little Fish Lake** – Little Fish Lake is a small, shallow natural lake located about 35 km east of Drumheller. Inflows to the lake are primarily from Fish Creek and several intermittent streams. Outflows from the lake are to Willow Creek, which eventually flows into the Red Deer River, however there have been no surface outflows from the lake since the 1960s. The lake surface area is 7.09 km<sup>2</sup>, mean depth is 1.76 and drainage area is 157 km<sup>2</sup>. The lake is the centerpiece of the Little Fish Lake Provincial Park.

Lakes are highly valued by Albertans and provide numerous environmental, recreational, social, and economic benefits. The *Status of Alberta Lake Levels* is a program undertaken by AESRD for lakes with available long-term data that are mostly responding to natural or near-natural fluctuations (Figure 10). This indicator primarily reflects the environment's response to fluctuations in weather and climate. In the Red Deer River watershed, Sylvan Lake and Pine Lake are part of the monitoring and reporting program (AESRD, 2013a). Since 2006, both lakes have exhibited normal or above normal levels.

Lake	Ranking of Annual Lake Levels								
	2004	2005	2006	2007	2008	2009	2010	2011	2012
23) Pine Lake	BN	MAN	AN	AN	N	N	AN*	N*	n/a
27) Sylvan Lake	BN	BN	N	AN	MAN	AN	AN	MAN	MAN*

Legend: N-Normal Condition, BN-Below Normal, MBN-Much Below Normal, AN-Above Normal, MAN-Much Above Normal, n/a - Not Enough Data, Blank-Data has not been reported, \*Data Considered as Preliminary

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**Figure 10. Ranking of Annual Lake Levels for Pine Lake and Sylvan Lake in the Red Deer River Watershed** (Source: <http://environment.alberta.ca/01719.html>)  
(Note: only Pine Lake and Sylvan Lake rankings are available for the Red Deer watershed)

### 3.1.8 Wetlands

Wetlands, including their hydrologic functions, were addressed in some detail in the Phase 2 Background Technical Report (O2, 2013). Key hydrologic functions and services to reiterate in this report include:

- **Flood Peak Reduction:** Wetlands have a sponge-like effect, capturing runoff and desynchronizing peak flows (Hey & Phillippi, 1995; Zedler & Kercher, 2005; Yang et al., 2008; O2, 2011).
- **Drought Buffering:** Wetlands can provide a valuable source of water during drought conditions. Many wetlands continue to supply aquifers and small tributaries with water during drought events and dry seasons (Baker & van Ejik, 2006; Pollock et al., 2003; Westbrook et al., 2006).
- **Groundwater Recharge:** Many wetlands recharge and maintain local and regional groundwater supplies. Although net recharge is often small, there is evidence that over long time periods, small pothole wetlands are a key source of recharge to regional prairie aquifers (Hayashi et al., 1998). Groundwater recharge by wetlands is also related to drought buffering and improved distribution of seasonal and inter-annual flows in streams and rivers (Gilbert et al., 2006).

#### Laurentide Glaciation and the Red Deer River Watershed

The landscape of the lower portion of the Red Deer River watershed has been strongly influenced by the Laurentide Glaciation; large coulees were carved out by glacial processes. These large valleys appear out of scale with the general landscape and are much too large for the streams that currently occupy them. The streams are often referred to as “underfit streams.” An example in the Red Deer River watershed is Matzhiwin Creek flowing through Crawling Valley.

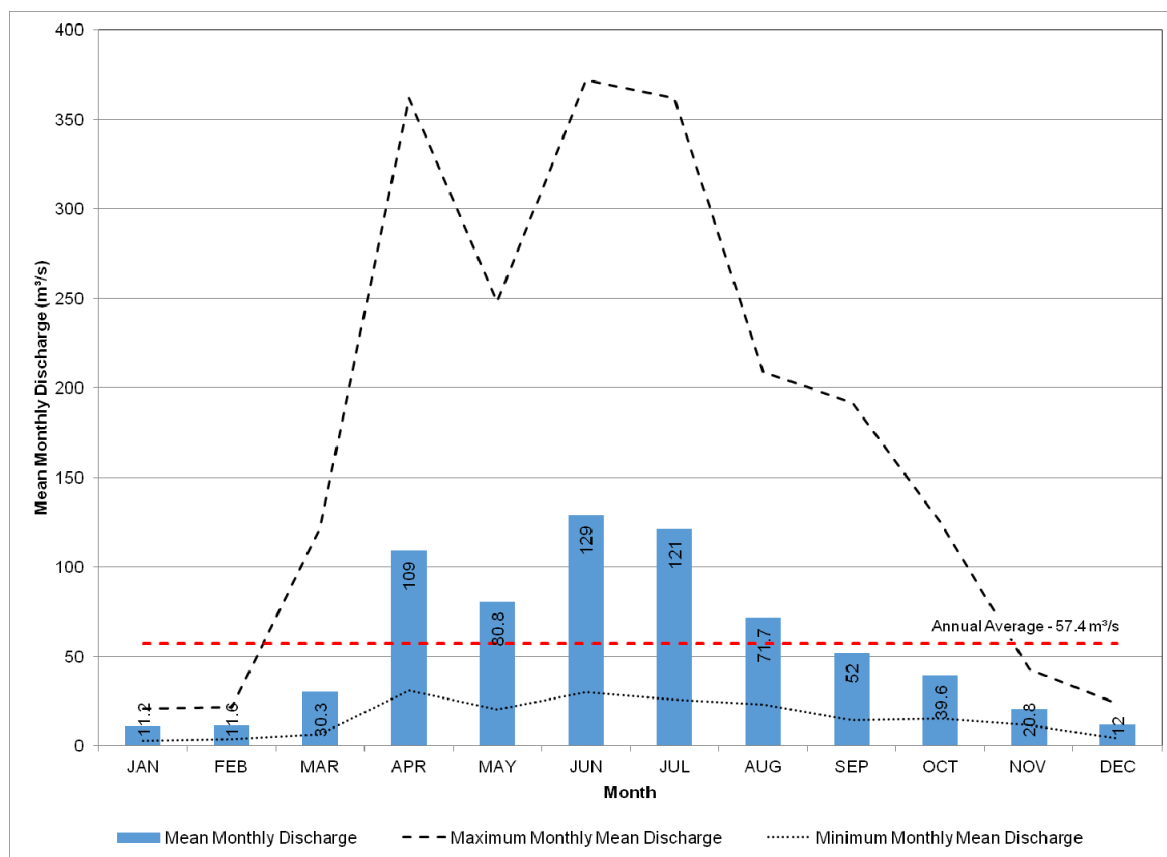
### 3.1.9 Rivers and Streams

The amount of water flowing in rivers and streams of the watershed varies considerably through time (seasonally, inter-annually) and space. There are three main types of streams/rivers in the watershed: (i) perennial streams, which generally flow throughout most of the year; (ii) intermittent streams, which have a distinct channel that usually flows after rain or snowmelt, and are dry for most of the year; and (iii) ephemeral streams, which are typically unmapped, have little to no channel development, and flow only during or immediately after rainfall or snowmelt events.

Although any particular stream can be locally important for water users and ecosystem dynamics, this study focuses primarily on those rivers and streams for which stream gauging information from the Water Survey of Canada (WSC) is readily available.

#### 3.1.9.1 Red Deer River

Water flows in the Red Deer River vary considerably over the year and seasonally (Figure 11). Annual average flows are approximately 57.4 m<sup>3</sup>/s at the Bindloss WSC Station, although maximum and minimum flows span a wide range (Figure 11).



**Figure 11. Average monthly runoff in cubic meters per second for the Red Deer River at Bindloss (WSC Station 05CK004)**

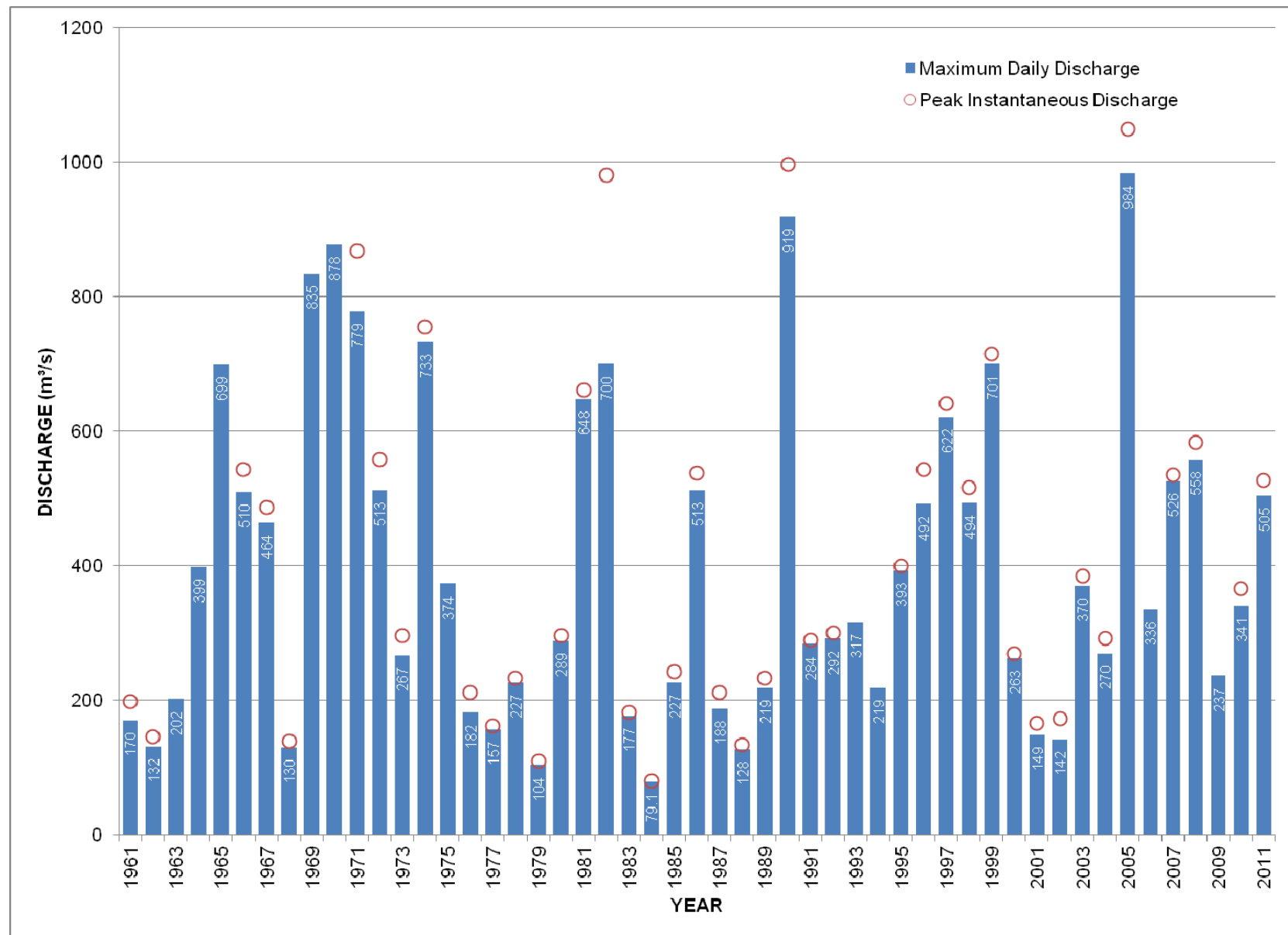
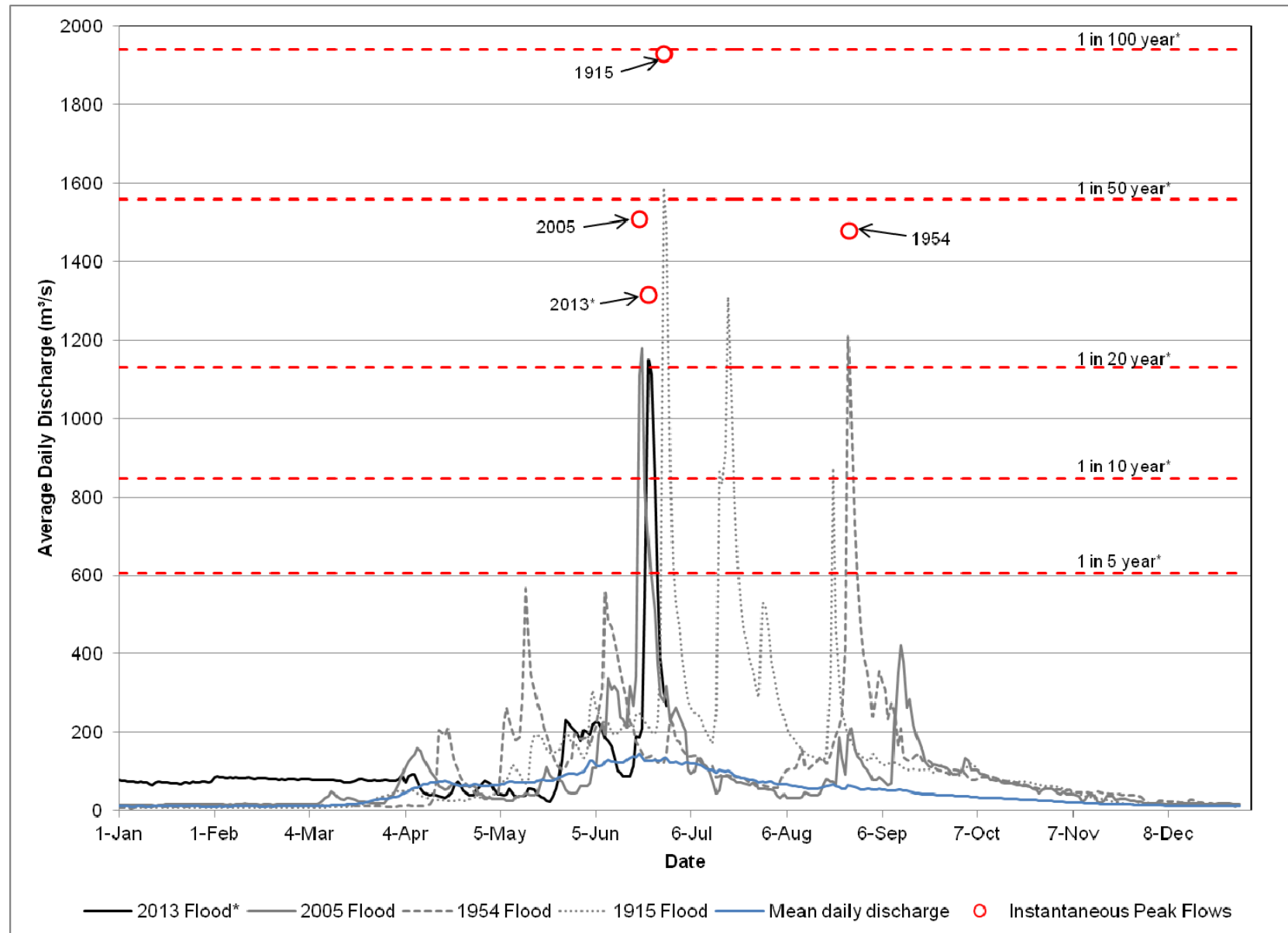


Figure 12. Maximum Daily and Maximum Instantaneous Discharge on the Red Deer River at Bindloss (WSC Station 05CK004)



**Figure 13. Average Daily Discharge for the Red Deer River at Red Deer (WCS Station 05CC002) during flood years**

*Notes: 2005 and 2013 flows were regulated by the Dickson Dam and under natural conditions would have been approximately 2600 m³/s and 1900 m³/s, respectively (Rick Friedl, Head, Central/Northern Operations Branch, AESRD, personal communication)*



### 3.1.9.2 Tributaries

Some of the largest and well-known tributaries in the watershed include the Panther River, James River, Raven River, Fallentimber Creek, Medicine River, Little Red Deer River, Blindman River, Dogpound Creek, Rosebud River, Three Hills Creek, Kneehills Creek, Ghostpine Creek, Berry Creek, Blood Indian Creek, and Alkali Creek.

### 3.1.10 Extreme Conditions

The Red Deer River watershed is frequently subject to extreme hydrologic conditions. Inter-annual variability in precipitation and runoff combined with the climatic influence of mountainous regions and climate cycles results in relatively frequent drought and flood events. Historical reconstruction of stream flows using tree ring and lake diatom studies indicates severe floods and prolonged droughts have occurred repeatedly across the region in the past (Axelson et al., 2009).

#### 3.1.10.1 Flooding

Flooding in the Red Deer Watershed has historically occurred during both the open water and ice-affected seasons. Open water flooding is typically caused by either intense summer rainstorms or a combination of spring rainfall and snowmelt runoff. Analysis of large rainstorm events by Alberta Transportation (2007) identified a typical rainstorm typology that causes widespread flooding in Alberta. These have mean rainfall values in the range of 200 mm over a 1000 km<sup>2</sup> area, and have durations in the 20 to 60 hour range.

Peak flows in the Red Deer River vary annually depending on precipitation and snowmelt (Figure 12), thus catastrophic flooding does not occur every year. The largest floods on record in the Red Deer River watershed occurred in 1915, 1954, 2005, and 2013 (Figure 13 and Table 7). The 2005 flood was in the range of a 1 in 50 year event at Red Deer (Figure 14) but much higher in the upper watershed (Figure 15). The upper watershed experienced much more severe flooding due to heavy localized rainfall in the mountains and foothills. Preliminary estimates for the 2013 flood event show that it was in the 1 in 20 year to 1 in 50 year event range at the City of Red Deer. Both the 2005 and 2013 flood events were attenuated by the Dickson Dam and would have been much larger flows under natural conditions. The 1915 flood was considered a 1 in 100 year event and occurred pre-construction of the Dickson Dam (Rood & Phelan, 2006). Flooding is most likely to occur in June and early July, although the 1954 floods occurred in late August.

**Table 7. Largest Floods on Record for the Red Deer River at Red Deer (WSC Station 05CC002)**

Year	Maximum Daily Discharge (m <sup>3</sup> /s)	Maximum Instantaneous Discharge (m <sup>3</sup> /s)	Approximate Return Period
1915	1590	1930	1 in 100 year
1954	1210	1480	±1 in 50 year
2005	1180	1510	1 in 50 year
2013	1150*	1325*	1 in 20 to 1 in 50 year

\*Note: Estimated from Water Survey of Canada records for Station 05CC002

Flooding due to ice jamming on the Red Deer River at Red Deer has historically been a problem. Three ice jam flood events in the same range of highwater elevations as the largest open water events were observed in 1920, 1929 and 1948 at downstream bridge crossings (Neill & Watt, 2001). Flooding caused by ice jam activity has not been considered a major concern since the construction of the Dickson Dam (AESRD, 2013b).



**Figure 14. Red Deer River near Drumheller in June 2005** (*Keller, 2006*)

#### **Flooding at Water Valley**

The previous historical maximum flow on the Little Red Deer River at Water Valley was 120 m<sup>3</sup>/s. On June 18, 2005 at 1:00 pm, the flow at Water Valley was manually measured as 568 m<sup>3</sup>/s, almost 5 times higher than normal flows.

(*Keller, 2006*)



**Figure 15. Little Red Deer River during 2005 flood at a bridge north of Harold Creek Road** (*Keller, 2006*)

### 3.1.10.2 Drought

Using historical reconstructions of stream flows with tree ring and lake diatom data, Sauchyn et al. (2007) have reconstructed the Palmer Drought Severity Index for Calgary and found frequent severe droughts have occurred in the past (Figure 17).

AESRD has defined hydrological droughts as years when the annual natural runoff volume is less than the lower decile (less than the 90% probability of exceedance mark) over the period of record (AENV, 2010). For the Red Deer River at Bindloss, this corresponds to an annual runoff volume of 967,000 dam<sup>3</sup> based on naturalized flow records from the AESRD WRMM model (AENV, 2010). According to these criteria, there have been droughts in 1930, 1937, 1941, 1949, 1950, 1979, 1984, 1988, and 2001 in the Red Deer River watershed. Average daily discharge for five particularly harsh drought years is shown in Figure 18.

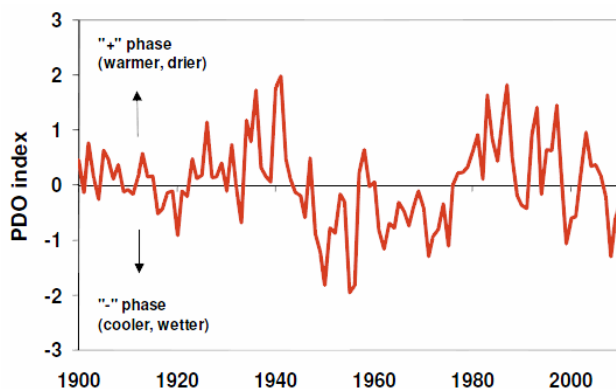


Figure 16. Historical PDO Index (1900-2005)

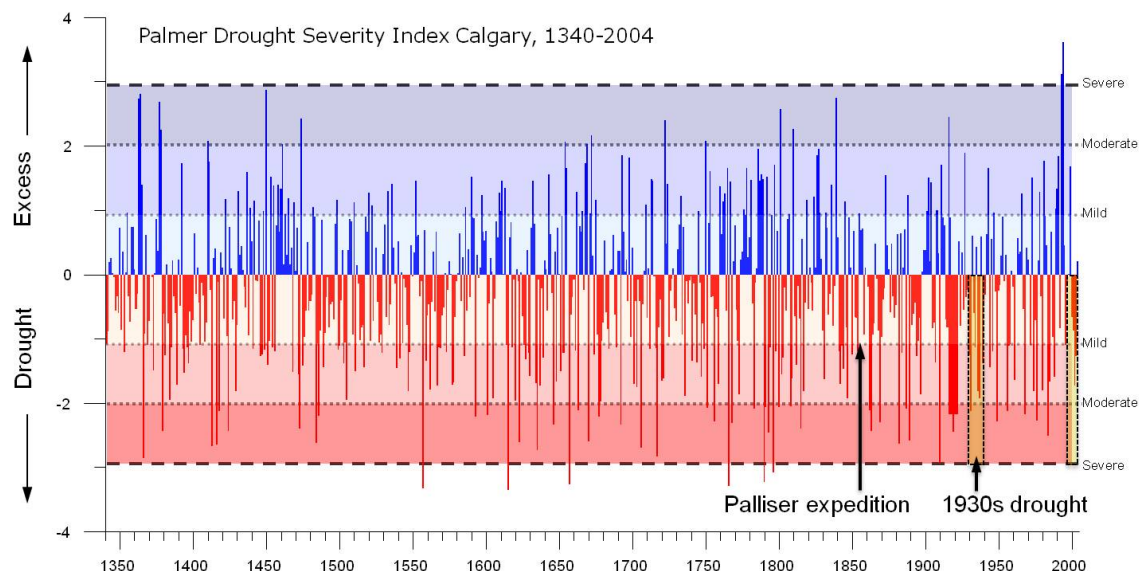
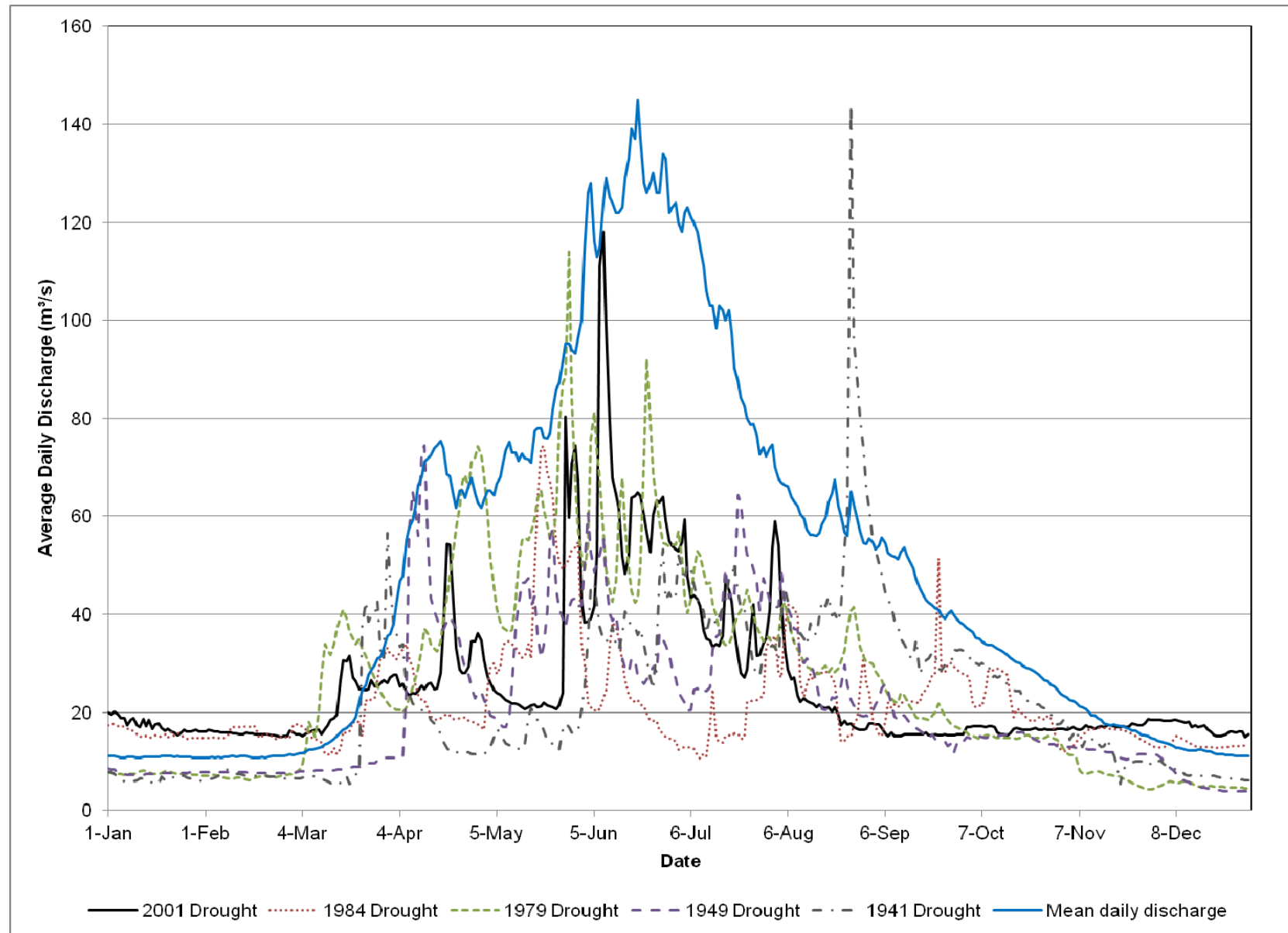


Figure 17. Palmer Drought Severity Index for Calgary, Alberta, 1340 to 2004 (Sauchyn et al., 2007)

#### Climate Oscillations and Water Resources

Multi-year climate oscillation cycles influence water supplies in the Red Deer River watershed. The Pacific Decadal Oscillation (PDO) involves a cycling of warm and cool phases in sea surface temperatures, which has a major influence on wet and dry cycles in Alberta. The PDO appears to operate in 50 to 60 year cycles, spending 20 to 30 years on average in each phase (Figure 16). Stream flow reconstructions indicate that the South Saskatchewan River Basin has demonstrated a relatively strong PDO-like signal for the past six centuries, including prolonged 20-35 year low-flow periods. There are indications that the PDO has recently reversed direction to the negative phase, which has been driving recent above average moisture conditions in Alberta over the last several years (Kienzie 2010).

The North Atlantic Oscillation (NAO), Arctic Oscillation (AO) and the El Nino/Southern Oscillation (ENSO) also influence temperature and precipitation patterns across North America. Neither the PDO nor the ENSO phenomena are well understood and climate change may be affecting these in ways that are both complex and unpredictable (BC MOE, 2007).



**Figure 18. Average daily discharges for historical droughts at the Red Deer River at Red Deer (WSC Station No. 05CC002)**

*Note: Red Deer River flows after 1983 were regulated by the Dickson Dam.*

### 3.1.11 Climate Change

Ongoing climate change is very likely to increase in severity as the 21<sup>st</sup> century progresses (IPCC, 2007; AESRD, 2013c). Extreme events such as drought and flooding are already a key characteristic of Alberta's climate as shown in the historical and paleoclimatic records (Figure 17). One of the major future challenges is that these climate extremes may be amplified, becoming more frequent and more severe (AENV, 2010).

Two scientific studies on climate variability and climate change in the South Saskatchewan River Basin were conducted for the province as summarized in AENV (2010). This included a study on climate variability in a long-term context (Axelson et al., 2009), and a hydroclimatic modelling study based on downscaled Global Circulation Models (GCMs) (Golder, 2010). Although there is a large degree of uncertainty in future precipitation predictions and hydrological responses, these studies indicate that increased variation in climate could result in more frequent and more severe drought events, moisture levels, or peak flood events (Axelson et al., 2009). More specifically, Golder (2010) determined that average annual stream flows in the South Saskatchewan River Basin can be expected to change somewhere in the range of +5% to -30% overall due to future climate change in the 21<sup>st</sup> century. In addition, climate variability was shown to further decrease stream flow by -25% or more during dry years, which suggests that low annual flows are affected to a larger degree by changes in climate variability than are high annual flows (Golder, 2010).

Gill et al. (2008) examined the impacts of climate change on hydrology specific to the Red Deer River Basin and concluded that the most reliable estimate of future flows of the Red Deer River at Red Deer is a decline by about 15% from 2005 to 2055, and that this decline will primarily reflect flow reductions in the summer and fall seasons. This study analyzed trends in stream flow, while also conducting hydroclimatic modelling under various GCM Scenarios. They found a statistically significant decline in mean annual flow for the Red Deer River over the period 1912-2007, with a decline of about 25% on average. They assumed that if the near future follows this historical pattern, annual flows would be further reduced by about 15% by 2055. In contrast, the future hydroclimatic modelling forecasted a slight increase in flows for most months, and slight increase in the overall annual flow of the Red Deer River. However, the model was not able to simulate actual historical data, leading to low confidence in the results. Overall, trend analysis over this time period is strongly affected by the wet period during 1900-1920 and must be interpreted very cautiously.

In contrast, a recent study by Kienzle (2011) examined streamflow trends in Alberta from 1971-2000, which corresponds with a substantial increase in temperature. This study did not detect any major significant streamflow trends over this time period in the watershed. This study identified slightly positive changes in streamflow over this period (e.g., +0.5 to +1.8% for most stations, and a decrease of -0.18% in the uppermost headwaters), and no high statistically significant trends with greater than >95% confidence (Kienzle 2011) (Figure 19). Maximum annual average flow also did not show any major relationships in the Red Deer River Watershed (Figure 19). However, examining minimum annual flows for weekly streamflows over the same time period, some significant changes were identified including:

- Significant decrease of -4.3% (>99% confidence) in minimum flow for areas downstream from Drumheller, including the Rosebud River sub-watershed
- Decline of -2.7% (>99% confidence) for central reaches in the Buffalo and Kneehills sub-watersheds
- Slight increase of +2.8% (95% confidence) for the Blindman sub-watershed.

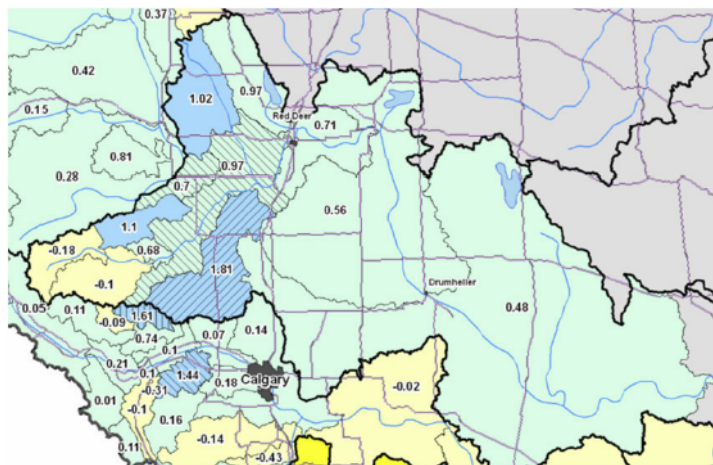
Although modelling is never a perfect forecasting tool, these studies highlight the risk that more extreme low flows may occur in addition to more extreme flooding events as climate change continues to unfold. In addition, areas that are already showing signs of water stress (e.g., lower reaches downstream from Drumheller, Buffalo, Kneehills, Rosebud sub-watersheds) are the same areas that seem to be experiencing the most change in minimum stream flows on an annual basis. Therefore, it appears that the driest portions of the watershed may be getting drier during critical periods of the year.

#### **Caveat for Streamflow Trend Analyses**

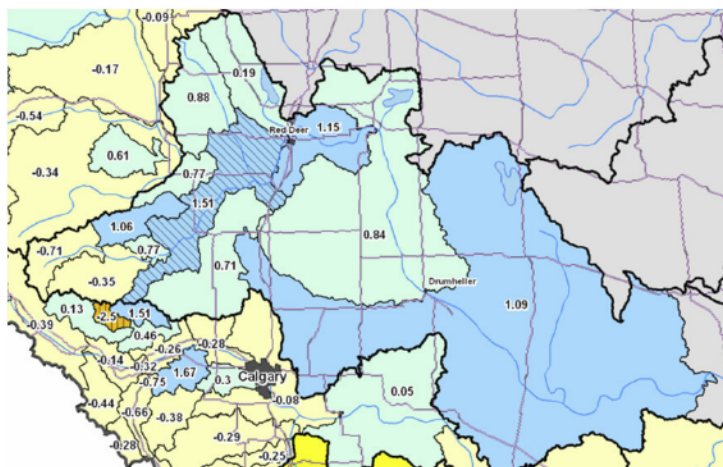
Streamflow trend analyses using linear statistical methods generally do not include the influence of climate cycles (e.g., PDO) and must therefore be taken with a grain of salt.



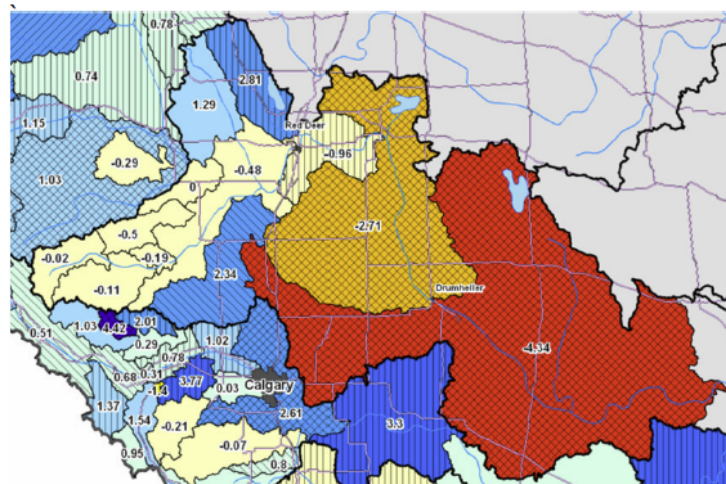
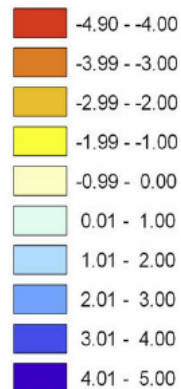
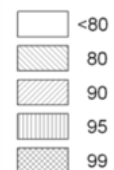
## Average annual flow (1971 to 2000)



## Maximum annual flow (1971 to 2000)



## Minimum annual flow (1971 to 2000)

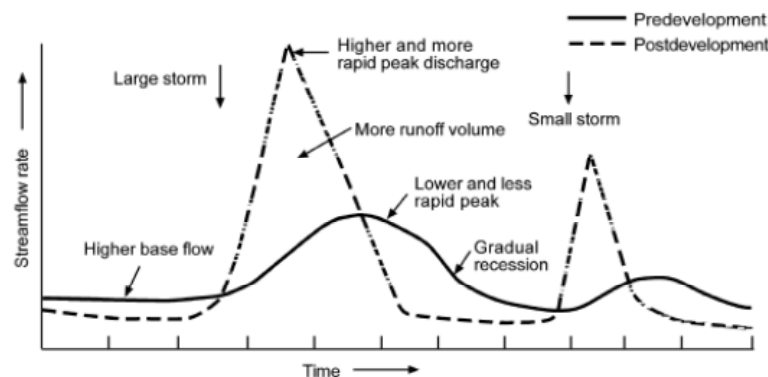
Trend as %  
of flowSignificance  
level (%)

**Figure 19. Trends in Streamflow (1971 to 2000) in the Red Deer River Basin (Kienzle & Mueller, 2010)**

### 3.1.12 Relationships between Land and Resource Use and Hydrology

Extensive land use across a watershed can change the distribution and timing of water yield. O2 (2013) provided some additional information on the potential impacts of land uses on basin hydrology. The two most important examples to draw attention to in this report include:

- Urbanization:** Urbanization and increasing impervious areas can lead to higher peak flows (more water when it is least needed), and slightly lower baseflows (less water when it is most needed) (Figure 17). Although urban land uses in general are sparse in the watershed, and localized in scale, they are concentrated in the vicinity of the City of Red Deer and may have impacts on small tributaries including Waskasoo Creek.



**Figure 20. Changes to Stream Hydrology in Urban Areas**

Source: (Schueler, 1992)

- Forestry:** Timber harvest typically decreases evapotranspiration and increases average annual local streamflow. One study found that for Rocky Mountain ecosystems, if 15% of a watershed is clear-cut, a measurable increase in annual water yield will be observed (Matheussen et al., 2000). Another study found that peak flow increases exceeded 40% if the area disturbed by forest clear-cuts exceeded 50% (Guillemette et al. 2005). Influences of forestry on flows during extreme events such as drought and flooding are not well quantified; however, in general peak flows will increase and low flows will decrease in response to clear-cutting as water will tend to move faster through a watershed without mature trees. The larger the proportion of a watershed affected, the larger will be the observed effects (Adams & Taratoot, 2001). These effects are temporary and forest regeneration results in hydrologic recovery over time as the forest re-establishes. In addition, there is a large degree of natural variability in interannual and seasonal precipitation, particularly in Alberta's foothill and mountain watersheds (Lejbak, 2007); consequently any forestry influences are superimposed on top of natural hydrologic variability, making it difficult to tease apart the effects of natural variability from the effects of forestry.

## 3.2 Surface Water Demand

This section synthesizes and summarizes updated surface water allocation, licensing, and demand data for the Red Deer Watershed. Included are sections on surface water licensing and use in the entire Red Deer Watershed (3.2.1), followed by a more specific breakdown by reach (3.2.2). Section 3.2.3 provides some exploratory analysis of finer-scale supply and demand issues in specific sub-watersheds.

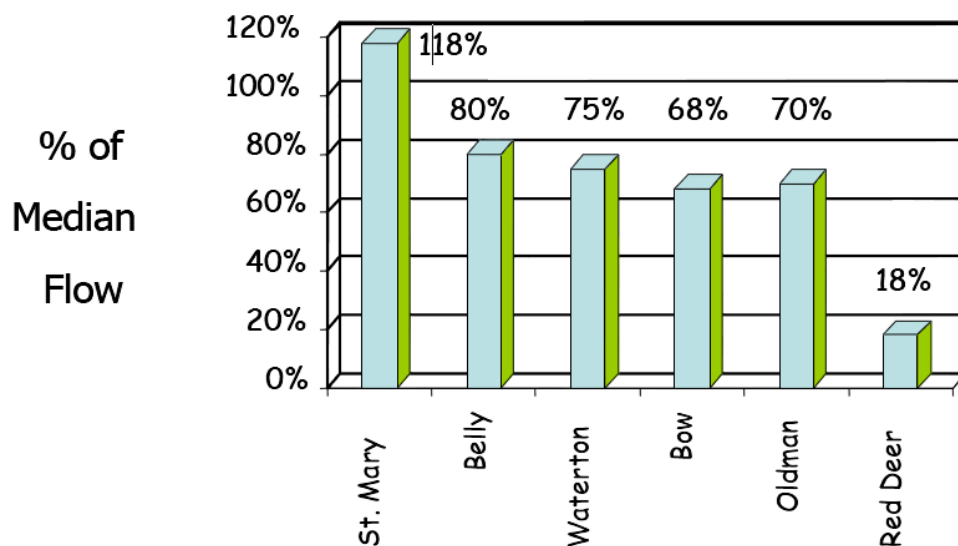
### 3.2.1 Surface Water Licences: Entire Watershed

Water licences issued by the Government of Alberta under the *Water Act* allocate how much water a licence holder is permitted to withdraw from a specific water source in one year for a specified purpose. Although allocations do not always reflect the actual use or consumption of water, the total volume of licensed allocations still provides an indication of the demand for water in a watershed (AESRD, 2012).

Many uses are not necessarily consumptive in nature. Municipalities tend to return a high proportion of diverted water after use and treatment, although there may be exceptions depending on the system as some municipal sewage lagoons can have very high evaporative losses. However, in summertime — when water is most needed in the river to meet instream flow needs — municipal uses often peak and return flows are often lower than average, which can lead to problems. In the provincial database, return flows are typically documented for municipalities as well as many agricultural licences. This data provides opportunities to remove estimated return flows prior to reporting on the remaining amounts, which can be assumed to be consumptive demand<sup>11</sup>.

Provincial surface water licence database queries were conducted on June 6, 2013. According to this analysis, there are over 16,000 licences for surface water in the entire watershed, and the maximum volume of diversions is currently 334,800 dam<sup>3</sup>/year. When accounting for the AESRD reported return flows of 58,149 dam<sup>3</sup>/year documented in the surface water licence database, the estimated total consumptive demand is 276,650 dam<sup>3</sup>/year. Expressed as a proportion of total available water supplies in an average year (based on the Bindloss station POE=50% amount), total consumptive demand is therefore approximately **17.7%** (276,650 dam<sup>3</sup> divided by 1,560,000 dam<sup>3</sup>).

This consumptive demand is fairly low compared to other rivers in southern Alberta, particularly the over-allocated river systems such as the St. Mary (118%), the Bow (68%), and the Oldman Rivers (70%) (Figure 21). Nonetheless, in a broader Canadian context, a consumptive water demand of 18% of the median flow is fairly high. For comparison, in Campbell River, BC, consumption represents only 0.3% of the annual mean flow. In addition, demand versus supply ratios for mean conditions can be misleading, since during low-flow periods and major droughts, consumptive uses can still pose risks to instream flow needs for fish, aquatic life, and other uses.



**Figure 21. Allocations in the Red Deer basin + Other Rivers in Southern Alberta**

Source: McGee (2012)

Water licence allocations were grouped into the following categories for interpretation: i) municipal, ii) agricultural (stock water and feedlot use), iii) agricultural irrigation, iv) commercial (e.g., gardening, golf courses, parks, aggregate washing, etc.), v) industrial (oilfield injection, gas/petrochemical plants), vi) environmental (management of fish, management of wildlife, habitat enhancement), and vii) other (recreation, water management, stabilization, flood control, and registrations). The proportion of licences by user-type for the entire Red Deer Watershed is illustrated in Figure 22.

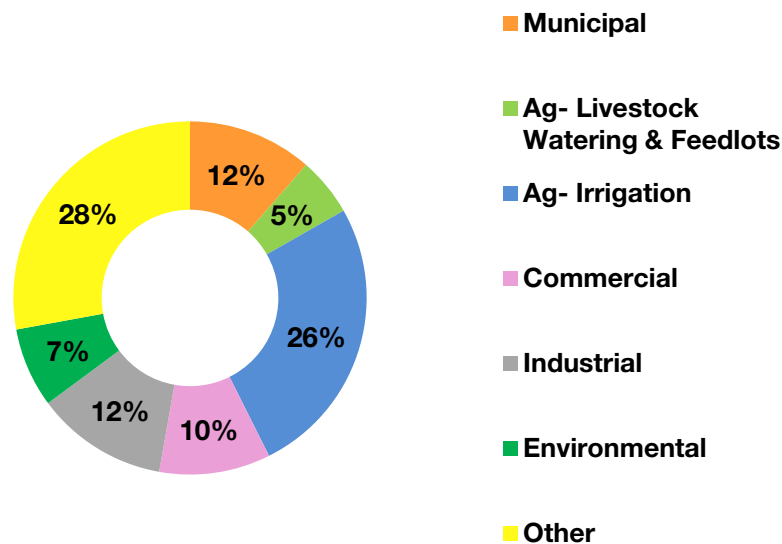
Consumptive water demand for the entire watershed is highest for the irrigation and “other” water use categories. Irrigation was the largest licensee by sector in the river basin, with a consumptive demand of 26% and an estimated volume of 71,451 dam<sup>3</sup>/year. The category of “other” included general uses such as

<sup>11</sup> This database is not perfect and return flows are not reported for all licence types.



recreation, water management, stabilization, flood control, and registrations. The volume of use for these subcategories varied, but was generally highest for flood control, and stabilization purposes. Industrial, commercial, and municipal demands accounted for 12%, 10%, and 12% of the demand, respectively. The estimated consumptive demand volume by user-group is presented in Table 8.

**Total Volume:**  
**276,651 dam<sup>3</sup>/year**



**Figure 22. Red Deer River Watershed Consumptive Demand Allocations**

**Table 8. Consumptive Demand Volume (Maximum Annual – Return Flows) by Major Sector**

User Group	Consumptive Demand Volume
Municipal	31,589
Agricultural	14,838
Irrigation	71,451
Commercial	28,198
Industrial	33,325
Environmental <sup>12</sup>	20,177
Other	77,073

The current water allocation management system in Alberta establishes priority based on the principle of “first in time, first in right.” Essentially, this means that if water scarcity occurs, senior (older) water licence holders are entitled to their allocation of water before more junior water licence holders. The entitled portion, however, may not necessarily be for the full allocated amount, depending on other system and security requirements, as outlined in individual water licences.

<sup>12</sup> Includes allocations for habitat enhancement (e.g., wetland enhancement/creation), fish and wildlife management, etc.  
O2 Planning + Design Inc.

### 3.2.2 Surface Water Licences: Specific Reaches

Proportional consumptive demand for licence user-groups are summarized for each of the four defined reaches in Figure 23. This includes licensing information for all tributaries upstream from each reach. Consumptive volume ranges and medians are summarized in box plots (Figure 24). The range and median consumptive demand volumes by user category for each reach are displayed with box plots (Figure 24).

Reach 1 has a very low total consumptive water demand volume of 4,097 dam<sup>3</sup>/year. Water demand in the upper Reach 1 was highest for commercial use (42%, 1,717 dam<sup>3</sup>/year), followed by industrial use (23%, 941 dam<sup>3</sup>/year) primarily for oil/gas well injection purposes. Commercial use activities included water for golf courses, aggregate washing, gardening, and “other” oil and gas drilling.

Total consumptive water demand in Reach 2 is 37,651 dam<sup>3</sup>/year. The municipal user-group had the highest proportional consumption for this reach (48%; 18,072 dam<sup>3</sup>/year). The City of Red Deer’s licence and several other smaller municipal licences are associated with this reach. Median volumes for municipal licences in this reach are 656 dam<sup>3</sup>/year (Figure 24). Industrial use demands were second highest (23% of total volume) and are related primarily to injection and gas/petroleum plant water users. Median volume for industrial licences in this reach is 941 dam<sup>3</sup>/year.

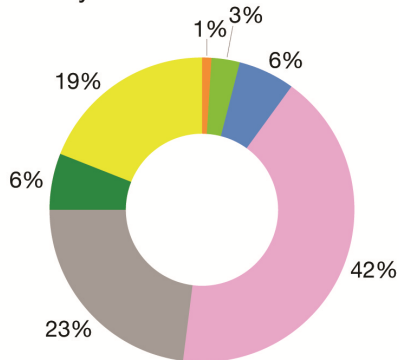
The total volume of consumptive water demand in Reach 3 is 117,113 dam<sup>3</sup>/year. Water demand in this reach was highest for the “Other” use category (53% of the total). The “Other” category includes water demands for water level stabilization, flood control, dugouts, recreation, as well as the “registries” category that in this reach includes a relatively large number of low-volume agricultural and rural water users. Industrial use demands are next highest (19% for this reach) and are related to many oil/gas field injection and gas plants and petrochemicals plants.

Reach 4 has the highest total consumptive demand of 117,789 dam<sup>3</sup>/year of all the reaches. Water demand in this reach is primarily related to irrigation (50%; 59,196 dam<sup>3</sup>/year), with 329 licences and a median licence volume of 48 dam<sup>3</sup>/year (Figure 24). Commercial demands were next highest at 16% (3,662 dam<sup>3</sup>/year). There were 27 licences for commercial use with a median licence volume of 18 dam<sup>3</sup>/year (Figure 24).

The information in the box plots highlights the range and median volumes used by user-groups in each reach. In Reach 1, licence volumes for industrial licensees were highest, with a median volume of 185 dam<sup>3</sup>/year. Municipal demand consumption was generally the highest in Reach 2, although this was skewed by the City of Red Deer’s licence. Industrial consumptive demand was generally highest per licence in Reach 3 with a median of 1,000 dam<sup>3</sup>/year. In Reach 4, median values for industrial consumptive use were highest, but there were very few industrial licences relative to other groups (e.g., agricultural user groups). The category ‘Other’ had the largest range in demand consumption volumes in all reaches representing the diverse types of licence uses grouped in this category.

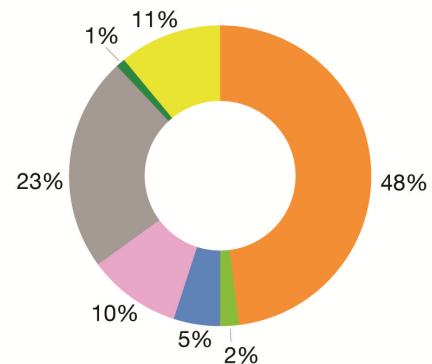
## Red Deer River: Licensing Types Per Stream Reach

Total Consumptive Demand:  
4,097 dam<sup>3</sup>/year



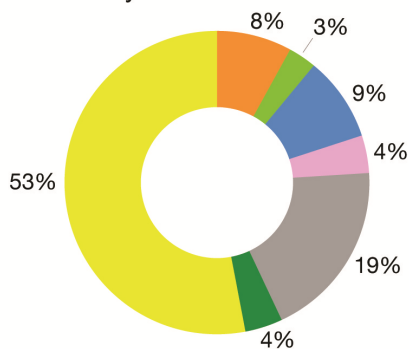
Reach 1: Headwaters to Dickson

Total Consumptive Demand:  
37,651 dam<sup>3</sup>/year



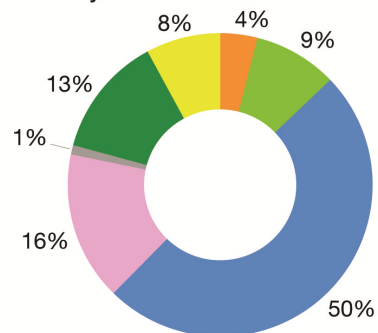
Reach 2: Dickson Dam to Red Deer

Total Consumptive Demand:  
117,113 dam<sup>3</sup>/year

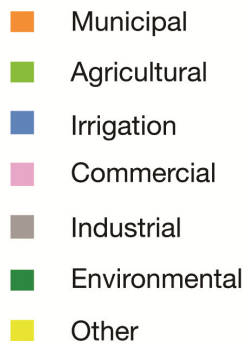


Reach 3: Red Deer to Drumheller

Total Consumptive Demand:  
117,790 dam<sup>3</sup>/year

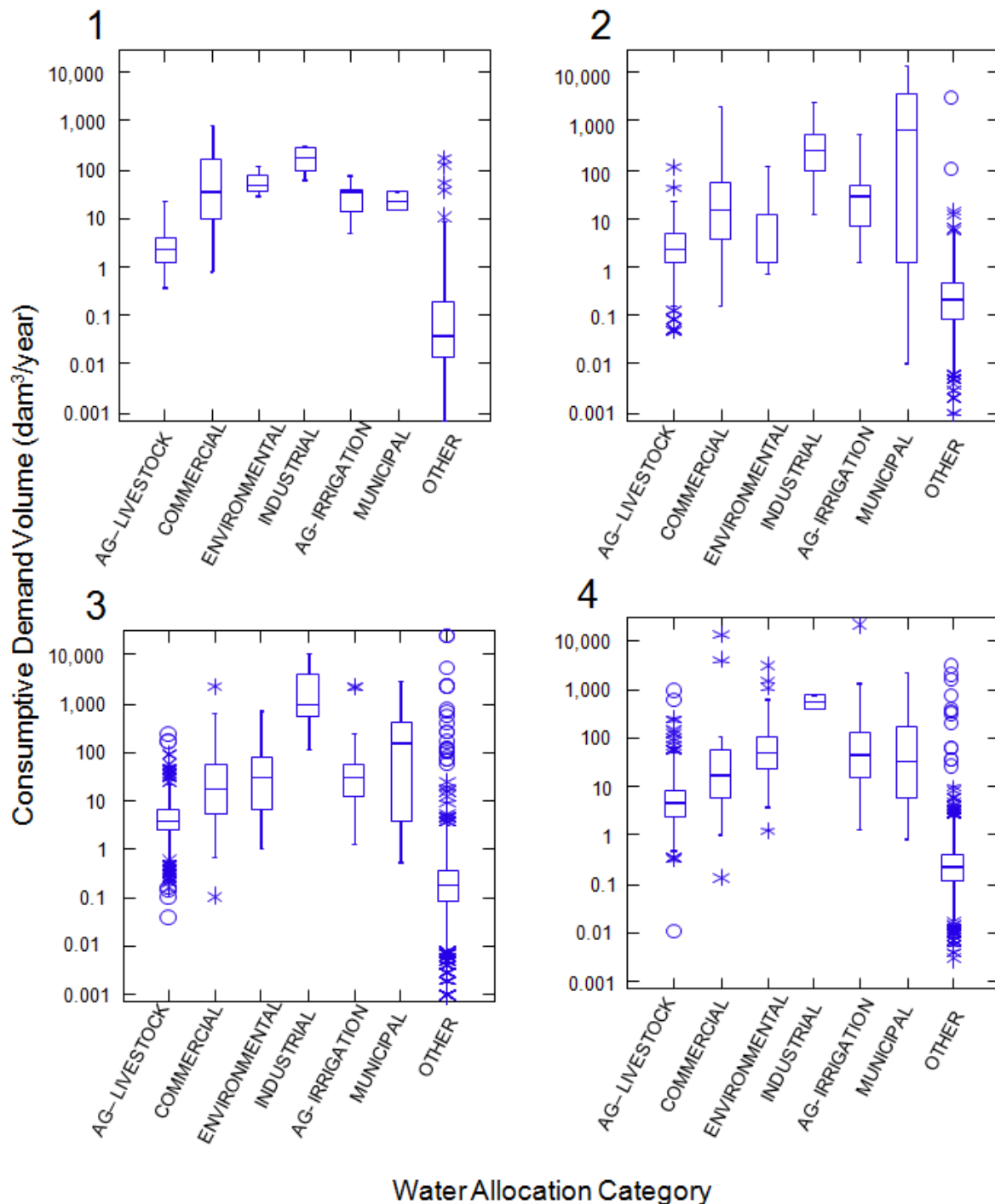


Reach 4: Drumheller to Saskatchewan



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**Figure 23. Red Deer River: Surface Water Licence Types Associated with Each River Reach**



**Figure 24. Box Plots of User Types Associated with Reaches 1 to 4**

The centre horizontal line of the box plot marks the median of the sample. The length of each box shows the range within which the central 50% of the values fall, with the box edges (hinges) at the first and third quartiles. The interquartile range of the two hinges is comparable to Hinge spread (Hspread). Fences define outside and far outside values and are defined as follows:

- lower and upper inner fence = lower hinge - (1.5 x (Hspread)); upper hinge + (1.5 x (Hspread))
- lower and upper outer fence = lower hinge - (3 x (Hspread)); upper hinge + (3 x (Hspread))

The whiskers show the range of observed values that fall within the inner fences or within 1.5 Hspreads of the hinges. Values between the inner and outer fences are plotted as asterisks. Values beyond the outer fences, considered far outside values, are plotted with empty circles.

Cumulative upstream water demand as a proportion of specific reaches was examined to spatially visualize demand versus supply issues on the Red Deer River main stem. This was calculated by summing total cumulative upstream licensed volumes, minus return flows, for each reach, then expressing that as a proportion of the total average water yield for the corresponding stream gauging station. Similarly, the total consumptive demand was also expressed as a proportion of the POE=90% (dry conditions), which represents a fairly regular annual dry period that can be expected to occur approximately 10% of the time. The results are shown on **Map 10: Red Deer River Demand vs. Supply**. Generally, the following trends are shown:

- **Reach 1: Upper Headwaters to the Dickson Dam:** the ratio of demand versus supply is miniscule (<1%) for both scenarios and therefore poses very few concerns
- **Reach 2: Dickson Dam to Red Deer:** the ratio of demand versus supply is < 5% for both the POE=50% and POE=90% water yield frequencies and poses very few concerns to this reach
- **Reach 3: Red Deer to Drumheller:** the ratio of demand versus supply is about 11% for average years (POE=50%), and increases to about 16% when compared to dry (POE=90%) conditions
- **Reach 4: Drumheller to Saskatchewan:** the ratio of demand versus supply is 18% overall, but increases considerably to 29% under the POE=90% (dry) conditions

Finer-scale analyses examining weekly natural flows versus weekly water demand are instructive and have been conducted by others previously. These generally do not show major concerns in demand versus supply mismatches for the Red Deer River itself, particularly compared with other river basins in Alberta (McGee 2012).

### 3.2.3 Surface Water Licences: Sub-watersheds

Overall results of surface water demand for the Red Deer River mainstem may mask more localized demand versus supply mismatches. Although water in the Red Deer River is generally not over-allocated, many surface water licences by virtue of their location cannot draw water from the Red Deer River and must use more local smaller tributaries. In these situations, local demand versus supply mismatches likely occur, particularly on a seasonal or inter-annual basis. In some situations, it is obvious that landowners and/or agencies have dealt with some of these mismatches by building farm dugouts or small reservoirs.

A comprehensive micro-scale analysis of these issues is a multi-faceted problem and specific local data gaps both spatially and temporally exist. However, for the purposes of this study a rough exploratory indication of potential demand versus supply mismatches on a sub-watershed basis was provided as follows:

- Surface water licences that draw directly from the Red Deer River mainstem were removed from the calculations
- Remaining surface water licences were attached to specific sub-watershed polygons in the GIS
- Total maximum annual licensing minus total return flows were summed for each sub-watershed
- Total annual average yield for each sub-watershed was estimated with GIS polygons, using a weighted average of the proportional coverage of the Kienzle (2011) water yield polygons
- For those situations where water yield is less than 0 as shown by Kienzle (2011), the sub-watershed analysis could not be completed and a value of "N/A" was assigned; however due to the dry nature of these areas the potential for local supply vs. demand mismatches is very high

The results of this analysis are shown below in Table 9.

**Table 9. Annual Surface Water Demand and Supply Comparisons for Sub-watersheds**

Sub-watershed	Grouped Reach	Weighted Average Yield (dam <sup>3</sup> )	Estimated consumptive demand (dam <sup>3</sup> )	Demand / Supply Ratio (%)
Fallentimber	1	52,196	198	0.4%
James	1	229,851	1,141	0.5%
Panther	1	673,883	3	~0%
Raven	1	81,593	470	1%
Little Red	2	145,340	8,310	6%
Medicine	2	173,401	2,779	2%
Waskaoo	2	14,644	1,040	7%
Blindman	3	109,360	7,721	7%
Buffalo	3	33,292	11,359	34%
Kneehills	3	25,141	2,789	11%
Michichi	3	18,191	10,745	59%
Threehills	3	42,105	3,172	8%
Alkali	4	N/A	9,396	N/A
Berry	4	N/A	28,600	N/A
Matzhwin	4	N/A	6,842	N/A
Rosebud	4	59,975	4,035	7%

Generally, demand versus supply ratios are relatively low (<10%) for average years and suggest that there are no immediate concerns. However, ratios in the Buffalo (34%) and Michichi (59%) watersheds indicate some concerns even under average conditions, although large portions of these sub-watersheds are non-contributing areas, which may lead to slightly inflated statistics. These results only summarize the demand versus supply ratios for the 50% POE event. Due to the format of the AAFC (2013) data it is not a straightforward exercise to calculate similar values for the 90% POE (dry) conditions. However, as one example, in the Rosebud sub-watershed the 90% POE (dry) water yield is estimated at approximately 1 mm, providing a total yield of only 4,391 dam<sup>3</sup> in comparison to an average yield of 59,975 dam<sup>3</sup> (over 14 times lower). Therefore, the consumptive demand expressed as a proportion of the 90% POE event would be 92% for this sub-watershed, indicating a major supply shortfall under these conditions as well as major impacts on this tributary. Under even drier conditions, demand would be expected to outstrip supply completely. Therefore, during dry years in certain areas, major water supply issues are apparent.

### 3.3 Synthesis of Current Policy and Management Issues

This section reviews key current policy and management issues related to surface water resources in the Red Deer Watershed. Included are sections on the Interprovincial Master Agreement on Apportionment, Water Conservation Objectives, results of the provincial “Water Conversation” held in 2013, the Special Areas Water Supply Project, and Inter-basin and Intra-basin transfers.

#### 3.3.1 Master Agreement on Apportionment + SSRB Water Management Plan

Alberta must deliver a percentage of the natural flow in the South Saskatchewan River basin to the Province of Saskatchewan every year. This is governed and administered by the Prairie Provinces Water Board (PPWB) through the Master Agreement on Apportionment between Alberta, Saskatchewan, and Manitoba. Requirements stemming from this agreement constrain new water licences in southern and central Alberta. There is currently high consumptive water use in the Bow and Oldman Rivers, which also drain into the South Saskatchewan River system, so flows originating in the Red Deer River currently help balance water volumes supplied downstream to Saskatchewan.

In 2006, Alberta Environment announced a closure on new water licences for the South Saskatchewan River Basin (SSRB) through regulatory means. However, the expansion of water licensing in the Red Deer River basin was not constrained by this provincial moratorium. Currently, the Red Deer River accounts for only about

6.4% of the total water allocated in the SSRB. Although there have been some concerns that increased water consumption through existing licences in the Bow and Oldman River basins could potentially require the Red Deer River to contribute more water to meet the inter-provincial apportionment agreement with Saskatchewan, this would occur very infrequently and is not a major concern for the Red Deer basin.

Currently, the Red Deer River watershed has a target allocation limit of 600,000 dam<sup>3</sup> and a specified temporary closure of new licences at 550,000 dam<sup>3</sup>. This future allocation limit represents 35% of mean flow, which is much lower than the allocations for other rivers in Southern Alberta (See Figure 22). The future allocation limit aimed to achieve a balance between the need for additional water allocations to allow future economic growth, vs. acceptable levels of impact on water quality and aquatic and riparian ecosystems as well as downstream water users. In addition, this is a living plan that can be adjusted in the future if necessary to meet changing priorities, needs, and societal expectations.

### **3.3.2 Instream Flow Needs**

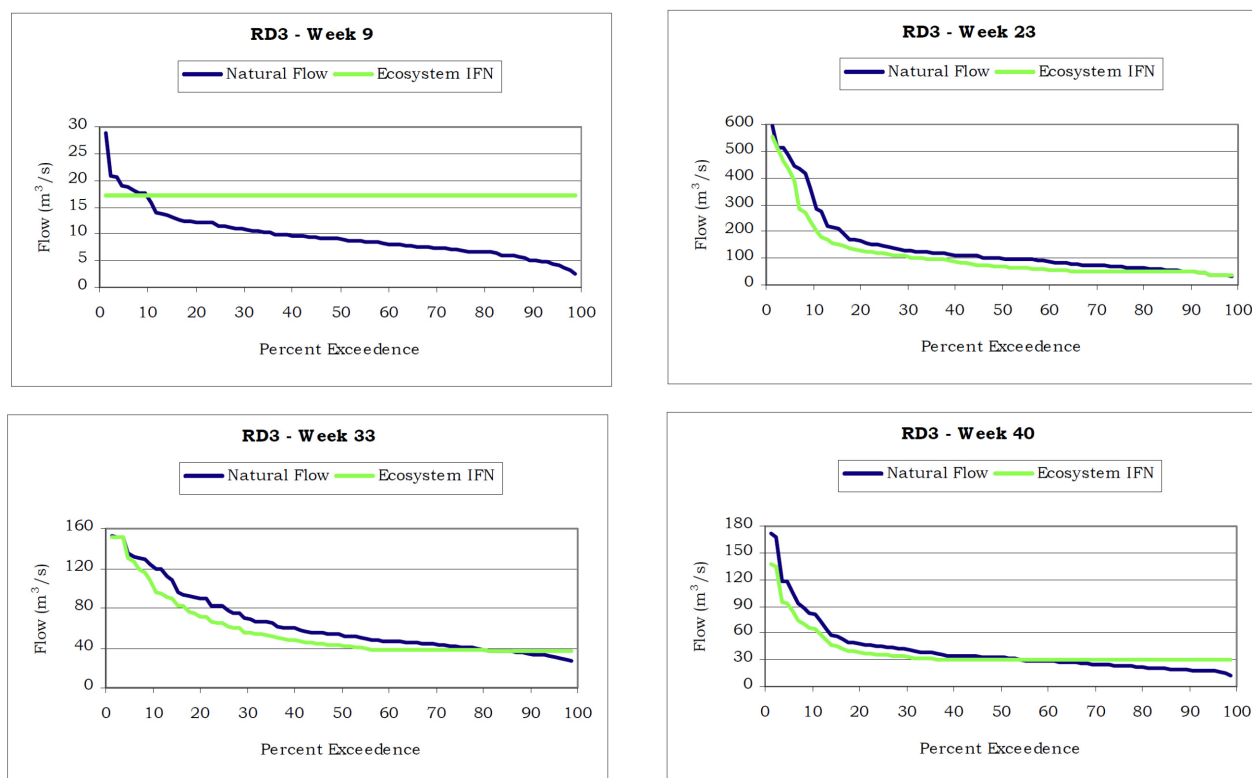
Instream Flow Needs (IFNs) are estimates of minimum flows required to maintain ecosystem components and provide a high level of protection for the aquatic environment over the long term (AESRD, 2012). Although calculated as a threshold, IFN estimates do not establish a commitment of water flow and are instead intended as information to be used in the decision-making process of establishing of a WCO or other planning objective. According to AESRD (2012), assessments should ideally report on the deviation from the Water Conservation Objective, as this target has been set in consideration of society's expectations and desired outcomes for that water body.

An IFN study for the SSRB was completed by Clipperton et al. (2003) that included reaches on the Red Deer River downstream of the Dickson Dam. IFNs were established based on the ecological need for natural flow variation to maintain four ecosystem components: water quality, fish habitat, riparian vegetation, and channel maintenance. These components were selected to represent the full extent of the aquatic ecosystem and address a broad range of natural flows in terms of magnitude, frequency and duration. The fish habitat component focused on the flows required to maintain fish habitat for several fish species at different life stages. The riparian vegetation component considered the flows required to permit cottonwoods to re-seed and grow new trees, as well as flows required to sustain tree health. The water quality component addressed the flow dependant variables of water temperature and dissolved oxygen concentrations, as required by fish. The channel maintenance component addressed the flows required for channel processes, including flushing fine particles from spawning substrates and high flows that shape the channel. The four ecosystem-component IFNs were then combined into an integrated flow duration curve using a weekly time-step.

For the purposes of the IFN study, the Red Deer River was divided into the following 7 reaches and IFN flow values were generated on a weekly time step in a duration curve format (Clipperton et al., 2003).

- Dickson Dam to upstream of Medicine River confluence (RD7)
- Medicine R. confluence to upstream of Blindman R. confluence (RD6)
- Blindman R. confluence to upstream of SAWSP diversion (RD5)
- SAWSP to Drumheller (RD4)
- Drumheller to Dinosaur Provincial Park (RD3)
- Dinosaur Provincial Park to upstream of Bindloss (RD2)
- Bindloss to Provincial Border (RD1)

The IFN study concluded that the Red Deer River is characterized by an IFN that exceeds the natural flow for much of the winter and, to a lesser extent, in the summer weeks of dry years (Clipperton et al., 2003). This is the result of a water quality IFN necessary to meet the current loadings into the river. Examples of integrated IFN curves for weeks 9, 23, 33 and 40 for the Red Deer River at Drumheller are shown in Figure 25. Water Conservation Objectives (Section 3.3.2) were established in part from the derived IFN curves.



**Figure 25. Red Deer River at Drumheller Integrated Ecosystem IFN for Weeks 9, 23, 33 and 40.**  
*Source: (Clipperton et al., 2003)*

The IFN study by Clipperton et al. (2003) provides IFN curves for the mainstem of the Red Deer River from the Dickson Dam to the confluence with the South Saskatchewan. In cases where an IFN is to be developed outside of the limits of the Clipperton et al. study and *in the absence of site-specific information that could otherwise be used to establish an Environmental Flow (IFN)* (Locke & Paul, 2011), AESRD has established the Alberta Desktop Method (ADM). The level of environmental flow recommended by the ADM is the greater of either (Locke & Paul, 2011):

- A 15% instantaneous reduction from natural flow
- The lesser of either the natural flow or the 80% exceedance natural flow based on a weekly or monthly (depending on the availability of hydrology data) time step

In essence, the recommendations from the ADM specify that water withdrawals should not be permitted during the lowest flows. The benchmark for low flows is set at flows that occur up to 20% of the time. During the remaining 80% of the time when flows are higher, up to 15% of the natural flow can be taken (Locke & Paul, 2011).

The ADM was developed for rivers that have natural flows and should not be used for regulated streams, i.e., only natural or naturalized flow data should be used to compute the recommended Environmental Flows from the ADM. Among other uses, the ADM is currently being used by AESRD to determine Environmental Flows for tributaries to the Red Deer River during the review process for new water licence applications, including temporary diversions for oil and gas developments (Terry Chamulak, Hydrologist, AESRD, personal communication).

The IFN study by Clipperton et al. (2003) was used as a basis for evaluating ecosystem impacts associated with alternative water-use scenarios for the Red Deer River (Goater et al., 2007). In this study, six flow scenarios were assessed based on a four-category impact ratings methodology. The four impact categories



were based on a qualitative and categorical scale of ecosystem effects and are defined as: i) slight, ii) marginal, iii) serious, and; iv) extreme. The six flow scenarios for the Red Deer River consisted of the following:

- **Natural Flow** – the naturalized flow of the Red Deer River from 1912 to 1995
- **Present Use of Existing Licences** – the pattern of flow in the Red Deer post-regulation by the Dickson Dam, including present estimated use of licences (not the maximum licensed usage)
- **Instream Flow Needs** – the pattern of flow that can sustain a natural aquatic system over the long term (after Clipperton et al. (2003))
- **Increased Use of Existing Licences** – the predicted outcome of all existing allocations and other commitments throughout the Red Deer River Basin being used to their fullest extent in the future
- **New Licences With High WCO** – the predicted outcome if new licenses were limited to 600,000 dam<sup>3</sup> and IFN was used as the WCO for new licences within the Red Deer River Basin
- **New Licences with Proposed WCO** – the predicted outcome of the WCO recommended in the draft SSRB water management plan, and an allocation limit of 600,000 dam<sup>3</sup> applied to new licences for the Red Deer River

Results from existing water quality modelling runs using the CE-QUAL-W2 software were used as the basis of assessing effects from different scenarios on several water quality parameters including water temperature, total dissolved solids (TDS), bacteria, phosphorus, ammonium, nitrate-nitrite, dissolved and particulate organic matter (DOM and POM, respectively), chemical and biological oxygen demand (COD and BOD, respectively), algae, epiphyton, and dissolved oxygen (DO). DO was chosen as the key parameter for assessing impacts since it has widespread effects and is sensitive to flow modifications (Goater et al., 2007).

The results of the assessment of the six flow scenarios are summarized in Figure 39 (Appendix A). By definition, the natural flow scenario resulted in no effect on the Red Deer River. The present use of existing licences and IFN scenarios was predicted to have only slight impacts on the aquatic environment. Increased use of existing licences was predicted to meet most water quality guidelines, but would impact fish communities and result in measurable reductions in cottonwood forests. The remaining two scenarios, new licences with high WCO, and new licences with proposed WCO, were predicted to result in serious impacts to the aquatic ecosystem, fisheries, and riparian areas (Goater et al., 2007).

There are some uncertainties associated with these impact assessments. In particular, defining and predicting

#### **WRMM MODEL** (Source: Government of Alberta, 2013)

The Water Resources Management Model (WRMM) is a computer program that simulates river flows and water uses. It is a tool used by Alberta Environment in managing and planning water resources in the South Saskatchewan River Basin (SSRB). It is used both for long-range planning and for short-term operations.

The WRMM compares a water supply option with a water demand option to identify potential problems. For long-range planning, such as work on the SSRB Water Management Plan, water supply is derived from the weather patterns observed in each of the 68 years (1928-2001). Against this, any water demand scenario for the SSRB can be tested. The model tracks thousands of possible water diversions and points out possible implications for water users and river flows.

The model includes all licences and their priority, international and interprovincial agreements on water sharing, and all water infrastructure (e.g., dams, canals, weirs) and the rules under which it operates. Other policies, such as instream flow objectives, are included. Results of simulations are usually shown as the numbers and patterns of years in which water allocation licences were unable to divert their licensed water or to meet their water needs.

what constitutes a “severe” impact can be difficult, and the labels have the potential to be misleading to a lay-audience. The summary figure does not separate reach-specific effects. Presumably, the impacts of increased water consumption would only be noticeable in the lower reaches of the river (e.g., downstream from Drumheller), due to overall low consumptive uses in the upper reaches (e.g., upstream from City of Red Deer).

Despite these caveats, the Goater et al. (2007) study found that the established WCO has the potential to lead to considerable environmental impacts in the future should water consumption in the basin increase. Careful water management by all stakeholders is necessary so as to limit future risks related to the environment and water resources. Re-assessing the established WCO in an adaptive management framework may be necessary over time.

### **3.3.3 Water Conservation Objectives**

Water Conservation Objectives (WCOs) are a tool under the *Water Act* that can establish protected volumetric water flow targets in river basins. They are created to ensure water volumes do not drop to levels that will cause significant harm to the viability of environmental systems, as well as to support tourism, recreation, and transportation needs. WCOs are science-based but community-informed, and are intended to be consistent with the public interest. WCOs are flow targets under the priority water allocation system. They define the socially desired balance between protecting the aquatic environment and water consumption.

WCOs can be implemented using a variety of means, including planned releases from reservoirs, and establishing a minimum flow criterion that would temporarily suspend new licences so the WCO is maintained (McGee, 2012). Another management option is to allocate a licence that would meet WCO objectives, which would then be assigned a date and priority in time just like any other licence. This WCO licence would not be “used” in the traditional sense, but would rather be left in the river to meet instream flow needs and downstream apportionment requirements. At the moment, only the Government of Alberta would be permitted to apply for a licence to meet WCO needs, and to date this potential tool has not been implemented (Dave McGee, AESRD, Senior Manager, Water Policy and Implementation, personal communications, 2013).

Water Conservation Objectives (WCOs) for the Red Deer River were established in 2007 under section 15(1) of the *Water Act* for the Red Deer River sub-basin. This followed from the approval of the Water Management Plan for the South Saskatchewan River Basin, which recommended that WCOs be established for the Red Deer River sub-basin. This includes separate WCOs for three different reaches on the Red Deer River (AENV, 2007), which are summarized in Table 10. According to the modelling results for the Red Deer River (based on the provincial AESRD Water Resources Management Model (WRMM) database), WCOs along the Red Deer River have been met under historical conditions, even on a weekly basis. However, in some cases meeting the WCO will require the management of junior licensees subject to the WCO restrictions, as shown by scenario modelling conducted in 2003 for the SSRB Water Management Plan (AENV, 2003).

Eight scenario simulations were carried out for base case, potential development and exploratory scenarios. Deficit years based on these scenarios were summarized for each water user-group (e.g., senior licensees, junior licensees subject to WCO, etc.) based on historical (1928 -1995) flows. In the base case scenario, there are few consumptive use deficits, and existing instream objectives are always met. In the development scenarios, there is a summary of junior allocation and future irrigation allocations volume and deficit frequency. Backfits in allocation, IFN priority assignment, 20% water consumption, fixed 50% of natural flow were modelled for the exploratory scenarios. The scenario titled “20% reduction of water consumption” had the most reduction in deficit years for junior allocations. Overall conclusions for the scenario modelling study, with respect to the Red Deer River Basin, suggested that there is potential to increase the instream objective values above the existing levels and provide for additional allocation.

However, from the existing data presented in this report, it appears there may be more localized challenges on heavily used tributaries of the Red Deer River, such as the Rosebud and Kneehills sub-watersheds. As discussed in section 3.2.3, the Rosebud sub-watershed has a consumptive demand representing 92% of the available supply during fairly regular dry (POE>90%) years.

**Table 10. Established Water Conservation Objectives (WCOs) for the Red Deer River Basin**

Reach	Water Conservation Objective	Applicability to Licences
Dickson Dam to the confluence with the Blindman River	16 m <sup>3</sup> /s, or 45% of the natural rate of flow, whichever is greater at any point in time	Applies to applications received or licences issued after May 1, 2005 and for existing licences with a retrofit provision
Confluence with the Blindman River to the Saskatchewan Border	<i>November through March</i> <sup>13</sup> : 16 m <sup>3</sup> /s, or 45% of the natural rate of flow, whichever is greater at any point in time	Applies to any applications received or licences issued after May 1, 2005
	<i>April through October</i> : 10 m <sup>3</sup> /s, or 45% of the natural rate of flow, whichever is greater at any point in time	Applies to any applications received or licences issued after May 1, 2005
Headwater Reaches above Dickson Dam  <i>and</i>  Tributaries of the Red Deer River	Not less than the existing instream objective or the WCO downstream on the mainstem, whichever is greater at any point in time, for any applications received or licences issued after May 1, 2005	Applies to any applications received or licences issued after May 1, 2005

### 3.3.4 Provincial Water Conversation (2013)

In 2013, the province held public consultations regarding water management under the “*Water Conversation with Albertans*.” This process sought input from the public on several key water resource management issues, including: i) healthy lakes, ii) hydraulic fracturing and water use, iii) drinking water and wastewater systems including regionalization, and iv) water management.

Several water optimization strategies were suggested by stakeholders, including<sup>14</sup>:

- Establishing protected water
- Optimizing water storage
- Facilitating water allocation transfers in a water market
- Strengthening water conservation
- Leveraging regional planning
- Expanding transparency and open data

Pursuing a “water optimization” approach was identified by the province as having the following key implications<sup>5</sup>:

- Changing the way water is used
- Investments to construct or upgrade facilities
- Collaborate with licence holders to optimize unused water
- Legislative changes and policy enhancements

<sup>13</sup> For future licences for withdrawals, and will apply to any applications received or licenses issued after May 1, 2005.

<sup>14</sup> <http://environment.alberta.ca/04128.html>

### 3.3.5 Special Areas Water Supply Project

The Special Areas Water Supply Project (SAWSP) is proposed as a means to provide a reliable supply of good quality water to a major portion of the Special Areas and parts of the counties of Stettler and Paintearth. The project involves diverting water from the Red Deer River eastwards to the Sounding and Berry Creek systems. Berry Creek is a tributary of the Red Deer River and flows southwards through Special Area 2. Berry Creek is part of the South Saskatchewan River Basin. Sounding Creek flows eastwards and northwards through Special Areas 2, 3 and 4, and eventually discharges into Sounding Lake. The Sounding Creek watershed is an internally drained system but is considered to be part of the North Saskatchewan River Basin.

Diverting water from the Red Deer River to the headwaters of the Sounding and Berry Creek systems would make water available to landholders along the conveyance route between the river and the headwaters of the creeks and take advantage of natural physiographic features to serve water users along the creek alignments. The diverted water would be used for multiple purposes including domestic use, stock watering, municipal and industrial use, waterfowl and wildlife conservation and enhancement, recreation, and irrigation. The project is seen by proponents as a key element for future sustainable economic development in the area.

Diversions from the Red Deer River for the SAWSP are subject to the Red Deer River Water Conservation Objectives established in the South Saskatchewan River Basin Water Management Plan. The proposed peak diversion rate from the Red Deer River is 2.5 m<sup>3</sup>/s. Water would be diverted from a point near Nevis into a 120 km long pipeline to the headwaters of Sounding and Berry Creeks (Dug O. Major, personal communication). Once the diverted water reaches the creek headwaters, it would be distributed through a 415 km network of natural creek channels, canals, water supply reservoirs, and multi-use reservoirs, collectively referred to as the In-Basin Distribution System (AMEC, 2004). Withdrawals from the Red Deer River would occur from approximately April 1 to October 31.

The SAWSP consists of the following proposed infrastructure (AMEC, 2004)(Dug O. Major, personal communication).

- Pump station on the Red Deer River south of the Hamlet of Nevis
- A 120 km main pipeline to convey water to the Sounding and Berry Creeks
- Instream Distribution System in the Sounding and Berry Creek basins that would involve upgrades to existing works or new construction of canals, channel improvements and water supply reservoirs
- Enhanced storage reservoirs in Sounding Creek including the Lehman reservoir and the newly designed Oyen Tributary reservoir that also have recreation potential
- Multi-use projects that will provide habitat for wildlife, livestock water availability and pumping to dugouts

The cost of the project is estimated to be about \$250 million (in 2007 dollars). This includes the cost of land acquisition, construction easements, contingency allowances, and costs for engineering services.

The next steps in the process are the public and stakeholder consultation and environmental assessment phases. Public and stakeholder groups will be asked for their input on a number of issues including: i) route selection, ii) irrigation allocation, iii) storage needs, and iv) benefits and drawbacks of canals versus pipes. A voluntary environmental impact assessment will be undertaken prior to final project approval. The assessment process will include a series of public and stakeholder consultation events (Dug O. Major, personal communication). Public and stakeholder consultation and environmental assessment will likely be completed by the end of 2015 (Passifiume, 2012).

In the short- to medium-term, the Special Areas Water Supply project remains one of the largest potential new consumptive uses in the basin. Simulation modelling by the province for the South Saskatchewan River Basin plan indicated that SAWSP demands could be met with occasional, acceptable level of shortages under present conditions and with projected needs in the future (SAB, 2006). Pumping from the Red Deer River is also proposed to be curtailed if necessary in order to meet instream flow requirements or higher priority downstream needs (SAB, 2006). Maximum possible diversions as a proportion of the river's median flow at Drumheller are approximately 2.2% of the median river volume at Drumheller (33,200 dam<sup>3</sup> / 1,500,000 dam<sup>3</sup>),

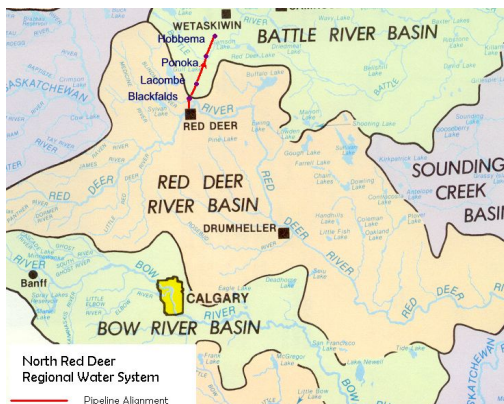
and about 3.4% of the 90% POE (dry conditions) river flow at Drumheller ( $33,200 \text{ dam}^3 / 968,000 \text{ dam}^3$ ). When added to the existing (baseline) surface water demands, this could increase the allocated proportion of river flow under POE 90% conditions at Drumheller to 32.4% of the available flow from the current status of about 29% allocated.

There are a range of complex environmental, political, social, and economic issues surrounding this project, including potential environmental impacts and benefits under a range of conditions, project costs, and social and economic benefits that must be considered. If the project proceeds, it is likely that current community susceptibility to seasonal droughts or dry years would decrease. On the other hand, if the project proceeds and additional development and/or settlement occur, this may increase the risk of impacts caused when a major long-term drought occurs. These risks and benefits must be weighed against one another in a public forum and are beyond the scope of this paper to fully address.

### 3.3.6 Inter-basin and Intra-basin Transfers: Policy Issues

An inter-basin transfer refers to a transfer of water from where it naturally occurs in one of the seven major basins identified in the *Water Act* to one of the other river basins (AENV, 2008b). For example, transferring water from the South Saskatchewan River Basin to the North Saskatchewan River Basin is considered an inter-basin transfer. Provincial law currently prohibits licences permitting inter-basin transfers unless authorized by a special Act of the Legislature preceded by public consultation. At first glance, the SAWSP project described in Section 3.3.5 is an example of a proposed inter-basin transfer, however there are ongoing discussions as to whether an intra or inter basin approval will be required. There are examples of approved inter-basin transfers to and from the Red Deer River watershed including the following:

- North Red Deer Regional Water System** (Figure 26) The City of Red Deer provides up to  $13.39 \text{ dam}^3$  of potable water to the communities of Blackfalds, Lacombe, and Ponoka, as well as the First Nations of Montana, Samson, Ermineskin, and Louis Bull through a 65 km pipeline. The communities are located in the Battle River watershed, which forms part of the North Saskatchewan River Basin. They originally relied on groundwater wells for water supplies but were experiencing problems with the quantity and quality of the available water.



**Figure 26. The North Red Deer Regional Water System Pipeline Alignment**

An intra-basin transfer refers to transferring water between sub-basins within a major basin (AENV, 2008b). In the intra-basin transfer case, the transferred water would have ended up in the same downstream place under natural conditions. For example, transferring water from the Bow River watershed to the Red Deer River watershed is considered an intra-basin transfer. Intra-basin transfers are regulated through the *Water Act* and are approved at the discretion of the Director in a manner similar to standard water licence applications (Alberta Water Council, 2008). The most important intra-basin transfer to the Red Deer River watershed is from the Bow River watershed through the return flows from the irrigation systems as described below.

### CrossIron Mills and the Red Deer River Watershed

The CrossIron Mills development just north of Calgary provides an interesting case study regarding a proposed intra-basin transfer that ultimately did not go ahead. This mall, horse racing track, and hotel complex is now constructed and is located in the Nose Creek watershed in Rocky View County (which drains to the Bow River). During development planning in 2006, it was not possible to obtain a new licence for water from the Bow River, which had been closed to new licences. Therefore, the developer proposed using water from the Red Deer River, to be piped in from Drumheller. Ultimately, the Town of Drumheller refused to provide treatment for this water system, partly due to infrastructure issues but also because the town was uncomfortable supplying water to a project located in a different watershed. This required the developer to seek out a different source of water. They ultimately purchased rights to a portion of the Western Irrigation District's water licence for \$15 million following a narrow vote by WID ratepayers. In return, the WID is investing this money to reduce system losses throughout their canal network.

- **Return flows from the Western Irrigation District (WID) and Eastern Irrigation District (EID):** The WID and the EID operate mostly in the Bow River watershed but extend into the Red Deer River watershed as shown in **Map 1: Surface Water Monitoring in the Red Deer River Basin**. Both districts draw their source water from the Bow River east. About 50% of the return flows from the WID system are discharged into the Red Deer River watershed through the Serviceberry Creek and Rosebud River. About 60% of the return flows from the EID system are discharged into the Red Deer River watershed through Matzhiwin Creek and Manson Creek (Erwin Braun, General Manager, Western Irrigation District, personal communication). Return flows into the Red Deer River from the irrigation systems represent net increases to river flows in the lower reaches of the river.

### 3.4 Key Surface Water Quantity Issues

Based on the above information, the key issues for surface water in the basin that all stakeholders must be aware of and prepared for include:

- **Risk of Severe Floods:** The past shows that the river and its tributaries are prone to flooding. Projected changes to hydrology due to climate change may increase these risks through changes to the intensity, duration and frequency of rainfall events.
- **Risk of Major Droughts:** Paleo-records indicate that drought events are not uncommon in the region, and can extend for significant periods of time, while current water storage infrastructure in the basin has minimal capability to assist with drought management.
- **Risk of Local Shortages:** Local mismatches between surface water supply and demand in specific areas without access to Red Deer River water were identified on a seasonal as well as an inter-annual basis. This poses risks of supply shortages as well as potential severe recurring ecological impacts on smaller tributaries.
- **Risk that Increased Development will Impact Downstream Reaches:** There is the potential that future increased water consumption will impact water quality, Instream Flow Needs and environmental values, although impacts would be concentrated more in the downstream reaches of the river basin.
- **Climate change amplification of risks:** Climate change has the potential to amplify or increase risks related to flooding, drought, and local supply versus demand issues.
- **Water quality impacts:** It is possible that the established WCO has the potential to lead to considerable water quality impacts and related environmental impacts in the future should water consumption increase in the basin.

- **Allocation Limits:** The future maximum quantity of water available for allocation to municipal, commercial, industrial and other uses is limited.
- **Water Conservation Strategies:** More widespread water conservation could be the key to enabling both additional long-term economic growth and water allocations, while potentially enhancing natural instream flows.

### 3.5 Draft Goals and Outcomes for Surface Water

The table below specifies draft goals and outcomes related to surface water quantity for the Red Deer River watershed.

**Table 11. Draft Goals and Outcomes for Surface Water Quantity in the Red Deer Watershed**

DRAFT MANAGEMENT GOALS FOR SURFACE WATER QUANTITY	DRAFT OUTCOMES FOR SURFACE WATER QUANTITY
1. Balance water demand with water supplies for all users, including the environment, through seasonal and extreme conditions	1. Safe, secure water supplies are available for municipal and domestic water users
	2. Water flow regimes in the Red Deer River maintain healthy aquatic and riparian ecosystems
	3. Water flow regimes in tributaries minimize impacts on aquatic ecosystems
	4. Surface water supplies for sustainable industrial, commercial, and agricultural uses are available and reliable
	5. Surface and groundwater supply and demand are integrated to optimize options (e.g., where suitable, use groundwater to leave more surface water flow)
	6. All industries apply water conservation techniques and technologies to reduce water use and to minimize the potential for impacts on water resources and future conflicts
2. Flooding events are anticipated proactively and mitigated	7. Land uses in the basin aim to conserve pre-development hydrology and minimize the risk of increased peak flows (e.g., forestry, urbanization, etc.)
	8. Restrict new development in flood-prone areas
	9. Build flood control infrastructure in select locations if absolutely necessary to protect human life and existing property
3. Knowledge of surface water resources continually improves	10. Knowledge of surface water resources at multiple scales is enhanced, as well as Beneficial Management Practices to mitigate impacts

\*Several goals and outcomes in the Phase 2 Background Technical Report (O2 2013) with respect to wetlands, riparian areas, also relate to surface water quantity objectives (e.g., WG1 - Wetlands as well as their functions and ecosystem services are protected, restored, or enhanced; LG1 - Land uses are located and managed in ways that do not result in unacceptable impacts to water quality, water quantity and aquatic ecosystem health)



### 3.6 Draft Indicators and Targets for Surface Water

The table below recommends key indicators and targets for surface water quantity.

**Table 12. Draft Indicators and Targets for Surface Water Quantity**

Indicator	Scale of Analysis	Targets	Notes
Total Surface Water Licence Allocations	Red Deer River Watershed	335,000 – 600,000 dam <sup>3</sup>	Lower end of range represents current volumes; higher end represents established new licence closure limits
Total Water Demand (Licences – Return Flows) as a Proportion of the 90% POE Water Yield (Dry Conditions)	Red Deer River reaches	A: Upstream from Dickson Dam: 0.5 to 1%	Expressed as cumulative demand divided by the 90% POE yield for each contributing area
	(nested contributing area analysis)	B: Upstream from Red Deer: 5% to 8%	Lower end of range represents current conditions. Higher end of range would allow approximately 64% expansion of licensed allocations consistent with established government policy.
		C: Upstream from Drumheller: 16% to 25%	
		D: Upstream from Saskatchewan: 29% to 48%	
Total water diversion during low flow periods as a proportion of natural flow	Unregulated tributaries	No diversions when flows are in the lowest 20 <sup>th</sup> percentile based on a weekly / monthly time step  If flows are above the 20 <sup>th</sup> percentile, no more than 15% of the natural flow can be taken	From: Locke and Paul (2011)
Number of New Licences in Local Areas with Supply Shortages	Specific areas determined to be water-short (e.g., Rosebud or Buffalo sub-watershed)	No more new surface water licences in these areas	Groundwater licensing or licensing from the Red Deer River main stem (where feasible) are alternatives for these areas  More detailed work may be needed to identify all local water supply shortage areas (e.g., Rosebud, Buffalo, Kneehills, Threehills, Michichi sub-watersheds)
Deviation of recorded flows from Water Conservation Objectives	All areas	No deviations from established WCOs (e.g., 16 m <sup>3</sup> /s – See Table 9 for additional details)  Maintain junior licence deficit frequency	Based on discussions and review of the WRMM data  Calculate junior licence deficit volume and frequency under historical and future climate change scenarios
Municipalities with water conservation management plans	Programmatic	100% <sup>15</sup>	AUMA (2013) has more specific targets:  -100% of municipalities with >10,000 population -75% of municipalities with 2500 to 10,000 people - 50% of municipalities with population < 2500
Industries with water conservation plans	Programmatic	All industries aim for a 30% increase in water productivity and efficiency	The Alberta Water Council recently established formal plans for a 30% improvement in water productivity and efficiency by 2015 for seven industrial sectors

<sup>15</sup> Red Deer and Olds are the only municipalities to date in the watershed with municipal Conservation and Efficiency Plans

### 3.7 Management Implications and Recommendations

The following recommendations relate specifically to surface water use and management in the Red Deer River watershed. Recommendations are listed under three main categories: i) monitoring and data acquisition, ii) research needs, and iii) key Beneficial Management Practices (BMPs).

#### 3.7.1 Monitoring and Data Acquisition

As previously noted in this and other background technical documents, a key recommendation is to **Establish an Integrated Monitoring and Reporting Framework**. A single integrated monitoring and reporting framework is required to track and report progress against established indicators and targets, including those related to surface water quantity. Regular reporting on indicators should be in a consistent format and databases should be maintained over time. Clear, meaningful, and measurable milestones for the plan and its implementation are required (Davenport, 2003). This database will be key for performance monitoring over time and adaptive management. Developing, implementing, and maintaining this framework will be a key component of the IWMP that requires close and on-going cooperation among agencies, stakeholders and partners and a clear definition of roles and responsibilities (Anderson, 2012). It is recommended that this framework take the form of a Watershed Cumulative Effects Management System (WCEMS) (Patrick & Noble, 2012).

Other, more specific monitoring and data acquisition actions recommended include:

- **Potential Additional Hydrological Gauging Stations:** Four new hydrological gauging stations have recently been installed, including two at the mouth of rivers that previously did not have gauging stations (Medicine River and Rosebud River). Depending on priorities, the potential for additional gauging stations to further monitor water resources at finer scales, including smaller tributaries, may be in order. This could help to quantify how land use changes affect the smaller basins. This may be particularly important to re-assess in light of recent flood events due to extremely high flows originating in the headwaters and a potential need for more monitoring stations.
- **Real-Time Monitoring:** The use of sophisticated equipment, satellite, and internet technologies to enable real-time monitoring of water flows in specific areas of interest as well as access to information for water users may potentially be very beneficial for water management. Expertise and success in setting up similar systems in the Milk River watershed were recently achieved (Dave McGee, AESRD, Senior Manager, Water Policy and Implementation, personal communications, 2013). Currently, there are plans to set up some real-time monitoring in the Red Deer Watershed but no specific timelines or details have been set to date (Terry Chamulak, AESRD Hydrologist, personal communications).
- **Water licence database spatial attributes quality control issue:** Approximately 410 (2.5%) of all the surface water licence records that occurred spatially in the watershed based on the lat/long values were assigned to other river basins other than the Red Deer in the surface licence attribute data field named "RIVER\_BASI." It is unknown whether errors are mostly in the "RIVER\_BASI" field vs. errors in the lat/long values but further investigations by the Government of Alberta are recommended. In addition, many licences that specify their water source as "Red Deer River" are located far from the Red Deer River main stem and it is unknown how many of these actually pipe in water from the river vs. those where the records are inaccurate and the actual source is a tributary. These minor inconsistencies are not expected to affect any of the substantive conclusions presented in this report; however errors evident in the database may unknowingly introduce errors for models that do not use spatial attribute information.
- **Usage vs. Licensing, including Return Flows:** Over the last few years, annual usage reporting has been required as a condition on AESRD water licences (Dave McGee, AESRD, Senior Manager, Water Policy and Implementation, personal communications, 2013). However, apart from irrigation districts, data on usage was generally unavailable, although it is understood that larger municipalities such as Red Deer and Drumheller do report annual usage. Another issue is that not all return flows are documented in the licensing database. A more complete picture of return flows may be useful as there may be the potential to increase future allocation limits to account for return flows or net usage.

### 3.7.2 Research Needs

The following outlines key research needs for surface water quantity under several categories.

- **Integrated Hydrologic Models.** Refine / develop hydrologic models that incorporate future climate change scenarios and water use predictions related to all sectors. This should examine impacts on instream flow needs at multiple spatial and temporal scales. The Water Resources Management Model (WRMM) is a good starting point for examining this problem, but needs to be updated to incorporate current licences. There are new initiatives being examined by Alberta WaterSMART specifically in relation to the Red Deer River basin, which will include a Red Deer mass balance river system model, climate variability scenarios for the basin, river system opportunities and adaptation options, and physically-based land use modelling integrated with the river system model. This project will be integrated and updated with the SSRB river system model and previous work completed for the Bow, Oldman, and South Saskatchewan Rivers. This model should build upon and leverage existing GOA models and information as well as the RDRWA IWMP process to ensure integration.
- **Surface Water – Groundwater Interactions Research.** Additional information on groundwater-surface water interactions, including the influence of groundwater on base flows during dry periods, is critical and should be incorporated as well as possible in the integrated models described above.
- **Improve Delineation of Supply vs. Demand Mismatches.** Specific areas experiencing water shortages on a seasonal or inter-annual basis should be delineated at a finer scale.
- **Non-Contributing Area Licences and Supply vs. Demand Issues.** There are many water licences attached specifically to non-contributing areas (e.g., drawing from a small wetland or ephemeral stream). Currently these are included in the licensing and use statistics that the government or watershed alliance reports. However, these areas will often have very weak relationships to the water yield or supply statistics for the mainstem or tributaries. Consequently, when comparing demand vs. supply, if non-contributing area licences are included there is an overestimation. Although the total volume associated with licences in non-contributing areas is relatively small, in future research studies, it should be considered whether licences in non-contributing areas should be excluded from the total allocation limits.
- **Technologies for Water Conservation and Efficiency.** All sectors should continue to research worldwide technological developments and opportunities for improving water conservation and efficiency, and if resources are available, conduct their own research regarding water conservation and efficiency.
- **Flood Risk Mapping.** Updated flood risk maps including defined floodway and flood fringe zones should be undertaken using the most up-to-date statistics. The nature of flood risk mapping is such that new observations of extreme events require recalculating event frequencies and associated inundation areas. In addition, delineation of 1:250 year and 1:500 year floodway and floodplain should be considered, so that municipalities and developers have more information to make informed risk decisions as opposed to a fixed single line from a 1:100 year design flood frequency. It would be beneficial for these maps to cover areas outside of urban municipalities as well, at least within a buffer area that may be under consideration for annexation, urban expansion, or country residential developments.

### 3.7.3 Beneficial Management Practices

Key Beneficial Management Practices (BMPs) for surface water quantity are synthesized / highlighted below.

#### 3.7.3.1 General BMPs

**Conserve Water:** All individuals and industries should aim to reduce water consumption and avoid profligate or wasteful water use, particularly during dry periods.

**Compliance and Enforcement:** Effective compliance and enforcement of existing / future regulations and policies is critical.

**Avoid Developing Areas of Ecological Infrastructure:** Avoid development or resource extraction in floodplains, wetlands, riparian areas, alluvial aquifers, steep slopes, Environmentally Significant Areas (ESAs), etc.

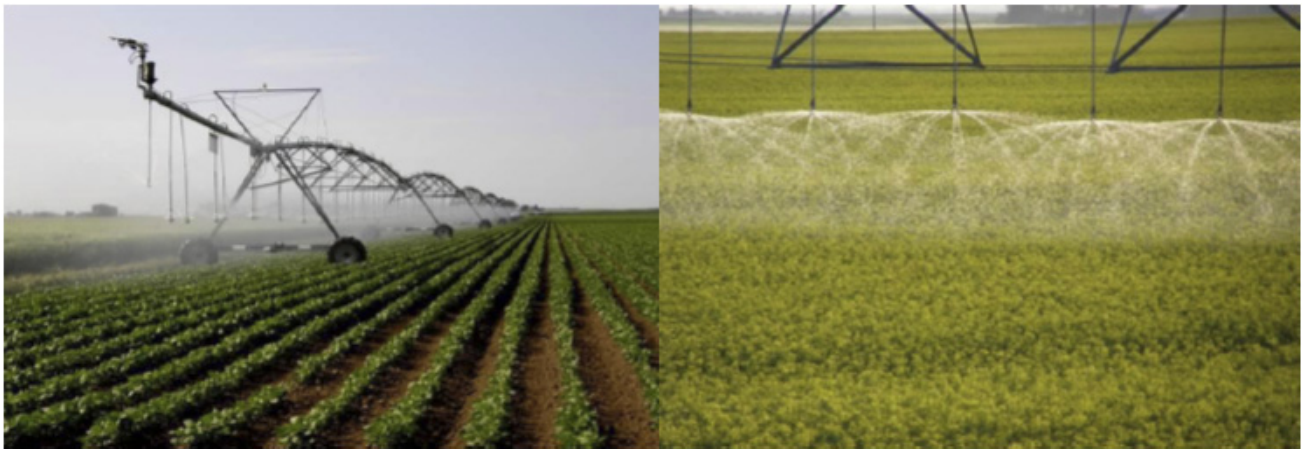
### 3.7.3.2 Agriculture

Agriculture and irrigation in particular tend to have high consumptive water use. Because of this, achieving more “crop per drop” may have the greatest impact compared to all other industries. One estimate showed that a 4.6% efficiency gain in the irrigation sector in Alberta would be equal to the estimated annual consumptive water use by all municipalities in the South Saskatchewan River Basin (AIPA, 2013). Some key BMPs for agriculture specifically related to hydrology and water consumption are summarized below.

- *Irrigation Practices:*
  - Select crops and agronomic practices to increase yield per unit of water
  - Automate irrigation water controls and deliveries with engineered systems
  - Encourage expansion of high efficiency low-pressure drop tube centre pivots from lower efficiency irrigation systems (e.g., flood, side roll wheel move, and high pressure pivots)<sup>16</sup>
  - Where present, line canals to reduce leakage and losses and replace irrigation canals<sup>17</sup> and laterals with pipelines to reduce seepage and evaporation losses
  - Where feasible, conduct irrigation at night or early morning to reduce evaporative losses

#### Improving Efficiency in Irrigation

The irrigation industry in Alberta aims to have 70% of all irrigated land on a low-pressure drop and pivot system by 2015, compared to 45% in 2005.



**Figure 27. Drop Tubes Increase Irrigation Efficiency (AIPA, 2013)**

#### *Other Farming Practices:*

- Conserve and restore wetlands and riparian areas, including incentives for landowners who may be forgoing some income in order to achieve this

<sup>16</sup>Alberta Agriculture offers an Irrigation Efficiency Program to assist producers under the Growing Forward 2 programs

<sup>17</sup> Most irrigation canals in the watershed use Bow River water, not Red Deer River water, although conservation still remains important

- Apply conservation tillage (no till and reduced till) to conserve soil organic matter and moisture, leading to better management of “green water” and lower need for irrigation (Shotyk 2012)
- Plan small-scale water storage (e.g., dugouts) to capture extra water during wet seasons or wet years, for use during dry seasons or years
- Feedlots, dairy producers, and other stock-intensive industries should refer to best practices related to water conservation and efficiency in the *Environmental Manual for Dairy Producers in Alberta* (AM + AARD, 2003) and the *Environmental Manual for Feedlot Producers in Alberta* (ACFA + AARD, 2002)

### 3.7.3.3 Municipalities

Municipalities can help deal with a variety of issues related to drought, water efficiency, and flood preparedness. Key BMPs for municipalities are provided below under the categories of water conservation and flood mitigation.

- *Water Conservation*<sup>18</sup>
  - Reduce leaks from aging infrastructure and replace / fix leaky water mains
  - Restrict outdoor watering during dry seasons or years, including the use of bylaws and enforcement
  - Xeriscaping to help reduce outdoor watering requirements (use incentives, Land Use Bylaw revisions, etc.)
  - Conserve urban topsoil (e.g., minimum 300 mm of topsoil for all landscaped areas)
  - Using rebates and other incentives, encourage much greater use of low flow water fixtures and toilets, as well as requiring low flow fixtures in new developments
  - Encourage small-scale rainwater harvesting
  - Encourage stormwater reuse
  - Consider grey water reuse and water recycling
  - Conduct water-use audits
- *Flooding:*
  - Review and update all existing 1:100 year floodplain maps
  - Prohibit any new development in flood-prone areas (note that “flood prone areas” may be much greater than the 1:100 year design flood identified in older provincial floodplain maps)
  - When development is in a flood-prone area but there are no applicable floodplain maps, the municipality should require a study to identify the flood fringe and floodway elevations

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<sup>18</sup> The Alberta Urban Municipalities Association (AUMA) approved its own Water Conservation and Efficiency Plan in 2009 following recommendations of the Alberta Water Council and *Water for Life* Strategy. The report recommended initiatives on water reporting, leak detection and efficient fixtures. In addition, by December 31, 2011, targets for urban municipalities that have developed Conservation, Efficiency and Productivity Plans were established as follows:

- 100% of municipalities with populations greater than 10,000
- 75% of municipalities with populations between 2,500 and 10,000
- 50% of municipalities with populations under 2,500

- Consider new studies to delineate the 1:250 year and 1:500 year defined floodplain including floodway and flood fringe, and regulations that would apply to these areas
- Revisit stormwater management policies and aim to construct systems that mimic predevelopment hydrology. Adopt Low Impact Development (LID) policies, design standards, and construction procedures. In addition to stormwater ponds to minimize peak flow discharge rates, LID includes decentralized networks of source control stormwater management facilities (e.g., rain gardens, bioswales, green roofs, pervious pavement, etc.)
- Reduce sprawl. Allocate urban and non-agricultural land uses in appropriate locations at appropriate densities to reduce the consumption of agricultural and natural lands. Use urban growth boundaries on a regional scale to prevent urban and rural sprawl and low density 'leapfrog' development. Within urban and semi-urban municipalities, specify minimum densities for greenfield development, and identify priority areas for redevelopment and rezoning.
- Build flood control infrastructure in select locations if absolutely necessary to protect human life and existing property.

#### Increasing Use of Saline Groundwater for Oil and Gas

The use of saline groundwater as a proportion of all oil and gas water licences in the province has been increasing steadily over time, and is now over 60% of all water use as opposed to just 10% in 1975.

#### 3.7.3.4 Oil and Gas

The oil and gas industry can use water for a variety of applications in the watershed, including drilling and completion of both oil and gas wells, hydraulic fracturing, enhanced oil recovery by injecting water into oil-producing formations, and gas and petrochemicals plants such as cooling towers. Overall, the upstream oil and gas industry aims to improve non-saline water use productivity by 24% by 2015 compared to 2002-2004 (CAPP, 2011).

Key BMPs identified for the oil and gas industry, including the petrochemicals sector, include:

- Apply technologies and processes for improving water conservation, efficiency, and productivity (e.g., water reuse and recycling, improved process efficiency, reduced water losses, etc.)
- Avoid using surface water and potable groundwater for industrial uses, particularly in areas vulnerable to local water scarcity
- Use saline groundwater for pressure maintenance purposes where available in sufficient quantities, with appropriate subsurface re-injection back to the source once it has been used
- Reuse municipal wastewater for industrial applications where feasible
- Treat and reuse produced water that would otherwise be disposed of by injection
- Provide for increased monitoring and sampling of local surface water and groundwater in areas that may be impacted by industrial activity to identify concerns

#### 3.7.3.5 Forestry

The forestry sector recently prepared a water conservation and efficiency plan focused on water licences for pulp and paper mills; none of these located in the Red Deer Watershed (AFPA 2012). However, for a watershed plan, the influence of forestry land uses on water yield at various time scales including both flood and drought

extremes is far more important than any consumptive use of water. In this regard, best practices for forestry should include (Diiwu, 2013):

- Conduct forest watershed assessments to examine water yield increases as required under the Alberta Forest Planning Standard and CSA SFM z808-08, as well as to reduce potential increased flood peak risks as much as possible
- Plan for multiple smaller entries into a watershed to minimize changes to hydrology
- Address a two pass / three pass harvesting system
- Model how linear features combined (e.g., seismic lines, pipelines, well site roads, long term resource roads) have an impact on increased peak flows
- Reclaim roads immediately after completion of harvesting
- Avoid harvesting and other activities on steep slopes
- Ensure sufficient frequency of cross drains and culverts to mitigate effects of roads on hydrology

### 3.7.3.6 *Special Section on Flood Risk Management*

The major flood disaster in southern Alberta along the Elbow, Highwood, Bow, and various tributaries over June 19 – June 21, 2013 has heightened public and political awareness of this issue. At the Canadian Water Summit held on June 27 in Calgary, a group of leading water experts identified five actions that all levels of government should consider today to avoid the impacts of similar flood events in the future:

- *Anticipate more extreme weather events and plan for them*
- *Improve operational predictive capacity through better modelling and data management*
- *Invest in infrastructure such as on and off stream storage, diversions, and natural storage such as wetlands*
- *Consider flood risks in municipal planning, including building in flood plains, and better engineering of electrical, mechanical and back-up systems*
- *Manage our water resources collaboratively, following the example of the Bow River Consortium, and ensure proper funding for the watershed planning and advisory councils across the province*

After the 2005 flood events across southern and central Alberta, a provincial Flood Mitigation Committee was struck and prepared a report with recommendations on what the province can do to better prepare for floods (Groeneveld, 2006). Complete recommendations and potential lead agencies are identified in Appendix C of this report, including 18 recommendations for a provincial flood mitigation program. Among the key recommendations of the report were the following (Groeneveld, 2006) (emphasis added to particular items):

- #1: Alberta Environment coordinate the completion of flood risk maps for identified urban flood risk areas in the province.
- #2: Alberta Environment develop a map maintenance program to ensure that the flood risk maps are updated when appropriate.
- #3: Alberta Environment to identify priority rural flood risk areas that require flood risk mapping and develop a program to prepare the maps.
- #4: Alberta Environment co-ordinate the determination of the 1:100 year still water lake elevation for all gauged lakes in the province.
- #5: Alberta Environment to continue to collect high water elevation, aerial photography and other appropriate data whenever a significant flood occurs and share this information with local authorities,

as well as continue to explore and evaluate other methods of collecting flood data such as satellite imagery.

- #6: Alberta Environment make historic flood information available to the public on its website. Suitable information would include historic high water elevations, flood risk reports, and flood photography.
- #7: The Minister of Environment designate a flood risk area after the responsible local authority has had an opportunity to review the maps and provide comments on the technical elements. The recommended time period for designation is within six months of receiving the maps.
- #8: A notification system be established that will inform any potential buyer that the property is located within a designated flood risk area.
- #9: Alberta Municipal Affairs, in consultation with Alberta Environment, prepare an information bulletin on the subject of planning for flood-prone lands to be circulated to municipalities
- **#10: The flood mitigation strategy to include a cessation of the sale of crown lands in known flood risk areas.**
- #11. The “Flood Risk Management Guidelines for Location of New Facilities Funded by Alberta Infrastructure” be followed when the province constructs or contributes funding towards new facilities
- #12: The provincial government develop programs to cost-share flood mitigation measures to protect existing development in urban and rural areas. The costs should be shared among the federal, provincial, and local governments. In the case of individuals, they could cost-share directly with the federal government.
- **#13: Disaster Recovery Regulations be amended to prohibit disaster recover payments for new inappropriate development in flood risk areas.**
- #14: The provincial government to continue to pursuing amendments to the federal disaster financial assistance arrangements to allow federal funding for disaster recovery compensation for damages to appropriate development in flood risk areas.
- #15: The provincial flood mitigation strategy not include provincially operated or funded flood insurance
- #16: The provincial government continue to support local authorities to educate their citizens on the flood risks to their communities
- #17: Alberta Environment expand its forecasting network to provide an appropriate level of warning for all local authorities exposed to a flood risk
- #18: Alberta Environment and Municipal Affairs work together to explore the potential for extending the provincial flood risk mapping program to an emergency mapping program



## 4. Groundwater Resources

Groundwater is a significant water supply source for the province of Alberta, and sustains roughly 24% of the population (mostly in rural areas). This chapter focuses on the groundwater resources of the Red Deer River watershed. Included are sections related to:

- Surficial geology (Section 4.1)
- Groundwater and aquifer types (Section 4.2)
- Groundwater quantity and yield (Section 4.3)
- Recharge (Section 4.4)
- Groundwater-surface water interactions (Section 4.5)
- Demand and use (Section 4.6)
- Groundwater quality (Section 4.7)
- Risks to the groundwater environment (Section 4.8)
- Effects of climate variability and change (Section 4.9)
- Vulnerability (Section 4.10)
- Current AESRD monitoring efforts (Section 4.11)
- Summary of current policy and management tools (Section 4.12)
- Key Issues and challenges (Section 4.13)
- Draft goals and outcomes (Section 4.14)
- Draft indicators and targets (Section 4.15)
- Management recommendations (Section 4.16)

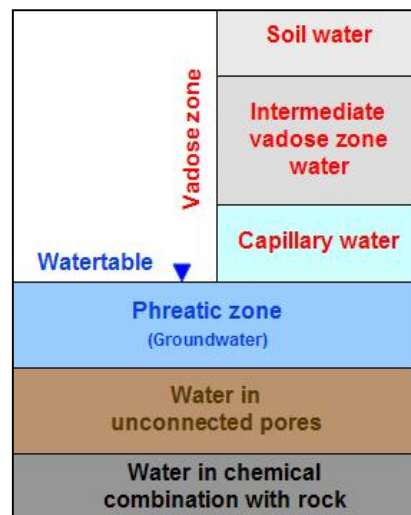
### 4.1 Surficial geology

The Red Deer River Watershed is blanketed by a veneer of unconsolidated sediments of variable thickness, mineral content, and origin. The uppermost deposits beneath the study area are defined by the surficial geology mapped by Fenton et al. (2013). **Map11: Surficial Geology** shows the distribution of different surficial genetic units. For the most part, the surficial geology is dominated by moraine (glacial debris consisting of sediment ranging from silt to boulder-sized material) and glacio-lacustrine deposits (silt to clay-sized materials deposited in glacial lakes) interspersed with fluvial deposits (sand to gravel-sized deposited by flowing water) either generated recently, prior to, and during the last glaciation.

In the upper reaches of the basin, the bedrock tends to be quite close to the surface, or at the surface, hence the thickness of deposits can be thin to non-existent. Further out in the basin to the east, the thickness can be substantial in places (>100 m). Over a majority of the basin the thickness is 25 m or less. **Map 13: Buried Channel Aquifers/Thalwegs** shows the thickness of unconsolidated sediments across the Red Deer River watershed.

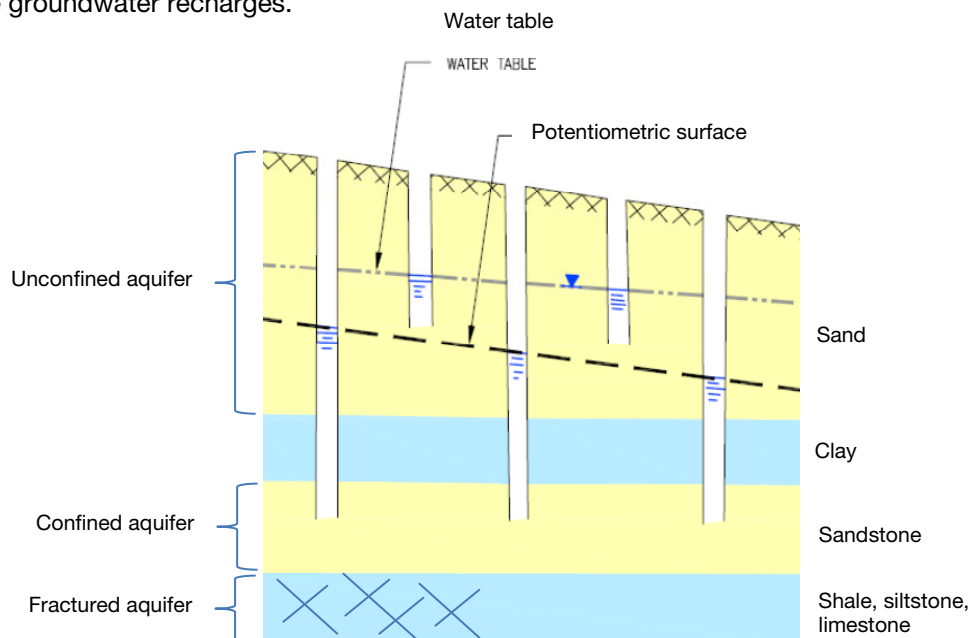
### 4.2 Groundwater, Aquifer Types and Flow

Water is an important resource for all Albertans. Much of our water comes from surface sources, like rivers and lakes, which are easily accessible. Some of our water, however, is accessed from underground sources to support our growing rural population. This water is commonly referred to as groundwater and resides in the saturated zone (or phreatic zone) of soil and rock formations beneath our feet (Figure 30).



**Figure 28. Distribution of water in the subsurface**

In the saturated zone, the voids between soil grains or fractures are completely filled with water and other fluids like oil and gas. The upper surface of the saturated zone represents the water table. Below the water table, the water pressure is great enough to allow water to enter wells, thus permitting groundwater to be withdrawn for use. The depth to the water table is highly variable and can range from zero, when it is at land surface, to great depths beneath some landscapes. Usually, the depth to the water table is small near permanent bodies of water such as streams, lakes, and wetlands. An important characteristic of the water table is that its elevation varies seasonally and from year to year. Timing of snowmelt and later season precipitation inherently affects variation of the water table elevation as the water infiltrates the subsurface to become groundwater recharges.



**Figure 29. Schematic of differences between unconfined (water table) and confined aquifers**

Although groundwater exists everywhere beneath the ground, some parts of the saturated zone contain more water than others. Underground formations that can yield useful quantities of water when accessed by a well are referred to as aquifers. Aquifers come in all types and sizes, and their origin and composition are varied. They may be small, only a few hectares in area, or very large, underlying thousands of square kilometres of the earth's surface. They may be only a few metres thick, or they may measure hundreds of metres from top to bottom.

The subsurface is comprised of layers of sediment and rock of varying ability to hold and transmit water. Intervals with the capacity to hold and convey large volumes of water are commonly referred to as “aquifer.” These tend to be the more porous types of sediments and rock, such as sands and gravels or sandstone. Those intervals that tend to be more fine-grained and less porous (e.g., clay and shale) are typically referred to as “aquitards”, or “aquicludes” for extremely tight formations (e.g., tight limestone, salt deposits). Fracturing of tight formations can turn an aquitard or aquiclude into an aquifer if the fracturing is extensive enough and well connected over large areas.

Aquifers can exist in two states: i) confined; and ii) unconfined. Many people are familiar with the term “water table.” The water table represents the surface of groundwater within an “unconfined aquifer.” An unconfined aquifer is one where the upper surface is open to the atmosphere (i.e., dashed and dotted line shown in Figure 29). The water table represents the surface at which the water pressure is equal to the atmospheric pressure.

The second type of aquifer is a “confined aquifer.” These aquifers are so-called because they are confined from above and below by aquitards or aquicludes. These lower permeability layers isolate the aquifer from direct interaction with the atmosphere or other overlying and underlying aquifer intervals. The sealing nature of the confining layers results in an increased pressure of the water in the aquifer, such that if a well is drilled and installed into this type of aquifer, the water level in the well will stabilize above the top of the aquifer sediments. The resulting surface provided by numerous wells completed in the same interval over a given area is called a “potentiometric surface” (i.e., lower dashed line in Figure 29).

There are three different types of aquifers beneath the Red Deer River Watershed, all of which can exist at unconfined or confined states. These include:

- Near surface sand and gravel deposits (sometimes referred to as “alluvial aquifers”)
- Buried channels and/or inter-till sands and gravels (of pre-glacial or glacial origin, respectively)
- Bedrock aquifers (sandstone, siltstone and/or fractured bedrock)

Each of these aquifers, and their respective attributes, are discussed in the following sections.

#### **4.2.1 Near-Surface Sand and Gravel Aquifers**

Near surface sands and gravels are generally characterized as granular deposits that exist within 30 m of surface. Some of these deposits were laid down by rivers and streams draining the region since the retreat of the last continental ice sheet some 10,000 to 15,000 years ago. These deposits are typically connected to the existing surface water features that generated them. The groundwater contained within these river- or stream-connected deposits is commonly referred to as “groundwater under the direct influence of surface water.” Other near surface sand and gravel deposits exist as defined areas of granular deposits associated with ice-contact (e.g., kames or moraines), deposits at the terminus of the continental ice sheet (i.e., outwash deposits), or deposits at the base of the continental ice sheet (i.e., eskers).

**Map 12: Near-surface Sand and Gravel Aquifers** shows the distribution of near-surface sand and gravel deposits across the Red Deer River Watershed. Based on a review of water well records available from AESRD, the number of wells drilled and installed in these deposits in the watershed is 254.

#### **4.2.2 Buried Channel Aquifers**

The province of Alberta is underlain by a series of buried channels containing notable accumulations of sand and gravel deposits. These channels represent two differing kinds: i) pre-glacial channels eroded into the bedrock surface and representative of the paleo-drainage network of the province prior to the last continental glaciation; and ii) channels of glacial origin containing granular deposits laid down at the terminus of the continental ice sheet or along drainage-ways leading from those areas, and confined by till deposits similarly laid down by the continental glaciers.

Typically, the deeper intervals in these buried channels tend to be more laterally constrained by the walls of the buried channels and their disposition is predictable. However, with proximity to the surface, buried channel control becomes less constraining and the deposits can become more distributed in extent. A general

thickening of buried channel deposits is noted moving from the western part of the basin (from less 1 m up to 30 m or so) towards the east (up to 80 m or more). **Map 13: Buried Channel Aquifers / Thalwegs** shows the distribution of buried channel deposits throughout the Red Deer River watershed.

#### 4.2.3 Bedrock Formations and Aquifers

There are a number of bedrock formations beneath the basin that provide groundwater supplies for industrial, agricultural, or domestic purposes. These bedrock deposits are extensive across the basin area and provide the largest potential for groundwater supply of all aquifer categories. They tend to be encountered at greater depths than the other aquifer types, particularly in the eastern half of the basin. **Map 14: Bedrock Formations and Aquifers** shows the distribution of sub-cropping bedrock formations beneath the surficial sediments.

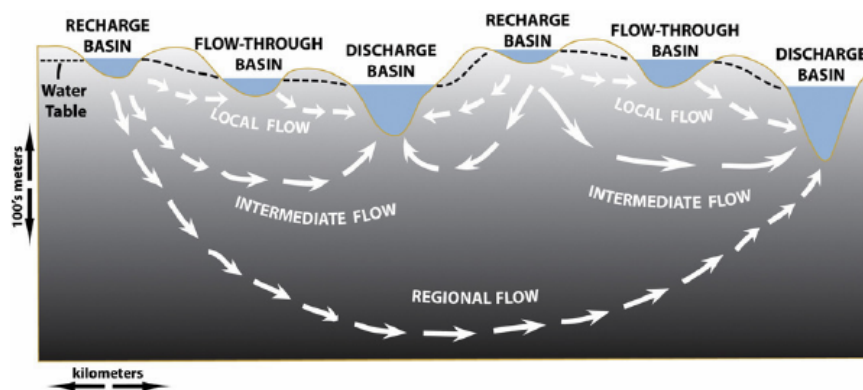
With respect to aquifers, the Paskapoo Formation represents the youngest and the most heavily utilized bedrock interval. Despite its popularity, its morphology is complex and may be described as a series of meandering, stacked, sandy channels and clay deposits contained within a mudstone and siltstone matrix (Lyster and Andriashek, 2012). As such, the predictability of encountering significant accumulations of permeable sandstone in any given location is low. In general, there are two main intervals in the Paskapoo that tend to be sandier. These include the Haynes Member, which resides at the base of the formation, and the Sunchild Member located at the top. These two intervals are separated by a relatively thick interval of finer-grained mudstone and siltstone-dominated layers referred to as the Lacombe Member (Lyster and Andriashek, 2012).

**Table 13. Bedrock formations beneath the Red Deer River Watershed**

Formation or Group	Age (approx. millions of years before present)	Depositional setting	Predominant lithology
Paskapoo Formation	Palaeocene (56 to 67 Ma)	Continental	Brown shale and mudstone with calcareous sandstone and siltstone interbeds composed of quartz, chert, and carbonate grains
Edmonton Group (Scollard / Horseshoe Canyon Formations)	Late Cretaceous (67 to 74 Ma)	Continental	Massive sandstone with clay, siltstone, coal interbeds and bentonite layers
Bearpaw Formation		Marine	Predominantly claystone with interbedded siltstone and sandstone; concretionary beds common
Belly River Group (Oldman / Foremost Formations)	Late Cretaceous (71 to 86 Ma)	Continental to marginal marine	Very fine-grained sandstone with coarse grained beds and minor bentonite, coal, green shale, and concretionary beds

#### 4.2.4 Groundwater Flow

Groundwater movement in the subsurface is complex, and forms hierarchical systems. Local flow systems tend to form on undulating landscapes where groundwater recharging beneath a small upland area reports to an adjacent low-lying area. Transit times for the water to move to the upland areas to the low-lying areas can be on the order of days to perhaps years. Intermediate flow systems form beneath larger areas incorporating many local flow systems, and have transit times on the order of several years to decades. Regional flow systems extend across very broad areas (i.e., several hundreds to perhaps thousands of kilometers), with transit times on the order of several thousands of years to millions of years. An example of a regional flow system in the Red Deer watershed would be the deep basinal flow that occurs from the recharge areas in the Rocky Mountains to the plains region. Figure 30 shows an example of how these flow systems tend to manifest themselves.



**Figure 30. Groundwater flow systems**

### 4.3 Groundwater Quantity and Yield

Estimates of groundwater quantity have been made for the various aquifer types residing beneath the Red Deer River watershed. These estimates formed part of the work conducted for the Alberta Water Research Institute (AWRI) study entitled “Dynamics of Alberta’s Water Supplies” (AWRI 2011), and are summarized in Table 14. It should be noted that these volumes represent a first-cut estimate, and are subject to refinement as more information about the various aquifer types becomes available.

**Table 14. Estimated volumes of groundwater in Unconsolidated and Bedrock Aquifers**

Aquifer Type		Estimated median pore volume (km <sup>3</sup> )	Percentile range (km <sup>3</sup> )		Estimated median storage volume (km <sup>3</sup> )	Percentile range (km <sup>3</sup> )	
			95 <sup>th</sup>	5 <sup>th</sup>		95 <sup>th</sup>	5 <sup>th</sup>
Unconsolidated	Near-surface sands and gravels	5	7	2	0.20	0.3	0.10
	Buried channels	14	142	<0.01	0.01	0.2	<0.01
Bedrock	Paskapoo Formation	32	129	4	0.20	0.6	0.03
	Scollard Formation	5	21	1	0.04	0.1	0.01
	Horseshoe Canyon Formation	33	158	4	0.40	1.0	0.05
	Oldman Formation	48	178	3	0.30	1.4	0.05

Note: 1 km<sup>3</sup> = 1 billion m<sup>3</sup>; volumes have been rounded to the nearest whole number.

Further details on methods used to estimate groundwater volumes are provided in AWRI (2011)<sup>19</sup>.

The amount of water that can be withdrawn from a well completed in one of the various types of aquifers beneath the Red Deer River watersheds can be quite variable from one location to another. This is a function of

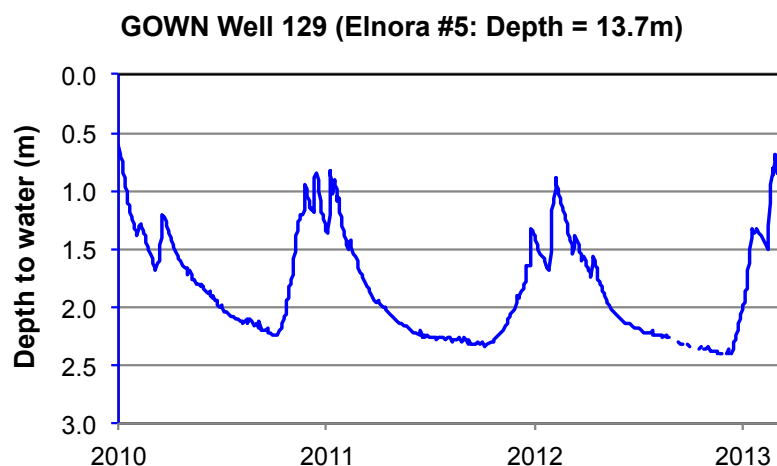
<sup>19</sup>Also available at the following website: <http://albertawater.com/index.php/projects-research/dynamics-of-alberta-s-water-supply/41-water-research/dynamics-of-alberta-s-water-supply/588-groundwater-in-alberta-an-assessment-of-source-use-and-change>

the variable nature of the sediments and rocks and the efficiency of the wells. **Map 16: Groundwater Yield and Springs** shows the distribution of groundwater withdrawal potential based on information obtained from water wells across the basins, as documented by Lemay and Guha (2009). Although useful as a guide, this information is purely based on well yields and is non-discriminatory of aquifer intervals, which will possess variable groundwater yield capability both internally and between intervals. Regardless, it appears that areas of highest water well yield potential occur more in the western half of the basin than the eastern half.

#### 4.4 Groundwater Recharge

Groundwater can be considered a renewable resource for both unconfined and confined aquifers, because each year as the snow melts and rain falls some of this water infiltrates the subsurface. As such, it is very much a function of precipitation received and the types of soil and near-surface rock materials. As this water infiltrates, it adds to the water that is stored beneath the ground – the result of which causes water levels to rise in wells penetrating these receiving intervals. Figure 31 shows a hydrograph from a Government of Alberta monitoring well established in the Red Deer River Watershed, where water levels indicate seasonal variability.

Recharge is a very difficult aspect to measure and quantify, and there are a number of approaches to estimate volumes of recharge beneath a given area. All things being equal, a region underlain by more granular materials, like sand, will tend to accept more recharge than an area underlain by lower permeability deposits like clay till or clay, as these sediments impede the entry of water to the water table and underlying aquifers.



**Figure 31. Groundwater hydrograph showing seasonal recharge events**

Previous work conducted for AESRD by Golder Associates (2008) was provided to assess the volumes and distribution of recharge across the Red Deer River Basin. The approach used was similar to the one described above, where surficial geology (**Map 11**) was used and a percentage of annual distributed precipitation was attributed to the various genetic units (e.g., moraine, glaciofluvial deposits, lacustrine deposits, etc.). **Map 15: Estimated Groundwater Recharge** shows the results of this assessment.

The total estimated annual recharge to the basin from Golder's assessment is 1.96 km<sup>3</sup>, or 1.96 billion m<sup>3</sup>. The majority of this recharge is noted to occur in the Upper and Lower Headwaters, and to a smaller degree the Central Urbanizing and Central Agricultural regions of the watershed. The volume of recharge estimated for the basin represents a high-level estimate, and is subject to uncertainty given the assumptions in the calculations made to derive this estimate. Nevertheless, the volume cited does provide some context to the degree of replenishment that the basin experiences on an annual basis.

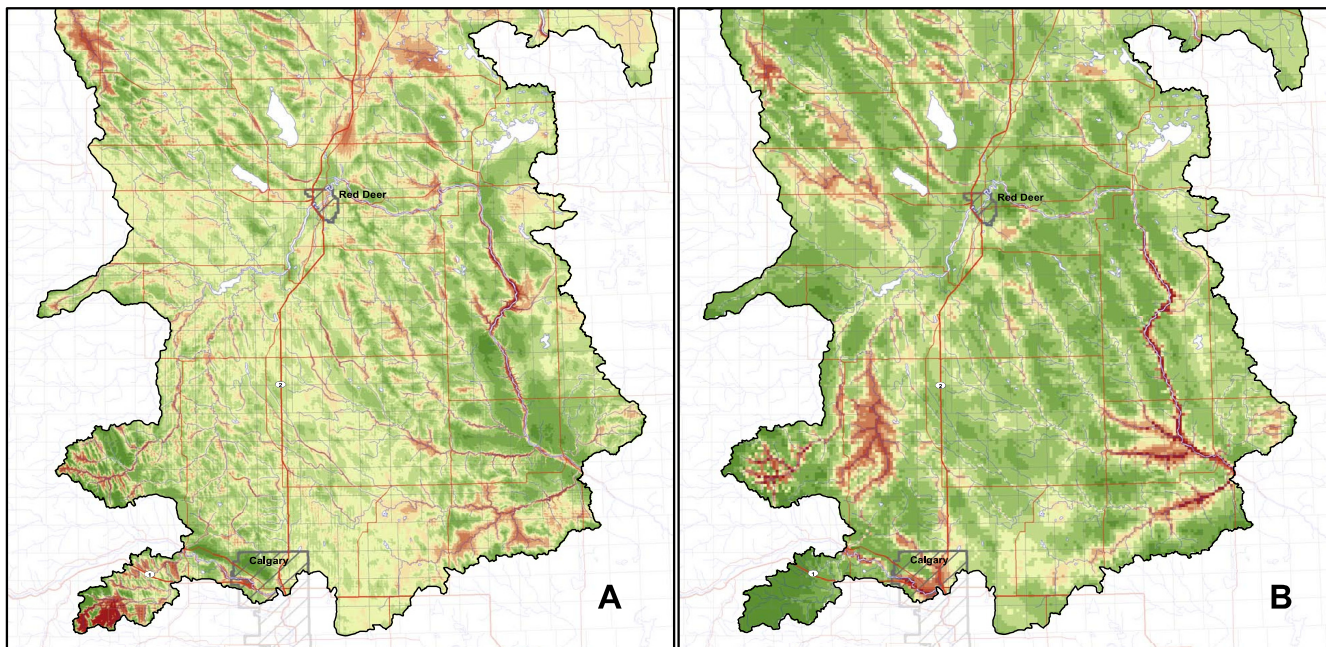
#### 4.5 Groundwater-Surface Water Interactions

Groundwater interacts with the surface environment in many different ways. For example, the flow of rivers and streams throughout the year is not only sustained by drainage of water from the landscape during the spring



melt or periods of sustained rainfall, but also by groundwater discharge during certain periods of the year (i.e., winter period when the ground is frozen and precipitation is in solid form). Similar interactions occur for lakes and wetlands. The relationship between groundwater and surface water can be complex, with some areas where groundwater is contributing to the surface water, and vice versa.

Although mapping of groundwater recharge and discharge features in the Red Deer River Basins is somewhat out of scope for this study, work conducted by the Alberta Geological Survey (AGS) for the Edmonton-Calgary Corridor Groundwater Atlas (Barker et al., 2011) provides some coverage of the basin, particularly in a portion of the Lower Headwaters, Central Urbanizing, and Central Agricultural regions. Figure 32 shows the location of anticipated recharge and discharge areas for the portion of the basin covered by their study. Panel A represents the difference in the mapped groundwater surface for the 10-20 m depth interval and ground surface elevations (i.e., local flow systems), and Panel B represents the difference between the mapped groundwater surface for the 70-80 m depth interval and the ground surface elevations (i.e., intermediate to regional-scale flow systems).



**Figure 32. Mapped recharge and discharge areas for a portion of the Red Deer River watershed**  
*Panel A = local-scale flow systems (upper 20 m); Panel B=intermediate to regional-scale flow systems (upper 80 m); Source: Barker et al. (2011)*

Areas on Figure 32 displaying the dark green to light green colours indicate areas of anticipated groundwater recharge, while areas displaying red to light orange colours indicate areas of anticipated discharge to the surface environment. It is evident that many of the mapped discharge areas (associated with either local or intermediate to deep flow systems) relate to established stream valleys and lowland areas across the basin.

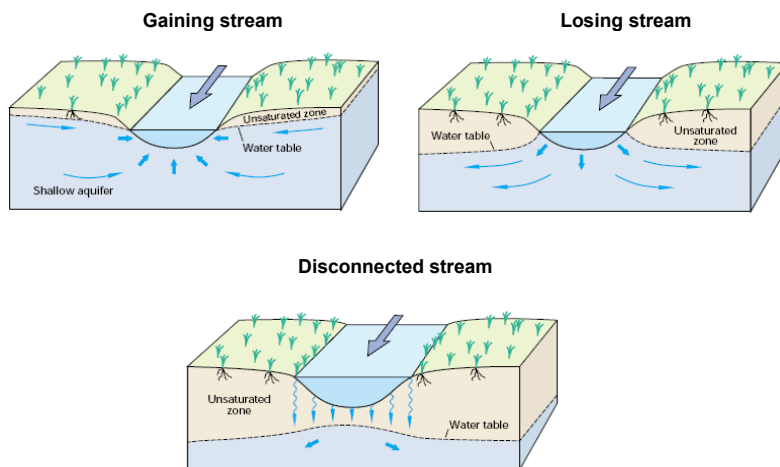
The relationship between groundwater and surface water not only relates to rivers and streams, but also lakes and wetlands. This relationship can be complex, with certain areas contributing groundwater to the surface environment, and others where the surface environment is contributing to the groundwater environment. Further description of the interactions between groundwater and surface water are provided in the following sub-sections.

#### 4.5.1 Groundwater interaction with rivers and streams

Generally, the interaction of groundwater with rivers and streams takes place in three ways:

- Streams gain water from inflow of groundwater through the streambed (gaining stream)
- Streams lose water to groundwater by outflow through the streambed (losing stream)
- Streams can become disconnected from the groundwater and slowly leak water to the water table during certain times of the year

This interaction is shown in schematic form in Figure 33. For groundwater to discharge into a stream channel, the elevation of the water table in the vicinity of the stream must be higher than the elevation of the stream-water surface. The opposite holds true for a losing stream. Losing streams can be connected to the groundwater system by a continuous saturated zone or can be disconnected from the groundwater system by an unsaturated zone.



**Figure 33.** Interaction of groundwater with streams  
(Source: USGS, 1998)

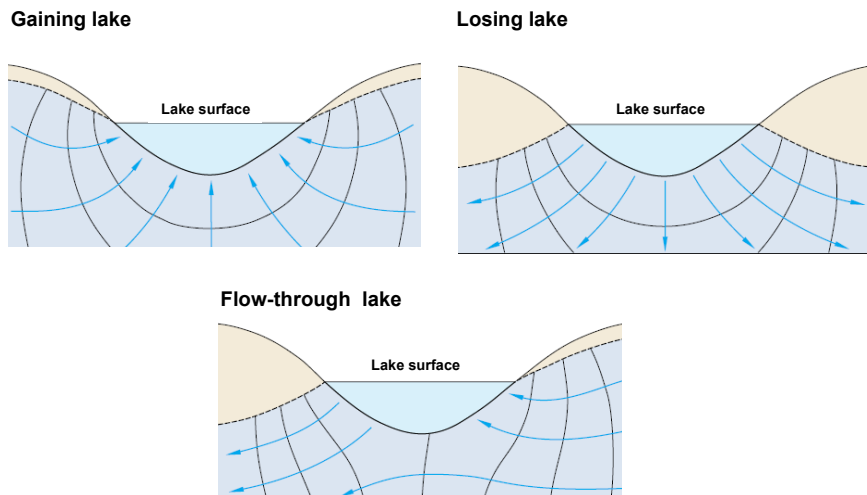
#### 4.5.2 Groundwater interaction with lakes

With respect to lakes (Figure 34), groundwater interacts with these features in three ways:

- Groundwater inflow (gaining lake)
- Seepage loss to the saturated zone (losing lake)
- Groundwater inflow in certain parts and seepage loss from others (flow-through lake)

Lakes can become disconnected from the water table, or perched. Effects on lakes from nearby groundwater withdrawals can occur if the magnitude of pumping is great enough to intercept groundwater that would otherwise discharge to the lake. Water contained in lakes may also be intercepted by pumping if the drawdown effects lower the groundwater surface below the base of the lake, leading to enhanced seepage losses.

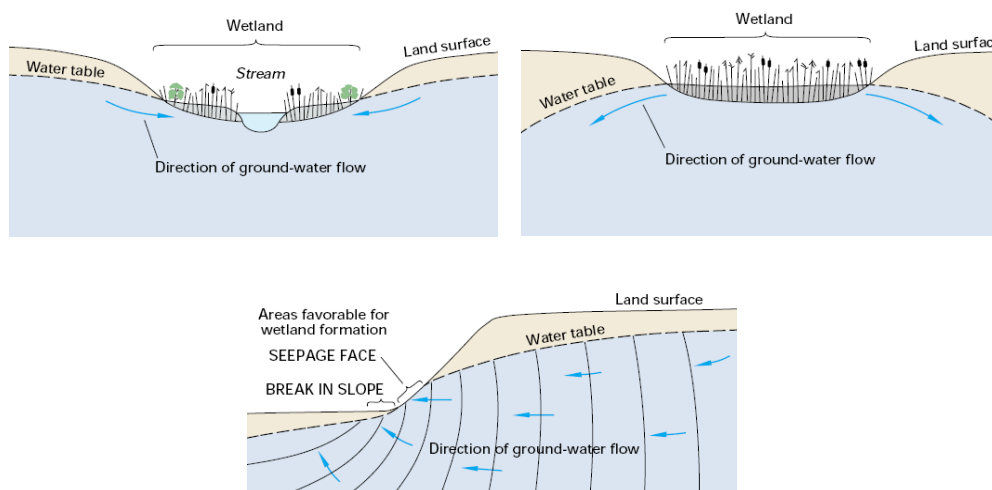




**Figure 34.** Interaction of groundwater with lakes  
(Source: USGS, 1998)

#### 4.5.3 Groundwater interaction with wetlands

Wetlands exist in areas where groundwater discharges to the land surface or on landscapes that prevent rapid drainage of water from the surface. Wetlands can receive groundwater inflow, recharge the groundwater system, or do both. Wetlands that occupy depressions in the land surface have interactions with groundwater similar to lakes and streams (Figure 35). Unlike lakes and streams, wetlands do not always occupy low points and depressions in the landscape. They can be present on slopes (such as fens) or even on drainage divides (such as some types of bogs).



**Figure 35.** Interaction of groundwater with wetlands  
(Source: USGS, 1998)

#### 4.5.4 Springs

The interaction of groundwater with the surface environment can take the form of various types of springs. Springs typically take the form of a sustained flow of water from a point on the ground surface, but can also represent discrete submerged discharge points into water bodies. In the Red Deer River Watershed there are three main types of springs (Figure 36):

- Depression springs

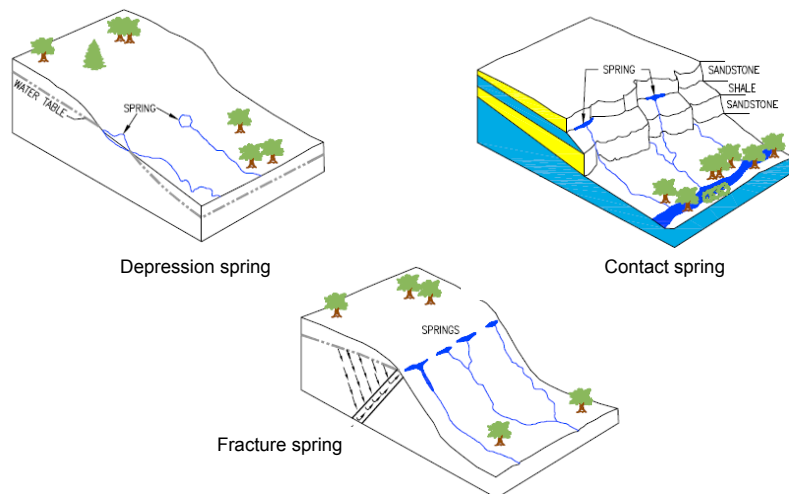
- Contact springs
- Fracture springs

Depression springs can occur in low-lying spots along a sloping landscape that intersects the water table. At the intersection point, water will flow out onto the surface and create a small drainage channel away from the discharge point.

Contact springs, on the other hand, occur where recharging groundwater meets a layer of lower permeability soil or rock. When this occurs, the groundwater will flow horizontally or sub-horizontally towards a discharge point, typically along a valley wall or break in slope where it discharges.

Fracture springs convey groundwater to a surface discharge point via a connected pathway through otherwise competent rock layers. In some cases, these springs can originate from considerable depth and sustain fairly significant flow rates. One example of a prolific set of springs is Butte Springs near Rocky Mountain House. The flow rate from this triad of springs ranges from 288 L/sec to 758 L/sec (Borneuf, 1983). Another well-studied spring in the Red Deer River watershed is Mudspring Lake in Starland County near Rumsey. This is the site of a large concentration of “soap hole” type springs with bentonitic mud and silts that ooze out of the earth and can present health and safety hazards for people and livestock (Borneuf 1983). The Raven Spring near Caroline, west of Innisfail, is a fracture spring that has produced calcareous tufa deposits and was once used commercially for trout rearing (Borneuf 1983).

**Map 16: Groundwater Yield and Springs** shows the locations of mapped springs within the Red Deer River Basin. It is evident that some of the springs have significant flow rates.



**Figure 36.** Various types of springs  
(Source: USGS, 1998)

#### 4.6 Groundwater Demand and Use

Licensed groundwater use in the Red Deer River Watershed amounts to 37 million m<sup>3</sup> per year. Licensed surface water use is almost ten times that of groundwater use (335 million m<sup>3</sup> per year). These volumes do not represent actual use, which is typically on the order of 50% or less. The agricultural sector is the largest user of groundwater, at 65%, followed by the oil and gas sector (16%), other uses (8.5%), municipal use (7.1%), and commercial (3.3%) and industrial (0.2%) sectors.

Conversely, there are a large number of unlicensed water wells in the study area based on an assessment of water well records available from AESRD. The number of records associated with each aquifer type and bedrock formations is as follows:

- Near-surface sands and gravels = 254 records

- Buried channels = 333 records
- Bedrock = 38,715 records
  - Paskapoo Formation = 29,927
  - Coalspur Formation = 215
  - Scollard Formation = 2,586
  - Horseshoe Canyon = 4,677
  - Bearpaw Formation = 711
  - Oldman Formation = 215
  - Brazeau Formation = 384

Based on AESRD (2012), the estimated amount of water used for household purposes is 365 m<sup>3</sup> per year. Using the total number of well records for all aquifers types and intervals (n = 39,302), and assuming that each well record is associated with a particular household, the total estimated volume of unlicensed water use would be in the order of 14 million m<sup>3</sup> per year. This should be considered a conservative, high-end, estimate as not all wells likely exist or are operational, and some residences may have multiple wells servicing the same household. Additionally, some of this groundwater is returned to the subsurface through, for example, septic leach fields and irrigated lawns and garden. Nevertheless, this does provide some context on the magnitude of groundwater that may be extracted annually in the watershed.

**Map 17: Groundwater Demand** shows the distribution of total estimated groundwater use by section across the study area. The map shows, for each section in the basin (i.e., 1.6 km<sup>2</sup>), the total licensed allocation minus the return flow, plus the estimated volume of unlicensed use based on number of registered water wells times an the assumed average withdrawal of 365 m<sup>3</sup>/year<sup>20</sup>. It is evident that the highest demand for water occurs in the Lower Headwaters, Central Urbanizing, and Central Agricultural regions.

#### 4.7 Groundwater Quality

Although a thorough assessment of groundwater quality in the Red Deer River Basin was not possible for this study, the following general pattern is noted from a cursory review of existing Alberta Research Council hydrogeological reports<sup>21</sup> and data provided by AESRD:

- Groundwater quality is highest in the headwaters area of the basin, particularly in the shallower unconsolidated and upper bedrock formations (e.g., TDS around 500 mg/L or less, mixed cation-bicarbonate type waters)
- Quality conditions appear to change across the basin to slightly lower quality in the eastern areas due to increased mineralization and presence of notable concentrations of constituents like sulphate (e.g., TDS generally 1,000 mg/L or higher; mixed cation- to sodium dominated-bicarbonate-sulphate type waters, sometimes with significant chloride content in bedrock formations).
- Based on data provided by AESRD, associated with the Baseline Water Well Testing program developed for coal bed methane development, the presence of dissolved hydrocarbon gases in groundwater beneath the watershed is not an uncommon occurrence. Concentrations of dissolved methane range from 0.08 to 68,700 µg/L (median = 28.2 µg/L; n = 47), and concentrations of ethane range from <0.01 to 37.5 µg/L (median = 0.5 µg/L; n = 47).

<sup>20</sup> 365 m<sup>3</sup>/year estimated household water use for rural groundwater wells is the figure used by AESRD (2012)

<sup>21</sup> <http://www.ags.gov.ab.ca/publications/pubs.aspx?tkey=hydrogeology>

## 4.8 Risks to the Groundwater Environment

A number of risks to groundwater quantity and quality exist in the Red Deer River Watershed, from large groundwater diversions to support agricultural and industrial activities to leaks and spills of materials either on or below the surface that may degrade local groundwater quality conditions. Many of these have been highlighted previously in the Phase 2 report (O2 2013). Those of particular relevance to the groundwater resources beneath the basin are presented below, along with a description of potential implications.

### 4.8.1 Oil and Gas

Oil and gas exploration and development activity in Alberta has been occurring since the late 1930s. With respect to the Red Deer River Watershed, this activity has been ongoing since at least the 1950s. Given the multiple production targets beneath the study area, a significant number of oil and gas wells have been drilled, operated and abandoned over the years.

Potential impacts to groundwater from oil and gas development are well known and relate to the activities and events such as:

- Drilling fluid losses in zones of very high permeability
- Poor well construction or cementing practices
- Operational upsets or casing failures
- Poor well maintenance practices
- Leaks and spills from underground pipeline infrastructure

The newly named Alberta Energy Regulator, or AER (formerly the Energy Resources Conservation Board, ERCB) is responsible for the licensing of all oil and gas wells in the province. For any well extending deeper than 150 m, regardless of whether it is for hydrocarbon exploration, production, or to access non-saline (defined in the *Water Act* as less than or equal to 4,000 mg/L total dissolved solids) or saline water (greater than 4,000 mg/L total dissolved solids), there is a requirement to obtain a licence from AER in advance of drilling.

A number of guidelines and directives have been developed over the years to reduce the risk to non-saline groundwater resources throughout the province. The Base of Groundwater Protection, as defined by the ERCB and Alberta Geological Survey, is the interval over which oil and gas companies are required to establish fully-cemented surface casing to reduce the risk to non-saline groundwater from production fluids migrating up the well annulus. Depending on the depth of the well, secondary and tertiary casings may be installed and cemented to provide an added degree of protection against fluid or gas migration towards the surface.

#### 4.8.1.1 Conventional Oil and Gas

Oil and gas development in the Red Deer River Watershed is a fairly prevalent activity. Based on information obtained from IHS Energy (Canada) Ltd., there are over 20,000 facilities operating throughout the Red Deer River Watershed, and over 130,000 oil and gas wells that are either operating or abandoned (IHS, 2012). In total there are in the order of 20,600 existing production and processing facilities located in the Red Deer River Watershed. The vast majority (15,544) are batteries, followed by compressor stations (1,440), operating gas processing plant (162) and other support facilities (3,487).

With respect to well infrastructure, as of 2012 there were just over 130,000 active or abandoned wells located in the basin. The vast majority relate to the miscellaneous category (41,905) entailing various mixed-fluid production wells (gas/oil/water), standing wells, etc., followed by flowing and pumping conventional gas wells (39,053), and operating oil wells (6,797). In addition, there are 26,146 abandoned wells identified in the study area (IHS, 2012). The balance is related to coal bed methane wells, which are described in more detail in the following section.

**Map 18: Oil and Gas Development** shows the density of active and abandoned oil and gas wells across the study area. The greatest density of active and abandoned wells occurs in the southern part of the Dry Grasslands region, and throughout the Central Agricultural region. Smaller areas of higher well density occur in the Lower Headwaters region of the basin, about 35 km west of the City of Red Deer.

#### 4.8.1.2 Unconventional Oil and Gas (including hydraulic fracturing)

Alberta hosts a number of unconventional oil and gas deposits. These take the form of methane extracted from deep (>400m) coal beds or seams (i.e., Coal Bed Methane, or CBM), oil and/or gas locked up in low permeability formations like siltstones (i.e., Tight Oil and Tight Gas), and even gas-rich shale deposits (i.e., Shale Gas). In order to access these hydrocarbon resources, different drilling and reservoir stimulation or permeability enhancement techniques are required. Recent advances in horizontal drilling and multi-stage hydraulic fracturing have increased the resource potential of oil and gas in Alberta.

Coal bed methane deposits are typically accessed by vertical wells. Once completed, these CBM wells are brought online by pumping any water out of the wells in order to reduce the overlying pressure of the standing water so that the gas can be released from the surface of the coal deposits or from the coal itself. Many of the wells drilled to date were established in the Horseshoe Canyon and Belly River formations. Development in these shallower formations (200 to 800 m deep<sup>22</sup>) has generally been less costly, in part due to the dry nature of the coals, which results in no water handling costs. Some CBM wells have been targeting the deeper (900 to 1,500 m deep) Mannville coals, located in the central Alberta Plains. These deeper coals tend to produce highly saline formation water, similar to conventional oil and gas wells at the same depth. The need to handle and dispose of this water impacts the cost of resource production in this area, hence the greater interest in the shallower, drier coals.

As for the tight oil and gas deposits (including shale gas) these deposits are typically accessed using horizontal wells. These wells usually start as vertical wells, which then are turned horizontal at the desired depth to extend across a larger part of the target formation. Some of the horizontal legs of these wells extend in excess of 1,000 m. Once completed, the well is perforated and the formation is stimulated by hydraulic fracturing to increase its ability to yield fluids and gases back to the well, and to the surface. This fracturing is done in stages, along the horizontal leg to ensure efficiency of the process, and entails the pumping of a sand:water mixture (typically with 1% or less other chemicals<sup>23</sup>) down into an oil or gas reservoir at high pressure to promote breaking of the rock. This fracturing is meant to stimulate the formation by enhancing formation permeability. The propagation of fractures from the well are typically in a vertical direction, and generally within 100 m, with the direction being controlled by the in situ stress regime. Micro-seismic monitoring is typically used to confirm the distances and directions of the fracturing process.

Hydraulic fracturing of oil and gas reservoirs in Alberta has been occurring since the 1950s. According to the AER, as of March 2013, more than 174,000 wells in Alberta have been stimulated through the application of hydraulic fracturing, with over 7,700 of those wells representing more current multi-stage horizontal fracturing<sup>24</sup>. Since that time, the frequency of incidents that could potentially affect non-saline groundwater has been low. Current requirements to case wells to the Base of Groundwater Protection (EUB 2007) has helped ensure against impacts non-saline groundwater resources.

Concerns with hydraulic fracturing relate to the following challenges:

- Ensuring integrity of wellbore completions (i.e., cement seals and structural integrity of production casing)
- Potential communication with offset wells completed in the same formation being fractured
- Potential communication with natural faults or fracture networks
- Density of subsurface well spacing
- Integrity of caprock formations

<sup>22</sup> <http://www.energy.alberta.ca/NaturalGas/754.asp>

<sup>23</sup> <http://www.fracfocus.ca/water-protection/drilling-usage>

<sup>24</sup> [http://www.aer.ca/documents/projects/URF/URF\\_Powerpoint.pdf](http://www.aer.ca/documents/projects/URF/URF_Powerpoint.pdf)

- Creation of induced seismic events
- Lack of monitoring to confirm integrity of confining formations and non-saline groundwater resources

The focus for many is the risk of creating connected pathways from the reservoir to non-saline aquifer intervals and pushing “frac” fluids up into intervals and compromising water quality. Considering the depth of much of the recent hydraulic fracturing in Alberta to support unconventional oil and gas development (greater than 1 km, and up to 3 km or more) the risk to non-saline groundwater, and the users of that water, is considered low. Stringent well construction requirements have been a requirement of the AER for many years to ensure against the creation of such induced pathways. This not only ensures protection of shallower groundwater intervals, but also ensures efficiency of production and elimination of fluid losses during recovery. Some situations have arisen where production fluids have been pushed to the surface during hydraulic fracturing operations. This has typically occurred as a result of connectivity between the fracturing interval and a nearby production well, or series of wells, completed in the same interval where the wellhead is not rated for the pressure experienced.

**CBC news (December 12, 2012): Fracking to blame for well blowout near Innisfail:**

*“Company essentially drilled too close to another well bore,” says Alberta's energy regulator.*

An investigation into the blowout of a well near Innisfail shows fracking was responsible. The blowout spewed nearly 500 barrels of oil and water onto a central Alberta field, affecting 4.5 hectares and requiring the removal of just over 1,000 tonnes of soil and snow.

**Red Deer Advocate (January 15, 2013): “The blowout of an oil well during a frac job on a neighbouring well in Red Deer County on Friday is raising nervous questions among rural landowners.”**

As of the end of 2011, there were a total of 18,263 producing CBM wells in the province of Alberta<sup>25</sup>. In the Red Deer River Watershed, most of the CBM activity has been occurring in the Central Agricultural region.

Hydraulic fracturing activity has been occurring in the Lower Headwaters and Central Urbanizing regions (**Map 19: Hydraulic Fracturing Activity**). Bedrock intervals targeted for hydraulic fracturing in those areas are as follows:

- Cardium Formation (360 wells)
- Viking Formation (46 wells)
- Mannville Group formations (296 wells)
- Devonian formations (67 wells)

As indicated previously, the depth at which the hydraulic fracturing is occurring is typically greater than 1,000 m and as deep as 2,500 m or more. To provide some perspective, depths of most domestic and livestock water wells are less than 100 m (as confirmed from water well records).

<sup>25</sup> <http://www.energy.alberta.ca/NaturalGas/750.asp>

## **4.8.2 Mining**

### **4.8.2.1 Coal Mining**

Coal mining is a minor component of the land-based activities in the Red Deer River Watershed. Based on work conducted for the Phase 2 study (O2 2013), only one coal mining operation is identified in the study area, and it is located south of the town of Hanna along Highway 36. This coal is mined to support electricity generation at an associated coal-fired power plant.

Outside of local effects from spills and leaks of chemicals, lubricants, and fuel to support mine activities, the main challenge to groundwater resources from coal mining operations relates to the need for dewatering of large areas to facilitate safe extraction of the coal deposit. The associated drawdown effects can extend considerable distances from the mine area and potentially impact water wells located nearby or waterbodies connected to the intervals being dewatered. The resulting effect can be to lower water levels in wells leading to added lifting costs, or potentially reduce levels to the point a well is no longer useful. Equally, interception of groundwater that would have otherwise discharged to a nearby stream as baseflow may have negative ramifications for sensitive streams relying on this groundwater discharge for local aquatic ecosystems.

### **4.8.2.2 Aggregate Mining**

Mining of near-surface sand and gravel for construction aggregate is a common occurrence in Alberta. As noted in the Phase 2 report (O2 2013), available provincial data indicates over 220 sand and gravel pits located in the watershed, with a total area of greater than 14 km<sup>2</sup>. This area represents a conservative estimate as some of these mines may have been reclaimed.

Based on an assessment of aggregate deposits in the basin, many of these near-surface sand and gravel deposits occur close to streams and rivers. For example, two large gravel extraction operations exist upstream of The City of Red Deer, and immediately adjacent the Red Deer River. Recently, AESRD reported that, under the *Code of Practice for Pits*, the Red Deer regional office has 253 pit registrations on file (more than any other regional office in the province), but only 19 reclamation certification applications (AESRD 2013 Pit Education Sessions).

Removal of these granular materials from the subsurface sometimes requires the dewatering of large areas so that safe extraction of the aggregate can occur. The effects of dewatering can negatively impact nearby water wells and/or surface water bodies that are directly or indirectly connected to the deposits being extracted. Similarly, the excavations left behind from such activities can alter local groundwater flow conditions for some time as the abandoned pits will act as sinks for the surrounding groundwater as pressure conditions and water levels re-establish themselves once activities cease.

Aggregate deposits located on or near floodplains, and directly connected to surface water bodies, represent the higher risk areas as the potential for impacts to aquatic ecosystems is much greater than deposits located at a more distant location. Unless properly managed and mitigated, the risk to aquatic environments dependent on groundwater that may be affected by mining operations is elevated. As such, the risks to the groundwater environment posed by each operation will be somewhat unique.



### 4.8.3 Agriculture

Agricultural activities in the Red Deer basin range from irrigated and dryland crop production to the rearing of livestock. A number of potential challenges exist to groundwater resources in relation to these activities. With respect to shallow groundwater quality, an increased groundwater salinization can occur from irrigation of the land and soil cultivation practices. The effect can be the leaching of salts into the water table and. Similarly, the widespread application of fertilizers and pesticides can lead to increased N and P loading to shallow groundwater environments or the introduction of persistent chemicals into the subsurface. The resulting non-point source impact to groundwater resources can be very difficult to attribute to any single operation or activity. Confined feeding operations represent more of a point-source type of situation, and they are much more easily managed through monitoring and management than non-point source operations.

The most active areas with respect to agricultural activity include the Central Agricultural and Dry Grasslands regions. Dominant crops include:

- Wheat (17.3%; covering 8,721 km<sup>2</sup>)
- Hay/pasture lands (12.4%; covering 6,247 km<sup>2</sup>)
- Barley (12.1%; covering 6,119 km<sup>2</sup>)
- Canola (10.5%; covering 5,298 km<sup>2</sup>)
- Peas/oats/lentils/flaxseed/mustard (1%; covering roughly 495 km<sup>2</sup>)

Given this activity, and the variable number of farms located in each sub-basin (see Table 15), the loading of nutrients such as phosphorus (P) and other contaminants such as pesticides to the land surface is notable in some areas. Based on 2006 census data, Table 14 summarizes the average annual P-loading per hectare, and as an analogue to pesticide use the money expended annually to purchase herbicides. The Lower Headwaters and Central Urbanizing areas are more heavily influenced with respect by agricultural activity.

As for livestock, the watershed has an estimates of over 2.2 million cows, greater than 700,000 pigs, more than 3 million chickens, and in excess of 130,000 turkeys (Aquality, 2009). **Map 20: Agricultural Livestock / Manure and GOWN Wells** shows the location of agricultural livestock operations and the annual loading of phosphorus from manure spreading across the basin. Similarly, the Lower Headwaters and Central Urbanizing regions, and to some degree the Central Agricultural region, indicate the highest density of development activity and related nutrient loading.

**Table 15. Nutrient loading and pesticide use in the Red Deer River Watershed**

Region	Number of farms	P from manure spreading (average kg/ha/year)	Expense of herbicides purchased each year	Cost of herbicides per hectare
Upper headwaters	45	0.7	\$154,996	\$0.06
Lower headwaters	610	6.0	\$7,439,793	\$0.99
Central urbanizing	259	8.4	\$5,203,843	\$1.84
Central agricultural	451	3.8	\$32,406,749	\$1.77
Dry grasslands	149	2.4	\$11,929,509	\$0.67
Total	1514	4.4 (area-weighted)	\$57,134,890.00	\$0.76



#### **4.8.4 Urban and Rural Development**

The impact of urban development on groundwater tends to receive much less attention than the other activities cited previously. Most of the issues relate to the creation of hard surface and the reduced ability for rainfall to infiltrate as recharge. Point sources of contamination include:

- Seepage of constituents from licensed or unlicensed landfills
- Leaks from underground petroleum storage tanks
- Leaching of pesticides and fertilizers from golf courses
- Impacts of road salting on shallow groundwater

Urban development in the Red Deer River Watershed is generally restricted to an area of roughly 1% of the entire basin area. Most of this development is located along the Queen Elizabeth highway (Hwy 2) corridor, the largest of which is the City of Red Deer. Also located along this corridor is a small portion of the City of Calgary, as well as the communities of Crossfield, Carstairs, Didsbury, Olds, Innisfail, Blackfalds, and the Town of Sylvan Lake. Other communities dispersed throughout the basin include Chestermere, Brooks, Strathmore, Drumheller, Three Hills, Hanna, Sundre, and Rimbey (O2, 2013).

In the basin, the population density ranges from roughly 1,200 people/km<sup>2</sup> or more in Red Deer, Chestermere, and Strathmore to fewer than 300 people/km<sup>2</sup> in the communities of Carstairs, Crossfield, Sundre, and Rimbey. Population growth during the period of 2006 to 2011 has been predominantly positive in all communities, and substantial for some (Chestermere: +50%; Strathmore: +20%; Sylvan Lake: +19%; Blackfalds: +36%; Carstairs: +28%) (O2, 2013).

Potential impacts to groundwater resources from rural development tend to be more diffuse given the lower density of development activities. Risks to groundwater posed from rural development include:

- Seepage of organic and chemical waste from septic fields
- Spills of chemicals and fuels related to farming activities
- Impacts of road salting on shallow groundwater

#### **4.8.5 Forestry**

The forestry sector presents a minor risk to groundwater resources in the Red Deer River Watershed given the relatively small areas where this activity occurs (i.e., Upper Headwaters region). Nevertheless, potential impacts to groundwater resources at the local watershed scale do exist, and relate to the clearing of vegetation over large areas and alteration to run-off coefficients that may adversely affect the ability of precipitation to recharge the subsurface. This may have implications for base flow contributions to the upper headwater streams. Current cut-block management practices employed mitigate such effects and reduce any impact to the groundwater environment.

Although spills of chemicals, lubricants, hydraulic fluids, or fuel during forestry activities present a risk to local groundwater quality, given their local nature and clean-up activities that typically ensue following a large spill, the potential to significantly impact the groundwater environment is considered negligible.

#### **4.8.6 Recreation and Tourism**

Potential impacts to groundwater resources from recreation and tourism in the basin is not seen as a major contributor considering the low density and frequency compared to other more intensive development activities. Any effects on groundwater quantity or quality would be localized effects that would likely become mitigated in the subsurface prior to presenting a major issue. Some of the potential impacts related to this activity include:

- Unauthorized dumping of organic and inorganic wastes and chemicals

- Spills of fuels and lubricants related to on- and off-road recreational vehicles
- Seepage from latrines

#### 4.8.7 Other Activities

Based on the review of work conducted in a previous study (O2, 2013), a number of other activities occur in the basin that may have an influence on groundwater resources. These include:

- Fertilizer plants (located at Benalto, Beiseker, Olds, Drumheller, etc.)
- Food processing/bottling/packaging plants (XL Foods, Brooks; Olymel Pork/Poultry and Armstrong Cheese, Red Deer, etc.)
- Industrial parks and factories (Edgar and Riverside Industrial parks, Red Deer; Insulation Factory, Innisfail)

Spill and leaks of wastes, chemicals, lubricants, and/or fuels for trucks and machinery have the potential to impact local groundwater resources if not managed quickly and appropriately. Nevertheless, the impacts from such event would be quite localized compared to the larger, and more dispersed activities (e.g., agricultural; oil and gas).

#### Groundwater mining of the High Plains Aquifer, Midwest USA

*"In most areas covering the Ogallala the water table has dropped 10-50 feet since groundwater mining began, with drops of over 100 feet recorded in several agricultural regions."*

*"The water deficit in the hardest hit portions of the aquifer can be visualized as one teacup of water being replaced for every gallon being removed because of this imbalance, which is clearly not sustainable."*

[http://hrd.apec.org/index.php/The\\_Ogallala\\_Aquifer\\_and\\_Its\\_Role\\_as\\_a\\_Threatened\\_American\\_Resource](http://hrd.apec.org/index.php/The_Ogallala_Aquifer_and_Its_Role_as_a_Threatened_American_Resource)

#### 4.8.8 Cumulative Effects

Taken individually, activities in certain parts of a basin may not necessarily represent a threat to groundwater quantity or quality conditions. However, when the density (or intensity) of activities increases, the resulting additive or cumulative effect on groundwater resources can be significant.

With respect to groundwater quantity, the location and overall extraction of water for consumptive use can lead to regionally extensive drawdowns and overall reductions in storage related to certain high-use aquifers (e.g., Paskapoo Formation). Without proper inventories, recharge estimates, levels of allocation, and monitoring infrastructure the risk of over-use exists. A recent example of where over-use has been occurring is in the High Plains aquifer of the central and southern United States of America. Water levels in that regionally extensive aquifer system have been declining over recent decades because more groundwater has been removed to support agricultural and urban development than is being recharged. Such "mining" of groundwater resources is obviously unsustainable, and could have serious ramifications if not properly mitigated.

The current level of pressure on groundwater volumes throughout the Red Deer River Watershed may be considered low (with the possible exception of some areas of higher withdrawal intensity). However, without continued management through allocation practices, long-term forecasting of supply and demand (via the use of models), and monitoring to ensure that performance goals are being met, certain areas may begin to experience increased risk to sustainable supplies. **Map 17: Groundwater Demand** shows that the highest demand for groundwater occurs in the Lower Headwaters, Central Urbanizing, and Central Agricultural regions of the watershed.

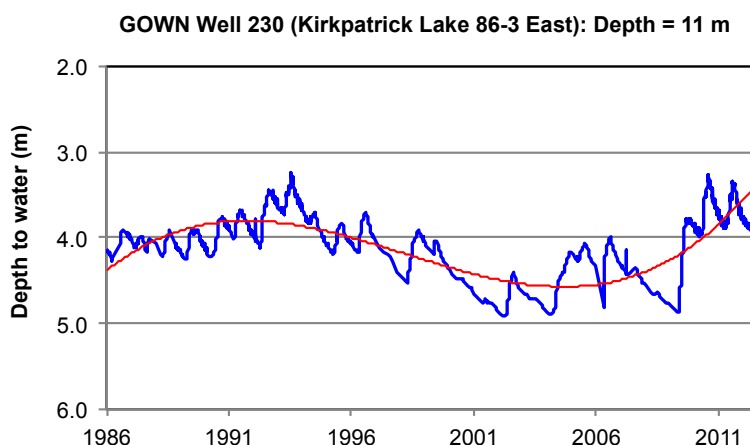
With respect to groundwater quality, the additive effects from multiple surface activities raises the risk profile for shallow groundwater environments in certain locations that are more vulnerable. Although the risks posed by more localized activities like intensive livestock operations may be more manageable through proper monitoring and mitigation if necessary, the more non-point source activities including agriculture and possibly

oil and gas development, pose a greater risk due to their widespread nature and related contaminants (e.g., persistent pesticides and other industrial chemicals, dissolved hydrocarbon gases, mobile trace elements).

#### 4.9 Effects of Climate Variability and Change on Groundwater Resources

Groundwater resources are not only affected by human activity, but also by the variations in climate that occur naturally and the effects that humans may be having on a global scale. Climate variability relates to changes in the statistical average and standard deviation of temperature, precipitation, wind, etc. that occur over longer time cycles than seasons (i.e., inter-annual, multi-year). This includes effects associated with events such as El Niño (dry) or La Niña (wet), or longer phase Pacific Decadal Oscillation (PDO) cycles. Climate change refers to long-term (decades or longer) trends in climate averages such as the global warming that has been observed over the past century, and long-term changes in variability (e.g. in the frequency, severity, and duration of extreme events).

Figure 37 is a hydrograph from one of the Groundwater Observation Well Network (GOWN) wells located east of Sullivan Lake and south of the Town of Coronation. Evident on the hydrograph are annual fluctuations consistent with the expected seasonal recharge followed by a water level decline over the year. Also evident on the hydrograph are longer phase cycles of wetter and drier periods. These longer cycles are the result of variability of moisture balance (i.e., gains versus losses) across the basin. In this example, it is apparent that a general declining trend occurred from 1993 until about 2003, when the water level dropped roughly 1.5 m. Since then, the trend has reversed to a positive one with water levels recovering to roughly the same levels as before.



**Figure 37. Annual and decadal water level fluctuations due to climate variability**

Fluctuations in water levels in a well result in a change in the amount of water stored in the groundwater system. Although a decline of 1.5 m may not seem significant, when considered across a broad region, the loss of stored water can be considerable. For example, in an unconfined sand and gravel aquifer covering an area of 1 km<sup>2</sup>, this could amount to an estimated loss of about 300,000 m<sup>3</sup>. The implications of climate variability on the basin's groundwater supplies are evident.

With respect to climate change, the answer is less clear but the implications can be anticipated. Based on projections made by several leading global climate models, the anticipated climate change effect in Alberta by the 2050s is one of warmer conditions (3 to 5°C), a shorter winter season, and a longer growing season (Barrow and Yu, 2005). The degree-days above 5°C (the designated threshold temperature) are projected to increase anywhere from 30% to 50%. For precipitation the projections range from a decline of 10% to an increase of up to 15%, with any decreases being driven by a reduction in summertime precipitation (Barrow and Yu, 2005).

Relating these projections back to the basin groundwater supplies, anticipated changes in recharge and basin groundwater storage are variable from deficit to surplus. Assuming that precipitation does increase, the increase in temperature, associated evapotranspiration rates, and growing days will place a greater burden on

the precipitation received in the basin. Therefore, an increase in precipitation of 15% does not automatically equate to an increase of 15% for recharge. Although groundwater is not a heavily used resource in the Red Deer River Watershed at the moment, future reliance on this resource in the event of lower surface water availability will increase the burden. This may become an issue for certain aquifers that are currently providing water to rural residences (e.g., Paskapoo Formation). As such, refined knowledge of the groundwater inventory and aquifer dynamics is key to ensuring sustainable supplies of water to basin residents in the event of multi-year deficit conditions.

#### 4.10 Groundwater Vulnerability

Vulnerability is defined as the degree to which a system or entity within that system is susceptible to harm, degradation, or destruction on being exposed to a hostile agent, factor, or activity. Conversely, sensitivity may be defined as the degree to which a system or associated entity responds to an external influence, the magnitude of change that occurs, and the ability of that system or entity to adapt. A system or entity within that system can be vulnerable and sensitive, in which case an effect may manifest itself in an adverse way. On the other hand, a system may be vulnerable but not sensitive and able to handle the stresses or effects placed on it.

With respect to groundwater, vulnerability presents itself as susceptibility to contamination, or negative effects due to groundwater pumping (i.e., excessive drawdown or “aquifer mining”). This is very much a factor of the local geological conditions and associated pathways that facilitate the propagation of an effect through the system. An example would be a spill of chemicals on a sandy soil, which allows easy access to a water table aquifer due to the easy flow downward of the spilled material. With respect to sensitivity, this is very much related to the type of receptor. For example, a groundwater well with low water level has the water level drawn down below the pump intake or base of the well due to excessive drawdown from a nearby pumping well, or even natural water level declines due to reduced precipitation (e.g., long-term drought). Similarly, application of chemicals on the landscape can induce the release of other substances bound to the surface of soil particles sensitive to complex reactions (e.g., phosphate displacement of arsenic on soil particles).

**Map 21: Groundwater Vulnerability** shows the vulnerability of the near-surface groundwater resources based on work conducted by Alberta Agriculture and Rural Development. The Aquifer Vulnerability Index (AVI) was used to develop this map of areas in the White Zone of the province to identify areas at higher risk to surface activities. The method is used for assessing the vulnerability of aquifers to surface contaminants (described in Dash et al 2002). In the assessment of aquifer vulnerability to potential contamination, the depth to the aquifer and the types of geological materials between the surface and the first aquifer encountered are considered. Aquifers situated closer to the ground surface overlain with high permeability soil material (e.g., sand and gravel) are therefore more vulnerable to impact, as compared to aquifers located deeper below the ground surface and protected with thick layers of low permeability soil materials (e.g., clay and glacial till).

It is evident from a review of **Map 21** that the western portion of the Red Deer River Watershed exhibits higher vulnerability to surface activities than the eastern part of the basin (with the exception of smaller areas in the southern extents). As such, surface activities occurring in the western part of the basin pose a greater potential risk to shallow aquifers due to the lower containment ability of the overlying sediments.

Those parts of the basin with higher vulnerability would therefore warrant proper monitoring of quality conditions to confirm, or detect, water quality issues due to agricultural and urban/rural development.

With respect to groundwater quantity, an assessment was conducted to identify areas where the demand for groundwater in particular areas of the basin may be significant with respect to the amount of recharge estimated to replenish the subsurface. The approach taken to assess this aspect of groundwater risk is considered quite conservative, as it assumes that full licensed amounts are used (minus the return flow), that all well records assessed represent existing wells taking their full “statutory right volume” of 1,250m<sup>3</sup>/year, and that all wells regardless of depth are accessing the recharge that occurs annually. This will of course overestimate the amount of recharge intercepted as some wells are situated at depths that are not considered directly connected to shallower intervals.

**Map 22: Sustainable Groundwater Use Indicator** shows the results of this assessment (note: level of refinement is to the Section scale). For most of the basin, the estimated groundwater amounts to less than 10% of the estimated recharge. In some isolated areas of the basin, the estimated groundwater use ranges

from 10-30%, and in some cases in excess of 50%, for example between Calgary and Strathmore, and several very localized areas near Bassano, Carbon, Rimbey, and Eckville.

#### 4.11 Current AESRD Monitoring Efforts

Currently, AESRD operates a number of observation wells in the Red Deer River Watershed. Intervals targeted for monitoring fall within three broad categories: i) shallow, which includes wells typically 30 m deep or less; ii) intermediate, which relates to wells with depths between 30 and 100 m; and iii) deep, which includes wells in excess of 100 m. Appendix A provides a summary of AESRD observation wells in the Red Deer River Watersheds. A total of 43 wells are documented, with 18 listed as shallow wells, 19 as intermediate, and 6 as deep. Some of these wells are co-located providing information on vertical hydraulic gradients, and comparative water level fluctuation responses. **Map 23: Groundwater Monitoring Wells** shows the locations of GOWN monitoring wells throughout the basin.

Groundwater quality has also been assessed at some of the same wells used to assess water level fluctuations, as well as others specifically dedicated to quality monitoring only. In total, 60 locations have been assessed for water quality throughout the watershed. This includes 32 shallow wells, 26 intermediate wells, and 2 springs. Locations are listed in Appendix A and cross-referenced with water level monitoring wells.

#### 4.12 Summary of Current Policy and Management Tools for Groundwater

All water in the province of Alberta is owned by the Crown, including groundwater, and its use is regulated by Alberta Environment and Sustainable Resource Development (AESRD). The *Water Act* (GoA, 2010a) and supporting documentation is the legislative tool used to manage water volumes in the province. In the *Water Act*, groundwater is defined as “*any water existing below the ground, whether it be in liquid or solid state.*” There are a number of existing policies and guidelines that have been developed to insure the intent of the *Water Act* is followed and proper management of non-saline groundwater resources (i.e., any water having a mineralization of 4,000 mg/L total dissolved solids or less) is supported.

The *Water Act*, which superseded the *Water Resources Act* in January 1, 1999, identifies the statutory right to water for household use, traditional agriculture (raising animals or use of water for pesticide application), or any activity exempt under Schedule 1 of the *Water (Ministerial) Regulation* (GoA, 2013), such as fire fighting. The statutory volume is set at 1,250 m<sup>3</sup>/year, or roughly 3.4 m<sup>3</sup>/day, for household use.

Any other activity requires application to AESRD for an authorization, approval, licence, or temporary diversion licence (TDL). Individuals or corporate entities wanting to access volumes of groundwater outside of statutory limits are required to apply to AESRD for a *Water Act* licence. This includes all sectors including industrial, oil and gas, agricultural, and municipal. Completion of a *Water Act* application requires the collection and submission of data and information regarding the aquifer being accessed, and the surrounding environment including other users of the aquifer or water bodies that may be influenced by groundwater pumping activities. Hydraulic testing of the aquifer is a requirement — the length of which is determined by the volume being applied for. Similarly, the installation of observation wells is required to facilitate assessment of zones of influence and safe long-term yield estimates (i.e., Q20, or 20-year safe yield). Details for the reconnaissance and testing in support of a groundwater licence are outlined in the Alberta Environment Guide to Groundwater Authorizations (GoA, 2011).

To support management of non-saline groundwater, a process to identify the Base of Groundwater Protection (BGP) was developed by the Alberta Geological Survey. The BGP identifies the estimated depth to the base of non-saline groundwater beneath the province, and hence the interval requiring application to AESRD for use, outside the statutory right to private residents.

To support management efforts regarding use of groundwater for enhanced oil and gas recovery efforts, AESRD developed the Water Conservation and Allocation Guideline for Oilfield Injection (GoA, 2006). This document identifies water-short and potential water-short areas of the province (which include parts of the Red Deer River Watershed), as well as areas that are not regionally water-short (i.e., North Saskatchewan, Athabasca, Peace and Hay River Basins). The goal of the guideline is to reduce or eliminate (on a case-by-case basis) the use of non-saline water for oilfield injection purposes, such as water-floods and generation of steam for in situ recovery of bitumen. Requirements under this guideline are to investigate alternative water sources

to support development activities. In situations where non-saline water use is the only option, the applicant is required to conduct an economic analysis, balanced against environmental impacts and the benefits of water conservation objectives, prior to approval.

Use of water for hydraulic fracturing in unconventional oil and gas recovery will be administered under the current Water Conservation and Allocation Guideline for Oilfield Injection (2006) or subsequent updates.

With respect to water quality, protection and management of this resource is administered under a separate piece of legislation known as the *Environmental Protection and Enhancement Act* (GoA, 2013a). This Act is supported by the Alberta Tier 1 and Tier 2 Soil and Groundwater Remediation Guidelines (GoA, 2010b; GoA, 2010c), which are designed to protect groundwater resources as well as soil quality. The Tier 1 guidelines set out a generic set of criteria for various physical and chemical (both inorganic and organic) constituents at a range of sites and given land uses. The Tier 2 guidelines provide a description of how to develop site-specific criteria for the same set of parameters and constituents through modification of the Tier 1 criteria. All development activities issued an approval under EPEA are required to steward to these published guidelines.

On May 21, 2013, the Alberta Energy Resources Conservation Board (ERCB) issued Directive 083: Hydraulic Fracturing - Subsurface Integrity (ERCB, 2013). Key objectives of the Directive include:

- Prevent the loss of well integrity at a subject well
- Reduce the likelihood of unintended inter-wellbore communication between a subject well and an offset well
- Manage well control at an offset well in the event of inter-wellbore communication with a subject well
- Prevent adverse effects to non-saline aquifers
- Prevent impacts to water wells
- Prevent surface impacts

Additionally, the Canadian Association of Petroleum Producers (CAPP) has recently released reporting guidelines for hydraulic fracturing fluids used to support unconventional oil and gas development (CAPP 2012). A website for reporting information on hydraulic fracturing, fracturing fluids, groundwater and surface water protection and related oil and gas activities in Canada was recently developed by the BC Oil & Gas Commission to assist in communication of relevant information and facts on the activity<sup>26</sup> (). Considerable attention is being given to this topic to ensure that risks are properly framed and communicated to directly affected stakeholders and the general public.

#### 4.13 Key Issues and Challenges

A number of key issues and challenges related to groundwater resources exist in the Red Deer River Watershed. These include:

- Lack of a refined understanding regarding:
  - Distribution of aquifers and associated variation in permeability within them
  - Related groundwater volumes
  - Recharge (where and how much)
  - Sustainable yields
  - Groundwater-surface water interaction
  - Potential for over-development in certain areas

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<sup>26</sup> <http://fracfocus.ca>



- Potential effects of unconventional oil and gas development, such as coal bed methane, tight oil and gas, and shale gas on groundwater quality in areas of development
- Effect of fertilizer, pesticide, and manure applications to the land surface on groundwater quality
- Impacts to groundwater dependent ecosystems (i.e., reduced baseflow; alteration to groundwater flow patterns; release of contaminants) from mining of river-connected near-surface sands and gravels for aggregate production
- Placement of hazardous infrastructure (e.g., landfills, oil and gas facilities) in vulnerable and sensitive locations for groundwater quality such as key recharge areas or zones of groundwater-surface water interaction
- Limited knowledge of risk related to aging pipeline infrastructure within the basin
- Lack of integrated system for monitoring and evaluating water levels and changes in groundwater storage for heavily used aquifers (e.g., Paskapoo Formation)
- Lack of integrated system for monitoring, evaluating, and reporting groundwater quality changes across the basin
- Impacts of climate variability and change on water security of basin communities (i.e., drought-proofing) and the implications of extreme flooding

#### 4.14 Draft Goals and Outcomes for Groundwater

Goals and outcomes need to strike a balance between stakeholder and community needs, economic growth, and protection of the environment. Table 4 provides a summary of suggested goals and desired outcomes to ensure a healthy watershed with respect to groundwater and connected ecosystems.

**Table 4. Draft Management Goals and Outcomes for Groundwater**

DRAFT MANAGEMENT GOALS FOR GROUNDWATER	DRAFT OUTCOMES FOR GROUNDWATER
1. Maintain and protect groundwater quantity of non-saline sources for human consumption and other uses	1. Adequate knowledge of groundwater resources is obtained through refined assessment
	2. Groundwater withdrawals for licensed diversions are allocated and operated sustainably
	3. Robust groundwater level monitoring in higher risk areas is implemented to identify changes outside historic variability
	4. Assistance is provided to AESRD and AGS with respect to provincial groundwater mapping and inventory initiative
	5. Alternative storage and management approaches (e.g., conjunctive use) are assessed for applicability on a sub-basin scale
	6. Sensitive areas (i.e., recharge zones; groundwater- surface water interaction areas) are identified and land-based activities are managed accordingly

2. Maintain and protect groundwater quality of non-saline sources for human consumption and other uses	7. Select locations in the basin are monitored to document groundwater quality and assess changes outside historic variability (i.e., TDS and major ions outside established control limits or exhibiting unacceptable trend), and managed accordingly.
	8. Groundwater quality in important GW-SW interaction areas (e.g., streams, lakes) is assessed for key nutrients (N, P), pathogens (fecal coliforms), major ions, TDS, trace elements (e.g., As), and other relevant organic and inorganic contaminants, and managed accordingly.
	9. Risks to groundwater from oil and gas development, nutrient loading, and pesticide use (i.e., transport and fate characteristics) are understood and monitored sufficiently.
	10. Activities in the upper headwaters are restricted in areas where GW-SW interaction is important to the health of the tributaries and related streams.
3. Protect and maintain groundwater-dependent ecosystems	11. Groundwater contributions to surface water bodies are not to be adversely affected, particularly 1 <sup>st</sup> and 2 <sup>nd</sup> order streams, sensitive lakes and important wetlands.
	12. Risks associated with gravel extraction from river-connected deposits are understood and managed to ensure against adverse impacts to connected aquatic systems or nearby groundwater users.
4. Understand saline aquifer water volumes and how this fossil resource is being managed	13. Volumes of saline groundwater used to support various development activities (e.g., oil and gas development) are properly allocated and sufficiently monitored to ensure sustainable use.
	14. Potential impacts effects (quantity or quality) stated in project applications compare well to actual monitoring results.
5. Understand the role the climate variability and change play on the balance of groundwater storage	15. Dynamic water storage due to changes in precipitation and recharge is understood, and higher-risk basins are identified.
	16. Mitigation strategies are identified in advance of upset events, including options to ensure water security for all uses.

#### 4.15 Draft Indicators and Targets for Groundwater

There are a number of useful indicators to assess conditions within a given aquifer interval, both from a quantity and quality perspective. Table 5 lists some suggested draft indicators that may be employed to assess the state of the groundwater environment and detect any changes that may be occurring outside of understanding or acceptance. Some preliminary targets have also been provided.



**Table 5. Draft Indicators and Targets for Groundwater**

Indicator	Scale of Analysis	Targets	Notes
Water levels	Areas with large diversions and risk of cumulative effects (i.e., overlapping drawdown cones)	Drawdown in major aquifers to be $\leq 50\%$ of available head near the pumping centre (i.e., 150 m radius).	Consistent with Water Conservation and Allocation Guideline (2006)
Water flows	Sensitive reaches of streams and rivers	No more than a 10% reduction in baseflow contribution to 1 <sup>st</sup> and 2 <sup>nd</sup> order streams	
		No more than a 15% reduction in baseflow contribution to 3 <sup>rd</sup> order streams and higher	
Nutrients (N and P) and trace elements	High loading areas; sensitive aquifers	No change in shallow groundwater (e.g., <30m depth) outside established statistical control limits (e.g., see Section 4.16.2)	Trace element scans to include Arsenic, Mercury, Selenium, and Uranium
Pesticides and pathogens	Local to sensitive aquifers	If detected, concentrations should be stabilized and reversed back towards natural conditions, if practical	
Dissolved gases	Basin-wide; high risk areas	Increased knowledge of presence in aquifers and related source(s)	Expand on current baseline monitoring related to CBM
Sectoral water use	Basin-wide	30% increase in water productivity and efficiency over next 5 years	Consistent with Alberta's <i>Water for Life</i> goal and recent Alberta Water Council sectoral plans
		Monitoring of key source aquifers (non-saline and saline) to ensure management within sustainable supplies (e.g., no more than a 50% reduction in available head)	
Monitoring programs	Basin-wide; high risk areas	Establishment of an adaptive, groundwater monitoring system	Should be consistent with regional planning initiatives (i.e., SSRP) and degree of data volume and quality (GOWN wells plus others)
		At least 12 sites commissioned by end of 2014	
Evaluation process	Basin-wide; major aquifers utilized	Evaluate existing GW quality data and initiate evaluation process by end of 2014	
		Knowledge of water level variability and implications of climate change acquired by 2017	A provincial-scale study has been commissioned by Alberta Innovates and will be completed by 2016
Communication	Basin-wide	Established website and fact sheet to communicate state of GW and SW conditions (inventory & dynamics)	
		Secure regular media coverage	

#### 4.16 Management Recommendations for Groundwater

The following recommendations relate specifically to groundwater management in the Red Deer River Watershed. Recommendations are listed under three main categories: monitoring and data acquisition, research needs, and key Beneficial Management Practices (BMPs).

##### 4.16.1 Monitoring and Data Acquisition for Groundwater

As previously noted in this and other Background Technical Reports, a key recommendation is to **Establish an Integrated Monitoring and Reporting Framework**. A single integrated monitoring and reporting framework is required to track and report progress against established indicators and targets, including those related to groundwater quantity and quality. Currently, some groundwater monitoring exists within the Red Deer River Watershed (conducted by AESRD), but it is unclear the extent to which the information is integrated to assess changes within the study area. Additionally, there are some noticeable gaps in the current monitoring infrastructure based on location of wells to areas of higher intensity of activities, and higher vulnerability to impacts from surface or subsurface developments.

##### 4.16.2 Data Evaluation Process for Groundwater

Collection of monitoring data is only part of the process of resource management. A robust evaluation process is required to determine if conditions are changing beyond the current understanding of Range of Historic Variability or trending in a direction and rate that is not conducive to future sustainability.

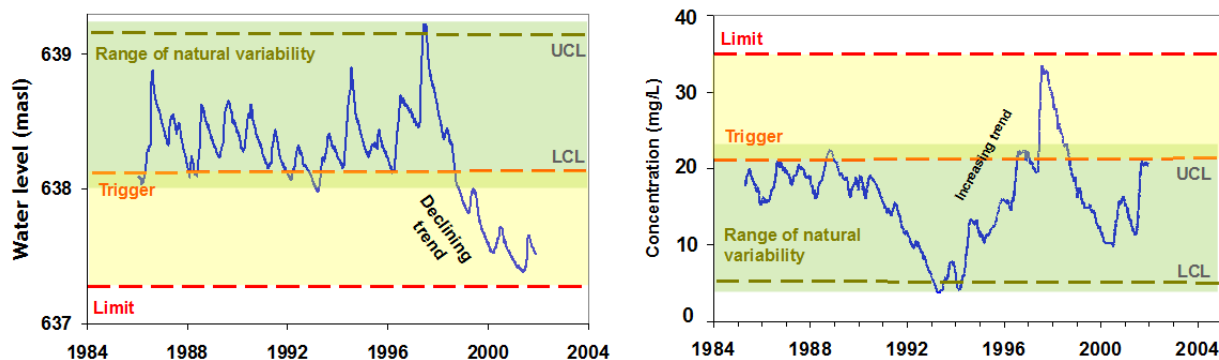
Data evaluation processes that have been applied in support of other groundwater management frameworks developed by industry and government (i.e., the Lower Athabasca Regional Plan) may have some utility in the Red Deer River Watershed for future monitoring efforts. The process is predicated on the development of statistical triggers defined by control charting procedures – in particular Shewhart-CUSUM (Gibbons, 1994; Lucas, 1982). This same approach has been suggested in the Draft Groundwater Monitoring Directive, currently being developed by the AESRD Water Policy Branch for comment earlier in 2013 (document not yet released). Control charting defines upper and lower limits to a data set that encompass, for example, the 95% confidence interval of a data set. The formulae are as follows:

$$\text{Upper Control Limit (UCL)} = \text{sample mean} + (Z) \text{ standard deviation}$$

$$\text{Lower Control Limit (LCL)} = \text{sample mean} - (Z) \text{ standard deviation}$$

where  $Z$  = a multiplier defined by the number of readings acquired to date, and the number of future comparisons to which the control limits are to apply. Lucas (1984) and the EPA (1989) have suggested the use of 4.5 for the value of  $Z$ . The overall confidence level for this value is 95%, when the sample size equals at least 8 and 35 future comparisons are being considered. If a more conservative approach is desirable, the  $Z$  value can be taken from a table of values relating to the desired number of future comparisons (e.g., sample size = 8, desired future comparisons = 5,  $Z = 3.0$ : Gibbons 1994, Table 1.2).

Figure 38 shows how this approach might apply to a water level data set and a chemical parameter:



**Figure 38. Example of control charting in the data evaluation process**

The statistical range of historic variability is thus defined within the upper control limits (UCL) and lower control limits (LCL) values calculated for a given dataset. As such, detection of a subsequent data value that falls outside these trigger values indicated that something may be wrong with the data value itself, or that something is occurring that warrants further investigation. The limit represents a point past which it is undesirable for an indicator value to exceed as it may result in an unacceptable change to the resource or receptor being protected.

Within this framework, the application of trend analysis based on a sufficient amount of data (e.g., 8 or more readings) enhances the detection and response to monitoring results by indicating a need to investigate in advance of a trigger exceedance. For example, a dataset exhibiting values within established control limits, but is exhibiting a statistically significant trend, would trigger an investigation into why the trend is occurring. In doing so, the gradual exceedance of a control limit can be avoided if the cause is linked to something outside of natural causes. Regardless, trend analysis provides an additional level of protection when assessing changes in monitoring data. One of the techniques favoured by AESRD is the Mann-Kendall Test for Trend (Mann, 1945; Kendall, 1975). Addition of Sen's Slope Estimator (Sen, 1968) can provide an additional filter for trending data by identifying the magnitude of a trend and screening out those that may reflect only a slight change in parameter values (e.g., change from 1 mg/L chloride to 2 mg/L chloride) or low magnitude changes (e.g., change of 1% per year: 1,000 mg/L chloride projected to increase by 10 mg/L the following year).

Response to a control limit exceedance or statistically significant trend should follow a logical progression of steps, such as:

- Verification (ensuring the data point is real, through QA/QC protocols or possibly by re-sampling)
- Investigation (to determine the source and cause of the event – i.e., natural or human-related)
- Evaluation (identifying if the exceedance is associated with a known activity or occurrence)
- Delineation (determining the spatial and/or temporal magnitude of the event)
- Mitigation (responding to protect the resource or receptor prior to reaching or exceeding an established limit)

By following a logical investigation, detections of anomalous monitoring data or trends can be better understood and responded to accordingly.

#### **4.16.3 Proposed Groundwater Monitoring Locations**

Establishing a robust groundwater monitoring network will be key to achieving the goals and outcomes of the Integrated Watershed Management Plan. With respect to groundwater resources monitoring **MAP 24: Groundwater Monitoring (Conceptual)** shows proposed areas within the basin to establish monitoring infrastructure. Selection of the locations has been based on an aggregate of the following aspects:

- Magnitude of groundwater demand
- Nutrient-loading and density of livestock operations
- Density of oil & gas activity (including hydraulic fracturing operations)
- Location of sensitive waterbodies
- Areas exhibiting high groundwater vulnerability
- Existing road access

As such, each location has been identified to address as many of the above-listed attributes as possible - at the same location. In a number of cases, existing GOWN wells have been identified in opportune areas, and could be integrated into any monitoring network. A number of other locations have been identified which would require the establishment of new monitoring wells.

Further refinement of this conceptual monitoring network would be useful, based on a more in-depth review of AESRD water level and water quality information provided in support of this study and/or available through other sources.

#### **4.16.4 Research Needs for Groundwater**

Some information and data gaps exist in the understanding of groundwater resources in the Red Deer River Watershed. The following are some key research needs for groundwater quantity and quality under several categories:

- Refinement of aquifer distributions, groundwater volumes, and sustainable yields in the Red Deer River Watershed, particularly in high-use aquifers (e.g., Paskapoo Formation)
- Refinement of recharge estimates using additional methods of analysis (e.g., water table fluctuation method, baseflow separation, etc.)
- Regional groundwater flow mapping to determine groundwater catchments and potential influences from development activities occurring in neighbouring basins
- Identification and mapping of recharge and discharge zones, including characterization and quantification of contributions to groundwater inventories and surface water bodies (i.e., streams, rivers, lakes, and wetlands)
- Better documentation and reporting of groundwater use patterns (locations of wells, actual amounts used, purpose of use, etc.) and quality conditions through development of robust monitoring
- Documentation of deep well injection of industrial wastes (e.g., location, amount, chemistry) and identification of high-risk areas related to groundwater resources above the Base of Groundwater Protection
- Assessment of the role of climate variability and climate change on groundwater level fluctuations, and ultimately storage volumes
- Identification of aquifer management areas and associated plans that include aspects such as forecasting effects (through modeling), performance monitoring (for quantity and quality), identification of sustainable yields, and a rigorous evaluation and communication process to inform basin residents
- Comprehensive groundwater risk mapping (by major aquifer type) to identify areas at greatest risk from current and future development (e.g., key recharge areas) and target these for protection or other management efforts

#### **4.16.5 Beneficial Management Practices for Groundwater**

Beneficial management practices (BMPs)<sup>27</sup> are essentially common-sense operating principles that are simple and economical to implement. With respect to groundwater, the purpose of BMPs is to help prevent the release of harmful or toxic substances to an aquifer and by extension any connected waterbody, and ensure the sustainable use so that storage volumes can be preserved for future use.

The following are a number of suggested BMPs, either documented through agencies such as the Alberta Energy Regulator, or AER (formerly EUB and ERCB), AESRD, CAPP, other industry organizations, or by the creators of this document. These BMPs are meant to enhance requirements already established under the current *Water Act* and *Environmental Enhancement and Protection Act* (including all supporting documents).

<sup>27</sup> Also known as best management practices  
O2 Planning + Design Inc.

#### 4.16.5.1 General BMPs

- Ensure adequate knowledge of groundwater quantity and quality conditions and water balances in all sub-basins through focused research studies, and pro-active and effective monitoring, evaluation and reporting.
- Completions of water wells across multiple discrete aquifer intervals is not to occur in order to eliminate the risk of induced connections between otherwise isolated intervals (AESRD).
- Spills of harmful or toxic substances must be contained and cleaned up as quickly as possible, and contaminated soil removed from the area, to protect shallow groundwater resources.
- Storage of fuels and chemicals should be done in dedicated and secured areas to ensure isolation of the substances from the groundwater environment and containment of any spills. Secondary containment should be employed for particularly toxic or harmful substances.
- Adequate wellhead protection areas should be established using a risk-based approach for water wells situated in developed areas to ensure that groundwater quality is sufficiently protected. Monitoring of water quality should be conducted regularly for constituents that may be related to nearby activities (e.g., volatile hydrocarbons for gas stations or fuel storage areas).
- Areas identified as being at higher-risk based on vulnerability and sensitivity mapping should have some form of groundwater monitoring established (either new wells or existing wells) to assess groundwater conditions (quality and/or quantity).
- Certain development activities (e.g., waste storage or management areas) should be restricted from key recharge areas, particularly those readily connected to nearby waterbodies. Adequate buffer zones should be established otherwise using a risk-based approach.
- Well owners should be made aware that management of private wells is their responsibility (AESRD Working Well program (<http://environment.alberta.ca/01317.html>)).
- The public should be informed as to the potential impacts of human activities on groundwater resource (AESRD Working Well program (<http://environment.alberta.ca/01317.html>)).

#### 4.16.5.2 Agriculture

- Adequate risk-based buffer distances should be established and maintained between manure management systems and nearby water wells.
- Routine soil testing should be conducted to ensure that over-fertilizing of soils used for crop development is not occurring (i.e., N and P). Proper setback distances from waterbodies should be established to ensure against unintended impacts (i.e., eutrophication).
- Application of pesticides or manure on the land surface should be minimized/optimized to protect shallow groundwater resources.
- Monitoring of groundwater quality around large livestock operations near aquatic or human receptors should include assessment of key pharmaceuticals, and key pathogens (e.g., E. coli O157:H7).
- Management and cultivation of croplands should be done in a manner to encourage groundwater recharge and reduce or eliminate soil salinization issues.

#### 4.16.5.3 Oil and Gas

- Groundwater risk assessments should be conducted on major fields and/or development areas employing hydraulic fracturing technology or recovering oil and gas via conventional means. This includes the risk of gas migration and production fluid releases to groundwater intervals above the Base of Groundwater Protection or BGP (AER).

- Risk assessments should be conducted in advance of any hydraulic fracturing near existing or abandoned production wells that may be completed within the same interval, or any interval that may be connected, unless it can be conclusively demonstrated that the activity will not create a risk to groundwater above the BGP (AER).
- Sound wellbore construction practices, sourcing fresh water alternatives where appropriate, and recycling water for reuse should be employed as much as practical to safeguard the quality and quantity of regional surface and groundwater resources (CAPP).
- A proper communication strategy should be developed to inform area residents of activities and monitoring efforts to ensure protection of groundwater above the BGP (AER). This communication strategy should include the disclosure of fracture fluid additives and the use of fluids with the least environmental risks (CAPP).
- Pipeline routing should be done to avoid sensitive groundwater areas such as near-surface sand and gravel deposits, near surface buried channels, and large outwash deposits either connected to waterbodies or used by local residents as a water supply. If unavoidable, proper setback distances from receptors should be established to protect against adverse impacts in the event of a pipeline rupture.
- Hydrocarbon storage and processing facilities should not be developed in sensitive recharge areas unless it can be clearly demonstrated that containment of any releases can be successfully achieved and sufficiently mitigated (if required) prior to impacting a nearby receptor.

#### 4.16.5.4 *Aggregate Mining*

- Adequate risk-based setback distances and mitigation measures should be established for aggregate mines located in deposits connected to water bodies, to ensure against negative impacts to baseflow contributions and water quality.
- Development of aggregate deposits located in extremely vulnerable and sensitive areas for aquatic habitat should be restricted, and these areas should be preserved, unless it can be clearly demonstrated that any mitigation employed by the developer will be successful and permanent.
- Completed mines should be properly reclaimed to re-establish groundwater flow and quality conditions that existed prior to development.
- Completed mine pits should be assessed for their usefulness as future artificial recharge areas or water storage areas.

#### 4.16.5.5 *Urban and Rural Development*

- New residential areas should be developed with stormwater management systems that encourage recharge (e.g., leaky stormwater collection ponds or established flood areas). Development layouts should also reduce large lot acreages in favour of smaller lots and larger areas for Environmental Reserve and green spaces.
- Permeable hard surfaces should be used where possible to facilitate infiltration to the subsurface and reduce issues with stormwater runoff.
- Residences established in areas where groundwater discharges to nearby water bodies should refrain from using pesticides on their lawns and gardens unless it can be clearly demonstrated that no impact to nearby water bodies will occur.
- Residences located in areas with highly permeable sediments (e.g., river gravels) should not establish septic leach field systems unless it can be conclusively demonstrated that the cumulative waste seepage will not compromise groundwater quality (e.g., Bragg Creek). If not, a secured system or communal process of waste management should be deployed.

#### 4.16.5.6 *Forestry*

- Forestry management plans should include maintaining or enhancing groundwater recharge to the basin.
- Sensitive groundwater-surface water interaction areas should be identified and protected from adverse impacts of forestry cut-block development with proper buffer zones.
- Equipment should be routinely checked (i.e., daily) for any signs of leaking fluids, and repaired prior to operation.
- Spill or leaks should be cleaned up immediately, and the soil recovered and disposed of or remediated properly.

#### 4.16.5.7 *Recreational Areas*

- Siting of latrines in campgrounds and other established recreational areas should avoid highly permeable sediments, particularly those that might be connected to nearby surface water bodies.
- Vulnerable and sensitive areas where off-road vehicular activity may adversely impact groundwater recharge and quality conditions should be identified, communicated to the public, and managed accordingly (including the establishment of no-access areas).
- Campground water wells should have a sufficient depth of installation, well completion process, and wellhead protection area to safeguard against any impacts.

## 5. CONCLUSIONS

A watershed plan needs a system of outcomes, indicators, and targets to synthesize information on watersheds and to help craft monitoring and management programs. Indicators and targets are critical to measure an organization's progress towards meeting their vision and specified outcomes. This can allow for a performance management system gauging success through time.

This document has compiled research on surface water quantity as well as groundwater quantity and quality in the Red Deer River Basin. It recommends a system of environmental, programmatic, and social indicators that can be monitored over time within an integrated monitoring and reporting framework. BMPs for different sectors have also been specified as well as areas requiring further research.

All targets are to be interpreted and applied with care, as they are based on existing baseline data inventories, and gaps may be present. In addition, targets represent averages over broad scales. Finer-scale targets could also be developed and specified at other scales using different boundaries for more specific aquifers, sub-basins, lakes, or streams, or political jurisdictions as well such as counties or the Land Use Framework regional planning regions.

Throughout the watershed planning and implementation process, indicators and targets should be refined and modified to reflect changing conditions and priorities in an adaptive management process.



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## LIST OF ACRONYMS

ADM – Alberta Desktop Method

AER – Alberta Energy Regulator (formerly Energy Resources Conservation Board)

AESRD – Alberta Environment and Sustainable Resource Development

AGS – Alberta Geological Survey

ARFQI – Alberta River Flow Quantity Index

AUMA – Alberta Urban Municipalities Association

BGP – Base of Groundwater Protection

BMP – Beneficial Management Practice

CAPP – Canadian Association of Petroleum Producers

CBM – Coal Bed Methane

DO – Dissolved Oxygen

EID – Eastern Irrigation District

ENSO – El Nino Southern Oscillation

ERCB – Energy Resources Conservation Board

GCM - Global Circulation Model (Climate)

GOA – Government of Alberta

GOWN – Groundwater Observation Well Network

GW - Groundwater

IFN – Instream Flow Needs

IWMP – Integrated Watershed Management Plan

LCL – Lower Control Limits

O2 – O2 Planning + Design Inc.

P – Phosphorus

PDO – Pacific Decadal Oscillation

PFRA – Prairie Farm Rehabilitation Agency (Agriculture Canada)

POE – Probability of Exceedance

PPWB – Prairie Provinces Water Board

RDRWA – Red Deer River Watershed Alliance

SAWSP – Special Areas Water Supply Project

SSRB – South Saskatchewan River Basin

TAC – Technical Advisory Committee

TDS – Total Dissolved Solids

O2 Planning + Design Inc.



UCL – Upper Control Limits

WCO – Water Conservation Objective

WID – Western Irrigation District

WPAC – Watershed Planning and Advisory Council

WRMM – Water Resources Management Model

WSC – Water Survey of Canada

## GLOSSARY

**Alberta River Flow Quantity Index** – Illustrates the difference between the average natural flow regime for the river and the actual flows recorded during an individual year. Although most year to year variations are natural, they can also be influenced at least partly by climate change, increased water consumption, or other human impacts.

**Alluvial aquifer** – The water-bearing alluvial sediments adjacent to rivers and streams and hydraulically connected aquifers

**Available head** – The distance between the resting water level in a well completed in an aquifer and the top of that aquifer interval. For unconfined aquifers this is the distance between the resting water level and the base of the aquifer.

**Conservation** – refers to any beneficial reduction in water use, loss or waste, or practices that improve the use of water to benefit people or the environment (Alberta Water Council 2006)

**Efficiency** – refers to the accomplishment of a function, task, process or results with the minimal amount of water feasible—efficiency is an indicator of the relationship between the amount of water required for a particular purpose and the quantity of water used or diverted

**Indicator** – Measurable surrogates for environmental end points of value to the public

**Instream Flow Needs (IFNs)** – The pattern of flow that can sustain a natural aquatic system over the long term (based on Clipperton et al. (2003). These are estimates of minimum flows required to maintain ecosystem components and provide a high level of aquatic environment protection over the long term (AESRD, 2012). Although calculated as a threshold, IFN estimates do not establish a commitment of water flow and are instead intended as information to be used in the decision-making process of establishing of a WCO or other planning objectives.

**Natural flow** – Flow that is not noticeably affected by direct human activities such as reservoir operation, water withdrawals, diversions or releases. The flow may, however, be indirectly affected by human activities such as land use change (AMEC 2010).

**Naturalized flow** – A flow record that has been reconstructed to reflect the volume of upstream diversions calculated by adjusting the historical flow record to remove the effects of regulation. In Alberta, much of the naturalization, extension, and transfer of data were carried out using computerized procedures in which daily flows were moved through the system using the US Army Corps of Engineers Streamflow Synthesis and Reservoir Regulation (SSARR) routing model. The calculations account for the effects of major reservoirs, irrigation withdrawals and return flows for irrigation districts, and municipal withdrawals and return flows at major urban centres (AMEC 2010).

**Non-contributing areas** – Topographically disconnected basins isolated from the regional drainage network that do not contribute surface flow to creeks and streams in a watershed for a median (1:2) annual runoff (note that during flood conditions, these areas can contribute flow to creeks and streams)

**Orographic precipitation - rain, snow, or other precipitation produced when moist air is lifted as it moves over a mountain range.**

**Outcome** – The desired future conditions that guide the development and implementation of an organization's recommendations

**Productivity** – refers to the amount of non-saline water required to produce a unit of any good, service, or societal value

**Regulated flow** – Flow that is noticeably affected by direct human activities.

**Targets** – Specific, quantitative values assigned to indicators that reflect a desired outcome

**Water Conservation Objectives** – A tool under the provincial *Water Act* that can establish protected volumetric water flow targets in river basins. They are created to ensure water volumes do not drop to levels

that will cause significant harm to the viability of environmental systems, as well as to support tourism, recreation, and transportation needs. WCOs are science-based but community-informed, and are intended to be consistent with the public interest. WCOs are also flow targets under the priority water allocation system. They define the socially desired balance between protecting the aquatic environment and water consumption.

**APPENDIX A:**  
**ESTIMATED EFFECTS OF RIVER FLOWS ON THE AQUATIC ENVIRONMENT OF THE RED DEER RIVER**

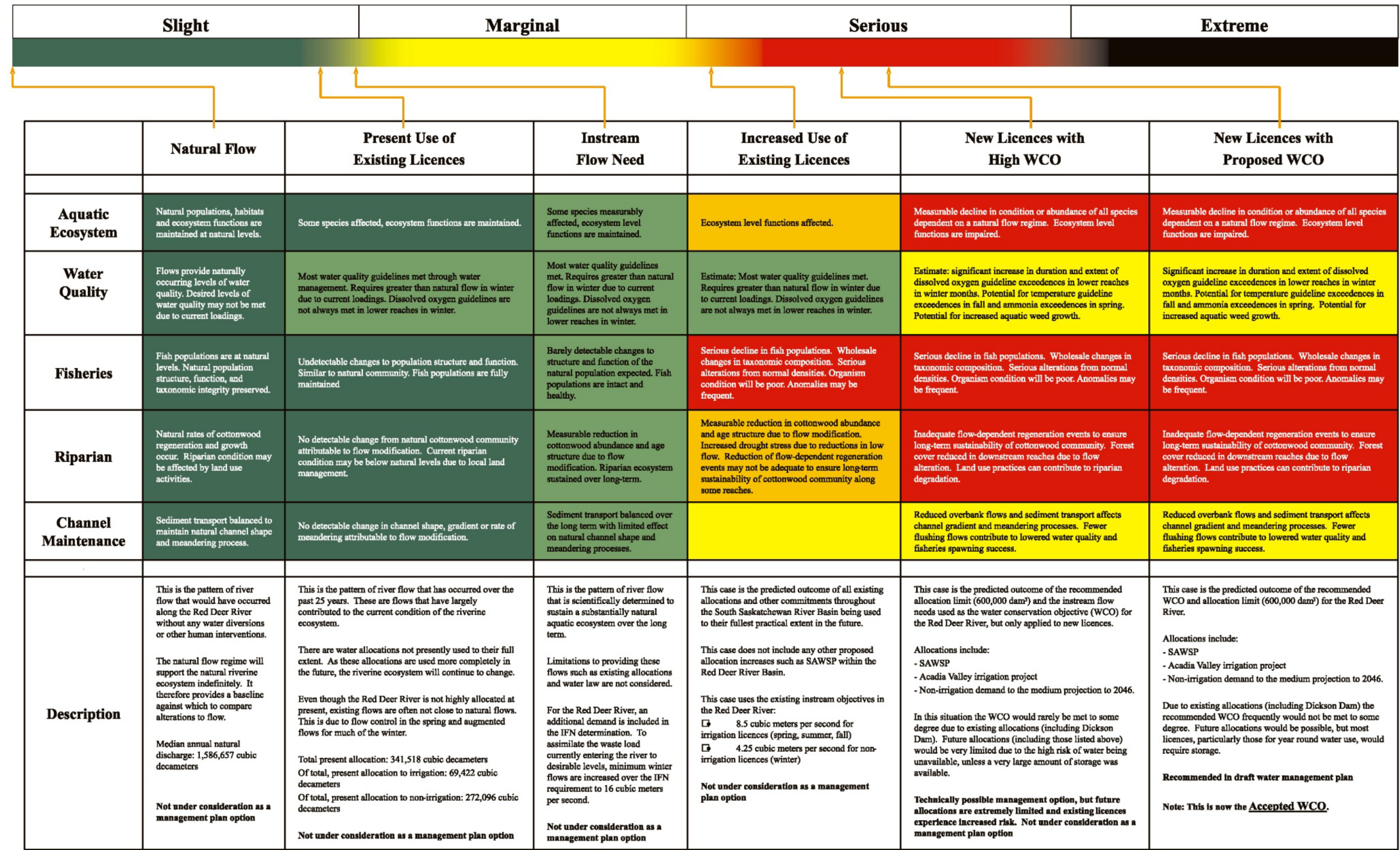


Figure 39. Estimated Effects of River Flows on the Aquatic Environment of the Red Deer River (Source: Goater et al. 2007)



## APPENDIX B: GOWN Wells in the Red Deer River Watershed

GOWN Well No.	LSD	Sec	Twp	Rge	Mer	Latitude	Longitude	Station Name	Depth of Completion	Water Levels	Quality	Dissolved gases (DG)	DG isotopes
95	3	5	36	5	5	-114.68873814	52.05908108	RAVEN TROUT BROODING STATION	PERFORATED 35.66 - 36.5M	✓	✓	✓	
120	15	23	23	6	4	-110.72893356	50.97769843	BUFFALO NORTH 85-2	SCREEN 65.9 - 70.4 M DEEP	✓	✓		
121	16	36	23	17	4	-112.23775000	51.00863889	GEM 66-7	SCREEN 24.4 - 30.5M	✓	✓	✓	✓
124	4	28	29	16	4	-112.20545055	51.50535479	Hand Hills #1 North_0124	91.7 - 96.0	✓	✓		✓
125	4	28	29	16	4	-112.20545055	51.50535479	Hand Hills #2 South_0125	SLOTTED 35.7 - 39.0M	✓	✓	✓	
126	4	30	32	28	4	-113.97029677	51.76733158	OLDS #147	OPEN 46 - 213M	✓	✓	✓	✓
127	13	21	34	26	4	-113.63961877	51.93815112	ELNORA #7	SLOTTED 39.6 - 45.7M	✓	✓		
128	9	34	34	26	4	-113.59842960	51.96324241	ELNORA #6	SLOTTED 3.0 - 4.9, 7.6 - 9.4M	✓	✓	✓	
129	16	36	34	26	4	-113.55116732	51.96683109	Elhora #5_0129	9.1 - 13.7	✓			
131	3	29	35	24	4	-113.40058074	52.02844419	Elhora #2_0131	3.7 - 4.3	✓			
133	12	13	35	25	4	-113.45396047	52.00654418	ELNORA #3 - RECLAIMED	SLOTTED 9.1 - 18.9M		✓		
134	4	6	36	28	4	-114.00100048	52.05855968	INNISFAIL	OPEN 27.4 - 44.2M		✓		
135	14	33	38	20	4	-112.80283330	52.31783333	STETTLE 1962-4	SCREEN 61 - 64M	✓	✓	✓	✓
208	11	2	20	10	4	-111.28812173	50.66870465	IDDESLEIGH 85-2 (SUSPEND)	SCREEN 6.04 - 7.75M		✓		
222	4	27	25	9	4	-111.18793795	51.15610994	BIGSTONE 2415E	SCREEN 32 - 35M	✓	✓	✓	
223	4	28	27	26	4	-113.61083482	51.33061749	IRRICANA 2376E	SCREEN 45.72 - 46.94M	✓	✓	✓	✓
224	1	17	28	13	4	-111.78947069	51.38887175	SHEERNESS 86-1	SCREEN 28.9 - 30.5M		✓		
227	4	30	32	28	4	-113.97029677	51.76733158	OLDS 2373E(2413E) (SOUTH)	SCREEN 45.1 - 48.2M	✓	✓	✓	✓
232	12	10	40	21	4	-112.95566667	52.43000000	BUFFALO LAKE 4004W	SCREEN 25.91 - 27.43M	✓	✓	✓	
258	4	25	23	13	4	-111.69967428	50.98145270	CESSFORD 85-2	SCREEN 47.65 - 49.46M	✓	✓	✓	
259	16	23	31	24	4	-113.29142149	51.67612316	THREE HILLS RCA 144	OPEN 28.7 - 60.9M	✓	✓	✓	
276	5	19	21	3	4	-110.41722305	50.79585271	CAVENDISH 2528E NORTH	SCREEN 91.4 - 94.5M	✓	✓	✓	✓
277	5	19	21	3	4	-110.41722305	50.79585271	CAVENDISH 2529E MIDDLE	SCREEN 50.3 - 51.8M	✓	✓	✓	
281	5	19	21	3	4	-110.41722305	50.79585271	CAVENDISH 2530E (2563E) (SOUTH)	SLOTTED/OPEN 16.5 - 18.3/21.9	✓	✓	✓	
282	6	15	22	14	4	-111.86559831	50.86865355	DUCHES 2513E	SCREEN 6.4 - 7.92M		✓		
289	6	15	22	14	4	-111.86559831	50.86865355	DUCHES 2564E	SCREEN 6.4 - 7.62 M DEEP	✓	✓	✓	
290	6	16	22	14	4	-111.88866981	50.86866009	DUCHES 2509E	SCREEN 30.48 - 32M		✓		
299	2	19	38	26	4	-113.70266670	52.27750000	Meadowglen TH1-92_0299	54.9 - 67.1	✓			
306	13	15	35	2	5	-114.21278811	52.01172243	DICKSON DAM 4015R	SCREEN 18.1 - 19.8M	✓	✓		
307	16	26	35	3	5	-114.31420930	52.04079447	DICKSON DAM 4026	SCREEN 18.1 - 19.8M	✓	✓		
308	7	33	35	2	5	-114.22490963	52.05166114	DICKSON DAM 82-1	SCREEN 28.95 - 32M	✓	✓	✓	
309	1	22	42	1	5	-114.05250000	52.62400000	GULL LAKE	OPEN 91.44 - 223.42M		✓	✓	✓
391	1	32	39	2	5	-114.24150000	52.39450000	SYLVAN LAKE 1_2623E	SCREEN 31.4 - 32.9M		✓		
398	2	24	36	25	4	-113.44224574	52.10113931	Pine Lake 2_2676E_0398	36.3 - 37.8	✓	✓	✓	✓
414	10	10	22	14	4	-111.85987937	50.85762915	DUCHES 2511E	SCREEN 83.2 - 85.9M		✓		
443	2	24	36	25	4	-113.44450000	52.10270000	Pine Lake 2_2677E_0443	DEPTH 1.2 - 4.3	✓			
444	2	24	36	25	4	-113.43930928	52.10294723	Pine Lake 2_2678E_0444	DEPTH 12.2 - 15.2	✓			
467	12	10	40	21	4	-112.95568040	52.42849210	Buffalo Lake 33_4004A_0467	20.1 - 20.7	✓			
468	12	10	40	21	4	-112.95567520	52.42837530	Buffalo Lake 33_4004B_0468	7.3 - 14	✓			
469	12	10	40	21	4	-112.95568160	52.42849210	Buffalo Lake 33_4004_0469	26.8 - 27.4	✓			
622	16	25	35	3	5	-114.28422706	52.04441229	Dickson Dam 4031R_0622	15.54 - 17.07	✓			
951	9	10	27	22	4	-113.00568800	51.29243700	REDLANDS	PERFORATED 49.38-52.12	✓	✓	✓	✓
972	--	--	--	--	--	--	--	ROSEBUD #2	PERFORATED 52.73-55.47		✓	✓	
974	--	--	--	--	--	--	--	ELNORA ARC A	DEPTH 91M		✓	✓	
975	--	--	--	--	--	--	--	ELNORA ARC B	DEPTH 31M		✓		
982	--	--	--	--	--	--	--	--	--	✓			
983	--	--	--	--	--	--	--	--	--	✓			
984	--	--	--	--	--	--	--	--	--	✓			
2004	12	35	26	23	4	-113.1147	51.2668	ROCKYFORD SPRING	SPRING		✓		
2006	3	19	37	5	5	-114.7087	52.1915	BUTTE SPRING	SPRING		✓		
3002	--	--	--	--	--	--	--	LEEDALE	10.06M DEEP		✓		
3008	SW	20	22	14	4	-111.9137	50.8812	DUCHES	8.53M DEEP		✓		
3009	NW	18	23	13	4	-111.8126	50.961	WARDLOW	5.49M DEEP	✓	✓		
3014	NW	10	30	26	4	-113.5843	51.5578	LINDEN/ACME	6.71M DEEP		✓		
3023	1	9	40	21	4	-112.9609	52.4229	BUFFALO LAKE	7.92M DEEP		✓		
3024	SE	25	37	3	5	-114.2924	52.2061	MARKERVILLE	5.49M DEEP		✓		
3026	SE	2	26	24	4	-113.2428	51.1868	ROCKYFORD	7.01M DEEP	✓	✓		
3027	SW	9	28	17	4	-112.3422	51.3759	LITTLE FISH LAKE	7.01M DEEP		✓		
3028	SW	3	31	10	4	-111.3443	51.6233	SCOTFIELD	7.01M DEEP	✓	✓		
3029	--	--	--	--	--	--	--	WAINWRIGHT E	11.58M DEEP		✓		
3044	--	--	--	--	--	--	--	WARDEN I	7.01M DEEP		✓		
3045	2	3	35	13	4	-111.7715	51.9718	SULLIVAN LAKE ES	5.49M DEEP		✓		
3055	NW	30	34	1	5	-114.1364	51.9513	BOWDEN WEST I	5.49M DEEP		✓		
3056	NW	27	34	2	5	-114.2073	51.9513	BOWDEN WEST II	13.11M DEEP		✓		
3058	10	9	40	21	4	-112.9609	52.4301	BUFFALO LAKE II	6.4M DEEP		✓		
4004	16	36	23	17	4	-112.2427	51.0048	GEM 66-7A	28.1M DEEP		✓		
4007	--	--	--	--	--	--	--	MEADOWGLEN TH1-92	SLOTTED 54.9 - 67.1M		✓	✓	
4011	11	12	36	25	4	-113.4497	52.0809	PINE LAKE 1_2674E	28M DEEP		✓		
4012	--	--	--	--	--	--	--	PINE LAKE 2_2676E	SCREEN 36.3 - 37.8M		✓	✓	
4013	13	7	36	24	4	-113.4259	52.0809	PINE LAKE 3_2679E	32.6M DEEP	✓	✓	✓	✓
4014	13	7	36	24	4	-113.4259	52.0809	PINE LAKE 3_2680E	9.4M DEEP	✓	✓	✓	✓
4015	10	23	36	25	4	-113.46179	52.10998	PINE LAKE 6_2688E	22.8M DEEP	✓	✓	✓	✓
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## Note:

1. "-" indicates no data available from ESRD files available or provided.

## **APPENDIX C: MAPS**