Running out of Steam?

Oil Sands Development and Water Use in the Athabasca River-Watershed: Science and Market based Solutions

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Preamble

Alberta's oil sands (174 billion barrels)[1] are not only the world's largest capital project but now represent 60 per cent of the world's investable oil reserves.[2] But to produce one million barrels of oil a day, industry requires withdrawals of enough water from the Athabasca River to sustain a city of two million people every year.[3] Despite some recycling, the majority of this water never returns to the river and is pumped into some of the world's largest man-made dykes containing toxic waste.[4]

During the past year a variety of industry and government agencies have recognized that the intensive water requirements of unconventional oil, combined with climate change, may threaten the water security of two northern territories, 300,000 aboriginal people and Canada's largest watershed: the Mackenzie River Basin. The Petroleum Technology Alliance Canada, for example, recently stated that its "largest concern" in the oil sands was water use and reuse because "bitumen production can be much more fresh water intensive than other oil production operations."[5]

A 2006 Alberta report (Investing In Our Future) noted that "over the long term the Athabasca River may not have sufficient flows to meet the needs of all the planned mining operations and maintain adequate stream flows."[6] The report also concluded that Alberta Environment had failed "to provide timely advice and direction" on water use. The National Energy Board has questioned the sustainability of water withdrawals[7], while the Department of Fisheries and Oceans now reports that the cumulative effects of water withdrawals "could not be predicted with confidence."[8] In addition, the World Wildlife Fund predicts that warming temperatures will significantly reduce both water quality and quantity in the region.[9]

By 2015, the Canadian Association of Petroleum Producers predicts that oil sands production may total as much as three million barrels a day.[10] At that point it will be too late to address the impacts of rapid energy development on water scarcity or to responsibly consider options.

To address these critical issues, the University of Alberta's Environmental Research and Studies Centre (ERSC) and the University of Toronto's Program on Water Issues (POWI) at the Munk Centre for International Studies recently asked two prominent scholars to assess the implications of current and planned water withdrawals from the Athabasca River and options for water management.

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[1] Alberta Energy:http://www.energy.gov.ab.ca/1876.asp.

[2] CIBC World Markets, December 8,2000, p 1.

[3] Down to the Last Drop: The Athabasca River and the Oil Sands, Pembina Institute, March 2006, p.ii.

[4] Canada's Oil Sands: Opportunities and Challenges to 2015: An Update, NEB, June 2006, p.38.

[5] Expanding Heavy Oil and Bitumen Resources while Mitigating GHG Emissions and Increasing Sustainability: A Technology Roadmap, May 31, 2006, p.19.

[6] Investing In Our Future: Responding to the Rapid Growth of Oil Sands Development, Doug Radke, December 29,2006, p.112 and p.133.

[7] Canada's Oil Sands: Opportunities and Challenges to 2015: An Update, p.38 and p.43.

[8] Joint Panel Review: Kearl Oil Sands Project, February 27, 2007, p.68.

[9] World Wildlife Fund, Implications of a 2 degree C Global Temperature Rise on Canada's Water Resources, November, 2006.

[10] Canadian Oil Sands Outlook, EIA 2007 Annual Energy Outlook, March 2007.

Their papers suggest that the time for critical decision-making has arrived; that energy production and the fate of water resources are inexorably linked and that innovative alternatives to business as usual are still possible.

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Section 1: Future Water Flows and Human Withdrawals in the Athabasca River

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1.0 Introduction

The Athabasca River stretches from the Columbia Ice Fields near the Alberta-British Columbia border to its mouth in Lake Athabasca, at the northeastern corner of Alberta (Figure 1). Its length is estimated to be 1400 km, making it the third longest undammed river in North America, behind the Yukon and Mackenzie, and slightly longer than the Fraser. Over its length the Athabasca River drops about 800 m, with two-thirds of this drop occurring in the first 450 km.

The delta of the Athabasca River joins that of the Peace and Birch rivers to form a large (6000 km^2) complex of wetlands and lakes at the western end of Lake Athabasca known as the Peace-Athabasca Delta, one of the world's largest freshwater deltas and the largest boreal delta. The delta contains over 1000 lakes which are flooded periodically during spring ice jams of the rivers. The delta has supported large communities of aboriginal people for millennia, and is an important staging area for migratory waterfowl. Up to 400,000 birds use the Delta in spring and more than 1 million use it in autumn. It is the prime range for 5000 bison. The Delta is still largely undisturbed by humans, and has been recognized internationally as a designated RAMSAR wetland site and a UNESCO World Heritage Site.

After passing through the Delta and in some seasons the western end of Lake Athabasca, the two rivers join to form the Slave River, which flows northward, reaching Great Slave Lake near Fort Resolution. Most of the Slave River's flow is diverted westward in Great Slave Lake, flowing into the Mackenzie River, then on to the Beaufort Sea.

1.1 *Past River Flows and Time Trends in the Athabasca River*

Long-term flow monitoring records are not available for the reaches of the Athabasca River below Fort McMurray, limiting the prediction of trends in flow in the area of oil sands development or in the Athabasca Delta. A short period of record was collected at Embarras, from 1971-1984. The Athabasca's average flow at Fort McMurray during April to November of 1954-2002 was 859 cms (cubic meters per second; Figure 2). Median flows were considerably lower, 177 cms, during December-March when the river is covered with ice and snow and runoff is reduced by cold weather. The reach below Fort McMurray is about 295 km in length but only drops by 11.5 m.

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[11]. Thanks to Brad Stelfox (Forem Technologies), Preston McEachern (Alberta Environment), Suzanne Bayley (University of Alberta), and Lyle Lockhart for figures 5, 11, 18, and 20 respectively, and to Beverly Levis and Margaret Foxcroft (University of Alberta) for help with the manuscript. We would like to acknowledge the Munk Centre for their financial support.

The highest flow recorded during the above period was 4700 cms on July 15, 1971. The lowest recorded flow was 75 cms on December 2, 2001 (Figure 2). During 2001, following a succession of dry years, flows were less than 100 cms for almost 4 months in winter. Flows have been well below average for most years since 1980. This is of concern, because current EUB regulations will require future oil sands plants to store water off river for only 30 days of operation, capturing the water at high flow conditions. As we shall discuss below, projections based on the combination of climate warming and increasing water withdrawals indicate that winter flows less than 100 cms will occur with increasing frequency in the future.

Climate warming, drought, human withdrawals and modifications to catchments in the prairie provinces are well known to be causing changes in the annual and seasonal flows of rivers and the levels and water quality of lakes and rivers. In the past century, river flows and lake levels have declined throughout the prairie provinces (Gan 2000; Schindler and Donahue 2006, Sauchyn et al. 2006, Schindler et al. 2004). Summer (May-Aug) flows in the Athabasca River at Fort McMurray had declined by 29% between 1970 and 2005 (Figure 3). The decline in summer flow has been less than that of any other river originating on the eastern slopes of the Rocky Mountains in Canada (Schindler and Donahue 2006), probably because relatively little water is withdrawn from the Athabasca River above Fort McMurray. The river has no dams or reservoirs that disturb seasonal flow patterns and compared to other major rivers there is relatively little development in the catchment upstream of Fort McMurray.

Oilsands mining already accounts for the largest consumption of water in the Athabasca River basin. Licences issued for withdrawals of surface water for all purposes allow up to 535,930 dam^3 (cubic decametres or 1000 cubic metres) to be used (consumed or lost). This represents 8% of all licenced surface water use in Alberta. Oil sands mines accounted for 76% of licenced water use in the Athabasca River basin in 2005 with another 8% for other petroleum purposes, including steam assisted gravity drainage (SAGD) and injection. (Figure 4; Golder Associates 2004). Most other licensed uses draw water from reaches of the river above Fort McMurray (Figure 6).

Until very recently, only two oil sands plants have been withdrawing water from the Athabasca River. These two plants, Suncor and Syncrude, produce less than 400,000 barrels per day of oil. In recent years, new oil sands plants by Albian Sands, CNRL, Shell, Fort Hills have begun operating or been approved, and current licensed bitumen production is about 1 million barrels per day, requiring water withdrawals at a maximum rate of 7.5 cms in 2010, dropping to 6.6 cms by 2013 (Figure 7).

As of 2005, 21 licences surface water have been issued for oilsands mining in the Athabasca River basin. These licences allow withdrawals of up to 453,051 dam^3 and account for 61 per cent of total surface water allocations in the entire Athabasca basin. These allocations are for six major oilsands projects (Table 1).

Table 1. Allocated and licensed water use for the six approved and operating oil sands projects (AMEC 2007).

Licensee	**Allocation (dam^3)**	**Licenced Use (dam^3)**	**Return Flow (dam^3)**
Albian Sands Energy Inc.	58,930	58,930	0
Canadian Natural Resources Limited (Horizon)	114,020	114,020	0
Fort Hills Energy Corporation	46,117	46,117	0
Shell Canada Limited (Jackpine)	72,400	72,400	0
Suncor Energy Inc.	68,550	29,895	38,655
Syncrude Canada Ltd	93,034	93,034	0
Total	**453,051**	**414,396**	**38,655**

Of these allocations, 82% is for water from the mainstem of the Athabasca River (341,657 dam^3) and 13% is water from major tributaries, including the Tar, Muskeg and Steepbank rivers and Beaver and McLean creeks (52,615 dam^3). The balance of licenced water use (5% or 20,124 dam^3) is for the collection and use of surface run-off. Some oilsands plants also have licences that allow them to withdraw and use up to 93,040 dam^3 of groundwater. Only one oilsands operation has return flow requirements in its licence. In total, existing licences allow up to 414,396 of surface water to be used, either through consumption or losses. This represents 77 per cent of licenced water use in the entire basin, and represents a maximum diversion of 12.5 cms from the Athabasca River and its tributaries.

Only three of the major oilsands projects were operating in 2005, including Suncor, Syncrude and Albian Sands. These three projects are allowed to withdraw up to 191,375 dam^3 from the Athabasca River, 9,015 dam^3 from tributaries, 8,932 dam^3 from groundwater, and 20,124 dam^3 from surface water run-off. For 2005, these three operations reported withdrawing about 98,900 dam^3 of water from the Athabasca River, equivalent to an average of 3.1 cms. This represents about 52 per cent of the water that these projects are allowed to withdraw. There is no information on withdrawals from other sources, such as surface run-off and groundwater, or on any amounts of water that may have been returned to the river after use.

In a recent 2007 decision, the Alberta Energy and Utilities Board (EUB) approved an application by Imperial Oil for the Kearl Oil Sands Project, despite that total water extractions for existing and already approved oilsands projects already exceed the maximum withdrawal permitted under the Phase 1 Water Management Framework, described below (Section 14.1.1, EUB 2007). The new project has requested a water license for 80 million m^3/y (2.5 cms) initially, increasing to 104 million m^3/y (average 3.3 cms) at the project's peak. Maximum withdrawal rates from the river by the Kearl project are expected to be 4.9 cms, and comprise 2.3% of historical average annual flows in the Athabasca River at Ft. McMurray (EUB 2007).

Various organizations have predicted future water requirements for bitumen extraction and these forecasts are quite different. Here we use recent preliminary forecasts prepared by AMEC. Figure 7 shows the maximum rates of water extraction by oil sands mines, measured in cubic metres per second (cms). The figure includes water use by the three existing operations, the three additional major projects (Jackpine, Horizon, Fort Hills), and the Imperial Oil/Exxon Kearl mine.. The forecasts show that maximum rates of extraction are expected to increase to 13.9 cms by 2010 and then decline to about 13.0 cms in 2015. As was the case in 2005, actual water use is expected to be less than the maximum allowed in the licences, with volumes depending on natural run-off, annual bitumen production, and changes in operating efficiency.

Two other oil sands mines are expected to start using water in 2010 and 2011, but their use is not shown in Figure 7. These include the Deer Creek (Total E&P Canada) Joslyn North Mine Project and the Synenco Energy/SinoCanada Petroleum Northern Lights Mining and Extraction Project. However, their water requirements are relatively small and would likely increase withdrawals by about seven per cent, reaching nearly 13.9 cms by 2015. These projections do not include the water requirements of any other future oilsands mines.

In the future, total bitumen production in the oil sands is expected to supply most of Canada's oil production of 5 million barrels per day by 2020 (Stringham 2007). About one third of this would be by thermal recovery, including steam assisted gravity drainage (SAGD). Allocations of surface water for thermal oil recovery allow withdrawals of up to 38,212 dam^3, of which 35,394 dam^3 can be used and the remainder (2,817 dam^3) is to be returned. Water licences issued for thermal recovery account for seven per cent of all surface water use in the Athabasca River Basin. Detailed estimates of water used for thermal purposes have been prepared by GEOWA based on EUB data and suggest that about 8,108 dam^3 of surface water was diverted for thermal purposes in 2005. This suggests that licensees were only using 23 per cent of their entitlements.

According to recent forecasts from the EUB and CAPP, the general trend in Alberta is for *in situ* bitumen production to increase as fields are developed. The EUB forecasts that *in situ* crude bitumen production (thermal) will increase from 69,700 m^3 per day in 2005 to 170,000 m^3 per day by 2015. CAPP forecasts that *in situ* crude oil production (thermal) will increase to 277,433 m^3 per day by 2015, and then decrease to 274,094 m^3 per day by 2020. Thermal production in the Athabasca/Peace basin is expected to follow the overall Alberta trend because the province's most important oilsands deposits, the Athabasca Wabiskaw-McMurray (AWM), are located within the basin. The forecast of future water use for thermal recovery in the Athabasca River Basin (Figure 8) assumes that the amount of water required for thermal activities will follow the trend in bitumen production: water use will increase significantly to 2015 and then decline slightly. Average withdrawals for thermal bitumen extraction from 2015 onward would average from1 to1.6 cms.

In summary, the total water used for oil sands mining and thermal extraction in the Athabasca River basin is expected to be 15-15.6 cms by about 2015.

1.2 *Instream Flow Needs (IFN)*

It is generally recognized that to keep the geometry, fisheries and water quality of rivers in a normal, productive condition, it is necessary to maintain a minimum amount of water in the river, referred to as the instream flow needs or IFN. Modern methods for estimating IFN recognize that different species have different habitat requirements at different seasons. They require high-intensity data sets and usually three-dimensional modelling procedures (reviewed by Richter et al. 1997). It is generally recognized that a flow regime to protect an aquatic ecosystem must account for a wide range of natural flow variation and consider multiple components of the aquatic ecosystem (Richter et al. 1997; Annear et al. 2004; Golder Associates

2004; Anderson et al. 2006). Recently, an IFN for the South Saskatchewan River based on multiple criteria concluded that the river required 85% of normal flow (Clipperton et al. 2003). IFNs have not been agreed upon for other rivers of the prairie provinces. IFN considerations are important for the ecological integrity of the Athabasca River, which contains 31 species of fish, several of which are important for subsistence in aboriginal communities. Some species of importance spawn in the spring, during high flow conditions, and others spawn in late fall, with larval development occurring over several months under winter ice. Therefore, IFN considerations will vary for different fish species, as well as for maintaining the various fluvial and riparian dynamics that are critical to a river's sustenance. The long period under ice and snow and the sensitivity of the Athabasca Delta to small differences in river levels may make the Athabasca River more sensitive than most rivers for which IFN have been estimated.

IFN also apply to navigation. During the summer months, the only surface transportation possible between Fort Chipewyan and Fort McMurray is by boat, using the Athabasca River. Residents are already complaining that low river levels in the past several years have made it difficult to use the river for transportation. Future changes in channel morphology and river flow will affect the possibility for transportation, especially for barges and other large watercraft. These too must be addressed by an IFN plan.

For the Athabasca River, in 2003, the Cumulative Environmental Management Association (CEMA) was directed by the Alberta Energy and Utilities Board in the 2003 CNRL and Shell hearings to recommend an IFN by December 2005. Alberta Environment and the Federal Department of Fisheries and Oceans (DFO) were directed by EUB to estimate the IFN if CEMA failed to do so by the required date. CEMA did not have an IFN prepared by December 2005 because a draft report prepared for CEMA by Golder Associates (2004) was not approved by CEMA's membership. Alberta Environment and DFO prepared draft IFNs during 2006 (AENV/DFO 2007). Their report recommended interim guidelines for IFN, termed the Phase 1 Water Management Framework, based on three very general flow-specific management zones: green, yellow and red, representing ample, borderline and low flow conditions, respectively (Figure 9). In brief, in the green zone, when flows are above approximately 140 cms (Termed HDA80), it is assumed that flows are sufficient for both ecosystem and human needs and that up to 15% of the river's flow can be taken for human and industrial needs. In the yellow zone (100-140 cms, the zone between HDA80 and Q95,), it is recognized that low flows may cause stress to aquatic ecosystems, requiring that water withdrawals for human use must be reduced. In the red zone (<100 cms, or Q95), the system is assumed to be under acute stress, equivalent to a 1 in 20 year drought during past conditions. Long-term ecological sustainability may be affected.

A Phase 2 Management Framework, based on specific ecological criteria, is to be in place by late 2010 (AENV/DFO 2007). AENV/DFO (2007) do not consider the effects of predicted climate warming on flows of the Athabasca River in the Phase 1 Management Framework, and it is not explicitly recognized in Phase 2. Also, it is noteworthy that current and approved withdrawals would already put the river in "red" zone conditions for several months in winter during low flow years (Figure 10). Indeed, "red zone" conditions would occur in some years with no human withdrawals at all. Such low flow conditions are likely to occur more frequently as climate warms in the 21st century, and withdrawals for oil sands and other human uses increase. As a result, the amount of water available to industry would decline. As we discuss below, the

Athabasca system shows evidence of being unusually sensitive to very high and very low flow conditions. The lack of consideration of climate change and high flow conditions in the currently-used Phase 1 Management Framework make it ineffective at protecting IFN in the Athabasca River.

On March 27-28, 2007, Alberta Sustainable Resource Development assembled the Instream Flow Needs Technical Task Group Expert Workshop to consider the data available and future needs to make a good estimate of IFN for the Athabasca River. It was generally recognized that the current data base is inadequate for the task. Among data identified as needed were more detailed analysis of dissolved oxygen in the river and its tributaries, more precise estimates of the relationship between river stage and flow rates under ice and in river reaches below Fort McMurray, and data that will permit identification of relationships between river flow and particular ecological processes. These include spawning success, recruitment, and sustainability of fisheries; frequency, duration, and degree of flooding in the Delta region; and fluvial dynamics involved in channel formation, scouring, and movement of riverbed sediments. Special emphasis was recommended on assessments of side channels and perched basins in the Athabasca Delta that flood periodically, providing spawning and nursery habitat for fish.

1.2.1 Winter: The most vulnerable period for the biota of the Athabasca River?

Because of the long period sealed under ice and snow, the Athabasca River is susceptible to low oxygen as a result of respiration and decomposition of organic matter in the water as it flows slowly toward the Athabasca Delta. This factor was of concern to the Alberta-Pacific Review Panel seventeen years ago (Alberta Pacific Environmental Impact Assessment Review Board 1990) and was studied in more detail during the Northern River Basins Study in the 1990s. A considerable oxygen sag was observed, and modelled with acceptable accuracy for the reach of the Athabasca River above the Grand Rapids (Chambers et al. 1995). Oxygen in the reach from Fort McMurray to the Athabasca Delta was not studied by the NRBS. The reach is slow flowing and largely covered with ice and snow, therefore low oxygen is of concern at low winter flow. Alberta Environment has compiled some data for lower reaches of the river and its tributaries. Values less than provincial water quality guidelines of 8.5 mg/L for early life stages and 6.5 mg/L for adults have been recorded at several locations, particularly near the mouths of tributaries (Figure 11). Data for the Muskeg River show the lowest oxygen at the lowest flows recorded under winter ice in early 2001, suggesting that declining flows will cause declining oxygen. Low oxygen concentrations under ice are known to be detrimental to the eggs and fry of fall-spawning species such as lake whitefish and bull trout. Other concerns are that late fall-early winter river stages may be too low for fall-spawning fish to reach spawning sites, or to allow fry to occupy key nursery sites in the river during winter.

In addition to the above-noted downward trend in summer flow, there has been an analogous downward long-term trend in lowest winter flows (Figure 12). Using predictions from several global climate models, Bruce (2006) projected a decrease in runoff from the Athabasca River basin below Fort McMurray of about 30% by the mid-21st century. He further noted that winter low flows had been less than 110 cms in 10 of the past 24 winters, and that more frequent low flows are projected for the future. Gan and Kerkhoven (2004) use a number of climate models to project that winter low flows would be 7 to 10 % lower in the next four decades. However, these reductions are far less than the projection from the long-term trend determined by linear regression from winter low flow measurements since 1970. These suggest that the decline in flow may be greater, with an average decrease in lowest winter flow of 1.5 cms per year (Figure 12). It is noteworthy that this trend line is projected from a period (1970-2002) of modest climate warming, when only two oil sands plants were in operation, and there were few other withdrawals of significance from the Athabasca River. With several more oil sands plants approved and planned, and the high potential for accelerated future climate warming, it is clear that under the Management Framework, there will be insufficient water for future oil sands development.

1.2.2 High flows may also be very important to the integrity of the river ecosystem

The above-mentioned IFN panel identified several factors of possible importance to IFN that relate to maximum flows. Firstly, highest flows are generally those that shape the morphometry of river channels (Leopold et al. 1964). In other ecosystems and in the Peace-Athabasca Delta, the damping of high flows has destroyed fish habitat (Ko and Day 2004; Valdez et al. 2001, Dalton 2003; Environment Canada 2005) and deltaic habitats (Zwarts et al. 2006; Peters et al. 2006). Secondly, high flows generally flood the shallow side channels and mouths of tributaries where spring spawning occurs in the Athabasca, and which are critical nursery habitats for young fish and other organisms. At present, there are not data that link river stage to the availability of spawning and nursery habitat, the recruitment of fish stocks, or the maintenance of deltaic wetland ecosystems. In the Athabasca River, perched basins in the delta area and side channels do not flood every year even without human water withdrawals or climate warming. In some important spawning and nursery areas, access can be allowed or denied by a few centimetres change in river stage (for example, Richardson Lake, a critical spawning and rearing habitat for walleye, depends on a few centimetres of water to maintain connectivity to the main river system. A recent study of 57 basins in the Peace-Athabasca Delta has shown that there is a wide range of flooding frequency, from every year to very seldom (Wolfe et al. 2007). In other river systems, it has become necessary to allow periodic floods to occur to regenerate fish stocks, fish habitats, or other riparian and deltaic features (Ko and Day 2004; Zwarts et al. 2006). Thus, the assumption of the Phase 1 Water Management Framework that high flow conditions do not affect fisheries or fish habitat are probably invalid, and more detailed field study is needed to verify whether the 15% removal indicated in the Phase 1 Management Framework can affect critical spawning and migration habitats.

It is noteworthy that in addition to withdrawals for extraction of bitumen, many of the oil sands companies are expecting to withdraw water from the river to fill End Pit Lakes, created at the end of mining operations and proposed as replacement fish habitat for tributaries damaged by mining operations. Griffiths et al. (2006) have calculated that in 2041, withdrawals from the river for filling end pit lakes will require 302.7 million m^3 of water, or an average of 9.6 cms. It is not stated whether these projections include expected evaporation losses from the end pit lakes, and it is not clear whether the needs to fill end pit lakes are included in existing water allocations.

1.2.3 Longitudinal time trends in runoff from the Athabasca River catchment

Rivers of the prairie provinces drain catchments that are sub-humid to semi-arid, except for the upper reaches in the Rocky Mountains and foothills. Typical runoff from low elevation parts of the catchments in the mid 20th century was from less than 50 to about 150 mm per year. We examined the water yields and recent trends for different reaches of the Athabasca River, using data from the gauging stations shown in Figure 13. While the flows at the most upstream station, Sunwapta, have increased due to accelerated glacial melt, the catchment runoff water yields to the Athabasca decline as one proceeds downstream (Figure 14). It is also noteworthy that there have been downward trends with time for runoff in all subcatchments below Hinton. In this lower 93.7% of the Athabasca River watershed, catchment water yield has declined by about 50% in the past 30 years (Figure 14).

1.3 *Past and Projected Changes in Climate of the Prairies and the Oil Sands Area*

Previously, we presented climate trends and projections for the prairies (Schindler and Donahue (2006). Most sites have already undergone a 2-3 ˚C increase in temperature, mostly since 1970. We also noted coincidental widespread large decreases in snowpacks at most locations on the prairies. Future projections for the prairies indicate increases in temperature of about 6 ˚C may occur by the end of the 21st century, if average climate model projections are realized (Figure 15).

Fort McMurray has already undergone an increase of more than 2 ˚C between 1945 and 2005 (Figure 16), and Fort Chipewyan has increased by more than 3 ˚C. Looking ahead, Ft. Chipewyan is projected to undergo a further 4.8 ˚C increase, with coincidental increases in precipitation of 32 mm. However, potential evapotranspiration is projected to be substantially higher than any projected increases in precipitation, as a result of warmer temperatures and longer summers. While potential evapotranspiration requires that moisture deficit does not inhibit evapotranspiration, land surfaces are wet throughout the summer in much of the Athabasca Basin below Fort McMurray, where lakes and wetlands are abundant. Also, lake evaporation and evapotranspiration were found to be equal in other northern studies (Newbury and Beaty 1980). Almost all sites in the prairie provinces have had declining winter periods with snow on the ground, and a trend toward shallower maximum snowpacks (Schindler and Donahue 2006).

We have used a climate-based model of streamflow, verified with historical data (1919-1998; $r^2 = 0.73$), to predict changes in water yield of several catchments of 278-30,800 km^2 in the Athabasca Lowlands of northeastern Alberta into the 21st century. The model predicts significant declines in total April-October streamflow for the entire range in catchment areas. With an average warming of 3 ˚C (projected for about 2050) average projected declines in streamflow were 8-26% for the various catchments, with maximum declines of 17-71% in the warmest and driest years. With an average warming of 6 ˚C (projected for about 2100, if carbon emissions remain near "business as usual"), projected streamflows declined by averages of 24-68, with declines of 52-100% in the warmest, driest years (Figure 17). These results suggest the kinds of risks to water supply that may accompany predicted warming and the associated increases in evapotranspirative water losses.

1.4 *Modifications to the Catchment of the Lower Athabasca River*

Much of the oilsands area is overlain by wetlands, especially wooded fens. In lay terms, this is several meters of peat, with spruce or larch trees of 10 m or so in height growing from the surface (Figure 18). The fen areas are crossed by many small streams that are tributary to the Athabasca River. This wetland complex serves an important hydrological function, absorbing snowmelt and large runoff events, and allowing the water to trickle slowly into the Athabasca River throughout the year. In this regard, the peatland/tributary complex serves much the same function as a capacitor in an electrical circuit. For example, development of the CNRL Horizon mine alone is expected to reduce discharge of groundwater into the Athabasca River by up to 30,000 m^3/day (Bruce 2006). If this estimate is correct, it would represent another 0.35 cms decline in average stream flow.

These vast areas of these peatlands and many kilometres of stream channels, such as the Muskeg River, are destroyed or drainage rerouted by oil sands mines in order to reach bitumen-containing layers. At present, there has been little reclamation attempted in most of the oilsands area, and no reclamation has been certified by Alberta Environment (Figure 19). The area has been visited and studied by several internationally-renowned wetland scientists, and it is generally agreed that the area cannot be reclaimed to its original condition, and it is unlikely to be restored to any condition with equivalent hydrological function. The possible effects of these modifications on river flows have not been considered by AENV/DFO (2007), and judging from the CNRL estimate above, the cumulative effect could be quite serious.

1.5 *Water Use by the Oil Sands: A Collision Course with River Flows*

The projected 15 to 15.6 cms for oil sands production in the Athabasca Basin represents 8.5 to 9 per cent of current median low flows, and 20 to 21 per cent of the lowest winter flows recorded to date. If climate continues to warm, runoff continues to decline and winter low flows continue to decrease as suggested in Figures 12 and 17, the water needs of the oil sands could reach a critical proportion of winter low flow. Similarly, if the lower Athabasca River is affected by climate warming as projected for nine of its lowland tributaries, substantial declines in river flow may be expected between April and October as well. Recent discussions on an Industry Water Sharing Agreement suggest that unused allocations will be distributed to new and future oilsands producers (EUB 2007). However, given the high proportion of allocations that is used (Table 1), there appears to be little opportunity for expansion given the likely water availability. The Phase 1 Management Framework provides some limitations on water use, but may be too generous in some seasons, based on our analysis.

1.6 *Water Flows and Water Quality Considerations*

The occasional low oxygen concentrations observed under winter ice near the mouths of tributaries to the Athabasca River were mentioned earlier. At present, it is not known whether oxygen depletion is aggravated by low winter flow conditions, and this knowledge will be necessary in order to predict the effects of climate warming and increased withdrawals on biota.

Similarly, the entire Athabasca River below Ft. McMurray contains sediments with high polycyclic aromatic hydrocarbon (PAH) concentrations. In many cases, concentrations were in excess of Interim Sediment Quality Guidelines (Canadian Council of Ministers of the Environment 1999; Evans et al. 2002). In addition, undisturbed tributaries to the Athabasca River contain sediments with particularly high concentrations of PAHs compared to the mainstream river (Headley et al. 2001). Concentrations of PAHs at some sites were sufficient to cause low survival of fishes and invertebrates in sediment toxicity studies (Evans et al. 2002). In an early study, Barton and Wallace (1979) showed that benthic invertebrate communities in the lower Athabasca River were less diverse than those upstream of the oil sands. However, because PAH concentrations were similar both above and below the oil sands, investigators concluded that the values were likely the natural result of seeps from geological deposits of oil sands (Evans et al. 2002). It is unknown whether recent increases in oilsands mining and activity have resulted in any changes in PAH loading since this mid-1990s study.

EROD (for ethoxyresorufin-*O*-deethylase) activity is a well established *in vivo* indicator of exposure to PAHs, dioxins, and similar chemicals. It is regarded as a highly sensitive indicator of contaminant uptake in fish, and it has been associated with embryonic deformity and mortality, and other biological effects. High EROD activities in fish were found in the oil sands region of the Athabasca River during the Northern River Basins study. Values below Fort McMurray were several times higher than those on the upstream reaches of the Athabasca River, despite the presence of organic pollutants known to induce EROD at some upstream sites (**Figure 20**). In this reach of the river, the most likely stressors that affect EROD are PAHs, including several known carcinogens. At present, baseline data on the concentrations and toxicity of these mixtures of pollutants are inadequate to develop adequate water quality guidelines and objectives.

The high levels of disturbance in wetlands and tributary reaches will expose large new deposits of oil sands and reroute groundwater flows, which could potentially increase exposure of fishes and other organisms to PAHs and other toxic compounds. Unfortunately, it is not known if concentrations are related to flow volumes.

1.7 *Special Concern for the Peace-Athabasca Delta*

The integrity of the Delta is very sensitive to water level, with perched shallow lakes and side channels of the river systems depending on a range of flooding conditions. Some lakes are flooded almost every year, and others seldom. The largest group of lakes are intermediate between these two extremes, providing a diversity of successional stages and habitat characteristics that support the high diversity of wildlife in the area. Typically the Delta floods in the spring, when ice jams block the Peace and/or Athabasca rivers, causing water to flood the area, rejuvenating lakes and wetland areas. Historically, the generation of major spring flood events has been triggered by large snowmelt events in tributaries in the mid- to lower-portions of the Peace and Athabasca basins (Prowse et al. 2006). Flooding of the Delta has already been compromised by climate-induced declines in spring snowmelt, and by the damping of spring flows on the Peace by Bennett Dam (Prowse et al. 2006). This has caused extensive losses of perched lakes, along with the muskrats, fish and waterfowl that supported the aboriginal communities (Green 1992). Projections are for continued reductions in the frequency of ice-jam flood, primarily because of reduced snowpack (Prowse et al. 2006). Consequently, even small changes in water level at high flow could further reduce the frequency, duration, and extent of flooding of the Delta, contributing even further to losses of ecological integrity (Environment Canada 2005). Development in the Peace Basin and its tributaries is also a concern, with potential for reducing water quantity and compromising water quality (NRBS 1996)

1.8 *Concern for the Slave River and Delta*

Flows in the Slave River have also declined considerably in the 20th century (Figure 21) reflecting changes to the Peace and Athabasca rivers, which supply most of the water. The Slave River Delta in Great Slave Lake is also dependent on spring flows and ice jams to rejuvenate lakes and river channels. It affords subsistence to several hundred aboriginal people in the Fort Resolution and Fort Fitzgerald area, and spawning habitat for fishes in Great Slave Lake. The decline has been blamed by many local residents on water removal by the oil sands. However, at present, climate warming and reductions in peak flows on the Peace River caused by the operation of Bennett Dam still appear to be the primary reasons for the decline (Prowse et al. 2006).

1.9 *Summary*

- Average summer and winter low flows of the Athabasca River have declined for over 30 years as a result of climate warming and decreased snow. Runoff has decreased by 50% in the 93.7% of the Athabasca Basin that is downstream of the Rocky Mountains. Flows have also declined in the Peace and Slave Rivers.

- Models based on forecast climate warming for the 21st century predict a further decrease in snowpacks, runoff, and river flow.

- The recently propose Phase 1 Water Management Framework is inadequate to protect the Athabasca River system. It does not ensure flooding of side channels and delta lakes that are critical spawning and nursery habitats for fish and other organisms at high flow. Its reliance on past conditions offers little protection for the ecosystem from low oxygen, high contaminant concentrations or reduced winter habitat under winter ice. It also offers no measures for protection of the large Delta wetland ecosystem and its great diversity of plants and animals. It does not account for the effects of climate warming.

- At present, data on instream flow needs are insufficient to allow construction of a plan that would protect the river system.

- Projected bitumen extraction in the oil sands will require too much water to sustain the river and Athabasca Delta, especially with the effects of predicted climate warming. Water levels in Lake Athabasca and flows in the Slave River will likely continue to decrease.

- To protect water resources and fisheries, and sustain aboriginal lifestyles in the lower Athabasca River and downstream, measures must be taken to reduce consumptive water use, and gain knowledge necessary to produce an effective, protective, science-based water management plan.

1.10 *Figures*

Figure 1. A map of the lower reaches of the Athabasca River.

Figure 2. Seasonal flows in the Athabasca River from 1957-2002. From Alberta Environment submission to EUB hearing, CNRL Horizon Project, 2003.

Figure 3. The decline in average summer flow in the Athabasca River.

Figure 4. Licensed water use from the Athabasca River by sector. Source AMEC.

Figure 5. Trends in bitumen extraction and water needs for oil sands operations. Figure by Brad Stelfox.

Figure 6. Distribution and type of licensed water withdrawals from the Athabasca River in 2005. From AMEC.

Figure 7. Projected maximum water diversions by major oil sands mines, Athabasca River Basin. Prepared by AMEC.

Figure 8. Projected future surface water use for thermal extraction, Athabasca River Basin. Prepared for Alberta Environment by AMEC.

Figure 9. A depiction of the weekly flow exceedance curves and the three management zones proposed in Management Phase 1, AENV/DFO 2007.

Figure 10. Per cent withdrawal from the Athabasca River by the oil sands at median winter low flow under historical conditions. From Alberta Environment presentation to EUB Hearing on CNRL Horizon Project, 2003.

Figure 11. Dissolved oxygen concentrations (mg/L) as measured with datasonde in winter at several stations on the Muskeg River, a tributary of the Athabasca River below Fort McMurray. The period shown is 1998-2001, with lowest values in December 2000 and January 2001. WSC is the Water Survey of Canada gauging site 6 km from the river's mouth. AWQG are the Alberta Water Quality Guidelines, shown as horizontal red bars. Mouth = Muskeg River 50-100 m upstream of its confluence with Jackpine Creek. Jackpine is at the confluence of Jackpine Creek with the Muskeg River. M u/s J is on the Muskeg just upstream of Jackpine Creek. Symbols preceded by Act are values, but measured by the chemical Winkler method. Source: Alberta Environment

Figure 12. The trend over time in lowest winter flows in the Athabasca River. The dotted line is the regression through measured data points.

Figure 13. The location of gauging stations on the Athabasca River (stars).

Figure 14. The change in average water yields from Athabasca River subcatchments over the period 1971-2001. The bars are the beginning and endpoint of the regression lines through all data points.

Figure 15. Projected changes in average annual temperature for the prairie provinces. From Schindler and Donahue (2006).

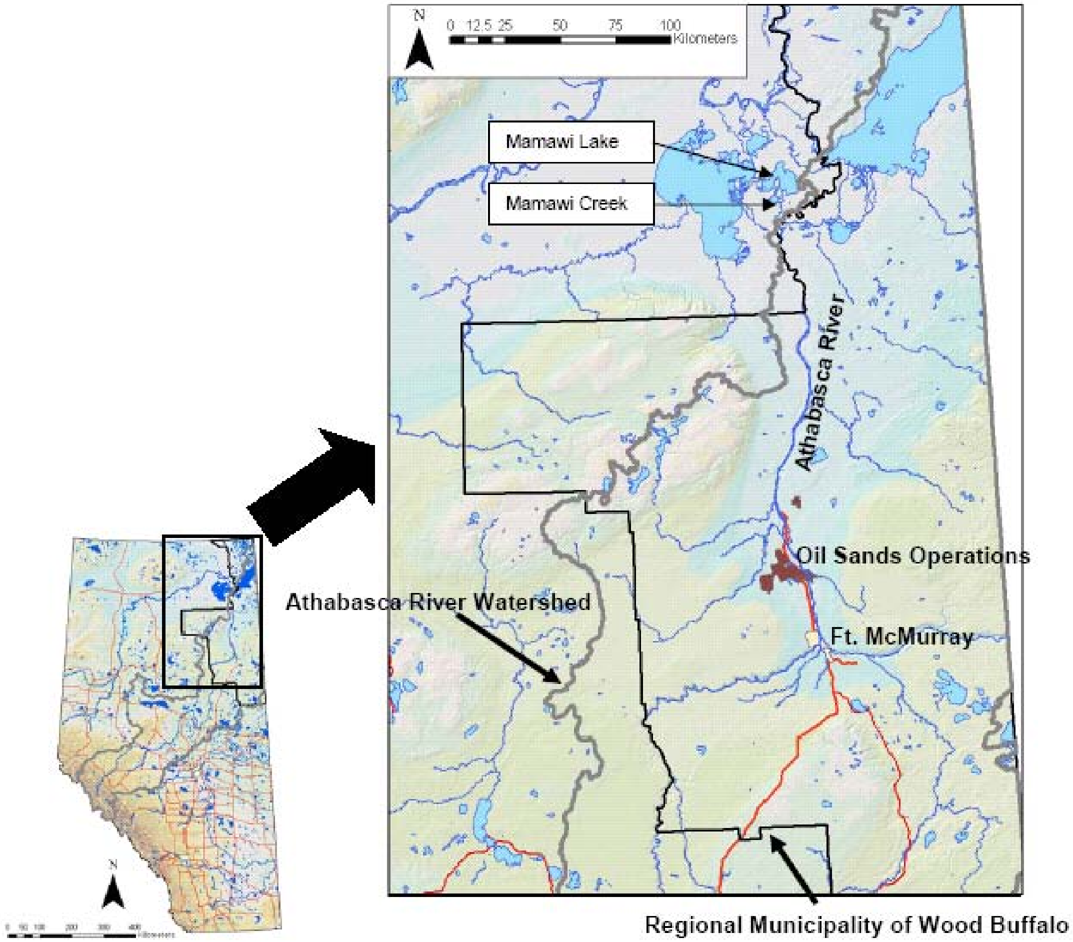
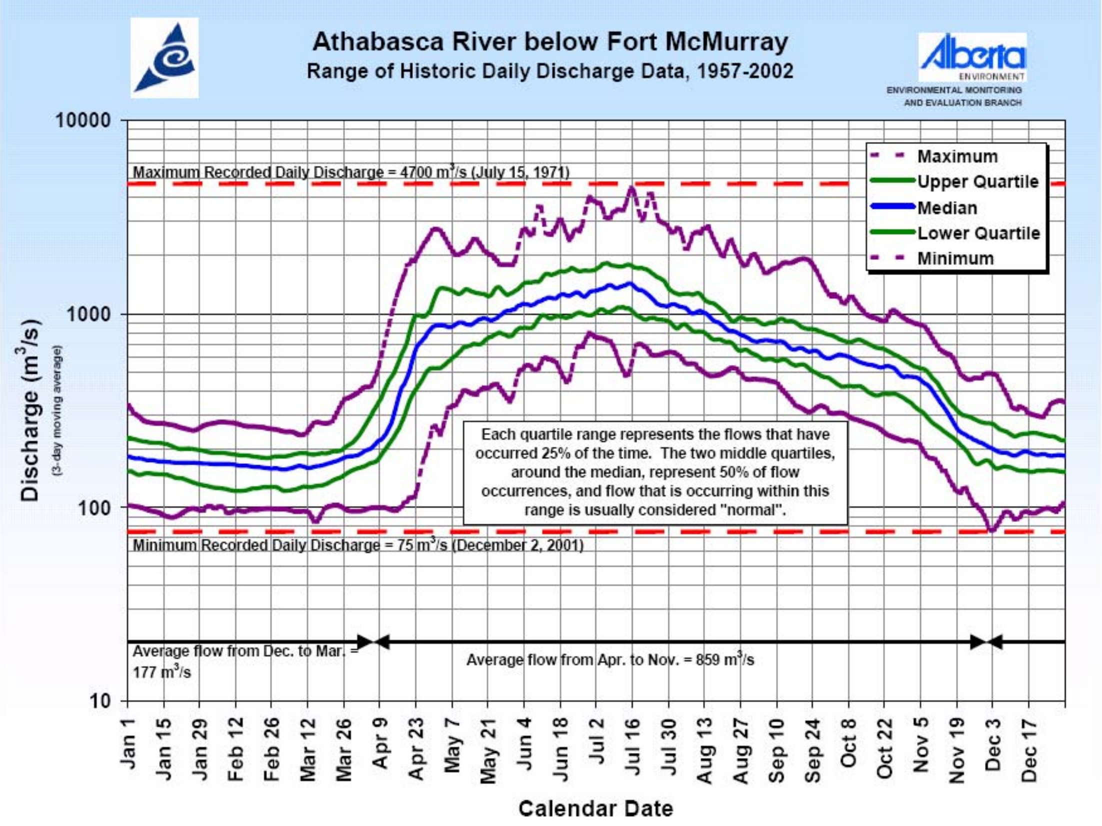


Figure 1. A map of the lower reaches of the Athabasca River.



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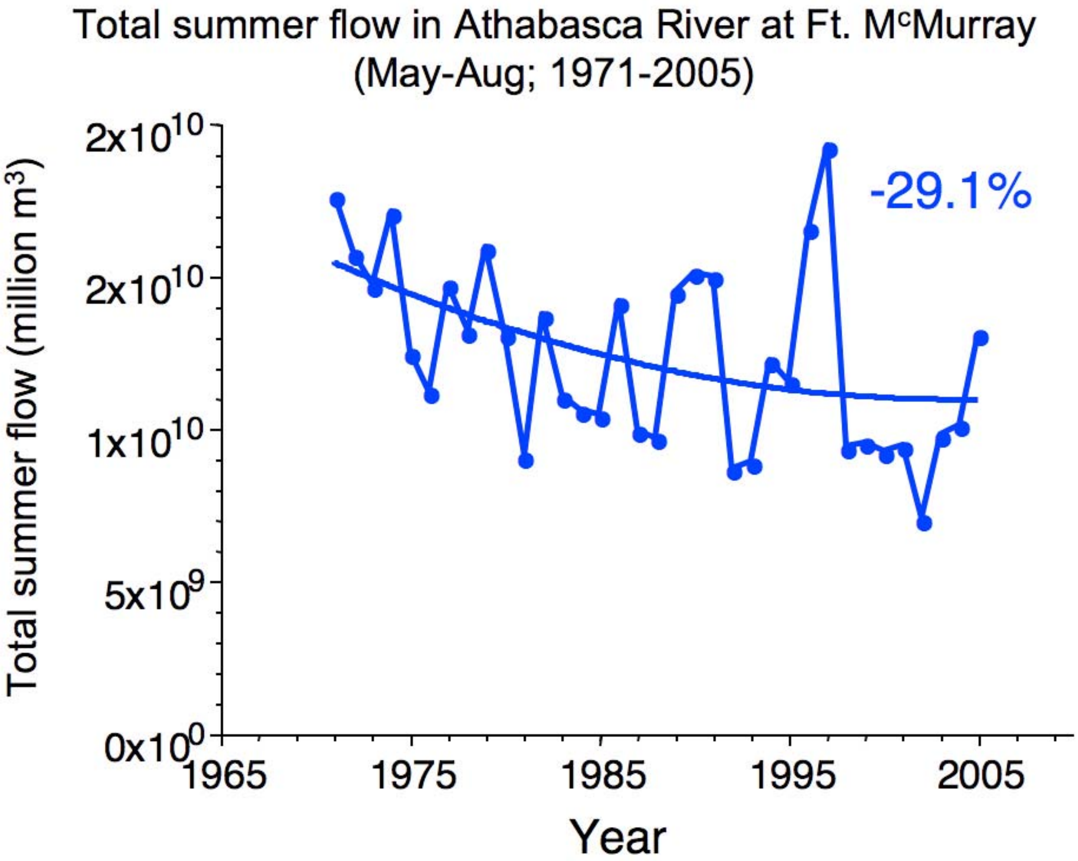


Figure 3. The decline in average summer flow in the Athabasca River.

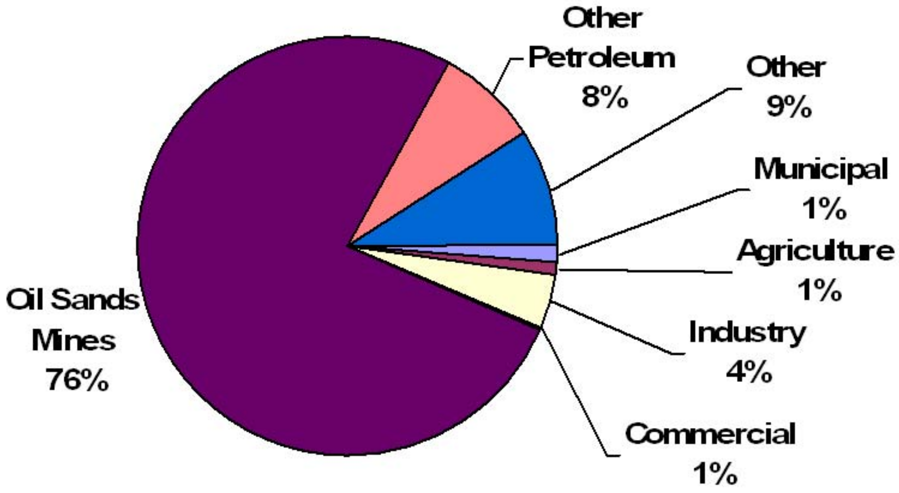


Figure 4. Licensed water use from the Athabasca River by sector. Source AMEC.

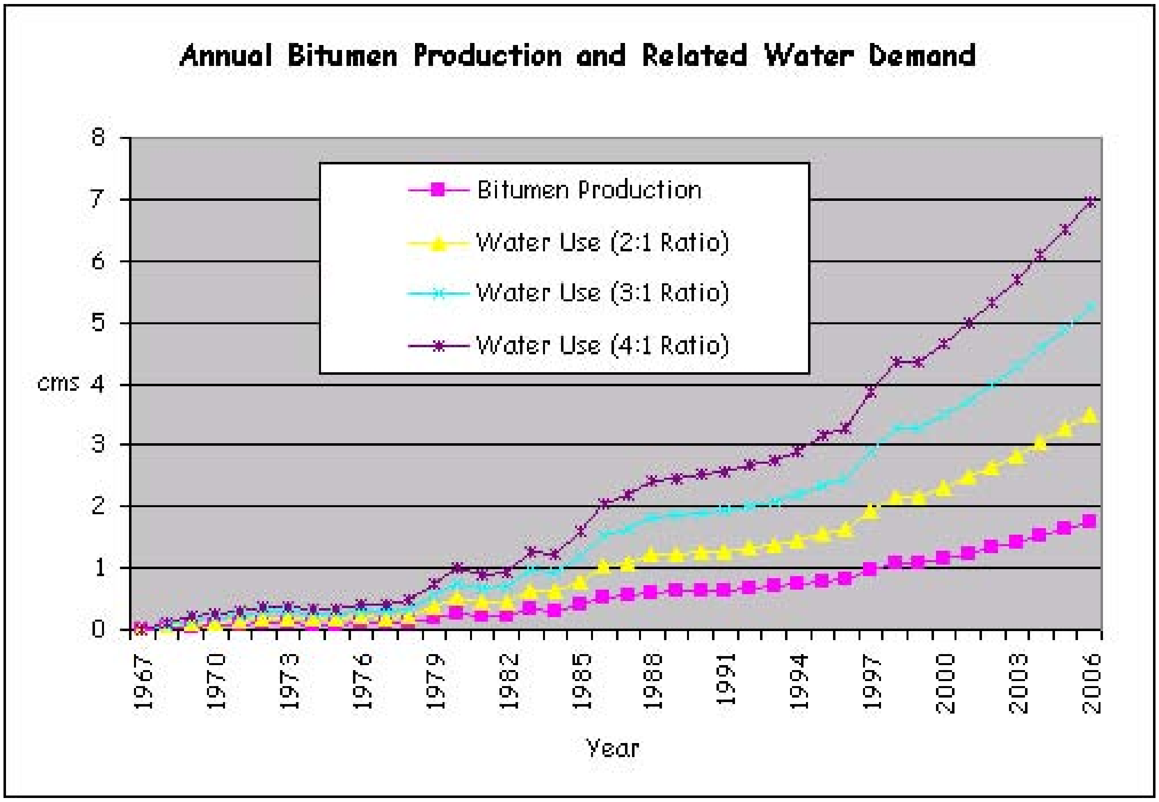
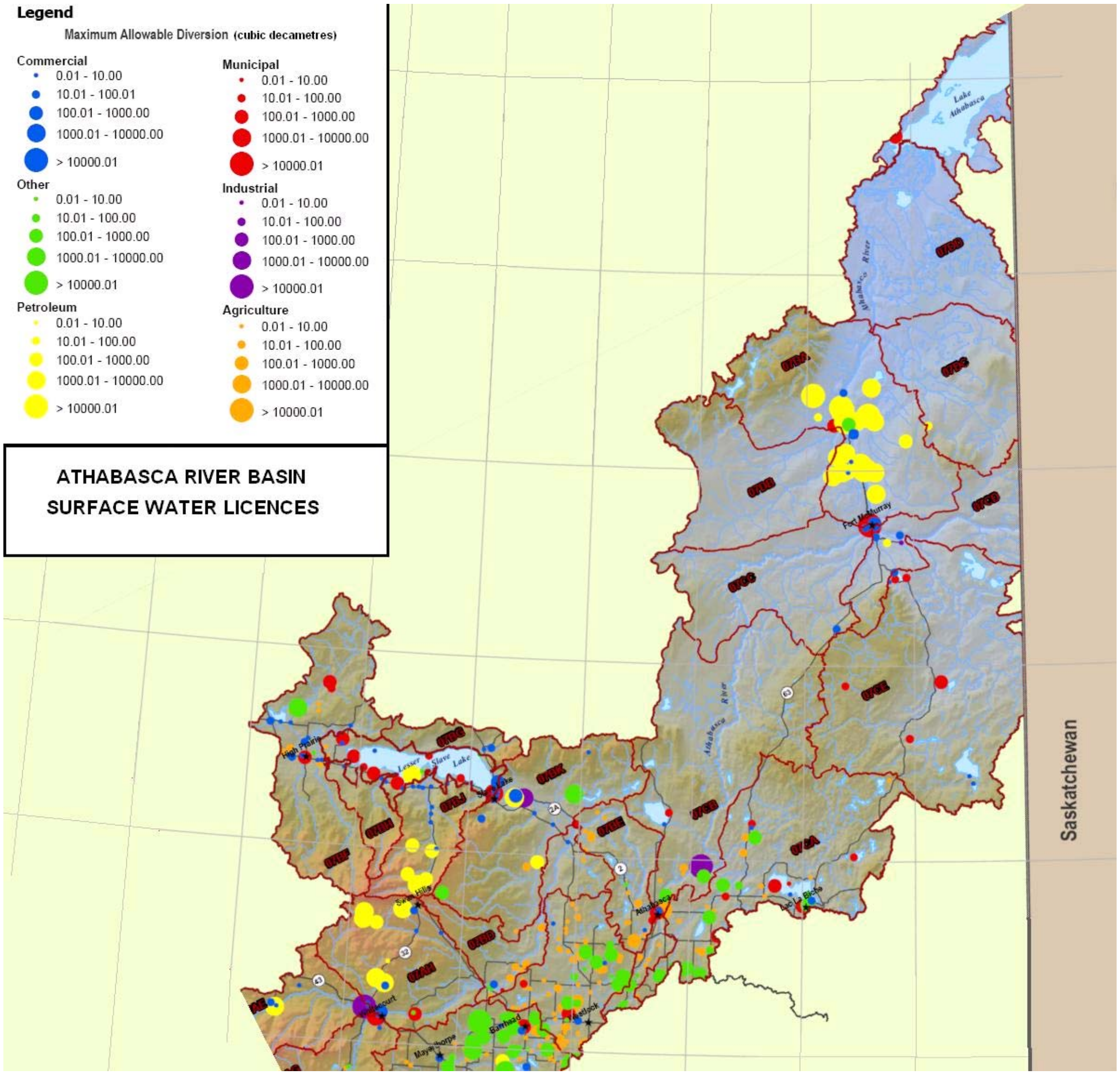


Figure 5. Trends in bitumen extraction and water needs for oil sands operations. Figure by Brad Stelfox.



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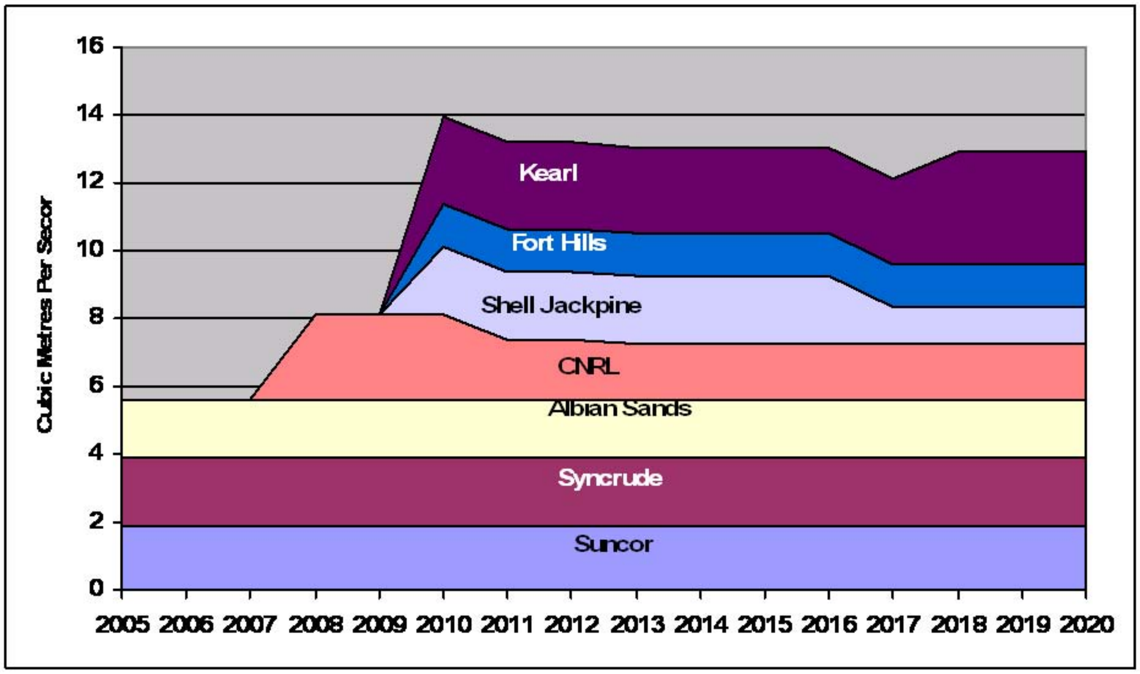


Figure 7. Projected maximum water diversions by major oil sands mines, Athabasca River Basin. Prepared by AMEC.

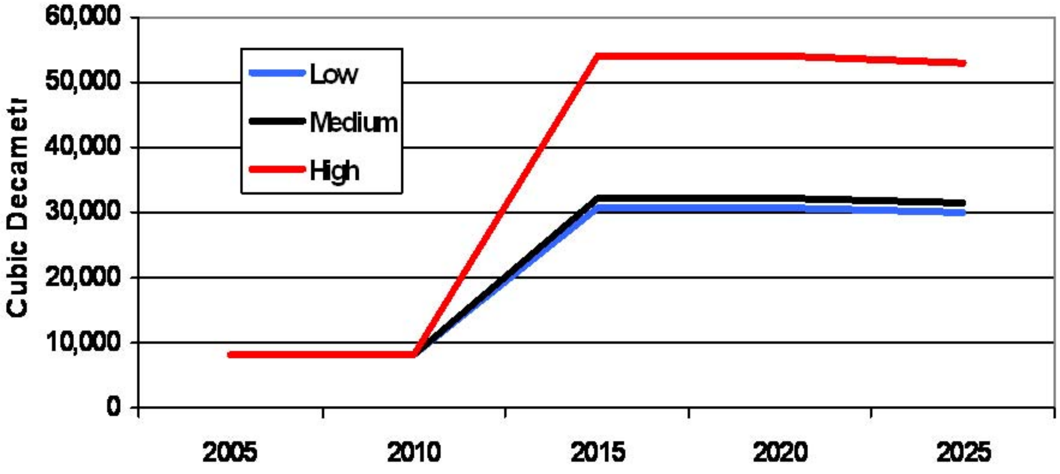
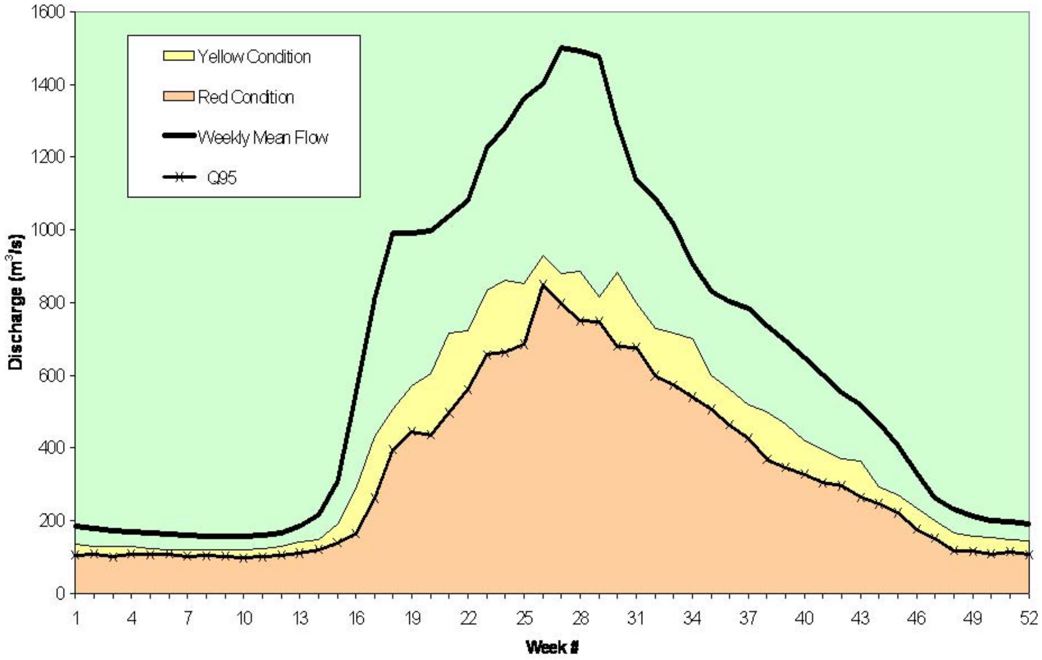
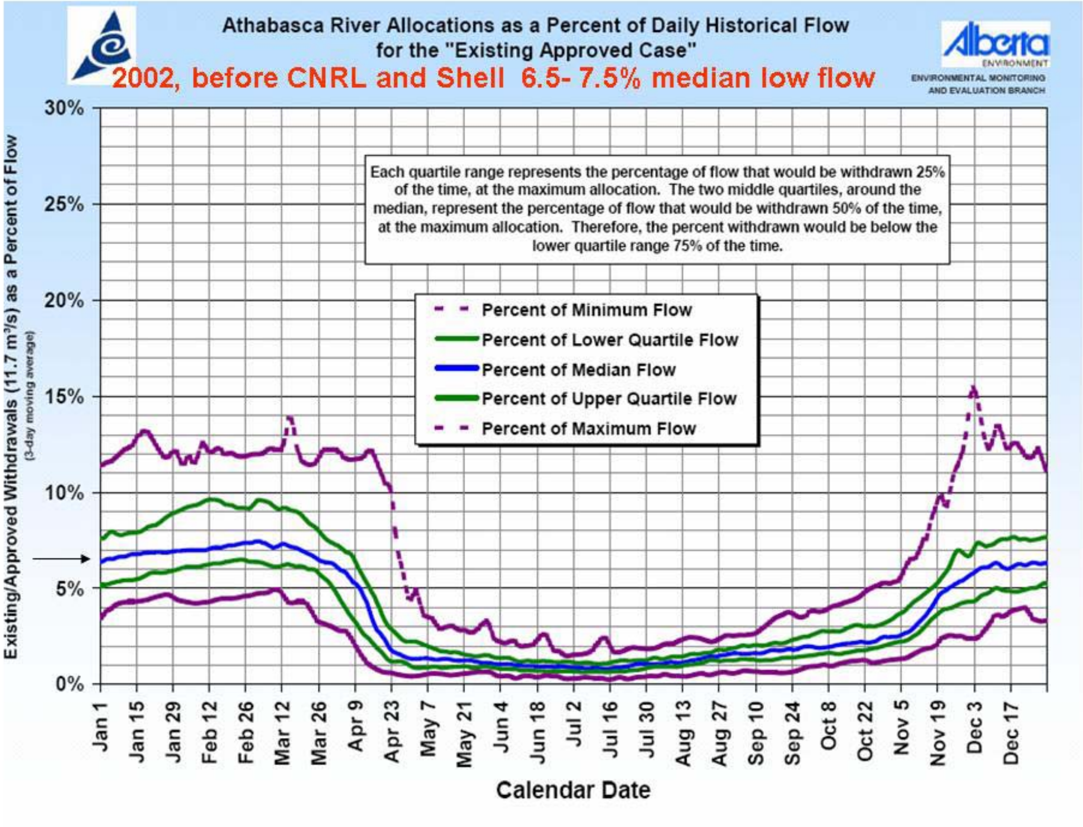


Figure 8. Projected future surface water use for thermal extraction, Athabasca River Basin. Prepared for Alberta Environment by AMEC.



Source: DFO/AENV 2007

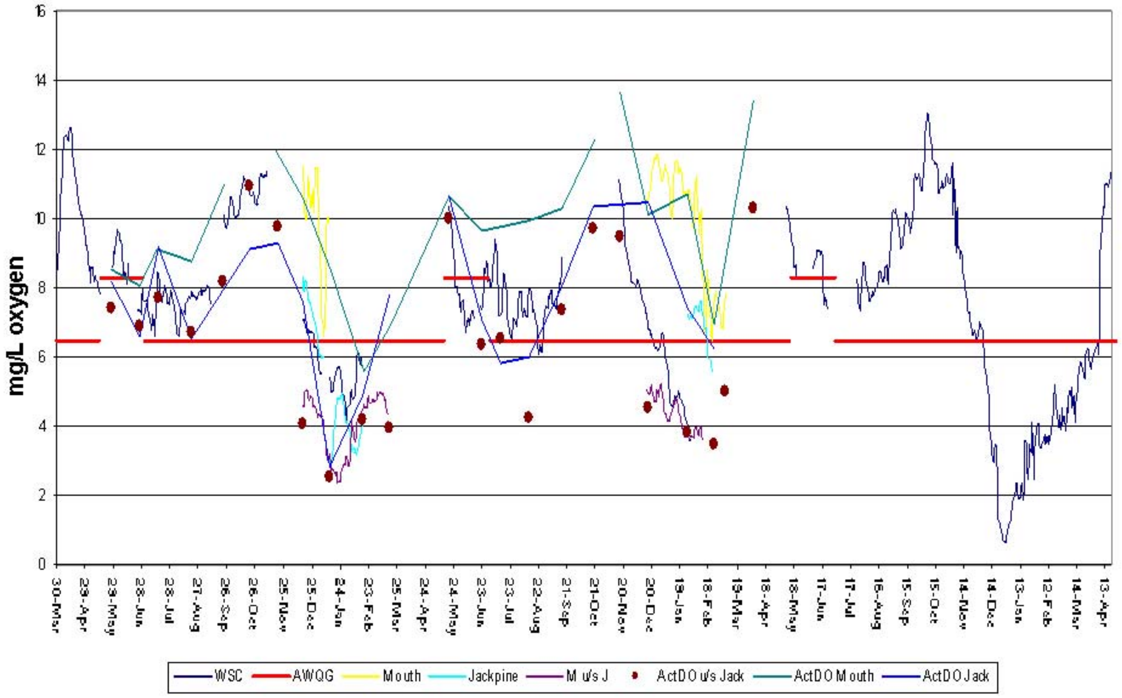
Figure 9. A depiction of the weekly flow exceedance curves and the three management zones proposed in Management Phase 1, AENV/DFO 2007.


Athabasca River Allocations as a Percent of Daily Historical Flow for the "Existing Approved Case"

2002, before CNRL and Shell 6.5- 7.5% median low flow

Each quartile range represents the percentage of flow that would be withdrawn 25% of the time, at the maximum allocation. The two middle quartiles, around the median, represent the percentage of flow that would be withdrawn 50% of the time, at the maximum allocation. Therefore, the percent withdrawn would be below the lower quartile range 75% of the time.

Figure 10. Percent withdrawal from the Athabasca River by the oil sands at median winter low flow under historical conditions. From Alberta Environment presentation to EUB Hearing on CNRL Horizon Project, 2003.



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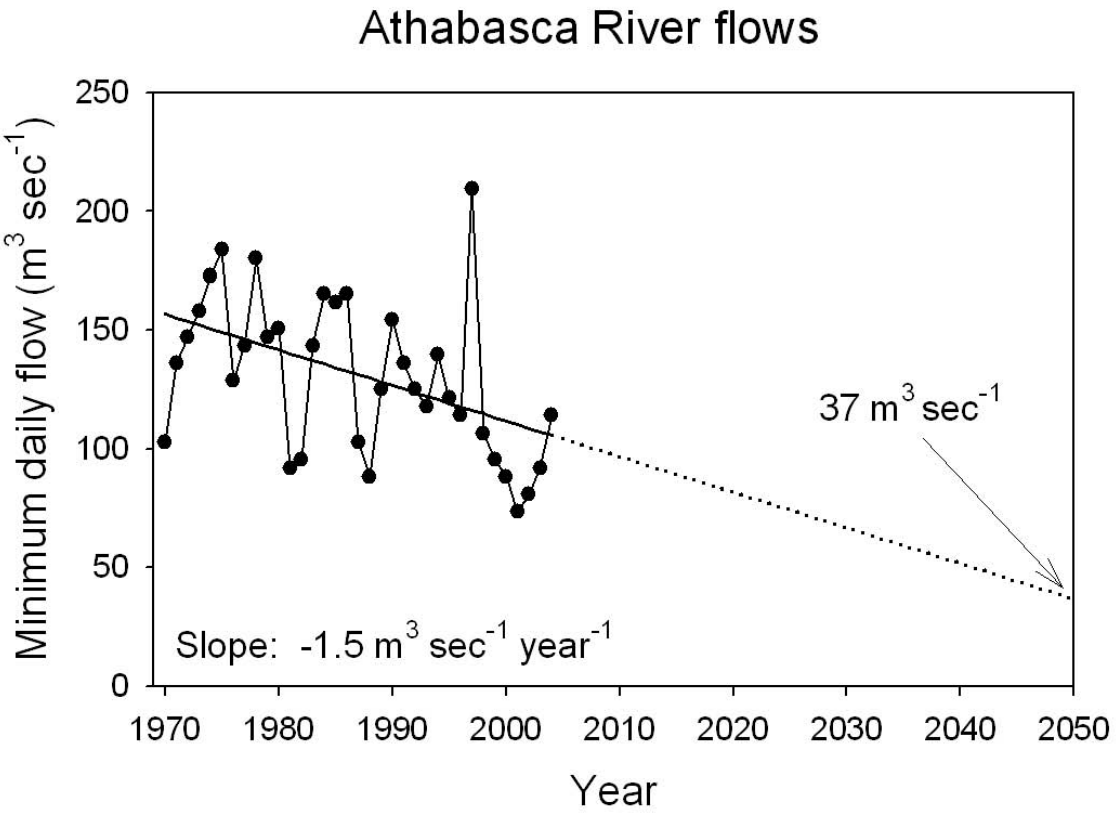

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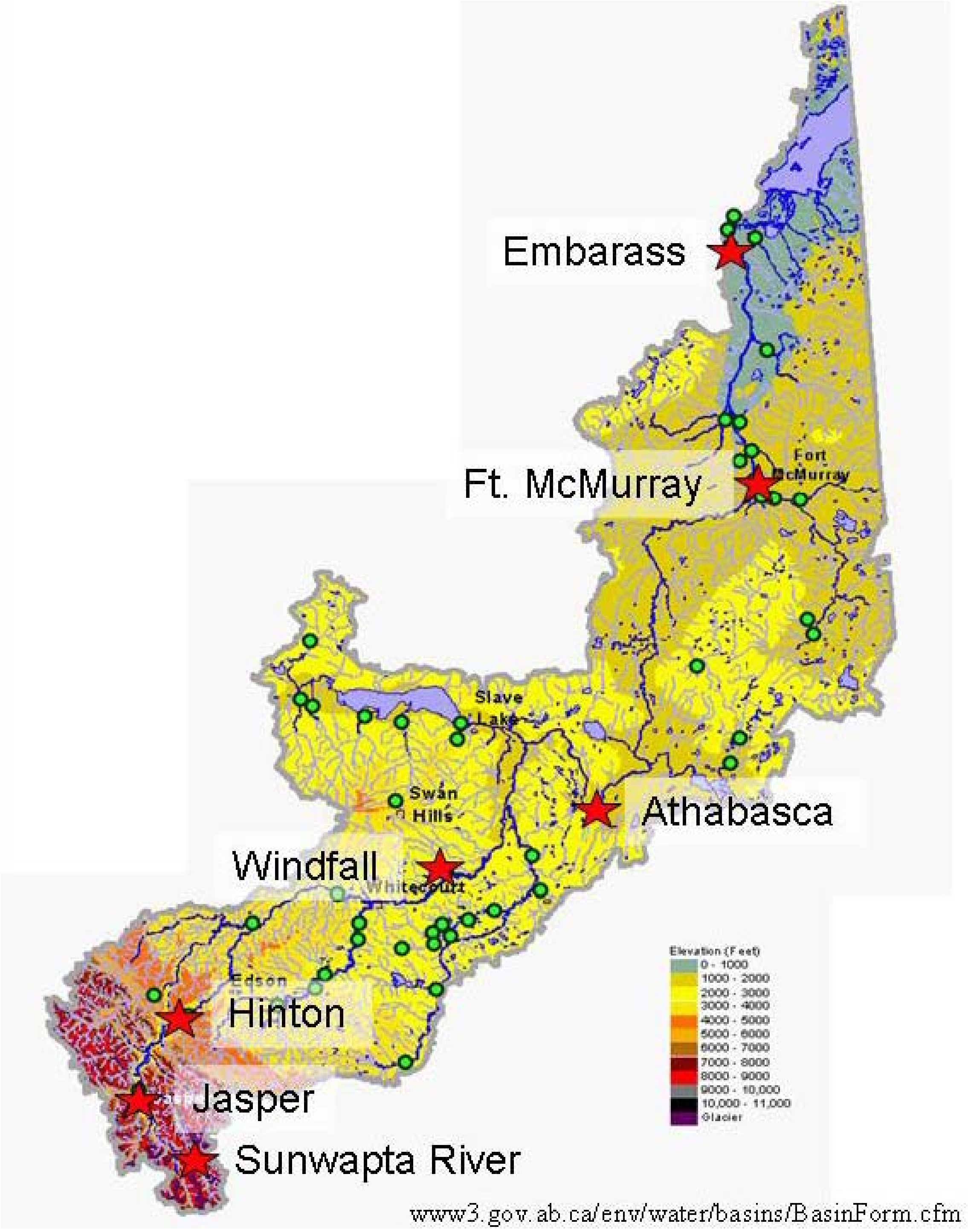
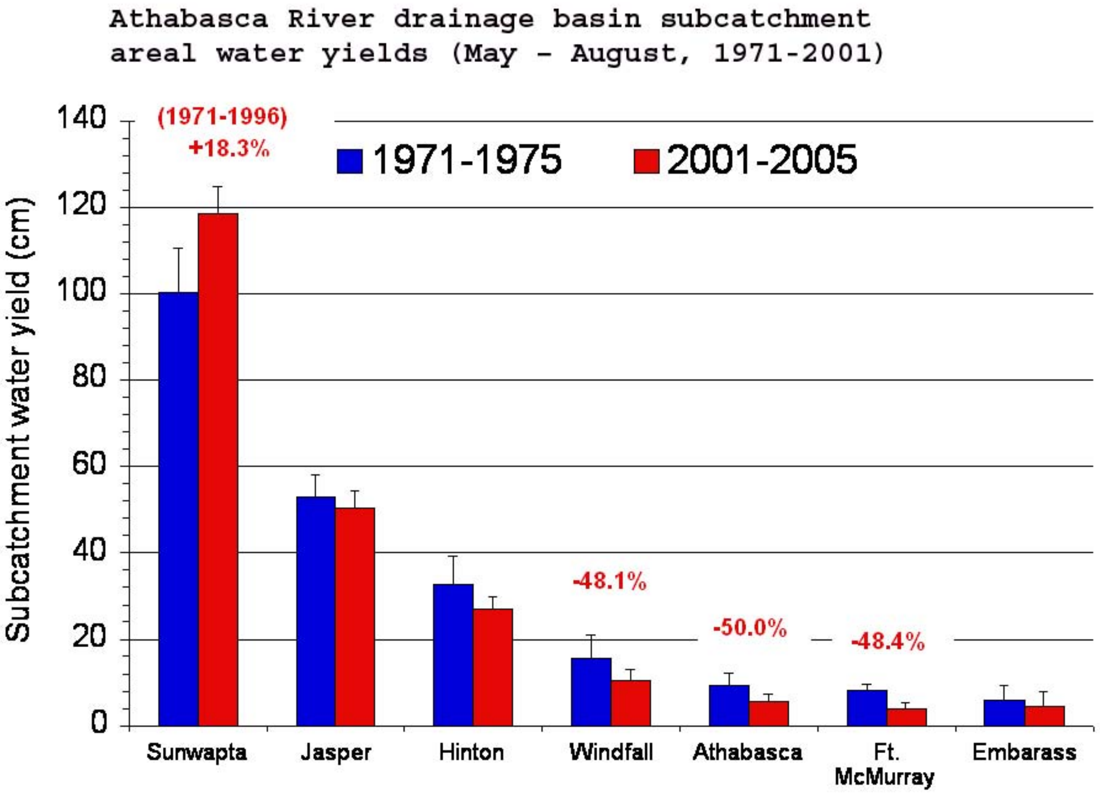


www3.gov.ab.ca/env/water/basins/BasinForm.cfm

Figure 13. The location of gauging stations on the Athabasca River (stars).



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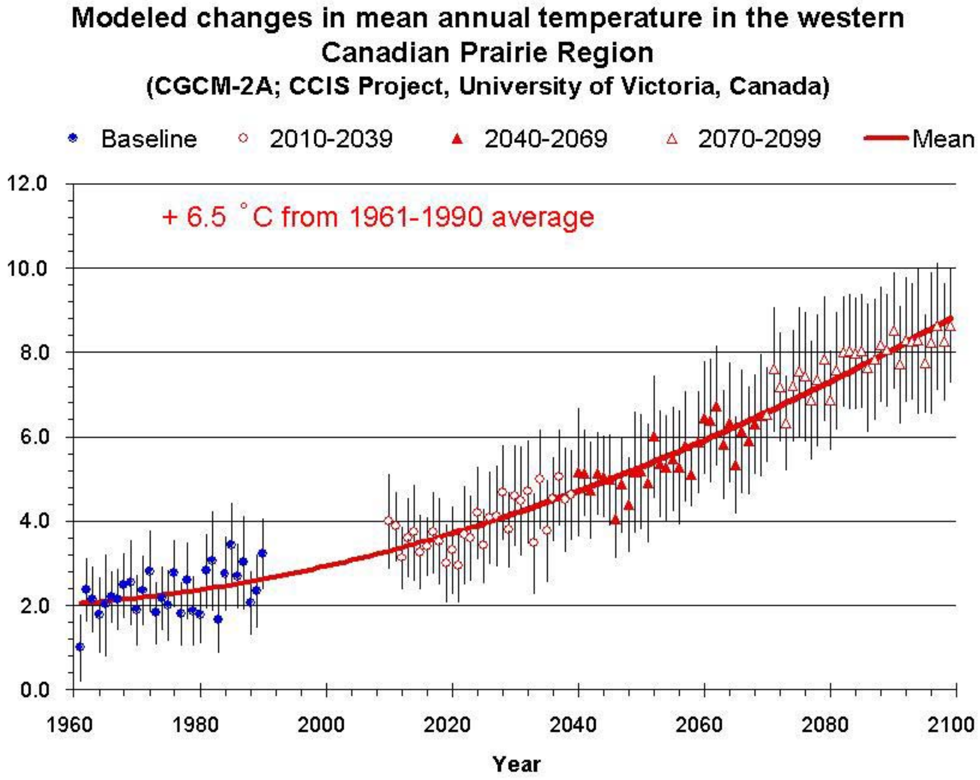


Figure 15. Projected changes in average annual temperature for the prairie provinces. From Schindler and Donahue (2006).

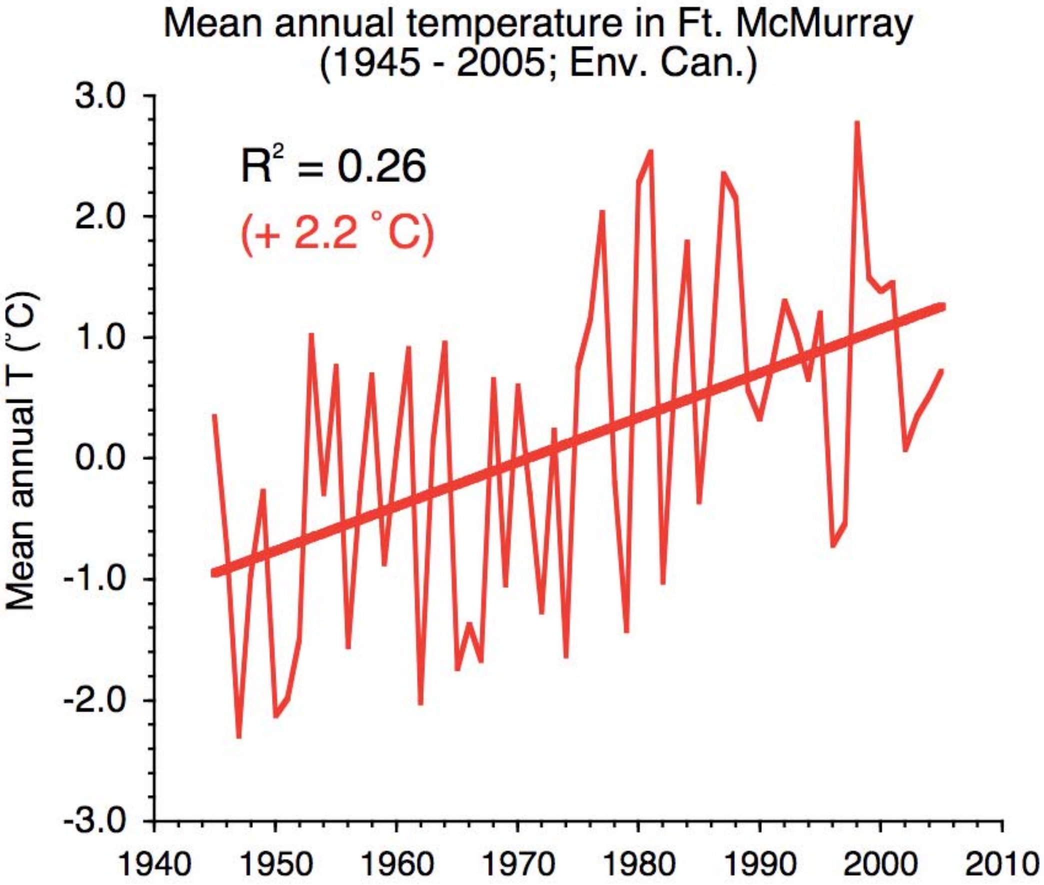


Figure 16. Trends in average annual temperature for Fort McMurray 1945-2005.

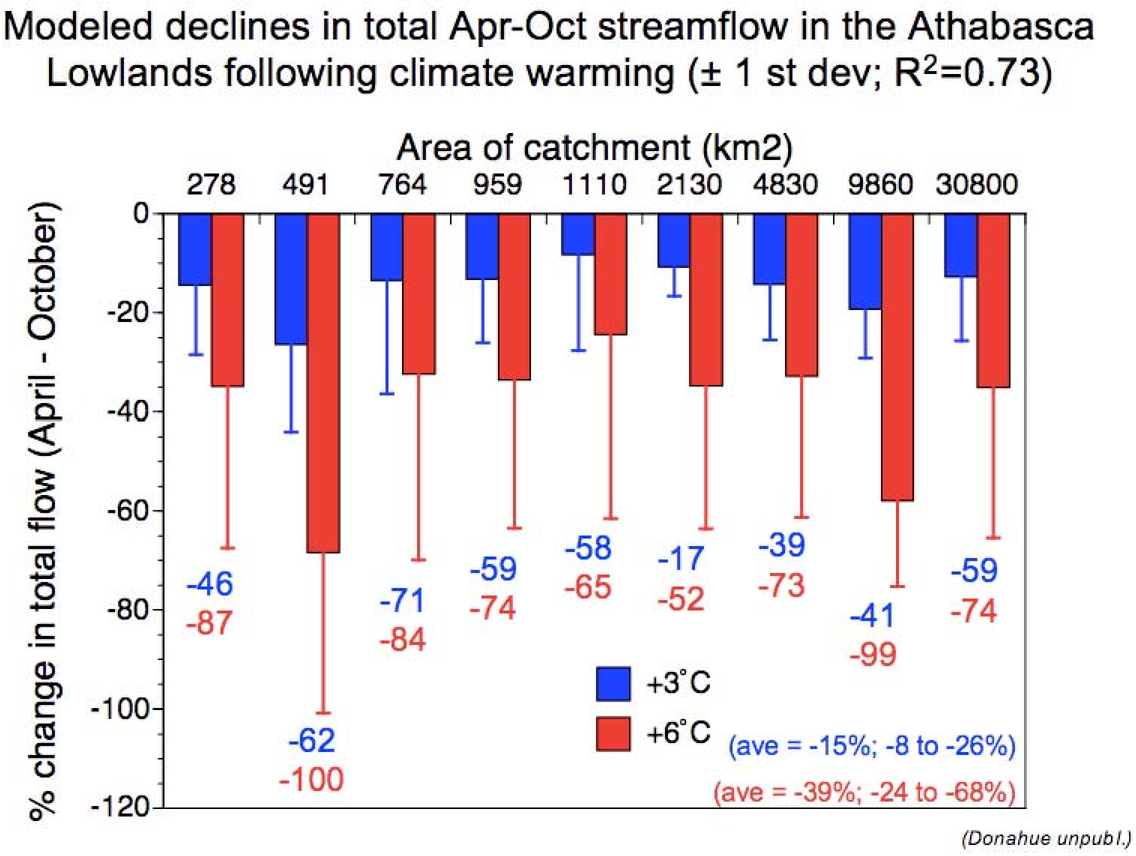
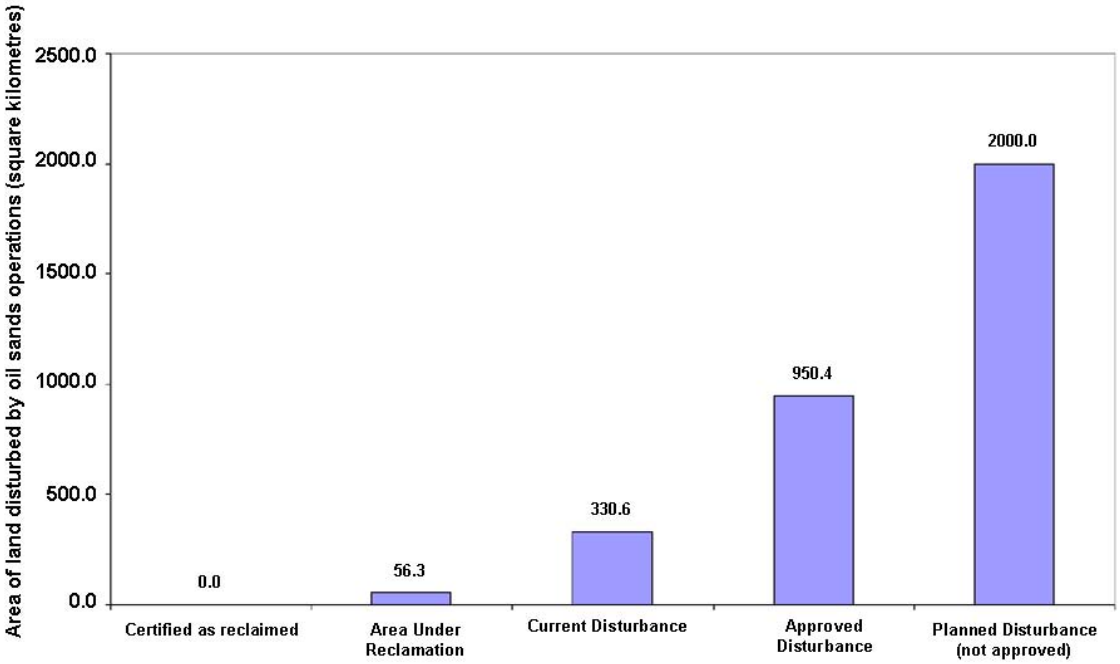


Figure 17. Modeled predictions of changes in runoff from several catchments in the Athabasca lowlands as the result of climate warming as the result of 3 degree (blue) and 6 degree (red) increases in average temperature.

Figure 18. A wooded fen, typical of 50-65% of the area mined by the oil sands. Photo by Dr. Suzanne Bayley.



The Pembina Institute

Figure 19. A summary of reclamation in the oil sands area, 2004. Source: Alberta Environment.

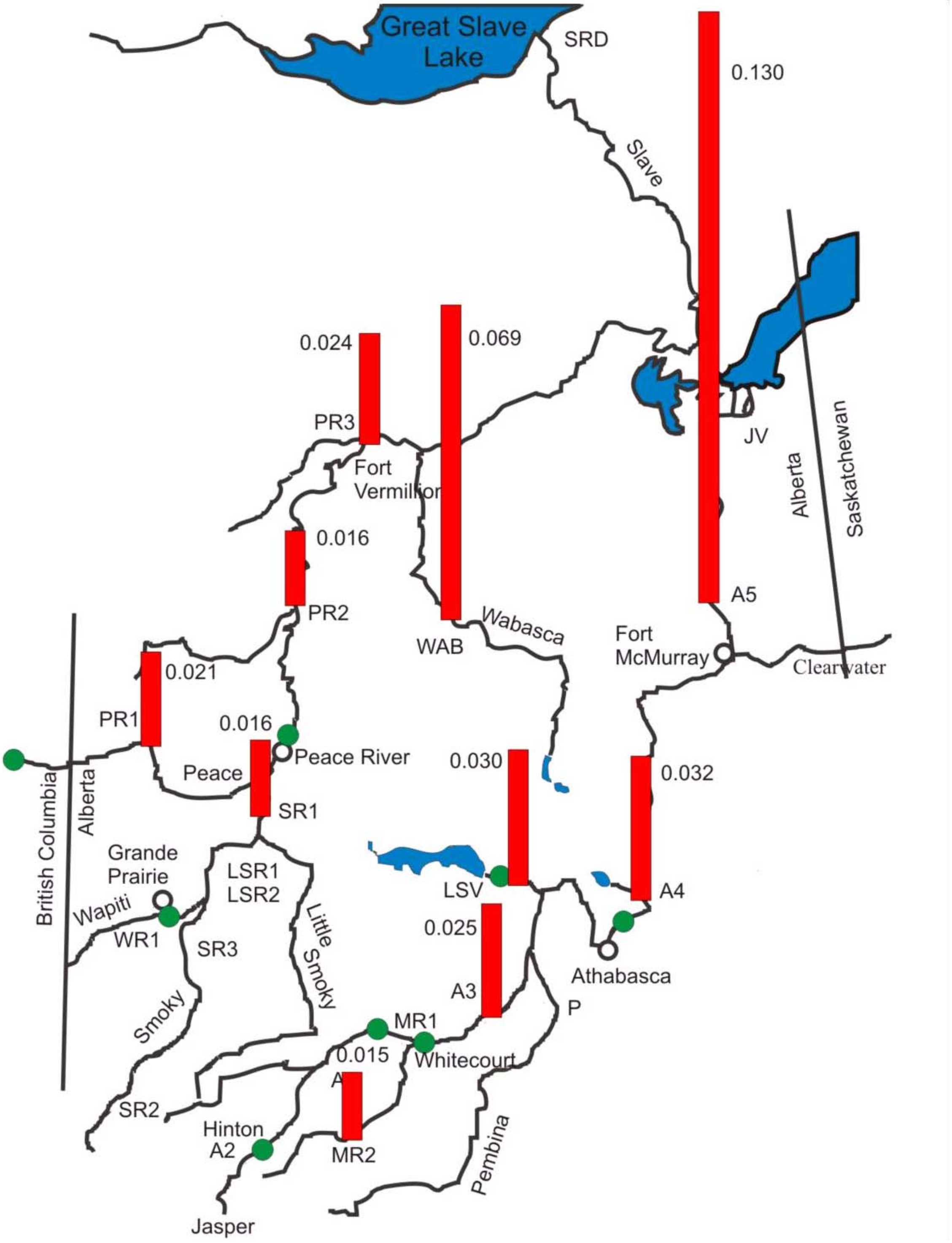


Figure 20. Relative EROD activities in immature burbot taken during the Northern River Basins study. Figure from Dr. Lyle Lockhart.

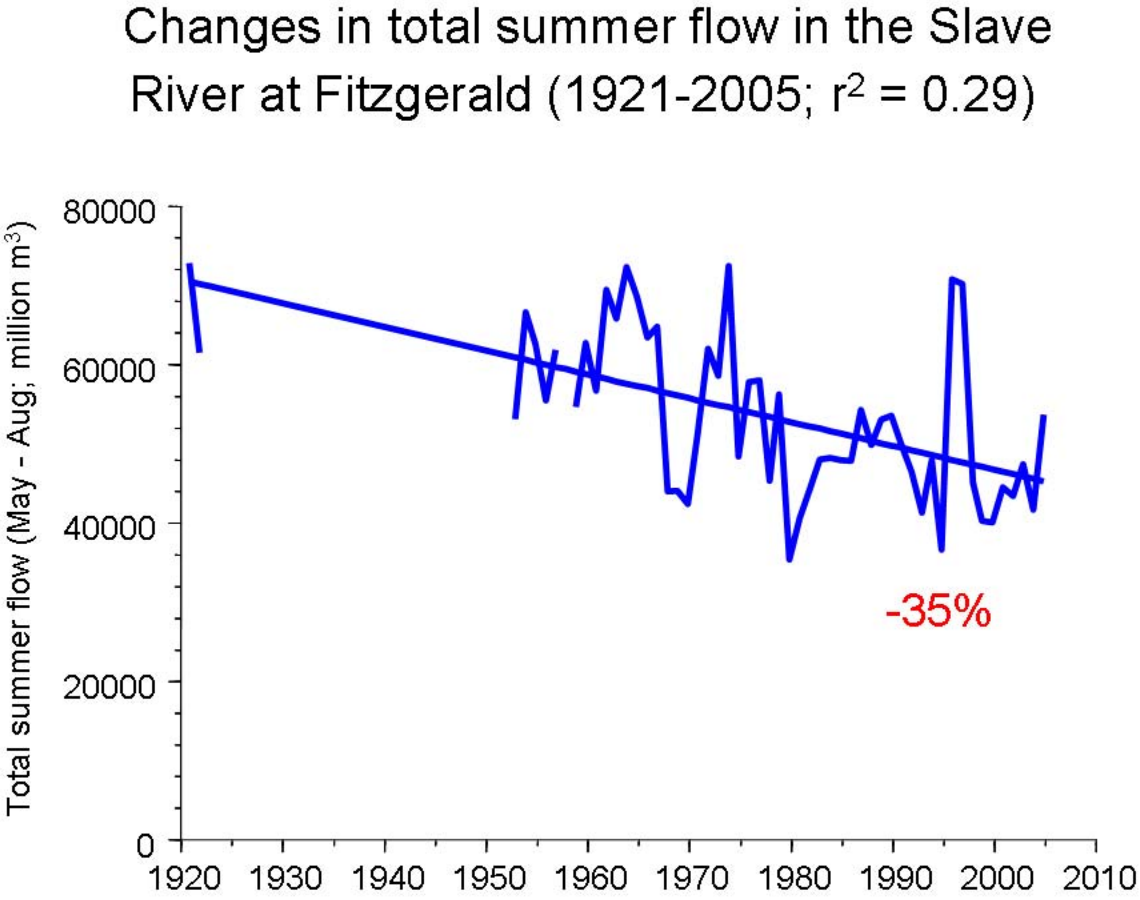


Figure 21. Summer flows in the Slave River at Ft. Fitzgerald, showing a 35 percent decline over the period of record (1921-2002). Note the large gap in records in the early part of the figure.

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Section 2: Water Use and Alberta Oil Sands Development-- Science and Solutions: An Analysis of Options

by Vic Adamowicz[12]

2.0 Introduction

The section above shows that economic activity, as well as ecological function and community well being will be limited by the availability of water in the Athabasca basin. Planned increases in economic activity may not be feasible, or may be more costly than originally thought, given water scarcity concerns. This section of the paper describes economic considerations in the allocation of water resources with a focus on balancing environmental, social and economic objectives. In particular, a set of policy options or "mechanisms" are presented in which environmental goals may be achieved more cost effectively. This discussion is intended to be consistent with Alberta's Water for Life Strategy (2003) in that it attempts to use science, information and novel policy tools to balance objectives in water resource allocation.

2.1 *Alberta's Current Framework*

Prior to the implementation of the *Water Act* (1999), Alberta employed the mechanism of administrative apportionment in which rights to water quantities are provided by the government. This "first in time, first in right" system provides older or senior licences priority in times of scarcity. Technically, demands from the oldest licences are to be met first with remaining water allocated based on an ordering implied by the date of licence. Unlike other jurisdictions (e.g., Australia) the licences are not based on a share of a determined flow but are defined by quantities of water. This approach to allocating water has been criticized for numerous reasons (Horbulyk 2007). While tying water rights to the land provided the security needed to encourage land settlement, this reduced the flexibility to move water to higher valued uses. The mechanism tends to result in water being used in lower value uses; if new higher value uses arise they are given a lower priority licence. Inability to trade water rights adds to the inflexibility of the system.

The new Alberta *Water Act* (1999) included several revisions that can help improve the allocation of water resources (see, e.g. Horbulyk 2007; CAPP 2002). In particular, the new *Act* included a framework for water rights trading to improve water resource allocation. The *Act* also included changes regarding term licences (licences with fixed end dates but with the option for renewal), and promoted the development of water management plans to facilitate improved conservation of water resources in regions of the province. Since the passing of the *Water Act* there has been some (albeit limited) activity in transferring permanent water rights (Horbulyk

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2007 reports that 10 such trades were completed by late 2006) and some temporary transfer activity. In 2001, a drought year in southern Alberta, trading activity took place and appeared to operate smoothly and efficiently (Nicol and Klein 2006). However, with the 2006 decision to cease accepting new applications for surface water licences in parts of the South Saskatchewan River Basin, water rights trading is the key mechanism by which future demands for water in these areas can be addressed. Within Alberta's Water for Life Strategy, there is interest in developing additional market based instruments (water pricing, etc.) to improve resource conservation and alleviate conflicts; implementing economic instruments is a goal for the medium term (2007/8 – 2009/10; http://www.waterforlife.gov.ab.ca/html/outcomes/healthy.asp).

The interest in water conservation has primarily focused on the southern region of the province because of water scarcities and the challenge of resource allocation between agricultural, municipal, industrial and other uses. The South Saskatchewan River Basin in particular has been the location of a variety of policy debates, research projects and planning exercises (Horbulyk 2007). The focus of this analysis however is on the Athabasca River basin and a somewhat different set of challenges. As the discussion above has shown, there are concerns about the degree to which water availability will be a limiting factor for economic development and the extent to which economic activity will adversely affect environmental quality in the river basin. In this section of the paper we examine a variety of approaches or mechanisms to deal with the scarcity concerns. We view these as options that should be debated and evaluated using a set of criteria for policy evaluation. In the latter sections of this paper we provide an initial evaluation using a relatively standard set of criteria. While some may view this discussion as premature given the current level of industrial activity and the availability of water, the climate change scenarios outlined above indicate that planning for potential reduced water availability and increased water quality concerns would be a prudent strategy.

2.2 *Conceptual Basis for Water Resource Allocation*

One of the challenges of water resource allocation is the multi-dimensional nature of water. Water has both stock and flow characteristics. Water has interrelated quality and quantity dimensions. Water is an important component of economic output and has economic value but it also has symbolic and cultural importance. Economists have struggled with the treatment of water as a commodity and with concepts of water value and price (Hanemann 2006). Water clearly has market value as both an input into productive processes and as an output and it has non-market value associated with ecological goods and services. It has public good and private good dimensions. One objective of policy is to allocate water to achieve the highest "value" from the resource (including environmental and market values) but the measurement required to achieve such objectives is challenging. In addition there are a number of equity concerns associated with water resource allocation including the needs of Aboriginal People and avoiding adverse impacts on sectors of society and on future generations, especially where rivers cross jurisdictional boundaries.

The challenge of water resource allocation can be viewed as a two stage process. First, given that there will be tradeoffs between economic activity and water flows, a set of objectives that balance the benefits of the economic activities and the benefits of instream water flows need to be developed. This balancing is difficult because of the diverse benefits associated with economic activities and water, the uncertainty about future economic and environmental conditions, and the diversity in needs, rights and preferences associated with water. While difficult in practice it is necessary to construct a set of objectives for water use. These may be framed as minimum instream flow needs, water management plans, determination of water needs for communities and Aboriginal People, or other strategies that provide the objectives for use as a result of the assessment of the tradeoffs associated with alternative water uses. Based on these objectives a set of mechanisms can be constructed that help guide economic activity to meet the objectives. These mechanisms provide signals through regulations, prices or other instruments that help guide the system towards the goal. There are tradeoffs associated with the choice of mechanisms as well. Some provide stronger incentives for conservation. Some are more cost effective than others – they provide a lower cost way to achieve the environmental goals. This set of tradeoffs between mechanisms is examined in detail below – in an attempt to find water allocation mechanisms that meet environmental and social goals with least cost or impact on economic goals.

If markets recognized all environmental values, they would guide water allocation in a way that meets environmental goals. While such markets do not exist, this concept of a “fully functioning market” can be used as a benchmark which maximizes the value of water use including environmental components and impacts on future resource use / availability. In this benchmark case the price of water to users includes the marginal private costs (withdrawal costs, etc.), marginal external costs (environmental costs) and the marginal user costs (impacts on future use) (Zilberman and Schoengold 2005). This conceptual approach would result in a market or an agency setting time and region varying water prices depending on the private, external and user costs. As no such market exists, nor do agencies set prices on the basis of the environmental and social costs, these aspects of water resource use go unaccounted for.

In principle, the price of water should include the impact of withdrawal or consumption on the environment. Measurement of such values, however, is clearly a challenge. While there have been many attempts to estimate components of the environmental value of water (e.g. the impact on recreational fishing values; Adamowicz et al. 1994, or recreational property values; Poor et al. 2001; see also Brown 2003) estimating the marginal value of water continues to be difficult. The measurement requires an understanding of the ecological and economic linkages between water use, hydrology, and ecosystem goods and services. Measurement of such values in the region also presents challenges. Assessing direct impacts of water quantity and quality changes on activities such as recreational fishing is possible but given the relatively low numbers of recreationists and commercial fisheries in the region these values will be relatively small. Values of traditional use by Aboriginal People are complex and difficult to measure in monetary terms. Since the human populations in the region are quite small, direct values associated with human activities such as recreation are expected to be relatively small. However, values associated with ecosystem goods and services and “passive use values” associated with fish and wildlife habitat may be significant. Unfortunately these values are the most challenging to estimate in terms of method and data collection. Increased effort in this area is to be encouraged as such analyses of the economic implications of water uses will aid in the incorporation of environmental values into planning and management decisions. At this point, and for this region, there is insufficient data to attempt to quantitatively incorporate all environmental value information into prices or to construct accurate full cost accounts for water. This continues to be an important research area that requires investment. Furthermore, this should not preclude the use of mechanisms that attempt to recognize the importance of ecosystem goods and service even if a precise measurement of their monetary value is missing.

The lack of information on environmental values rules out the direct incorporation of marginal external costs into a pricing mechanism. However, various mechanisms can be used to attempt to achieve environmental objectives in an efficient fashion. The remainder of this section examines these mechanisms. Given a target for instream flow, what mechanisms will help achieve that target and at the same time result in the least impact on economic, environmental and social objectives?

2.3 *Policy Targets and Mechanisms*

Based on the discussion above, the policy targets include maintaining instream flows in the Athabasca river and avoiding shortages (particularly seasonal shortages) that may adversely affect economic activities, communities and ecosystems. The focus here will be on water quantity recognizing that water quality is a related and critically important issue within the basin (Griffiths et al. 2006). The range of mechanisms to achieve these targets include:

- The current framework for allocation and licensing, including the recently proposed approach to recognize instream flow needs.
- Demand management approaches including:
    - Tradable water rights;
    - Water pricing, including pricing / rebate schemes;
    - Technology based standards including tradable performance standards.
- Water storage options:
    - Off-stream storage

Each of these mechanisms will be examined in light of the specific issues in the basin as well as the structure of the industry.

2.4 *Policy Options*

2.4.1 Option A: The “Status Quo”

The current framework for water resource allocation includes a mixture of permanent and temporary (term) licences for water users in the region. The recently announced water management framework for the Athabasca River includes a “green, yellow, red” scheme that implements restrictions on water withdrawals depending on the flow conditions of the river. Oilsands companies have been required to submit plans that outline how they will reduce water withdrawals at time of scarcity (http://www3.gov.ab.ca/env/water/Management/Athabasca_RWMF/ pubs/Athabasca_RWMF_ Technical.pdf).

The discussion of the mechanisms for response to water scarcity illustrates some of the difficulties of operating within the current policy framework. If the flow conditions enter the "cautionary threshold" (yellow management zone), recent and new licences will be most directly affected as their licences will include provisions for reduced use. This continues the impact of the historical property rights that differentiate by date of licence rather than value of water use. In the red management zone condition ("potential sustainability threshold"), maximum withdrawal caps will be implemented. One approach being evaluated in this case is a restriction to a percentage of annual allocation over all licensed users (Water Management Framework 2007).

The current approach is a form of "command and control" system in which users have little incentive to reduce water use unless there is a "yellow" or "red" condition. Even when the condition of the river worsens and the reduction plans take effect, these are not implemented on a basis that recognizes that different users of water have different marginal values for water. Perhaps most importantly there are few incentives, beyond reducing private costs, for development and adoption of new technologies as there is no advantage to an individual firm for doing so (including, to a certain degree, incentives to use allocations to avoid risks of losing them – Wilkie 2005). This threshold system will help in avoiding worst-case scenarios in ecological terms, but it may do so at a very high cost to economic activity in the long run. In terms of comparison to the benchmark (where prices provide signals of scarcity) this system will not send appropriate signals to individual firms or users of water and administrative mechanisms will continue to be used to allocate water in times of scarcity. This will almost certainly be an expensive approach to water management, relative to market based mechanisms, in the long run.

2.4.2 Option B: Tradable Water Rights

Tradable or transferable water rights are emerging as a preferred instrument in various parts of the world over the past 25 years (Chong and Sunding 2006). Australia, states in the Western United States, Chile and various other jurisdictions have implemented tradable water rights. In southern Alberta the tradable water rights system is beginning to take shape helping to address the scarcity issues in the South Saskatchewan River Basin. In this section, we review the issues surrounding tradable water rights and the applicability of trading to the Athabasca case.[13]

Tradable water rights are a type of "cap and trade" system or market based instrument for environmental protection. Tradable water rights do not create an unencumbered "free market" in water, rather they provide a strict legal and administrative framework for trading water rights in a fashion that allows water to be transferred voluntarily from low value users to high value users. Maximum total withdrawals remain capped and trading is only allowed within the cap and when there are no adverse impacts on other users or on environmental quality. Typically, trading systems have approval mechanisms that provide for the assessment of impacts on third parties when such impacts are common (e.g., Section 82(3) of the *Water Act*; California's water trading system – see Chong and Sunding 2006). Tradable water rights separate the water from the land or project for which they were originally licensed, allowing entities that save water through

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[13] Similar tradable permits mechanisms have been shown to provide significant cost saving in achieving environmental quality goals. For example, the U.S. SO_2 emissions permit trading market resulted in cost savings of $1B per year relative to command and control approaches (Stavins 2005).

implementation of improved technology to benefit by selling the rights to that amount of water. Rights trading has involved temporary and permanent trades in many jurisdictions and increased flexibility in the trading system tends to lead to increased frequency of trades and lower overall costs of achieving the environmental goals (Zilberman and Schoengold 2005). In Australia, temporary trades are far more numerous than permanent trades and act as effective mechanisms for addressing short term water scarcities (Bjornlund 2003). Water rights trading cannot occur without approved basin management plans (both as an enabling mechanism and for establishing environmental and distributional objectives) and without administrative systems that clearly define what is being traded and are able to monitor trades with the same security as financial institutions monitor financial accounts (Young and McColl 2003).

Tradable water rights systems have the potential to achieve water quantity goals at least cost. However, there are several potential challenges in a tradable rights system:

- Is there an ability to monitor and verify water use and enforce water use limits at low cost?
- Is the potential for third party effects substantial enough to limit the gains associated with trading?
- Will establishment of a rights trading system result in rights holders trading units that they would never have used – resulting in increased overall use of water (so called "sleeper" or "dozer" licences; Young and McColl 2003.)?
- How will the trading system account for rights with differing priority dates (e.g., permanent old licences versus temporary new licences)? In principle the market can be designed to differentiate between different types of licences, but this will make the market more complex and potentially limit the number of transactions (reducing the efficiency of the market). An alternative is to "buy back" senior water rights in exchange for term rights that may facilitate trading and a simpler market.
- Will there be sufficient heterogeneity in water value to the firms involved in the market to result in trades? If there is no variation in firms' technologies or activities then there will be no gains from trading – the system will essentially be a command and control mechanism. A somewhat related issue is the question of the extent of the market. Typically an intrabasin market only is considered, but the set of industries, municipalities and other users to be included will have to be determined. In addition, sufficient water for communities and ecosystem services will have to be maintained. Will such a market include the possibility of trades outside of the province (Horbulyk 2005 discusses issues surrounding an interprovincial trading scheme for water).
- How will the initial set of rights be allocated? It is most common to distribute the initial tradable rights on the basis of historical use (Tietenberg 2001). However, in protecting their historical rights and investments, this also provides existing rights holders with a windfall gain of an asset – however this pattern of gains may be similar to the gains that would arise from establishing a market. Auction mechanisms have also been proposed but seldom used. Given the recently rapid development of the oilsands area an approach based on historical allocation would seem problematic in that barriers to entry in an imperfectly competitive system may arise. There is considerable literature on the

potential difficulties in cases with imperfect competition on the output or tradable rights market (Requate 2005).

- Will the system be designed with sufficient interest paid to fundamental water needs for people and the environment in the region, and in particular to Aboriginal Peoples' rights associated with water and the environment, both in Alberta and the Northwest Territories? Associated with these equity and environmental concerns, will the tradable water rights system provide the opportunity for the government or other parties (e.g., Environmental Non-governmental Organizations) to participate in the market and hold water rights to remain in the river and enhance environmental quality? In California, for example, the government frequently intervenes in the water market making purchases to address environmental concern (Chong and Sunding 2006 state that in California in 2001, one third of the water rights trades were for environmental purchases).
- Water rights trading may provide incentives to construct and implement storage to offset seasonal variability. Brennan (undated; 2006) describes how water storage markets may emerge from storage that serves multiple firms – increasing the efficiency of resource allocation over time.

This long list of design issues suggests that tradable water rights will need to be carefully designed for this region. However, there is evidence from other parts of the world that tradable water rights systems can be established with relatively low transactions costs, with mechanisms to reduce or address third party effects and with the flexibility of both permanent and temporary transfers that help reduce the costs of achieving social, economic and environmental goals for water.[14]

In the case of the Athabasca, the key issues include the definition of the cap or maximum amount of withdrawal in a fashion that recognizes the seasonal nature of the water scarcities, long term variations in water flows arising from climate change and other factors, and the equity and environmental issues. Establishment of the cap also requires the development of an approved water management plan for at least this part of the Athabasca River and the plan would also be used to allow licence transfers, provide for holdbacks on trades (if required), and establish how any unallocated water in excess of the cap will be managed. The initial allocation of rights can be based on historical use or some other criteria, however, as mentioned above, this creates some difficulties in a rapidly evolving economy such as that of the oilsands area. The relationship between the current priority rights system, the heterogeneity of rights (those that do not expire versus those that do; priority order) and a trading system must be defined. This transition may be quite challenging (M. Young, Professor and Research Chair in Water and Water Management, University of Adelaide, personal communication, March 2007). Some innovative systems for addressing equity issues have been proposed elsewhere. M. Young (2007, personal communication) described a system in which a percentage of water allocation was reserved for

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[14] There is a large literature on emissions trading that applies to the case of water rights trading and market based approaches to water resource allocation. The analysis of mechanisms for allocation of initial rights or for recycling revenues from auctions or charges in the emissions control case for example will inform the design of mechanisms in water resource allocations. Summaries of this literature can be found in NCEE (2001), European Environment Agency (2006) and Stavins (2001). A survey of approaches including the case of water allocation can be found in NCEE (2004).

auctions, with the proceeds going to Aboriginal People to address water treatment or other community needs. Water rights trading is increasing in popularity in various jurisdictions, and Alberta is beginning to embrace water trading in the south, yet there remain issues particular to the Athabasca river that present challenges.

2.4.3 Option C: Water Charges

While water rights trading puts a constraint on the quantity of water available and prices emerge from the market, water pricing attempts to simulate a market by setting charges that account for the environmental and user cost (future use) components of water. In principle, a set of time and spatially varying charges that were based on knowledge of the environmental and user costs could result in perfect correspondence with the benchmark of water resource allocation that economists consider efficient use.[15] In practice, setting charges will have to be based on estimates of these impacts. Water pricing does not directly provide limits to water use the way that tradable rights do, but prices provide signals that would encourage demand management, such as reduced use and adoption of technology to reduce use. Water pricing may also provide signals for supply management, such as the development of storage structures and storage markets. Pricing requires metering and reporting of use (ideally withdrawals less return flows – Horbulyk 2005) – something that is already in place for most oilsands uses (Griffiths et al. 2006).

Three issues that arise with the use of charges are: (1) the responsiveness of water use to charges; (2) the cost implications for firms; and (3) the use of the revenues from the water charges (see Griffiths et al 2006 for additional discussion). There is evidence that increases in costs of water do result in substitution of other technologies (recycling, recirculation, etc) and reduced use (Renzetti and Dupont 2001). Renzetti (2005) suggests that industry responsiveness to increases in water costs may be more sensitive than agricultural or residential sectors. Renzetti (2005) provides an average estimate of the price elasticity of water intake (% change in water intake for a 1% change in water price) for Canadian manufacturing sectors of -0.80.[16] Dupont and Renzetti (2001) report ranges that are somewhat smaller in magnitude (-.015 to -0.59). Renzetti (2005) also cautions that there is some evidence of a substitution effect between water and energy and thus if some form of "carbon tax" were implemented it might result in increased water use. Regarding the extent to which increases in water costs will affect the overall costs in the sector, Renzetti (2005) shows that industrial water costs in Canada in general make up a small proportion of overall costs. Dupont and Renzetti (1999) state that modest water prices may only have minor effects on overall costs. For example, they suggest that after imposition of a \$0.003 per m^3 water price, water costs in Ontario manufacturing would increase from 0.01% of costs to 0.2% of costs. Note that these are estimates for the manufacturing sector - this is an issue that will need to be studied more closely for the oilsands sector. Information on elasticities, impacts of pricing strategies and potential for substitution / technical change will be required to develop a successful pricing approach (Griffiths, et al. 2006; Renzetti 2005).

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[15] In addition the system of charges would have to differentiate between surface water, ground water and saline water use – see discussion below.

[16] Note however that this is an elasticity of withdrawals and not of "uses" of water. The latter will be more important for policy analysis.

The final issues in pricing are the establishment of the price levels and the use of the revenues from water charges. As a simple example, using the estimates from above of 15 cubic metres per second of water use at maximum production levels, modest charges ($.03 to $.05 per m^3) would yield between approximately $14M and $23M per year if no changes in use occurred. These are within the range of charges for water in agricultural or irrigation cases (OECD 2002 – Transition to full cost pricing of irrigation water for agriculture in OECD countries) or in some industrial settings (OECD 2004 – Competition and regulation in the water sector). However, substantially larger prices (an order of magnitude larger) have been observed as typical industrial and municipal water charges in other parts of the world[17] (e.g., for Australian water tariffs http://www.esc.vic.gov.au/public/Water/Regulation+and+Compliance/Tariff+Approvals/Tariff+Schedules/) and in temporary trades in Australian water markets (Brennan 2006). Water charges in this range will have an impact on the cost of production of energy resources – depending on the degree of substitution and the potential for technical innovation. The opportunities for recycling, water substitution (between surface water, ground water and saline water), substitution of other inputs for water, and process innovations are important factors to assess if a system of water charges is to be used.

An issue arising from the use of charges is the use of the revenues raised. Typically these revenues go to general revenues in a jurisdiction, maximizing the flexibility of the use of the funds. Increasingly, there has been interest in earmarking such revenues for environmental projects, to reduce impacts on affected third parties, or for other uses. An intriguing scheme used in Sweden to provide incentives for the reduction of NO_x is a Refunded Emissions Payments Scheme (REP) (Sterner and Hoglund Isaksson 2006). This scheme charges industry per unit of NO_x emitted, but refunds (a large portion of) the revenue to the industry on the basis of the output of the industry (measured in terms of energy production in the Swedish case).[18] The REP scheme provides incentives for reduced "emissions" yet recycles the revenue to the same industry, softening the blow in terms of impact on firms (making the scheme more acceptable to the sector) and allowing firms to compete in terms of the share of the recycled revenue. Since firms are taxed on emissions but revenues are recycled on outputs (or intensities), this encourages reductions in emissions intensity but does so by directly targeting the emissions. In terms of comparison with the benchmark case in which water is priced in terms of the marginal environmental damage and the marginal user cost, the REP scheme is not efficient relative to the benchmark as firms can capture the revenues generating an output effect (Fisher, 2001; Bernard et al 2006). However, in some cases (imperfect competition – or few firms in the output market) these schemes have desirable properties (Gersbach and Requate, 2004). On the other hand when firms have a relatively large share of output this scheme sends less of a conservation signal (Sterner and Hoglund Isaksson 2006). Sterner and Hoglund Isaksson (2006) review the Swedish experience with the REP and argue that in terms of acceptance of the mechanism and effectiveness in reducing overall emissions, the approach has been very

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[17] Dinar (1997) lists industrial water prices in Canada as ranging from $0.17 to$1.52 / m^3 (1996 US $) with global examples ranging from zero to $7.82/ m^3 (1996 US $) but these are somewhat dated values.

[18] Alternative forms of this scheme have been proposed including refunding on the basis of the share of output over the share of "emissions". The net effects (refund less charge) to the average firm would be zero while firms with higher outputs per emission shares (or higher environmental effectiveness) would receive refunds and firms lower in outputs per emission shares would have net payments.

effective. Over an 8 year period (1992 – 2000) emissions were reduced by 40% (Sterner and Hoglund Isaksson, 2006).

Notable design features in the Swedish NO_x case are that a large price was charged per unit of emissions (the prices were approximately $6000US / ton compared to typical charges in non-refunded schemes of $150 - $100 US / ton; Sterner and Hoglund Isaksson, 2006).[19] This large charge was chosen to induce reductions and technical change in the sector. Without recycling this large charge would likely not have been feasible. Secondly, a small fraction of the collected revenue (2-3%) was used for administrative and monitoring purposes (Sterner and Hoglund Isaksson 2006). This meant that the vast majority of the revenues were recycled. There are "winners and losers" in this scheme – but in aggregate the sector is largely unaffected yet the incentive to reduce emissions is maintained. There were concerns that the scheme would lead to output effects but since the size of the charges relative to overall costs were low and there were opportunities for reductions in emissions, these impacts were minor (Sterner and Hoglund Isaksson 2006). This scheme has many properties that are similar to a tradable permits scheme with permits allocated based on historical output levels – but without many of the transactions costs associated with tradable permits schemes.

Such a REP scheme might be effective in the case of water fees in the oilsands region. It would be relatively easy to determine the output used to recycle the revenues and it would lessen the impact on a sector that may be facing various other costs associated with environmental effects. The prices or charges could be large enough to induce significant water conservation practices yet the recycling would allow firms to compete in intensity terms to capture the returns. The monitoring and enforcements costs would be relatively low as water use and outputs are currently tracked and monitored. A remaining research question is the extent to which this recycling scheme for reduction of use of an "input" (water) would differ theoretically from recycling schemes based on reductions of an emission. The remaining design issues include the establishment of the level of a charge (including provision to adjust for inflation and changing supply and demand over time), the extent of the program (which sectors or industries are included in the program), the portion of the revenue that is not recycled, and the establishing the appropriate mechanism that would allow earmarking of revenues. Regarding the portion of revenue not recycled these amounts could be used to provide support for parties adversely affected by water use (e.g., Aboriginal communities in the region), to support environmental improvements through projects and research, and to fund administration of the program.

2.4.4 Option D: Performance Standards and Tradable Performance Standards

A common approach to encourage firms to reduce emissions (or water use) is to implement performance standards or targets. For example, a target or goal for the number of barrels of water required to produce a barrel of oil at a level lower than the current industry average might be developed for the sector with disclosure on progress towards this goal. Firms could be encouraged to achieve these targets voluntarily, by setting technology based standards, by

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[19] Prices from NOx trading in the U.S. SIP (State Implementation Plan) program in 2004 were in the range of $2,500 /ton (http://www.epa.gov/airtrends/2005/ozonenbp/onbpchap4.pdf#page=1)

subsidizing technology to help achieve the goal, and/or by incentive based mechanisms associated with deviations from the target.

Experience with voluntary standards has met with mixed reviews at best. Harrison and Antewiler (2003) describe the relatively weak performance of some voluntary pollution control mechanisms in Canada. On the other hand the energy sector in Alberta has made significant progress in reducing water use per unit output (CAPP 2002). In general economists are concerned about the lack of incentives associated with voluntary approaches, subsidies, or technology based standards. The latter provide little incentive to improve beyond the standard and the standards tend to be based on negotiations that do not typically meet the benchmark for efficient treatment of emissions – although there is some evidence that voluntary standard setting can result in more flexibility for firms in achieving the standard (Khana 2001; Anton et al. 2004). Subsidies can help result in the adoption of technology but they do not send the correct signals regarding conservation. These concerns translate directly to the case of water use.

Tradable performance standards are a slightly different case. In this case the desired emissions intensity (emissions per unit output) is set as a target. If a firm has an emissions intensity lower than this target they can sell some "permits" up to the point where they meet the intensity target. If a firm is above the target they must buy "permits" to reduce their intensity to the target (Fisher 2001; 2003). This scheme, when applied to water, has many parallels to the case of tradable water rights with initial allocations based on output levels, or to the REP scheme in that a firm's water use and their output (oil production) factor into the mechanism to achieve the target. As in the case of the REP scheme, tradable performance standards do not achieve the level of the benchmark of economic efficiency (Fisher 2001). The most important difference between these three schemes is the way that they set targets or employ charges to reach targets. In the case of tradable water rights with free initial allocation – the key design feature is the "cap" and maximum water allocation. The mechanism maximizes water use efficiency within the cap. With the REP scheme, the key design feature is the water charge and the mechanism sends signals for efficient use of water but does not explicitly cap water use. A supplementary framework is required to implement the cap. In the case of tradable performance standards the key feature is the target water use per unit output (or water use intensity) and as with water charges supporting regulations are required to limit water use to be within a cap. The choice of instrument depends in large part on the desirability of each of these mechanisms and the feasibility / transactions costs of the approach.

2.4.5 Option E: Water Storage – A Technology Based Option

One mechanism to deal with the scarcity of water in winter in the Athabasca basin is the construction of off-stream storage sufficient to meet winter flow needs. Griffiths et al. (2006) describe off-stream storage as a feasible option to address low flows. A study undertaken by Golder Associates (2004) also concluded that off-stream storage represented a practical solution for addressing low winter flows in the Athabasca River. Golder Associates (2004) estimates costs of \$0.50 m^3 to develop sufficient storage to address current concerns. The ecological aspects of such storage should be an avenue for further research – as should the assessment of costs, funding and management options for off-stream storage developments.

A strategy that may lead to desirable outcomes is one that signals the scarcity of water in low flow periods to which firms may respond by constructing storage. For example, a system of water charges that is low for high flow periods and higher for low flow periods would provide incentives to conserve water and to shift water withdrawals in time. Storage would be one logical option in this case and collaboration to develop off-stream storage may result.

2.5 *Scope of Application of the Mechanisms*

The mechanisms described above discuss impacts on the economy, and impacts on water use, in general terms. Detailed assessments of which components of the economy are included in each mechanism are required. For example, in the case of water charges, which economic sectors (oilsands, conventional oil, forestry?) are to be included? If a large “unregulated” sector exists then perverse incentives can arise and the mechanisms may not operate as desired (Bernard et al. 2005). However, the transactions costs associated with the incorporation of all economic entities may be high. Also, the discussion above has focused on surface water but there are important interactions between surface water, ground water and saline water. In the case of tradable rights, trading may differentiate between sources of water. In the case of charges, differential or relative water charges would likely have to be established on all water sources to provide signals for conservation. These are important design elements that apply to all mechanisms.

2.6 *Evaluation of Mechanisms*

A variety of options have been presented and some of these options could be considered in combinations. As with any set of options there are tradeoffs between aspects of the options. Olewiler (2007) provides a policy evaluation framework that facilitates a comparison of policy options on the following dimensions:

- Economic efficiency / cost effectiveness (comparison with the economic benchmark described above; is there an incentive to reduce water consumption?).
- Political feasibility (are there conflicts with existing policies, ministry strategies, etc. will the approach remain feasible through fluctuating environmental, economic or social conditions?).
- Stakeholder acceptance (is there support from the industrial sector for the mechanism relative to other mechanisms?).
- Public acceptance (is there public support or challenges to the proposed approach?).
- Impact on environmental goal (will the environmental goal – maintaining adequate water flows for ecological function and economic activity – be met?).
- Implementation cost / transactions costs (what are the costs of designing the system to support the approach?).
- Adverse selection (would the water have been conserved without such policies – implicitly penalizing those acting to conserve water before the implementation of the mechanism?).

- Complexity and cost of monitoring / enforcement.
- Equity (will affected firms be treated fairly; will the approach have adverse effects on other users; will the condition of land and waters for use by Aboriginal People be improved or degraded by the mechanism?).
- Long term prospects (will the policy provide long term protection for the environmental goal in the face of climate change, changing demand and supply of water, changing economic conditions, changing technologies, etc.?).

The following matrix summarizes the options and the evaluation criteria. While the evaluation provided is qualitative and there are several questions that require additional information to fully complete the matrix, the evaluation framework provides some insights into desirable and undesirable aspects of each of the options.

Option	Economic efficiency	Political feasibility	Stakeholder acceptance	Public acceptance	Impact on environmental goal	Implementation cost / transactions costs	Adverse selection	Complexity and cost of monitoring/ enforcement	Equity	Long term prospects
Current Approach	Incentives for conservation based on private costs and voluntary actions. Not economically efficient	Clearly feasible but there are discussions regarding the need for improvements	Stakeholder strategies to respond to scarcity are being developed – implies some level of acceptance	Mixed views.	Unlikely to achieve the environmental goal without voluntary actions or significant technological advance.	N/A	N/A	Low	Inter and intra generational equity concerns.	Unlikely to be viable over the long term
Tradable Water Rights	May be very efficient depending on the design.	Currently being utilized in southern Alberta – consistent with Water for Life strategy	May be acceptable depending on the design.	Generally acceptable with some reservations on equity grounds. The public would likely be in general support of water trading.	Environmental goal defined by the "cap" – meets environmental goal by definition	Depends on design – may be significant in developing approved water management plan and trading system; ongoing costs unlikely to be much different than under status quo	May penalize those who have improved conservation practices – depending on design	Moderate	Concerns based on initial allocations of rights and third party effects (on other users, communities, Aboriginal People).	Very good long term prospects of meeting the environmental goal at low cost. Provides some resilience or ability to adapt to climate change impacts and changing supply and demand conditions.
Water Charges – with recycling of revenues	May be very efficient depending on the design. Some concerns about undesirable effects from the revenue recycling schemes.	Unlikely to be feasible unless the policy addresses fairness between industry sectors and/or recycles revenues.	May be acceptable depending on the design – but likely less acceptable than tradable water rights.	Support for environmental improvements but there may be concerns regarding the use of revenues and recycling (e.g. distribution, earmarking).	Does not necessarily meet environmental goal – depends on level of charge and use of time varying charge and/or a supplemental cap on water use.	Modest – water use and output are monitored.	May penalize those who have improved conservation practices – depending on design	Low	Concerns may arise regarding differential impacts on firms / industrial sectors. Concerns may also arise from the use of the revenues	Good long term prospects of meeting the environmental goal at low cost. Provides some resilience or ability to adapt to climate change impacts.

Option	Economic efficiency	Political feasibility	Stakeholder acceptance	Public acceptance	Impact on environmental goal	Implementation cost / transactions costs	Adverse selection	Complexity and cost of monitoring/ enforcement	Equity	Long term prospects
Performance standards	Not efficient. Can be improved if incorporated into a market based scheme but will not be as effective as a fully functioning tradable water rights approach.	Feasible – similar approaches have been employed in other environmental policies. Incentive based scheme will be less feasible	May be acceptable	Generally acceptable as long as environmental quality improves.	Does not necessarily meet environmental goal – depends on efficacy of implementing performance standards and level of industry growth.	Modest – depending on design	May penalize those who have improved conservation practices – depending on design	Low to Moderate	Depending on the standards established – there may be concerns within industrial sectors and/or concerns by communities, Aboriginal People	May be viable over the long term but will not result in a cost effective outcome.
Technology Options – Off stream storage	Does not provide conservation signals per unit of water but may provide a solution to seasonal shortages. May be the outcome of an efficient water charge strategy.	Feasible	Probably acceptable depending on cost.	May be acceptable as long as environmental quality improves.	May meet environmental goal – especially if in concert with other instruments (e.g. charges, defined limits on use)	Potentially significant implementation costs	Depending on approach and costs sharing – may have negative effects on some.	Low	Depends on the location and ecological impact – may generate significant concerns from communities / Aboriginal People.	May be viable in the long term depending on the degree to which storage can address low flow levels and if the ecological effects of storage are low.

2.7 *Conclusions*

This paper has provided an assessment of the water flows in the Athabasca River with projections of the impact that climate change and increased industrial activity may have on the river. Given the potential for significant water scarcity in the river and associated impacts on the potential for economic growth and environmental quality, a set of options for managing water scarcity was presented. An initial attempt to evaluate these options has also been provided. The following summarizes the recommendations.

A key first step should be to complete the development of a basin management plan to identify the distributional and environmental goals of water allocation and to enable the development of mechanisms for conservation – providing incentives for reuse, recycling, and substitution of scarce water resources.

To attain long term economic, social and environmental goals it is likely that one or a combination of mechanisms will have to be implemented. In the absence of a cap on withdrawals, a combination of a seasonally adjusted water charges with development of off-stream storage may be able to achieve the water quantity goals by providing incentives for conservation and development of cost-effective technological options. If a cap on withdrawals in established, transferable water rights may be able to provide signals for technological improvement and generate cost effective solutions, while clearly protecting the Athabasca's instream flow needs. A system of charges may be a short term solution while the development of the trading system occurs.

Both trading and charging mechanisms have desirable properties in terms of resource conservation. A combination and/or sequencing of charges and trading may also provide significant benefits in terms of conservation and in meeting the environmental goals at least cost. An important issue to consider is the degree to which these mechanisms provide resilience or ability to adapt to climate change (and to economic and environmental shocks in general). Climate change will undoubtedly affect the economy of Northern Alberta through water and other changes – but a system that signals the scarcity of resources to users through prices (water prices or tradable permit prices) will be able to adapt and innovate in the face of change.

A number of topics have not been adequately addressed in this paper, including the need for research on the environmental value of water, impacts of policy and mechanisms on communities and Aboriginal People both in Alberta and the Northwest Territories, the degree to which on-going technological change in the sector will address water quantity challenges, and instream flow needs for the basin. In addition, this paper has focused on water quantity while water quality concerns also require attention. Nevertheless we hope the objectives of this paper – to evaluate concerns regarding the region's water flows and to provide a set of options, will begin a discussion and debate on the best approaches to address water resource concerns on the Athabasca River while maintaining the opportunities for economic growth, community development and environmental quality improvement.

2.8 *References*

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