Oil and water – Will they mix in a changing climate?
The Athabasca River story

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1. Abstract[1]

Unless major efforts are made soon to reduce global greenhouse gas emissions, a 2ºC rise in global mean temperature by about mid century, and 4 degrees increase by late in the century, are expected. Central and northwestern parts of Canada will warm even more rapidly. This effect has already been observed with the greenhouse gas-driven climate change to date. This has resulted for the Athabasca River basin, in up to three times the 0.6ºC increase in average global temperature rise, observed to 2000. With a 2ºC rise in global mean temperature by 2050, the increase in the Athabasca River basin is projected to be 3.5ºC to 4ºC. With little change in precipitation, shrinking glaciers in the headwaters, and increased evaporation with higher temperatures a decline in flows of the Athabasca River has been measured just below Fort McMurray in the period 1972-2004. This trend is expected to continue with continued increases in greenhouse gas concentrations.

This river is the main source of water for oil sands developments, which use large amounts of water to extract oil from bitumen. For deposits deeper than about 75m, the water is used in the "in situ" method through steam injection. For shallower deposits, water is needed for mining and processing the bitumen scraped from the landscape, along with peat, trees and other vegetation, in strip mining operations. The latter process uses 2 to 4.5 barrels of water for every barrel of oil produced, although several companies are investigating measures to conserve water. The oil sands yielded more than one million barrels/day in 2005, and the known deposits, in an area larger than England, make Alberta second only to Saudi Arabia in oil reserves. Projected production by 2015 is expected to more than double.

Climate change is exacerbated by carbon dioxide and methane from oil sand developments. This results in the largest single source of growth of greenhouse gas emissions in Canada. At the same time, lower flows of the Athabasca River with climate change, and increased water withdrawals as new oil sands projects develop, threaten instream flow needs in the lower Athabasca River. These factors together put the projects and their water supply on a collision course. Instream flow needs are critical for protecting downstream ecosystems and for the First Nations and other communities who rely on fishing, hunting and trapping in the lower Athabasca, including in the Peace Athabasca Delta. The Delta is also being adversely affected by warmer winters.

Withdrawals for oil sands development, from the river, and adjacent groundwater which affects the river, have been projected to reach as much as 19m^3/sec. with planned and projected developments. Minimum winter flows in recent years have dropped to as

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[1] Note: This review has been prepared in a semi-popular style, based on sound scientific findings. It is hoped that it will be accessible to a wide audience.

low as 75m^3/sec (2001-2002). Yet projects have apparently been approved on the basis that the long term average winter flow has been 169m^3/sec, without taking downward trends into account. Projections of Athabasca River flows to 2050 have been made. This is about the latest expected date of 2ºC average global warming, and the expected time of near completion of oil sands bitumen extraction. These projections use global climate model results driving a proven hydrologic model. They suggest further declines in annual runoff of up to 30%, but additional declines in minimum flows of 7% to 10%. The Alberta government has proposed calculation of instream flow needs (IFN) on the river below the project, which, in a Yellow alert case (short-term impacts) would require that total withdrawals be limited "voluntarily" to 10% of minimum flow, i.e. 7.5m^3/sec on occasion in winter 2001-2002, and up to 10% less in future. This is far less than the 19m^3/sec (or even 11.2m^3/sec in a more conservative estimate) expected to be required with full project developments. Indeed, flows less than 110m^3/year have been observed in 10 of the past 24 years, requiring some withdrawal reductions under this guideline even with the conservative estimate of requirements. Thus, presently projected rates of oil sands development will have to be curtailed if reasonable instream flow requirements are to be met downstream. There are many scientific uncertainties surrounding these issues discussed briefly in the text, which should also lead to a precautionary approach in approving additional water withdrawals.

In addition to the widespread, devastating, environmental effects in the area of the projects themselves, the combined impacts of project water withdrawals and climate change can have other serious consequences. These include:

- threats to the productivity of the Peace Athabasca Delta,
- compromise of fair sharing of water with downstream jurisdictions in the Mackenzie River system, and
- downstream water quality and ecosystem degradation.

The many measures and research activities advanced by the Pembina Institute (Griffiths, et al., 2006) should be adopted to reduce the environmental footprint of oil sands development.

Climate change and water withdrawals need to be taken into account in an agreement between the three provinces and two territories (B.C., Alta., Sask., NWT, and Yukon) concerning sharing of the waters of the Mackenzie River system and protection of water quality.

In order to assess the compatibility between oil sands projects and ecosystems' water needs, consideration was given to:

- the projected water requirements of fully developed oil sands projects (estimated 11.2 to 19m^3/sec);
- Alberta's Instream Flow Needs guidelines which have been defined in order to protect downstream ecosystems; and
- the minimum flows of the Athabasca River in the past 25 years.

It was found that, even at the lower end of the water withdrawals from oil sands projects, there would have been 10 times during the past 25 years where the minimum flows of the Athabasca River would have been insufficient to avoid short term impacts on ecosystems. For longer term ecosystem impacts, the recommended water restrictions on oil sands project withdrawals, indicate that minimum flows would not have met full development needs in 34 of the past 35 years. (See fig. 3)

Climate change is projected to continue to decrease the mean and minimum flows of the Athabasca River at Fort McMurray. Inadequate water will be available for full oil sands development, unless significant water savings can be achieved in the projects.

2. Introduction: Purpose of study

A globally averaged warming of 2ºC rising to 4ºC are expected to occur by the middle and before the end of this century, unless significant efforts are made in all countries to reduce greenhouse gas emissions. Central and northwest Canada have been experiencing much greater warming than the global average to date, and this is expected to continue, with average temperatures in this region increasing 3.5ºC to 4ºC by mid-century.

The Intergovernmental Panel on Climate Change (IPCC), in its Third Assessment Report (2001) summarized studies that showed that up until the mid 1960s, natural forcing factors, such as changes in sun's energy, earth's orbit and volcanic emissions, had significant effects along with greenhouse gases on the global mean temperature fluctuations, and related climate. However, since about 1970, the rising concentrations of greenhouse gases have been the almost exclusive cause of the rapid warming observed. These IPCC findings have been reinforced by later studies (Meehl, et al., 2004) (Knutson, et al., 2006). Greenhouse gases and aerosol concentrations will undoubtedly be the driving factors on changes in earth's climate, over this century, and beyond. Thus, observed trends since 1970 in geophysical factors, such as temperature and precipitation, river flows and water levels, are reasonably reliable harbingers of changes in coming decades.

This is especially so if extension of trends since 1970 are consistent with projections by Atmosphere-Ocean General Circulation Models (AOGCMs) driven by scenarios of present and future greenhouse gas emissions and concentrations.

The Athabasca River, and oil production involving river water, have two important connections to human-induced climate change. The first, and perhaps most obvious, are the emissions of greenhouse gases from the energy industry in the basin, a major contribution to the global burden. The second is the impact of the changing climate on flows of the Athabasca River, the main source for the water-voracious oil sands projects. Both of these issues have been previously examined separately. The Oil Sands have been studied from an environmental perspective by Pembina Institute researchers including suggested means of reducing greenhouse gas emissions. (Griffiths, et al., 2006, Woynillowicz and Severson-Baker, 2006). The impact of climate change on the Athabasca River and the Peace Athabasca Delta has been the subject of a number of scientific papers (Burn, et al., 2004, Gan and Kerkhoven, 2004, Pietroniro, et al., 2006, Woo and Thorne, 2003 and Schindler and Donahue, 2006).

However, there has been little analysis of the combination of the trends in water availability due to climate change, and the trends in water demand for the oil sands project. Nor has there been much analysis of downstream impacts of these combined stresses on water quantity, quality and ecosystem sustainability. This analysis addresses these issues to the extent that available data and knowledge permit. Uncertainties remain. This paper suggests actions required to reduce adverse impacts.

3. Description of the oil sands projects – greenhouse gas emissions

3.1 Description

The Wall Street Journal headline was “As prices surge, oil giants turn sludge into gold” in an article by Russell Gold, reprinted by the Globe and Mail, 27 March 2006. The sub-heading was “France’s Total (Oil Company) leads push in northern Alberta to process oil sands”, with other international major companies close behind in percentage of oil reserves. Announced investment in oil sands recovery from 2006-2015 amount to $125 billion. (NEB, 2006)

Two types of operations are undertaken as described by Gold:

- One uses “colossal” drum boilers to generate steam, which is pumped underground to about 90m. This produces a tar-like mix of oil and sand from which the crude is extracted.
- In other nearby operations, on oil-soaked sands within 75 metres of the surface, bitumen is obtained by “scraping away an ancient forest of spruce and poplars” and large areas of peat and muskeg. These “scrapings” are dumped into 2-storey trucks which, “when fully loaded, weigh as much as a Boeing 747”.

The first of these processes is usually called “in situ” recovery either a Cyclical Steam Simulation (CSS) or Steam Assisted Gravity Drainage (SAGD) process. (Griffiths, et al., 2006). The second is termed mining or sometimes “strip mining”. The mining projects are around Fort McMurray, mostly to the north and close to the Athabasca River. “In situ” recovery is practiced in the more southern Cold Lake region in the Beaver River watershed on the Alberta-Saskatchewan border, as well as adjacent to the area being mined near the Athabasca River. Some of these projects are south east of Fort McMurray and in the Peace River Basin. (see Fig. 1)

Figure 1
Location map of oil sands projects

Eric Leinberger, *University of British Columbia*

3.2 Water Use

Both processes use large amounts of water. The mining operations leading to synthetic crude oil, or upgraded bitumen, uses 2 to 4.5 m^3 of water (net) per cubic metre of synthetic crude oil (Griffiths, 2006). Water allocations by Alberta to mining projects from the Athabasca River add up to 359 million m^3 per year (twice the amount of water required for Calgary); although to 2005 such allocations have not been fully used. Additional licenses for ground water, surface waters and diversions amount to 159 million m^3 per year. A further 50% increase in the total water requirements is expected when currently planned projects proceed. The Alberta EUB (2006) expects that production of bitumen will more than double by 2015. Only about 10% of the water used is returned to the river since the water becomes heavily polluted in the process and is held in huge storage ponds. Reclamation methods have not yet proven viable. (Alberta EUB, 2004) These projects also have other significant impacts on water resources. To begin mining operations, the companies must drain wetlands, peatlands, muskeg and forests, interrupting streams and groundwater to prevent flooding of the mine sites.

The mining operations result in “enormous volumes” (Gold, 2006) of liquid waste. These wastes are stored in large ponds, really lakes, with high concentrations of metal pollutants and napthenic acid, often used as a drying agent in paints. These lakes now cover 50km^2 and are expected to extend over the landscape for many years to come since, according to the National Energy Board (2004), “There is currently no demonstrated means to reclaim fluid fine tailings.”

“In situ” production also uses less water but substantial amounts of both groundwater and surface waters to meet steam requirements. Waters taken are mostly not directly from the Athabasca River. This process uses typically 0.2m^3 to 0.5m^3 to extract 1m^3 of oil from the bitumen and additional water for the upgrading process where this is undertaken. Bitumen reserve areas for “in situ” operations cover 14 times as much land as that suitable for mining. However, the recovery rate from mining is much higher than from “in situ” recovery (Griffiths et al., 2006). Total in situ and mineable reserves are estimated at 174 billion barrels. Only 2.8% of the total available had been extracted by 2005 (Alberta EUB, 2004).

These environmental damages related to bitumen production by both mining and in situ production could eventually affect an area about 1/5 the size of Alberta, or about the size of England or Greece, since this is the extent of the deposits. The deposits are all in the boreal forest region.

3.3 Emissions – Greenhouse Gases and others

By 2015, the Fort McMurray region (population 61,000) is projected to emit more greenhouse gases than Denmark (population 5.4 million). This does not take into account the loss of carbon sequestration by the peat lands and forests being destroyed, nor the emissions from these natural sources when, or immediately after, they are scraped away. Between 1990 and 2000, oil sands production was the fastest growing single emission source in Canada, up 47%, making it difficult to meet national Kyoto targets. This trend has continued unabated and total emissions are projected to rise from 28 to 67 Mt/year between 2002 and 2015. (NEB, 2006).

Oil sands production exceeded 1 million barrels per day in 2005, originally not projected to occur until 2012 (CBC, 1 May 2006). 59% was from mined areas and 41% from in situ production. (EUB 2006) Sulphur dioxide and NOx emissions are such as to cause acid deposition in downwind areas especially in northern Saskatchewan. Small particles with harmful health effects ($PM_{2.5}$) as they lodge in human and animal lungs, are also likely to have serious downwind effects as ground is laid bare. Bare ground has been shown in USA to be a large source of small, $PM_{2.5,}$ particles. (Saxton, 1995)

There is no sign that the growth in exploitation of the oil sands will slacken. Continuing high oil prices globally, with western Canada now holding the largest known reserve after Saudi Arabia, means large profits for the companies involved and an economic and employment boom in Alberta. As Alberta's Energy Minister put it, "It's worth it. There is a cost to it, but the benefits are substantially greater". (Globe and Mail, 27 March, 2006) Development is encouraged by low provincial royalty charges (1% until producers recover capital costs), and a federal accelerated capital cost allowance. (Reguly, 2006)

Many, concerned with greenhouse gases and climate change, had hoped that higher prices would reduce oil consumption. So far there has been little evidence of this in North America, but much evidence that the higher prices have driven oil producers to exploit dirtier "unconventional" sources with much higher energy input costs and emissions per barrel of oil than conventional fields. This is particularly evident in Alberta, but is also occurring in the very large unconventional sources of Venezuela. Most of the Canadian oil sands production is exported to USA. Bitumen produced from mining was upgraded to synthetic crude oil (SCO) amounting to 200 million barrels in 2005. In situ production was mainly not upgraded and marketed as bitumen. (Alberta EUB 2006)

For more information, the reader is referred to a comprehensive description of the oil sands projects and their environmental footprint which has been published by the Pembina Institute (Griffiths, et al., 2006), as well as Alberta EUB reports.

4. Athabasca River and Climate Change

4.1 Description

The Athabasca River is the southernmost tributary of the Mackenzie River which drains to the Arctic Ocean, from Canada's largest watershed (1.7 million km^2). The Athabasca rises on the east slopes of the Rocky Mountains from the Athabasca glacier, flows across central Alberta, then turns northward near Fort McMurray, through the Peace Athabasca Delta into Lake Athabasca. The Delta, one of the most productive in the world, is also fed by the Peace River which arises in the British Columbia mountains and flows eastward across northern Alberta. The Peace River flows are affected by a large dam and reservoir in British Columbia, but the Athabasca is an unregulated river. Its drainage basin to the gauge below Fort McMurray is 133,000 km^2. The oil sands projects draw water from the river mostly between Fort McMurray and the Delta. The Athabasca contributes 7% of the flow of the Mackenzie River, the Peace 24%, and the Liard 27% (Fig. 1).

4.2 Historic River Flows and Water Demands

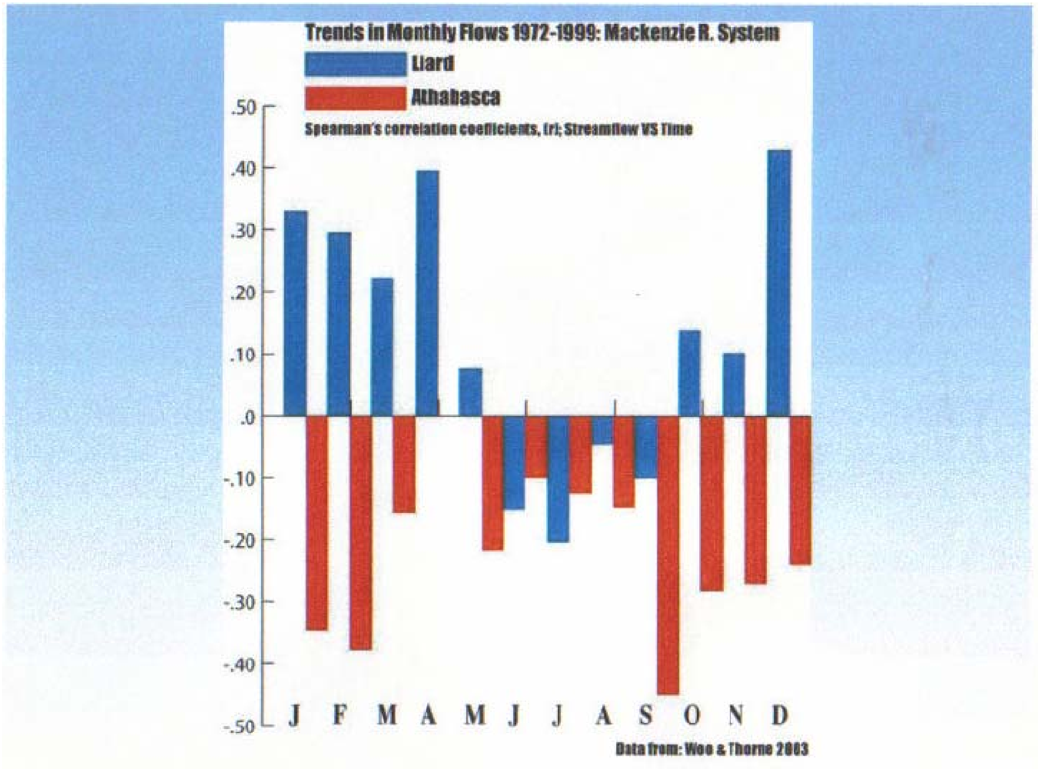
The annual average flow (1961-2000) of the Athabasca River at the gauging station below Fort McMurray, was a very substantial 630 m^3/sec. It is the winter low flow period, averaging 169 m^3/sec over this period, mostly under an ice cover, which is of most concern in connection with oil sands water withdrawals. It should be noted that Environmental Impact Statements for some individual Oil Sands Projects base their water takings on flow and climate data averaged for the period 1953-1999. (e.g. CNRL-Horizon Oil Sands Project Statement, 2003) The total projected water takings are estimated by the companies to be 8.5 to 11.5% of the minimum flow calculated on this historic average. (CNRL 2003) Since in 2004, the predicted freshwater use, including groundwater for the in situ enhanced oil recovery was less than 1/3 of actual use (5.5 mill m^3 vs. 16.2 mill m^3 actual) (Griffiths, 2006), it is probably reasonable to assume that the higher percentage (11.5% of average minimum) or more, is a likely outcome. 11.5% of 169 m^3/sec is 19.4 m^3/sec.

The Oil Sands Mining activities, however, are not the only withdrawals authorized on the Athabasca River. They represent 2/3 of the licensed allocations, with other industrial and commercial users being another 23%. Agricultural and municipal allocations account to about 1.5%. (Griffiths, et al., 2006) These are mostly before the river reaches Fort McMurray, and the oil sands area located beyond the "below Fort McMurray" gauging station.

4.3 *Observed Trends in Athabasca River Flow*

Several studies have documented the trends in flow of the river (Burn and Pietroniro, 2004, Woo and Thorne, 2003, Schindler and Donahue, 2006). Woo calculated Spearman's correlation coefficients which, with declining flows over time, are negative. These were indeed negative for every month but April (zero) for the 1972-1999 period. (Fig. 2)[2] The declines were statistically significant, at the 10% level, in the critical low flow months of January and February, and substantially negative but not significantly so in November and December.

Figure 2
Trends in Monthly Flows 1972-1999 Mackenzie R. System



In the Schindler and Donahue 2006 paper, the summer flow at the below Fort McMurray gauge declined 19.8% from 1958-2003, but 33.3% (significant at 5% level) since 1970, when greenhouse gases became the dominant driving force in the changing climate. This paper also provides analyses of past trends in temperature, snowfall, etc. over the Prairies consistent with declining Athabasca River flows. The work of Burn and Pietroniro (2004) considered trends at 13 gauging stations in the Athabasca basin. 58%

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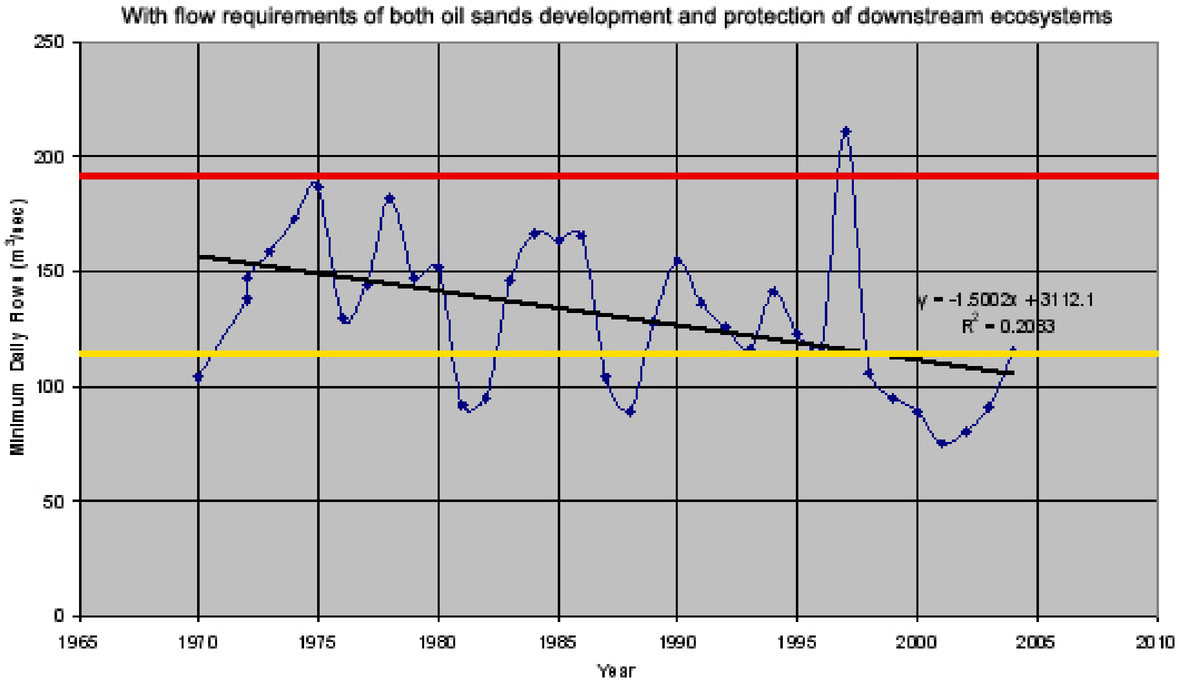
[2] Fig 2 also shows time trends for the Liard River, a more northerly tributary of the Mackenzie River arising in the Yukon, with trends towards greater flows, winter and spring, but declining trends June to September. (see Sec. 4.4)

of the stations had downward trends in annual mean flow from 1971-2000. For 1961-2000, the negative trends were not quite as pronounced but with statistically significant declines in flows for the below Fort McMurray station in January and February, as well as for the 25% percentile flows (at a rate of minus 3.2m^3/sec/decade) were determined. Some headwater stations showed increased minimum flows 1961-2000. The spring freshet date was also shown to be significantly earlier at a number of stations near and just downstream of the headwaters. Minimum daily flows, below Fort McMurray, declined to 75 m^3/sec in 2001 (December) (Fig. 3). Minimum flows in the decade of the 1970s averaged 151m^3/sec compared to 110m^3/sec on average from 1995-2004, a 27% reduction.

Figure 3
Annual Minimum Daily Flows (m^3/sec)
Athabasca River at Fort McMurray



Alberta requirements for protection of downstream ecosystems
- **Yellow impact (short term impacts) allows 10% of minimum flows for oil sands projects**
- **Red impact (long term impacts) allows 6% of minimum flows for oil sands projects**

Based on estimated water requirements at full oil sands development: 11.2 m3/sec (lower estimate)

From these analyses, it could be inferred that higher winter air temperatures in the headwaters, in the warming climate, has maintained minimum winter flows near the headwaters from snow and glacier melt. However, this advantage has been overwhelmed by losses in the long traverse across Alberta. Increased water withdrawals before the Fort McMurray gauge did not contribute significantly to this trend. It should be noted that the Athabasca glacier has shrunk 25% (Watson, 2004) over the last century and will soon, if not now, be providing reduced melt water.

Air temperatures rose 1.5ºC to 1.8ºC in the period 1961-2000 in this region. (Environment Canada) From 1971-2000 autumn precipitation declined about 6%, and winter precipitation by about 12%. In spring, rain amounts increased while snow declined with a net positive trend. Summer rainfall was essentially unchanged, leaving annual precipitation up about 4%. Annual evapotranspiration losses increase as temperatures of shallow water bodies and soils increase. Estimates of this effect are about 15% increase per degree C in a similar climate in northern Europe. (Jurak, 1989) Schindler and Donahue, 2006, related Potential Evapotranspiration (PET) increases to air temperature changes in western Canada using a modified Thornthwaite method.[3] They calculated that a 1ºC increase for Fort Chipewyan near the mouth of the Athabasca River, would result in an additional 29 mm PET. However, PET assumes that all surfaces in the basin are continuously wet or have ready access to moisture. This condition rarely occurs in the whole Athabasca River basin, so actual evapotranspiration losses are much less than potential. Nevertheless, the rate of increase in evapotranspiration as temperatures rise, suggests that significant increases in precipitation would be required to maintain flows. Such increases in precipitation are not consistent with 35 years trends, nor those projected by climate models. Thus, increases in actual evapotranspiration are expected to overwhelm small increases or decreases in precipitation, in coming decades.

The minimum daily flows at the Fort McMurray gauge from 1970-2004 show great variability from year to year. However, the downward trend to recent years is very evident in the plot of Fig. 3 with the winter flows in the 2001-2002 drought reaching the lowest values. If one assumes a continuation of the recent trends in future decades, minimum flows by 2050 could be as low as 37m^3/sec. Paleo-climate records of past conditions from tree-ring analysis suggest that even more severe drought periods can be expected in future (Sauchyn, D., et al., 2002). Schindler and Donahue, 2006, note that paleodiatom studies confirm these tree-ring results. Climate models also project more severe droughts in future over continental interiors. (IPCC 2001)

4.4 Future Climate, Flows and Water Levels

The future evolution of the climate of the Athabasca basin can be estimated in two main ways. One is through use of Atmosphere-Ocean Global Climate Models (AOGCM's) driven with estimates of future greenhouse gas emissions and concentrations. A second approach, generally more suitable for the near future, i.e. 20 to 30 years, is through projection of the observed trends from the 1960s to 2005, responding almost exclusively to greenhouse forcing. When there is agreement between these two approaches, greater confidence can be placed in the results.

There are perhaps a dozen major climate modeling groups world-wide. In selecting appropriate models to use in a particular region, it is important to choose those models which have best simulated the observed climatic conditions and trends for that area. An analysis was undertaken for the Mackenzie Basin of 7 model results compared

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[3] Thornthwaite method – a technique for estimating evapotranspiration from continuously wet surfaces (i.e. Potential Evaportranspiration) from monthly mean temperatures and length of daylight.

to the actually observed conditions (Dornes, et al, 2004). For temperature all models performed well in simulating 1961-1990 temperature, especially:

1. CCSR-NIES (Japan) – a little too warm in winter,
2. CGCM2 (Canada) – a little warm in fall and winter,
3. ECHAM4 (Germany) – a little warm in winter,
4. HadCM3 (United Kingdom) – a little cool in summer.

The situation was very different for precipitation, CCSR overestimated by as much as 100% in all seasons. CGCM2 also overestimated substantially, especially in winter. ECHAM4 was fairly close to observed values over the summer period but also overestimated the winter precipitation. HadCM3 was just the opposite, with good simulation of winter precipitation and significant over- estimates for spring and summer. From these results, and consideration of availability of projections with different greenhouse gas scenarios, it was decided to use ECHAM4, CGCM2, and HadCM3, but to keep in mind the bias, that all of the models overestimated precipitation as compared to observed values.

The good agreement for temperature between trend extension and the AOGCM projections is illustrated in Fig. 4. This shows that linear extension of the 1961 to 2000 temperature trend and model results for 2025, 2055 and 2085 give similar amounts of annual warming, with HadCM3 being somewhat cooler in 2025 and 2055. The model projections are from Gan and Kerkhoven, 2004, and are averages from 4 different IPCC-SRES[4] scenarios of emissions (A1F1, A21, B11, B21) and the projection years shown in Fig. 4, are in the middle of 30 year time slices.

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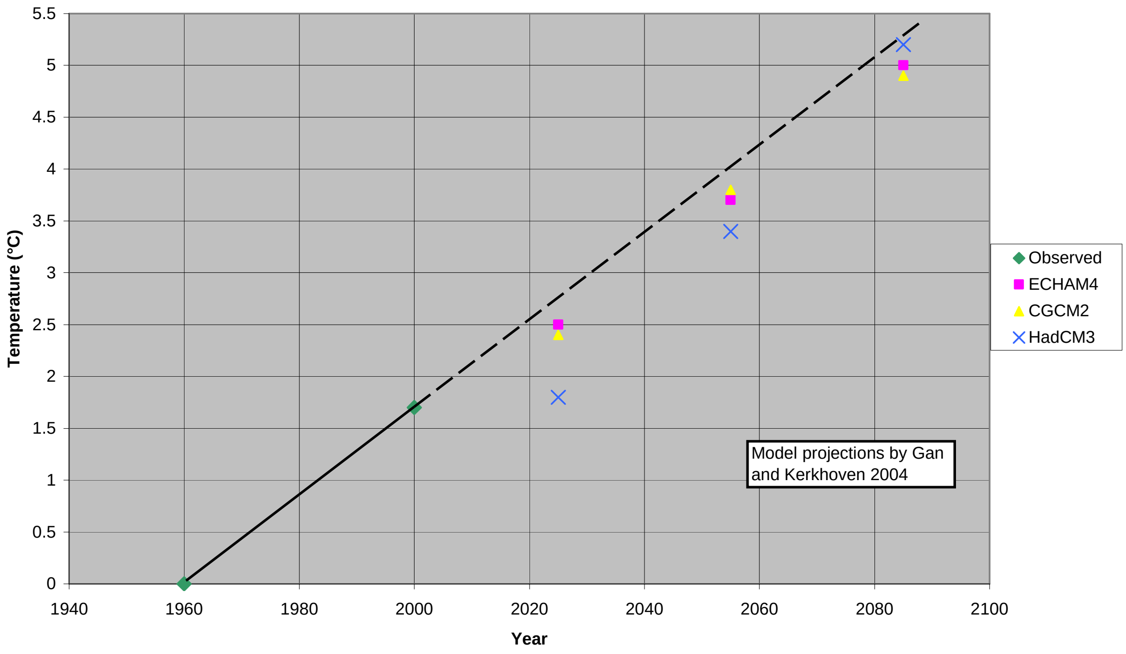
[4] SRES (Special Report on Emission Scenarios) were developed by the IPCC, 2000, and are projections to 2100 of future global greenhouse gas and sulphate aerosol emissions under various assumptions of population growth, economic change, energy and technology uses.

Figure 4
Temperature Trends and Projections
Athabasca River Basin



As expected, a similar concurrence is not evident for precipitation. The observed average annual trend (see above) is upward about 4% for the period from 1976, less than needed to offset evaporation increases. ECHAM4, the model which best simulated the 1961-1990 seasonal and annual precipitation although over- predicting winter amounts, projects on average for the 4 emission scenarios, future declines in precipitation of 1-3%. CGCM2 projects increased precipitation of 4% up to 2055 and 8% by 2085. But it must be recalled that CGCM2 overestimated annual precipitation 1961-1990. HadCM3 model indicates greater precipitation by 8% to 12% later in this century, but also overestimated the 1961-1990 annual by about 30%. Linear extension of the 4% observed increase 1976-2000 would suggest future increases between those given by CGCM2 and HadCM3. In short, precipitation will increase or decline slightly, so any increases in the decades to 2055 will likely continue to be more than offset by increased evaportransporation in the warming climate.

4.5 Modeling of Future Flows

Efforts to model the combined effects of temperature and precipitation changes on flow of the Athabasca River have been undertaken under MAGS (Mackenzie GEWEX[5] Study, Gan and Kerkhoven, 2004). Fig. 5. illustrates the changes projected by the three models. All models project declines in annual runoff. As expected, ECHAM4 projects

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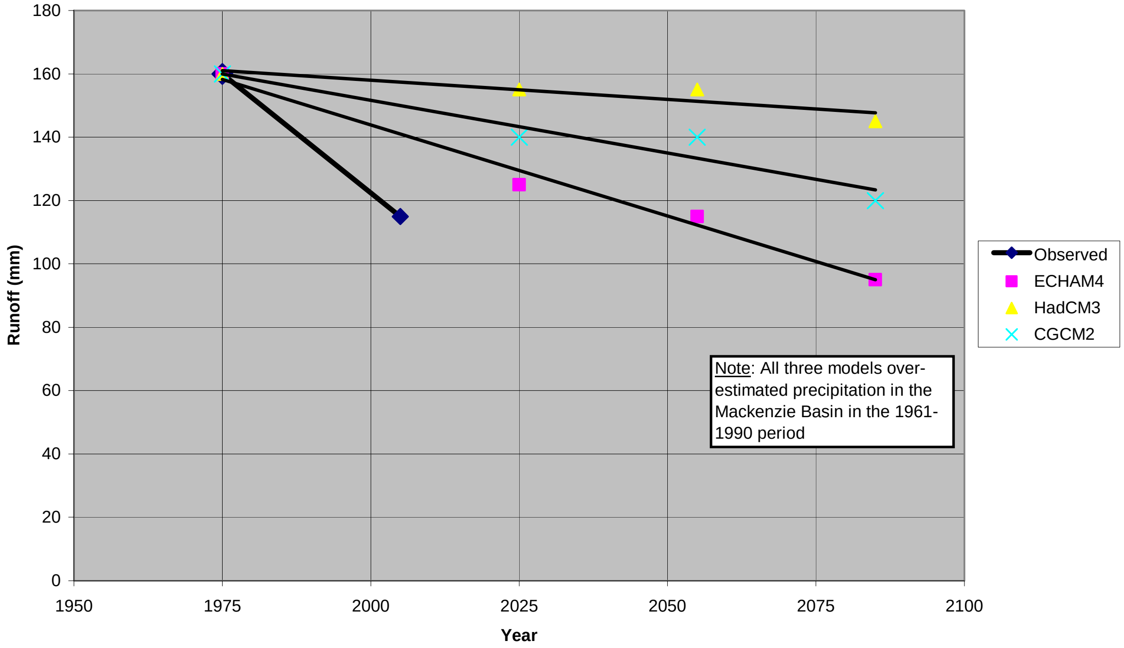
[5] GEWEX – Global Water and Energy Cycle Experiment, a component of the World Climate Research Program. (WMO, ICSU)

largest runoff declines in mm over the basin. These are from 160mm currently to 125 by (2010-2039), 112mm by 2040-2069 and under 100mm by 2070-2099. The most optimistic, HadCM3 averaged over 3 SRES scenarios, a decline of about 5mm by the first period, about the same for the second, and about 15mm for the third. CGCM2 and other models were between these results. Hence, the projected decline ranges from 3% to 30% for the time of 2°C global warming, as represented by the model period 2040-2069. It should be noted that the results are much more model dependent rather than being affected by the 4 different SRES emission scenarios used. Minimum flows under future climates, declined less than mean annual runoff by the model runs. The largest modeled decline was 10% and the average decline 7% for all models used.

Figure 5
Observed and Projected Annual Runoff
Athabasca River below Fort McMurray



Note: All three models over-estimated precipitation in the Mackenzie Basin in the 1961-1990 period

To convert from the climate parameters to runoff, the analysts (Gan and Kerkhoven) used a modified version of an atmospheric-land surface model developed by Meteo France (Kerkhoven 2005). The original model was ISBA (Interactions between Soil, Biosphere and Atmosphere) a land surface vertical water budget model. It was modified to provide for non-linear formulations for surface and subsurface runoff, and also for the heterogeneity of the Athabasca Basin. The new formulation was dubbed MISBA and was shown to realistically simulate average, maximum and minimum flows of the Athabasca using 40 years of data. The WATFLOOD hydrological model from the University of Waterloo gave a 29% overestimation of flows below Fort McMurray. (Toth, et al, 2006)

It should be noted that natural variations in climate in Alberta, driven in part by the Pacific Decadal Oscillation (PDO), may have made a contribution to the warmer, drier conditions of the past 25 years. However, climate models incorporate such natural modes of variability in their projections to the future (Wang and Schimel, 2003). Thus, just as there are significant variations from the overall trend, from year to year, or decade to decade, in the observed data (Fig. 3), such fluctuations above and below the overall downward trend are to be expected in future.

4.6 Ice Effects

Ice cover and ice jams can have effects on river levels such as on the lower Athabasca. In general, it was found that warmer winters result in hydrodynamic effects which resulted in short lived lower levels and flows in both the Athabasca and Peace Rivers near their outlets. Warmer winters also result in lower levels of lakes in the Peace Athabasca Delta (see 4.2) (Leconte, Pietroniro, 2006). This has effects with a longer term than on the rivers, that propagate from winter and spring through to summer. In summer under Geophysical Fluid Dynamic Laboratory (Princeton University) and ECHAM4 models, by 2080 average decline in levels is estimated at 0.29m, in years with projected level decreases. (see also estimates in 4.2)

Maintaining water levels in the Delta is key to preserving its biological productivity. (Environment Canada, 2005), and this is threatened by both climate change and water withdrawals on the Athabasca River.

5. Combined Downstream Impacts of Climate Change and Oil Sand Projects

5.1 Instream Flow Needs

The Athabasca River after a 1538 km journey, flows into Lake Athabasca through the Peace Athabasca Delta. The lower reach, below Fort McMurray, including the oil sands region is habitat for a number of prized fish species. Walleye, Northern Pike and Goldeye are among 31 species found there (Woynillowicz and Severson-Baker, 2006). This part of the river also provides a migratory route for fish from Lake Athabasca to reach spawning areas upstream of Fort McMurray. Adequate flows and quality are needed to support the ecosystems which include these fish species. Another concern is that the mining activity removes such wooded fen, a large hydrologic “capacitor” and its removal will serve to make the lower Athabasca River more “flashy”, i.e. higher high flows and lower low flows. Quantification of this effect is not possible at present but it will be important for ecosystems.

Instream Flow Needs (IFNs) calculations are being developed by Alberta as a guide to provide aquatic ecosystems with sufficient flow under the “Water for Life” strategy.[6] An “Interim Framework” for the lower Athabasca was implemented in January 2006 with public comment requested by March 2006. (Alberta Environment, 2006) The Interim Framework defines 4 categories or “zones” of increasing impact, Green, Yellow, Red and Black. While the IFN Interim Framework does not mention climate change

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[6] Alberta’s Water for Life strategy is designed to protect safe drinking water and aquatic ecosystems through effective management that also supports sustainable economic development.

impacts on flow, it does call for a reliable monitoring system which would trigger "management actions" in the oil sands projects. With the projected lower flows with climate change, these diversion limitations would have to be invoked more frequently, interrupting oil production operations. For example, the Yellow Zone (short term ecological impacts) management actions call for a voluntary target of withdrawals limited to 10% of available river flow. If we take the minimum flows observed in the declining trends to winter 2003-2004, this would mean a total diversion for oil sands projects of as little as 7.5m^3/sec., much less than the maximum19m^3/sec. estimated by the oil companies as the projected requirements (up to 11.5% of minimum flow, based on historic average of 169m^3/sec.) (CNRL, Horizon Oil Sands, Environmental Impact Statement) or even the more conservative estimate of 11.2m^3/sec.[7] For the Red Zone, when long term ecological impacts are anticipated, the proposed cumulative diversion rate target is only 6% of minimum flow, approximately 1/2 to 1/3 of projected requirements of the projects. Indeed minimum winter flows less than 110m^3/sec, which are less than enough to support the conservative demand estimate with Yellow Zone conditions, have been observed in 10 of the past 24 winters, and are projected to be more frequent in future.

To assess the adequacy to protect ecosystems, the suggestions in the interim framework have been under review by the multi-stakeholder Cumulative Environmental Management Association. (CEMA) Some participants consider that these guidelines are not sufficiently precautionary, given the large unknowns associated with the lower Athabasca ecosystems, and impacts of climate change (Woynillowicz and Severson-Baker, 2006).

In future, minimum flows would continue to decline another 7% to 10% as projected by a number of climate models over the coming four decades (Gan and Kerkhoven, 2004), the amount of water allowed to be diverted by these Guidelines would decline further, as the demand from the projects increases. This should increase the urgency of the Oil Sands projects operators to find ways to reduce their needs through storage, recycling and other means especially in winter months. A number of suggestions and recommendations have been provided by Pembina Institute. (Woynillowicz and Severson-Baker, 2006)

5.2 Peace Athabasca Delta (PAD)

The PAD is fed by the two rivers (Peace and Athabasca), and is in Wood Buffalo National Park, one of Canada's most extensive. It is one of the world's largest freshwater deltas and an internationally recognized wetland under the RAMSAR Convention, an international agreement to protect wetlands, as well as being a UNESCO World Heritage Site. It includes large undisturbed grass and sedge meadows, and is home to extensive

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[7] Note: Golder Associates in material for the CEMA group estimated approved and planned operations would require a peak of only 11.21m^3/sec.

populations of waterfowl, muskrat, beaver and wood bison. It has been used traditionally by many First Nations hunters and trappers as a major source of income and sustenance.

The Delta wetlands require periodic high water to survive. This was compromised by the initial filling of the W.A.C. Bennett hydro-electric dam's reservoir on the Peace River in British Columbia between 1968 and 1971. Some weirs were subsequently constructed in the Delta at the joint expense of federal and provincial governments in order to sustain adequate levels. It is known that the periodic flooding required to maintain wetland health is often due to ice jams in winter and spring months.

It has been found that, in general, warmer winters lower river levels for short durations, as water flows into the Delta. However, the effects of lowering water levels on the Delta itself, are much longer lasting, extending into summer. Milder winters, more frequent in the warming climate, could reduce the ice cover season by 28 days with lowered Delta levels by almost 10cm. (Leconte, et al. 2006) *Note: other estimates give declines of up to 29cm – section 3.5.*

While ice jams of significance occur in the lower Athabasca which, when released, can contribute to valuable temporary flooding of the Delta, it is the jams on the lower reaches of the Peace River which are mainly responsible for flooding of the PAD (Prowse, et al, 1996). Operation of the Bennett Dam by B.C. Hydro in a manner that would stimulate formation of ice jams on the lower Peace were recommended by National Water Research Institute, Environment Canada, and were successfully undertaken in 1996. The influence of climate change on ice jam formation and release is a complex issue but has been studied. (Beltaos & Prowse, 2001). Warmer winters, in general, as well as lowered flows due to effects of withdrawals, and climate change on the Athabasca River, will contribute to lower water levels and adverse impacts in the biologically productive PAD.

5.3 Water Quality Concerns

Little data are readily available on downstream water quality impacts of the oil sands projects and most of the waste water from the projects is stored in huge ponds on site or recycled rather than discharged to the river. Concerns focus on fish contamination, since they are a main dietary source for First Nations and Métis communities downstream.

Mobilization of naturally occurring arsenic can occur in nearby wells from **in situ** steam projects of the Cyclic Steam Stimulations (CSS) type, and aquifers can be contaminated due to leaks from casing failures. Waste water disposal in deep saline aquifers, below the bitumen level, has caused limited concern since it is usually done with impermeable layers above and below. However, a geophysicist from University of Alberta points out that "We haven't measured how water migrates from one area to another…….There is no such thing as an impermeable layer." (E. Nyland, Edmonton Journal, Oct. 17, 1999)

For mining operations, dewatering of basal aquifers is at times necessary to prevent flooding of the mining areas. For example, the Canadian Natural Resource's Horizon mine may reduce discharge of groundwater into the Athabasca River by up to 30,000m^3/day according to the company's environmental impact statement. The effects of this type of groundwater disruption on water quality are not well understood.

However, the major water quality concerns relate to the tailing ponds where waste waters are stored, and their long term management. These are said to be among the largest structures on the planet made by humans, and in 2004 already covered over 50 km^2 of landscape. While the companies are vigilant in their monitoring of these highly contaminated lakes, the threat of seepage into groundwater and soils, and the threat of breaches of containment hang over the area. This is a special concern in the long term, after the mining operations have ended.

Methane, a powerful greenhouse gas, produced by methangenic bacteria is emitted from the tailing ponds. Napthenic acids and other substances that are found in the residual bitumen in the tailing ponds are persistent in the environment, are toxic to fish and birds and cause fish tainting. Measurements to date of such acids indicate below 1 mg/l concentrations in the river but up to 110 mg/l in tailing pond waters, which have been found to be acutely toxic to aquatic organisms and mammals. Hundreds of forms of these acids are found in the bitumen being removed and processed. (Griffiths, et al., 2006)

The growth of NO_x and SO_2 emissions from oil sands projects is increasing acid deposition in water bodies in the region, especially those downwind in the prevailing wind directions (W, NW). Increased release of mercury is also a concern, expressed by the Mikesew Cree First Nations because of their dependence on fish. This could arise from the stripping of wetlands and small watersheds in mining the bitumen. Some of these areas contain high mercury levels naturally, and this can be mobilized into the river by the projects. Whole small watersheds, or a large part of them, tributary to the Athabasca (e.g. Muskeg River) are being re-routed or essentially obliterated by the large scale surface mining activities. The impacts of these changes on the hydrologic system and water quality in the Athabasca River are not well understood. (Griffiths, et al., 2006) In addition to impacts on lower Athabasca River from oil sands projects, increased biological oxygen demand and other contaminants from pulp and paper mills are a concern.

5.4 Effects in Downstream Jurisdictions

The Athabasca is a tributary of the much larger Mackenzie River System which flows northward through the Northwest Territories to the Arctic Sea. As noted earlier, with climate change, declining flows on average in the most southerly tributary, the Athabasca, are more than offset by increasing annual discharge from the more northerly Liard which rises in the Yukon. (Fig. 2) This latter basin has received substantially more precipitation in the past three to four decades and this is projected to continue with greenhouse forcing, although summer flows have been declining. In the Peace River from 1972 to 1999, winter and spring flows have been increasing (D.J.F.M.A.) but summer and autumn flows declining. (Woo and Thorne, 2003)

The net effect of these changes on the main stem of the Mackenzie River as indicated in the changing climate from 1972 to 1999, has been lowering of discharge over summer and fall, significant at the 10% level in November, but increasing flows from December to May. (Woo and Thorne, 2003) The variability from year to year of monthly flows has increased significantly in the Mackenzie in spring (A.M.J.) and in December. On the Athabasca, this increased variability from year to year is evident in March, May, August and September. (Woo and Thorne, 2003) Increased variability in future flows has also been projected with continuing climate change, in other modeling work (Pietroniro et al., 2006).

Of major concern, with lower summer flows on the Mackenzie, is navigation by barges for re-supply of northern communities in summer. The climatic trends, of lower summer flows and greater variability, exacerbated to a small extent by water withdrawals from the Athabasca, can jeopardize this vital low cost transportation of essential goods. In addition, with lower flows, pollution concentrations from all sources increase.

Alberta is an active supporter of the Prairie Provinces water sharing agreement, overseen by the Prairie Provinces Water Board, to provide for passing of agreed amounts of water of a high quality to Saskatchewan and thence Manitoba on the eastward flowing Saskatchewan River system. While the Mackenzie River Basin Transboundary Water Agreement aims at “equitable utilization” of waters of the Basin, there is, as yet, no binding agreement or regulatory provision as on the Saskatchewan River. Such a binding agreement has not been signed by British Columbia and Alberta with the Northwest Territories or Saskatchewan on sharing the waters of the Mackenzie River system. Saskatchewan borders on Lake Athabasca affected by Athabasca and Peace River flows. In view of increasing withdrawals of water in Alberta, combined with the effects of climate change, a firm agreement between the provincial and territorial governments is urgent. This agreement should reflect commitments on water sharing and protecting water quality.

5. Conclusion and Recommendations

Conclusion:

The projected rate of water use from the Athabasca River, in the Oil Sands projects, is unsustainable. This is in spite of efforts to date of some operators to conserve and recycle water. Estimates of water requirements for all projects as presently planned and projected exceed Alberta’s “Interim Framework” target for protection of aquatic ecosystems downstream in the Athabasca River in recent winter low flow periods. The annual flow and winter low flows on the Athabasca River, the main source of water supply, have been decreasing with climate change in the period from 1970 to 2004. This decline is expected to continue with still growing global emissions of greenhouse gases, including those from the Oil Sands Projects themselves, and continuing changes in climate.

Recommendations:

1. Climate change and water withdrawals need to be taken into account in an agreement between the three provinces and two territories. (B.C., Alta, Sask., NWT and Yukon) concerning sharing of the waters of the Mackenzie River system and protection of water quality.

2. The Government of Alberta should consider withholding approval of any oil sands projects and related water taking licenses until:
   i) substantial water conservation measures are implemented in the projects, and
   ii) assurances can be made that Instream Flow Needs to protect ecosystems in the lower Athabasca can be met in the face of the changing climate.

3. Research and practices should be accelerated by the oil producing companies to reduce water demands through recycling, re-use and alternative processes in existing projects. (See recommendations of Woynillowicz and Severson-Baker, 2006)

4. Since oil sands projects are likely to be among those adversely affected by climate change, in their own interests, the companies should redouble efforts to improve technology to reduce greenhouse gas emissions from the full range of their operations and for both carbon dioxide and methane.

5. Measures to reduce pollution and direct environmental damages from the projects themselves as suggested by Pembina Institute (Griffiths, et al., 2006) should be actively pursued.

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