UNIVERSITY OF CALGARY

and

UNIVERSIDAD de SAN FRANCISCO de QUITO

Oil Sands and Water

by

Sheri Bownes

Supervisor: Ródny Peñafiel

A Masters Degree Project submitted to the Faculty of Graduate Studies in Partial Fulfilment of the Requirements for the Degree of

Master of Science in Sustainable Energy Development

Faculty of Graduate Studies

Calgary, Alberta, Canada

January, 2010

CERTIFICATE OF COMPLETION OF INDIVIDUAL PROJECT

FOR THE UNIVERSITY OF CALGARY

and

UNIVERSIDAD de SAN FRANCISCO de QUITO

MASTER OF SCIENCE DEGREE IN SUSTAINABLE ENERGY DEVELOPMENT

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, the Individual Project Report entitled "Oil Sands and Water" submitted by Sheri Bownes in partial fulfillment of the requirement for the degree of Master of Science in Sustainable Energy Development.

Ródny [signature] 23/04/2010

Supervisor: Ródny Peñafiel Date

ABSTRACT

The oil sands of Northern Alberta contain extensive reservoirs of bitumen. This resource is very important for enhancement of domestic and international energy supplies as well for positive impacts to Canada's economy. However, development of the oil sands is very controversial because of many issues, both social and environmental. In order to operate the oil sands industry in Northern Alberta must comply with government regulatory standards which are in place to address environmental impacts and public concern. Nevertheless, the pace of development and stringency of regulations may not be sufficient to consider long term and cumulative impacts to both available water quantity and quality. Technologies such as centrifuges, coagulants, in situ combustion, and steam/solvent in situ recovery, are in development which will reduce quantity of water use and impacts to water quality from oil sands development. It is the role and responsibility of government to ensure regulations are in place which allow this resource to be developed in a manner which ensures long term sustainability.

ACKNOWLEDGEMENTS

I would like to thank Dr. Ródny Peñafiel for the guidance and counsel he provided during my work on this project. I am also grateful to the recapitulation panel, including Dr. Peñafiel, Dr. Bill Ross, Dr. Julie Rowney, Dr. Ximena Córdova and Dr. David Lansdale for their words of encouragement and approval. I would like to acknowledge our Program Administrator Andrea Horra for her valuable support and encouragement. I could not have completed this work without her assistance, patience and enthusiasm. I would also like to thank all of my classmates in this Master's Program, I truly enjoyed our collaboration and friendship.

TABLE OF CONTENTS

LIST OF FIGURES

1 CHAPTER ONE: OIL SANDS DEVELOPMENT

1.1. Relevance in the Energy Sector

Oil sands are located in the northern portion of Alberta, Canada. They underlie roughly 140,000 square kilometres, an area around the size of Florida or approximately 20% of Alberta (Government of Alberta, 2008). Alberta's development of the oil sands is a controversial topic that has gained a global audience. Besides the benefits of increasing available oil for energy production, development of the oil sands provide employment and economic benefits to the province and to Canada. However, negative environmental impacts include water usage, land disturbance and air emissions. Heinrich calls production in the oil sands "the biggest oil boom in North American history" (Heinrich, 2008). Government and industry face the challenge of proving that economic development and environmental protection are not mutually exclusive.

1.1.1. Energy Demand

Energy requirements around the world are continually growing. The total world demand for energy is projected to increase by 44% from 2006 to 2030 (EIA, 2009). Although renewable energy projects are important and are increasingly being utilized, this source supplied only about 7% of the world's energy consumption in 2004 (EIA, 2009). By 2035, global oil demand is projected to increase between 13% and 33%, from 85 million barrels per day (mb/d) to between 97 mb/d and 113 mb/d (CERA, 2009). A significant portion of this demand is expected to be supplied by the oil sands.

In Canada, the largest sources of energy consumption are oil and hydroelectricity, making up 32 and 25% respectively (EIA, 2006). Natural gas, coal, and nuclear energy provide 41% and other renewables supply only 1% (EIA, 2006). Canada is the sixth largest user of primary energy in the world (EIA, 2005). This is due to a combination of an energy intensive industrial base, long travel distances, cold climates and high standard of living.

1.1.2. Energy Supply

According to the Organization of the Petroleum Exporting Countries (OPEC), in 2007 the world's proven crude oil reserves were 1.2 trillion barrels, 78% of which are supplied by OPEC (Fig.1). In Canada, proven oil reserves total 1.5 billion barrels from conventional sources and 172.7 billion barrels, or 99.1% of the total, from the oil sands (Figure) (Government of Alberta, 2007). This amount is eight times the proven oil reserves in the whole of the U.S. (Kunzig, 2009). The oil sands represent one of the few remaining reliable, long term deposits available (Government of Alberta, 2008). In the two largest known sources of oil sands bitumen, located in Alberta and in Venezuela, there is more petroleum than the entire proven conventional oil reserves of the Persian Gulf (JuneWarren-Nickle's Energy Group, 2009). At current utilization rates the oil sands would be sufficient to satisfy total Canadian domestic demand for crude oil for approximately 250 years (National Energy Board, 2008).

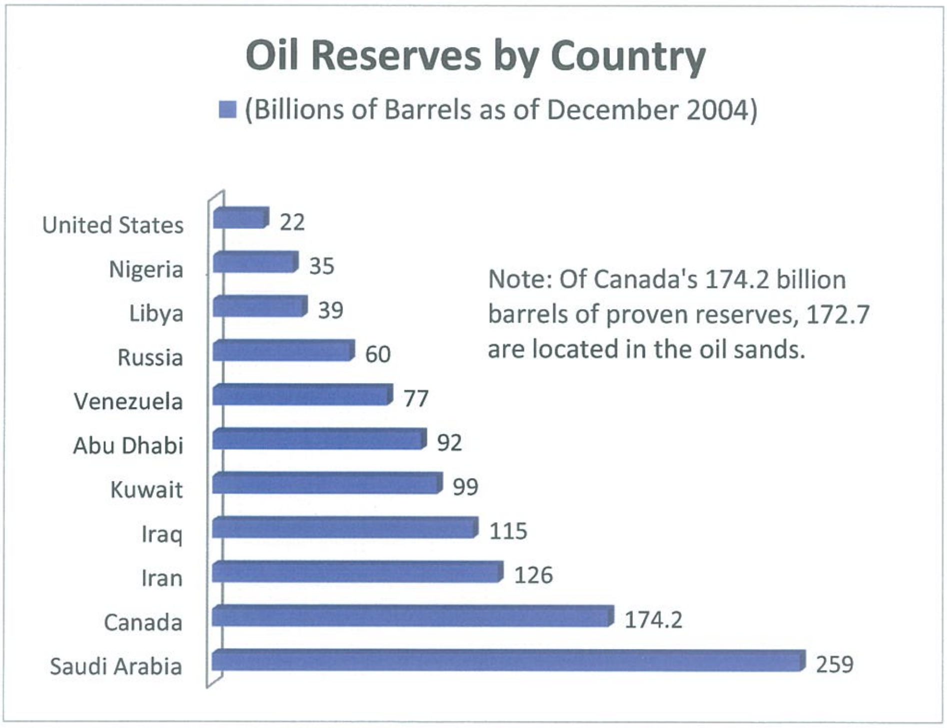


Figure 1.1: World proven oil reserves (Government of Alberta, 2007) and (OPEC, 2007)

The crude bitumen of the oil sands is not produced by ordinary oil extraction methods. Oil sands bitumen is commercially used for the production of synthetic crude oil, which is then further refined to different end products (Chalaturnyk, Scott, & Ozum, 2002). Compared to conventional oil, synthetic crude from bitumen is expensive and complicated to produce (JuneWarren-Nickle's Energy Group, 2009). However as oil prices raise and energy supplies diminish reservoirs like the oil sands, previously found too difficult or expensive to extract, are being increasingly utilized. In the past thirty years, oil sands have gone from 2% to 30% of Canada's total annual oil production (Deutsch and McLennan, 2005). According to Heinrich, the oil sands mega-projects in Alberta rival the pyramids of Giza and the Great Wall of China as a feat of engineering achievement (Heinrich, 2008). Present oil production from the oil sands is over 1 million barrels a day with future growth estimated at 3 million by 2020 and 5 million by 2030 (Paes and Throckmorton, 2008). Operators in Alberta already producing from mines include Suncor, Syncrude, Albian Sands, and Canadian Natural Resources (ERCB, 2009). Petro-Canada, Shell and Imperial Oil are also currently developing mining projects (ERCB, 2009).

"Oil is a limited, non-renewable resource, and oil peak is inevitable" (Zhao, Feng, & Hall, 2009). Peak oil was first discussed by geologist M. King Hubbert in 1956. This theory proposes that oil production will reach a peak when half of the extractable reserves have been used, then decrease until the rate of production was no longer economically viable (Zhao, Feng, & Hall, 2009). It is predicted that global conventional oil production will peak between 2020 or 2030, with decreases in production of around 3% expected after this point (Bentley, 2002). There are concerns that nonconventional sources, like the oil sands, may not increase production quick enough to compensate for the decline in conventional oil production, causing a sustained global oil shortage (Bentley, 2002). As production of conventional oil falls, hydrocarbon shortages will occur unless there are drastic changes in demand, or supply of nonconventional oil drastically increases (Bentley, 2002). Research into the role of nonconventional oil as a substitute indicate that substantial increases in nonconventional oil production will be necessary in order to maintain the growth of the global economy (de Castro, Miguel, & Mediavilla, 2009).

1.2. Structure of the Oil Sands

Oil sands development is more water intensive and disturbs a greater land surface than conventional oil production (CERA, 2009) (Dyer, 2006). This is mainly because of the structure and location of the oil sands. However, recovery rates from this resource are higher than from conventional sources of oil, as seen in Figure 1.2 (Canadian Center for Energy Information, 2009).

Production type	Recovery rate
Conventional light oil	30% on average
Conventional heavy oil	Up to 20%
In situ oil sands	25-50%
Oil sands mining	82+%

Figure 1.2: Recovery rates for various types of production (Canadian Center for Energy Information, 2009)

The structure of the oil sands causes difficulties in extraction. Whereas conventional crude oil flows naturally or is pumped from the ground but the Alberta oil sands contain deposits of bitumen that do not flow at room temperature. They must be mined or recovered in situ (in place). In the oil sands, the sand particles are coated with a layer of water that is then coated with a layer of bitumen. Therefore, the oil sands must be heated in order to separate bitumen from the sand particles (JuneWarren-Nickle's Energy Group, 2009).

Bitumen is the heaviest, thickest form of petroleum (JuneWarren-Nickle's Energy Group, 2009). At room temperature the consistency of bitumen is similar to molasses. Bitumen viscosity is a function of temperature, therefore in order to transport it, it must be heated or diluted with lighter hydrocarbons so that it will flow (Government of Alberta, 2009). For these reasons oil sands bitumen cannot be produced using conventional oil wells, they must be recovered using in situ or surface mining techniques.

There are oil sands in three areas of Alberta – the Athabasca, Peace River, and Cold Lake regions (Figure 1.3). These deposits are located under an overburden of muskeg, glacial till and Cretaceous bedrock (Chalaturnyk, Scott, & Ozum, 2002).

Figure 1.3: Location of oil sands deposits in Alberta, Canada, reproduced with permission (Alberta Geological Survey, 2009)

About 10% of the oil sands reserves are located near the surface; the remaining reserves are at a depth greater than 75m (Sparks, Kotlyar, O'Carroll, & Chung, 2003). Surface mining can be used to recover those reserves near the surface; the rest must be extracted using in situ techniques. Both of these methods have considerable impacts. Surface mining disturbs large areas of land and uses large quantities of water to separate the bitumen from the sand; in situ techniques use large amounts of water for steam creation to heat the reservoir.

1.3. Economics of Oil Sands Development

As of June 2009, of all major projects in Alberta that have been recently completed, are currently under construction, or are proposed to start construction within two years, 57% (in terms of dollars) are oil sands projects(Government of Alberta, 2009). Oil sands development is obviously very important to the province of Alberta.

The oil sands are the world's largest energy project (Nikiforuk, 2008). Nothing in any sector matches it for capital investment. Total proposed investment in oil sands related projects is more than $60 billion (Canadian dollars) with around $20 billion invested in completed projects already (National Energy Board, 2008). The current economic crisis may have put many oil sands expansion projects on hold but it has not changed the long-term prospects of the oil sands (Mergent, 2008).

The oil sands sector is important to the economic prosperity of Alberta but also to other provinces and to Canada as a whole, as seen in Figure 1.4 (CAPP, 2008). The oil sands are expected to contribute around $789 billion to Canada's GDP between 2000 and 2020. This is an increase from 2000, when oil sands contributed around 1.5% of the domestic GDP to 3% in 2020 (CERI, 2009). This is an estimated annual contribution of between $16 and $40 billion.

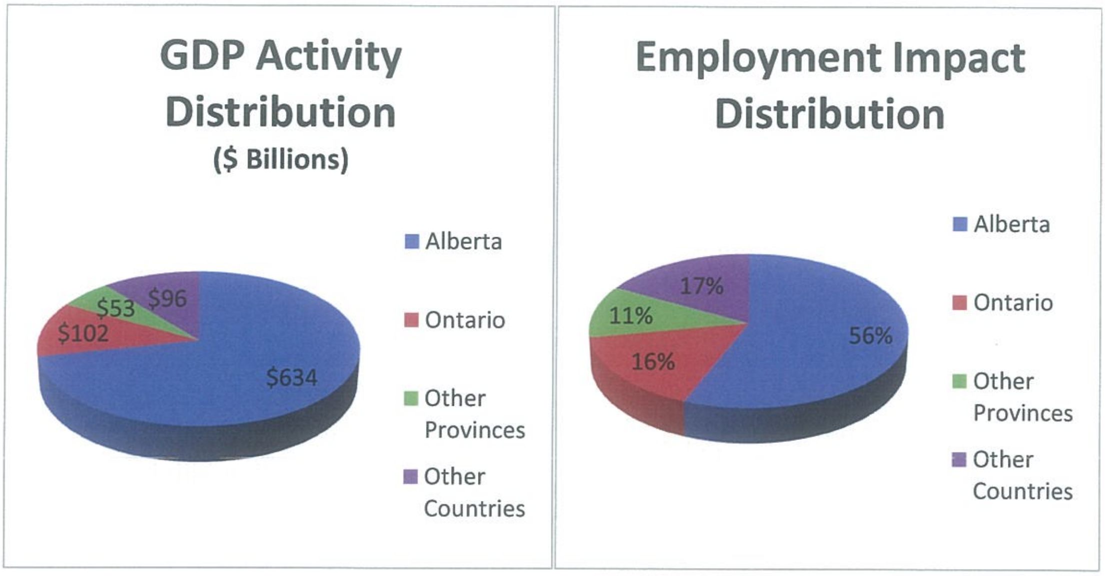


Figure 1.4: Benefits distribution according to GDP and employment provided in Alberta and other areas by oil sands development (CAPP, 2008)

The development of the oil sands generates government income in the form of income tax, royalties, corporate tax, provincial sales tax, Goods and Services tax, and property tax. A large proportion (41%) of the government revenue goes to the Federal Government of Canada, 36% goes to the Government of Alberta, and 23% is shared by other governments and municipalities (CAPP, 2008).

The benefits of oil sand development are substantial in terms of income, employment, and energy provision. Oil sands projects are predicted to comprise 17% of Alberta's GDP and 2.7% of Canada's GDP in 2010 (CERI, 2009). Oil sands related jobs are predicted to account for 9% of total employment in Alberta in 2010 (CERI, 2009).

1.4. Oil Sands Development and Water Use

Many forms of energy production depend on the availability of water (Hoffman, 2004). Water plays an important role in the production of fossil fuels such as oil sands bitumen (Lowell, 2006). Water is used in the extraction, separation, transportation, and heating of oil sands bitumen, as well as in the potable water and sewage systems of oil sands operations.

The oil sands industry accounts for about 5% of the total water allocated in the province of Alberta (CAPP, 2009). Conventional oil and gas, which still supplies nearly 70% of Alberta's oil production (Deutsch & McLennan, 2005), accounts for only 2% of Alberta's water allocations (CAPP, 2009).

Recovery of bitumen from oil sands is generally done in one of two different methods, surface mining or in situ extraction. In oil sands mining, oil sands near the surface are dug out, mixed with water, and the bitumen is recovered from a froth. In situ extraction is the method used for deposits too deep to mine. These deposits are only economical to produce if recovered while still underground (in place). Currently, about 60%, or 485 million barrels, of Alberta's total bitumen production is extracted by open pit mining, the rest of Alberta's production is by in situ methods (ERCB, 2009). As of January 2009, there were 91 active oil sands projects in Alberta. Of these, five are mining projects; the remaining projects are types of various in-situ projects (Government of Alberta, 2009). Nearly 82% of the remaining oil sands reserves are only accessible using in situ methods (ERCB, 2009).

The volume of water required for oil sands extraction depends on a variety of factors including operating conditions, ore grade, and recycle rate. It also varies over time. Although much of the water is recycled (75% in mining, 95% for in situ), the massive scale of oil sands development results in large amounts of water usage. Large increases in the demand for water for oil sands extraction and processing can be expected. Water can be lost in the treatment process as a waste stream (deep well disposal), as well as in the formation (water capture in void spaces) (Lowell, 2006). Surface mining uses between 3 and 4 cubic meters of water per cubic meter of oil produced. In situ processes use less than 1 cubic meter of water per cubic meter of oil produced (Lowell, 2006). Makeup water usually comes from surface waters or groundwater reservoirs.

The biggest freshwater challenge from the oil sands will be from the growth of mining operations because of their lower recycle rates (Sturgess, 2008). However, only 12% of the total oil sands reserves are accessible through mining techniques, the rest will be extracted using in situ methods (ERCB, 2009). Over the long-term, water demand for in situ extraction will be "as great or greater" than that for oil sands mining (CERA, 2009). Whereas mining uses primarily freshwater withdrawals, in situ operations use mainly groundwater (CAPP, 2009). Deep saline aquifers are expected to supply about 40% of the water required for in situ operations over the next 20 years (CERA, 2009).

During the past years industry and government have recognized that the intensive water requirements of oil sands extraction, combined with expected climate change impacts, may threaten Alberta's water security (Davidson & Hurley, 2007). The Athabasca River is the third largest river in Alberta and is located near to the oil sands development. Oil sand operations are the largest users of water from this river making up almost 65% of the water withdrawals (Woynillowicz & Severson-Baker, 2006). There are concerns that the Athabasca River may not have sufficient flows to meet the needs of planned mining operations while maintaining adequate stream flows for ecological system functioning (Davidson & Hurley, 2007).

Many parts of the world are already facing severe water shortages (Hoffman, 2004). The Intergovernmental Panel on Climate Change (IPCC) also predicts that by the 2050s, the area of land subject to increasing water stress due to climate change is projected to be more than double that of areas with decreasing water stress (IPCC, 2008). Population growth and economic development are causing increases in water demands (Hoffman, 2004). Water security is a growing threat in the 21st century and has implications for energy supply (Hoffman, 2004).

In the development of the oil sands there is an important opportunity to pursue sustainable water management. Increasing water demands and changing water quality and quantity are predicted. Policy makers and managers must place proper emphasis on the maintenance of a safe, secure drinking water supply, healthy aquatic ecosystems, and reliable water supplies for a sustainable economy. Important decisions about water use must consider the long term implications of current actions.

1.5. Emphasis of this Report

Although there are many important issues surrounding the oil sands development, this report will focus on the magnitude of water usage by oil sands projects in Alberta, what is being done and what can further be done to reduce water use and the impacts that may be seen by this usage.

As discussed in this chapter the rationale and assumptions on which this study is based include the idea that the oil sands play a growing role in the energy market as conventional oil supplies diminish and the fact that the economic benefits of oil sands development are essential to Alberta and Canada's economy.

Water is a scarce resource requiring wise use. The scale of use by industry and the continued dramatic growth in industrial development make conserving and increasing efficiency of water usage a necessity for these operations. The growing threat of a global freshwater crisis will be discussed in chapter two.

Oil sands bitumen is recovered differently than conventional oil. An overview of oil sands surface mining and the hot water extraction process, as well as the various in situ recovery techniques is covered in chapter three.

Best practices will be outlined in terms of recycle rates and water usage reduction for oil bitumen extraction by both mining and in situ methods. New and innovative technologies for oil sands production which are in use or currently undergoing testing are examined in chapter four.

Over the long term it is expected that technological developments will improve the environmental impacts of oil sands extraction (Miller, 2007). In the meantime, water management must determine ways to accommodate proposed developments in the region while maintaining viability of important waterways. Oil sands development is regulated by the Energy Resources Conservation Board (ERCB), the Alberta Department of the Environment (AENV) and other agencies. The Alberta Water Act was created to address water management and conservation issues. Regulations regarding groundwater extraction (saline and non-saline) as well as river withdrawals, tailings production and wetlands usage will be considered in chapter five.

The protection of water resources is important for human uses and for ecological integrity as well. Adequate river flows are essential to meet the needs of fish and other aquatic biota. The impacts of diversion of water for use by the oil industry may be extensive. Reductions in even the seasonal flow of rivers can have serious impacts downstream. Flows affect water levels in wetlands, lakes and ponds and have significant consequences for water quality (DFO, 2009). Groundwater is also very important as drawdown may impact wetlands or water tables in areas where aquifers are actively recharged from the surface. Wetlands can contain rare plants and animals, these unique ecosystems need protecting. The importance of minimizing water use as demonstrated by potential environmental impacts and loss of ecosystem services is discussed in chapter six.

Sustainable development of the oil sands is the key to finding a balance between the economic benefits of oil sand development and the environmental impacts of that development.

2 CHAPTER TWO: WATER RESOURCES

Global water shortages are a real and serious possibility. "The freshwater crisis is easily as great a threat to the Earth and humans as climate change (to which it is deeply linked) but has very little attention paid to it in comparison" (Barlow, 2007). The economic and ecological systems that human lives rely on are driven by clean and predictable water supplies (Natural Resources Canada, 2007).

"Water is needed in all aspects of life" (UN Department of Economic and Social Affairs - Division for Sustainable Development, 1992). An objective of the Earth Summit in Rio De Janiero was to ensure adequate water quantity and quality for the global population and to maintain ecosystems (UN Department of Economic and Social Affairs - Division for Sustainable Development, 1992). The sustainable use of the world's water resources is an important and urgent issue (Natural Resources Canada, 2007). Economic and social development will be jeopardized by scarcity of clean water supplies (Natural Resources Canada, 2007).

2.1. Water Quantity

2.1.1. Canada's Water Resources

Canada is commonly perceived as particularly fortunate in having plentiful freshwater resources- a common statistic is that Canada has 1/5th of the world's freshwater supply (Environment Canada, 2004). However when considering renewable freshwater, Canada has 7%, a proportional amount since it also has 7% of the earth's land surface (Environment Canada, 2004). The rest of Canada's freshwater is "fossil water", trapped in ice, snow and glaciers (Environment Canada, 2008).

Canadian people and industries are among the world's highest users of water (Environment Canada, 2004). Per capita Canada is second only to Americans in water usage and more than double the average European rate (Environment Canada, 2004). The measureable contribution of water to the Canadian economy ranges from $7.5 to $23 billion CAD annually (Environment Canada, 2004). "Water scarcity issues can have serious implications for Canada's environment, economy and society" (CWRA, 2008).

Significant threats to water quantity and quality exist throughout Canada (CWRA, 2008). Municipalities are already reporting water shortages caused by increased consumption, drought or infrastructure problems, most commonly in areas which rely on groundwater (Environment Canada, 2004). Twenty percent of Canadian municipalities have faced shortages in recent years (Council of Canadians, 2006).

2.1.2. Alberta's Water Resources

Alberta has about 10% percent of Canada's population and 7% of its land area, but only about 2% of Canada's fresh water resources (AB Government, 2005). Alberta, along with Saskatchewan and Manitoba, make up the Prairies, which are "Canada's major dryland" (Environment Canada, 2004).

The Athabasca River is the third largest river in Alberta and the third longest undammed river in North America (Davidson & Hurley, 2007). The Athabasca's waters flow north from the Rocky Mountains through the oil sands region in northern Alberta and into the Peace-Athabasca Delta. This delta is one of the world's largest freshwater deltas and the largest boreal delta (Davidson & Hurley, 2007). The waters then flow through the Slave and Mackenzie Rivers until they reach the Arctic Ocean.

Northern Alberta and the Athabasca sub-basin are part of the huge Mackenzie River Basin. It is made up of bogs, fens, swamps, and marshes and has a total area of 166,000 km^2 (Keddy, et al., 2009). The Mackenzie River Basin is the 5th largest wetland in the world (Keddy, et al., 2009).

Oil sand operations are the largest users of water from the Athabasca River with almost 65% of the water withdrawals (Figure 2.1). In 2007, the oil sands industry withdrew around 5 million m^3/s (160 million m^3/y) from the Athabasca River (CAPP, 2009). Around

10% of the water taken from the Athabasca River for mining is returned to the river; the rest is used and diverted to tailings ponds (Jede, 2007).

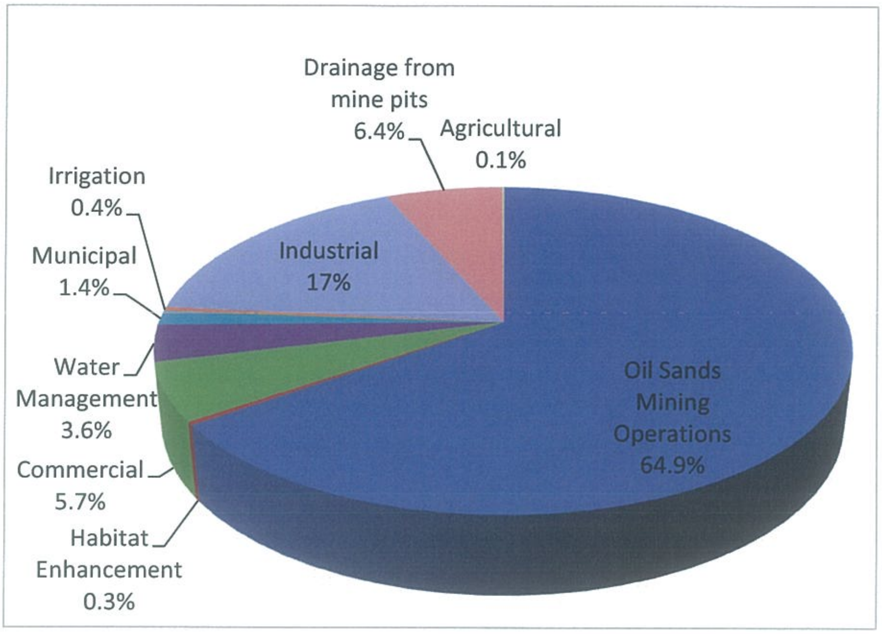


Figure 2.1: Athabasca River water use (Woynillowicz & Severson-Baker, 2006)

2.1.3. Climate Change and Water Resources

To consider only direct usage impacts on water supply would not be an accurate forecast of water supply in the future. Quantity of water available may also be affected by climate change.

"Canada's climate is changing, and projections show that it will continue to change in the future" (Natural Resources Canada, 2007). Changes in temperature and precipitation extremes, as well as sea level, sea ice, and other climate related measures have been projected and observed (Natural Resources Canada, 2007). Changes will affect social and economic factors (Natural Resources Canada, 2007).

Most climate change models project the largest increases in mean annual temperature in the high latitudes of the Northern Hemisphere (Houghton, et al., 2001) and temperature records already show increasing trends in these regions (Natural Resources Canada, 2007).

The resultant longer growing season may be beneficial however there will also be greater water losses to evapotranspiration which is not offset by equally increased precipitation (Schindler & Donahue, 2006). This will serve to even further decrease water supply in these areas.

"Seasonal water deficits occur in all regions of Canada, but only in the Prairies can precipitation cease for more than a month, surface waters disappear for entire seasons, and water deficits persist for a decade or more, putting landscapes at risk for desertification" (Natural Resources Canada, 2007). The Prairies already suffer from periodic drought, with the higher temperatures expected from climate change, these droughts are expected to become more frequent (Environment Canada, 2004).

Changing climate is reflected in the components of the hydrologic cycle such as temperature, evapotranspiration, rain intensity, precipitation, and snow and ice amounts (Natural Resources Canada, 2007). Climate change is affecting water resources in Alberta (Holroyd & Simieritsch, 2009). It is changing annual and seasonal flows of rivers and levels and water quality of lake and rivers, as well as freeze-up and break-up dates (Davidson & Hurley, 2007).

Glacial retreat during the last century has caused declines in summer and fall runoff amounts, resulting in impacts during the lowest flow and highest demand periods of a river (Natural Resources Canada, 2007). Most major rivers in the Prairie Provinces originate in the Rocky Mountains, where deep snowpacks and melting glaciers are a major source for river and groundwater supply (Schindler & Donahue, 2006). Average low flows in the Athabasca River have declined over the last 30 years, summer flows have declined by 29% from 1970 to 2005 and lowest winter flows also show a downward long-term trend (Davidson & Hurley, 2007). Prairie lakes also show a downward trend from historical water levels over the last 50 years (van der Kamp & Goudriaan, 2005).

Climate change affects on groundwater may be less apparent than those on surface waters. Groundwater resources may decrease in some areas but may increase in other areas (Natural Resources Canada, 2007). Wetlands need a water supply which supports saturated soils for at least part of the year. Wetlands in the oil sands region are at or near a water deficit most years; the water supply needed for saturated soils may not be possible considering future water trends (Alberta Environment, 2008).

2.2. Water Quality Issues

In general, threats to water quality in Canada include increasing urban expansion and its impact on storage and runoff patterns; dams; forestry operations and forest fires; the oil and gas industry, particularly oil sands; and new chemicals of concern (Environment Canada, 2004).

Threats to water quality associated with oils sands production operations include wastewaters from sewage; site drainage water; tailings release water; potential contaminant seepage from unstable tailings long-term storage; and deep disposal of high mineral-content blowdown and potential leakage of leachate from landfills where concentrated brine waste is disposed of (Griffiths, Taylor, & Woynillowicz, 2006) (Peachey, 2005).

In oil sands mining, large amounts of overburden (rocks and soil) are moved to expose the oil sands below. When overburden is exposed to precipitation and atmospheric oxygen, chemical changes can occur and contaminant compounds can be released (Veil & Puder, 2006). Water leaching from the site can impact groundwater quality and storm water runoff from the site can impact surface waters (Veil & Puder, 2006).

In oil sands deposits which must be extracted through in situ methods the formations are likely to come in contact with solvents that may eventually leach to the groundwater in the surrounding area (Veil & Puder, 2006).

Over pumping of groundwater sources can result in adverse affects to water quality and supply (Natural Resources Canada, 2007). Lowered water tables in freshwater aquifers can cause movement of surrounding non-freshwater into these areas and lead to increased salinization of water wells (Natural Resources Canada, 2007).

2.2.1. Contaminants of Concern

In the oil sands industry the contaminants of concern include polycyclic aromatic hydrocarbons (PAHs), naphthenic acids, trace metals such as arsenic and mercury; and salinity (Timoney, 2007).

PAHs are organic ring compounds that can be formed during combustion or by microbial degradation. Some PAHs are expected human carcinogens and studies using laboratory animals have demonstrated PAH exposure can cause reproductive difficulties; birth defects and low birth weights; harmful effects on skin, body fluids and the immune system (ATSDR, 2007).

Naphthenic acids are naturally occurring constituents of bitumen. They are soluble and concentrate in tailings ponds. Naphthenic acids have been demonstrated to have adverse health effects in mammals after chronic exposure (Rogers, Wickstrom, Liber, & MacKinnon, 2002).

Arsenic is naturally occurring in the earth's crust. It is carcinogenic to humans and can cause many other health problems including kidney damage, decreased blood cell production; blood vessel damage; and abnormal heart rhythm (Timoney, 2007).

When wetlands containing naturally high levels of mercury are stripped or flooded, mercury can be released into the surrounding waters (Griffiths, Taylor, & Woynillowicz, 2006). High levels of mercury can cause loss of balance and coordination, and leg paralysis in mammals (Timoney, 2007). Serious neurological disorders are associated with human exposure to mercury (Timoney, 2007).

The rapid pace of growth in oil sands operations leaves very little time to anticipate and prepare for potential impacts of increasing surface water and groundwater uses (Davidson & Hurley, 2007). The combined impacts of climate change and water use by oil sands and other industry on water supplies could damage the ecological health of these areas (Holroyd & Simieritsch, 2009). Agriculture, forestry, transportation, communities, human health, energy, tourism, and recreation all have the potential to be adversely impacted by the projected water shortages (Natural Resources Canada, 2007).

3 CHAPTER THREE: OIL SANDS BITUMEN RECOVERY

The properties of oil sands bitumen necessitates the use of special extraction procedures compared to conventional oil production techniques. Water is an essential resource for the production of oil sands bitumen. Water is used to separate the bitumen from the sand, as a transportation medium, for operation of utilities, for void replacement in reservoirs, and in bitumen upgrading.

The primary source of water used in Alberta oil sands mining operations is the Athabasca River (CAPP, 2009). The Athabasca River is the third largest in Alberta and is located near to the oil sands deposits. Other important sources of water for oil sands mining are precipitation captured from the mine area and groundwater that must be pumped out of the surrounding area to prevent mines from filling with water (mine dewatering) (CAPP, 2009).

3.1. Composition of Oil Sands

The oil sands in Alberta are comprised of about 10-12% bitumen, 80-85% mineral matter (sand and clay) and 4-6% water (Rach, 2004). Although unproven, it is speculated that a thin film of water exists between the silica sand grains and the bitumen, as seen in Figure 3.1 (Czarnecki, Radoev, Schramm, & Slavchev, 2005). The oil sands must be specifically treated to separate the bitumen from the sand.

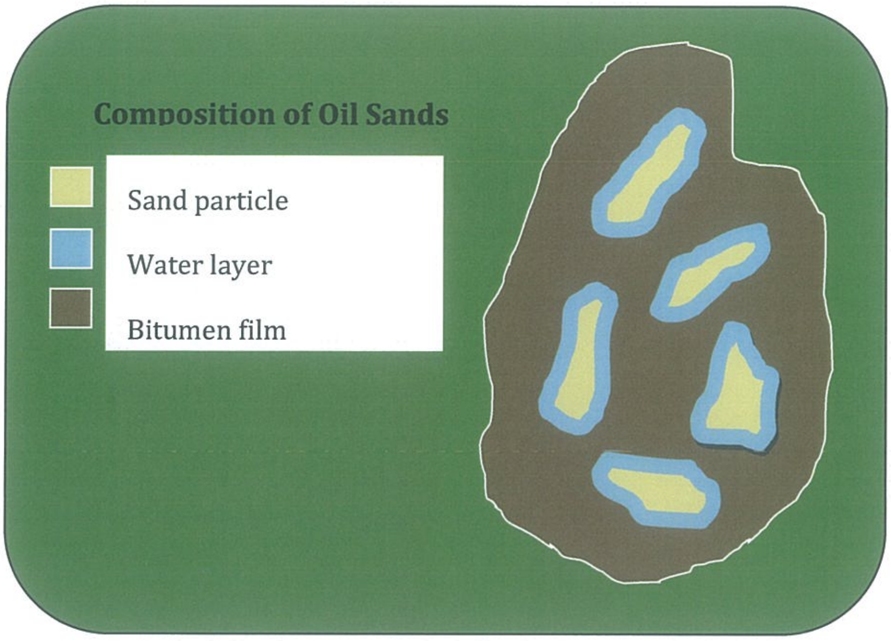


Figure 3.1: Composition of the oil sands (Canadian Center for Energy Information, 2009)

Bitumen recovery from oil sands deposits is done in one of two general methods, surface mining and the hot water extraction process (HWEP) to separate the bitumen from the sand or in situ methods which use steam to separate the bitumen from the sand while in place. The depth of the deposit determines if it will be extracted in situ or by mining. Deposits deeper than about 75m must be mined using in situ thermal recovery techniques. Only about 10% of the bitumen in the Athabasca oil sands deposits is recoverable by surface mining techniques (Sparks, Kotlyar, O'Carroll, & Chung, 2003).

3.2. In situ Extraction – Steam Assisted Gravity Drainage

The most commonly used in situ technique is the steam assisted gravity drainage (SAGD) process. SAGD was invented in 1978 by petroleum engineer Roger Butler. The first SAGD operation was drilled and completed in Fort McMurray, Alberta in 1995 and is still producing today.

3.2.1. Process Description

In the SAGD process a steam injection well is used to heat the reservoir and the heated fluid is recovered from a producer well (Figure 3.2). These horizontal well pairs are drilled 5 to 8 meters apart. The lower well is often drilled first because it has a smaller diameter and is easier to place. A magnetic guidance tool (MGT) is often used while drilling the upper well, it is run into the lower well while the driller steers the upper well to it using magnetic sensors.

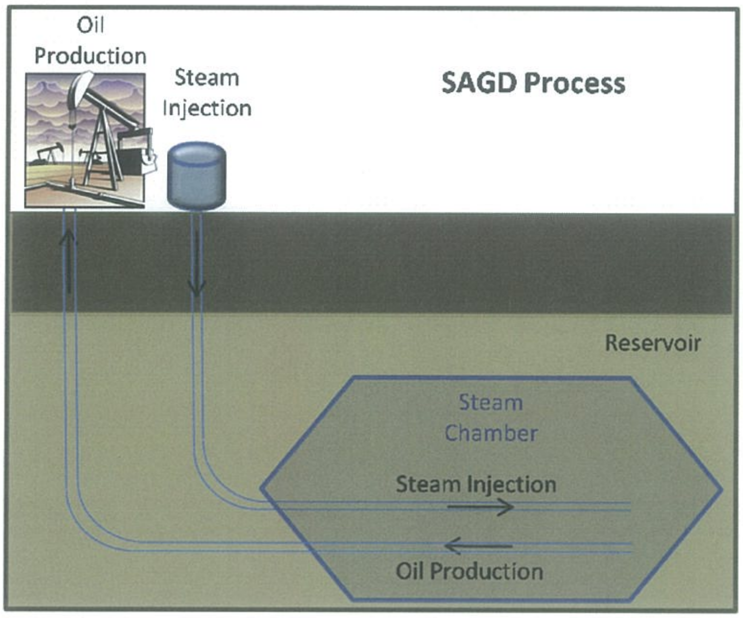


Figure 3.2: Oil sands production through the SAGD process (Government of Alberta, 2008)

The lower production well is located under the reservoir. Steam is injected into the upper well and is often circulated in both wells to heat the reservoir. When the reservoir is sufficiently heated, steam is then continuously injected into the upper well and heated oil and condensate are produced from the lower well. The production well must be long and horizontal to avoid steam coning and to achieve an economic oil production rate (Butler, 2001). Reduced viscosity allows the heated oil and condensate to drain to the production well below. The warmed, pressurized steam chamber pushes the produced fluid to the production well by natural lift. As extraction continues injection pressure slowly declines, necessitating the use of a pump.

The producer well produces to a well pad and the produced fluids then travel to the central processing facility where the bitumen is treated and processed. The separated water undergoes de-oiling and treatment (Figure 3.3).

The produced water from SAGD operations often contains free oil, dispersed oil and dissolved hydrocarbons (Minnich, 2008). Process water is placed in skim tanks to remove the bitumen using induced gas flotation and granular media filtration (Jede, 2007). Dissolved solids are also often present and range from 1500 to 6000 mg/L (Minnich, 2008). Produced water can also contain high levels of silica (275 to 400 ppm) (Minnich, 2008), hardness of less than 50 mg/L and oil between 20 to 100 mg/L (Sandy, 2005). BFW for some steam generators must have TDS of between 150 and 350 mg/L; silica of less than 50 mg/L; hardness of less than 1ppm and oil less than 5 mg/L (Sandy, 2005). Some SAGD projects use drum-type boilers that require water of essentially 0 TDS (Krutzak, 2004).

Produced water and makeup water must be treated before it can be used in steam generation. The water must be filtered to remove solids (sand and bitumen), softened (remove magnesium and calcium), and treated for salinity (Jede, 2007).

The water undergoes hot or warm lime softener treatment to remove hardness and silica, then filtration removes the suspended solids and ion exchange removes residual hardness. Sludge from the lime softener goes to the lime sludge storage where sedimentation occurs (Figure 3.3). The supernatant is returned to the lime softener and the sludge is sent for disposal. The purified water is destined to be boiler feed water and is sent to the steam plant.

Most SAGD facilities generate steam using once-through steam generators (OTSGs) (Heins, McNeill, & Albion, 2005). The purified water is used in the OTSG to produce about 80% quality steam (80% vapour, 20% liquid) steam separators remove the steam condensate and it is returned to the water treatment plant. The OTSG blow down (water used to clean up solids built up in the boiler) is concentrated brine and is usually disposed of by deep well injection (Heins, McNeill, & Albion, 2005). The "high quality" steam (100% steam) returns to the well pad and is sent to the injection well (Krutzak, 2004) (Figure 3.3).

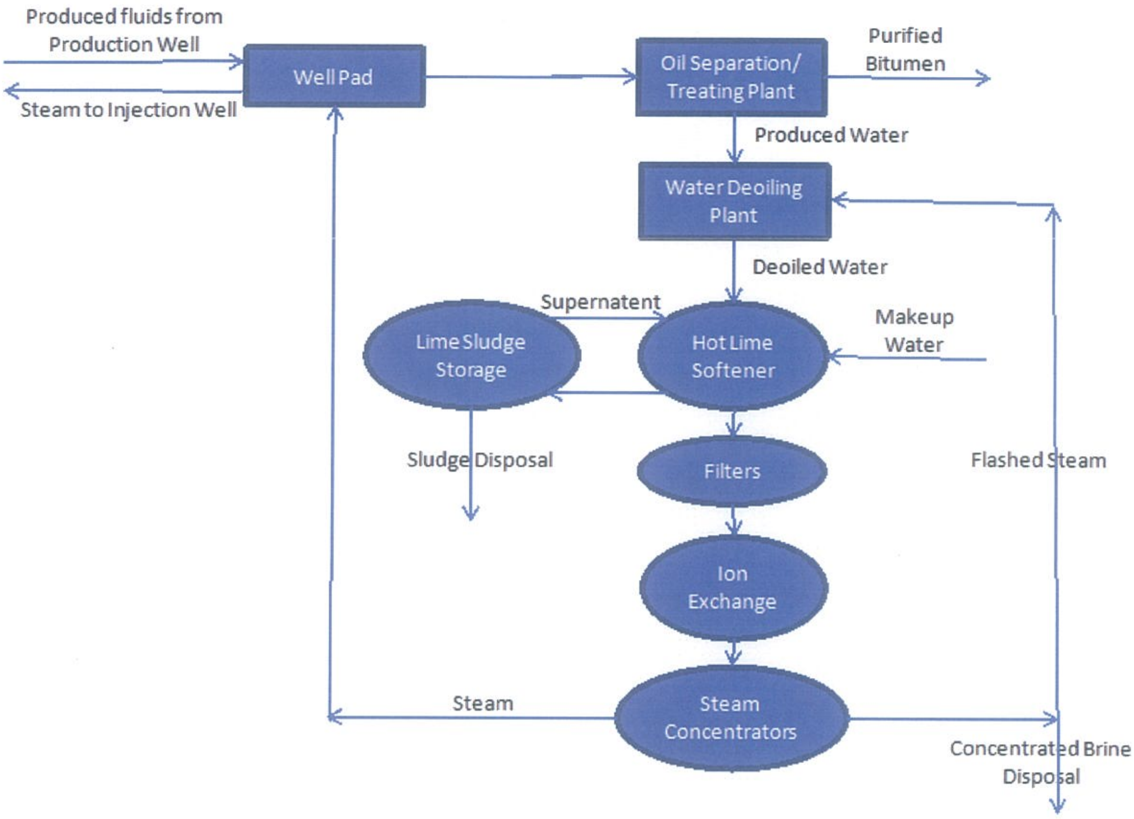


Figure 3.3: SAGD production process and water treatment (From Krutzak, 2004)

Water can be lost in the purification process as a waste stream, remaining in the lime sludge or in the concentrated brine waste. Generally 85-95% of produced water is reused for steam generation, depending on the steam generation technology used (Minnich, 2008). Water is also lost to the formation as water fills the pore spaces left when oil is removed. Retention in the reservoir is typically between 5-10% (Kutzak, 2004). Net permanent loss of water for in situ oil sands recovery is approximately 0.2 to 0.3 of a barrel for every barrel of oil recovered (Natural Resources Canada, 2009).

Makeup water for in situ production usually comes from brackish groundwater from deep aquifers. Efforts are undertaken to limit freshwater withdrawals to minimize impacts on water resources. Saline sources are considered whenever possible. Using this salty water frees up more freshwater for other uses but requires more treatment before it can be used. This means greater costs, higher energy use and larger amounts of waste generated from the water treatment process (CERA, 2009). The waste stream from water treatment is either injected into approved deep disposal zones or is discarded at a waste facility (CAPP, 2009).

Of the total water allocated in the province of Alberta, 1.9% is allocated for water and steam injection operations (enhanced oil recovery). In 1973, 88.7 million cubic meters were used and in 2001, 47.5 million cubic meters were used (Alberta Environment, 2004). Overall water usage and surface water usage has been decreasing, however, between 2002 and 2007 groundwater usage has doubled (Water Matters, 2008).

Thermal in situ recovery of oil sands bitumen requires less water than recovery by mining. Currently oil sands mining accounts for a higher proportion of production than in situ, however the Energy Resources Conservation Board (ERCB) estimates that 82% of the remaining oil sands reserves would be accessed using in situ methods (ERCB, 2009).

3.3. Mining

Near Fort McMurray, Alberta, Syncrude and Suncor oil sands operations are extracting bitumen using open-pit mining techniques. Mining projects process about 2 tonnes (or six barrels) of oil sand in order to produce one barrel of bitumen (Government of Alberta, 2009).

Preparation of the mine site entails clearing the forests and wetlands in the area so that the overburden (rocks and soil) on top of the bitumen can be stripped away. Oil sand is mined from an open-pit with the world's largest shovels and trucks. Shovels dig into the sand and load it into huge trucks which then take it to crushers where it is prepared for extraction. To help separate the bitumen from the sand, hot water is added and the slurry mixture is sent by pipeline to the extraction plant. At the extraction plant bitumen is separated from the sand by the Hot Water Extraction Process (HWEP). The used water is then pumped to tailings ponds from which much is recycled back into the process after a settling period.

3.3.1. Bitumen Separation Techniques

Water is used in oil sands mining operations mainly in the process of separating the bitumen from the oil sands (CAPP, 2009). The hot water extraction process (HWEP) and variations of this process are most commonly used to separate bitumen from the oil sands (Canadian Center for Energy Information, 2009). The original bitumen extraction method was the hot water extraction method developed by Dr. K.A. Clark (Clark & Pasternack, 1932).

Water based extraction is possible because of the hydrophilic nature of sand grains of the oil sands (Masliyah, Zhiang, Xu, Czarnecki, & Hamza, 2004). The grain of sand is coated by a thin film of water which is then coated by a film of bitumen (Canadian Center for Energy Information, 2009). Aeration is needed because bitumen is heavier than water.

In this method large pieces of oil sand are crushed and mixed with hot recycled process water then sent through rotary breakers to be further broken up. Early methods used large tumbler drums to condition the slurry but today hydrotransport pipelines are used to condition and transport the oil sand from the mine to the extraction plant. The slurry enters a separation vessel where three layers develop – sand, water, and bitumen. Bitumen is released from the sand grains and then introduced air attaches to the bitumen to make it float to the surface. The surface bitumen is skimmed off to be cleaned and further processed and secondary bitumen recovery is done of the middling area to return smaller quantities of bitumen. The bitumen froth is then de-aerated, diluted with solvents (to reduce viscosity and provide density difference for solid and water removal) and the tailings are disposed of in a tailings pond. After settling, solids separate from the water and it is recycled from the pond back to the extraction plant to be used again (Figure3.4). Bitumen is recovered from the ponds as it floats to the surface and clean sand is returned by pipeline to open mine pit areas (Canadian Center for Energy Information, 2009).

Composition of Typical Oil Sands Process Water	
pH (units)	7.8-8.1
Dissolved Solids (% by wt)	0.20-0.25
Suspended Solids (% by wt)	0.01-0.20
Conductivity (μS/cm)	3000-4000
Alkalinity (mg/L)	600-800
COD (mg/L)	175-225
BOD (mg/L)	<10
Phenols (mg/L)	<0.01
Cyanide (mg/L)	<0.01
Total Petroleum Hydrocarbon (mg/L)	<10
DOC (mgC/L)	40-65
Naphthenic Acids (mg/L)	50-80
Hardness (as $CaCO_3$)	50-100
Ammonia (mgN/L)	5-15

Figure 3.6: Composition of typical Syncrude oil sands process affected water (Fu H. , El-Din, Smith, MacKinnon, & Zubot, 2008)

Bitumen production by mining is very water intensive; it takes about 12 barrels of water to produce one barrel of bitumen by this method (Mikula, Munoz, & Omotoso, 2008). Of these 12 barrels, around 70% is recycled and the other 30% is trapped in the pore spaces of the oil sand material (Mikula, Munoz, & Omotoso, 2008). As seen in Figure 3.7, water is trapped in slow-settling mature fine tails (MFT) (Kaminsky, Etsell, Ivey, & Omotoso, 2009). This entrapment of water accounts for a large proportion of the water usage in bitumen extraction. Every cubic meter of mined ore results in 1.3 cubic meters of MFT (Kaminsky, Etsell, Ivey, & Omotoso, 2009) and about 1.8 million cubic meters of tailings are produced every day (Holroyd & Simieritsch, 2009). Currently around 3.5 barrels of water per barrel of produced bitumen becomes "tailings" (Mikula, Munoz, & Omotoso, 2008).

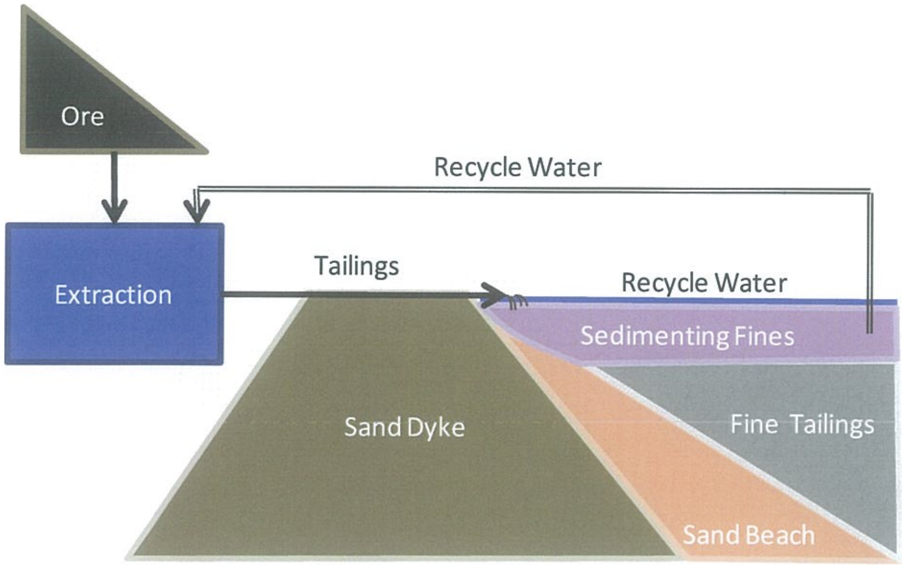


Figure 3.7: Typical tailings pond (McRoberts, 2008)

The primary source of water used in oil sands mining operations in Alberta is the Athabasca River (CAPP, 2009). Other important sources of water are precipitation captured from the mine area and groundwater which is pumped out of the area to prevent mines from filling with water (mine dewatering) (CAPP, 2009). Over the next ten years the demand for freshwater is expected to be greatest from oil sands mining operations, increasing from around 40 million cubic meters per year (m^3/y) to nearly 200 million m^3/y.

Research and development to improve bitumen extraction from oil sands, specifically, how to improve extraction from poor ores, reduce water content in the bitumen froth as well as improving water re-use remain a challenge (Masliyah, Zhiang, Xu, Czarnecki, & Hamza, 2004). This will be further addressed in Chapter 4.

4 CHAPTER FOUR: RECYCLING AND REUSE OPPORTUNITIES

4.1. Mining

The hot water extraction process (HWEP) of oil sands bitumen results in high efficiency of bitumen recovery but the structure of the oil sands complicates water recycle and therefore increases the amount of makeup water that must be used in oil sands mining operations. HWEP produces tailings which have poor consolidation and water release characteristics (Chalaturnyk, Scott, & Ozum, 2002).

The following mass balance example illustrates where and how water is lost in an oil sands mining operation. The diagram (Figure 4.1) is from the Environmental Impact Assessment (EIA) of the True North application for the Fort Hills Oil Sands Mining Project (Odegaard, MacFarlane, & Cheadle, 2001). This is the design and proposed performance numbers (tonnes per hour) for a calendar day (actual production quantity less planned shut downs, not design capacity) in summer. This project is owned by PetroCanada, UTS, and Teck Cominco at this date and has been granted approval. Start up is projected for 2011.

4.1.1. Case Study – Water Mass Balance

At the mine, chunks of oil sand are crushed and mixed with hot recycled process water and then sent through a hydrotransport pipeline as a slurry to the extraction plant. Here, as seen in Figure 4.1, hot water, steam and agitation releases the bitumen from the sand grains, then introduced air attaches to the bitumen to make it float to the surface. This bitumen is skimmed off to be cleaned and processed. The froth is deaerated, diluted with solvents and the tailings are disposed of in tailings ponds. For this project a thickened tailings process is planned. The Cogeneration/HRSG step involves simultaneous generation of electric power with heat and steam as a by-product. This was included to supply thermal energy requirements for the process while efficiently generating power for the site needs (Odegaard, MacFarlane, & Cheadle, 2001). The HRSG is a heat recovery steam generator.

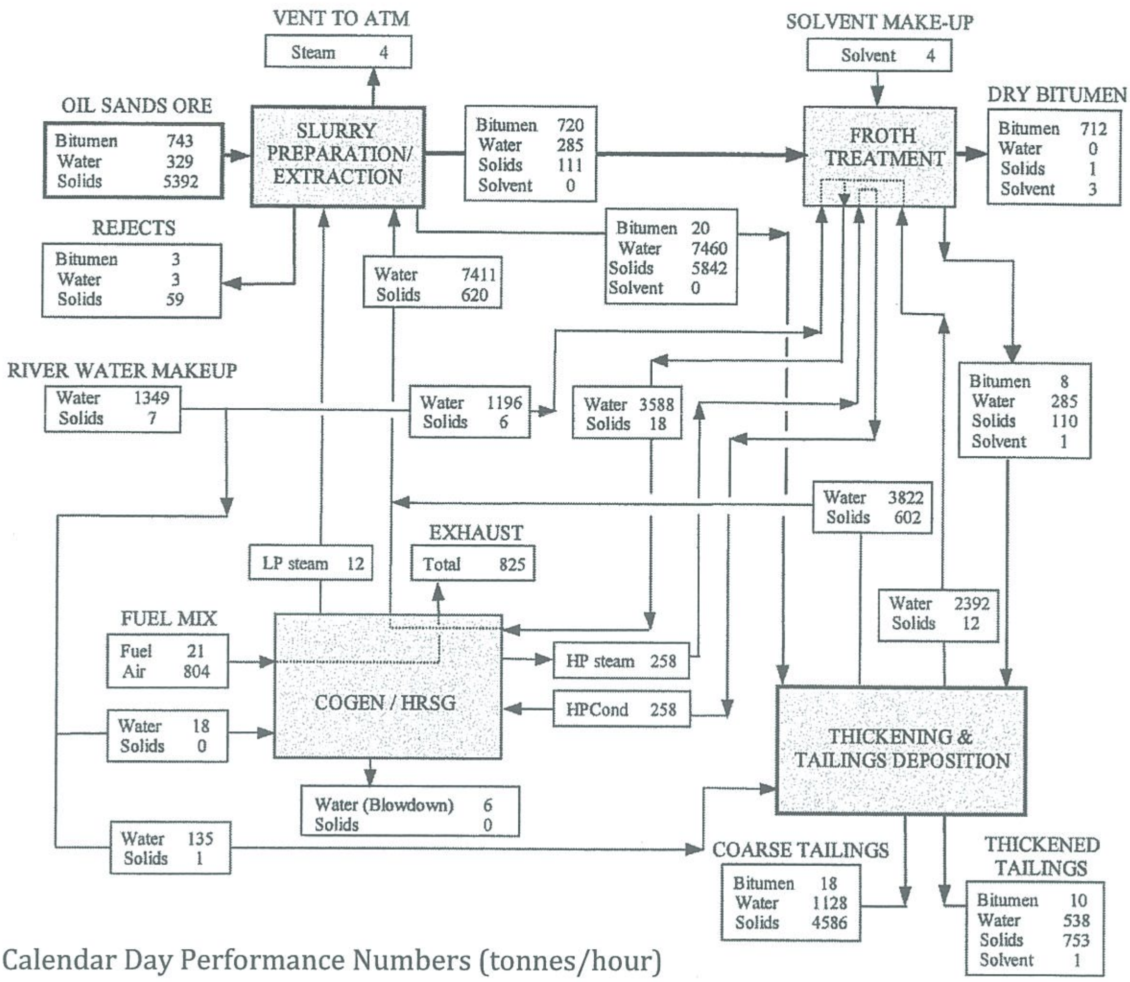


Figure 4.1: Fort Hills Oil Sands Project (Odegaard, MacFarlane, & Cheadle, 2001)

As seen in the following table (Figure 4.2), the ratio of total water input to dry bitumen produced varies from 2.33 to 2.62 depending on calendar or stream day, or summer or winter production. According to the design numbers, water is lost mainly (98.67% to 99.28%) to the tailings, and very small amounts to steam, boiler blowdown, and rejects.

	True North			
	Calendar Day Summer	Calendar Day Winter	Stream Day Summer	Stream Day Winter
Ratios				
Total water input : Dry bitumen	2.36	2.36	2.62	2.62
Tailings produced : Dry bitumen	2.34	2.33	2.56	2.55
Water loss				
Tailings	99.23%	98.70%	99.28%	98.67%
Steam	0.24%	0.18%	0.19%	0.19%
Blowdown	0.36%	0.36%	0.34%	0.38%
Rejects	0.18%	0.77%	0.19%	0.76%

Figure 4.2: Fort Hills Mining Project Design Production Ratios (Odegaard, MacFarlane, & Cheadle, 2001)

Although these figures are only design ratios, they are comparable to ratios found in presently operating projects. In 2007, Suncor's oil sands mining operation used 2.3 m^3 of river water to produce 1 m^3 of oil, a 2.3 input water to dry bitumen produced ratio (Suncor Energy Inc., 2007).

4.1.2. Tailings

The hot water extraction process produces a waste stream known as tailings. Tailings are a mixture of sand particles, dispersed fines, water and residual bitumen. This slurry is about 55% solids, of which 82% is sand, 17% are small fines and 1% is residual bitumen (by weight) (Chalaturnyk, Scott, & Ozum, 2002). After deposition into a tailings pond, the coarse sand particles (particle size greater than 44 microns) quickly segregate and remaining fine tails of 6-10% solids (by weight) accumulate in the tailings ponds (Chalaturnyk, Scott, & Ozum, 2002). Fine tails generally have a particle size of less than 44 microns and eventually settle to 20-30% solids content (86% by volume water); they are then known as mature fine tails (MFT). MFT have a very slow consolidation rate and remain in this state for decades (Chalaturnyk, Scott, & Ozum, 2002). The slow settling speed of these tailings and the rate at which they are produced necessitates the construction and maintenance of large tailings and recycle water containment ponds (Mikula, Munoz, & Omotoso, 2008).

The production of MFT is the reason that oil sands mining results in an average loss of four barrels of water for each barrel of bitumen produced (Natural Resources Canada, 2009). "Until recently there have been no compelling economic or social reasons to drive improvements in water conservation and treatment in the mining process" (Sturgess, 2008). With the increasing concern over water shortages and new requirements for rapid reclamation of tailings ponds it is necessary to improve the settling characteristics of these tailings in an economical and environmentally acceptable manner.

4.1.3. Tailings Technology

Coagulants

The use of gypsum, acid, lime, acid/lime combinations, alum or polymers has been shown to collapse the structure of the mature fine tailings clays and therefore release the water (CAPP, 2009). This process is known as consolidated, composite, or non-segregating tailings (CEMA, 2006). Using the consolidated tailings process on all available fine tailings increases the amount of water which can be recycled back into the extraction process (Mikula, Munoz, & Omotoso, 2008).

In this process, the extraction tailings are separated into coarse sand, fine tailings and water using a hydrocyclone (MacKinnon, Matthews, Shaw, & Cuddy, 2000). The sand is then combined with (previously settled) mature fine tails (30% solids) and a coagulant, gypsum, for example (Bott, 2009). The addition of gypsum causes the collapse of the electrical double layer surrounding the clay particles and changes the aggregation behaviour of the clays (Mikula, Munoz, Kasperski, & Omotoso, 1998). The resulting flocculated clay matrix will support the coarse quartz tailings that ordinarily separate from the fine clays. The close association of the clay and sand results in internal stress because of the weight of the quartz and causes rapid consolidation of the clay, releasing water (Mikula, Munoz, Kasperski, & Omotoso, 1998). Through this process, a non-segregating mixture forms which will consolidate to a geotechnically stable material (approximately 80% solids) within one year (Bott, 2009). The process is diagrammed in Figure 4.3.

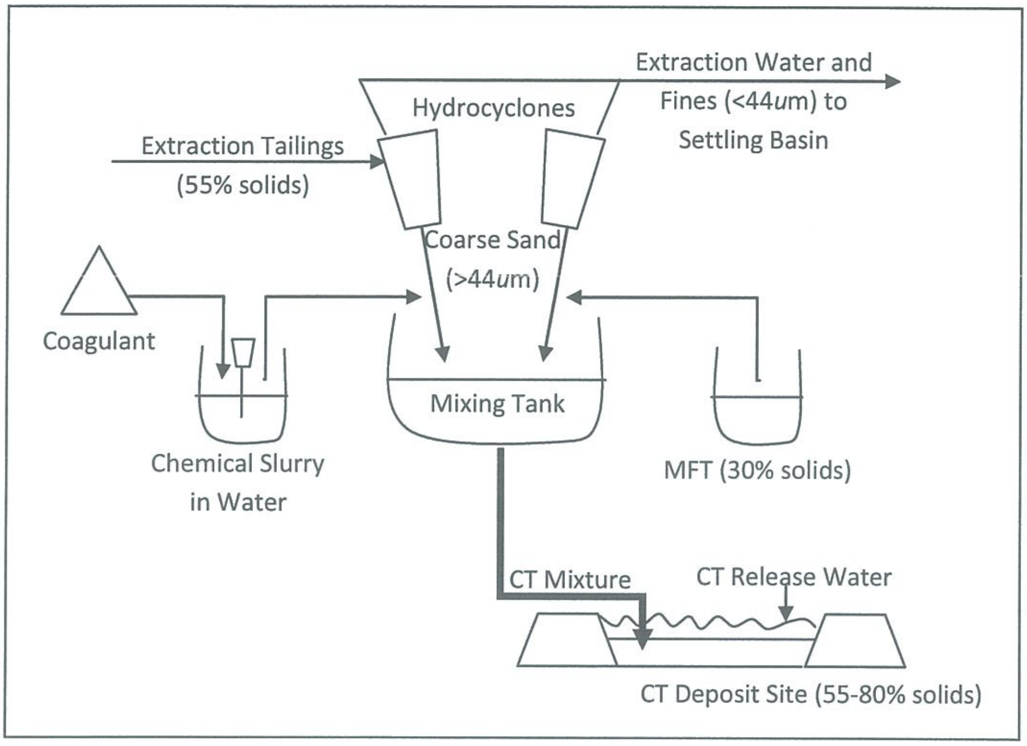


Figure 4.3: Composite tailings process steps. Solids contents expressed as wt%. Modified from (MacKinnon, Matthews, Shaw, & Cuddy, 2000)

Water released during the consolidated tailings process will vary in quality depending on the coagulant used. Some problems that can arise are: increasing salinity, scaling potential, pH changes, corrosion potential, effects on oil sand processing, impact on recycle and reclamation (MacKinnon, Matthews, Shaw, & Cuddy, 2000). Using gypsum (calcium sulphate) as a coagulant has the drawback of producing water with an increased calcium and sulphate content (CEMA, 2006). This can cause an impact on the bitumen recovery rate if calcium concentrations increase to a level which causes too much scaling of the equipment. Water treatments such as softening with lime or caustic soda and addition of a scale inhibitor can reduce the calcium content of the water and reduce the scaling potential (CEMA, 2006). This calcium rich water can also be added to the fine tailings separated out by the initial hydrocyclone process in order to accelerate settling to mature fine tailings (Bott, 2009). Suncor first commercialized this process using gypsum because they had excess produced from a flue gas desulphurization process (Mikula, Munoz, & Omotoso, 2008)

Centrifuge Technologies

Centrifuges can also be used to separate the water from the fine tailings. Evaluating the long term costs of treatment and management of mature fine tailings has caused companies to reconsider centrifuge technologies to produce dry tailings (Mikula, Munoz, & Omotoso, 2008). These dry tailings can be dewatered to a point of approximately 80% solids by weight (Mikula, Munoz, & Omotoso, 2008), at which point the tailings can accommodate overburden and soil replacement. This technology can increase the amount of water that can be recycled in the mining process, therefore decreasing the amount of makeup water needed from rivers and the area of storage needed for tailings (Mikula, Munoz, & Omotoso, 2008). On average production of dry tailings can result in a significant reduction of water lost per barrel of bitumen (Mikula, Munoz, & Omotoso, 2008).

MFT dewatering retains the separated water for recycle, as opposed to drying processes. Although dewatering with centrifuges has be successfully demonstrated, further work is needed to determine the optimum conditions for this method (Mikula, Munoz, & Omotoso, Centrifuge options for production of "Dry stackable tailings" in surface mined oil sands tailings management, 2008). MFT can also be dewatered using organic polymers and CO_2 addition. As seen in the following table (Figure 4.4), MFT dewatering is a method which produces higher water savings when compared to CT technology (Mikula, Omotoso, & Kasperski, 2008).

Tailings Treatment	Volume water lost per volume bitumen produced	% Water Saved
No Treatment	3.7	
CT	2.9	22%
MFT dewatering	2.0	45%

Figure 4.4: Treatment results (Using ore type with 10% fines) (Mikula, Omotoso, & Kasperski, 2008)

The use of centrifuges has been successfully tested at the Asphalt Ridge tar sands in Utah (Mikula, Munoz, & Omotoso, 2008). More testing is required to determine if centrifugal technologies are applicable for implementation at the scale required for the Athabasca oil sands operations and the clay content of the fluid fine tailings produced from these oil sands (Mikula, Munoz, & Omotoso, 2008). Dewatering in this fashion could reduce the water needed to produce oil sands bitumen as well as reduce the land disturbance and consequent environmental impact from long term, large scale tailings storage (Mikula, Munoz, & Omotoso, 2008).

New Technologies

A method being researched by Canadian Natural Resources Ltd. (CNRL) captures CO_2 from the facility and combines it with the tailings (CAPP, 2009). This mixture reacts to form a solid that then settles more quickly (CAPP, 2009). This process permanently traps the CO_2 and also allows water to be recycled while still hot, reducing the energy requirements to reheat it (CAPP, 2009).

The Alberta Water Research Institute is working on a $1.6 million project in coordination with industry to look at the use of biological processes to accelerate the de-watering of oil sands fine tailings (AWRI, 2009). They are studying ways to increase the rate and degree of release of pore water from the tailings in order to increase water re-use rates for oil sands mining operations (AWRI, 2009). Through microbial metabolization of the petroleum hydrocarbons (n-alkanes and BTEX) from the solvent found in tailings, methane is produced which appears to increase the densification of the tailings and results in the release of pore water (AWRI, 2009). The chemistry of the pore water and properties of the tailings are still being studied to understand the mechanism of densification and how this process can increase water recycle rates in oil sands mining.

Dry tailings processes such as the Bitmin extraction technology reduce the water content of the fine tailings (Griffiths, Taylor, & Woynillowicz, 2006). This technology uses a combination of mild agitation, moderate temperatures and process pH control to remove bitumen from the sand while leaving the clays largely undisturbed (Bitmin Resources Inc., 2007). In this way clay lumps are rejected with the coarse tailings without being dispersed into the process stream.

Industry, academic institutions and government have been testing new technologies to reduce the production of fine tailings and to increase the rate of solidification of the existing tailings. The Alberta government spent over $7 million in grants for this research (Government of Alberta, 2009). The Alberta Research Council, CANMET Energy Technology Center, and the University of Alberta have been researching tailings management for decades (Government of Alberta, 2009).

To reduce water requirements with the current extraction technology, reductions in the production of tailings is necessary (Griffiths, Taylor, & Woynillowicz, 2006). However, enhanced water recycle is just an "end-of pipe" solution which doesn't address reliance on water-based extraction processes (Griffiths, Taylor, & Woynillowicz, 2006) nevertheless it may take a lot of time until a non-water-based extraction technology is discovered.

4.2. In situ Extraction

4.2.1. SAGD Technology

In situ oil sands operations have high recycle rates for produced water (Griffiths, Taylor, & Woynillowicz, 2006). The primary reuse of water in the SAGD process is for steam production. The degree of water reuse is dependent on the quality of bitumen recovered and on the steam generation technology, as seen in Figure 4.5 (Minnich, 2008). Typical water recycle ratios for commercial projects exceed 90% (Griffiths and Woynillowicz, 2003).

Technology	% Recovery of Produced Water	Relative Cost of Water Treatment per cubic meter
Conventional Once Through Steam Generator	85-90%	100%
Conventional Once Through Steam Generator with Blowdown Evaporation	95%	110%
Evaporation and Drum Boiler	95%	110%
Steam Generation with Zero Liquid Discharge	>98%	500-1000%

Figure 4.5: SAGD produced water recycle (Minnich, 2008)

The majority of water reused in SAGD operations is used as steam generator boiler feed water (BFW). Water is recycled from the boiler blowdown, filter back wash and ion exchange regeneration waste (Nelson, Aggarwal, & Babel, 2007). Reuse water for steam generation often requires treatment. Recycle water concerns are TDS treatment and organic build up but membrane technologies make it possible to reduce TDS and reverse osmosis for desalination can produce suitable boiler feed water. Ion exchange for elimination of dissolved solids is suitable for high pressure boiler feed water.

Evaporation and crystallization provide the highest recovery rates and allow zero liquid discharge (Minnich, 2008). This system uses a distillation column to recycle produced water and uses few chemicals in treatment (Griffiths, Taylor, & Woynillowicz, 2006). Suncor's Firebag operation (Stage 2) uses this system to purify recycled production water before it is used to generate steam. The concentrated brine waste which results from the evaporation system is separated into solid waste and residual liquid. The solid is sent to the landfill and the liquid is disposed of in a disposal well (Griffiths, Taylor, & Woynillowicz, 2006). The Deer Creek Joslyn facility (Phase II) uses a fully integrated system of evaporator and zero liquid discharge crystallizer system which enables almost all liquids to be recycled (Griffiths, Taylor, & Woynillowicz, 2006).

All water treatment processes create a waste stream that must then be dealt with. There are long term environmental impacts associated with landfilling the solid waste, as well as with deep well disposal of liquid wastes (Griffiths, Taylor, & Woynillowicz, 2006). A more innovative solution to decreasing water use in the oil sands is technologies for oil sands extraction which simply require less water. This will reduce the water treatment waste streams, as well as the energy and money used for water treatment.

4.2.2. New In situ Technologies

Technologies to reduce water usage rates for in situ extraction are the use of solvents; solvents and heat combination; in situ combustion or gasification of the bitumen; electrical heaters for warming the bitumen; electro-magnetic stimulation; and other technologies (Jede, 2007). Emerging in situ technologies are pulse technology, vapor recovery extraction (VAPEX) and toe-to-heel air injection (THAI) (Government of Alberta, 2009).

There are several new technologies which could bring radical changes to oil sands production once they have been proven effective and economical (Chalaturnyk, Scott, & Ozum, 2002). Figure: 4.6 shows an estimated timeline for the availability of some new technologies.

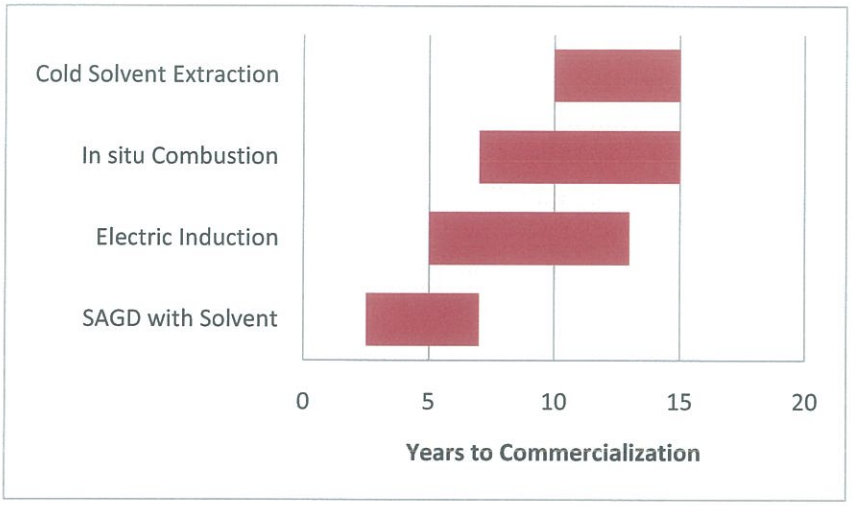


Figure 4.6: Current estimated timeline for innovative oil sands technologies (CERA, 2009)

Cold Solvent

Cold solvent extraction includes the Vapour Extraction Process (VAPEX), a new in-situ technology that uses less water than SAGD (Sturgess, 2008). VAPEX uses propane, butane or CO2 as a vaporized solvent in the extraction process. Solvent used alone can also save energy since the process occurs at atmospheric temperatures (Sturgess, 2008). The Vapex process is expensive due to solvent costs and production rates are lower than SAGD but it is more energy efficient than SAGD (MacFarlane, 2007). It is not yet considered to be fully commercial but is being studied (MacFarlane, 2007). This process is being tested at the Encana Foster Creek project (Encana Corporation, 2007).

In situ Combustion

In situ combustion is the technology used in THAI, or toe-to-heel air injection. This method relies primarily on combustion rather than steam to liquefy bitumen underground and uses a vertical injector well and a horizontal producer well (Canadian Association of Petroleum Producers, 2007). A small amount of steam is injected through a vertical well to heat the bitumen and create void spaces in the reservoir. Then air is injected which combines with the heat and pressure in the reservoir and ignites the bitumen. This combustion creates more heat to reduce the viscosity of the oil which then flows to the horizontal production well. The combustion moves from the toe to the heel of the horizontal well. The controlled combustion process produces connate water contained in the reservoir for reuse (Sturgess, 2008) and uses freshwater only for steam in preliminary heating phase.

This method can have recovery rates of around 80% and partially upgrades bitumen in situ (Canadian Association of Petroleum Producers, 2007). There can be difficulties controlling the fire front and the danger of a ruptured well and hot gases escaping to the surface. THAI technology is currently being developed for commercial use.

Electric induction technologies can be used to heat the bitumen in place in combination with steam injection to produce higher recoveries and reduce water usage (steam to oil ratio of 0.5 to 1) (CERA, 2009).

SAGD and Solvents

SAGD with solvent includes the expanding solvent SAGD (ES-SAGD) process. In this process bitumen viscosity is reduced by dilution with solvent instead of solely by warming with steam. The steam-solvent combination system uses half as much water as regular SAGD and can provide up to a 19% increase in oil production (Deutsch & McLennan, 2005). Vapex is a non-thermal bitumen recovery method which uses solvents to reduce oil viscosity and increase oil recovery (MacFarlane, 2007). Like SAGD, this method uses horizontal well pairs but instead of steam, natural gas is injected into the upper well. Liquids such as ethane, propane or butane act as solvents to make the bitumen flow to the lower well. The solvent is injected into the upper well and as the oil viscosity is reduced it drains to the lower production well. A non-condensable gas is injected along with the solvent to increase the pressure of the reservoir. The higher the solvent concentration in the oil causes more methane in the accumulated gas and reduced concentration of vaporized solvent in the vapour chamber – which reduces the process effectiveness. The solvent concentration in the gas phase must be controlled. This method can also be applied to a single well, in which the solvent is injected from the toe of the horizontal well.

Other Techniques

Pulse technology uses a fluid pulse to momentarily expand the pore structure of rock and soil to move fluid through the ground. It can dramatically improve the liquid flow in the ground to improve oil recovery rates.

The Alberta Ingenuity Center for In Situ Energy (AICISE) was established in October of 2004 and is developing advanced catalysts to be injected directly into oil sands reservoirs for enhanced in situ recovery. The resultant controlled chemical reaction would bring only valuable energy products to the surface, leaving all unwanted by products- production water, metals, sulphur, petroleum coke and carbon dioxide, behind underground (Lowey, 2006).

The CAPRI process (controlled atmospheric pressure resin infusion) is used in conjunction with THAI to upgrade bitumen with catalysts while still in place. This process is being tested in Petrobank's Whitesands pilot project (Sturgess, 2008).

Other technologies for in-situ recovery of oil sands are being investigated, including microwave energy and the use of microbes to reduce viscosity (Sturgess, 2008). Nanotechnology research could represent a breakthrough for water treatment or oil recovery without using water. Specifically, nanotechnology could be used to design substance-specific filtration processes or to produce unique catalysts for hydrocarbon treating (Sturgess, 2008).

New technologies require significant investments and time for development and testing. Pilot studies are also necessary before implementation into commercial operation. These studies can cost up to $100 million and take up to 10 years (Clark B. , 2007).

5 CHAPTER FIVE: OIL SANDS DEVELOPMENT WATER USE REGULATIONS

5.1. Regulatory Framework

Regulations concerning oil sands development are the responsibility of the Energy Resources Conservation Board (ERCB), the Alberta Department of the Environment (AENV) and other agencies. The individual regulations which deal with oil sands development are under the legislation of the Environmental Protection and Enhancement Act or the Water Act (Government of Alberta, 1993). Development in areas of fish habitat or navigable waters also triggers regulation at the federal level. Because of the magnitude of requirements for oil sands development, the following section is not comprehensive and focuses on those regulations dealing with water use and having consequences for water availability and quality.

The ERCB is an independent agency of the Alberta government which regulates responsible and efficient development of energy resources, including oil sands (ERCB, 2008). The ERCB is responsible for the oversight of all oil sands mining and processing operations, including regulation of discard sites for waste streams generated in these operations. The Oil Sands Conservation Act and Oil Sands Conservation Regulations are administered by the ERCB for the development of oil sands resources. ERCB coordinates with the AENV for the approval process for major oil sands development applications.

The AENV has jurisdiction over water use in Alberta. Non-saline water use is governed by the Water Conservation and Allocation Policy for Oilfield Injection, 2006, administered by AENV. The policy requires the developer to evaluate all potential alternatives to non-saline water that may exist or efficiencies for water use that maybe available to minimize the use of fresh water.

Alberta Sustainable Resource Development (ASRD) is responsible for cumulative effects planning projects, monitoring and compliance with a focus on impacts to public land and wildlife (ERCB, 2009). ASRD works with AENV, the ERCB and the Natural Resource

Conservation Board (NRCB) on the Environmental Impact Assessment (EIA) process (ASRD, 2008). According to the Environmental Protection and Assessment Act, an EIA is mandatory for all oil sands mining projects and any in situ project which processes more than 2000 cubic meters per day (Alberta Environment, 2008).

5.2. Regulations/ Acts Concerning:

5.2.1. River Withdrawals

Alberta is located to the east and in the rain shadow of the Rocky Mountains. This topography contributes to making southern Alberta and the southern portion of the other Prairie Provinces (Saskatchewan and Manitoba) the driest part of Canada. Oil sands development in Alberta occurs in the northern portion of the province where water supply is relatively more abundant and water use (and population) is low. 85% of Alberta's water supply (CAPP, 2009) and 10% of its population is in northern Alberta. However, it is still necessary to closely regulate water usage in this area.

Because of these dry conditions, in 1894, the North-West Irrigation Act was enacted to encourage settlement in Canada by giving access to long term water licenses for irrigation purposes (Percy, 2005). These licences specified the amount and area of withdrawal and were essentially permanent since the license could be passed to its successors. A senior license was determined by the date of application and senior licenses were allowed to obtain the full amount indicated in their license before a junior license is entitled to receive any water (Percy, 2005).

In 1920 it was realized that this method of water licensing would soon exhaust available water supplies (Percy, 2005). In order to ensure that municipalities would have access to water, a change was made to Alberta water law to allow the transfer of rights from a lower to a higher priority user (Percy, 2005). This allowance for transfer of water licenses was an incentive to reduce waste however, water use intensified as water that was previously returned to river flows was then saved and transferred for another user to use (Percy, 2005).

According to the Canadian Constitution, federal and provincial/territorial governments share control over water resources. Federal government regulates water on federal lands, in the territories, in national parks and on First Nation's reserves (Holroyd & Simieritsch, 2009). The Federal Water Policy of 1987 encourages sustainable use of water in these regions and emphasizes integrated water use and planning. The Alberta government has control over its natural resources, including water, in all other areas of the province.

As of 1996, the Alberta Water Act requires a license for any diversion of surface water or fresh groundwater. Water licenses specify annual withdrawal volume and maximum instantaneous rates of extraction. The Alberta Water Act also has conditions that allow the Director of the Act to ensure that a license will not impair the rights of other water users and will not have significant adverse effects on the aquatic environment (Percy, 2005). These provisions as well as a holdback provision for maintenance of river system functioning were added in order to provide a mechanism for considering environmental objectives while making water licensing decisions. However, the holdback provision only allows a reduction of up to 10% for environmental purposes and is considered "modest and unlikely to restore large quantities of water to a river system" (Percy, 2005).

In 2003, The Alberta government put in place the Water for Life Strategy with the goals of a safe, secure drinking water supply; healthy aquatic ecosystems; and a reliable quality of water supply for a sustainable economy (Government of Alberta, 2003). This strategy set a target of a 30% increase in efficiency and productivity of water use in Alberta by 2015 (Government of Alberta, 2003).

The primary source of water used in Alberta oil sands mining operations is the Athabasca River (CAPP, 2009). Alberta Environment (AENV) and the federal Department of Fisheries (DFO) implemented a program of river water allocation known as, "Alberta's Regulatory Backstop to Protect the Athabasca River" in 2007 (Water Matters, 2009). Phase 1 is a program of allocation that varies with variations of river flows for each week of the year and considers the amount of water needed to sustain fish. It works like a stoplight. Green-light conditions allow industry to withdraw up to 15% of the river flow; a yellow light encourages industry to proceed with caution by reducing withdrawals to 10% of flow; and a red light restricts allocations even further, to 5.2% of historic median weekly flow (AENV, 2009). However, even during a drought, with red light conditions, industry is still able to withdraw enough water from the Athabasca river to fill 50 bathtubs per second (Nikiforuk, 2008).

The goal of this framework is to balance ecosystem sustainability with water needs throughout the life of the oil sands projects (AENV, 2009). A problem with this framework is that restrictions are put on how much water the whole oil sands industry can cumulatively withdraw from the Athabasca and it requires all oil sands operators to work together to stay within the limits. This has led to the development of an Oil Sands Mining Water Management Agreement for the Winter Period between Suncor, Syncrude, and other current oil sands operators which is modified each year (Water Matters, 2009). It entails Suncor and Syncrude withdrawing at a maximum of their average annual allocation rate and other companies using water storage to supplement their withdrawals when the river is under red flow conditions (AENV & DFO, 2007).

Criticisms of this regulatory framework regard the lack of implementation plans or enforcement measures (Water Matters, 2009). This plan has no authority in law or policy and relies largely on self-monitoring by the oil sands companies. The agreement sets a weekly maximum instantaneous withdrawal rate for each oil sands company but doesn't specify monitoring or reporting. It is indicated that companies must report exceedances to Alberta Environment; however they are only required to report withdrawals on an annual basis according to law (AENV & DFO, 2007). Phase 2 of the Framework is currently being developed for 2010. This step would likely clarify enforcement methods and address long term implementation plans (AENV & DFO, 2007).

5.2.2. Tailings Regulations

Oil sands mining tailings ponds are regulated by the ERCB from operational phase to abandonment. The ERCB is responsible for the oversight of all mining and processing operations, including discard sites for the waste streams. The Oil Sands Conservation

Regulations are administered by the ERCB for the development of oil sands resources. This regulation states that the operator must minimize the disposal of water and maximize the recycling of produced water (Province of Alberta, 2009).

Other regulatory bodies that review the design and location of newly proposed tailings ponds are AENV and ASRD. Applications are reviewed to ensure suitability from an environmental, resource conservation and economic point of view (Government of Alberta, 2009). Alberta's "zero discharge policy" means that tailings pond design must incorporate technologies to monitor and capture seepage to groundwater (Government of Alberta, 2009).

The ERCB released a new directive regarding tailings performance criteria and requirements in February of 2009. Directive 074 contains criteria for managing tailings and includes specific enforcement actions if performance targets are not met (ERCB, 2009). The new directive requires operators to submit, by September 30 of 2009, a timeline for closing the tailings ponds. Reclamation to the point that they are able to support a soil overburden is required within five years of the pond no longer being used. Companies operating in the oil sands must also prepare tailings plans and report on the tailing ponds annually (ERCB, 2009). These regulatory requirements include performance based criteria to allow different projects to use different methods at the discretion of the operators as long as they achieve the same or better rate of reduction of fluid fine tailings accumulation.

This directive will allow the ERCB to hold operators accountable and includes steps for enforcement in cases of non-compliance (Houlihan & Mian, 2009). The directive refers to another document, Directive 019, for the specifics about enforcement actions. In an assessment of oil sands company plans submitted for compliance to this directive, the Pembina Institute found that 7 out of 9 plans were not in complete compliance (Simieritsch, Obad, & Dyer, 2009). It is important that government set consistent goals and enforce them to control the growing problem of tailings management. As stated in Directive 019: ERCB Compliance Assurance – Enforcement, noncompliance can result in fees, partial or full suspension of permits, licenses, or approvals (EUB, 2005).

Oil sands mine operators must also provide a reclamation security bond ($675 million as of February, 2009) to be held by the government of Alberta to ensure that reclamation costs will be covered (Government of Alberta, 2009). It is currently unknown if this amount will be sufficient since criteria to evaluate reclamation success are not yet defined for wetlands (Alberta Environment, 2008). This directive also emphasizes effective bird deterrence after an incident in 2008. Several hundred migrating ducks died from exposure after landing on a tailings pond where the bitumen surface layer reduced the insulating capacity of their feathers (Holroyd & Simieritsch, 2009).

Current tailings technologies do not exist to rapidly deal with the volume of the problem (Godwaldt, 2009). Research and technology improvements are needed in order to treat mining tailings and reclaim the tailings ponds (CERA, 2009). As of 2008 there were more than 720 million cubic meters of MFT in tailings ponds covering more than 130 square kilometres of northern Alberta (ERCB, 2008) (Holroyd & Simieritsch, 2009). A more effective approach may be to consider a resource extraction rate which is in line with the rate of tailings reclamation (Godwaldt, 2009).

Another option is to define discharge limits for releases of tailings ponds into the environment. The impacts of discharge to the river should be weighed against the impacts of long term, large-scale storage of tailings or landfilling the concentrated brine waste product from treating process water (Mikula, Munoz, & Omotoso, 2008). A small, steady discharge to the river may be a better option in terms of long term impacts from eventual reclamation (Godwaldt, 2009). As seen in Chapter 4 (Figure 4.2), when analyzing mass balances of water use in oil sands mining, it becomes clear that there are few areas, other than tailings production and management, in which improvements can be made. Salts and dissolved solids will concentrate in tailings ponds and eventually leak; an improvement in tailings policies to allow an amount of tailings which will not negatively impact river ecosystems may avoid this concentration and the subsequent problems (Godwaldt, 2009).

5.2.3. Wetlands Destruction/ Habitat Loss

The Alberta Environmental Protection and Enhancement Act (EPEA) states the reclamation objective of returning disturbed landscapes to "equivalent land capability" (Government of Alberta, 2009). This is defined as the ability of the land to support similar but not necessarily identical land uses to those that existed before disturbance (Government of Alberta, 2009). The wetlands in northern Alberta are a very important ecosystem, they aid in water purification; minimize soil erosion; provide carbon storage; and offer habitat for many plants and animals (Holroyd & Simieritsch, 2009). Currently, a criterion for certification of reclaimed wetlands has not been established (Alberta Environment, 2008).

At the federal level, the Fisheries Act, which is administered and enforced by Fisheries and Oceans Canada (DFO), contains provisions that prohibit harmful changes to fish habitat as well as discharges of deleterious substances into fish habitat areas unless authorized by the Minister of DFO or through regulations under the Fisheries Act (DFO, 2005). The framework for administration and enforcement of this Act is provided in the Policy for the Management of Fish Habitat (DFO, 2005). The goals of this Habitat Policy include conservation, restoration, and development of fish habitat (DFO, 2005). A key principle of this policy is "no net loss of the productive capacity of fish habitat" (DFO, 2005). Accordingly authorization of proposed projects is only given when unavoidable habitat losses for a project are balanced by newly created or restored fish habitat (DFO, 2005).

Alberta's New Wetland Policy which was meant to be introduced sometime during 2009 has been further delayed until 2012. It was meant to provide a comprehensive policy for the entire province and replace the current Wetland Management in the Settled Area of Alberta – An Interim Policy. This policy was put in place in 1993 and only applies to wetlands in settled areas (Alberta Water Resources Commission, 1993); there is currently no policy in place for the rest of Alberta. The new policy, once in place, would likely ensure the maintenance of the ecological, social, and economic benefits provided by wetlands. An important direction of this policy would require projects near wetlands to first avoid wetland loss and degradation, second minimize disturbance when avoidance is impossible, and third compensate for wetland loss (Aquality, 2009).

5.2.4. Groundwater Withdrawals

In situ oil sands extraction uses mainly groundwater sources (CAPP, 2009). The Alberta Water Act requires a license for any diversion of surface water or fresh groundwater. The Energy and Resource Conservation Board (ERCB) and Alberta Environment (AENV) released a joint draft directive in February of 2009 with new requirements for water measurement, reporting, and use of water for thermal, in situ oil sands operations (ERCB/AENV, 2009). Of the total remaining established reserves, about 18% is considered recoverable by surface mining techniques and the other 82% must be recovered using in situ methods (ERCB, 2009). It is estimated that this directive could save 35 million cubic meters of freshwater in the next 10 years (ERCB, 2008).

Although this directive would be progressive in terms of the recycle of saline and non-saline water for in situ oil sands operations, "it fails to adequately address the long-term cumulative impact on water resources from increasing in situ oil sands production" (Dyer, 2009). The level of water recycling currently proposed is possible with current technologies and will therefore not encourage any innovative technology in this area (Dyer, 2009). Also, recycling water is an energy and waste intensive method of reducing water use (Barlow, 2007); therefore, it would be more constructive to encourage the development of other new technologies which reduce overall water use by means other than increased recycle rates (Dyer, 2009).

This directive does not require in depth reporting on the use of saline water. Only total volume, not where and how much was taken from which reservoir is required in the directive. As these deep, saline aquifers replenish very slowly and they may be necessary in the future to deal with water shortages (Barlow, 2007), it is important to track this usage as well. This information can also be used along with monitoring of saline aquifers to determine the impacts of draining deep water aquifers (Dyer, 2009).

It would also be useful, to ensure that goals are being met, to review and monitor the changes which result from implementing this new directive and consider improvements or updates to the directive after several years. As technology improves, regulation should reflect these changes and motivate continuous innovations.

Alberta Environment is developing Groundwater Management Frameworks for the oil sands region based on information from regional groundwater studies (CAPP, 2009). The objective of these frameworks will be to identify groundwater contamination, maintain groundwater quality, prevent dewatering of aquifers, and develop a monitoring strategy to measure the impacts of oil sands development (CAPP, 2009). A new policy of assessing and managing non-saline groundwater which is in contact with the oil sands is also in the works (CAPP, 2009).

5.3. Role of Regulations in Reducing Oil Sands Water Use

Although current regulations have a place in helping reduce water usage in the oil sands, more effective regulations could provide incentive to continually improve water recycle rates. As seen in the following chapter, water use at current and projected levels of may have serious negative impacts on the environment.

Industry, government, and the public have recently recognized that the intensive water requirements of oil sands, combined with expected climate change impacts and other uses, may threaten Alberta's water security. More specifically, in Alberta there is concern that the Athabasca River may not have sufficient flows to meet the needs of planned mining operations while maintaining adequate stream flows (Davidson & Hurley, 2007). Regulations that govern water use in the oil sands need to address the cumulative impacts of the industry's growth; existing regulation is simply for individual projects and project-level impacts (CERA, 2009). Legislation that would promote conservation of water is necessary. Current legislation has allowed the Alberta oil sands to proceed without effective contingency plans for how to manage low water conditions (Schindler 2007). As of December, 2008, the Government of Alberta has approved every oil sands mining and in situ project that has been proposed (Grant, Dyer, & Woynillowicz, 2008). Since the level of water usage approved for new and existing projects exceeds the level of water needed to maintain instream flow needs, current regulations are not adequate to sustain a healthy ecosystem.

Currently, much money is being invested into innovative new ways to treat tailings or decrease tailings production as well as on less water intensive in situ methods; however, this research would become a more central focus if regulations were stricter. According to Porter and van der Linde (1995), "properly designed environmental standards can trigger innovations". Innovation can be driven by effective environmental regulations on industry. Porter and van der Linde (1995) cite a particularly relevant example, in the article "Green and Competitive". In 1987 Dow Chemical in California was using evaporation ponds to store wastewater produced as a by-product of chemical manufacturing. One year before federal regulations required the closure of these ponds, Dow underwent a redesign of its production process to comply with the new law. This resulted in a reduction its waste production by 6,080 tons per year (Porter & van der Linde, 1995). The company also found a novel way to reuse a portion of the waste stream in another part of the plant. This innovation cost Dow a total of $250,000 and provided savings of $2.4 million per year (Porter & van der Linde, 1995).

Using raw materials more effectively leads to resource productivity that can make a company more competitive and lower its environmental impact (Porter & van der Linde, 1995). Even in instances where innovation will prove to be highly profitable, companies often need a regulatory push in order to implement them. This is because of competitive realities in the market. Managers often don't have access to complete information or time to interpret and integrate information into operating strategies (Porter & van der Linde, 1995). The new directive 074 is a step towards this type of action but implementation is too slow for the scale of water use in oil sands development.

Porter and van der Linde (1995) outline the necessary principles of regulatory design which will promote innovation and resource productivity from companies (Porter & van der Linde, 1995). Resource productivity in oil sands development could be decreasing overall water usage or using the total water allocation more efficiently. These principles include moving away from command and control techniques towards focusing on outcomes, not technologies. According to Porter and van der Linde, strict regulations are more likely to promote innovation than lenient ones (Porter & van der Linde, 1995). Regulations applied closer to the end user allows for innovation possibilities at every stage of production. Current oil sands development regulations focus on cleaning up the pollution after it is created. Mitigation at an early stage of production or completely avoiding pollution is more efficient and most likely less expensive than cleaning up the pollution after the fact.

According to Porter and van der Linde (1995), one of the reasons why effective regulations are necessary to trigger innovative solutions is to ensure that companies cannot gain competitive advantage by not implementing environmentally sound technologies when the cost of new technologies are not covered by resource productivity gains. Another reason is to create demand for environmental improvement while resource inefficiencies and pollution are not measured completely or accurately (Porter & van der Linde, 1995). This is further explored in Chapter 6 by the assignment of costs to ecosystem services.

In natural resource industries in Canada, such as the oil sands, regulations must be "responsive, intelligent and innovative" in order to "break down the barriers that have constrained thought, action, and innovation" (Vredenburg & Westley, 1997). Governments must find a balance between over and under-regulating and create partnerships with industry to promote information dissemination to promote new technologies (Vredenburg & Westley, 1997).

Jaffe, Newell and Stavins suggest that regulations may decrease the risk and uncertainty of investing in new technology and innovations; and regulation can help to break down the internal company barriers to change (Jaffe, Newell, & Stavins, 2001). To implement an expensive new technology, such as the Bitmin technology, the cost is significant. When used appropriately, government regulations can provide companies with a push towards developing new, more effective ways to operate.

Considering the above arguments, it is clear that stronger and more effective water use regulations will be the key to increasing efficiency in the oil sands and maintaining necessary flows in the Athabasca River. By reducing the water allocated to oil sands operations, efficiency innovations will quickly follow. The surface and groundwater demands of oil sands production combined with the amount of water trapped in long term containment ponds necessitate immediate and innovative changes to development of the oil sands in Alberta in order to avoid serious impacts to aquatic ecosystems and possible water shortages in the future.

5.4. Oil Sands Developers Water Management

Companies which propose to develop oil sands projects must meet many requirements in order to meet regulatory requirements and gain approval, as seen in the previous sections. Oil sands developers also have their own, internal policies for water management. Excess water use as well as tailings production and storage are all factors which represent huge costs in this industry. It is in the best interests of oil sands developers to research innovations in these areas. Public opinion and social legitimacy are also important issues that strongly influence the behaviour of oil sands developers. Due to the increasing public scrutiny concerning industry impacts on the environment, it has become clear that the industry must continuously be improving environmental performance and working in consultation with all stakeholders to address these concerns.

Suncor's water management plan has a goal of making Suncor the lowest intensity water user in the industry, reducing water intake by 12% by 2015 (Suncor Energy, 2009). They also expect to be the first in the industry to have a trafficable tailings pond surface in 2010 (Suncor Energy, 2009). In pursuit of reducing long term tailings storage in the 1990's Suncor helped to pioneer the consolidated tailings technology and achieve solid surfaces within years instead of decades (Suncor Energy, 2009). They are currently working on new dewatering technologies to further accelerate reclamation of tailings ponds.

6 CHAPTER SIX: ENVIRONMENTAL CONSEQUENCES OF OIL SANDS WATER USE

6.1. Water Withdrawals

The primary source of water used in Alberta oil sands mining operations is the Athabasca River (CAPP, 2009). Oil sand operations are the largest users of water from this river accounting for almost 65% of the water withdrawals (Woynillowicz & Severson-Baker, 2006). In 2007, the oil sands industry withdrew around 5 cubic meters of water per second (160 million cubic meters per year) from the Athabasca River (CAPP, 2009).

Instream flow refers to the amount of water flowing in a river at a specific point in time (DFO, 2009). It varies with season, snowmelt, rainfall and temperature. Instream flow is used to determine the Instream Flow Need (IFN) of a river. The IFN is "a scientific recommendation about the amount of water, flow rate, water level, or water quality that is required to sustain a healthy ecosystem" in a river, lake or other water body (AENV & DFO, 2007). To determine the IFN threshold value for the Athabasca River, hydrology, biology, geomorphology, water quality, and connectivity were all considered (DFO, 2009). Instream flow needs were determined to be maintained by a maximum withdrawal of 5.2% of the median annual flow. In the Athabasca, average seasonal flow is naturally low in the winter around 860 m^3/s in the summer and 180 m^3/s in the winter (AENV & DFO, 2007). There is a maximum withdrawal of 15 m^3/s in winter and 34 m^3/s during spawning and summer (AENV & DFO, 2007).

Low winter flows are a problem because of low oxygen concentrations. These are known to be detrimental to the eggs and fry of species of fish, such as Lake Whitefish and bull trout (Davidson & Hurley, 2007). Other problems with low flows can be the inability of some fish to reach their spawning sites and loss of fry nursery sites (Davidson & Hurley, 2007).

In 2007, the oil sands industry withdrew around 5 m^3/s, well under the amount currently allocated to these operations (CAPP, 2009). However during winter months, current plus approved (projects which have not yet been built) allocations are over the 5.2% of median flow which is considered appropriate to maintain Instream Flow Needs, as seen in Figure 6.1 (CERA, 2009).

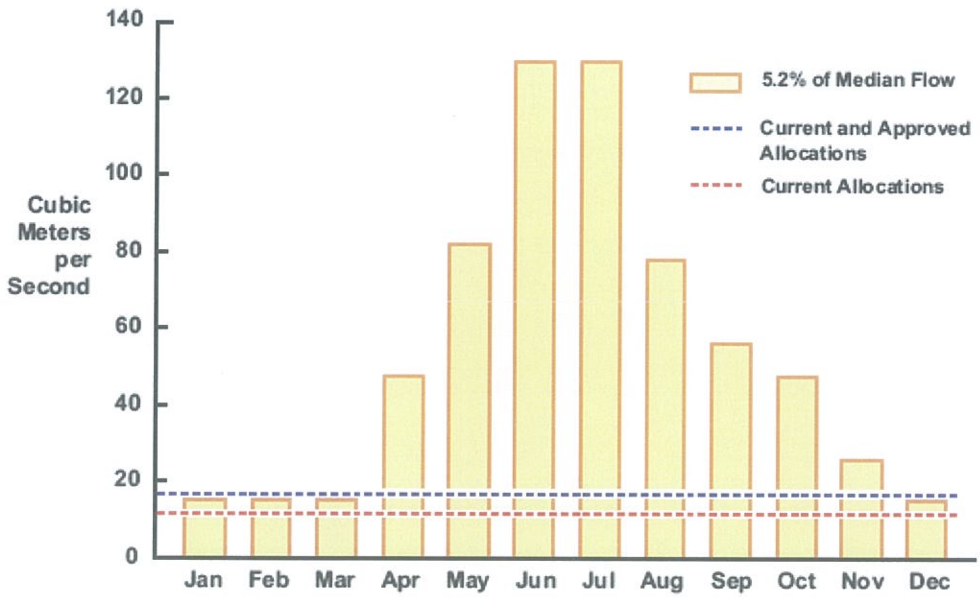


Figure 6.1: Athabasca River flow: 5.2% of median flow compared to allocated withdrawals (CERA, 2009)

Average low flows in the Athabasca River have been declining over the last 30 years largely because of climate warming and decreased snow fall (Davidson & Hurley, 2007). Summer flows have declined by 29% from 1970 to 2005 and lowest winter flows also show a downward long-term trend (Davidson & Hurley, 2007).

Large increases in the demand for water for oil sands extraction and processing can be expected in the future. Considering estimates of the increase in oil sands development, by 2020, the demand for water by oil sands production could be nearly half of the Athabasca's low winter flow (Schindler & Donahue, 2006). Water allocations from the Athabasca are based on annual withdrawal amounts and therefore larger amounts than can be sustained during the winter months will be allotted. New mine projects will have to store water during the summer months in order to allow for continued operation in the winter months when water flow from the Athabasca is restricted (CERA, 2009).

6.2. Tailings Ponds

Tailings are a waste by-product of oil sands production. Tailings are a result of oil sands development which can alter both water quality and quantity, quality through seepage from tailings ponds into groundwater or surface waters; and quantity through long term entrapment in tailings ponds. They are generated during the extraction process which separates the bitumen from the oil sand. The tailings are stored in lake-sized reservoirs while they separate into sand, water, and a slurry called mature fine tailings (MFT). The water is recycled and the sand reclaimed, but the silt and clay portion of the MFT do not support the soil overburden required for reclamation, even after 40 years of settling (Mikula, Munoz, & Omotoso, 2008). MFT have to bearing strength, no vegetative potential and are toxic to aquatic organisms. MFT are 60 to 70% water and 30 to 40% solids (of which 50% is clays) (Jede, 2007), they tie up water and reduce the amount of recycle available to continued operations.

Currently around 3.5 barrels of water per barrel of produced bitumen becomes "tailings" (Mikula, Munoz, & Omotoso, 2008). Considering projected production levels for 2015, if current extraction practices and tailings treatment remain unchanged, approximately 750 thousand m^3 of MFT will be produced from oil sands bitumen extraction each day (Grant, Dyer, & Woynillowicz, 2008). In June of 2008, the Energy Resources Conservation Board (ERCB) of Alberta stated that there was an estimated 720 million m^3 of MFT which require long term containment (ERCB, 2008). As seen in Figure 6.2, these ponds have been increasing in size since 1968 (Houlihan & Mian, 2009). They cover an area of 130 km^2 of northern Alberta land that was initially boreal forest and wetlands (Jede, 2007) and, as of yet, there has been no successful reclamation of a tailings pond demonstrated (Grant, Dyer, & Woynillowicz, 2009).

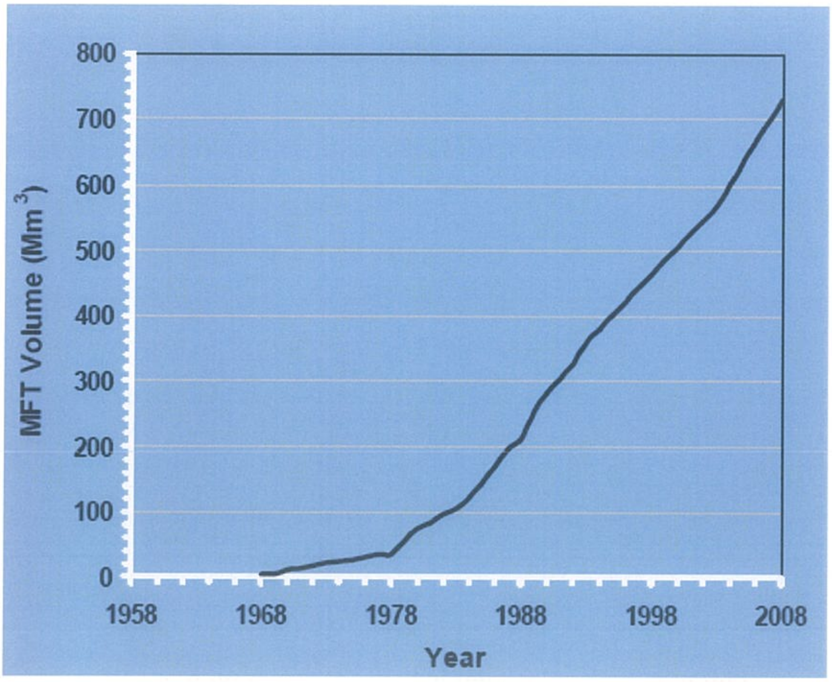


Figure 6.2: Existing mature fine tails (MFT) volumes (Houlihan & Mian, 2009)

Tailings are made up of a mixture of water and sand, as well as a slurry of silt and clay known as mature fine tails (MFT). These MFT contain naphthenic acids which are known to be toxic to aquatic organisms (Rogers, Wickstrom, Liber, & MacKinnon, 2002). Tailings pond waters may contain concentrations of naphthenic acids as high as 110 mg/L (Headley & McMartin, 2004). Other substances which exceed the ambient water quality guidelines for protection of aquatic life (Canadian Environmental Quality Guidelines) include benzene, phenols, toluene, polycyclic aromatic hydrocarbons, ammonia, aluminum, arsenic, copper, cyanide, and iron (CERA, 2009). The concentration of polycyclic aromatic compounds (PACs) in the pore water of the settled tailings can reach as high as 2.6 μg/L (Madill, Orzechowski, Chen, Brownlee, & Bunce, 2001).

Alberta has a "zero discharge policy" which prohibits intentional releases of tailings material to the environment but it is assumed that these earthen pits do seep into the nearby Athabasca River at an unknown rate (Grant, Dyer, & Woynillowicz, 2009) however there is no public data available about tailings ponds seepage. "Seepage from tailings ponds into the groundwater does occur" (CAPP, 2009). The clay content in the tailings which settle to the bottom of the pond creates a low permeability layer so it is assumed that seepage rates are very low (CAPP, 2009).

Groundwater quality has been monitored as well as water quality in the Athabasca River and surrounding lakes with no significant regional changes related to oil sands development or tailings pond seepage (RAMP, 2008). Water quality monitoring is carried out by a multi-stakeholder, multi group which is funded mainly by oil companies. An independent scientific peer review of RAMP's reports was completed in 2004 and found significant problems, including lack of details of methods, inappropriate statistical analysis and unsupported conclusions (Ayles, Dubé, & Rosenberg, 2004). Concerns were also raised about the structure of the Program itself. The peer review team found problems related to the scientific leadership of the Program, lack of overall regional plan, significant problems with statistical design of individual Program components (Ayles, Dubé, & Rosenberg, 2004).

Mitigation measures are used by the oil sands industry to minimize the extent of tailings pond leakage. Ditches are constructed to collect runoff from the tailings facility, this water is then pumped back into the tailings pond (CAPP, 2009). Groundwater interception wells are used to capture pond seepage, which is also pumped back into the pond (CAPP, 2009). Cut off walls are also constructed to prevent seepage migration (CAPP, 2009).

The tailings ponds are covered in a surface layer of bitumen. In 2008, around 1600 migrating ducks died after landing on a Syncrude tailings pond (Holroyd & Simieritsch, 2009). Cannons, scarecrows, decoy predators and radar/laser deterrent systems usually prevent birds from landing on the tailings ponds but extreme weather conditions kept these devices from being employed at the time of this incident.

Another concern dealing with the tailings ponds is the possibility of dyke failure. Although the likelihood is low, the impacts to aquatic ecosystems would be catastrophic considering the size of the ponds and their proximity to the Athabasca River (Grant, Dyer, & Woynillowicz, 2009). In April of 1998, a large tailings pond dam failed at Los Frailes, a lead-zinc mine in Spain. Acidic, toxic water spilled out and contaminated several rivers as well as a large area of farmland (Holroyd & Simieritsch, 2009).

One way to manage tailings is end pit lakes (EPLs). Once a mining operation is completed the mine pit would be filled with tailings and then capped with water. The lake would be very deep (65-100 meters) which would prevent mixing of the tailings and surface water (Holroyd & Simieritsch, 2009). This type of wet landscape reclamation is difficult and has several unknown long term monitoring liabilities (Mikula, Munoz, & Omotoso, 2008).

End pit lakes (EPLs) are used in other mining sectors but only as water drainage control before water is discharged into the environment (Grant, Dyer, & Woynillowicz, 2009). It is hoped that ultimately these lakes will become biologically active, self-sustaining and functional ecosystems (Westcott & Watson, 2007). However, "there are uncertainties regarding the construction, maintenance and final success of EPLs" (Westcott & Watson, 2007). "Historical data are insufficient to determine a realistic outcome of the final features of EPLs" (Westcott & Watson, 2007). Modelling has been the basis of the research about these lakes. EPLs have been approved by the Energy Resources Conservation Board (ERCB) subject to successful full-scale demonstration (Westcott & Watson, 2007). End pit lakes are currently the lowest cost reclamation option for mature fine tailings (MFT) (Mikula, Munoz, & Omotoso, 2008). However a functioning end pit lake has not yet been constructed (Westcott & Watson, 2007).

6.3. Wetland Destruction/ Habitat Loss

The oil sands region of northern Alberta is mainly boreal forest and the majority of the landscape (30-40%) is made up of wetlands (CERA, 2009), mainly bog and fen peatlands (Alberta Environment, 2008). It is estimated that more than 60% of Alberta's sloughs, marshes, potholes and ponds have been lost since the beginning of settlements in this area (NAWMP, 2009). With increased knowledge of the benefits of wetlands, focus has shifted to land management practices that allow both wetlands and people to benefit (NAWMP, 2009). Policy worldwide is changing to protect the future of these valuable ecosystems.

The United States has implemented a national policy of no net loss of wetlands, with provisions stipulating the destruction of one area of wetland must be compensated for with another area of similar wetland (Keddy, et al., 2009).

Vast areas of these peatlands are destroyed or drained by oil sands mines in order to reach bitumen containing layers (Davidson & Hurley, 2007). Another concern is mine dewatering; this is the drainage of the wetlands around a mine so that the mine pit doesn't fill with water. "Mining operations result in a total loss of the ecological character of the disturbed land" (CERA, 2009). This type of ecosystem is a very important component of the boreal forest (Alberta Environment, 2008). Wetlands improve diversity, purify surface and groundwater, and minimize soil erosion (Holroyd & Simieritsch, 2009). Wetlands in the oil sands region are at or near a water deficit most years (Alberta Environment, 2008). They need a water supply which supports saturated soils for at least part of the year which may not be possible with the current water trends (Alberta Environment, 2008).

The destruction of these vital areas is especially concerning since successful reclamation of peatlands has never been demonstrated (Grant, Dyer, & Woynillowicz, 2009). In fact, some believe that the area cannot be reclaimed to its original condition and may not even be restored to a condition with equivalent hydrological function (Davidson & Hurley, 2007). The complex interaction of climate, hydrology, geology, ecology and time which occurs in nature will be difficult to replicate. Reclamation efforts will likely result in a combination of highland forest and wetlands (CERA, 2009).

In situ projects disturb a smaller surface area in comparison to mining, however in terms of total projects nearly 18% of the total area of Alberta is leased for in situ development (CERA, 2009). Decreases in the populations of certain species, such as lynx, wolves, and caribou are expected as a result of the forest fragmentation by this development (CERA, 2009).

The Regional Aquatic Monitoring Program (RAMP) monitors watersheds where oil sands development is occurring or is planned in the future (RAMP, 2008). The Athabasca River basin is shown in Fig 2. Water quality is monitored, as well as fish populations and benthic invertebrate communities (RAMP, 2008). In 2007, sampling results showed that there were only detectable changes attributable to oil sands development in three tributaries of the Athabasca River, Muskeg River, Poplar Creek, and Tar River (RAMP, 2008). Muskeg River, entering the Athabasca from the east, has experienced an increase in runoff due to land clearing (RAMP, 2008). Poplar Creek from the west has undergone changes because of spillway output regulation (RAMP, 2008).

The Tar River reaches the Athabasca from the west (Figure 6.3). In 2004, Fisheries and Oceans Canada (DFO) gave authorization to Canadian Natural Resources Ltd. (CNRL) to divert the lower Tar River for use in the Horizon Oil Sands Project (RAMP, 2008). A 76.7 hectare compensation lake was constructed to make up for this loss of fish habitat according to the No Net Loss Plan (RAMP, 2008). The lake creates twice as much fish habitat as will be lost by the development (CAPP, 2009). It was designed to create different habitats and spawning areas to sustain at least eight fish species important to the nearby community (CAPP, 2009). The lake was created in May of 2008 and has been a success (CAPP, 2009).

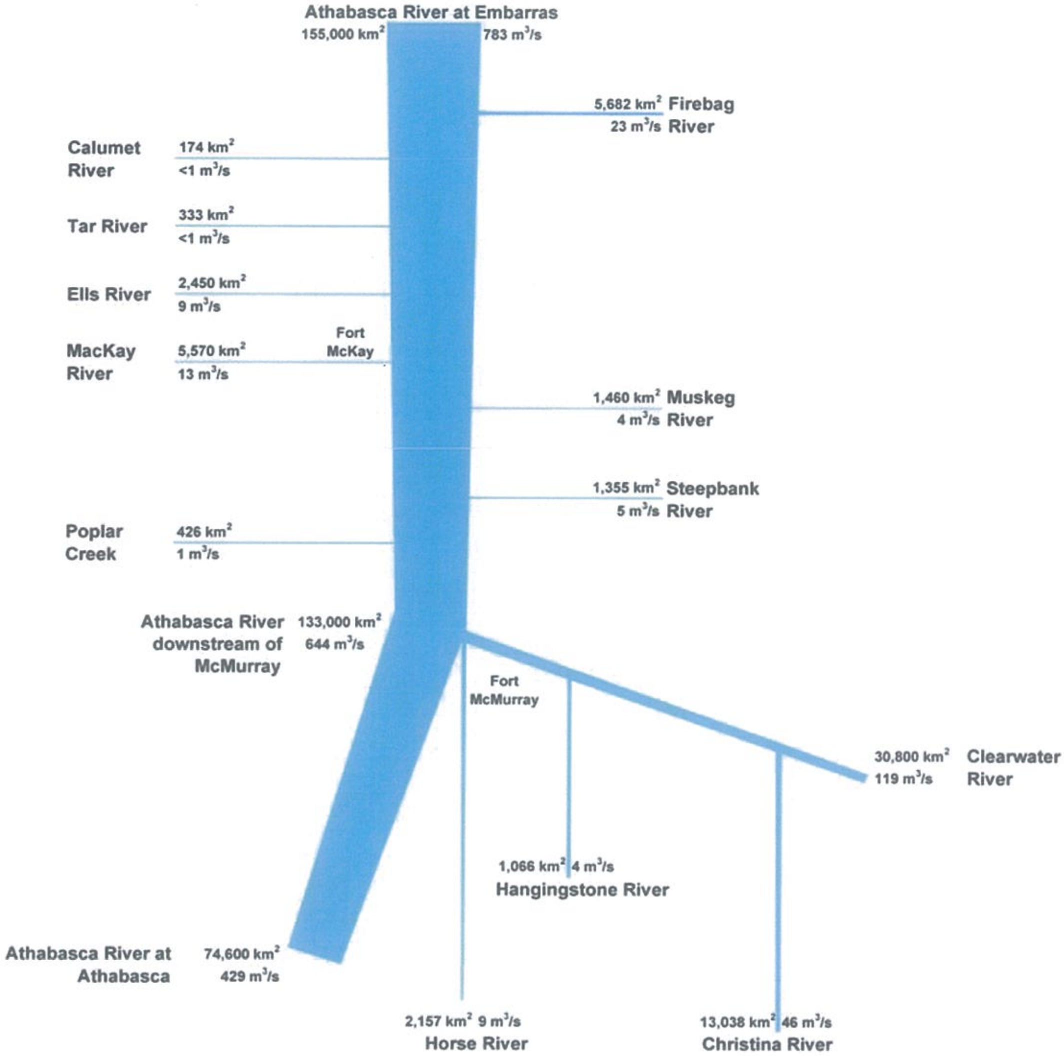


Figure 6.3: Tributaries of the Athabasca River within the Athabasca oil sands region

6.4. Groundwater Withdrawals

Oil sands extraction through in situ methods requires large amounts of water for steam generation. Brackish (saline) and fresh sources of groundwater are used in oil sands operations. This water is drawn mainly from underground aquifers and can reduce the water available for downstream ecosystems (Holroyd & Simieritsch, 2009). Basal aquifer depressurization affects groundwater volumes, aquifers and surface water levels (Jede, 2007). In situ extraction also effects water resources by deep well waste water disposal leaching into surrounding aquifers as well as pipeline and road river crossings increasing sediment flows (Holroyd & Simieritsch, 2009).

Fresh water aquifers are generally shallow and renewable, meaning they will eventually recharge from precipitation and surrounding water bodies. In 2007, 9 million m^3 of non-saline groundwater was used for in situ operations (Water Matters, 2009). The rate of water extraction from these water bodies that does not damage the surrounding wetlands is unknown and difficult to determine (CERA, 2009). The hydrogeology of these aquifers is complicated and poorly understood partly because of their hydraulic connection to the wetlands of the boreal forest (CERA, 2009). However, the effects of this extensive use of groundwater are predicted to be profound (Water Matters, 2009). Groundwater quality may also be affected as the high temperatures used to heat bitumen formations during in situ extraction may release naturally occurring arsenic into the groundwater (Water Matters, 2009). Studies by Imperial Oil found that arsenic was released from sediments when samples were heated from 50 to 200°C, with the rate of arsenic release increasing with increasing temperature (Imperial Oil Limited, 2003). The release stops when steaming operations stop and it is unknown if or how much of the arsenic is later re-adsorbed (Imperial Oil Limited, 2003).

Brackish sources of groundwater are very deep and very extensive, however these sources will not recharge with time unlike freshwater aquifers. In some areas they may be hydraulically connected to fresh sources closer to the surface (CERA, 2009). Studies are underway but it is generally unknown what the impact of depleting these water sources will be.

The Oil Sands Consultations Multistakeholder Committee Final Report recommended complete mapping and inventory of groundwater aquifers in Alberta, as well as quality and quantity reporting improvements throughout the oil sands area (Government of Alberta, 2007). Monitoring wells are necessary to understand the cumulative impact to these groundwater resources (Water Matters, 2008). Records of water withdrawals from specific aquifers are also essential to determining the impacts (Water Matters, 2008).

6.5. Ecosystem Services

Ecosystem services are defined as the "benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious, and other nonmaterial benefits." (Costanza, et al., 1997)

Wetland ecosystem services are very important to human well being (Costanza, et al., 1997). Wetlands increase biodiversity, purify surface and groundwater; minimize soil erosion, water storage, groundwater recharge, flood control, microclimate regulation, habitat, recreation, and aboriginal cultural use. "The health of plants, animals and communities is determined by the availability and quality of water resources" (Holroyd & Simieritsch, 2009). Some of the most important ecosystem services provided by wetlands are gas regulation, disturbance regulation, water regulation, water supply, waste treatment, habitat/refugia, food production, raw materials, recreation, and cultural (Costanza, et al., 1997).

Ecological functions can be broken down into four categories, including habitat functions, regulation functions, production functions and information functions (de Groot, Wilson, & Boumans, 2002). These functions provide the goods and services which are valued by society in various ways (de Groot, Wilson, & Boumans, 2002).

The habitat function of wetland ecosystems is especially important in this area of Northern Alberta as it is critical territory for Woodland Caribou, moose, muskrat, beaver, waterfowl (especially diving ducks), and amphibians (Alberta Environment, 2008). Wetlands provide refuge and reproduction habitat as well as the main food source for many of these animals, such as the lichens that Woodland Caribou rely on (Alberta Environment, 2008). Studies have shown that at least 158 species of bird depend on wetlands in Alberta for some part of their life cycle (NAWMP, 2009). There are 17 species of mammals and 15 species of amphibians and reptiles which must have wetland habitat to survive (NAWMP, 2009).

Nearly one third of Alberta's species-at-risk are supported by Alberta's wetlands, including the peregrine falcon, piping plover, yellow rail, long-billed Curlew and whooping crane (NAWMP, 2009). Wetlands are also home to more than 20 rare plants (NAWMP, 2009).

The Athabasca River flows north through the oil sands region and into the Peace-Athabasca Delta, one of the world's largest freshwater deltas and the largest boreal delta (Davidson & Hurley, 2007). The waters then flow through the Slave and Mackenzie Rivers until they reach the Arctic Ocean.

The Peace-Athabasca delta is a very important nesting and migration staging area for waterfowl in North America (CERA, 2009) and is on the Ramsar list of Wetlands of International Importance (Holroyd & Simieritsch, 2009). It is used by 400,000 birds in spring and more than 1 million in the fall and is prime range for 5000 bison (Davidson & Hurley, 2007). The Peace-Athabasca Delta also has supported large communities of aboriginal people for millennia (Davidson & Hurley, 2007).

The Peace-Athabasca delta is part of the Mackenzie River Basin which is the world`s fifth largest wetland by area (Keddy, et al., 2009). Most wetland services increase with area, in fact some services, like fish production or stream flow maintenance may be directly proportional to area (Keddy, et al., 2009). Carbon sequestration and biodiversity support have more complex relationships to area (Keddy, et al., 2009).

Gas regulation and climate regulation are two closely related regulation functions (de Groot, Wilson, & Boumans, 2002). These functions are especially important in this area as peatlands are the most effective at carbon storage out of all ecosystem types (UNEP/GRID-Arendal, 2009). They store an average of 1,450 tonnes (t) of carbon per hectare (UNEP/GRID-Arendal, 2009). Peatland degradation contributes up to 800 million tonnes of carbon each year (UNEP/GRID-Arendal, 2009). Instead of expensive programs of carbon capture and storage underground, natural ecosystem approaches should be considered (UNEP/GRID-Arendal, 2009). However, as wetlands also release methane into the atmosphere, the cooling effects of carbon storage may be nearly offset (Keddy, et al., 2009).

The wetland ecosystem function of regulation can positively affect water quality (de Groot, Wilson, & Boumans, 2002). Wetland vegetation can take up and store nutrients and chemicals, thereby decreasing contamination problems (NAWMP, 2009). Microorganisms can also breakdown harmful sediments (NAWMP, 2009). Wetlands are a valuable resource for cleansing wastewater from industry before it enters drinking water sources and other water bodies (NAWMP, 2009).

The loss the valuable wetland ecosystem and the regulation function of water purification can cause stress and toxicity to aquatic organisms through contaminated water. Studies have shown that tailings pond water can disrupt normal endocrine functioning and alter biosynthesis of reproductive hormones of exposed goldfish (Lister, Nero, Farwell, Dixon, & Van Der Kraak, 2008). Repeated exposure to naphthenic acids has also been found to have adverse health effects in mammals (Rogers, Wickstrom, Liber, & MacKinnon, 2002).

Unsuccessful water purification can also lead to serious health effects. In the community of Fort Chipewyan, there are questions as to the rates of some chronic diseases such as Graves disease, kidney failure, and blood cancers. Multiple studies have been conducted with inconclusive results (CERA, 2009). Because of the small sample size (population of about 1,200) and other contributing factors (other industries in the area, natural oil sands seeps) it is difficult to attribute incidence of illness to a particular contamination source (CERA, 2009).

Further downstream from Fort Chipewyan, in the Northwest Territories, people are concerned about the possibility of poor water quality affecting drinking water, traditional subsistence activities, tourism, and commercial fishing (Holroyd & Simieritsch, 2009). Local residents feel their water resources are in jeopardy and wish to see effective water management standards in place before irreparable damage is done (Holroyd & Simieritsch, 2009).

The production function of wetlands can include provision of food and raw materials (de Groot, Wilson, & Boumans, 2002). Many residents of these northern communities rely on hunting, fishing, trapping and gathering for their subsistence and have a close relationship with their environment (CERA, 2009). Northern Aboriginal people have an extensive knowledge of their surroundings and the capacity to observe and perceive changes in their environment because of a strong relationship with their surroundings (Furgal & Seguin, 2006). Their close relationship with the environment as well as their reliance on the land for subsistence often makes indigenous populations more vulnerable to environmental changes and contaminants (Furgal & Seguin, 2006) (CERA, 2009).

Information functions include providing opportunity for spiritual enrichment, learning, recreation, and aesthetic experience (de Groot, Wilson, & Boumans, 2002). This area provides recreation for local communities as well as traditional land use opportunities (CERA, 2009). However, First Nation's people are losing the ability to pursue their traditional way of life (Water Matters, 2009). In one small indigenous community nearly 60% of local trap lines were lost because of oil sand developments and 57% of the land within 20 km of the community is either mined or approved for mining (Water Matters, 2009). These issues may also hinder the ability of native peoples to pass on their traditional knowledge to younger generations. Wetlands in the oil sands region have traditionally been highly valued for indigenous cultural and spiritual growth as well as Aboriginal cultural integrity (Alberta Environment, 2008). Recreation activities supported by wetlands include fishing, hunting, wildlife viewing, trapping, and even gardening through the horticulture peat industry (Costanza, et al., 1997).

The assessment of the value of ecosystem functions, goods and services can be attributed to ecological, socio-cultural and economic merit (de Groot, Wilson, & Boumans, 2002). New approaches to conservation include an alignment with economic forces that emphasize the link between human and environmental well-being (Daily & Matson, 2008). The estimated total value per hectare is calculated as $14,785/year (Costanza, et al., 1997). This amount is not completely captured by the market system and therefore ecosystem services are often not given the proper emphasis in policy decisions (Costanza, et al., 1997). The environment must increasingly be managed in a way that accurately reflects the social value of ecosystem services to society (Daily & Matson, 2008).

According to the Millennium Ecosystem Assessment, global climate change is expected to increase the loss and degradation of wetlands, and the decline of their associated species (Millennium Ecosystem Assessment, 2005). Decisions involving the fate of wetlands need to take into account the full range of benefits and values provided by wetland ecosystem services (Millennium Ecosystem Assessment, 2005). Regulators need to meet the challenge of recognizing the full value of natural capital assets and the life-support services that they provide (Daily & Matson, 2008). "In an era of rapidly growing human populations, and forecasts of extensive climate change and enormous losses of biodiversity, the wise management of the world's largest wetlands is vital" (Keddy, et al., 2009).

7 CHAPTER SEVEN: CONCLUSIONS

Alberta's development of the oil sands is a controversial issue that has no easy solutions. According to a compilation of viewpoints gathered by the Alberta Oil Sands Consultation Multi-Stakeholder Committee, an important and commonly shared idea was that "an orderly pace of development requires responsible environmental management" (Government of Alberta, 2007). To the committee it was obvious that oil sands development will, and should, go forward but the pace of development was in question. They stated that oil sands companies should not be expanding operations until it is shown that current and long term impacts to natural resources, including water, are being adequately addressed (Government of Alberta, 2007).

In the introductory chapter, it was shown that as global and domestic energy demands expand, oil sands development is becoming increasingly relevant to the energy sector. Although the bitumen contained in the Athabasca oil sands is more costly to recover than conventional oil reserves, as energy supplies decrease, the oil sands have become economical to produce. In addition to supplying energy, development of the oil sands in Alberta produces financial benefits for all of Canada. Oil sands projects are an essential component of the economy and labour market in Alberta (Government of Alberta, 2009).

As discussed in Chapter Two, water use by industry and individuals in Canada is among the highest in the world and the oil sands industry is particularly water intensive. Surface waters, groundwater resources, and wetlands can all be affected by changes in water quantity. Quality of water resources can also be affected by oil sands development through tailings ponds seepage and site drainage (Veil & Puder, 2006). Polycyclic aromatic hydrocarbons, naphthenic acids, trace metals and salts are contaminants of concern specific to the oil sands industry which can have harmful effects on humans.

Global freshwater shortages are a real and growing threat, to which climate change and extensive use are exacerbating. Adequate water quantity and quality is essential to both economic and ecological systems, therefore the sustainable use of this resource is crucial to maintain economic and social development. For these reasons, water was the focus of this report.

As demonstrated in Chapter Three, the majority of the water used in oil sands mining is used in the hot water extraction process to separate the bitumen from the sand. Furthermore, water usage rates for oil sands mining will decline by reducing the amount of water which becomes entrapped in mature fine tails and then must be stored in tailings ponds. Coagulants, such as gypsum, can be used to rapidly release water from tailings produced through the hot water extraction process. Centrifuge technology can also be used to separate water from the fine tails. There are many de-watering techniques being studied to accelerate water release from tailings, however these technologies also lead to reduced water quality and therefore increased need for treatment of water for recycle. Research into a non-water based extraction method is necessary to further reduce water use during oil sands mining.

Thermal in situ recovery requires a lot of water for the production of steam used in bitumen extraction. Most of the water used for steam production is from brackish groundwater sources. As discussed in Chapter Four, water usage rates for the recovery of deep oil sands reservoirs can be reduced by using in situ methods which requires less, or preferably, no, steam. The use of solvents, in situ combustion, and electric induction are being tested and may significantly decrease the water usage if successful. This is extremely important since the majority of the remaining oil sand reserves will be recovered through in situ techniques.

Although there are many regulatory and approval processes which oil sands companies must complete before they are able to operate, as outlined in Chapter Five, no oil sands development project has ever been rejected. Research into the role of government regulation in industry indicates that technological innovation and resource productivity are accelerated by properly designed environmental regulations (Porter & van der Linde, 1995). Additionally, regulatory controls are important to ensure companies will not gain competitive advantage by ignoring environmentally sound technologies. In the oil sands industry, new technologies require considerable investments and time for development and testing. Significant investments into technologies which decrease fresh water usage and tailings production are an important component of the internal environmental management plans of oil sands companies because of costs as well as public opinion. However, government regulation can also be a driver, decreasing the financial risk of investing in new technology and accelerating the pace of research advances.

It is necessary that Phase 2 of the Regulatory Backstop to Protect the Athabasca River address implementation and enforcement plans as well as ensure that withdrawals from the Athabasca are not cumulatively over those needed to maintain instream flow needs. Compliance with Directive 074 must be enforced in order to ensure that leaders in terms of tailings advances are recognized and have incentive to continue innovating. Introduction of Alberta's New Wetland Policy is essential to ensure no net loss of wetlands. Quantification, reporting, and analysis of the use of groundwater (both saline and fresh) are important to avoid future impacts to wetlands and water tables.

Given that no oil sands development project has ever been rejected, consequences to water resources discussed in Chapter Six include over-allocation of Athabasca River withdrawals (above levels determined to be necessary to protect instream flow needs) (AENV & DFO, 2007); accumulations of tailings since 1968 which now cover a combined area of 120 square kilometres (Houlihan & Mian, 2009); loss of wetlands without construction of compensatory wetlands and no proven reclamation capabilities (Grant, Dyer, & Woynillowicz, 2009); as well as unknown long term impacts to groundwater sources.

"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" (Davidson & Hurley, 2007). In addition to the environmental impacts and loss of ecosystem services mentioned in this report, other motivators for improvements in water use practices in the oil sands are conservation of energy and consequent cost savings as well as public concerns about water shortages. A balance must be found among water requirements for the oil sands industry and water requirements for ecosystem maintenance in order to realize the oil sands potential and protect the environment.

Through appropriate regulation of oil sands development, Alberta has an opportunity to provide revenue and energy for many years to come. Given the potential for water scarcity and the associated impacts on economic growth and environmental quality, sustainable water management is essential.

REFERENCES

AENV & DFO. (2007). *Water Management Framework: Instream Flow Needs and Water Management System for the Lower Athabasca River.* Alberta Environment and Fisheries and Oceans Canada.

AENV. (2009). *Athabasca River Water Management Framework.* Edmonton: Alberta Environment.

Alberta Energy Research Institute. (2005, October 20). *Alberta's Oil Sands: Not Just for Caulking Canoes.* Retrieved June 1, 2009, from Rigzone: http://www.rigzone.com/training/heavyoil/insight.asp?i_id=186

Alberta Environment. (2008). *Alberta's Environmental Assessment Process.* Edmonton: Environmental Assessment Program.

Alberta Environment. (2008). *Guideline for Wetland Establishment on Reclaimed Oil Sands Leases.* Fort McMurray: Cumulative Environmental Management Association.

Alberta Environment. (2004). *Water and Oil: An Overview of the Use of Water for Enhanced Oil Recovery in Alberta.* Edmonton: Government of Alberta.

Alberta Geological Survey. (2009, March 27). *Alberta Oil Sands.* Retrieved June 19, 2009, from Alberta Geological Survey: http://www.ags.gov.ab.ca/energy/oilsands/alberta_oil_sands.html

Alberta Water Resources Commission. (1993). *Water Management in the Settled Area of Alberta: An Interim Policy.* Edmonton: Government of Alberta.

Aquality. (2009). *Alberta Wetland Policy.* Retrieved August 24, 2009, from Alberta's New Wetland Policy: http://www.wetlandpolicy.ca/alberta-wetland-policy/wetland-policy.html

ASRD. (2008, May 21). *Oil Sands Branch*. Retrieved August 11, 2009, from Government of Alberta - Sustainable Resource Development: http://www.srd.gov.ab.ca/lands/oilsands/environmentalimpact.aspx

ATSDR. (2007, September 11). *ToxFAQs - Polycyclic Aromatic Hydrocarbons*. Retrieved October 21, 2009, from Agency for Toxic Substances and Disease Registry: http://www.atsdr.cdc.gov/tfacts69.html

AWRI. (2009). *Accelerated De-watering of Oil Sands Fine Tailing through Biological Processes*. Retrieved August 21, 2009, from Alberta Water Research Institute: http://www.waterinstitute.ca/accelerating_dewatering_of_oil_fine_tailing.htm

Ayles, G. B., Dubé, M., & Rosenberg, D. (2004). *Oil Sands Regional Aquatic Monitoring Program (RAMP) Scientific Peer Review of the Five Year Report (1997-2001)*. Calgary: RAMP Review Team.

Bakker, K. (2006). *Eau Canada: The Future of Canada's Water*. Vancouver: University of British Columbia Press.

Barlow, M. (2007). *Blue Covenant: The Global Water Crisis and the Coming Battle for the Right to Water*. Toronto: McClelland & Stewart Ltd.

Bentley, R. (2002). Global oil and gas depletion: an overview. *Energy Policy*, 189-205.

Bitmin Resources Inc. (2007, September 18). *The Bitmin Process*. Retrieved August 25, 2009, from Bitmin Resources: http://www.bitminresources.com/Process/bitmin_process.htm

Bott, R. D. (2009). *Oil Sands: Questions and Answers*. Calgary: Canadian Centre for Energy Information.

Butler, R. (2001). Application of SAGD, related processes growing in Canada. *Oil & Gas Journal*, 18-22.

Canadian Center for Energy Information. (2009). *Canada's Oilsands.* Edmonton: Canadian Center for Energy Information.

CAPP. (2007). *CAPP Stewardship Report.* Calgary: Canadian Association of Petroleum Producers.

CAPP. (2006). *Environmental Aspects of Oil Sands Development.* Retrieved June 1, 2009, from Canadian Association of Petroleum Producers: http://membernet.capp.ca/raw.asp?x=1&dt=PDF&dn=105401

CAPP. (2009). *Managing Water Use in Canada's Oil Sands.* Edmonton: Canadian Association of Petroleum Producers.

CAPP. (2008). *Oil Sands Economic Impact Across Canada.* Edmonton: Canadian Association of Petroleum Producers.

CEMA. (2006). *Surface Oil Sands Water Management Summary Report.* Fort McMurray: Cumulative Environmental Management Association.

CERA. (2009). *Growth in the Canadian Oil Sands: Finding the New Balance.* Cambridge: Cambridge Energy Research Associates.

CERI. (2009). *Economic Impacts of the Petroleum Industry in Canada.* Calgary: Canadian Energy Research Institute.

Chakrabarty, C., Fossey, J.-P., Renard, G., & Gadelle, C. (1998). *SAGD Process in the East Senlac Field: From Reservoir Characterization to Field Application.* Houston: Beicip-Franlab.

Chalaturnyk, R. J., Scott, J. D., & Ozum, B. (2002). Management of Oil Sands Tailings. *Petroleum Science and Technology* , 1025-1046.

Clark, B. (2007). *Topic Paper 22: Heavy Oil.* National Petroleum Committee on Global Oil and Gas.

ERCB. (2008, January 24). *About the ERCB.* Retrieved August 11, 2009, from Energy Resources Conservation Board: http://www.ercb.ca/portal/server.pt?open=512&objID=260&PageID=0&cached=true&mode=2

ERCB. (2009). *Directive 074: Tailings Performance Criteria and Requirements for Oil Sands Mining Schemes.* Calgary: Energy Resources Conservation Board.

ERCB. (2009). *EnerFAQs.* Edmonton: Energy Resources Conservation Board.

ERCB. (2008, June 26). *Energy Resources Conservation Board - Newsroom.* Retrieved July 25, 2009, from Government of Alberta: http://alberta.ca/home/NewsFrame.cfm?ReleaseID=/acn/200806/23893C59EF805-AA40-FBA3-243F477669C206C6.html

ERCB/AENV. (2009). *Draft ERCB/AENV Directive XXX: Water Measurement, Reporting, and Water Use for Thermal In Situ Oil Sands Schemes.* Edmonton: Energy Resources Conservation Board and Alberta Environment.

ERCB/AENV. (1989). *Water Recycle Guidelines and Reporting of Water Use Information for In Situ Oil Sands Facilities in Alberta.* Edmonton: Alberta Energy and Utilities Board.

EUB. (2005). *Understanding Directive 019: EUB Compliance Assurance-Enforcement.* Calgary: Energy and Utilities Board.

Fu, H., El-Din, M. G., Smith, D. W., MacKinnon, M. D., & Zubot, W. (2008). *Degradation of Naphthenic Acids in Athabasca Oil Sands Process Affected Water Using Ozone.* Edmonton: International Oil Sands Tailings Conference.

Fu, H., El-Din, M. G., Smith, D. W., MacKinnon, M. D., & Zubot, W. (2008). *Degradation of Naphthenic Acids in Athabasca Oil Sands Process Affected Water Using Ozone.* Edmonton: University of Alberta.

Furgal, C., & Seguin, J. (2006). Climate Change, Health, and Vulnerability in Canadian Northern Aboriginal Communities. *Environmental Health Perspectives* , 1964-1970.

Godwaldt, C. (2009, August 12). Water Management Program Director - WaterSMART. (S. Bownes, Interviewer)

Government of Alberta. (2009, May 25). *Alberta Energy: What is Oil Sands*. Retrieved June 2, 2009, from Government of Alberta: http://www.energy.gov.ab.ca/OilSands/793.asp

Government of Alberta. (2009). *Alberta's Oil Sands*. Retrieved August 25, 2009, from Government of Alberta: http://oilsands.alberta.ca/1.cfm

Government of Alberta. (2008). *Environmental Management of Alberta's Oil Sands.* Edmonton: Oil Sands Environmental Management Division.

Government of Alberta. (1993). *Environmental Protection and Enhancement Act.* Edmonton: Queen's Printer.

Government of Alberta. (2009). *Facts about Tailings Management.* Edmonton: Government of Alberta.

Government of Alberta. (2006, October 27). *Groundwater Introduction.* Retrieved January 19, 2009, from Groundwater/Surface Water Quantity: http://www3.gov.ab.ca/env/water/GWSW/quantity/learn/what/GW_GroundWater/GW1_introduction.html

Government of Alberta. (2009). *Legislation/Guidelines*. Retrieved August 24, 2009, from Environment: http://www.environment.alberta.ca/3.html

Government of Alberta. (2009, August 11). *Major Alberta Projects*. Retrieved August 21, 2009, from Alberta, Canada: http://www.albertacanada.com/statpub/1120.html

Government of Alberta. (2007). *Oil Reserves and Production 2007.* Edmonton: Alberta Energy.

Government of Alberta. (2000). *Oil Sands Conservation Act.* Edmonton: Queen's Printer.

Government of Alberta. (2007). *Oil Sands Consultations - Multistakeholder Final Report.* Edmonton: Government of Alberta.

Government of Alberta. (2003). *Water for Life.* Edmonton: Alberta Environment.

Government of Alberta. (2005, September 12). *Water in Alberta.* Retrieved January 19, 2009, from Groundwater/Surface Water Quantity: http://www3.gov.ab.ca/env/water/gwsw/quantity/waterinalberta/index.html

Grant, J., Dyer, J., & Woynillowicz, D. (2009). *Clearing the Air on Oil Sands Myths.* Drayton Valley: The Pembina Institute.

Grant, J., Dyer, S., & Woynillowicz, D. (2008). *Fact or Fiction? Oil Sands Reclamation.* Drayton Valley: The Pembina Institute.

Griffiths, M., & Woynillowicz, D. (2003). *Oil and Troubled Waters: Reducing the impact of the oil and gas industry on Alberta's water resources.* Drayton Valley: Pembina Institute.

Griffiths, M., Taylor, A., & Woynillowicz, D. (2006). *Troubled Waters, Troubling Trends.* Drayton Valley: The Pembina Institute.

Headley, J. V., & McMartin, D. W. (2004). A Review of the Occurrence and Fate of Naphthenic Acids in Aquatic Environments. *Journal of Environmental Science and Health* , 1989-2010.

Heinrich, E. (2008, May 22). Well-Oiled Machine. *Time Magazine* .

Heins, W. F., McNeill, R., & Albion, S. (2005). World's First SAGD Facility Using Evaporators, Drum Boilers, and Zero Discharge Crystallizers to Treat Produced Water. *Petroleum Society Journals* , 1-10.

Hoffman, A. R. (2004). The Connection: Water and Energy Security. *Institute for the Analysis of Global Security* , 1-6.

Holroyd, P., & Simieritsch, T. (2009). *The Waters That Bind Us: Transboundary Implications of Oil Sands Development.* Drayton Valley: The Pembina Institute.

Houlihan, R., & Mian, H. (2009). *ERCB Tailings Directive 074.* Fort McMurray: Energy Resources Conservation Board.

Imperial Oil Limited. (2003). *Cold Lake Expansion Projects: Nabiye and Mahihkan North Additional Supplemental Information Update.* Calgary: Imperial Oil Limited.

Industry Canada. (2009, January 8). *Canadian Technology in the Oil and Gas Industry.* Retrieved May 20, 2009, from Canadian Oil and Gas Industry: http://www.ic.gc.ca/eic/site/ogt-ipg.nsf/eng/dk00095.html

IPCC. (2008). *IPCC Technical Paper on Climate Change and Water.* Intergovernmental Panel on Climate Change.

Jaffe, A. B., Newell, R. G., & Stavins, R. N. (2001). *Technological Change and Environment.* Washington, D.C.: Resources for the Future.

Jede, N. (2007). *Water Use in Alberta Oil Sands.* Edmonton: Government of Alberta.

JuneWarren-Nickle's Energy Group. (2009). *Oilsands Glossary.* Retrieved August 27, 2009, from Oilsands Review: http://www.oilsandsreview.com/page.asp?id=glossary

Kaminsky, H. A., Etsell, T. H., Ivey, D. G., & Omotoso, O. (2009). Distribution of Clay Minerals in the Process Streams Produced by the Extraction of Bitumen from Athabasca Oil Sands. *Canadian Journal of Chemical Engineering* , 85-94.

Keddy, P. A., Fraser, H. L., Solomeshch, A. I., Junk, W. J., Campbell, D. R., Arroyo, M. T., et al. (2009). Wet and Wonderful: The World's Largest Wetlands are Conservation Priorities. *Bioscience* , 39-51.

Kunzig, R. (2009, March). Scraping Bottom. *National Geographic* .

Kutzak, A. (2004). Effect of Potential Limits on Water Withdrawal on SAGD Operations. *Oil Sands Water Usage Workshop* (pp. 1-14). Fort McMurray: CONRAD Research Group.

Lowell, S. (2006, July 27). *The Canadian Oil Sands - Suncor's Experience.* Retrieved June 6, 2009, from Colorado Water Workshop: www.western.edu/water/ww31_archives/Lowell.ppt

Lowey, M. (2006). The Big Picture - Alberta Ingenuity Center for In Situ Energy wants oil sands to be clean and profitable. *Alberta Heavy Oil Guidebook* , 140-149.

MacFarlane, B. (2007). VAPEX - Vapour Extraction. In A. G. Association, *Western Gold - Heavy Oil and Oilsands in Canada* (p. 45). Calgary: June Warren Publishing Ltd.

MacKinnon, M. D., Matthews, J. G., Shaw, W. H., & Cuddy, R. G. (2000). Water quality issues associated with implementation of composite tailings (CT) technology for managing oil sands tailings. In R. K. Singhal, & A. K. Mehrotra, *Environmental issues and management of waste in energy and minerial production* (pp. 443-454). Rotterdam: A.A. Balkema Publ.

Madill, R. E., Orzechowski, M. T., Chen, G., Brownlee, B. G., & Bunce, N. J. (2001). Preliminary risk assessment of the wet landscape option for reclamation of oil sands mine tailings: Bioassays with mature fine tailings pore water. *Environmental Toxicology* , 197-208.

Masliyah, J., Zhiang, Z., Xu, Z., Czarnecki, J., & Hamza, H. (2004). Understanding Water-Based Bitumen Extraction from Athabasca Oil Sands. *Canadian Journal of Chemical Engineering* , 628-654.

McRoberts, E. (2008). *Oil Sands Tailings Retention.* Edmonton: AMEC Earth and Environmental.

Mergent. (2008). *North America Oil and Gas Sectors - A Company and Industry Analysis.* New York: Mergent.

Mikula, R. J., Munoz, V. A., & Omotoso, O. (2008). *Centrifuge options for production of "Dry stackable tailings" in surface mined oil sands tailings management.* Calgary: Canadian International Petroleum Conference.

Mikula, R. J., Munoz, V. A., & Omotoso, O. (2008). *Water Use in Bitumen Production: Tailings Management in Surface Mined Oil Sands.* Calgary: Canadian International Petroleum Conference.

Mikula, R. J., Munoz, V. A., Kasperski, K. L., & Omotoso, O. E. (1998). *Commercial Implementation of a Dry Landscape Oil Sands Tailings Reclamation Option: Consolidated Tailings.* Devon: CANMET.

Mikula, R. J., Omotoso, O. E., & Kasperski, K. L. (2008). *The Chemistry of Oil Sands Tailings: Production to Treatment.* Devon: CanmetEnergy.

Millennium Ecosystem Assessment. (2005). *Ecosystems and Human Well-Being: Wetlands and Water.* Washington, DC: World Resources Institute.

Miller, P. (2007). *Oil and Water: Producing One, Protecting the Other.* Calgary: Imperial Oil.

Minnich, K. (2008). *Industrial Wastewater Recovery and Reuse Technology and Experience in the Hydrocarbon Processing Industry.* Calgary: Petroleum Technology Alliance Canada.

National Energy Board. (2008, September 8). *Energy Reports- Canada's Oil Sands - Opportunities and Challenges.* Retrieved April 2, 2009, from National Energy Board: http://www.neb.gc.ca/clf-nsi/rnrgynfmtn/nrgyrprt/lsnd/pprtntsndchllngs20152004/qapprtntsndchllngs20152004-eng.html

Natural Resources Canada. (2009, May 5). *Freshwater: The Role and Contribution of Natural Resources Canada: Sustainable Development.* Retrieved November 28, 2009, from Natural Resources Canada: http://www.nrcan-rncan.gc.ca/sd-dd/pubs/h2o/issque-2-eng.php

Natural Resources Canada. (2007). *From Impacts to Adaptation: Canada in a Changing Climate 2007.* Ottawa: Natural Resources Canada.

NAWMP. (2009). *Alberta's Wetlands.* Edmonton: North American Waterfowl Management Plan.

Nelson, R., Aggarwal, R., & Babel, L. (2007). *Feasibility Study for a SAGD Produced Water Treatment Test Facility.* Calgary: Petroleum Technology Alliance Canada.

Nikiforuk, A. (2008, March 28). *Liquid Asset.* Retrieved January 17, 2009, from Polaris Institute: http://www.polarisinstitute.org/liquid_asset

Odegaard, V., MacFarlane, P., & Cheadle, B. (2001). *Integrated Mine Planning for the Fort Hills Oil Sands Project.* Calgary: Canadian Society of Petroleum Geologists.

OPEC. (2007). *How much proven crude oil reserves exist in the world?* Retrieved June 19, 2009, from Organization of the Petroleum Exporting Countries: http://www.opec.org/library/FAQs/CrudeOil/q3.htm

Paes, R., & Throckmorton, M. (2008, June 10). An Overview of Canadian Oil Sand Mega Projects. *Petroleum and Chemical Industry Conference Europe - Electrical and Instrumentation Applications, 2008* , pp. 1-9.

Peachey, B. (2005). *Strategic Needs for Energy Related Water Use Technologies: Water and the EnergyINet.* Calgary: Alberta Energy Research Institute.

Percy, D. R. (2005). Responding to Water Scarcity in Western Canada. *Texas Law Review* , 2091-2107.

Porter, M. E., & van der Linde, C. (1995). Green and Competitive. *Harvard Business Review* , 120-134.

Province of Alberta. (2009). *Alberta Regulation 76/88 - Oil Sands Conservation Act.* Retrieved December 2, 2009, from Alberta Queen's Printer:

http://www.qp.alberta.ca/574.cfm?page=1988_076.cfm&leg_type=Regs&isbncln=9780779732272

Rach, N. M. (2004, June 7). SAGD Drilling Parameters Evolve for Oil Sands. *Oil and Gas Journal* , pp. 53-55.

RAMP. (2008). *RAMP Monitoring*. Retrieved August 11, 2009, from Regional Aquatics Monitoring Program: http://www.ramp-alberta.org/ramp/design+and+monitoring.aspx

RAMP. (2008). *Tar River Hydrological Profile*. Retrieved August 20, 2009, from Regional Aquatics Monitoring Program: http://www.ramp-alberta.org/river/hydrology/river+hydrology/tar+river.aspx

Rogers, M., & Alva-Argaez, A. (2008). *Water use in the oil sands - An overview of priorities.* Devon: Canmet Energy.

Rogers, V. V., Wickstrom, M., Liber, K., & MacKinnon, M. D. (2002). Acute and Subchronic Mammalian Toxicity of Naphthenic Acids from Oil Sands Tailings. *Toxicological Sciences* , 347-355.

Sandy, T. (2005). *Water Reduction and Reuse in the Petroleum Industry.* Annapolis: Petroleum Environmental Research Forum.

Schindler, D. W., & Donahue, W. F. (2006). An impending water crisis in Canada's western prairie provinces. *Proceedings of the National Academy of Sciences* , 7210-7216.

Schlumberger Limited. (2009). *Term "cyclic steam injection".* Retrieved June 2, 2009, from Oilfield Glossary: http://www.glossary.oilfield.slb.com/Display.cfm?Term=cyclic%20steam%20injection

Schramm, L. L. (2000). *Surfactants: Fundamentals and Applications in the Petroleum Industry.* Cambridge: Cambridge University Press.

Simieritsch, T., Obad, J., & Dyer, S. (2009). *Tailings Plan Review.* Drayton Valley: Pembina Institute.

Sparks, B. D., Kotlyar, L. S., O'Carroll, J. B., & Chung, K. H. (2003). Athabasca oil sands: effect of organic coated solids on bitumen recovery and quality. *Journal of Petroleum Science and Engineering* , 417-430.

Sturgess, P. K. (2008). *A 2020 Fresh Water Neutral Upstream Petroleum Industry.* Calgary: Alberta Energy Research Institute.

Suncor Energy. (2009). *2009 Summary Report on Sustainability.* Calgary: Suncor Energy.

Timoney, K. P. (2007). *A study of water and sediment quality as related to public health issues, Fort Chipewyan, Alberta.* Fort Chipewyan: Nunee Health Board Society.

UN Department of Economic and Social Affairs - Division for Sustainable Development. (1992). *Agenda 21.* Rio de Janerio: UN Department of Economic and Social Affairs.

UNEP/GRID-Arendal. (2009, June 5). *Press Releases.* Retrieved August 13, 2009, from UNEP/GRID-Arendal: http://www.grida.no/news/press/3702.aspx

van der Kamp, G., & Goudriaan, J. (2005). *Vulnerability of prairie lakes and wetlands to climate change - past, present and future.* Banff: Canadian Geophysical Union.

Veil, J. A., & Puder, M. G. (2006). *Potential Ground Water and Surface Water Impacts from Oil Shale and Tar Sands Energy-Production Operations.* Oklahoma City: Argonne National Laboratory.

Vredenburg, H., & Westley, F. R. (1997). Innovation and sustainability in natural resource industries. *Optimum, The Journal of Public Sector Management* , 32-40.

Water Matters. (2009, June 9). *A stronger role for the federal government in the oil sands?* Retrieved August 5, 2009, from Water Matters: http://www.water-matters.org/node/302

Water Matters. (2009, February 4). *Oil sands diversions and the lower Athabasca River*. Retrieved August 5, 2009, from Water Matters: http://www.water-matters.org/node/266

Water Matters. (2008). *Water Use by Thermal In Situ Operations Backgrounder.* Canmore: Water Matters Society of Alberta.

Westcott, F., & Watson, L. (2007). *End Pit Lakes Technical Guidance Document.* Fort McMurray: Cumulative Environmental Management Association.

Woynillowicz, D., & Severson-Baker, C. (2006). *Down to the Last Drop: The Athabasca River and Oil Sands.* Drayton Valley: Pembina Institute.

Wu, S. (2009). *Tailings processes using natural processes: Field experiment of biological dewatering.* Edmonton: Oil Sands Tailings Research Facility - University of Alberta.

Zhao, L., Feng, L., & Hall, C. A. (2009). Is peakoilism coming? *Energy Policy* , 2136-2138.

APPENDIX A: Regulations Excerpts

A.1 **Oil Sands Conservation Regulation** (Province of Alberta, 2009)

"Sections 33 to 47 – Apply to In situ Operations

Section 36: Unless the Board otherwise approves, an operator shall conduct all operations in a manner that, under normal operating conditions, will

(a) maximize the recovery of the crude bitumen,

(b) maximize the gathering and utilization of oil sands products produced from the scheme,

(c) minimize the use of fresh make-up water,

(d) minimize the disposal of water,

(e) maximize the recycle of produced water, and

(f) maximize the recovery from all oil sands zones within the approval area.

Daily record and reporting

Section 44(1): If a well is producing or is capable of producing crude bitumen, gas or water the operator shall keep at its field office or other place of business in Alberta a daily record of the production operations of the well in a form satisfactory to the Board and the original recording of measurements used to determine the particulars for the record, which record shall show, unless the Board otherwise directs,

(a) the crude bitumen, gas, water or other substance produced or reproduced from the well,

(b) the total number of hours of production at each well during each month, and

(c) particulars of the inventories and dispositions of all production from the well.

(2) If steam, water, air or other substance is being injected into a well, the operator shall keep at its field office or other place of business in Alberta, a daily record of the injection operations of the well and the original recording of measurements used to determine the particulars for the record, which record shall show, unless the Board otherwise directs,

(a) the amounts of steam as water equivalent, water, air or other substances injected into the well,

(b) the source from which the water or other substances were obtained,

(c) particulars of any treatment to which the steam, water, air or other substance has been subjected including pressures at the steam generator and steam quality,

(d) the number of hours during which each substance was injected into the well, and

(e) the average wellhead injection pressure while each substance was injected into the well.

(3) The licensee of a well that, during the preceding month, produced crude bitumen, gas, water or other substance, or into which steam, water, air or other substance was injected or disposed of, shall file with the Board on the approved formatted media, not later than the 18th day of the month or the first business day following the 18th day of the month, a report for the preceding month setting out

(a) the amounts of crude bitumen, gas, water or other substance produced from the well,

(b) the amounts of steam as water equivalent, water, air or other substance injected or disposed of into the well, including a measurement or estimation of steam quality,

(c) the number of hours during which the well produced, was injected or was used for disposal purposes,

(d) the particulars of any receipts, inventories, dispositions or deliveries of crude bitumen, gas, water or other substance associated with the production, injection or disposal operations, and

(e) any further particulars the Board requires.

(4) The licensee of a well that, during the entire preceding month was shut in, shall file with the Board on the approved formatted media, not later than the 18th day of the month or the first business day following the 18th day of the month, a report for the preceding month setting out only the unique well identifier, and shall continue to do so in each subsequent month until such time as production, injection or disposal operations have been resumed or the well has been suspended or abandoned.

(5) The operator of a battery or an injection or disposal facility at which all wells were shut in, suspended or abandoned or where no wells were associated with the battery or the injection or disposal facility during the entire preceding month shall file with the Board on the approved formatted media, not later than the 18th day of the month or the first business day following the 18th day of the month, a report for the preceding month setting out the particulars of any receipts, inventories, dispositions or deliveries of crude oil, condensate, crude bitumen, gas, solvent, water, air or other substance associated with the production, injection or disposal operations, and shall continue to do so in each subsequent month deliveries.

(6) The operator of a well shall keep any other records and file with the Board any other reports that the Board may, by order, require." (Province of Alberta, 2009)

A.2 Water Recycle Guidelines and Reporting of Water Use Information for In Situ Oil Sands Facilities in Alberta (ERCB/AENV, 1989)

GUIDELINES FOR WATER RECYCLE

"1. All in situ operators with freshwater requirements exceeding approximately 500 dam3/year (500 000 m3/year) will be required to recycle produced water. All in situ operators with freshwater requirements below 500 dam3/year will be required to actively investigate and latest recycle technology.

Oil sands operators have demonstrated that water recycle at large-scale projects can be efficient and economic. Experience to date would indicate that recycling is practical for projects where the freshwater demand exceeds approximately 500 dam3/year. Recycling at some smaller projects may not be as practical given the absence of the economics of scale characteristic of larger projects. Also, in some other cases, there may be only limited data available on produced water quality and quantity. In each case, however, the ERCB and AE would require that operators actively pursue the development and implementation of an appropriate recycle technology.

2. The target recycle rate assigned to a project will be based on produced water and will be defined as an annual level.

As produced water recycle accounts for the greater part of the potential water reuse, target recycle rates will be based on produced water. The upper limit of the target rate will be 100 percent or a rate sufficient to meet the total project water requirement, whichever is less.

The actual target recycle rate designated by the ERCB and AE would be based primarily on the produced water quality - more specifically, the concentration of dissolved solids, the hardness, and the silica content. The target recycle rate would also take into consideration any environmental, technical, and economic factors that are demonstrated to be significant and limiting. It will be the responsibility of the applicant to demonstrate that factors are significant and limiting for a specific project.

The ERCB and AE recognize that, in the province, experience with water recycle technology is varied and with some companies limited. Therefore, for those projects where new recycle facilities are to be incorporated into the plant, a phase-in period of 1 year, or other such periods stipulated in approvals and licences, would be allowed to reach the designated target recycle rate "granted".

3. These guidelines must be addressed in regulatory applications that are reviewed by the ERCB and AE.

The ERCB and AE consider the development and incorporation of water recycle technology an integral part of all in situ oil sands projects. As such, water recycling must be addressed in the appropriate regulatory applications and supporting documents for these projects. These may include but are not limited to Environmental Impact Assessments, project and subsurface disposal applications to the ERCB, and any application to AE pursuant to the Water Resources Act and the Clean Water Act.

WATER USE REPORTING

Improved reporting of water use information is required by Alberta Environment to confirm that this goal is being achieved. A review of industry monitoring indicates the basic data needed by Alberta Environment is currently collected as part of the S series of monthly reports to the ERCB. The ERCB has agreed to provide the Department with the pertinent water information reported on these forms.

The resulting administrative change between the ERCB and Alberta Environment will not require any major changes in data collection or reporting by industry. More effective use of information now reported by industry to the ERCB will improve decision-making, minimize duplication, and reduce reporting under environmental protection approvals." (ERCB/AENV, 1989)

A.3 Directive 074 – Tailings Performance Criteria and Requirements for Oil Sands Mining Schemes (ERCB, 2009)

1 Purpose of This Directive

"This directive sets out new requirements for the regulation of tailings operations associated with mineable oil sands. It is the first component of a larger initiative to regulate tailings management. The directive specifies performance criteria for the reduction of fluid tailings and the formation of trafficable deposits. These criteria are required to ensure that the Energy Resources Conservation Board (ERCB/Board) can hold mineable oil sands operators accountable for tailings management. Operators may use a suite of technologies to meet the requirements of this directive.

1.1 Direction from Alberta Energy and Utilities Board and Joint Panel Decision Reports

In past applications, mineable oils sands operators proposed the conversion of fluid tailings into deposits that would become trafficable and ready for reclamation. While operators have applied fluid tailings reduction technologies, they have not met the targets set out in their applications; as a result, the inventories of fluid tailings that require long-term containment have grown. With each successive application and approval, public concerns have also grown.

Decision reports issued by the Alberta Energy and Utilities Board (EUB—predecessor to the ERCB) and joint panels of the EUB and the Canadian Environmental Assessment Agency (CEAA)1 identified several long-term objectives respecting tailings management: to minimize and eventually eliminate long-term storage of fluid tailings in the reclamation landscape; to create a trafficable landscape at the earliest opportunity to facilitate progressive reclamation; to eliminate or reduce containment of fluid tailings in an external tailings disposal area during operations; to reduce stored process-affected waste water volumes on site; to maximize intermediate process water recycling to increase energy efficiency and reduce fresh water import; to minimize resource sterilization associated with tailings ponds; and to ensure that the liability for tailings is managed through reclamation of tailings ponds.

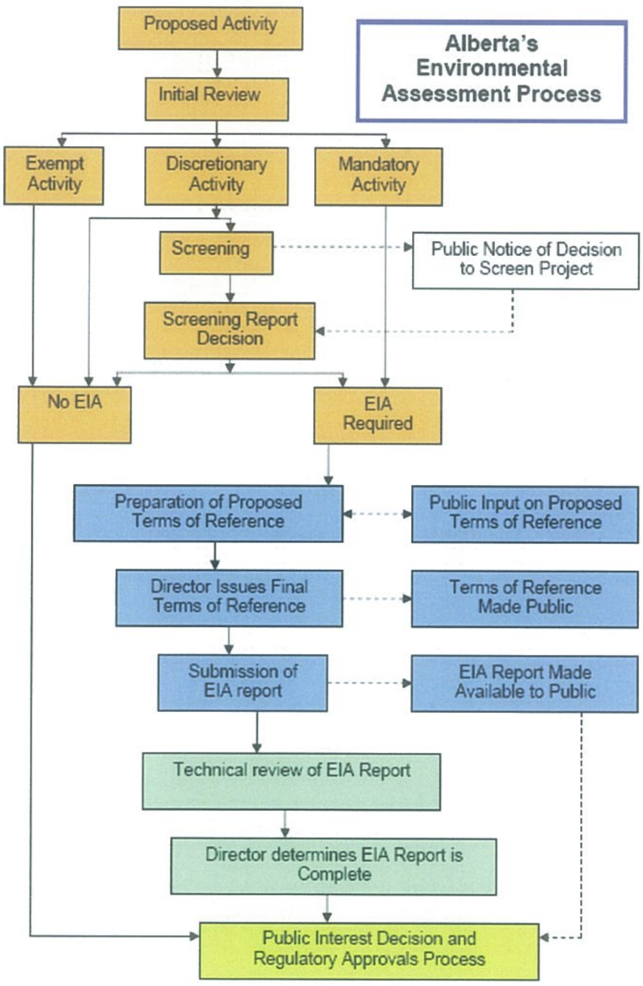
Two joint panel decision reports issued in early July 2004 directed EUB staff to address tailings management issues through the establishment of industry-wide performance criteria by March 2008. Recognizing that the above objectives will take time to accomplish, the EUB initiated a phased approach. This directive focuses on the reduction of fluid tailings volumes and the formation of trafficable deposits." (ERCB, 2009)

A.4 Environmental Impact Assessment Process (Alberta Environment, 2008)

"The EIA process covers all activities that begin with a company's disclosing its intent to begin a new industrial activity and conclude with Sustainable Resource Development's granting access to public lands.

During this process, the Oil Sands Branch represents Alberta's goals and objectives with respect to: fish; forests; public lands; and wildlife.

The Oil Sands Branch ensures effective review of major resource projects and alignment of the Government of Alberta's messages at hearings, approvals and negotiations." (Alberta Environment, 2008)



A.5 Wetland Management in the Settled Area of Alberta: An Interim Policy

(Alberta Water Resources Commission, 1993)

"This interim policy provides direction for the management of slough/marsh wetlands in the Settled Area of Alberta (see Figure below). It was prepared in response to the loss of wetlands and the need for consistent direction to guide provincial government department. The interim policy was developed cooperatively by the Alberta Water Resources Commission and the provincial departments of Agriculture, Food and Rural Development; Environmental Protection; Municipal Affairs; and Transportation and Utilities. This policy is consistent with the principles of sustainable development." (Alberta Water Resources Commission, 1993)

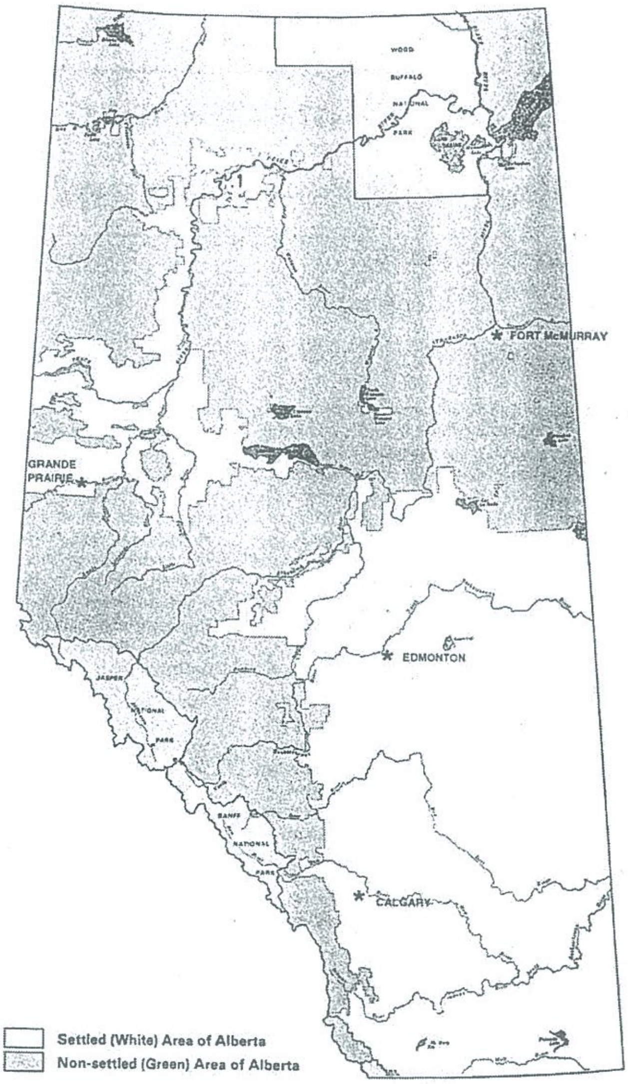


Figure 1. The Settled and Non-settled Areas of Alberta
(Source: Alberta Forestry, Lands and Wildlife)

A.6 Requirements for Water Measurement, Reporting, and Use for Thermal In Situ Oil Sands Schemes (ERCB/AENV, 2009)

Purpose of This Joint Directive

"The ERCB and AENV have specific but interdependent regulatory responsibilities respecting water use at thermal in situ oil sands developments and have therefore decided to issue this directive jointly. While AENV has jurisdiction over water use in the province, the ERCB is responsible for regulating energy developments and minimizing the impacts of their operation on water resources.

This directive is part of an overall provincial strategy to enhance the conservation and protection of Alberta's water in order to: ensure reliable quality water supplies to support a sustainable economy, as envisioned in *Water for Life: Alberta's Strategy for Sustainability*; manage provincial water resources allocated for thermal in situ oil sands schemes in a way that achieves the purpose of Alberta's *Water Act*; and achieve continuous improvement in water conservation, water efficiency, and water productivity, as committed to in *Water for Life: Alberta's Strategy for Sustainability*, thus reducing the demand for water, increasing water use productivity, conserving resources to maintain healthy aquatic ecosystems, enhancing water quality.

The directive contributes to the above strategy by: limiting the use of fresh and brackish water resources by maximizing produced water recycle at thermal in situ oil sands schemes, a fundamental objective of the *Water Conservation and Allocation Guideline for Oilfield Injection (2006)* and associated policy; improving the measurement and reporting of all major water streams at thermal in situ oil sands schemes; and minimizing the disposal of water from thermal in situ oil sands schemes to improve water and energy efficiency and reduce the risk of contamination of water resources.

Should the Energy Resources Conservation Board (ERCB) and Alberta Environment (AENV) determine it is necessary, the requirements of this directive will be reviewed to ensure that the above goals are being met. In this regard operators are expected to implement continuous improvement practices in water conservation efficiency and productivity. In addition, the requirements of this directive may need updating as a result of changes in technology, changes in water availability, and continued growth in the number and size of schemes and the associated water-handling infrastructure.

Measurement, Reporting, and Water Use Limits

This directive sets out requirements for all thermal in situ oil sands schemes in the Athabasca, Cold Lake, and Peace River Oil Sands Areas, as follows: water measurement accuracy (Section 5 and Appendix B), reporting of water streams to the Petroleum Registry of Alberta (Registry) and AENV water use reporting system (Section 6 and Appendices C and D), ERCB facility water balance (Section 6 and Appendix E), maximum limits to fresh and brackish water use and minimum limits to produced water use (Section 7 and Appendix H), and compliance and enforcement (Section 8)." (ERCB/AENV, 2009)