Oil Sands Tailings Management Project

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OSRIN
Oil Sands Research and Information Network

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

REPORT SUMMARY

The Oil Sands Leadership Initiative (OSLI) is a collaboration of five progressive oil sands operators (ConocoPhillips Canada, Nexen Inc., Statoil Canada, Suncor Energy Inc. and Total E&P Canada), with the Government of Alberta participating as an observer, working to advance the development of the oil sands industry in an environmentally, economically and socially responsible manner. The OSLI members identified Water Management as one of the target areas for a step change improvement in performance through collaborative efforts. Alberta WaterSMART was engaged to help develop and manage the various projects arising from the work in water management. One of the projects with the highest potential for achieving results was the development of a regional water management solution.

Currently, oil sands producers in the Athabasca Region optimize water sourcing and disposal individually with a focus on fresh water conservation and economics. Mines source water from the Athabasca River with no discharge of process-affected water to the river, while Steam Assisted Gravity Drainage (SAGD) operators are considering distant saline aquifers for their source water requirements.

The Tailings Water Management Project is Phase 1 of a four phase project to study the Environmental and Economic Footprint (EEF) benefit of collaborative solutions for Athabasca oil sands production water supply and disposal. The specific goal of this Project was to identify tailings treatment technologies which could be implemented today, and to develop and assess options for optimizing regional oil sands production water sourcing and disposal. Alternatives were split between sub-regionally integrated and regionally integrated solutions in which sub-regional systems used a common SAGD supply and mines managed their disposal needs independently, and regionally integrated solutions involving completely integrated mining/SAGD solutions by transferring tailings water to SAGD operations. Sub–regionally integrated SAGD water source alternatives included the Athabasca River, saline aquifers, and municipal wastewater. Regionally integrated alternatives combined mine water disposal and SAGD water supply. Rather than focusing solely on fresh water conservation and economics, alternatives were assessed on the basis of their total EEF, including greenhouse gas emissions, wastes produced, and land disturbance. Alternatives were evaluated using a consequential life-cycle assessment methodology, focusing on quantifying key performance indicators relative to baseline operations.

While the intent of the Tailings Water Management Project was to develop and present solution alternatives and opportunities for regional optimization, the project did not attempt to rank potential solutions. Impact categories quantitatively assessed footprint. However, it was not possible to quantify the effects of all issues (for example the degradation of a saline aquifer or the reduction in tailings TDS) in these numerical calculations. As ranking systems are ultimately the result of an assessment of social choices which are qualitative in nature, there is inherent uncertainty regarding how stakeholders will value different quantitative and qualitative impacts. While methods exist to help stakeholders arrive at such decisions, rankings will still vary depending on group composition and goals. Thus, the results of this project provided the “raw material” to advance subsequent discussions on this topic.

Directionally, Phase 1 results supported the premise that large, regionally integrated solutions have a lower EEF than sub-regional systems. Results further indicated that there are existing tailings treatment technologies which, with more testing and development, may be viable for commercial deployment by 2015. Regional water management solutions out-performed sub-regional options on all indicators, except for Fresh Water Consumption. Sub-regional water management solutions out-performed regional water management solutions for Fresh Water Consumption only by degrading saline aquifers. However, it was questionable whether saline aquifers had the capacity to deliver the volumes of water needed to support future SAGD operations. Based on this analysis, OSLI is proceeding to Phase 2 of the project, developing the most promising alternatives including the business models to implement the selected solutions.

While the OSLI Tailings Water Management Project was able to conclude that regionally integrated solutions have a lower EEF, the work conducted was directional in nature due to the limited time available, data used, and knowledge gaps identified. In addition to selection and development of preferred alternatives, Phase 2 of the Regional Water Management Solutions Project will need to address the following issues:

- Improving data reliability through incorporating actual operational data and company forecasts
- Conducting research to fill the knowledge gaps identified
- Piloting tailings treatment technologies to generate data required for design of full scale facilities

Finally, while operational data, further analysis, research and piloting will allow more accurate calculation of the impacts of the different design alternatives, ranking the design alternatives requires engaging with stakeholders to rank these solutions based on the quantitative and qualitative factors discussed above. This requires guidance from both government and industry regarding which stakeholders to engage in order to validate and select the "best" solution for implementation.

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- Suncor Energy and TOTAL, and their subcontractor AECOM, for the tailings treatment technology evaluation.
- Alberta Innovates – Technology Futures staff member Craig Aumann for his work on the Life Cycle Analysis.

1 INTRODUCTION

The Oil Sands Leadership Initiative (OSLI) is a collaboration of five progressive oil sands operators comprised of Suncor Energy Inc., Total E&P Canada, Nexen Inc., ConocoPhillips Canada, and Statoil Canada, with the Government of Alberta participating as an observer. Through its collaborative efforts, OSLI is committed to ensuring responsible development of the Alberta oil sands in an environmentally friendly, economical, and socially sustainable manner. The group works jointly, and as individual corporations, to advance oil sands research, development, technology and operations to improve the environmental and economic performance of the industry.

Across OSLI, a number of working groups have been formed to develop key strategies and implement pilot projects to deliver sustainable solutions for water management, land stewardship, communities, technology breakthroughs, and carbon management/energy efficiency[1]. Each of these working groups is focused on exchanging and sharing information, developing goals, and developing projects to meet those goals.

The goal of the OSLI Water Management Working Group (WMWG) is to improve water management practices in oil sands in an effort to address the critical water challenges facing oil sands operators, with a focus on:

- Improving water management practices in oil sands through collaborative solutions
- Reducing water consumption
- Improving water use efficiency, using lower quality makeup water
- Reducing energy consumption and waste production associated with water treatment.

The WMWG has identified a number of projects to tackle these challenges, including the Tailings Water Management Project, which is the focus of this paper. These projects are all elements of a larger multi-phase initiative called the OSLI Regional Water Management Project. The primary objective of the project is to optimize regional Athabasca oil sands water management by reducing environmental footprint and costs through the collaboration of oil sands companies.

During initial project scoping, it was quickly determined that it would be impossible to analyze water challenges in oil sands operations and develop potential water management solutions in isolation. Rather, to develop the best possible solutions, analyses would have to be expanded to include a number of oil sands companies and alternatives, with the goal of developing a more effective integrated regional approach. This collaborative approach requires a paradigm shift in the current attitudes regarding the optimization of water usage, necessitating a change in focus from optimizing on a site-by-site basis, to optimizing water management costs and environmental impact (water, land, waste, greenhouse gas (GHG) emissions) for the entire region.

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[1] See http://www.osli.ca/

Ensuring more limited use of fresh water, and more efficient use of water in operations, are two of the most important challenges facing oil sands operators. The oil sands industry and groups like OSLI are working collaboratively to develop new technologies and processes that will further reduce fresh water use or even eliminate the need for water in oil sands production, as well as manage tailings water more effectively. It is hoped that that other oil sands facilities and other industrial applications will elect to join the Regional Water Management Solution at a future date, and as of the writing of this report OSLI has been approached by several other oil sands operators who are interested in participating in the project.

2 BACKGROUND

2.1 Oil Sands Operations: Mining and In-Situ Processes

Bituminous sands are a major source of unconventional oil. Unlike conventional crude oil, naturally occurring or crude bitumen is a sticky, tar-like form of petroleum that has a consistency like cold molasses. Because bitumen flows very slowly, if at all, the sands which contain bitumen must be extracted by surface mining, or the oil made to flow into wells by in situ-techniques which reduce its viscosity by injecting steam, solvents, or hot air into the sands. Athabasca oil sands operators use both mining and in-situ extraction methods. Water is a key component in both production methods; however, each has its own unique set of water challenges.

2.2 Water Challenges in Oil Sands Mining Operations

Mining operations typically involve truck-and-shovel operations. Once the bitumen-containing sands are excavated, a hot water mixture is added, and the resulting slurry is piped to an extraction plant where the bitumen is removed. Oil sand tailings, composed of water, sands, silt, residual bitumen, and other materials are by-products of the extraction process. Tailings are pumped into ponds to allow the sedimentation (or separation) of solid particles from the water, also called produced water, which is recycled.

Mines use water in several areas of their operation, including extraction, upgrading, and utilities. The primary source of the freshwater requirements for the mines is the Athabasca River. Extraction of fresh water from the Athabasca River is based on licensed allocations and is tightly regulated by Alberta Environment. While the quantity of water from the Athabasca River that is used for mining operations constitutes only a small portion of allocated and available regional water supplies, there has been considerable concern expressed by local communities and stakeholders regarding the amounts of water being used. Stakeholders and communities also consider tailings ponds to be an environmental concern because of the process-affected water they contain. Further, tailings require surface storage in large ponds (usually aboveground) to settle out solids, and this sedimentation process takes time. Due to current technology limitations, the volume of tailings water on some mine sites has accumulated above and beyond the process requirements. This results in imbalances in water usage and available supply.

2.3 Water Challenges in Oil Sands In-Situ Operations

The most common form of in-situ operation in the Athabasca region is Steam Assisted Gravity Drainage (SAGD). SAGD is an advanced form of steam stimulation in which low quality steam is continuously injected into a wellbore to heat the crude bitumen and reduce its viscosity. The bitumen and steam mixture flows into a piping system that carries the mixture to a surface well pad, and from there it is piped to a central processing facility. Once the bitumen is removed from the stream, the water is recycled and the whole process starts over again.

In SAGD operations, the greatest use of water is for generating the steam required to reduce the viscosity of the bitumen. Most of the produced water and boiler blowdown is recycled and is the main source of boiler feedwater. SAGD operators have been restricted from accessing surface water (e.g., from the Athabasca River), and therefore they typically use non-potable saline water from deep underground zones to meet their water needs. However, SAGD operations are generally located in areas where it is difficult to secure a guaranteed supply of water, either due to regulatory restrictions or geological conditions. So, while mining operators are challenged with excess water, SAGD operators are often short of water.

3 TAILINGS WATER MANAGEMENT PROJECT

Given the contrasting nature of the water challenges faced by oil sands mining versus in-situ operators, the OSLI Regional Water Management Project undertook a review of the opportunities to use tailings water from mining operations to supply water for in-situ operations. The project aimed to investigate options that could reduce the environmental liability of stored tailings water, as well as examine water supply options for in-situ operations. The EEF of several water source and disposition scenarios was calculated as part of this project.

In early 2009, preliminary research completed by the OSLI's WMWG indicated that the EEF associated with the sourcing and disposal of water for bitumen extraction and processing operations across the Athabasca region could be significantly reduced through the cooperative management of water by the region's oil sands operators. In addition, such efforts could also result in capital and operational savings for operators.

This research resulted in the development of the Tailings Water Management Project. The goal of the project was to better understand the nature of water supply and disposal requirements in the Athabasca oil sands region, and use this information to develop a collaborative, regional water supply and drawdown solution for oil sands bitumen operations that results in a minimal EEF. This approach results in the following benefits:

- Removes Legacy Tailings Water
- Deals with build-up of dissolved salts, metals and other contaminants without requiring discharge to the Athabasca River
- Does not compromise the Athabasca River during periods of low flow
- Reduces greenhouse gas (GHG) emissions
- Reduces land disturbance by reducing pond, drilling and water collection footprint

- Shows that action is being taken to deal with the most visible oil sands development issues.

Potential solutions were evaluated based on their environmental and financial impacts and benefits, taking into account a variety of environmental impacts in addition to monetary cost. Such an evaluation enabled identification of solutions with a minimum EEF.

3.1 Project Scope

The Tailings Water Management (TWM) Project is being undertaken by Alberta WaterSMART on behalf of and in participation with the OSLI WMWG. The TWM Project is comprised of four phases (Figure 1), with this report documenting the conclusions reached for Phase 1. Subsequent phases are focused on further development of the proposed solutions, to eventually achieve full-scale application.

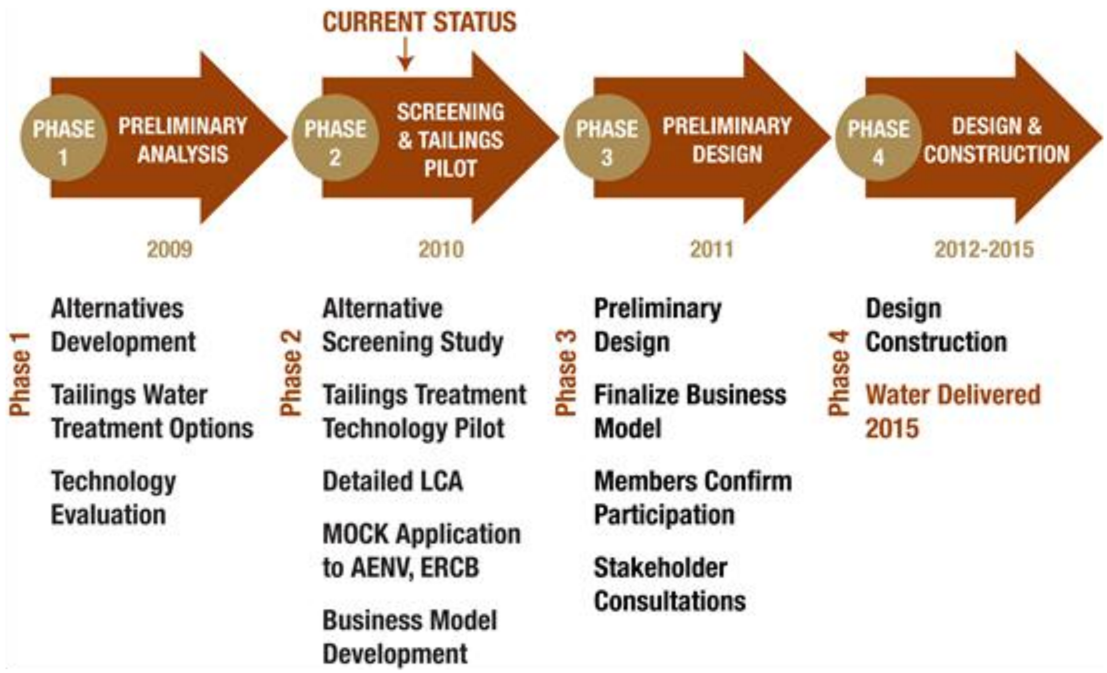


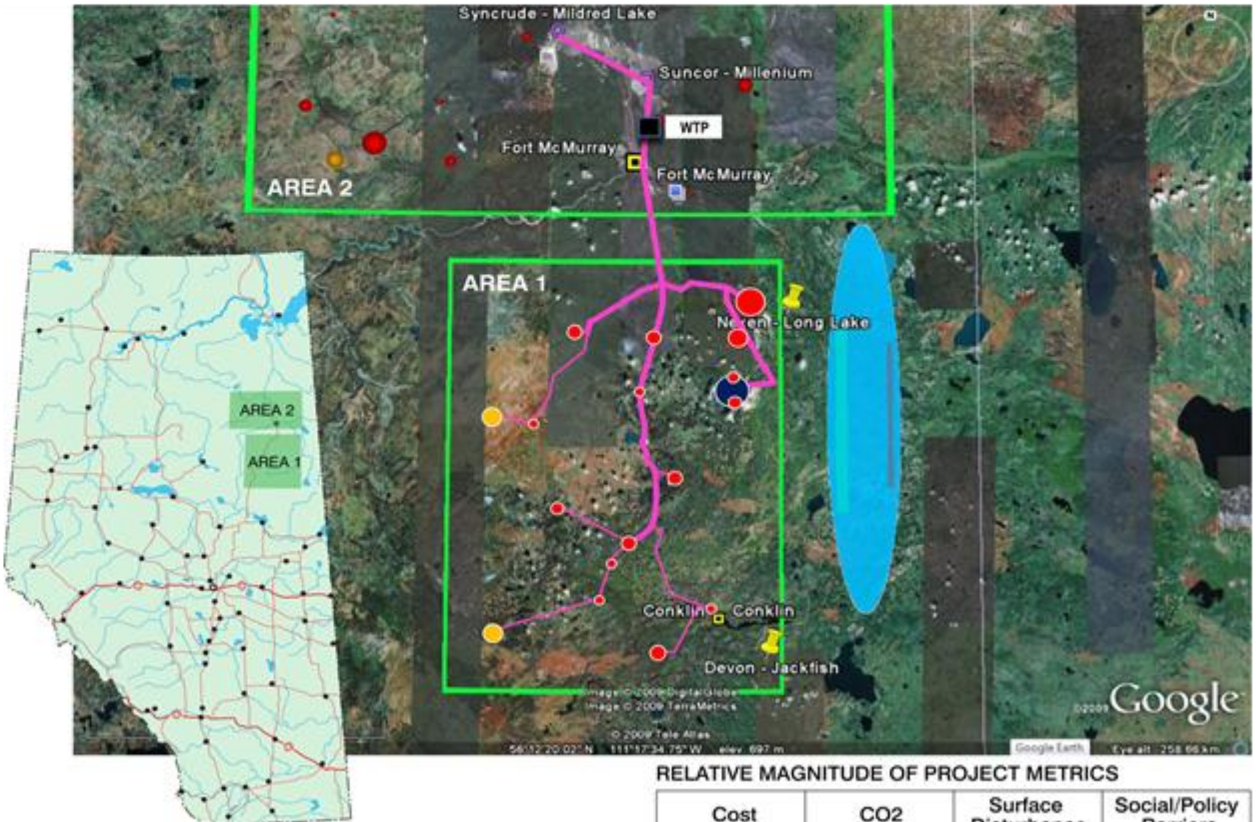
Figure 1. Project Phases

3.2 Project Boundaries

Due to project timelines, lack of access to regional operations information, and the complexity of potential solutions, the TWM Project Team chose to focus on the water supply and demand for only those operations that are part of OSLI.

Although all oil sands operators need water, it was felt that integrating all mining and SAGD users within the Athabasca Region into one system would add a level of detail and complexity that was not necessary to successfully assess alternative water supply options, and thus would significantly reduce the probability of successfully completing the first phase. As a result, the TWM Project focused on a select number of oil sands facilities to establish the cumulative demand for water. The water demand from these facilities is hereafter referred to as the *OSLI SAGD Water Demand*.

For the purpose of this report, the Athabasca Region was divided into two areas (Figure 2): Area 1 includes all regional SAGD production south of the Town of Fort McMurray; and Area 2 includes all regional SAGD production north of the Town of Fort McMurray.



Cost	CO2	Surface Disturbance	Social/Policy Barriers
1.1 x BASE	1.4 x BASE	423 km	Medium

Figure 2. Bitumen Production Operations

3.3 Region of Optimization

A critical premise of the TWM Project is that regional cooperation can improve operational and environmental performance in water use and management. This conceptual shift is shown in Figure 3.

Building on the regional cooperation premise, the TWM Project used the following alternatives to arrive at solutions concepts to optimize water use across Areas 1 and 2:

- **Alternative One**: Individual Solutions – Each oil sands mining and SAGD producer continues to solve their water supply and surplus challenges independently.
- **Alternative Two**: Sub-Regional Water Management Solutions – SAGD operators source water collectively, gaining scales of economy, while mine operators continue to source and dispose of their water independently.

- **Alternative Three**: Regional Water Management Solutions – Mine operators collaborate with and share mining wastewater with SAGD operators.

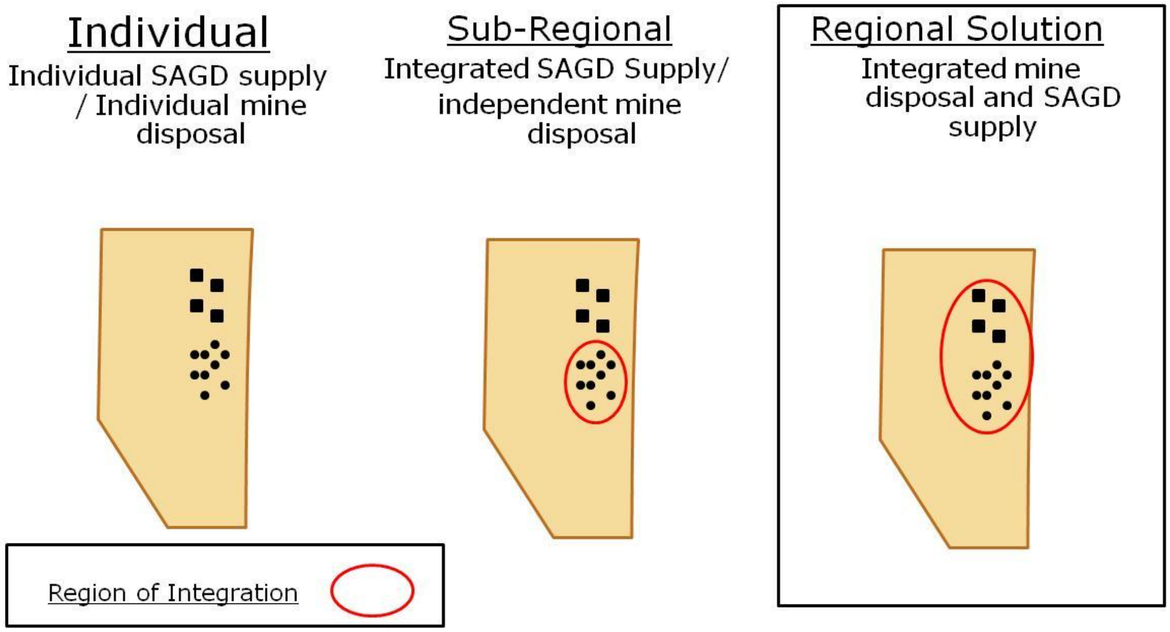


Figure 3. Regional Optimization Boundaries (3 Concepts)

Note: It is critical to understand that Phase 1 of the TWM Project did not produce a ranking of potential alternatives; rather, it produced a side-by-side comparison of each of the solutions and their parameters. The judgment about the relative importance of each analysis parameter was beyond the scope of this phase of the project.

4 ANALYTICAL APPROACH

This section describes the process used to develop the various alternatives for each of the three possible Regional Water Management Solution concepts, and the approach used to quantify the potential impacts and benefits of each.

Seven analysis steps were undertaken; each of these steps will be discussed in detail in the sections that follow.

- STEP 1. Identify the demand volumes and quality requirements for SAGD water
- STEP 2. Identify surplus volumes and quality requirements of tailings water from mining operations
- STEP 3. Identify alternatives to drawdown mine tailings water
- STEP 4. Identify alternative water sources
- STEP 5. Identify suitable tailings treatment technologies

- STEP 6. Develop scenarios for the regional water management solutions
- STEP 7. Calculate the financial and environmental impact indicators for each solution using Life-Cycle Assessment

4.1 Source Data and Modeling Tools

SAGD demand data were developed using proprietary OLSI member company data and oil sands development project modeling applications that are publicly available. Mine data were developed using internal company information provided by Suncor and Total.

5 ANALYSIS

This section outlines the analysis which has been conducted as per the Analytical Approach described in Section 4.

The work from this phase of the project is directional and for the most part the results predicted by the models developed have not yet been validated against operator internally developed models or empirical data. Thus, any numbers in this document should not be taken as an official projection of water consumption or water quality.

5.1 Step1: Identify the Demand Volumes and Quality Requirements for SAGD Water

The first step in the analysis process involved identification of the total volume and timing of water demand, as well as the quality of water required by SAGD operation.

5.1.1 *Demand for SAGD Water*

SAGD water demand is directly tied to bitumen production. Currently, SAGD bitumen production requires approximately 0.6 units of water per unit of bitumen produced. Based on discussions with OSLI members, the assumption was made that this ratio would improve to 0.3 units of water per unit of bitumen produced by 2050. Using these bitumen production and water demand ratios, the projected water demand was then calculated.

5.1.1.1 SAGD Bitumen Production Forecast

To accurately forecast bitumen production and its associated demand for water, a model was developed to calculate water demand from the present to 2073. Input data were derived from publicly available information.

Using the model, OSLI SAGD bitumen production was projected to reach a maximum of 1,824,200 barrels per day by the year 2034. Total SAGD bitumen production for the region was projected to reach a maximum of 2,912,700 barrels per day by the year 2036. Figure 4 illustrates the Total and OSLI-only time distribution of bitumen production.

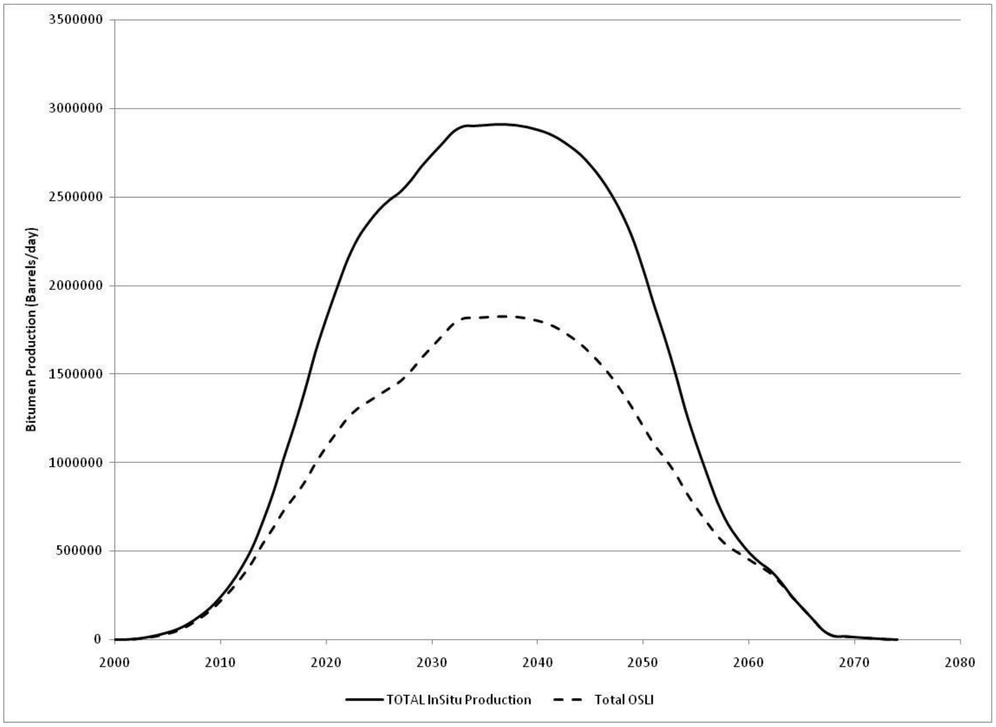


Figure 4. Projected Bitumen Production in the Athabasca Region

5.1.1.2 SAGD Water Demand Forecast

As noted in section 5.1.1, SAGD bitumen production currently requires approximately 0.6 units of water per unit of bitumen produced. By 2050, this ratio was forecasted to improve to 0.3 units of water per unit of bitumen produced, with a linear reduction in water demand intensity. Using these data, water demand was calculated and plotted for Area 1 and Area 2 as a function of time (Figure 5).

As mentioned in section 3.2, Phase 1 of the TWM Project included only OSLI member company facilities, in Area 1 to the south of Fort McMurray, in the scope of projected cumulative demand for water for Sub-Regional and Regional Water Management Solutions. The maximum projected daily water demand for these facilities was 77,000 m^3 in 2033, with a cumulative demand of 925 Mm^3 (Figure 6).

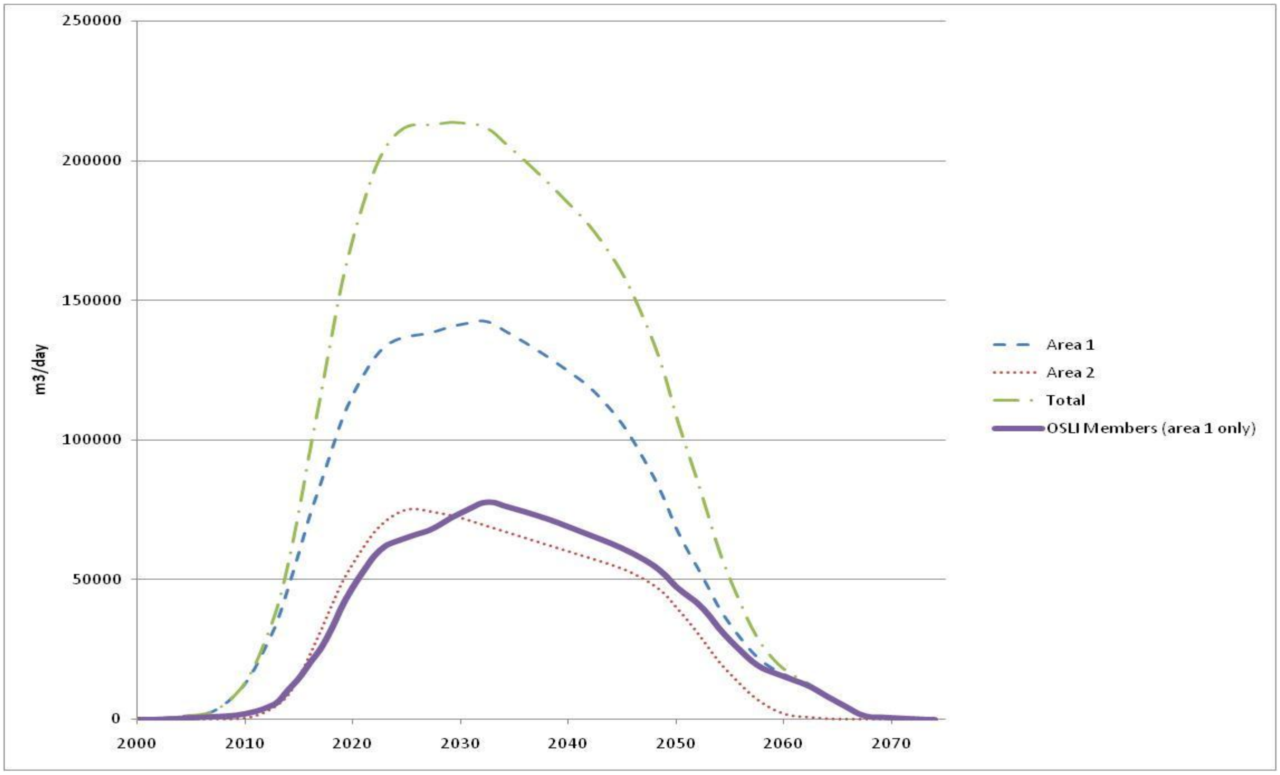


Figure 5. SAGD Water Demand

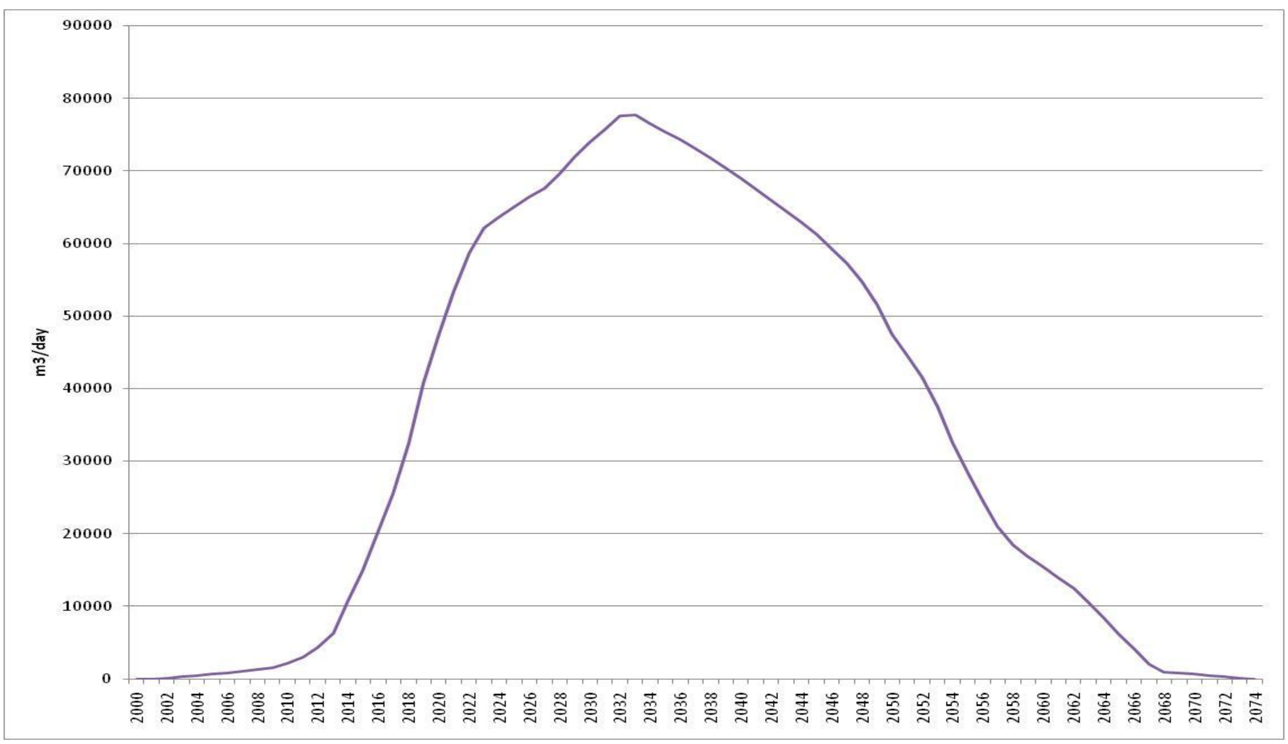


Figure 6. OSLI Area 1 SAGD Water Demand

5.2 Step 2: Identify Surplus Volumes and Quality Requirements of Tailings Water from Mining Operations

The second step of the analysis involved identifying the source, volume, quality and scenarios for the treatment and elimination of tailings water or the treatment and elimination of elevated levels of tailings water ion species in mining operations.

In mining operations, there are a number of water streams 'imported' to the tailings balance, including: connate water; mine surface water drainage (i.e., rain water) that is diverted to the tailings ponds; basal depressurization water that is diverted to the tailings ponds; and river water (including oily water, cooling water blowdown, and stripped sour water for integrated upgrading operations). Water imported into the tailings system serves to "make up" water lost to fine or coarse tailings deposits. Water can also be brought on site to start up a new tailings pond.

In a balanced tailings water system, no water is 'exported' from the tailings ponds until the end of plant operations. Therefore, over time, all of the conservative ion species in these import streams will cycle up to an equilibrium level determined by the chemistry of the incoming streams. Depending on the chemistry of the incoming streams (most notably the ore connate water and basal depressurization water), ions may cycle up to a level which may be undesirable from either a process or a reclamation standpoint. Work is being undertaken as part of the overall OSLI Regional Water Management Solutions Project to validate this hypothesis and understand the risks. Figure 7 shows an overview of the generalized tailings water balance. The dotted box represents the conceptual boundary of the tailings ponds where all water is 'imported' into the ponds.

5.2.1 *Water Volume and Quality Data for Mining Operations*

A mass balance model was developed to project the tailings water consumption volumes and tailings pond water quality data cited in this report. Key model inputs, including projected production rates, were collected from the tailings plan submissions made by operators to the Energy Resource Conservation Board (ERCB) in September 2009. Data were collected for the following mines:

- Syncrude (including Mildred Lake, Aurora North, and Aurora South) (Syncrude Canada Limited 2009a, b, c)
- Suncor (including Millennium and North Steepbank Extension, but NOT including Voyageur South)(Suncor Energy Inc. 2009a, b, c)
- Shell (including Muskeg River and Jackpine, but NOT Pierre River) (Shell Canada 2009a, b)
- CNRL (Horizon)(Canadian Natural Resources Limited 2009)
- Imperial (Kearl)(Imperial Oil Resources Ventures Ltd. 2009)
- Fort Hills (Fort Hills Energy Corp. 2009)

The key model outputs included:

- Projected tailings water consumption volumes per mine site
- Projected tailings pond water chloride and Total Dissolved Solids (TDS) concentrations per mine site
- Potential cumulative tailings water export volume and quality to SAGD under different solutions.

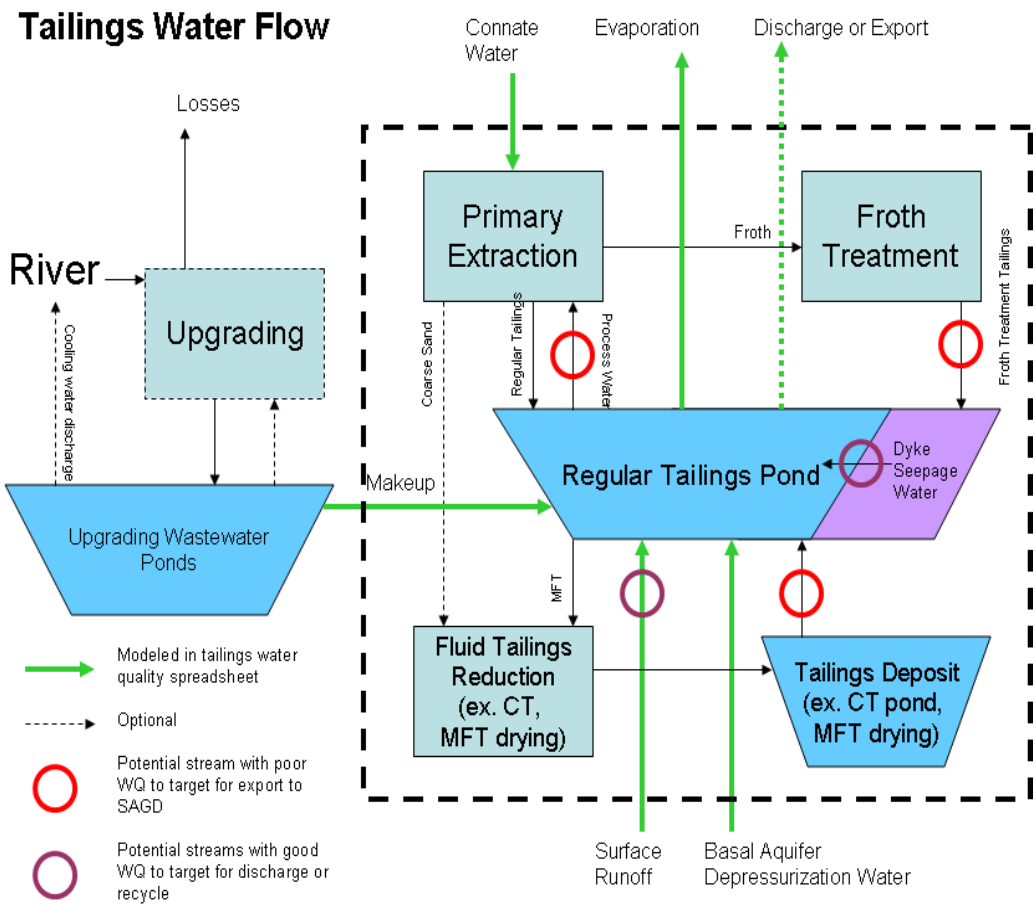


Figure 7. Generalized Tailings Water Balance in Oil Sands Mining Operations

In the developed water quality model, pond water chemistry was dominated by the following factors:

- Incoming ore connate water quality
- Water volume entering the system
- Water volume exiting the system (including water lost to tailings voids).

With the current model assumptions, most mines modeled did not have significant buffering capacity; that is, changes in any of the parameters year to year would cause the predicted pond quality to quickly change to a new equilibrium level. As such, temporary changes in one of the above parameters (e.g., water 'exported' from the tailings ponds) would not necessarily effect significant long-term changes; continuous export and/or dilution would be necessary to meet long-term pond water chemistry targets.

5.2.2 *Potential Tailings Export Sources for Mining Operations*

There are scenarios where the export of tailings water from mining operations may be desirable, such as:

- when the tailings water balance of the facility requires water to be exported to maintain containment volumes;
- when tailings water chemistry cycles up to levels where tailings recycled water use reduces performance in extraction or upgrading (for integrated facilities); or
- where there is a desire to improve tailings water quality to reduce potential liability issues in reclamation processes (e.g., saline landscape or heavy metal contamination).

For the purpose of this report, water that is exported to maintain containment volumes is called "Legacy Tailings Water", and all other potential volumes are called "TDS Control Water". The potential water sources available for export include:

- Water imports as described above
- Thickened tailings or coarse tailings water release
- Consolidated tailings (CT) or MFT drying tailings water release
- Dyke seepage water
- Froth treatment tailings water release
- A combination of the above.

In instances where the reason to export water is to reduce tailings water volume, the streams with the best water quality (clean water streams) to enable discharge or recycle with the least amount of treatment required include:

- Processes using river water sources as make-up water
- Dyke seepage water
- Surface water run-off.

Of these streams, wastewater produced by processes sourcing water from the Athabasca River (e.g., bitumen upgrading or utility wastewater sources) would be the easiest to target for source reduction, and to capture for treatment and recycling or discharge. Although there is usually a system of collection wells to capture dyke seepage water and return to the tailings ponds, the captured volumes tend to be small and inconsistent. Process affected surface water run-off is quite large. This stream also tends to be fugitive, but certain large sources may be captured as part of a site specific mine drainage strategy and directed to one stream. All three of these water quality streams could be considered 'clean' since they do not have significant quantities of organics, nutrients, or TDS, and can therefore be efficiently recycled internally and/or exported to other producers with minimal treatment requirements (suspended solids removal only).

On the other hand, where the reason to export water is an improvement to tailings water quality, the streams with the worst quality (dirty water streams), that would be ideal as a blow-down from the tailings water systems, include:

- Basal depressurization water (high TDS)
- Froth treatment tailings (high TDS and organics)
- Thickened tailings or coarse tailings water release
- Consolidated tailings (CT) or MFT drying tailings water release.

The last two streams may be separate or combination streams of froth treatment tailings, coarse tailings, or CT release water. In some operations, it is difficult to capture the water from these streams separately. It should be noted that based on water quality data of water released from various tailings deposits, the froth treatment tailings has the worst quality of water with respect to inorganics, acid reducing compounds (ARCs), organics (including naphthenic acids), and nutrients. Basal depressurization water also contains high TDS and would be an ideal source of blow-down water. Data currently predict that this stream is small relative to the excess tailings water.

In summary, although each mining operation is unique, from a water management hierarchy, the 'clean water' streams should be recycled and/or discharged to acceptable cycles of concentration within the mining operation. This would maximize the reuse of water with no or minimal treatment (solids removal only). The rejects from the treatment plant could then be discharged to tailings or to a separate tailings water treatment facility where it would be managed with the 'dirty water' streams.

The 'dirty water' streams would require higher levels of treatment (e.g., organics or TDS removal) to enable reuse for boiler feedwater or discharge within the mining operation. The focus of the Tailings Treatment Technology Evaluation, later in this document, was on the 'dirty water' streams.

5.2.3 *Potential Tailings Recycle Water Quality for Mining Operations*

Potential water quality of the dirty water streams, including recycled pond water (which is a combination of all the streams), basal depressurization water, and froth treatment tailings water, needs to be considered. In addition to the water quality of the tailings water sources, water quality criteria are presented for various end uses, including:

- Water to SAGD (make-up water upstream of lime softening process for a once-through steam generator)
- Water for discharge to the environment
- Water for recycle on-site (make-up water directly for a drum boiler).

Other end uses can be compared to the above streams, based on similar water quality requirements. For example, make-up water to cooling towers would require a similar level of treatment as water directed to SAGD operations. (It should be noted that the ability to use this water as cooling tower make-up would be specific to each operator. For example, Suncor currently releases its cooling tower blowdown water to the environment, preventing the use of process-affected water streams for cooling tower makeup without further treatment.)

In summary, there are many possible water sources from which water could be exported either to control the volume of water stored on-site, or to control the quality of the water stored on-site. Selection of the specific water sources to be exported requires additional information not available until later in the project. As a result, the analysis of available volumes of tailings water was conducted at a higher level, with the relatively simple objective of identifying the absolute volume of surplus water currently available (Legacy Tailings Water), or the volume of water required to be drawn down to the desired ion concentration targets.

5.2.4 *Potential Tailings Water Volumes and Supply in Mining Operations*

Although the analysis in Section 5.2.3 identifies very specific potential sources of tailings water, the analysis of the specific volume of water available in the TWM Project is focused at a much higher level, combining all potential streams, and referring to these combined streams as "tailings water."

The following assumptions have been made with regards to tailings water supply:

- There is a limited and specific known quantity of surplus tailings water (Legacy Tailings Water) stored on oil sands mining sites, which mines need to draw down and eliminate from their sites;
- Tailings TDS Control Water will be available for discharge from the mines, where the specific volume of TDS control water is determined by the target objectives for tailings pond TDS concentration.

5.2.4.1 Legacy Tailings Water

Legacy Tailings Water requires both footprint space and additional dykes to store, and represents a liability and ongoing cost to the oil sands mining operators.

Figure 8 illustrates the desired drawdown volumes. The TWM Project has made the assumption that, if permitted, oil sands mining operations would choose to discharge Legacy Tailings Water.

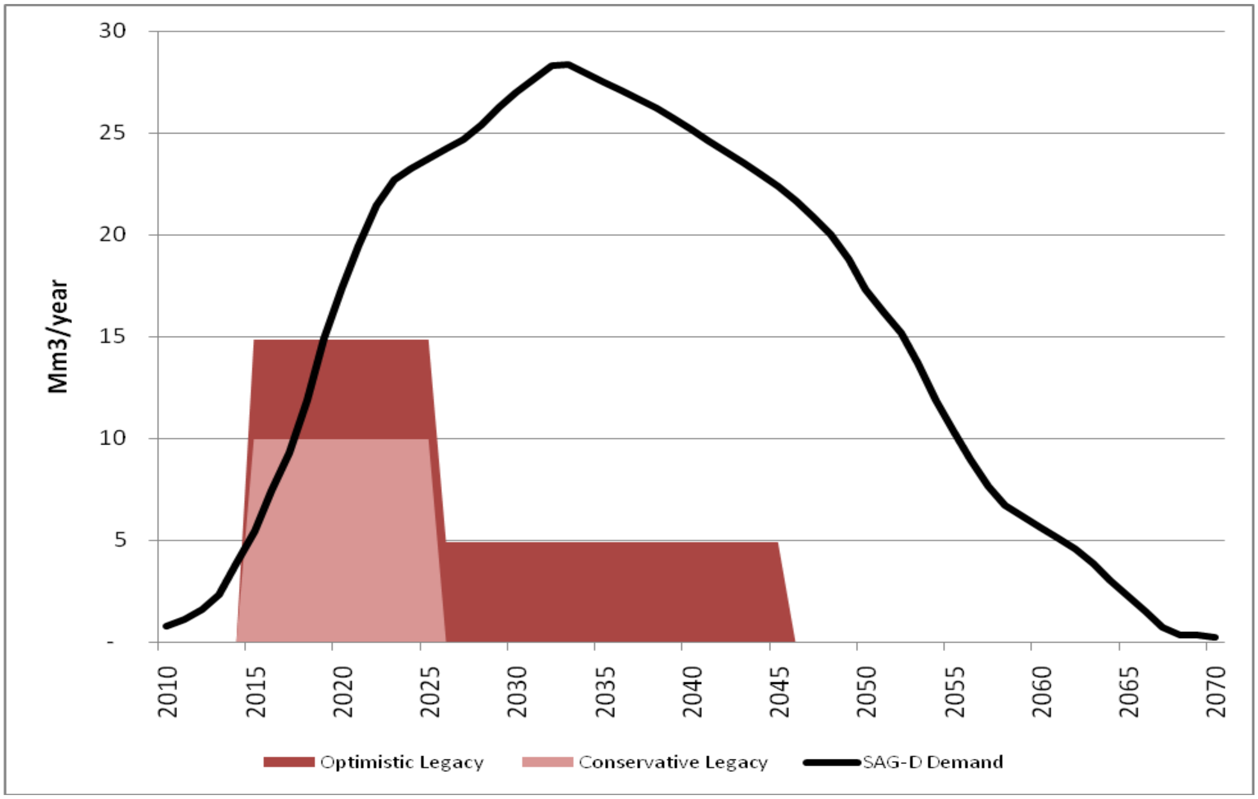


Figure 8. Legacy Tailings Water Volumes

5.2.4.2 Tailings TDS Control Water

Currently, various alternatives for remediation of tailings are under consideration in mining operations, posing an unknown future risk. Conversely, the export of Tailings TDS Control Water is a potential method for controlling tailings pond water quality today with existing technologies, and within existing financial capacity.

The purpose of Tailings TDS Control Water is to reduce the ion level in mine tailings water. This in turn:

- Reduces the environmental liability resulting from retention of elevated ion concentrations;
- Accelerates final site reclamation; and,
- Reduces potential extraction recovery issues.

As is the case for Legacy Tailings Water treatment, there are four primary alternatives for Tailings TDS Control Water:

- Internal recycling within the oil sands mining facility
- Transfer to a SAGD facility
- Transfer to SAGD with concentration

- Treatment and discharge to the environment.

Unlike Legacy Tailings Water, which is assumed to be a limited volume, there is no specific volume of Tailings TDS Control Water; rather, the volume of water to be discharged is set by the desired TDS concentration in the tailings ponds.

The Regional Solution scenario was analyzed to determine whether sufficient volume of tailings water could be provided to meet SAGD demand at a potentially lower EEF than the other sources proposed to supply SAGD operations. **It must be understood that any volume of Tailings TDS Control Water discharged from a mine site would require the intake of additional water from the Athabasca River.** As such, a decision would be required in the near future to justify the additional withdrawal through some other offsetting environmental impact, such as land disturbance, or greenhouse gas production. This is beyond the scope of this project.

For this study, 2,000 mg/L TDS (400 mg/L of chlorides) was selected as the target to maintain TDS closer to background river concentrations, reducing environmental liability and time and effort to reclaim and re-incorporate water into the environment upon mine closure. Above 400 mg/L, chlorides begin to affect extraction efficiency, and result in additional corrosion and as a result more expensive metallurgy in the extraction process train. More detailed analysis should be conducted to determine the optimum TDS and chloride levels for each mine.

Discharge of Tailings TDS Control Water is calculated on a situation by situation basis with specific objectives in mind:

- Keeping chloride levels to an acceptable level to control corrosion issues;
- Minimizing sodium, calcium and other cations which may affect extraction;
- Maintaining the tailings facilities at ion concentrations closer to ambient environmental conditions, which may result in the acceleration of their reclamation and re-integration with the environment upon the closure of the mine.

Figure 9 illustrates the volume of water which would have to be discharged from selected mine tailings ponds to achieve a tailings chloride concentration of 400 mg/L, which corresponds approximately to a TDS of 2,000 mg/L. These thresholds were selected with consideration of both a remediation perspective and an operations perspective. In Figure 10, the Legacy Tailings Water available is illustrated by the solid blocks, whereas the two lines indicate the Tailings TDS Control Water volumes. Two Tailings Water TDS Control volumes were calculated; the dotted line is the volume of water required to be transferred to reduce the ion load if only suspended solids are removed, and the second solid line represents the volume of water which would have to be transferred if there was some concentration of the ions, thereby allowing smaller volume of water to be discharged.

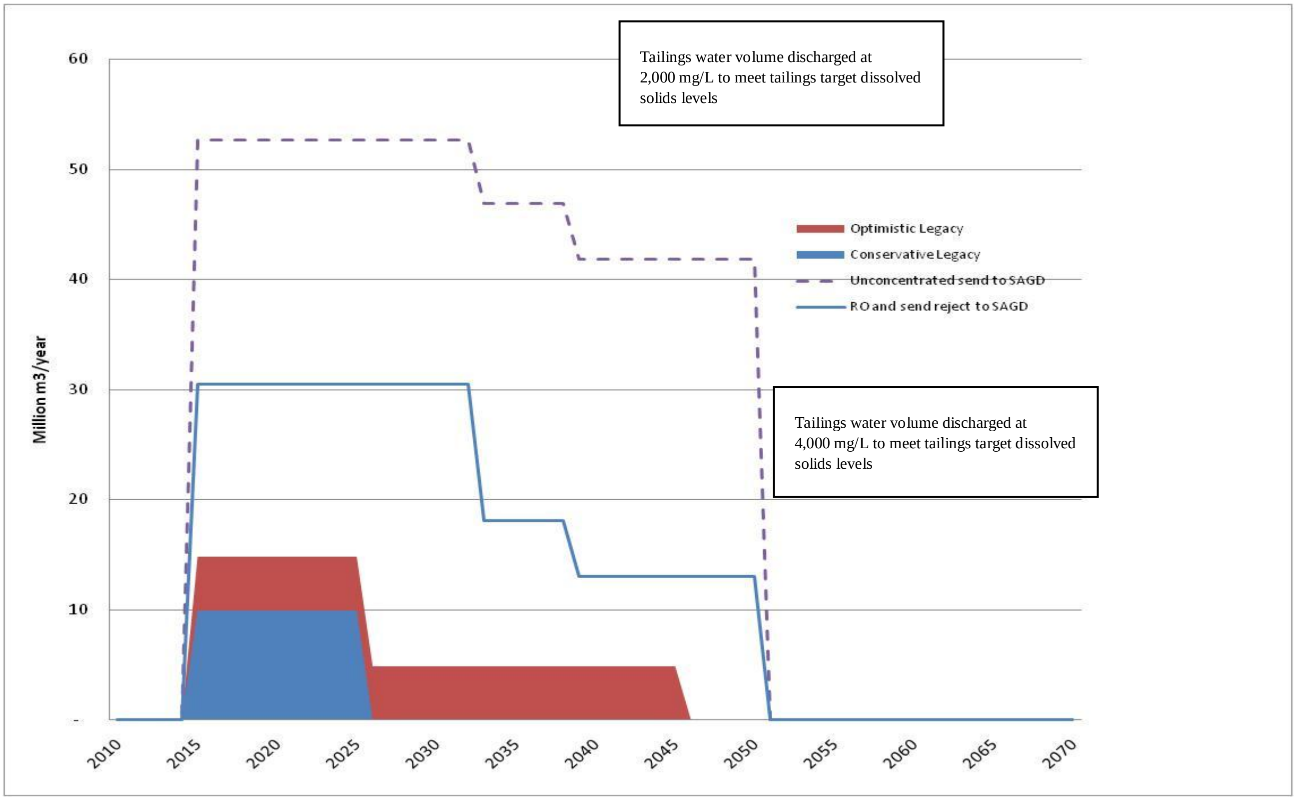


Figure 9. Tailings TDS Control Water Quantity

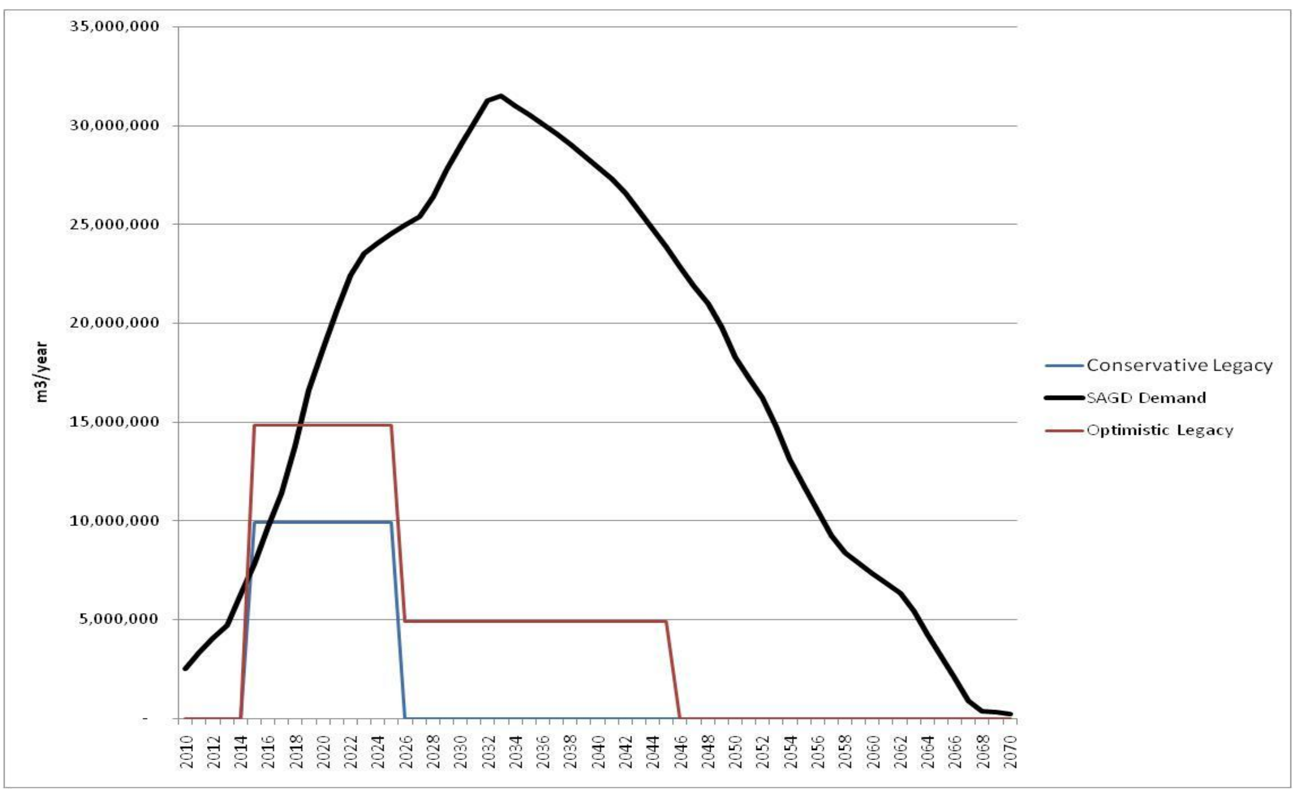


Figure 10. Volume of Legacy Mine Water Available

5.3 Step 3. Identify Alternatives to Drawdown Mine Tailings Water

5.3.1 *Legacy Tailings Water Drawdown Volumes and Alternatives*

The purpose of legacy tailings drawdown is to remove excess tailings water from oil sands mine sites. Alternatives for the elimination of Legacy Tailings Water are listed in Table 1, along with their respective water sources and uses.

Table 1. Mine Related Tailings: Alternatives and Treatment Processes

	Scenario	Treatment Processes
Legacy Tailings Drawdown	Internal Recycle, Waste to Tailings	TSS Removal, Reverse Osmosis
	Internal Recycle, Crystallization of Waste	TSS Removal, Reverse Osmosis, Crystallization
	Transfer to SAGD	TSS Removal
	Discharge of Treated Tailings Water to the Environment	TSS Removal, Organic Destruction
Tailings TDS Control	Internal Recycle	TSS Removal, Reverse Osmosis
	Treat & Discharge to the Environment	TSS Removal, Organic Destruction
	Treat & Transfer to SAGD	TSS Removal
	Treat, Concentrate & Transfer to SAGD	TSS Removal, Reverse Osmosis

Table 2 shows that under no circumstance does the drawdown of Legacy Tailings Water increase the volume of water required from the Athabasca River, including when treated Legacy Tailings Water is transferred to the environment during the entire duration of the Legacy Tailings Water drawdown. The Life-Cycle Assessment section will examine each alternative listed in this table using the relevant total life cycle and economic costs.

Table 2. Lifetime Legacy Cumulative Water Source and Use Volumes

	Water Source & Uses (millions m3)								
	Sources				Treatment Capacity	Uses			
	River Withdrawl	Surface Runoff	Optimistic Legacy	Total Source		Used by Mine	Transfered to SAG-D	Return To River	Total Use
Status Quo	4,435	3,744	-	8,179	N/A	8,179	-	-	8,179
Leg. Rec., Waste to tails	4,174	3,744	261	8,179	261	8,179	-	-	8,179
Leg. Rec., Waste to Crystalizer	4,174	3,744	261	8,179	261	8,179	-	-	8,179
Leg. Rec., Waste to SAG-D	4,435	3,744	261	8,440	261	8,179	261	-	8,440
Leg. Treat and Disch to Env.	4,283	3,744	261	8,288	261	8,179	-	109	8,288

Figure 10 (above) illustrates the volume of free Legacy Tailings Water that is available from oil sands mining sites, and the OSLI SAGD water demand. This figure shows that there is not sufficient volume of Legacy Tailings Water available to meet the entire OSLI SAGD water demand, and thus any regional water management solution that uses Legacy Tailings Water will also require additional sources of water.

5.3.2 *Discussion of Tailings Drawdown Alternatives*

This section will present alternative configurations for the drawdown of Legacy Tailings Water.

The TWM Project considered three tailings treatment alternatives:

- Internal recycling of tailings water, with waste going to tailing ponds or crystallization;
- Transfer of tailings water to SAGD facilities; and,
- Treatment and discharge of tailings water to the environment.

A fourth alternative (treatment and discharge of tailings water to the environment) was not deemed feasible, and while included below is not considered in the analysis.

Each alternative is described with a figure illustrating its configuration below.

5.3.2.1 Internal Recycling, Waste to Tailings

In this alternative, free tailings water is treated for the removal of suspended solids, and the filtrate is passed through reverse osmosis (RO). The permeate is recycled to upgrading, and the reject is returned to the tailings ponds. Internal recycling meets the objective of reducing volumes of water stored on site, and requires no additional raw water or significant increased energy demands, but it increases the rate of TDS accumulation within the tailings.

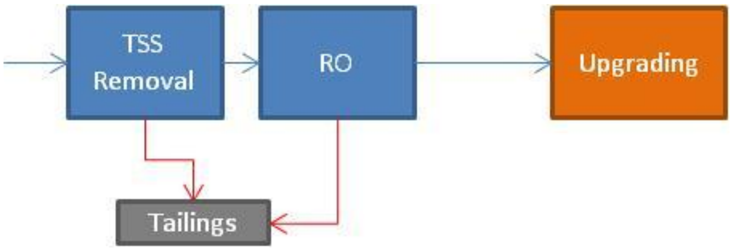


Figure 11. Recycling with Waste to SAGD

5.3.2.2 Internal Recycling, Crystallization of Waste

Internal recycling with crystallization uses exactly the same process as internal recycling, but rather than returning the waste to tailings, the RO reject stream is crystallized, creating a solid waste stream that must then be sent to landfill. This alternative meets the objective of eliminating legacy water, and has the additional benefit of removing TDS.

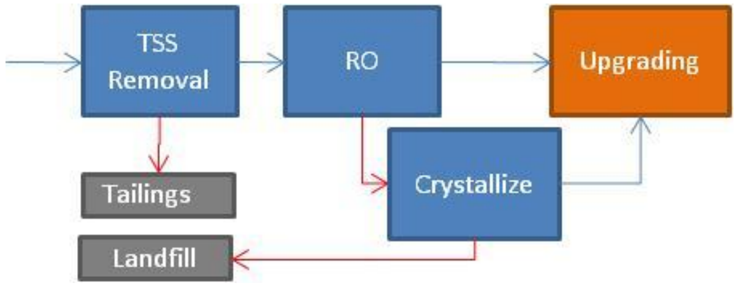


Figure 12. Recycling with Crystallization of Waste

5.3.2.3 Transfer to SAGD Facilities

In this alternative, free tailings water is treated for the removal of suspended solids, and the filtrate is transferred to SAGD facilities (Figure 13). The transfer of Legacy Tailings Water to SAGD facilities removes suspended solids, with the filtrate and entrained TDS transferred to a SAGD facility, and the filter waste returned to tailings.

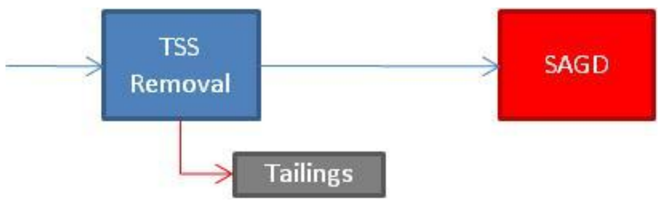


Figure 13. Discharge of Treated Water to SAGD Facility

5.3.2.4 Treatment and Discharge to the Environment

The treatment and discharge of tailings water to the environment requires the removal of suspended solids, as well as the removal of organic and other contaminants. Bench-scale testing was conducted as part of the TWM Project to identify potential technologies for the treatment of these contaminants. The technologies identified included ion exchange and reverse osmosis, which create an extremely pure treated water stream significantly superior to Athabasca River water (Figure 14). As the treated water quality is better than river water, discharging it to the river and withdrawing more river water would have a greater environmental impact than reusing the water. Further, the treatment and discharge of the purified water would also create a significant waste stream which would have to be crystallized and sent to landfill, defeating the purpose of discharge to the environment, which is to blow down accumulated ions. As a result of this finding, the treatment and discharge to the environment alternative was deemed not feasible, and was not evaluated.

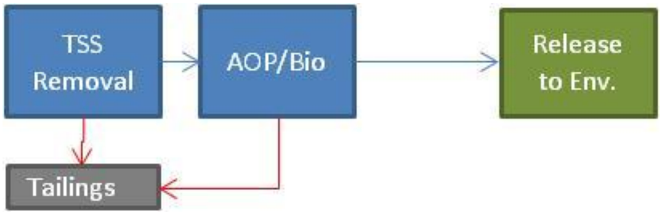


Figure 14. Discharge of Treated Water to SAGD Facility

5.3.3 *Tailings TDS Reduction Alternatives*

The purpose of Tailings TDS Control is to reduce the ion level in mine tailings water to:

- Reduce the environmental liability resulting from retention of elevated ion concentrations
- Accelerate final site reclamation
- Improve extraction.

As is the case for legacy tailings treatment, there are three primary alternatives for Tailings TDS Control:

- Internal recycling within the oil sands mining facility
- Transfer to a SAGD facility
- Transfer to SAGD with concentration

5.3.3.1 Dissolved Solids Concentrations

Tailings TDS reduction alternatives require calculations of the volume of water required to be recycled, discharged, or transferred to a SAGD facility to maintain target TDS concentrations in the tailings ponds, which this report approximated by chloride levels at 400 mg/L (equivalent to a TDS level of about 2,000 mg/L). These volumes were subsequently matched against SAGD demand.

It should be noted that a key assumption of the TDS model was that there was no mixing of the water between the active tailings water and tailings water in the buried tailings, and as a result little buffering in the TDS of the tailings water. Should this assumption be incorrect, the calculated TDS would change significantly.

Figure 15 illustrates the Tailings TDS concentration under different TDS drawdown scenarios. The Maximum Recycle (red line), is the base case, where less fresh water is brought onto the site and water recycle intensity increases without any treatment other that filtration, allowing TDS concentrations to climb from a little over 2,000 mg/L to almost 3,500 mg/L. The green line, Case OR1, assumes treatment of Legacy Tailings Water only and as a result shows a marked drop in tailings TDS during treatment, but a rapid increase again following the termination of transfer to SAGD. Cases OR3A, OR4A and OR4B show the effect of operation of TDS control through mine closure, and show significantly lower Tailings TDS at end of mine life. Section 5.3.3.3 provides further detail regarding the effect of TDS on each alternative.

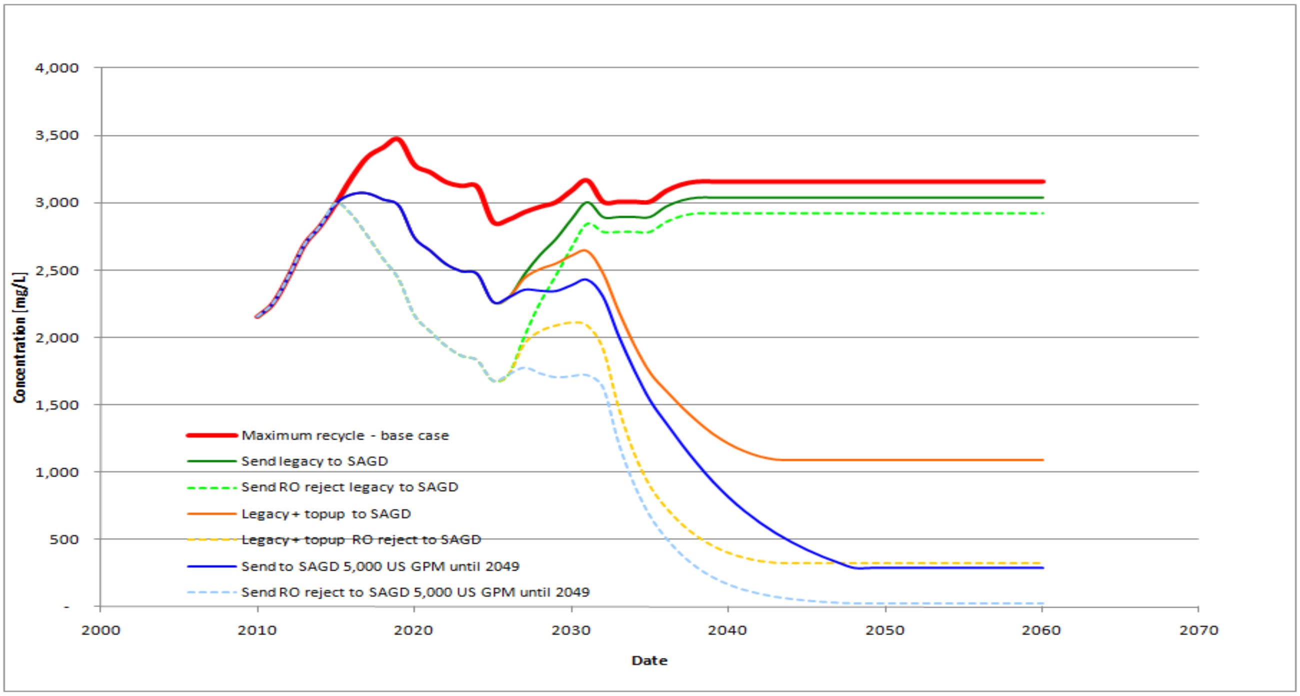


Figure 15. TDS Drawdown Curves

5.3.3.2 Water Demands

The second component of the TDS reduction scenario is the water demand under each scenario. Figures 16 and 17 illustrate maximum water sources and allocation; these data were used in the development of scenarios. It should be noted that TDS, RO and discharge to SAGD has an identical volume to Treat and Discharge to SAGD, as the SAGD demand remains constant and must be met, but through concentration with RO a greater dissolved solids load can be transferred to SAGD.

Figure 16 shows the cumulative water withdrawal for each alternative, broken down by source. Also illustrated is the additional water required to be brought onto the mine site when water is transferred from the mine site.

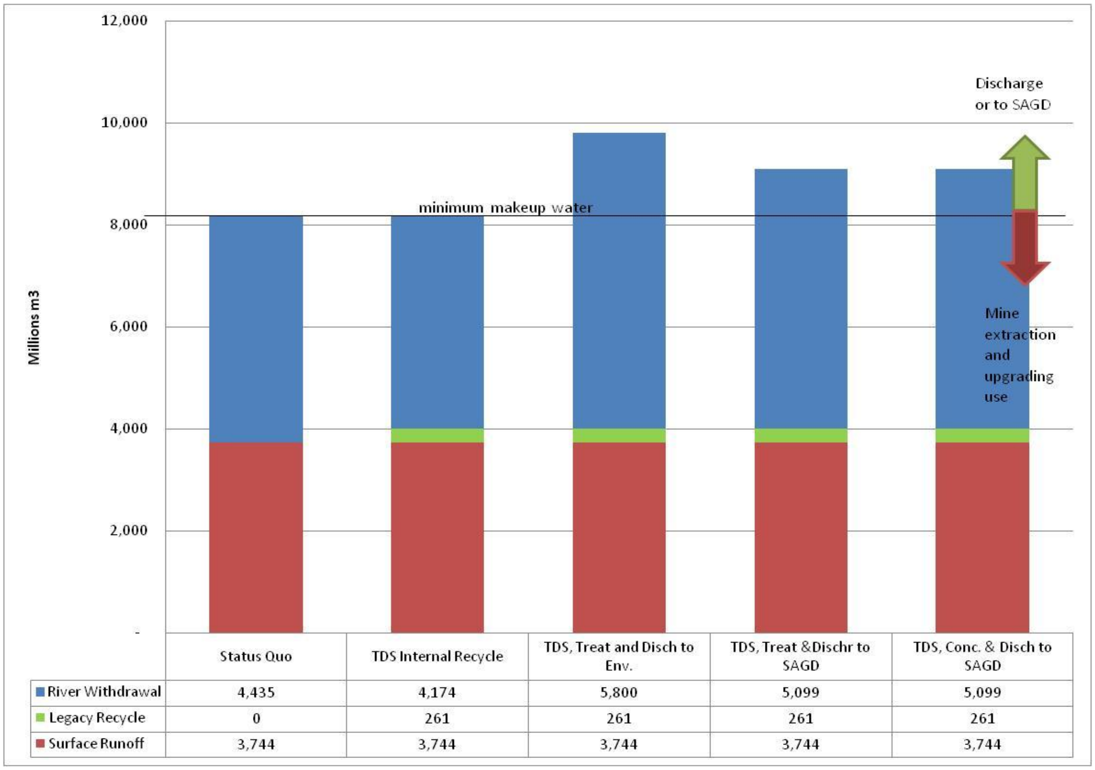


Figure 16. Cumulative Withdrawals by Source (Mm^3)

Figure 17 shows the cumulative water demand for each alternative broken down by allocated use. The last two alternatives, "treat and discharge" and "concentrate and discharge", have the same cumulative volumes, but the concentration alternative transfers significantly more dissolved solids than the unconcentrated alternative.

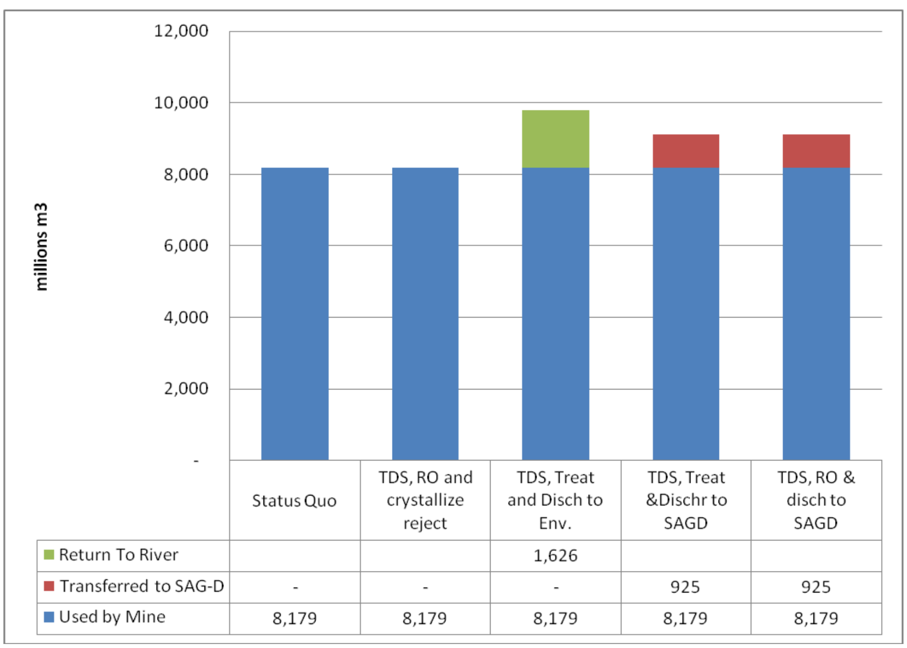


Figure 17. Cumulative Withdrawal by Use (Mm^3)

5.3.3.3 Discussion of Tailings TDS Control Alternatives

The following section discusses each of the alternatives for the drawdown of tailings TDS concentrations beyond the reduction achieved through the reduction in Legacy Tailings Water. Each of the scenarios, with the exception of internal recycle, required the discharge of more water than is sustainable for ongoing mine operations (Figure 17) and as a result required the additional import of water onto the mine sites. (Note: Configuration figures are identical to Legacy Tailings Water, thus were not included in this section.)

Alternative 1: Internal Recycle: RO and Crystallize Reject

In this alternative, internal recycle reduces tailing TDS concentrations through recycling of tailings within the mine. Tailings water is treated with reverse osmosis, and the RO permeate is recycled. The RO reject concentrated TDS stream is crystallized to removing dissolved solids from the tailings systems. Internal recycling has the ability to yield the needed TDS reductions, without increasing the volume of water withdrawn from the Athabasca River.

Alternative 2: Treatment and Discharge to the Environment

The treatment and discharge to the environment alternative involves treating tailings water to a level where it is suitable for discharge to the environment. Figure 17 illustrates the need for additional water from the river if this alternative is used. This scenario can reduce organic and suspended solids to levels acceptable for discharge to the environment, but also requires advanced treatment to reduce all parameters to levels acceptable for discharge. The treatment technologies create treated water of significantly higher quality than raw Athabasca River water. As a result, the EEF of recycling the treated water within the process is less than that associated with the discharge and withdrawal of additional river water and its treatment. For reasons noted in Section 5.3.2.4, this alternative has therefore not been evaluated.

Alternative 3: Treatment and Discharge to a SAGD Facility

In this alternative, treatment and discharge to a SAGD facility can meet the needed TDS objectives, but requires the cumulative transfer of 1,626 Mm^3 of PAW, which exceeds the total cumulative SAGD demand of 1,025 Mm^3.

Figure 18 illustrates the surplus volumes of water from both un-concentrated and concentrated discharge to SAGD, as well as the excess of supply relative to SAGD demand. The volume of water that could be transferred, assuming there is no concentrated treatment of tailings (un-concentrated) far exceeds the demand from SAGD facilities. Thus, if un-concentrated water were to be transferred to SAGD operations, ion concentration targets could not be met.

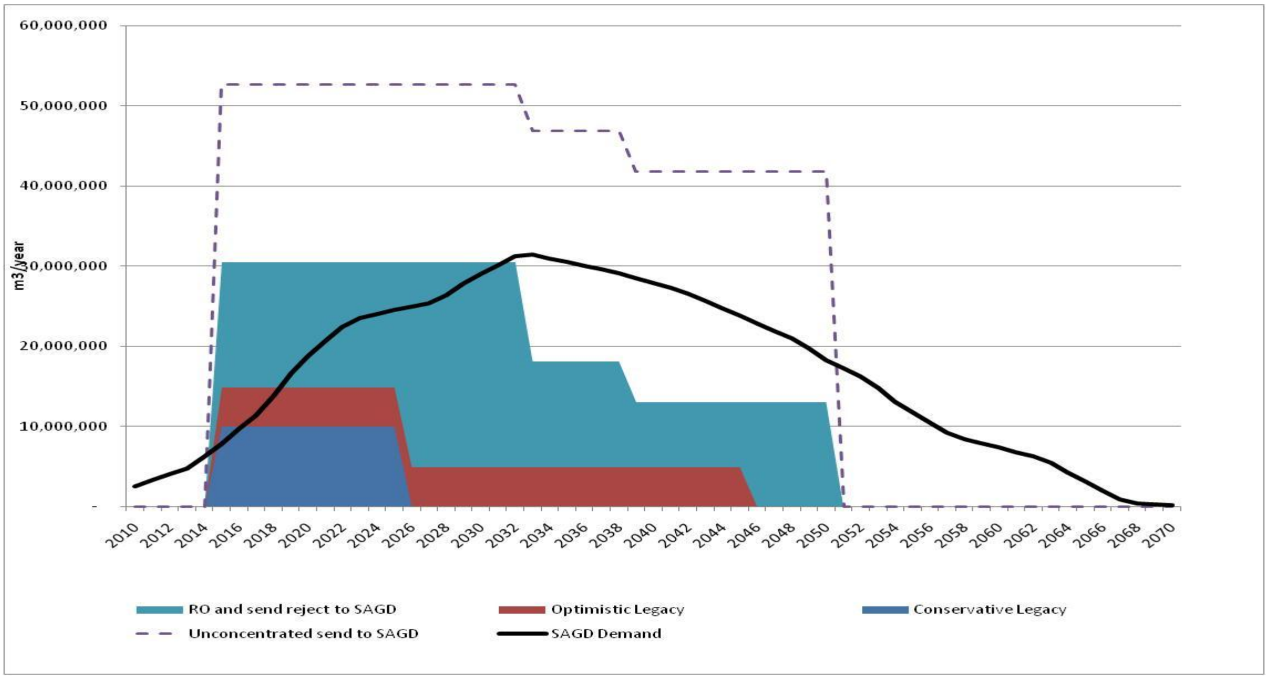


Figure 18. TDS Control Water Volume

Alternative 4: Concentrating Treated Tailings Water and Transferring to a SAGD Facility

The concentrating treated tailings water alternative is identical to treatment and discharge, with the addition of reverse osmosis as a final step to concentrate the ions transferred to SAGD operations. This requires a smaller volume of water to transfer the ions, and at the same time creates a high quality water stream suitable for high quality applications within mines. It also meets the goals of reducing the tailings ion concentrations, and providing the needed volumes of water to SAGD facilities.

5.3.3.4 Areas Requiring Further Investigation

Several areas of the model should be investigated to provide further validation in the model results:

- There is significant uncertainty surrounding the predictions of the future model results, due to uncertainty in model input parameters (e.g., ore connate water quality, surface runoff volumes). Further sensitivity analysis and Monte Carlo simulations should be run to produce confidence bands for the results.
- The base model assumption is that water lost to tailings voids is completely segregated from free water. However, if there is significant mixing between tailings void water and free water, the buffering capacity (resistance to change in chemistry) of the ponds may be increased substantially.
- The pond water chloride levels for Suncor, predicted by the base assumptions in the model, do not match the internally predicted levels, and as such a calibration factor is needed to account for this difference. A better understanding is needed as to why

this is the case. Some potential explanations include errors in connate water chemistry prediction, inequalities in water chemistry between different tailings streams, or interaction between tailings void water and the free water phase.

5.4 Step 4: Identify Alternative Water Sources

While a primary goal of Phase 1 of the TWM Project was to determine the feasibility of treatment and transfer of tailings water to SAGD operations, this alternative was compared to all other sources of water, to determine the Regional Water Management Solution Scenario with the lowest EEF. As a result, in addition to tailings water from oil sands mining operations, other available water sources in the region were evaluated, including:

- Fort McMurray Municipal Wastewater
- Athabasca River
- McMurray Saline Aquifer (East of the Bitumen Edge)

Although there is some question as to the total volume of water available from the McMurray aquifer and the Athabasca River, during this phase of the TWM Project evaluation process both sources were assumed to have sufficient capacity to supply the demand needs for the various OSLI SAGD facilities, assuming that additional storage is provided to bridge low flow periods in the Athabasca River. Later project stages will likely include specific studies to determine the capacity of the McMurray aquifer and the Athabasca River.

The following section discusses each of these sources, their capacity and the potential volume of water available from each.

5.4.1 *Fort McMurray Municipal Wastewater*

Municipal wastewater is produced by the Town of Fort McMurray. Currently, raw water is withdrawn from the Athabasca River, treated, distributed, and the returned wastewater is collected. Following treatment, the wastewater is discharged to the Athabasca River, introducing a nutrient loading to the river. While the diversion of this treated wastewater from the Athabasca River would remove flow from the river, potential benefits include reduced nutrient loading and a potential source of water for SAGD operators.

For this analysis, factors such as seasonal variation, inflow/infiltration and river in-stream winter demands were not considered, but would have to be introduced in any detailed analysis if wastewater alternatives were to be carried to the next phase. Storage was assumed for all solutions using wastewater to make up for any period when river flows dictate flow needs to be returned to the river.

Municipal water volumes were calculated using current facility production volumes (sourced from the facility staff members) and projected into the future using population projections.

Figure 19 illustrates the potential supply of municipal wastewater compared to OSLI SAGD demand. As can be seen in the figure, there is an insufficient volume of wastewater available, thus any solution using municipal wastewater will require additional sources of water.

Furthermore, while the transfer of wastewater to SAGD would reduce the nutrient load on the Athabasca, during low flow periods, municipal wastewater may have to be returned to the river to maintain minimum flow. Therefore, any scenario using municipal wastewater from the Athabasca River has to include some storage allowance for low flow periods.

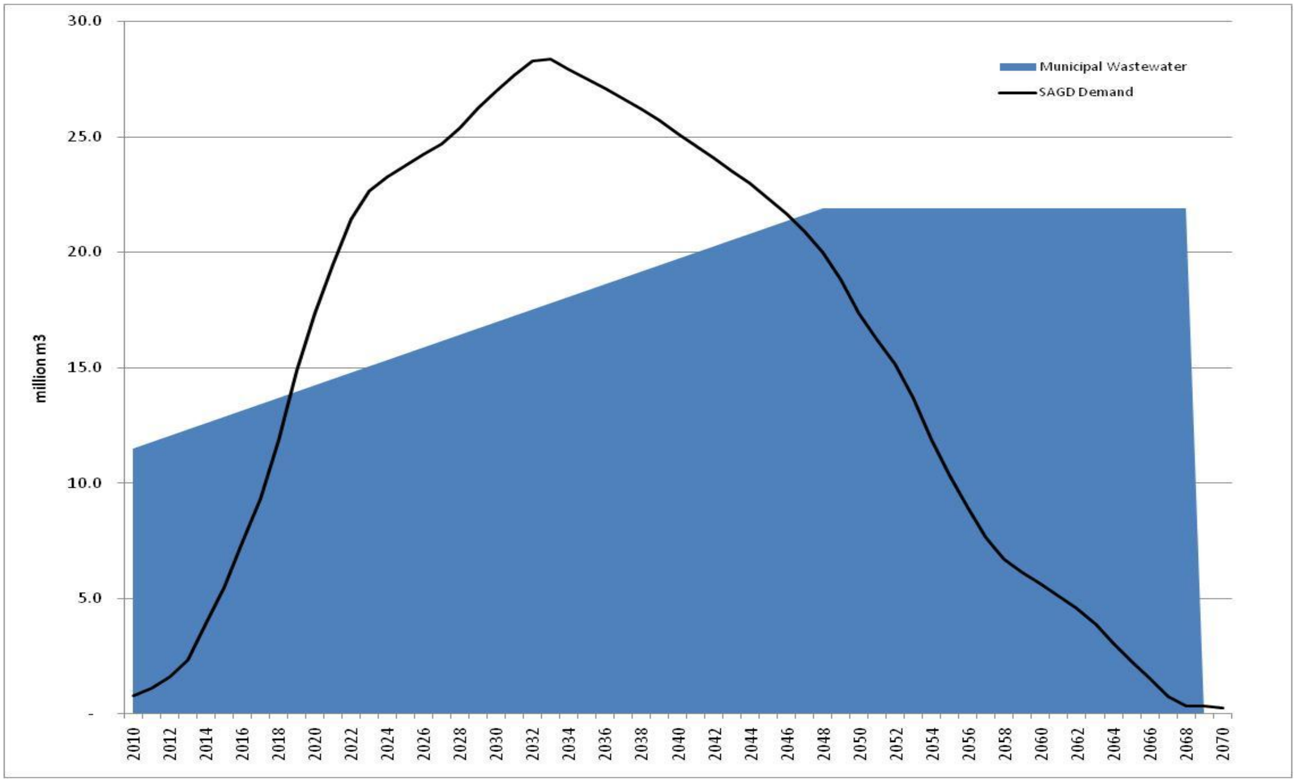


Figure 19. Municipal Wastewater Volumes (Town of Fort McMurray)

5.4.2 *Athabasca River Water*

Although there is some question as to the total volume of water available from the Athabasca River, in this phase of the project the river was assumed to have sufficient capacity to supply the water demand needs for the various OSLI SAGD facilities, assuming that additional storage is provided to bridge low flow periods in the river (Note: verification of the capacity of the Athabasca River will be determined and incorporated in future project stages).

5.4.3 *McMurray Saline Aquifer*

Although there is some question as to the total volume of water available from the McMurray aquifer, for this analysis the aquifer was assumed to have sufficient capacity to supply the demand needs for the various OSLI SAGD facilities. (Note: verification of the capacity, and quality of the McMurray aquifer is critical and is incorporated in future project stages).

The McMurray aquifer was assumed to have a TDS of 20,000 mg/L (ocean water has a TDS of 32,000 mg/L to 38,000 mg/L). One high level well field design assumes wells spaced at 1.5 km intervals pumping at a rate of 1,000 m^3/day with a recovery rate of 60%, meaning that for every unit of water pumped from the aquifer only 60% would be recovered (this is called 'the permeate') and 40% would be rejected as a waste stream. The TDS of this waste stream would be two times higher than the source water and is disposed of into a different part of the same aquifer some distance from the source wells, which would impair any future use of this resource. Figure 20 illustrates the treatment configuration.

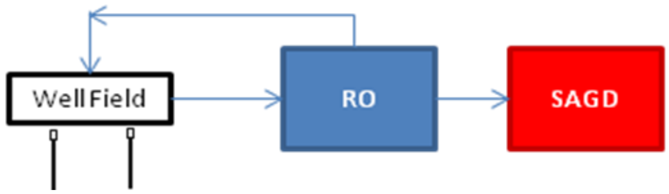


Figure 20. Saline Aquifer Configuration and Treatment Technologies

5.5 Step 5: Identify Suitable Tailings Treatment Technologies

This step identified promising tailings treatment technologies. Three water qualities were required and the required water quality standards are illustrated in Table 3.

Table 3. Parameters Requiring Treatment

Application	Parameters Requiring Treatment
Internal Mine/Upgrader Reuse	Total suspended solids Oil and grease Total dissolved solids
SAGD Reuse	Suspended solids Oil and grease
Discharge to the Environment	Total suspended solids Dissolved organics Oil and grease Nutrients (e.g., ammonia) Toxicity (thought to be primarily due to naphthenic acids) Select metals

Both a literature review and bench testing were conducted to identify suitable technologies. All the technology alternatives evaluated had to be at a sufficient stage in their development where they could be commercially deployed at full scale within 3 to 4 years. As a result only very mature technologies were selected, based on their treatment efficacy and their capital and operational costs. Finally, to prove without a doubt that the identified technologies could treat tailings water at a large scale, those selected will be pilot tested in Phase 2 of the TWM Project.

Figure 21 illustrates the selected technologies in the pilot configuration which will be piloted in Phase 2.

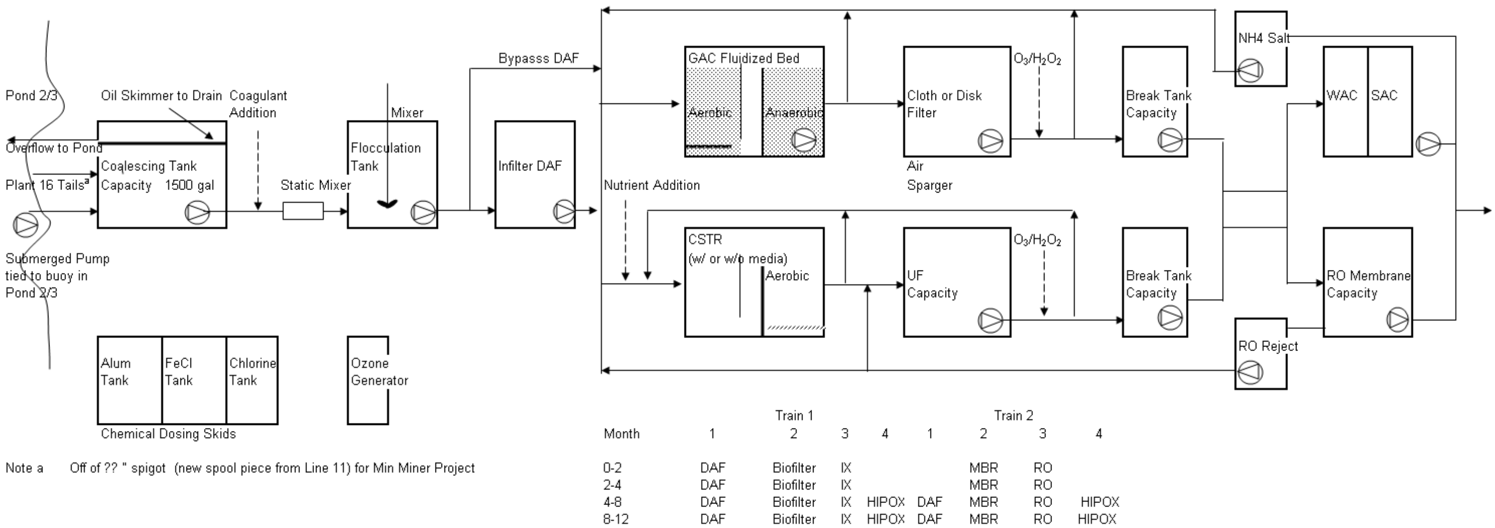


Figure 21. Pilot Plant Testing Configuration

5.6 Step 6: Develop Scenarios for the Regional Water Management Solutions

In this step, possible solution scenarios were examined. Each scenario was designed to provide the same functions:

- Provide same amount of water to SAGD,
- Process the same amount of Legacy Tailings Water, and,
- Provide the mines with the water they require.

A comparison across the designs was completed to satisfy these three criteria.

Seven scenarios were identified for analysis. Common to each solution was the premise that EEF was calculated for each solution across the entire region, thus whether the mines worked together with SAGD regionally or each producer worked independently, the total EEF of any solution was summed to determine the Regional EEF.

The solutions outlined in this section formed the input into the LCA process.

5.6.1 *Solution Category Descriptions*

Individual Solutions – Maintains the status quo with each oil sands mining and SAGD producer continuing to solve their water supply and surplus challenges independently. The aggregate land, water, air and economic loads are summarized to arrive at the total EEF of each project.

Sub-Regional Water Management Solutions – SAGD operators collaborate to develop a regional SAGD solution and the associated EEF which is combined with the EEF associated with individual stand-alone oil sands mine solutions; SAGD operators gain efficiencies from collaboration, but mining operators continue to solve their water problems independently.

Regionally Collaborative Solutions – Integration of the mine surplus Legacy Tailings Water and Tailings TDS Control water to supply the total water demand from SAGD operators.

Of the three categories, only the sub-regional and regional water management solution alternatives were developed and analyzed. The Individual Solution was excluded from the analysis due to the complexity of predicting individual project characteristics, the difficulty getting accurate data and information about specific oil sands projects, and because it is generally believed that the cooperative regional water management solutions inherently have economies of scale over individual solutions that source water from the same location. The cumulative EEF of individual solutions will be conducted in the next stage of the project when individual operators are on board and can provide their individual analysis for calculation of the individual EEF.

Each alternative had as a minimum threshold requirement/criteria: the elimination of mining Legacy Tailings Water (261 Mm^3), and the supply of water (925 Mm^3 total, over the 61 years of the project life) to OSLI SAGD operations.

The water sources considered in evaluating these seven sub-regional and regional alternatives, included:

- Fort McMurray Municipal Wastewater
- Athabasca River
- Fort McMurray Saline Aquifer
- Mine Tailings TDS Control Water.

Table 4 presents the seven scenarios and each scenario's cumulative water source volumes. The table summarizes cumulative water sources over the project life for both sub-regional and regional scenarios.

Table 4. Sub-Regional and Regional Scenarios

Alternative	Optimum Subregional Solution w/ Leg Only			Optimum Regional			
	Opt / Saline	Opt / Waste + Athabasca	Opt/ Athabasca	Trans + Saline	Trens+ Athabasca	Trans+TDS+Waste	Trans+ TDS
	OSR1	OSR2	OSR3	OR1	OR2	OR3	OR4
Legacy Water Drawdown							
Recycle Waste to tails							
Recycle Waste to Crystallizer	261	261	261				
Recycle Waste to SAGD				261	261	261	261
Treat and Disch to Env.	Not Technically Feasible						
TAILINGS CONTROL Scenarios							
RO and crystallize reject							
Treat and Disch to Env.	Not Technically Feasible						
Treat &Dischr to SAGD							
RO & disch to SAG-D						47	664
Sub Regional Elements							
Saline Ground Water	925			664			
McMurray Wastewater		739				617	
Athabasca River Water		186	925		664		
TOTal Water Supplied to SAGD	925	925	925	926	925	925	925

Note: Volumes = cummulative water supply/Demand Millions m3 over the life of the project

Each of the three sub-regional scenarios assumes that the mines will independently manage their water sources and disposal requirements (261 Mm^3), while the SAGD producers will collaborate regionally securing the total required water (925 Mm^3) for total managed water volumes of 1,186 Mm^3 over the life of the project.

In developing each sub-regional and regional scenario, priority was always given first to the use of Legacy Tailings Water, followed by the use of other major alternative water sources. If the timing, availability and demand did not result in an optimal match, another water source was then selected to supply the additional water required, assuming this required minimal additional piping/infrastructure, or included dual-purpose water treatment equipment.

The alternative sources for each of the regional scenarios had a minimum 261 Mm^3 of water from Legacy Tailings Water and additional water required to reach 925 Mm^3 from alternate sources.

Figures 22 to 29 illustrate the distribution of sources, with the coloured section beneath the curve contrasted to the demand illustrated by the curve.

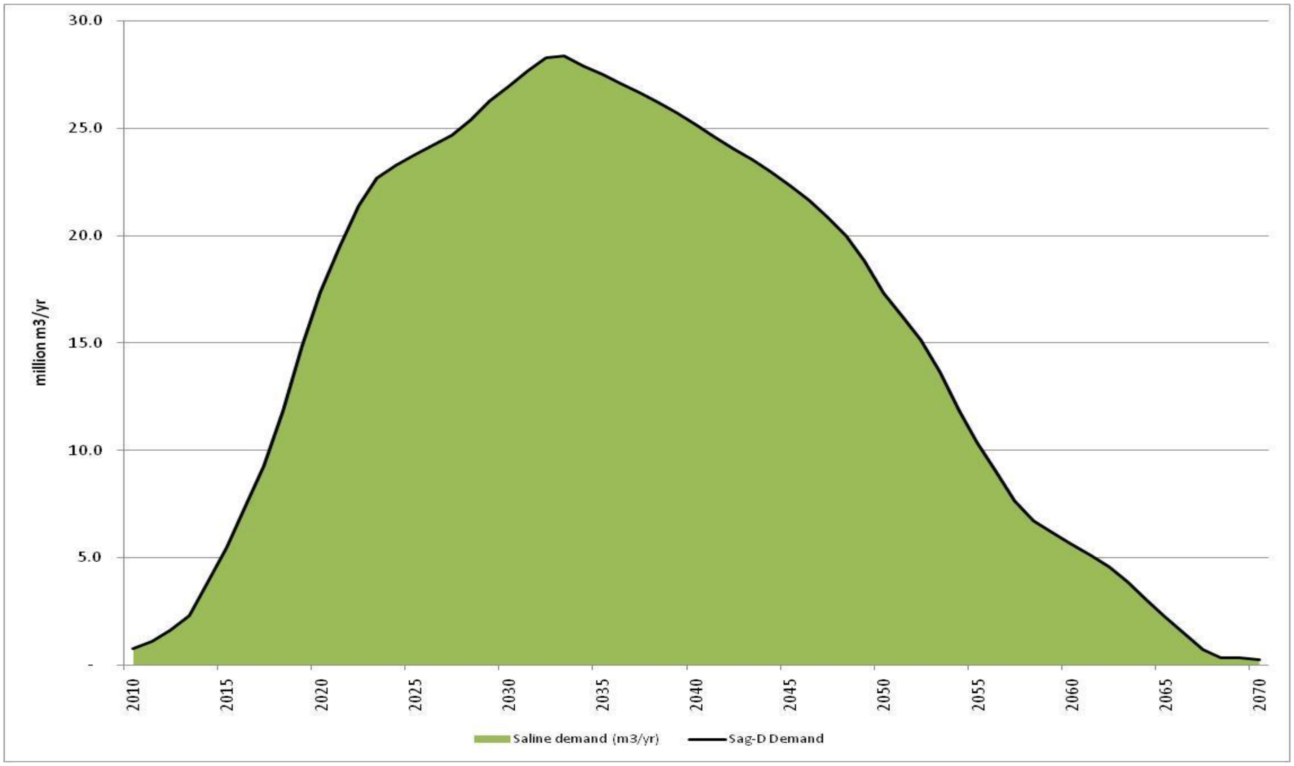


Figure 22. Sub-Regional 1 (Optimal Solution): SAGD Water Supply = Saline Ground Water

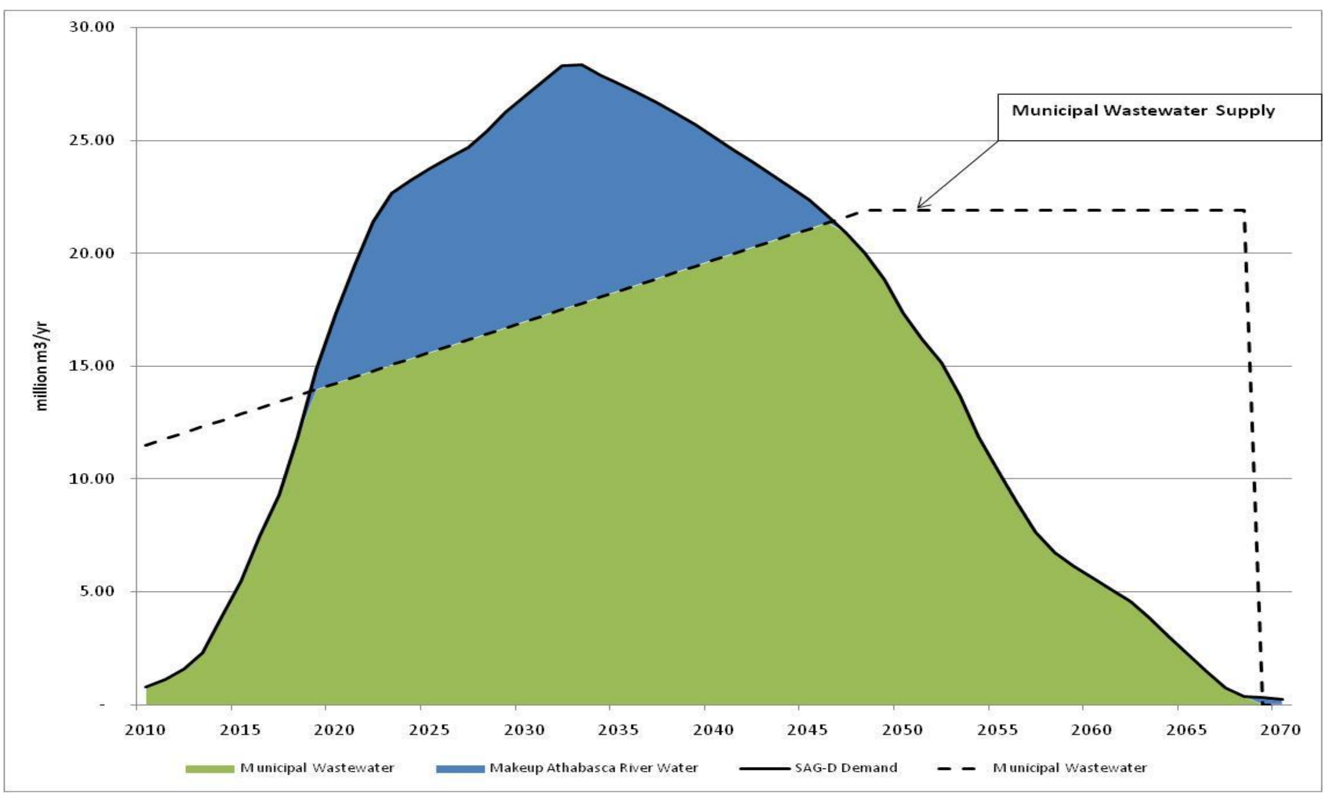


Figure 23. Sub-Regional 2 (Optimal Solution): SAGD Water Supply = Municipal Wastewater

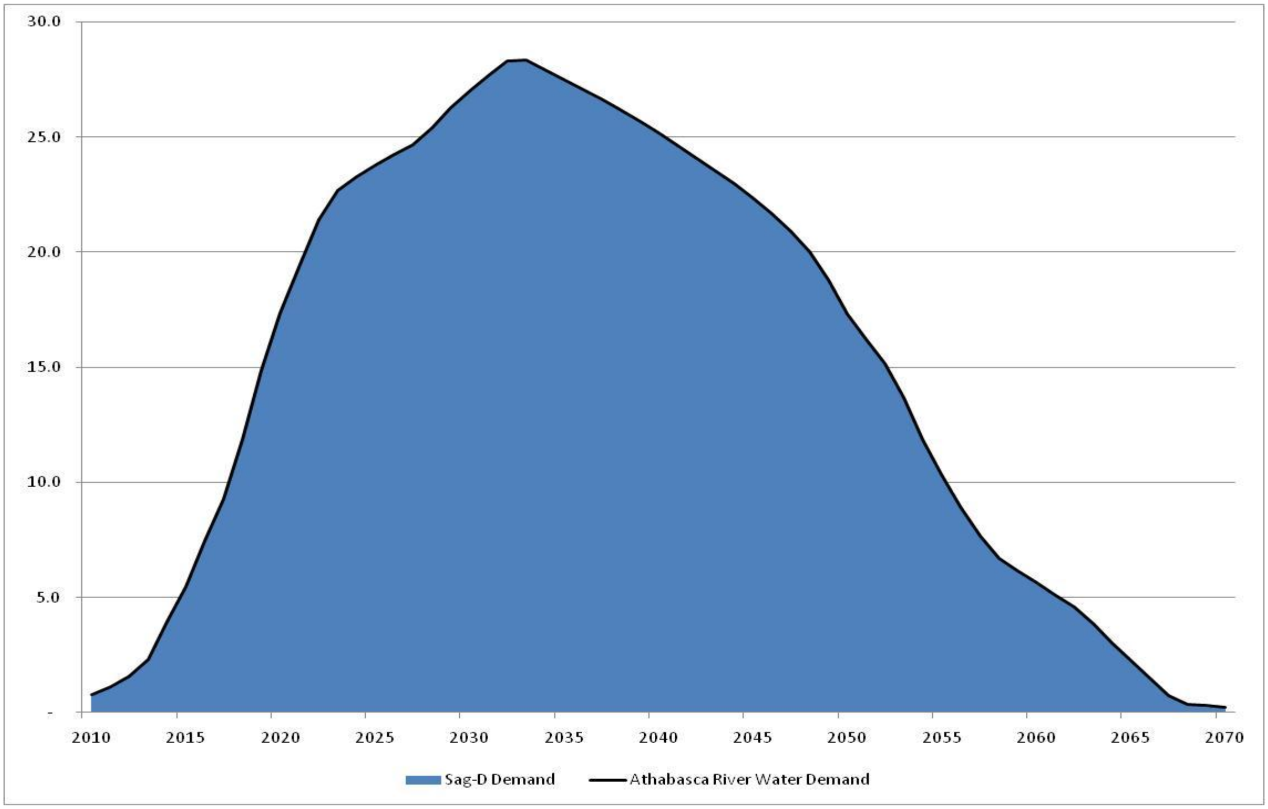


Figure 24. Sub-Regional 3 (Optimal Solution): SAGD Water Supply = Athabasca River

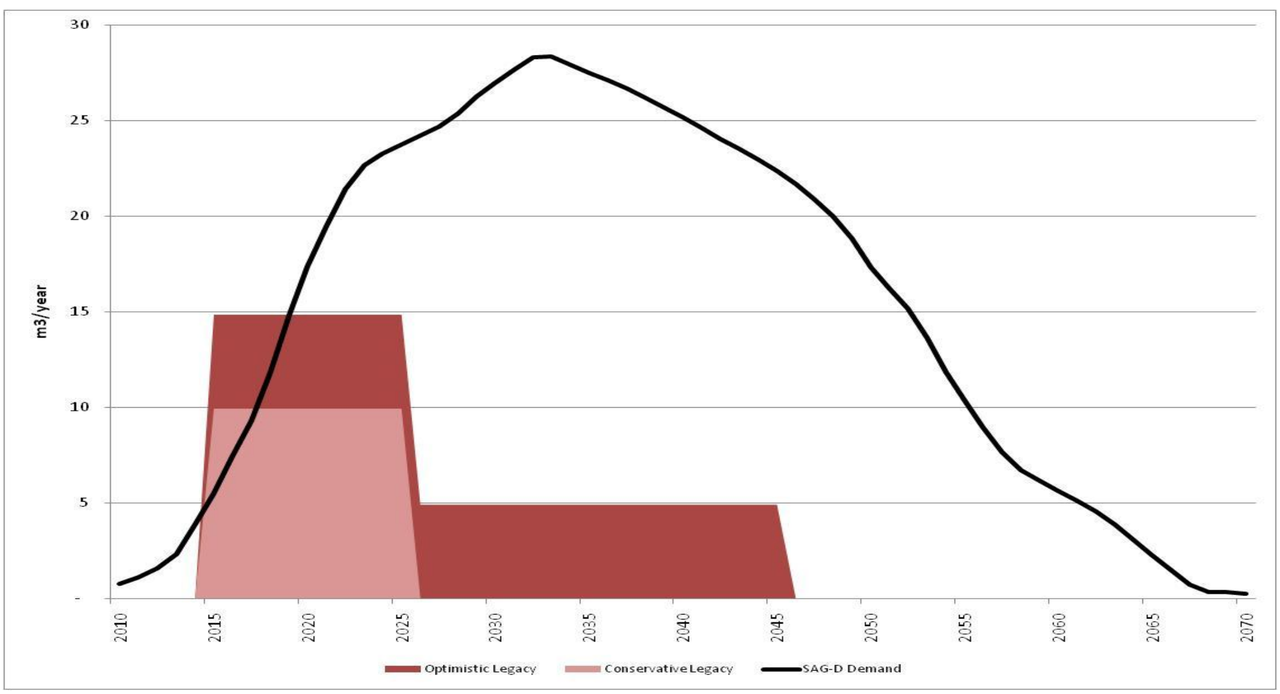


Figure 25. Legacy Tailings Water Supply vs. SAGD Demand

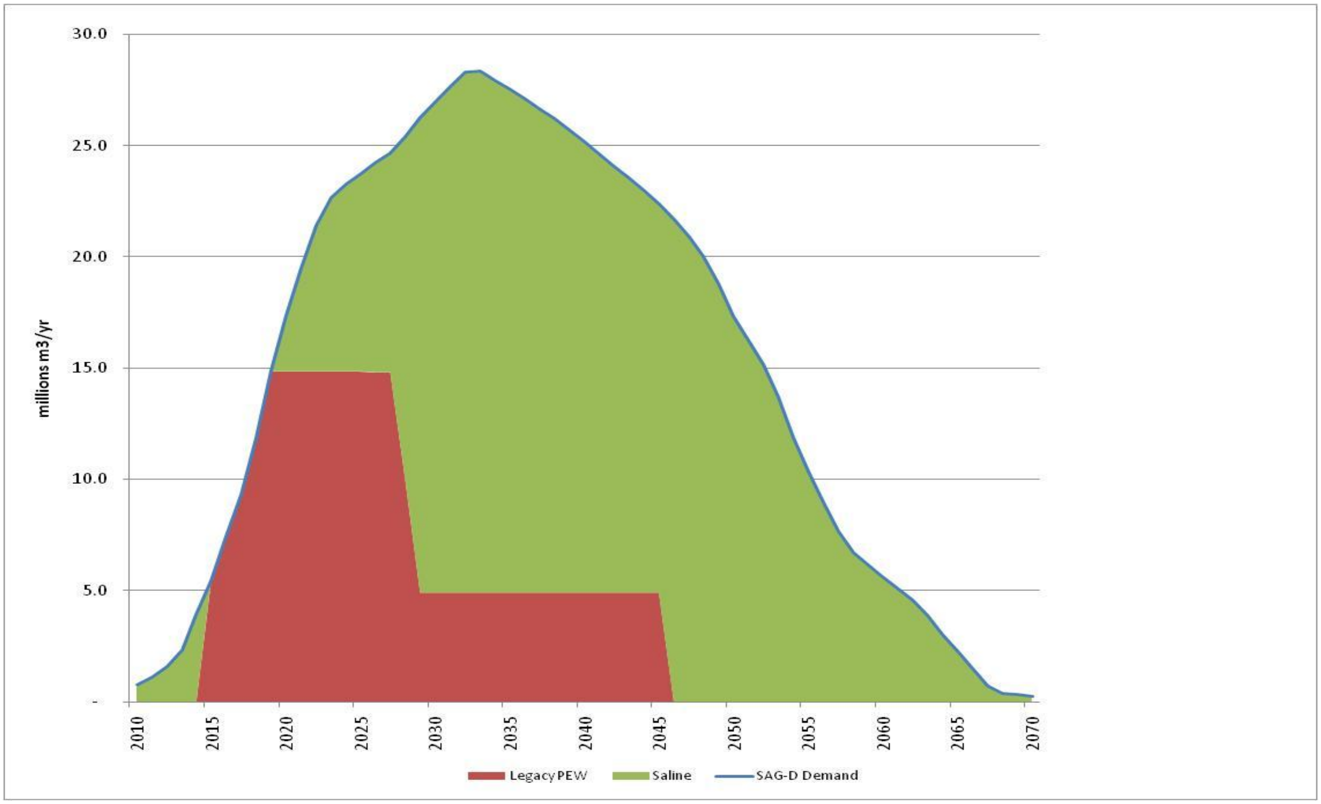


Figure 26. Regional 1 – Makeup Supply = Saline McMurray Groundwater Aquifer

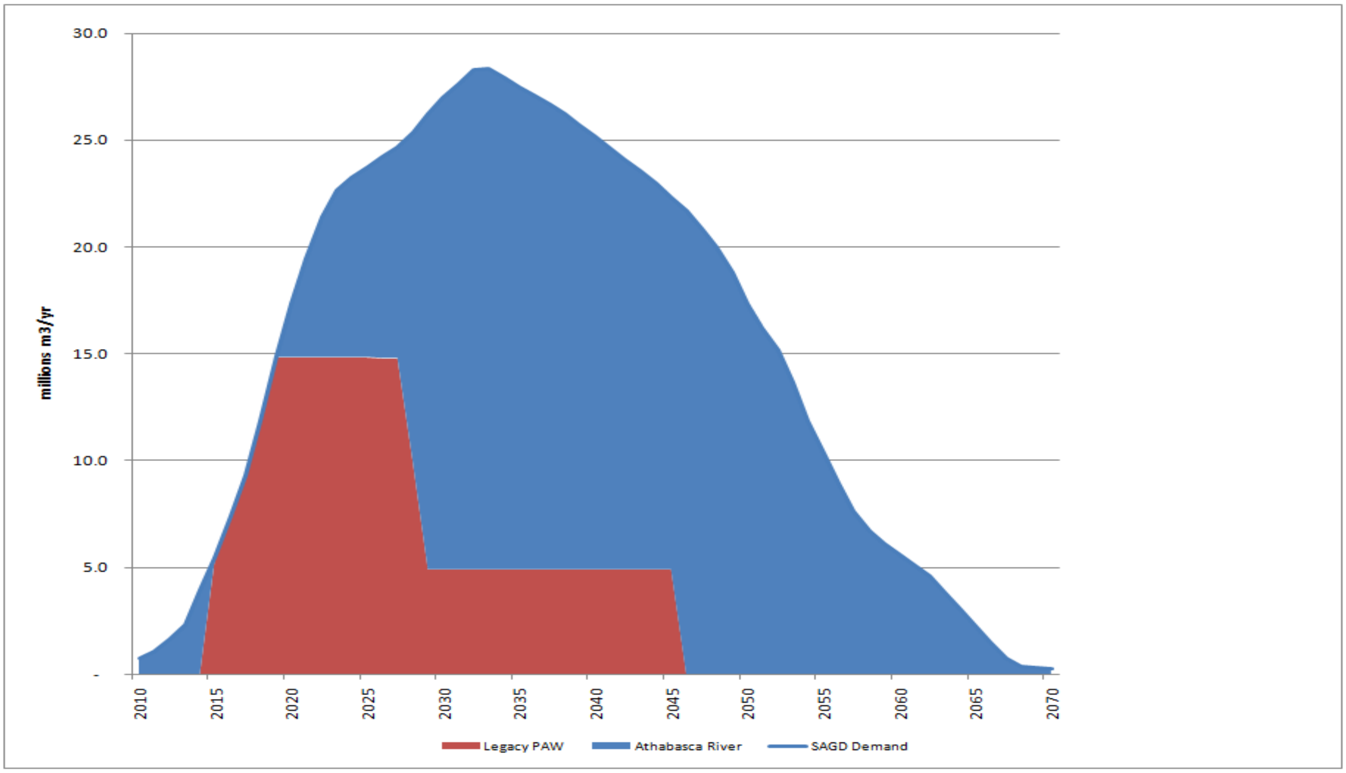


Figure 27. Regional 2 – Makeup Supply = Athabasca River

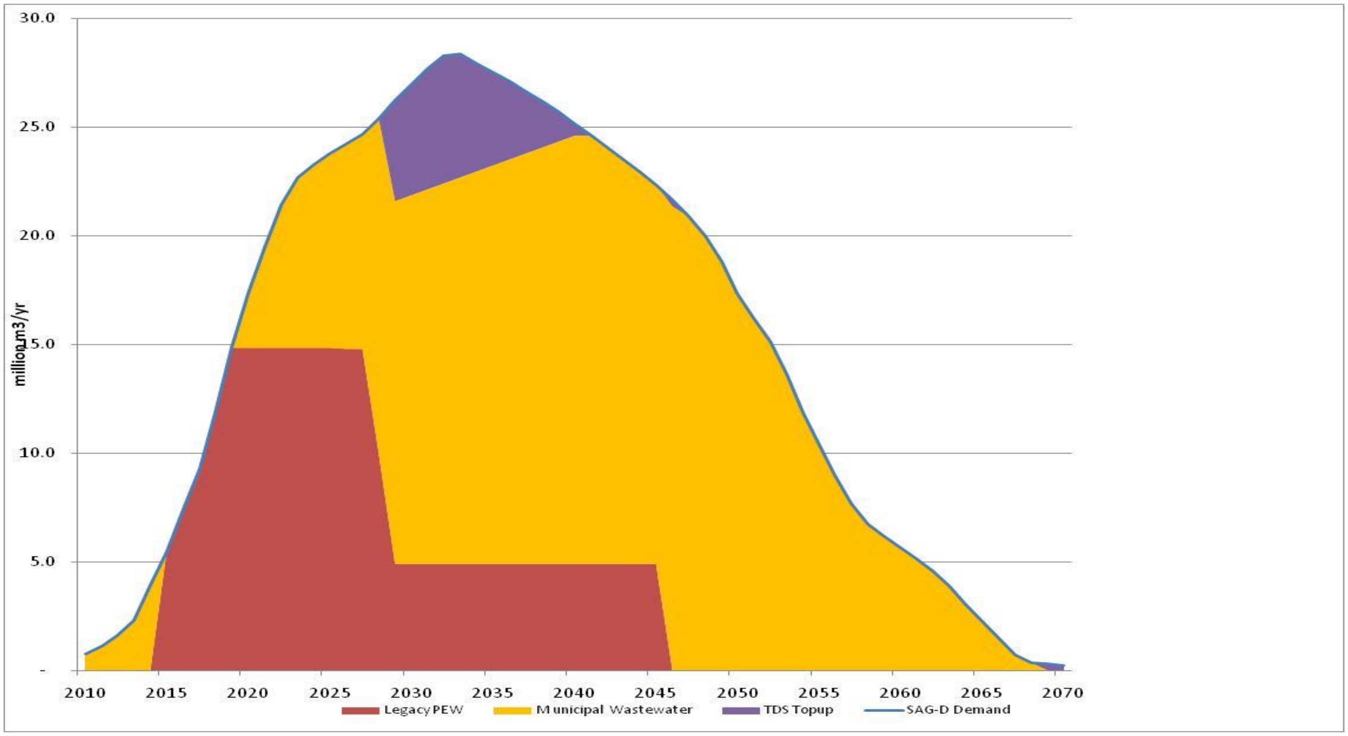


Figure 28. Regional 3 – Makeup Supply = Municipal Wastewater with TDS Control Water Top Up

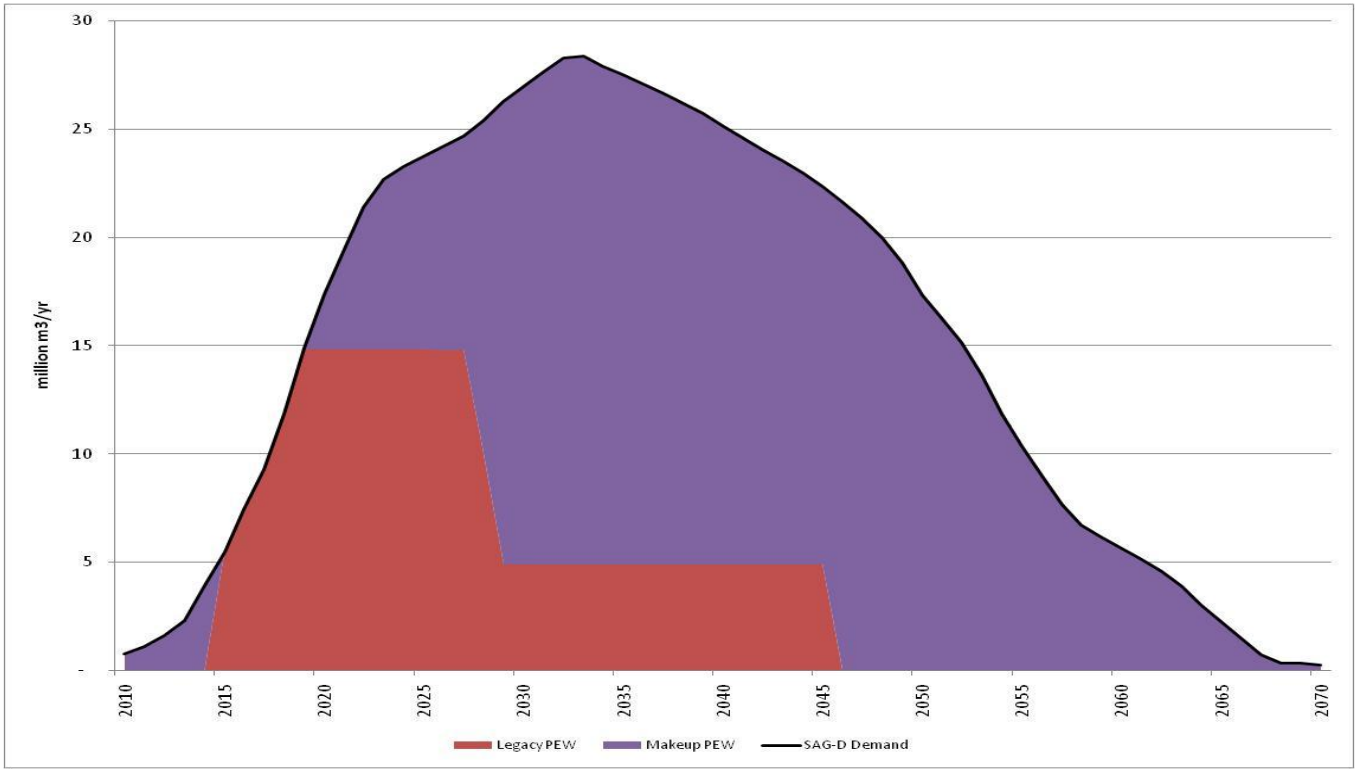


Figure 29. Regional 4 – Makeup Supply = TDS Control Water

6 FINANCIAL AND ENVIRONMENTAL IMPACT INDICATORS FOR EACH SOLUTION USING LIFE-CYCLE ASSESSMENT

The assessment of water management scenario indicators was conducted using a consequential Life-Cycle Assessment (LCA) methodology focusing on describing how relevant indicators change if different decisions are made. Thus, the analysis done here focuses on quantifying the changes in key performance indicators relative to baseline operations, rather than trying to establish the absolute values of the impacts of development as would be done in an attributional LCA. Given time and budget constraints for this project, the completion of an attributional LCA was not possible.

A consequential LCA proceeds as follows:

- Define the scope and purpose of the analysis relative to the decision that is to be made
- List the foreseeable environmental consequences of the decision that are potentially relevant
- Determine which (if any) of these foreseeable consequences should be quantified
- Identify which tools or approaches are adequate to analyze and quantify these consequences
- Analyze and describe the separate consequences
- Interpret the results of the analysis.

Step 1 is discussed in Section 4. The foreseeable environmental consequences (Step 2) and which of these consequences should be quantified (Step 3) are discussed in Section 6.1. Quantification was completed based on the description of the technologies discussed in Section 5.

Models were used to compute the indicators of interest. LCA results for the different design options or solutions are presented and discussed in Section 7, while the interpretation of these results is presented in Section 7.3.

To meaningfully compare the environmental impacts and costs of the different designs, care was taken to ensure that all designs provided the same types and levels of functions, namely:

- Providing same amount of water to SAGD,
- Processing the same amount of process-affected water from mining, and
- Providing the mines with the water they require.

For all designs satisfying these criteria, the total cumulative impacts and costs were calculated over the life of the project and are reported.

6.1 Environmental Consequences Evaluated

The goal of the LCA is to understand the impacts of different designs relative to a small number of "areas of protection". Typically, the four broad areas of protection considered in an LCA include human health, the natural environment, natural resources, and the man-made environment. To determine how a particular design option will impact these areas of protection, the assessment proceeds by quantifying the impacts on a smaller number of impact categories, which in turn define each area of protection. For the natural environment, such impact categories include climate change, water consumption, land disturbance, and wastes generated; while for human health the categories include factors like toxicity, radiation, particulate formation, and climate change. Given the time and budgetary constraints of the current phase, the approach used was to first identify the most relevant impact categories for assessing the different designs, and then decide which indicators could be used to quantify these impact categories.

Based on recent impact assessment frameworks (e.g., ReCiPe 2008) and the description of the technologies outlined in Section 5.5, the categories and indicators deemed relevant to the current study included:

- **Greenhouse Gas Emissions** – all designs require varying energy inputs resulting in the emission of CO_2e. The indicator used was tonnes of CO_2e.
- **Water Consumption** – all designs differ in the withdrawal and use of fresh, saline, and process-affected water. The indicators quantified were m^3 of fresh water, saline water, and process-affected water consumed under the different designs.
- **Wastes Generated** – all designs differ in the quantities of wastes produced. The indicators used were solid wastes (tonne) or liquid wastes (m^3).
- **Land Disturbance** – all designs require some transformation of the natural landscape for facilities, pipelines, roads and other infrastructure. The direct amount of landscape lost by the addition of such features (ha) was calculated and used as a surrogate of relative biotic impacts.
- **Financial Costs** – were quantified through indicators of construction costs ($) and the Net Present Value of the operating costs ($).

7 LCA RESULTS

The impacts of different design solutions were considered relative to the SAGD production per barrel (Table 5), and also in terms of total regional impacts (Table 6). Considering the impacts per barrel of production enabled interpretation relative to what is known about present day impacts of SAGD production, while the total regional impacts over the entire production life enabled understanding of the regional issues likely to be encountered from potential designs.

Within the different design options, one of the key design decisions was whether to pursue a sub-regional or regional water management solution. The sub-regional and regional LCA impacts expressed per barrel of SAGD production or regionally are shown in the figures that follow.

Sub-regional design options had greater environmental impacts and economic cost than most of the regional designs for all indicators except Fresh Water Consumption. For example, design options OR–4A and OR–2A outperformed all of the sub-regional options (OSR–1B, OSR–2B, & OSR–3B) on all indicators except for Fresh Water Consumption. However, the two regional design options OR–1A and OR–4B were out-performed by the sub-regional water management solutions on one or more indicators (e.g., OR–1A was outperformed by OSR–2B and OSR–3B on Construction Cost, Total Water Consumption, Saline Aquifer Consumption, Additional CO_2e, and Additional Liquid Waste). Thus, regional design options provided advantages in terms of minimizing environmental impacts and costs relative to sub-regional options.

Table 5. LCA Impacts per Barrel of SAGD Production

Scenario	Construction Cost ($/barrel)	NPV of Operating Cost ($/barrel)	Total Water Consumption (barrel/barrel)	Fresh Water Consumption (barrel/barrel)	Saline Aquifer Consumption (barrel/barrel)	Additional CO2e (kg/barrel)	Additional Solid Waste (kg/barrel)	Additional Liquid Waste (barrel/barrel)	Land Disturbance (% of Current)
OSR-1B: Saline (925) & Leg Crystalizer (261)	0.18	0.08	1.00	-0.17	0.60	0.65	0.12	1.00	0.21
OSR-2B: Waste Water (664), River, Leg Cryst (261)	0.11	0.07	0.60	0.43	0.00	0.06	0.07	0.00	0.16
OSR-3B: River (925) & Leg Crystalizer (261)	0.12	0.07	0.60	0.43	0.00	0.06	0.09	0.00	-0.25
OR-1A: Saline (664) & Leg SAG-D (261)	0.19	0.05	0.89	0.00	0.43	0.43	0.04	0.72	0.60
OR-2A: River (664) & Leg SAG-D (261)	0.09	0.04	0.60	0.43	0.00	0.01	0.01	0.00	0.14
OR-3A: Waste Water (617)& TDS (308)	0.09	0.04	0.60	0.43	0.00	0.01	0.00	0.00	0.14
OR-4A: TDS SAGD (925)	0.11	0.04	0.60	0.43	0.00	0.01	0.01	0.00	-0.27
OR-4B: TDS SAGD w/RO(925)	0.13	0.04	0.60	0.43	0.00	0.15	0.06	0.00	-0.27

Table 6. Total Regional LCA Impacts

Scenario	Construction Cost (million $)	NPV of Operating Cost (million $)	Total Water Consumption (million m3)	Fresh Water Consumption (million m3)	Saline Aquifer Consumption (million m3)	Additional CO2e (tonnes)	Additional Solid Waste (tonnes)	Additional Liquid Waste (million m3)	Land Disturbance (ha)
OSR-1B: Saline (925) & Leg Crystalizer (261)	1,771	776	1,542	-261	925	6,288,453	1,136,439	1,542	432
OSR-2B: Waste Water (664), River, Leg Cryst (261)	1,091	689	925	664	0	573,243	726,943	0	321
OSR-3B: River (925) & Leg Crystalizer (261)	1,132	683	925	664	0	597,332	838,891	0	-515
OR-1A: Saline (664) & Leg SAG-D (261)	1,812	455	1,368	0	664	4,187,852	353,723	1,107	1,231
OR-2A: River (664) & Leg SAG-D (261)	903	399	925	664	0	101,248	140,064	0	284
OR-3A: Waste Water (617)& TDS (308)	887	397	925	664	0	82,828	46,508	0	284
OR-4A: TDS SAGD (925)	1,075	403	925	664	0	125,712	139,675	0	-552
OR-4B: TDS SAGD w/RO(925)	1,280	435	925	664	0	1,456,355	623,758	0	-552

7.1 LCA Impacts per Barrel of SAGD Production

Construction (CAPEX) and operating (OPEX) costs per barrel of SAGD production are shown in Figure 30. Design options OR–3A and OR–2A were the least expensive in terms of construction costs, while OSR–1B and OR–1A (both involving saline) were the most expensive. All sub-regional water management solutions (OSR–1B, OSR–2B, & OSR–3B) were more expensive to operate (OPEX) than the regional water management solutions.

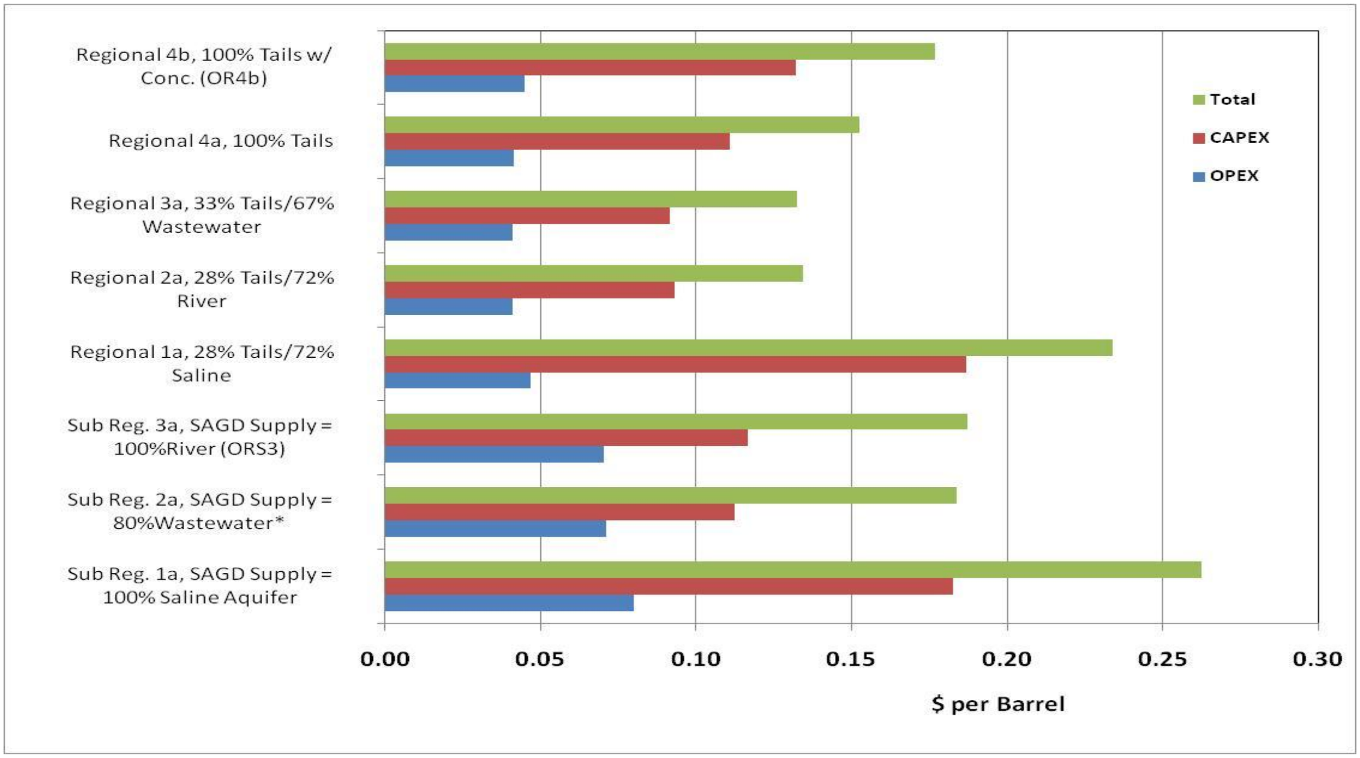


Figure 30. Capital and Operating Costs per Barrel

The indicator Total Water Consumption (Figure 31) included fresh water, saline water and tailings water and was called consumption because the quality of these waters is sufficiently lowered so that they cannot be released back to the environment. For example, the waste streams from the RO process are disposed of in the McMurray aquifer and SAGD disposes of its waste water underground. Water consumption in Figure 31 is the total amount of water of each type required per barrel of SAGD bitumen production assuming that a constant 0.6 barrel of water is required per barrel of SAGD bitumen produced. Total water consumption was largest for any solution involving the McMurray saline aquifer – 1.0 barrel/barrel under OSR–1B and 0.89 barrel/barrel for OR–1A. However, these two options also had the lowest fresh water consumption. Thus, OSR–1B frees up 0.169 (barrel/barrel) of fresh water while OR–1A required no additional fresh water inputs. Saline aquifer consumption (denoting the water that is removed from the aquifer and transferred to SAGD) was also highest under these options. Across all the other options which do not use saline water, using tailings water reduced the overall fresh water consumption from 0.6 to 0.43 barrel/barrel.

According to the Pembina Institute (Moorhouse et al. 2010), the average total water consumption per barrel of bitumen is about 1.1 while on average about 0.7 barrels of freshwater is consumed. To evaluate the water consumption results above relative to the values reported by Pembina, it must be remembered that it was assumed that SAGD operators in the present study would require 0.6 barrels of water per barrel of bitumen initially and decrease over the life of the project to 0.3 barrels of water per barrel of bitumen. The initial 0.6 value is within the range of water use numbers reported by Pembina.

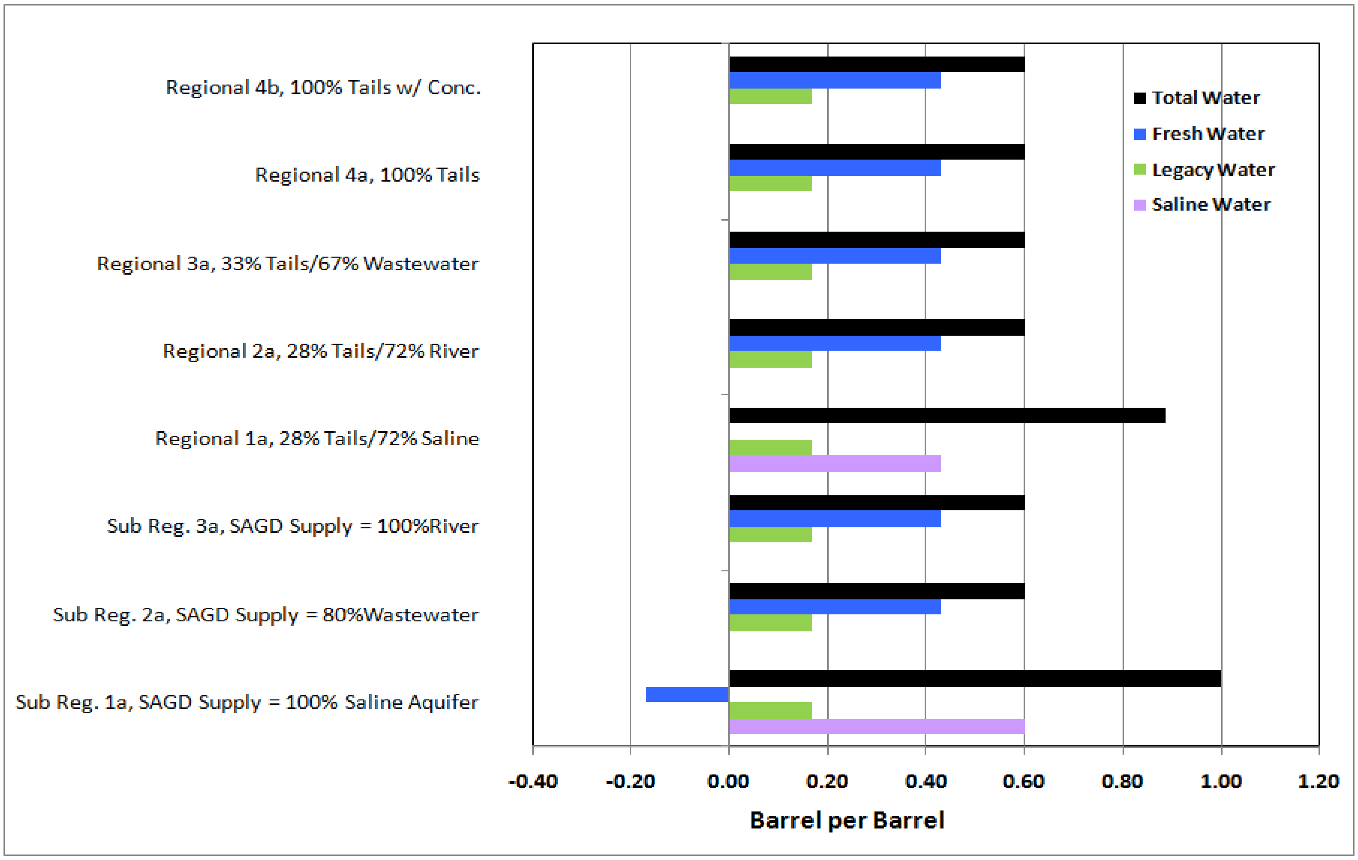


Figure 31. Total Water Requirements per Barrel of SAGD Production

The additional kilograms of CO_2e generated per barrel of SAGD production across these design options (Figure 32) ranged from 0.01 to 0.65 (kg/barrel), or a factor of about 72. Any solution involving RO or crystallization produced the largest additional CO_2e emissions (OSR–1B, OR–1A, OR–4B). Alternatively, solutions that relied more heavily on either wastewater or river water (OR–2A, OR–3A) had the lowest CO_2e emissions per barrel. The emissions of design option OR–4A were only slightly larger than of OR–2A and OR–3A at 0.013 kg/barrel. On average, Moorhouse et al. (2010) found that each barrel of bitumen produced 91 kg of CO_2e meaning that the additional CO_2e for all design options considered is less than one percent of the average emissions produced per barrel of bitumen.

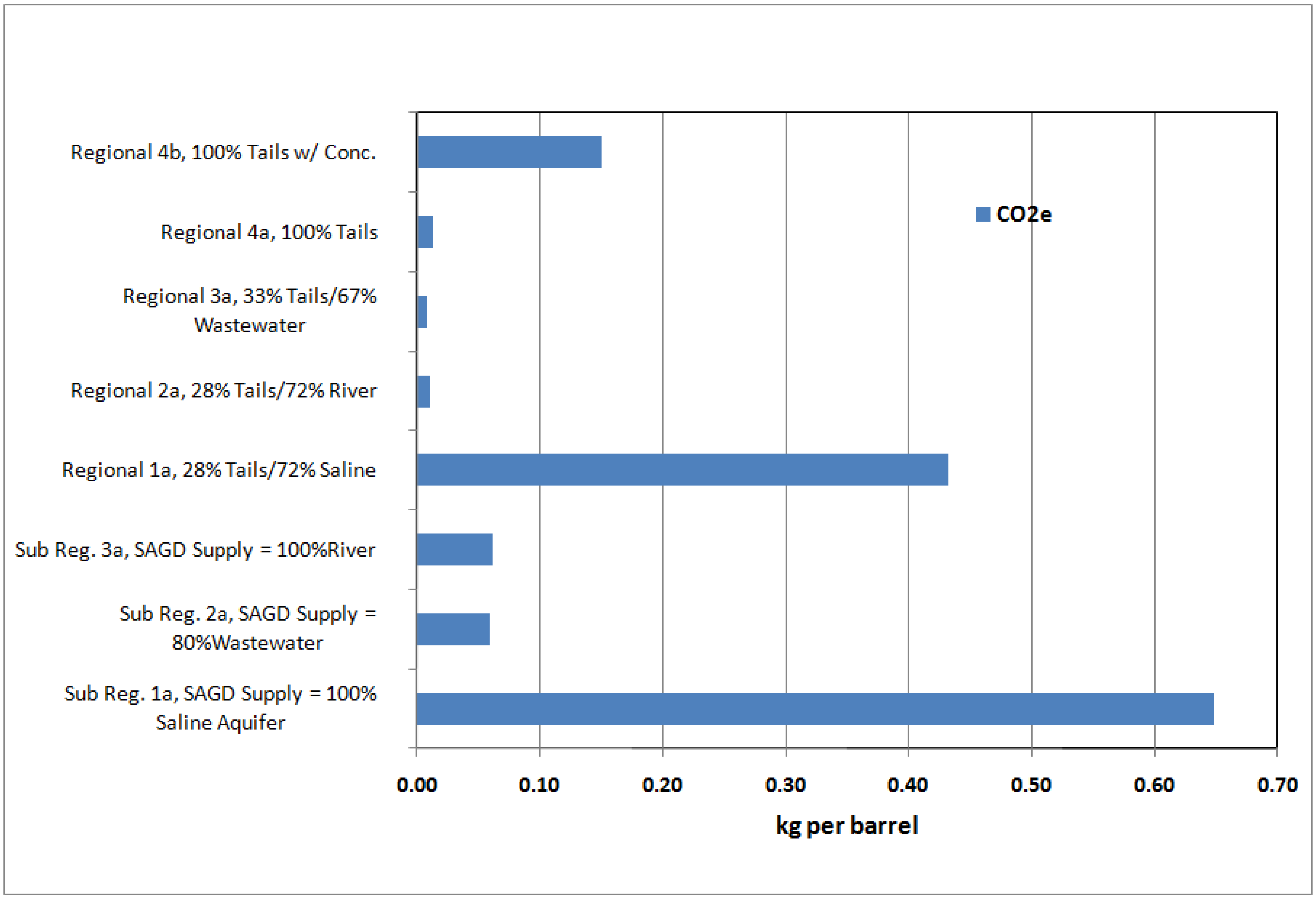


Figure 32. Additional kg of CO_2e Emissions per Barrel of SAGD Production

The additional solid or liquid wastes generated per barrel (Figure 33) increase as reverse osmosis or crystallization are utilized, and decrease as more fresh water sources are used. Thus, OSR–1B and OR–1A produced the most waste while OR–2A, OR–3A, and OR–4A produced the least waste. OR–4A was notable since it had low wastes even though it relied on reverse osmosis or crystallization. Moorhouse et al. (2010) reported that the average amount of liquid waste generated per barrel of bitumen is 0.4 barrel/barrel and any saline option (OSR–1B, OR–1A) would more than double the amount of liquid waste produced.

It should be noted that the lime sludges resulting from some SAGD produced water recycle processes were excluded from waste totals, as the analysis only included makeup water treatment, not produced water recycle.

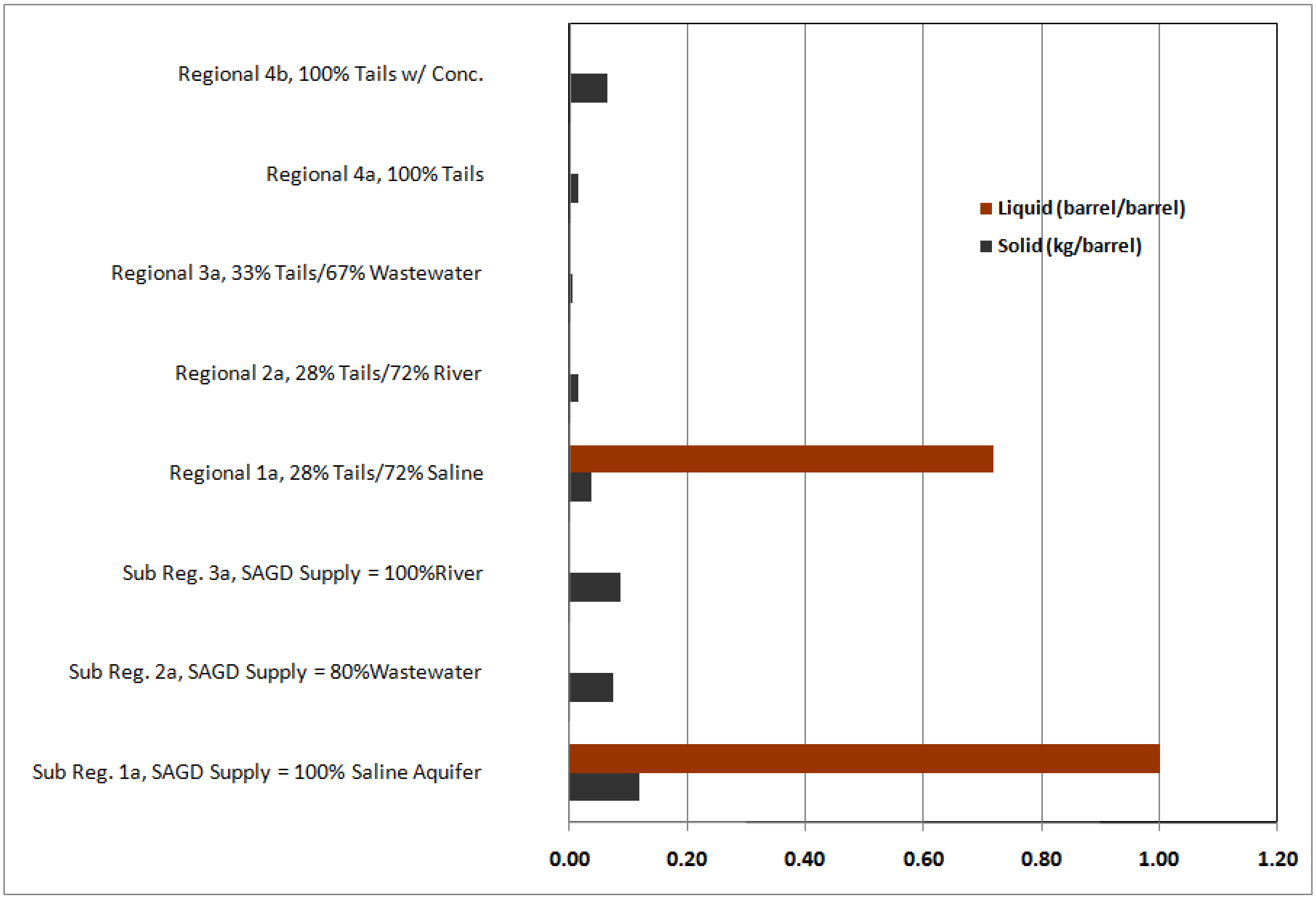


Figure 33. Additional Liquid and Solid Wastes per Barrel of SAGD Production

The land-use impacts associated with the different design options are expressed relative to the total direct cumulative anthropogenic footprint existing across the Lower Athabasca Regional Planning (LARP) area in 2009 – not relative to the barrels of SAGD production as done with the other indicators. The LARP area is 9,111,250 ha with 2.25% of this area taken up by anthropogenic disturbances like seismic lines, pipelines, wellsites, mines, tailings ponds, industrial facilities, etc.

The total direct anthropogenic footprint for each design option was calculated in the same manner as was completed for LARP, and was expressed as a percentage relative to the existing LARP anthropogenic footprint. Figure 34 shows that the additional land-use impacts (relative to current conditions) were all less than ~0.6% – meaning that the additional land disturbed would at most be 0.6% of the disturbance existing today. Negative values mean that over the project time horizon, increased reclamation (due to the use of tailings water) would reduce the amount of land disturbed relative to existing footprint.

Designs which combine use of the McMurray saline aquifer with other options had the largest relative land disturbance. Use of fresh-water sources generally reduced land-use impacts, while solutions OR–4A and OR–4B involving TDS Control Water transfer to SAGD had the lowest land impacts overall.

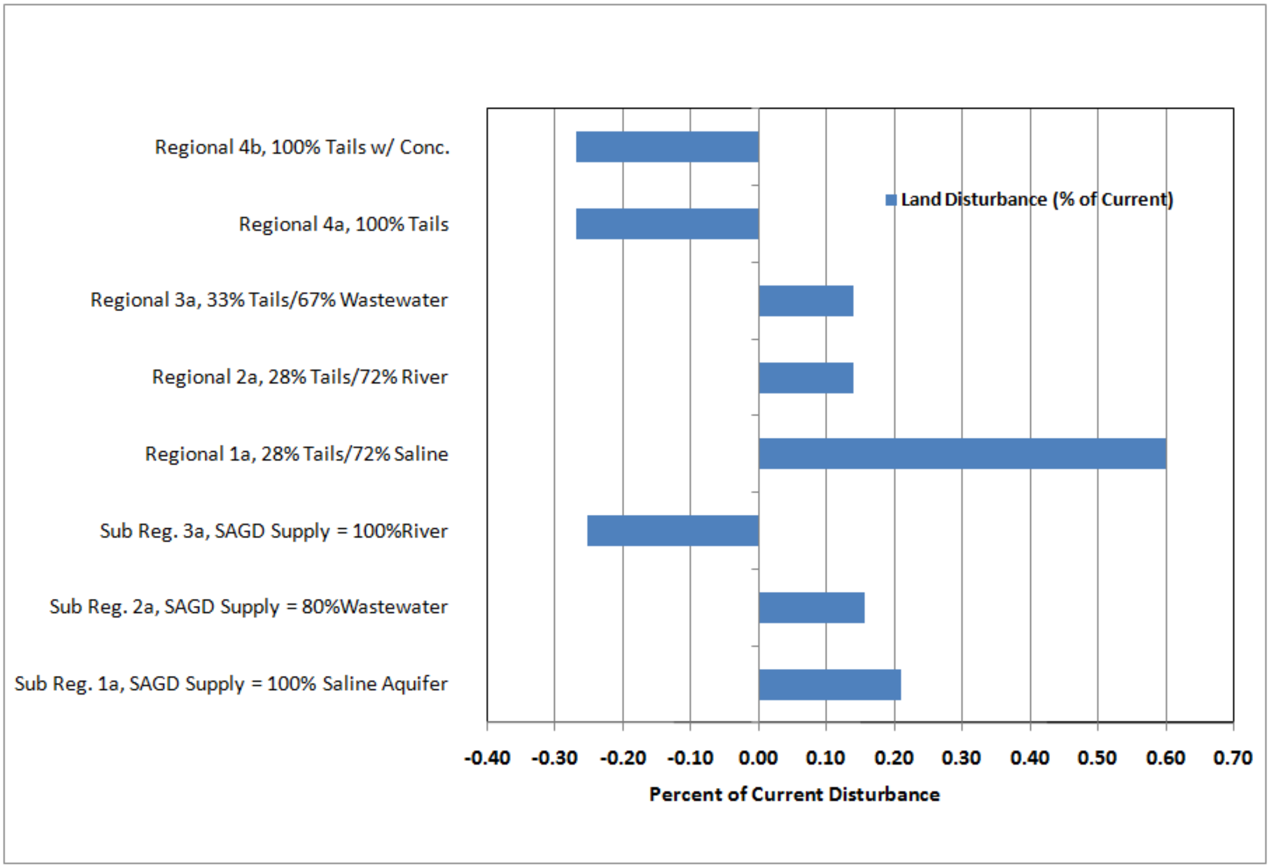


Figure 34. Percent of Additional Land Disturbance Relative to the Existing Land Disturbance

7.2 Regional LCA Impacts

Given that any solution must operate within the environmental constraints of the LARP region, it is also important to understand the absolute magnitude of the regional impacts of the different design options. Table 6 and Figures 35 to 39 summarize these results. It should be noted that the results in Table 5 are scaled relative to those in Table 6 by the same assumed SAGD bitumen production (or current total landscape disturbance for Land Disturbance). As a result, the overall rankings or relative performance of the design options discussed in Section 7.1 will be the same.

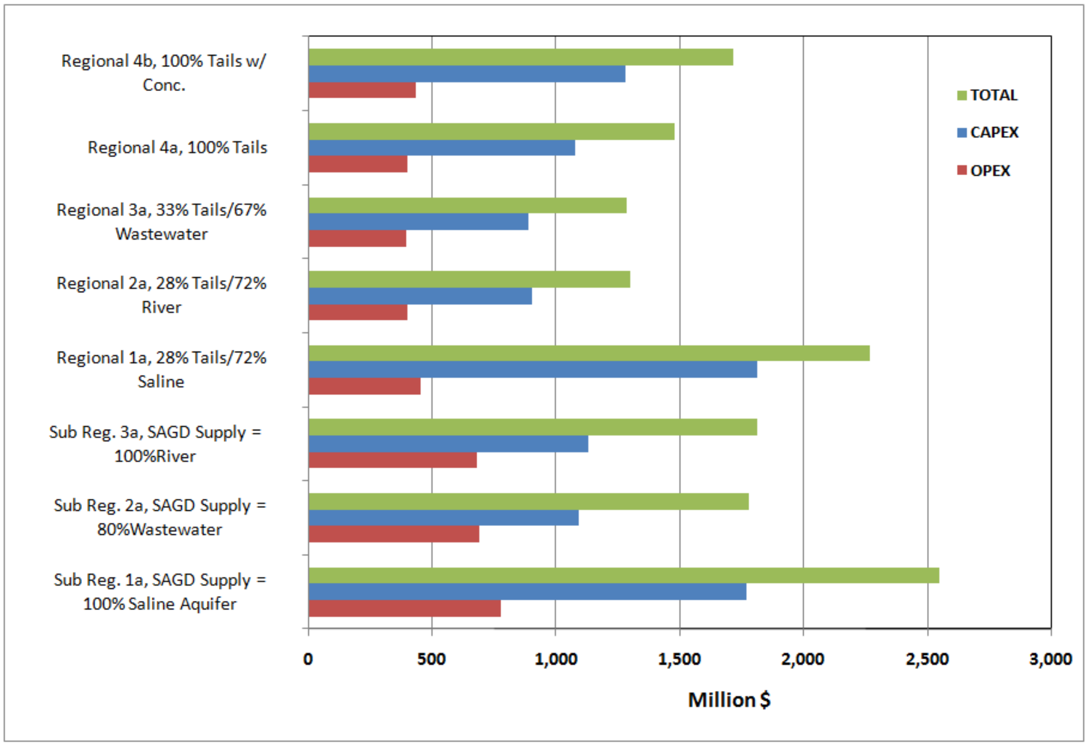


Figure 35. Absolute Construction and Operating Costs

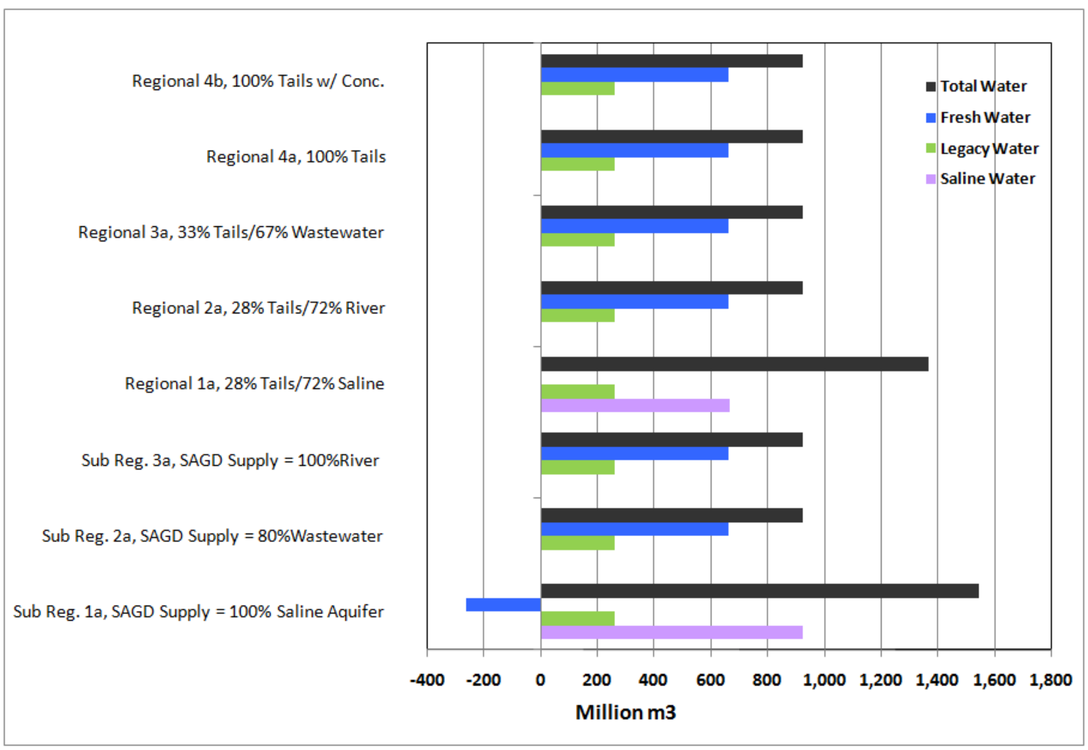


Figure 36. Absolute Amounts of Water Consumed

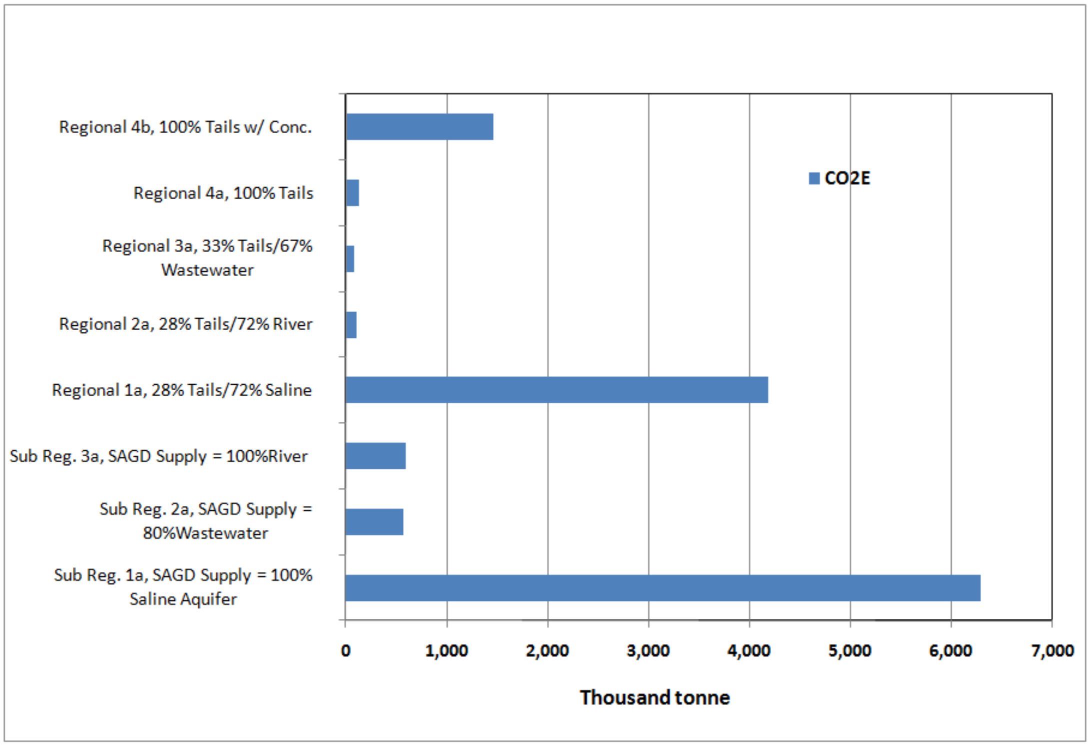


Figure 37. Absolute Amounts of Additional CO_2e Emitted

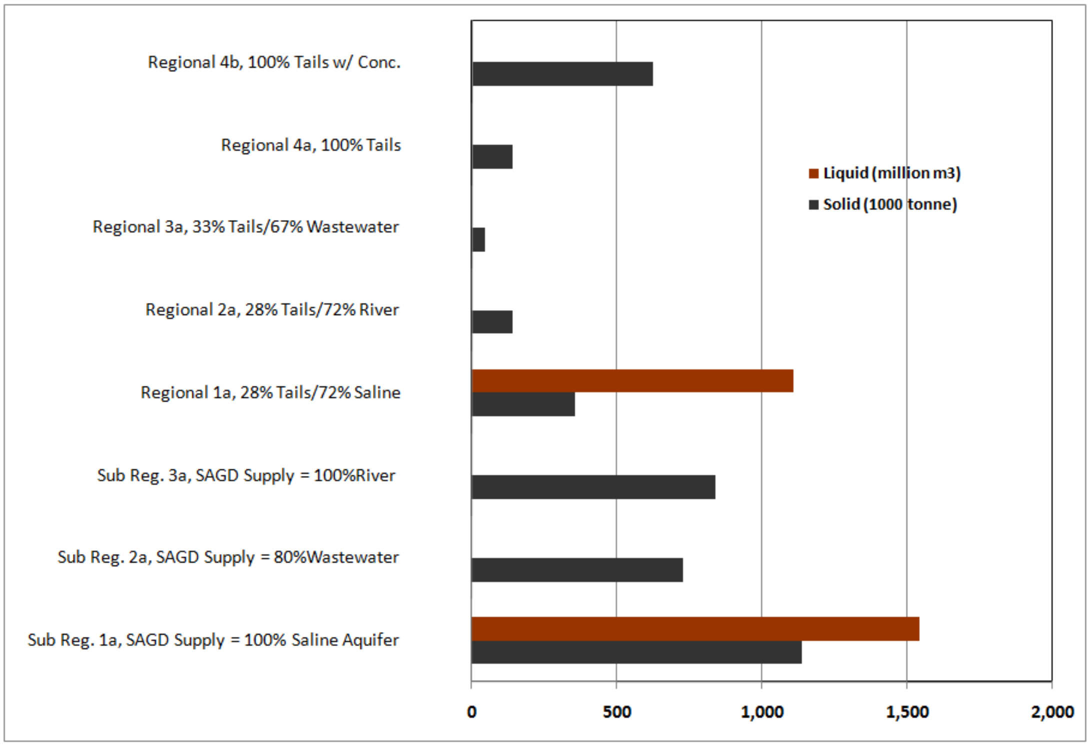


Figure 38. Absolute Amount of Additional Wastes Generated

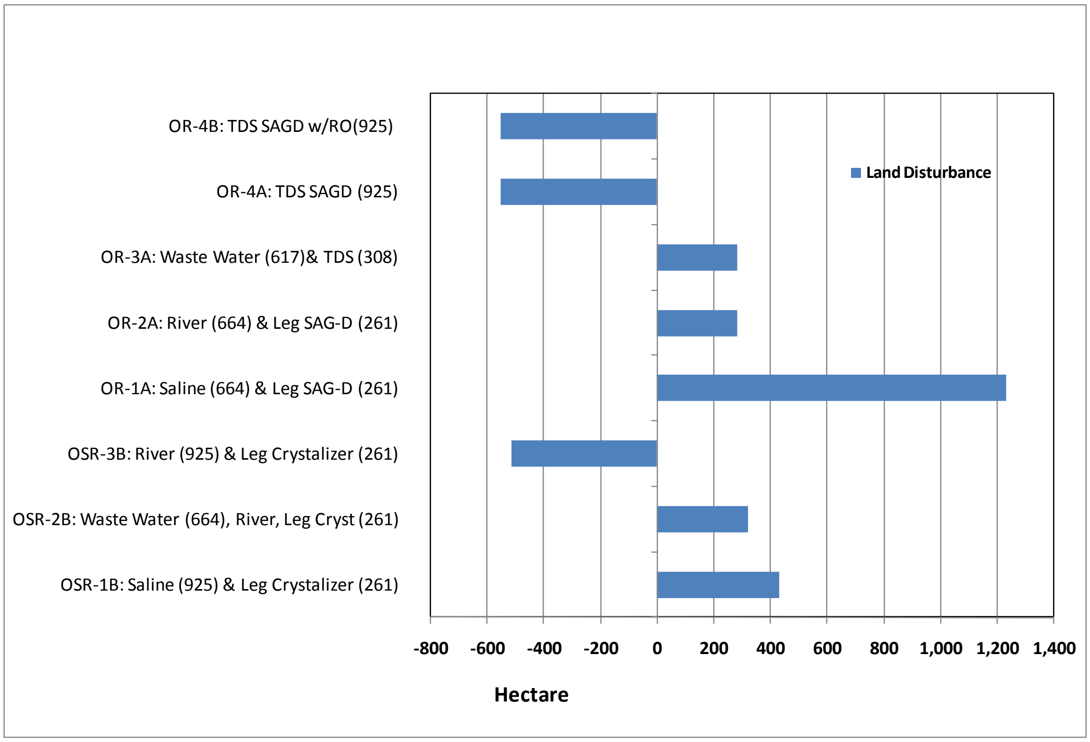
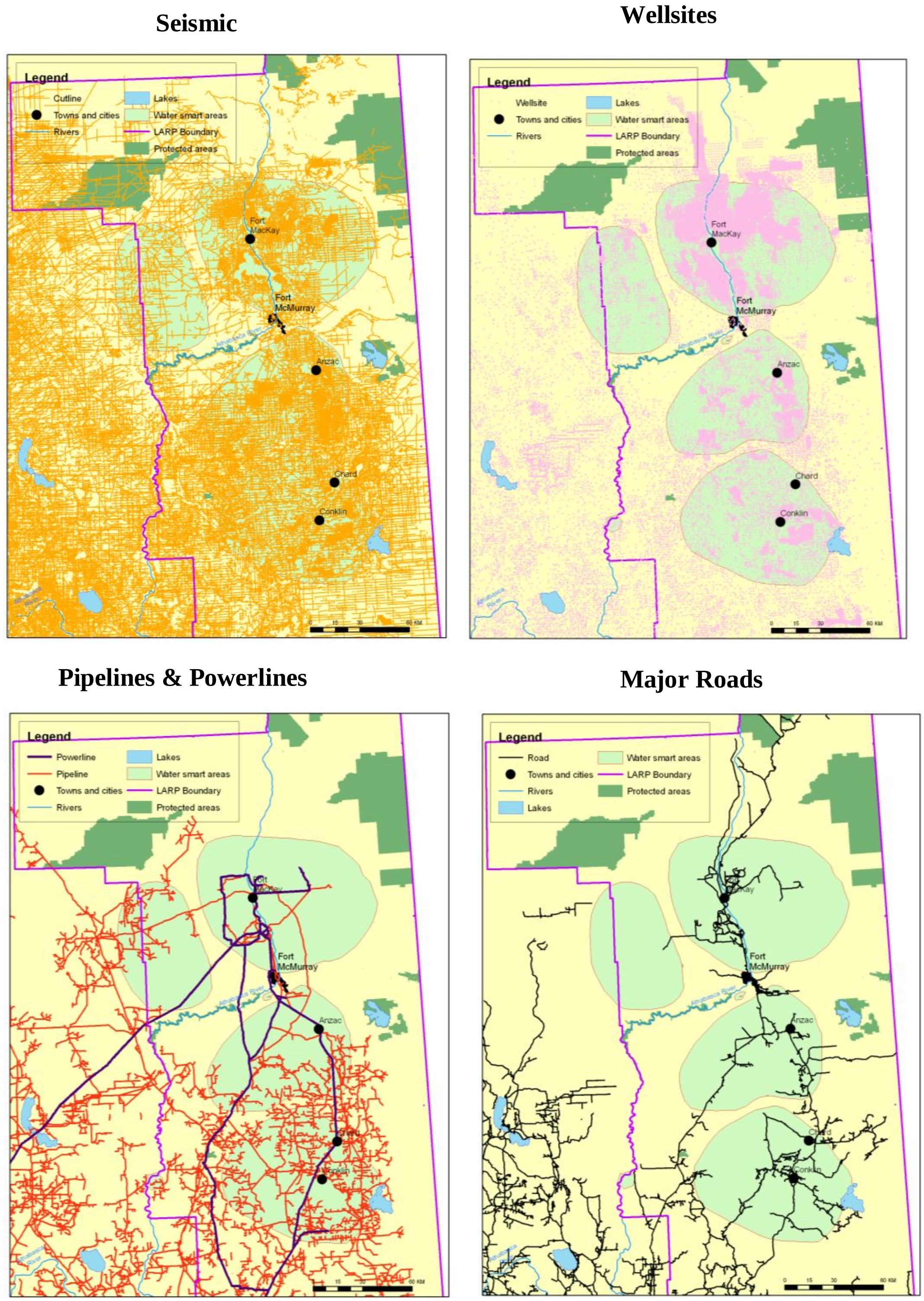


Figure 39. Absolute Amount of Direct Land Disturbance

The relative impact of new land disturbance depends on where the disturbance is located spatially. This is important, regardless of whether the new disturbance occurs in relatively pristine areas or in areas of high existing disturbance. Figure 40 illustrates existing disturbance. Existing footprints were super-imposed spatially over Areas 1 and 2 in Figure 2 to qualitatively assess the relative impacts of the new disturbance created by the design options. The results in Figure 39 indicate that all designs were creating relatively small amounts of new disturbance in regions with a lot of existing anthropogenic disturbance. Thus, it is unlikely that the potential land-use disturbance created by any of these designs would be a primary driver of which design to investigate further.



Note: Purple line is the LARP boundary.

Figure 40. Selected Impact Footprint Spatial Distribution Footprints

7.3 Deciding Which Options to Examine Further in Phases 2 and 3

To enable stakeholders to reach a decision regarding which design options should be explored further in subsequent phases of this Project, it is important to note that while the LCA results presented should inform such a decision process, the relative importance attached to the different indicators by stakeholders will always be highly variable. Indeed, for studies of comparisons that are to be disclosed to the public, the ISO standard for life-cycle impact assessment does not permit weighting of indicators to arrive at a single index (ISO 2006). Thus, the separate performance indicators computed above will not be arbitrarily aggregated into a single index to determine which design option is "best". Instead, the purpose of this section is to highlight and comment on the additional qualitative factors that need to be considered when deciding among the different design options. This discussion will focus on two main areas:

- The existing policy and political contexts in which the different designs operate, and
- A summary of the benefits and risks of the different design options.

7.3.1 *Existing Policy and Social Contexts*

7.3.1.1 Policy

The Alberta Government has issued a number of policies pertaining to water, air and land that are relevant to evaluating the design options:

- Alberta Water for Life (AENV 2003) – This Policy expresses the government's goals of ensuring a safe, secure drinking water supply, healthy aquatic ecosystems, and reliable, quality water supplies for a sustainable economy. Design options that are supportive of these goals will achieve greater regulatory support.
- Water Management Framework for the Lower Athabasca (AENV and FOC 2007) – This Policy sets water withdrawal thresholds (green, yellow and red limits) that vary weekly to protect the ecological integrity of the lower Athabasca River.
    - Green (sufficient water availability) – applies when instantaneous flows are greater than approximately 140 m^3/s. Under such conditions, up to 15% of the instantaneous flow (> ~21 m^3/s) in the river is available for industry use.
    - Yellow (cautionary threshold) – the cautionary threshold is ~120 m^3/s to 140 m^3/s during the winter (see AENV and FOC 2007, Table 4) when up to 10% of instantaneous flow is available for us.
    - Red (potential sustainability threshold) – this threshold applies when instantaneous flows are ~97 m^3/s to 110 m^3/s (see AENV and FOC 2007, Table 4) and set a target for maximum withdrawals of 5.2% of historical median flow in each week.

  Such withdrawal limits are of greatest concern during the winter when river flows are lowest. The implication is that fresh water for all operators in the region will be limited during low flow periods.

- Land-use Framework (ASRD 2008) – The Alberta Land Stewardship Act formally launched the Land-use Framework, which will involve the development of seven regional land-use plans. The framework envisions using a cumulative effects management system at a regional level to manage the impacts of development, recognizing that watersheds, airsheds, and landscapes have finite limits. The Lower Athabasca Regional Plan (LARP) is the first plan initiated under the Land-use Framework, and according to the terms or reference given to the Regional Advisory Council with respect to water, during times of low flow (winter), future total potential water use from all operators is projected to exceed the limits set by the Framework.

  The Terms of Reference for the Lower Athabasca Regional Plan (Government of Alberta 2009) directed the planning team to consider three different development scenarios:

  - **Current State Scenario** – production of 1.5 to 2.0 Mbpd. Under this scenario it was anticipated that water required from the Athabasca River would grow from 4.4 m^3/s to 10.6 m^3/s. By 2016, some operators would require storage to accommodate low flow periods, although most have sufficient on-site storage.
  - **Mid-Range Scenario** – production of 4.0 to 4.5 Mbpd. Water requirements were anticipated to increase to17 m^3/s. Sustaining such production levels would require 8 to 10 weeks of storage roughly every three years.
  - **High-End Scenario** – 6 Mbpd of bitumen production, with water requirements projected to increase to approximately 27 m^3/s by 2030. This would require approximately 28 weeks of storage every two years.

  The current study only considered the water needs of a small number of SAGD operators and did not consider the overall needs of all operators in the region. Further, the current study did not consider how much of the existing licensed capacity is currently being used by those participating in the study, or by all operators within the region.

- Directive 074 (ERCB 2009) – This Directive sets out new requirements for the regulation of tailings operations associated with mineable oil sands, and is the first component of a larger initiative to regulate tailings management. In addition to requiring operators to reduce the accumulation of fine tailings, operators must report yearly on their tailings, prepare a reclamation plan, and abandon each tailings area in accordance with the ERCB approvals they obtained.

  The EUB (predecessor to the ERCB) identified several long-term objectives for tailings management which included:

  - Minimizing and eventually eliminating long-term storage of fluid tailings in the reclamation landscape

- Creating a trafficable landscape at the earliest opportunity to facilitate progressive reclamation
- Eliminating or reducing containment of fluid tailings in an external tailings disposal area
- Reducing stored process-affected waste water volumes on site
- Maximizing intermediate process water recycling to increase energy efficiency and reduce fresh water import. (Section 49 of the *Oil Sands Conservation Regulation* requires operators to minimize the use of fresh make-up water and the disposal of waste water, as well as maximize the recycling of produced water.)
- Ensuring that the liability for tailings is managed through reclamation of tailings ponds.

The implication of this directive is that design options contributing to decreasing tailings and process-affected water while also reducing the use of fresh water would be viewed favourably by the ERCB.

- There do not appear to be any Alberta Environment barriers to transferring water from the oil sands mines to SAGD facilities, although the Water Conservation and Allocation Guideline for Oilfield Injection (AENV 2006) appears to dissuade fresh water make-up (i.e., TDS Control Water Option) . However, the draft ERCB In-Situ Reuse Directive appears to consider recycled water as fresh. This directive would thus have to be modified so that reclaimed water could be transferred from mines to SAGD facilities.
- Climate Change Strategy (AENV 2008) – This Strategy aims to reduce CO_2e emissions to 14% below 2005 levels or 200 Megatonnes by 2050 by placing a charge on emissions that are above a given threshold. The implication is that increased CO_2e emissions would lead to higher costs.

Support for the direction of these different policies has also been expressed across other branches of government. For example, in 2009 the Treasury Board released *Responsible Actions: A Plan for Alberta's Oil Sands* (Alberta Treasury Board 2009) which includes the goals and objectives of:

- Implementing the Land-use Framework to manage the cumulative effects of oil sands development to protect air, land, water, biodiversity, and human health
- Enhancing reclamation to minimize Crown liability and protect environmental health
- Meeting or exceed Alberta's greenhouse gas reduction objectives.

In summary, given the relative magnitudes of the environmental impacts of the different designs, the most relevant policy issues revolve around fresh water use from the Athabasca River and drawing down tailings – not increases in CO_2e emissions, which are relatively small per barrel but large cumulatively.

7.3.1.2 Social Contexts

The oil sands region exists both within local and global political contexts. Locally within Alberta, and also across Canada, this region is experiencing ever greater public awareness and scrutiny. For example:

- Numerous reports have been issued by local environmental organizations such as the Pembina Institute (Griffiths et al., 2006; Moorhouse et al., 2010; Simieritsch et al., 2009)
- Increasing numbers of stories are appearing in national and international magazines (e.g., Macleans; National Geographic).
- Local academics argue (University of Alberta 2007) that the thresholds imposed by the Phase 1 Water Management Framework for the Lower Athabasca may be too generous given decreasing supplies of water from the Athabasca catchments due to climate change and the potential ecological impacts such withdrawals will have on the Athabasca Delta.

Globally, Alberta is fighting a "dirty-oil image" which has been portrayed by international groups like Greenpeace and the Audubon Society. The implication of both the local and global social contexts is that any design which increases fresh water withdrawals and/or further increases CO_2e emissions will likely be viewed skeptically by local and global audiences even if such solutions reduce on-site process-affected water. It is also unclear how local and global audiences might value a saline aquifer solution, or perceive the risks of disposing of liquid wastes underground versus disposing of greater quantities of solid wastes as part of mine reclamation.

7.3.1.3 Implications of Existing Policy and Social Contexts

Table 7 summarizes the policy and political contexts for each of the impact categories.

Table 7. Policy and Political Context for Each Impact Category

	Policy Context	**Political Context**
Water	Reduce use of fresh water Potential limits on withdrawals from Athabasca Issues of transferring water from mines to SAGD	Reduce use of fresh water Use alternative water sources
Tailings and PAW	Reduce tailings and eliminate need for tailings ponds Develop discharge criteria	Reduce tailings without generating additional environmental impacts

	Policy Context	**Political Context**
CO_2e	Increase costs for large emitters	Reduce emissions to counter "dirty-oil" image
Wastes	Beyond tailings, limited guidance	Fewer are better
Land Disturbance	LARP will establish management zones (e.g., working landscape, special management, and protected areas) to enable the regional objectives to be satisfied, along with thresholds under a cumulative effects management system	Less new is better Less cumulative is better

Table 8 provides a summary each of the scenarios against each impact category with impacts ranked using a relative ranking of one to five, with five representing the most disturbance, cost, discharge etc., and one the least, allowing the side by side comparison of impacts. While useful in comparing alternatives, this side by side comparison of alternatives still lacks analysis of the relative importance of each impact.

Table 8. Summary of Benefits and Risks

Scenario	Relative Rankings*								Potential Benefits	Potential Risks/Liabilities
	Total Cost	Total Water	Fresh Water	Saline Water	CO_2e	Solid Wastes	Liquid	Land Disturb.		
OSR-1B: Saline (925) & Leg Crystallizer (261)	5	5	1	5	5	5	5	3	- Frees up fresh-water	- Saline aquifer degradation from injection of wastes from reverse osmosis - Disposal of solid wastes from legacy crystallization poses long-term storage risks - Greater CO_2e emissions - Most expensive option
OSR-2B: Waste Water (664), River, Leg Cryst (261)	2	1	5	1	1	4	1	3	- Reduction in waste water treatment costs and nutrient discharge to river - Lowest total water requirements	- Additional water withdrawals from river - Potential need for storage during periods of low flow - Disposal of solid wastes from legacy crystallization poses long-term storage risks
OSR-3B: River (925) & Leg Crystallizer (261)	2	1	5	1	1	4	1	1	- Lowest total water requirements	- Additional water withdrawals from river - Potential need for storage during periods of low flow - Disposal of solid wastes from legacy crystallization poses long-term storage risks
OR-1A: Saline (664) & Leg SAGD (261)	5	4	2	4	4	2	4	5	- Requires no additional fresh-water - Mine liquid wastes disposed of in SAGD	- Saline aquifer degradation from injection of wastes from reverse osmosis - High total cost - Highest land disturbance
OR-2A: River (664) & Leg SAGD (261)	1	1	5	1	1	1	1	3	- Low total cost - Lowest total water requirements	- Additional water withdrawals from river - Potential need for storage during periods of low flow
OR-3A: Waste Water (617)& TDS (308)	1	1	5	1	1	1	1	3	- Lowest total cost - Lowest total water requirements	- Additional water withdrawals from river - Potential need for storage during periods of low flow
OR-4A: TDS SAGD (925)	1	1	5	1	1	1	1	1	- Low total cost - Lowest total water requirements - Reduction of tailings TDS	- Additional water withdrawals from river - Potential need for storage during periods of low flow - Lowest land disturbance
OR-4B: TDS SAGD w/RO(925)	2	1	5	1	2	3	1	1	- Lowest total water requirements - Reduction of tailings TDS	- Additional water withdrawals from river - Potential need for storage during periods of low flow - CO_2e emissions - Lowest land disturbance

* Note that a relative ranking of 1 indicates a lower impact (or cost) than a ranking of 5. All relative rankings are comparisons between Scenarios.

8 SUMMARY AND NEXT STEPS

8.1 Summary

This report summarized the Phase One directional work for the Tailings Water Management Project, a part of the Regional Water Management Solution Project. Work focused on presenting a number of potential solutions to optimize oil sands water management within the Athabasca Region, as well as quantifying the impacts of these potential solutions in terms of water, greenhouse gases, land disturbance, waste products, and monetary cost. Results are summarized in Section 7.2.

While the intent of the Phase 1 study was to develop and present potential solutions and opportunities for regional optimization, the analysis did not attempt to rank potential solutions. There are two reasons why this ranking was not undertaken. First, while a number of impact categories were computed quantitatively, it was not possible to include the effects of all issues (e.g., the degradation of a saline aquifer or the reduction in tailings TDS) in these numerical calculations, as it was unclear how to compute such impacts. Second, any ranking ultimately comes down to an assessment of social choices, where impacts have a larger social effect and agenda. As such, there is inherent uncertainty in how stakeholders would value the different quantitative and qualitative impacts. While methods exist to help a group of stakeholders arrive at such rankings, these rankings would vary depending on group composition and goals. Thus, the intent of this study was to provide the "raw material" to advance subsequent discussions on this topic.

The results for the indicators that were computed clearly supported the belief that regionally integrated solutions have a lower Environmental and Economic Footprint or Net Environmental Impact, than do sub-regional systems. Regional water management solutions out-performed sub-regional options on all indicators, except for Fresh Water Consumption. However, sub-regional water management solutions that out-performed regional water management solutions on Fresh Water Consumption did so by degrading a saline aquifer, the capacity of which to deliver the needed volumes remains in question.

The completion of this study meets the Tailings Water Management Project Phase 1 goal of evaluating different regional design options, so that the scope of potential solutions and opportunities is now better defined and manageable. As such, it is recommended the project now move onto the next phase of work, and begin to identify those optimal regional water solutions that merit further review, in greater detail.

8.2 OSLI Next Steps

The immediate next steps for this project are focused in three areas.

8.2.1 *Decide Which Solutions to Develop Further*

While this report attempted to calculate the impacts of the different design options, ranking the design options (to determine which ones to advance in subsequent phases of this project) requires engaging with stakeholders to rank these solutions based on the quantitative and qualitative factors discussed above. Once this report has been critiqued by a broader stakeholder group, guidance will be needed from both government and industry regarding which stakeholders to obtain such feedback from, so that a ranking session can be implemented.

8.2.2 *Improving Data Reliability*

This report can be improved in two ways. The first area for improvement would involve using better data. Thus, where estimated or public data have been used, industry data should be substituted (where available). Although working with OSLI provided access to some operational data, there are still many areas where assumptions had to be made, due to the inability to obtain actual data.

Subsequent stages in the project should incorporate actual operational data for:

- SAGD production from different operators – Several scenarios for confirmed developments and probable developments should also be developed to understand the larger potential dynamics of the system.
- Actual Tailings Legacy Volumes and Qualities – The current analysis only used data from Suncor.
- Actual Tailings TDS Control Volumes – Further analysis will require actual mine data and agreement on withdrawal of makeup water quantities from the Athabasca River.
- Detailed Material Takeoffs – The material takeoff and estimates carried out in Phase One are high level estimates. Subsequent phases will include more detailed design, material takeoffs and estimates on both treatment processes and pipelines.
- Water License capacity and usage – If a solution relying on fresh-water is chosen, then more detailed information on existing water license capacity and water license usage will be required to assess the feasibility of this solution.

The second area for improvement would involve expanding the research. The work completed in Phase One identified a number of areas where additional research and modeling is required including:

- Expanding EEF calculations to incorporate secondary benefits/costs from solution implementation including SAGD treatment footprint, mine extraction/upgrading footprint, etc.
- Establishing mine tailings water target TDS/chloride concentrations, since the target of 400 mg/L used in the analysis was selected without rigorous analysis.
- Analyzing the benefit (financial and environmental risk reduction) of reducing tailings TDS today rather than at some unknown future date.
- Studying the interaction between free tailings water and tailings water trapped in submerged tailings (the current models assume no interactions between free and trapped tailings water).
- Evaluating the capacity of the McMurray Aquifer – The model used in the analysis assumed that the McMurray aquifer has the ability to supply all the water needed, but early indications are that the McMurray aquifer may not have the required capacity, and that aquifer capacity is very complex to calculate, influenced by bitumen production, gas production and source water production.
- Analysis of the effects of Saline Aquifer Degradation, as liquid wastes generated from using reverse osmosis (concentrated brine) are disposed of in the same saline aquifer. These wastes are of sufficient quantity that the aquifer will be degraded, meaning it would be harder to use this aquifer in the future and in this sense this

aquifer has been degraded. It should be noted that in arid parts of the world (e.g., the Middle East), the existence of such a saline aquifer would have significant value.

- Technologies suitable for the treatment of tailings water with release to the environment – Results from bench testing in Phase One indicate that there are currently no technologies capable of treating tailings water for discharge to the environment which will produce water with an EEF equal or greater that that required to treat tailings for recycle.

8.2.3 *Expansion of the Regional Water Management Solution Analysis*

For a regional water management solution to be implemented, it is likely that companies beyond those that are currently members of OSLI need to be involved. The analysis to date was deliberately limited to OSLI companies, but should be expanded to include mining and SAGD companies which would benefit from a regional water management solution within the Athabasca oil sands area to determine if the OSLI regional water management solution is indeed practical and optimal for all companies within the region.

Companies whose participation would be beneficial and who would likely be interested in joining the study need to be identified and contacted. It should be noted that OSLI has already been approached by several of these companies.

8.3 Regulatory Next Steps

While this study develops alternatives for regional water management solutions and calculates the strength of each of the Environmental Net Effect parameters, it stops short of ranking alternatives as no weighting exists to determine the relative importance of the parameters and select between the options. To facilitate the implementation of Net Environmental Impact for the selection between alternatives, the regulators must provide guidance to industry on which parameters should be considered, and their relative strength, or develop a process by which the relative strength of the alternatives can be determined by project proponents sourcing water for their projects.

The Alberta Environment Oilfield Injection Policy Section 3.2.5 Cumulative Effects, specifically invites project proponents to develop such criteria when it states *It is recommended that applicants consult with AENV staff regarding the evaluation of cumulative effects for individual applications* and also states *In some cases, the use of an alternative technology or alternative water source may result in more environmental impacts than the use of non-saline water*.

To facilitate this process OSLI should propose to work with the regulators using the regional water management solution project as a test case to:

- Establish parameters which should be included in an analysis
- Establish calculation methodologies for selected parameters.

9 REFERENCES AND RELATED READING

9.1 References

AENV, 2003. *Water for Life – Alberta's Strategy for Sustainability*. Alberta Environment, Edmonton, Alberta. http://www.waterforlife.alberta.ca/ [Last accessed November 10, 2010].

AENV, 2006. *Water Conservation and Allocation Guideline for Oilfield Injection*. Alberta Environment, Edmonton, Alberta. http://environment.gov.ab.ca/info/library/7700.pdf [Last accessed November 10, 2010].

AENV, 2008. *Alberta's 2008 Climate Change Strategy*. Alberta Environment, Edmonton, Alberta. http://environment.alberta.ca/01757.html [Last accessed November 10, 2010].

AENV and FOC, 2007. *Water Management Framework: Instream Flow Needs and Water Management System for the Lower Athabasca River*. Alberta Environment, Edmonton, Alberta and Fisheries and Oceans Canada, Edmonton, Alberta.

Alberta Treasury Board, 2009. *Responsible Actions: A Plan for Alberta's Oil Sands*. Alberta Treasury Board, Edmonton, Alberta. http://www.treasuryboard.alberta.ca/ResponsibleActions.cfm [Last accessed November 10, 2010].

ASRD, 2008. *Land-use Framework*. Alberta Sustainable Resource Development, Edmonton, Alberta. http://www.landuse.alberta.ca/ [Last accessed November 10, 2010].

Canadian Natural Resources Ltd., 2009. *2009 Horizon Tailings Management Plan*. http://www.ercb.ca/docs/products/TailingsPlans/CNRL_2009_Horizon_TailingsPlans.pdf[Last accessed November 10, 2010].

ERCB, 2009. *Directive 074 – Tailings Performance Criteria and Requirements for Oil Sands Mining Schemes*. Energy Resources Conservation Board, Calgary, Alberta. http://www.ercb.ca/portal/server.pt/gateway/PTARGS_0_0_323_253_0_43/http%3B/ercbContent/publishedcontent/publish/ercb_home/industry_zone/rules__regulations__requirements/directives/directive074.aspx [Last accessed November 10, 2010].

Fort Hills Energy Corp., 2009. *ERCB Directive 074 Annual Tailings Management Plan*. http://www.ercb.ca/docs/products/TailingsPlans/FortHills_2009_TailingsPlans.pdf[Last accessed November 10, 2010].

Government of Alberta, 2009. *Terms of Reference for Developing the Lower Athabasca Regional Plan*. http://www.landuse.alberta.ca/RegionalPlans/LowerAthabasca/Default.aspx [Last accessed November 10, 2010].

Griffiths, M., A. Taylor and D. Woynillowicz, 2006. *Troubled Waters, Troubling Trends*. Pembina Institute, Calgary, Alberta. http://pubs.pembina.org/reports/TroubledW_Full.pdf [Last accessed November 10, 2010].

Imperial Oil Resources Ventures Ltd., 2009. *2009 Annual Tailings Plan Submission*. http://www.ercb.ca/docs/products/TailingsPlans/Imperial_2009_Kearl_TailingsPlans.pdf

ISO, 2006. Environmental Management – Life Cycle Assessment – Requirements and Guidelines. International Organization for Standardisation, Geneva, Switzerland. ISO 14044. http://www.iso.org/iso/catalogue_detail?csnumber=38498 [Last accessed November 10, 2010].

Moorhouse, J., M. Hout and S. Dyer, 2010. *Drilling Deeper – the In-Situ Oil Sands Report Card*. Pembina Institute, Calgary, Alberta. http://pubs.pembina.org/reports/in-situ-report-card.pdf [Last accessed November 10, 2010].

ReCiPe, 2008. *A Life Cycle Impact Assessment Method which Comprises Harmonized Category Indicators at the Midpoint and the Endpoint Level*. First Edition. Report I: Characterization.

Shell Canada Inc., 2009a. *Jackpine Mine ERCB Directive 074 Submission*. http://www.ercb.ca/docs/products/TailingsPlans/Shell_2009_Jackpine_TailingsPlans.pdf [Last accessed November 10, 2010].

Shell Canada Inc., 2009b. *Muskeg River Mine ERCB Directive 074 Submission*. http://www.ercb.ca/docs/products/TailingsPlans/Shell_2009_Muskeg_TailingsPlans.pdf [Last accessed November 10, 2010].

Simieritsch, T., J. Obad and S. Dyer, 2009. *Tailings Plan Review*. Pembina Institute, Calgary, Alberta and Water Matters Society of Alberta, Canmore, Alberta. http://pubs.pembina.org/reports/tailings-plan-review-report.pdf [Last accessed November 10, 2010].

Suncor Energy Inc., 2009a. *Part I Annual Tailings Management Plan*. http://www.ercb.ca/docs/products/TailingsPlans/Suncor_2009_TailingsPlans.pdf [Last accessed November 10, 2010].

Suncor Energy Inc., 2009b. *Tailings Reduction Operations Volume 1*. http://www.ercb.ca/docs/products/TailingsPlans/Suncor_TRO_Application_-_Volume_1.pdf [Last accessed November 10, 2010].

Suncor Energy Inc., 2009c. *Tailings Reduction Operations Volume 2*. http://www.ercb.ca/docs/products/TailingsPlans/Suncor_TRO_Application_-_Volume_2.pdf [Last accessed November 10, 2010].

Syncrude Canada Limited, 2009a. *2009 Annual Tailings Plan Submission Syncrude Mildred Lake*. http://www.ercb.ca/docs/products/TailingsPlans/Syncrude_2009_MildredLake_TailingsPlans.pdf [Last accessed November 10, 2010].

Syncrude Canada Limited, 2009b. *2009 Annual Tailings Plan Submission Syncrude Aurora North*. http://www.ercb.ca/docs/products/TailingsPlans/Syncrude_2009_AuroraNorth_TailingsPlans.pdf [Last accessed November 10, 2010].

Syncrude Canada Limited, 2009c. *2009 Annual Tailings Plan Submission Syncrude Aurora South*. http://www.ercb.ca/docs/products/TailingsPlans/Syncrude_2009_AuroraSouth_TailingsPlans.pdf [Last accessed November 10, 2010].

University of Alberta, 2007. *Running out of Steam? Oil Sands Development and Water Use in the Athabasca River Watershed: Science and Market-based Solutions*. Environmental Research and Studies Centre, University of Alberta, Edmonton, Alberta.

9.2 Related Reading

Alberta Energy, 2008. *Launching Alberta's Energy Future: Provincial Energy Strategy*. Alberta Energy, Edmonton, Alberta. http://www.energy.alberta.ca/Initiatives/strategy.asp [Last accessed November 10, 2010].

CEMA SWWG, 2005. *A Compilation of Information and Data on Water Supply and Demand in the Lower Athabasca River Reach*. CEMA Surface Water Working Group, Cumulative Environmental Management Association, Fort McMurray, Alberta. http://cemaonline.ca/component/docman/doc_download/1622-a-compilation-of-information-and-data-on-water-supply-and-demand-in-the-lower-athabasca-river-golde.html [Last accessed November 10, 2010].

CEMA SWWG, 2006. *Surface Oil Sands Water Management Summary Report*. CEMA Surface Water Working Group, Cumulative Environmental Management Association, Fort McMurray, Alberta. http://cemaonline.ca/component/docman/doc_download/518-surface-oil-sands-water-management-summary-report.html [Last accessed November 10, 2010].

Finnveden, G., M. Z. Hauschild, T. Ekvall, J. Guinee, R. Heijungs, S. Hellweg, A. Koehler, D. Pennington, and S. Suh, 2009. *Recent Developments in Life Cycle Assessment*. Journal of Environmental Management 91: 1-21.

Toffoletto, L., C. Bulle, J. Godin, C. Reid, and L. Deschenes, 2007. *LUCAS – a new LCIA Method Used for a Canadian-Specific Context*. International Journal of Life-Cycle Assessment 12(2): 93-102.

10 GLOSSARY OF TERMS AND ACRONYMS

AENV

Alberta Environment

ARC

Acid Reducing Compounds

Basal aquifer

The groundwater zone that lies beneath the oil sands.

Basal depressurization water

The basal water that needs to be removed from the basal aquifer so the mining pit does not fill with water.

CAPEX

Capital Expenditures; money spent to acquire or upgrade physical assets.

Cation

An ion with a net positive charge.

CEMA

Cumulative Environmental Management Association

CO_2e

Carbon dioxide equivalent; a measure of describing how much global warming a given type and amount of greenhouse gas (e.g., methane) may cause.

Connate Water

The water present in a petroleum reservoir in the same zone occupied by oil and gas; considered by some to be the residue of the primal sea, connate water occurs as a film of water around each grain of sand in granular reservoir rock and is held in place by capillary attraction.

CT

Consolidated/Composite Tailings

Dirty Water Streams

The mine wastewater streams with the worst quality:

- Basal depressurization water (high TDS)
- Froth treatment tailings (high TDS and organics)
- Thickened tailings or coarse tailings water release
- Consolidated tailings (CT) or MFT drying tailings water release.

EEF

The estimated Environmental and Economic Footprint of the alternatives based on water use, tailings water, CO_2e, wastes, and land disturbance.

ERCB

Energy Resource Conservation Board

In-situ

Recovery techniques which apply heat or solvents to bitumen reserves beneath the earth.

LCA

Life Cycle Analysis

Legacy Tailings Water

Water exported from tailings ponds to maintain desired water volumes.

Mbpd

Million barrels per day

MFT

Mature Fine Tailings

OPEX

Operating Expenditures. A company's expenses related to the production of its goods and services. Examples of operating expenses include wages for employees, research and development, and costs of raw materials. Operating expenses do not include taxes, debt service, or other expenses inherent to the operation of a business but unrelated to production.

OR

Options – regional solution

OSLI

Oil Sands Leadership Initiative

OSLI SAGD Water Demand

The water demand from select in-situ facilities operated by OSLI members in Area 1 on Figure 2.

OSR

Options – sub-regional solution

PAW

Process-affected water; tailings water.

Reclamation

The process of returning the land used for operations to as close to its original state as possible; in the case of a tailings pond, this mean removing the water and tailings, replacing subsoil and coversoil, and planting revegetating the site.

Reverse Osmosis (RO)

A water treatment technology which removes many types of large molecules and ions from solutions by applying pressure when it is on one side of a membrane.

SAGD

Steam Assisted Gravity Drainage, an in-situ oil sands bitumen extraction method.

Saline Water

Salt water, generally with a TDS over 4,000 mg/L.

Sour Water

During the upgrading process, molecules are separated from the ore; the water that is cycled through collects the separated molecules (such as sulphur) and is called sour water; when the molecules are stripped from the water, so it can be recycled or placed back into a river, it is called stripped sour water.

SWWG

Surface Water Working Group (CEMA)

TDS Control Water

Water exported from tailings that is not Legacy Tailings Water.

TSS

Total suspended solids; refers to water solute concentration.

TWM Project

Tailings Water Management Project; refers to the Phase One Project that is the topic of this Report.

TDS

Total dissolved solids; refers to water solute concentration.

WMWG

Water Management Working Group; responsible for improving water management practices in the oil sands.

WQ

Water Quality

APPENDIX 1. Explanation of Environmental Impact Indicators and Calculations Used in the Analysis

Water Consumption

Water quantities are calculated based on the contribution from the individual solution elements, and are presented as total water volume (PAW, fresh, and saline), fresh water volume and saline water volume. Liquid waste volume, which includes RO brine volume are included in waste volumes. Fresh water volumes are calculated strictly on the actual required or surplus water volumes while saline volumes are calculated based upon fresh water requirements and recovery rates.

While water requirements directly related to each sourcing solution have been included, indirect water saving or additional consumption relating to the quality of water produced or delivered has not been included in the calculations.

Greenhouse Gas Emissions (CO_2e)

Water treatment does not create any greenhouse gasses directly through the combustion of hydrocarbons, but does create greenhouse gasses indirectly through the consumption of electricity produced on site or purchased from the electrical grid. CO_2e production rates have been conservatively assumed for regionally produced and transmitted electricity, rather than on-site cogeneration values, which tend be lower than grid values.

Greenhouse gas numbers have been calculated based on the direct kWh used to power pumps utilized in well intakes, treatment process and distribution. These numbers do not include indirect consumption as a result of additional treatment or disposal resulting from incremental treatment by SAGD operators.

Wastes Produced

Wastes produced have been divided into solids and liquid waste produced, with solid waste including consumables, salt and sludges. Liquid wastes include for the most part the liquid reject streams from saline water desalinization.

Land Disturbance

Land disturbance numbers have been calculated as hectares of land base disturbed for pipelines, treatment facilities, off stream storage, and tailings pond volume reductions in areas resulting from the elimination of Legacy Tailings Water.

Financial Costs

Financial elements are built up from the individual solution components costing data.

The CAPEX component of the costing is based on values provided by the Suncor estimation group for individual solution elements including the saline aquifer, Athabasca River, McMurray Wastewater, and tailings water and specific capacities. Costing from each of the individual elements has then been scaled up or down to match the demand for individual regional water management solution alternative (i.e., OSR1–3 and OR1–4). CAPEX costing can be assumed to be within the tolerances of a Class 5 estimate, accurate for a scoping study. CAPEX estimates allow for capital equipment cost, installation costs are factored for installation in the McMurray region, using Suncor's experience, and additional installation costs have been assumed for individual alternatives based upon the remoteness of each particular alternative. All CAPEX costs are assumed in 2010 dollars and have not been escalated for future start dates as costing is relative, and would not lead to any further differentiation of solutions.

OPEX costs are calculated based upon unit cost per cubic metre of water treated accounting for energy usage, ongoing maintenance, waste products and consumables. Costs are inflated at 8%, and net present values are calculated back to the present using a discount rate of 15%.