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Land and Water Impacts of Oil Sands Production in Alberta

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Expansion of oil sands development results not only in the release of greenhouse gas emissions, but also impacts land and water resources. Though less discussed internationally due to to their inherently local nature, land and water impacts can be severe. Research in key areas is needed to manage oil sands operations effectively; including improved monitoring of ground and surface water quality. The resulting information gap means that such impacts are not well understood. Improved analyses of oil sands products are required that compare land and water use with other transportation fuel pathways and use a regional perspective so local effects can be considered and mitigated.

INTRODUCTION

Oil sands production in Alberta has rapidly expanded over the past decade, with growing concern about a range of environmental impacts. The production of bitumen, the molasses-like hydrocarbon that is mixed in the sand, has grown from 0.7 to 1.6 million barrels per day since 2000 and is expected to double over the next 10 years.[1] While the greenhouse gas emissions from this energy source are relatively well studied,[2−4] there has been less discussion of water and land use impacts due to their inherently local nature and much greater complexity. The ecological impacts associated with land use are of particular concern due to the large scale of the resource. The oil sands resource is found within 140 000 km^2 (54 000 square miles) of land in northern Alberta, an area comparable to the state of Florida. The life cycle water consumption for oil sands is roughly double that of conventional oil,[5] suggesting water use may be an issue. Concern has been raised regarding tailings ponds and other impacts to water quality in the media.[6] Monitoring programs have already been recognized as being inadequate, indicating a need for improved data acquisition and transparent reporting.[7−10]

In this article, the current state of knowledge about the land and water impacts of Alberta's oil sands industry is reviewed and areas in need of research are highlighted. Topics include the different land and water impacts of the two primary oil sands extraction technologies, the impacts of oil sands products compared to other transportation fuel pathways, the importance of regional context when making such comparisons, and the key uncertainties related to water quality. Efforts to manage impacts, such as zoning and monitoring programs, are then discussed. Bitumen production in Canada as a conventional oil substitute provides a point of reference that we can use to observe and better manage the impacts of a rapid transition to unconventional fuels.

LAND AND WATER IMPACTS OF OIL SANDS TECHNOLOGIES

1. How Different Are the Impacts of Oil Sands Extraction Technologies? Bitumen is extracted from the oil sands using two technologies, surface mining or in situ recovery, each of which have different land and water impacts. Surface mining techniques remove shallow depth oil sand deposits by truck and shovel and extract the bitumen with the Clarke hot water extraction process by mixing the oil sand with water warmed using natural gas.[11] In situ technology is predominantly used for extracting deeper deposits. Thermal in situ technologies use natural gas to produce steam that is subsequently injected to reduce the viscosity of the bitumen so that it can be pumped to the surface using production wells. It is understood that oil sands technologies produce 10−20% more greenhouse gases than the average conventional fuel when calculating life cycle emissions from well to wheel,[4] yet much less emphasis has been placed on quantifying water and land impacts.

Land use of surface mining is comprised largely of polygonal features (mine sites, overburden storage, tailing ponds, and end pit lakes). In situ development has a different footprint, mostly defined by linear features that extend across the lease area (networks of seismic lines, access roads, pipelines and well sites).[12,14]As of 2009, only 600 km^2 of land were disturbed by surface mining, accounting for 0.3% of the area where oil sands resources are present, or less than 0.1% of the total land area of Alberta. Eighty percent of the resource is currently expected to be extracted using in situ technologies, affecting approximately 136 000 km^2 (97% of the total oil sands area).[13] While natural gas is used in surface mining, in situ recovery can use on the order of four times more than surface mining.[11] The cumulative footprint of the future oil sands operations may extend over approximately the 140 000 km^2 during the course of the development, comprising of 20% of Alberta, and even more if the upstream footprint from the infrastructure required for natural gas production is included.[14]

Surface mining results in the conversion of large tracts of land, whereas in situ recovery fragments landscapes, both of which result in ecological impacts. Landscape fragmentation occurs when a landscape is broken up into smaller intact units. There are a wide variety of impacts arising from landscape

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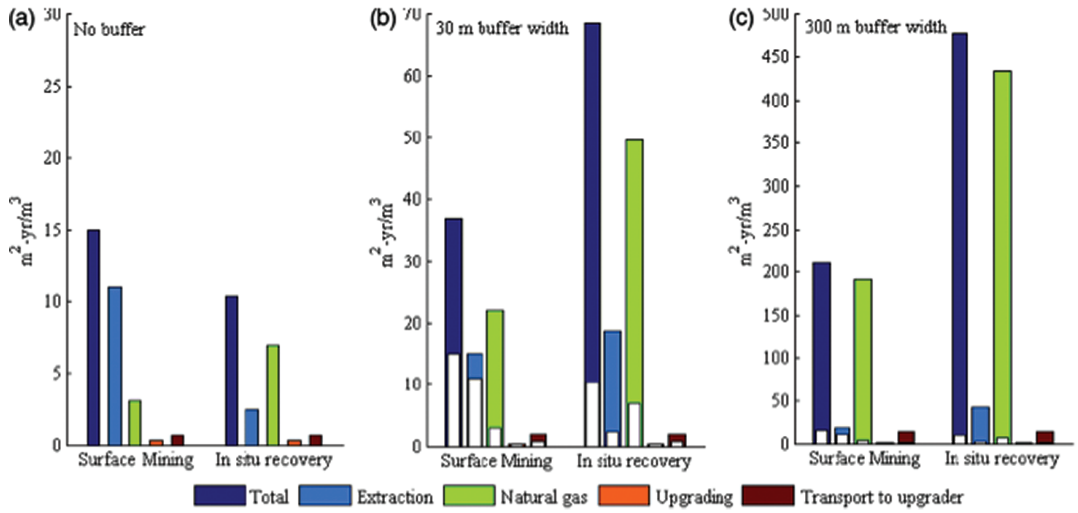

Figure 1. Land disturbance and fragmentation from oil sands surface mining and in situ recovery.[14] Edge effects are included as a proxy for habitat fragmentation by applying a parametric buffer to linear features. (a) shows the land occupation without accounting for edge effects, (b) shows the land influenced when considering edge effects that extend 30 m from the disturbance and (c) shows the land influenced when considering edge effects that extend 300 m from the disturbance. The values used in this study were collected based on two focused studies on the land use footprint of oil sands and natural gas in Alberta[12,21] and were verified with data from GIS analyses[22] and previous studies.[14] (reprinted from ref 14 with permission from IOP Publishing).

fragmentation. For example, when large tracts of land are converted or land is fragmented, species migration corridors can be lost affecting species diversity and viability at larger scales. In the boreal forest of Alberta, studies have shown linear disturbance can impact a variety of species populations, from songbirds to carnivores.[15−19] The conventional wisdom is that mining operations have a much larger landscape impact than in situ recovery—the latter has typically been viewed as more environmentally benign in terms of land use.[11,20] This conclusion does not reflect landscape fragmentation caused by in situ projects and upstream natural gas production. The land impacts of in situ recovery may be comparable and even greater than that of surface mining when these are considered per unit of synthetic crude oil.[14] To show this, fragmentation was examined through a measure of edge effects, defined as the ecological impacts extending from the juxtaposition of two different landscape types (Figure 1).

As with land, the amount of water consumed depends on the extraction technology. Surface mining has been reported to use from 3 to 4.5 barrels of water per barrel of bitumen produced.[23,24] Another study provided a range of 2−4 barrels of water per barrel of bitumen produced.[24] In situ operators use brackish water where possible from underground aquifers. Where brackish water is used then only roughly 0.5 to 0.9 barrels of fresh water are used to produce one barrel of bitumen.[23,24] Over 90% and 80−95% of the water can be recycled for in situ recovery and surface mining, respectively,[23] which is included within the numbers cited above.

Technologies can be used to improve impacts, though they may have trade-offs such as the potential for increased emissions and costs.[4] The additional land footprint associated with natural gas consumption can be reduced, which is particularly important for in situ recovery as it uses more natural gas than surface mining per unit bitumen extracted. Natural gas consumption can be reduced if bitumen is gasified to produce natural gas required for steam production. Nuclear and biomass have also been suggested as alternative energy inputs.[4] Water use may be reduced for in situ recovery by injecting solvent instead of steam to reduce the viscosity of the bitumen, by employing electric heating the reservoir and by using in situ combustion of the reservoir. Water storage can be used to mitigate water use of oil sands mining during low flow times. A key learning point for emerging players in unconventional fuel production is the use of brackish water in oil sands operations to reduced fresh water use where constrained by water scarcity or policy.

2. How Do These Impacts Compare to Other Transportation Fuel Options? While the land and water impacts of oil sands development are significant, it is important to keep them in perspective in comparison with other transportation fuel options. At the broadest level, the amount of land disturbed for oil sands is minimal when compared to first generation corn ethanol. Based on the heating values of the fuels, it would take all 66 million ha of Alberta approximately 210 years to produce the same amount of energy contained in the oil sands from corn ethanol in the U.S.[25] This land area is roughly 5 times greater than the area that could be affected by the oil sands development. It should be noted that cellulosic ethanol and biodiesel from yellow grease both have negligible land disturbance in comparison to oil sands. Keeping this in mind, there are several challenges to comparing land and water use impacts of different transportation fuel pathways, mostly related to the choice of temporal scale and spatial resolution.

There is no accepted methodology regarding the treatment of time for analyses of land impacts, making it difficult to ensure results are comparable. Analytic horizons, the time over which the impacts are counted,[26] can be used to demonstrate the particular challenges to the treatment of time in oil sands development. Much like global warming potential, the choice of this time horizon is a policy, not a scientific decision. An analyst may refer to the amount of time that infrastructure remains on the landscape or the amount of time it takes to be reclaimed or restored. Reclamation, of course, does not promptly return landscapes to their predisturbance ecosystems. This is of particular importance for oil sands mining, where large tracts of land are disturbed in high latitude areas where ecosystems are less productive and thus slower to regenerate. Peatlands can require on the order of thousands to tens of thousands of years to form naturally[27] and recovery to their original state is not

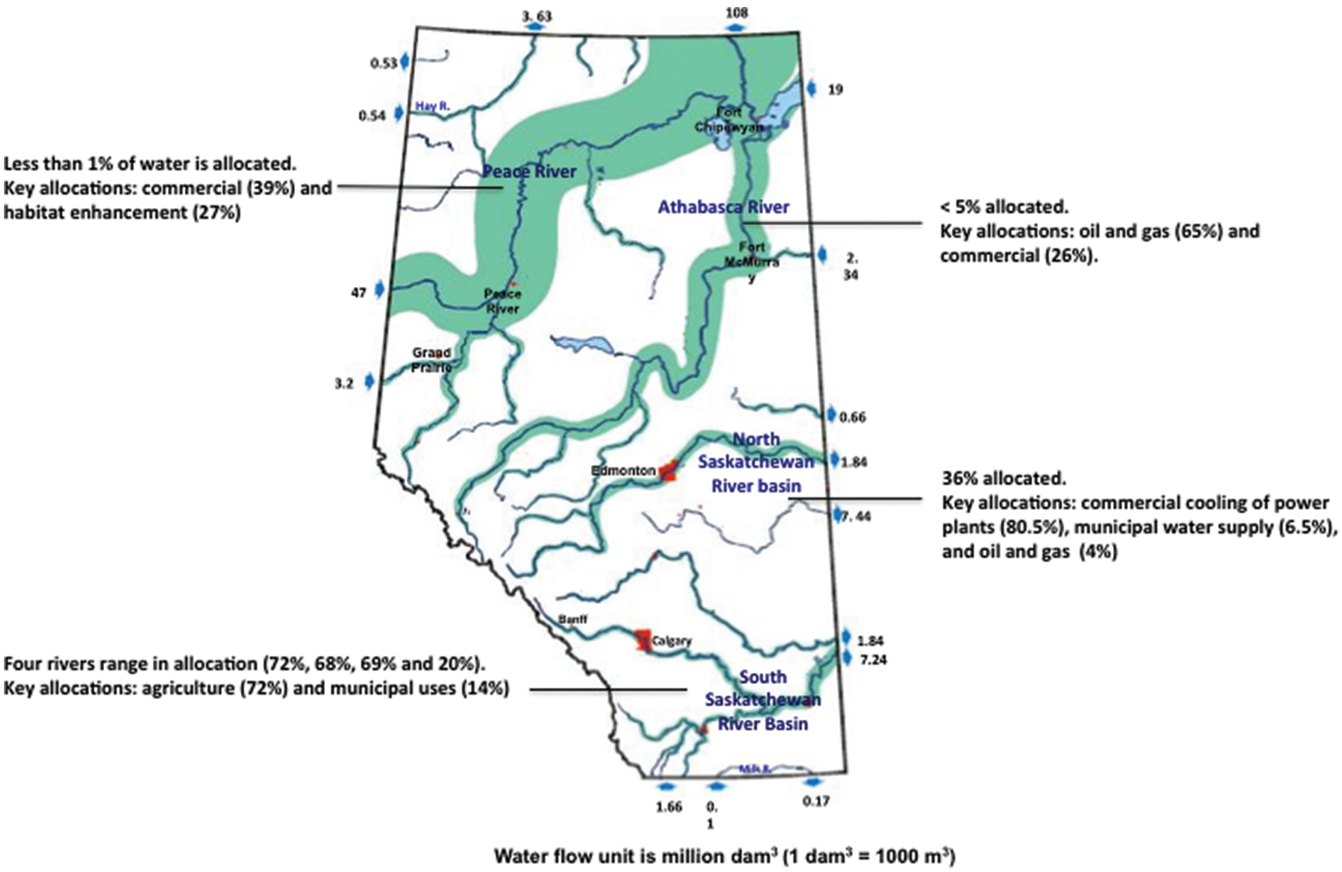

Figure 2. Annual flow and water allocation of major water basins in Alberta (modified with permission from Water Policy Branch, Alberta Environment and Water).[33]

viable with current methods. Surface mines developed on peatlands are currently reclaimed to a mixture of uplands and wetlands. There is likely to be further challenges for restoring hydrology and biogeochemistry due to the large scale of the development and lack of planning.[28] Similar challenges exist for in situ projects in peatland areas, where compaction can occur under roads and well pads and the land is reclaimed to upland. While uplands are considered to have high potential for reclamation of soil and vegetation, it is unlikely that postdisturbance landscapes will include peatlands unless significant progress is made with reclamation methods.[7,29]

The ultimate goal of comparing the land and water impacts of energy technologies is to understand trade-offs related not only resource use, but also to larger scale landscapes and watersheds. Intensity metrics for land and water are limited not only temporally, but also spatially. They cannot capture cumulative effects of resource extraction that are necessary to understanding the incremental impacts of development. Furthermore, the heterogeneity of landscapes and watersheds creates challenges in placing value on impacts. This highlights the need for more research, not only on the impacts, but also how to include societal values and at what scale values should be considered (e.g., regional versus national). Comparative analyses for water and land intensity of energy technologies are ultimately very useful, but we cannot determine impacts without understanding the regional implications.

3. Water and Land Impacts Are Inherently Local—The Significance of Region. Studies that compare the land and water intensity of energy extraction typically ignore spatial considerations. Most existing studies examine land use without local implications,[30,31,14] though some emerging studies are beginning to include spatial scale and regional impacts.[22] The same trend is occurring for research on comparing the water use of energy extraction technologies, with more recent studies beginning to consider regional effects.[32] It is necessary to consider local land and water availability and use due to the local nature of the impacts. The surface water consumed by oil sands operations is a prime example of this phenomenon. At a provincial scale, surface water requirements from oil sands operations are not overly significant when compared to that from agriculture (Figure 2). The northern river basins of Alberta, where oil sands deposits are situated, have a relative abundance of water in contrast to the south where water is already scarce and there is significant agricultural development.

As oil sands production rises, so will water consumption. While water allocations are increasing the fastest in the Athabasca River Basin (by 88% since 2000, 9 times faster than the provincial average), the government no longer accepts water allocation applications in the South Saskatchewan River.[33] In the immediate term, there is little risk of water restrictions with the current framework.[34]

Water use from oil sands development is not without impacts and uncertainties. Water availability in the Athabasca River is expected to decline due to climate change in the future while oil sands development expands.[34,35] Impacts are more likely during the winter when flows are naturally lower.[33] Withdrawals during this time may affect a larger portion of fish habitat and decrease the amount of dissolved oxygen available to fish in the winter. Lower levels of dissolved oxygen may delay hatching, change the mass of posthatched fish and change spawning periods for certain species of fish.[36] The combined effects of the water use of oil sands operations and other industries should be better examined to determine the significance of these additive impacts on ecological processes. In addition, the level to which groundwater withdrawals can affect surface water availability is not well understood. In situ recovery predominantly depends on groundwater and will likely be used for the majority of bitumen extraction. There is a need to develop better scientific knowledge regarding the links between ground and surface water flows.[7,37]

4. Thirsty for Information on Water Quality. The significance of surface water quality impacts of oil sands development is uncertain due to the lack of adequate monitoring and transparent data.[7,8,37] The Government of Alberta has monitored water quality in the oil sands region for over 30 years and their data had indicated no increased contaminants of surface water.[38] Elevated levels of polycyclic aromatic compounds (PACs) have been found downstream of oil sands development, contradicting results reported by the Alberta Government.[9] Though the PACs were not found to reach nearby communities in this study, they were found to be at levels high enough that are likely toxic to fish embryos. A second study indicated that the levels of seven pollutants (cadmium, copper, lead, mercury, nickel, silver, and zinc) were found to have exceeded Canada or Alberta's guidelines for the protection of aquatic life in melted snow and/or water collected near or downstream of oil sands development.[39] The conclusions, reinforced by external review, are that current monitoring of water quality is inadequate and in need of improvement.[7,8,39,40] The inevitable conclusion is that there is a need for an improved model and methodology for monitoring water quality. Steps to fulfill this are currenly underway.[37]

Once water is used for bitumen extraction in the Clarke hot water extraction process, it is not of sufficient quality to return to the environment and is stored in tailings ponds. The produced water has a variety of harmful chemicals, from heavy metals to napthenic acids, which are of concern due to their toxicity to aquatic organisms, birds and wildlife.[7] Impacts related to tailing ponds are controversial, most notably their toxicity, the perceived risk of seepage, and the uncertain time scales associated with their existence. Most recently, Syncrude Canada has been found guilty of environmental charges stemming from the deaths of over 1600 birds in their tailings ponds as deterrents were not deployed quickly or early enough to deter the birds from landing on the ponds.[6] Reports on the magnitude of tailing pond seepage are conflicting.[41,42,7] A recent Environmental Defense report estimated that 11 million liters of tailings might have been seeping daily in 2007 and this may increase to as much as 70 million liters per day by 2012.[42] The Royal Society of Canada concluded that the Environmental Defense estimates are high and that it is unclear to what extent this issue is being managed due to the lack of transparent public data. Some tailing ponds are located on the edge of the Athabasca river, which has caused concern among environmental organizations regarding the potential for dyke breaches.[10,43] Confounding these concerns is the uncertainty surrounding the time scales at which tailings ponds will exist on landscapes. One reclamation plan for tailings waste is the "wet landscape" approach in which the waste would be transferred to an abandoned mine pit and then capped with water to form end pit lakes.[44,45] The acute and chronic toxicity of these end pit lakes may be harmful to aquatic organisms decades after reclamation.[7] Alternatively, "dry landscape" reclamation experiments such as adding calcium sulfate to the wastewater quickly releases most of water within hours allow revegetation on top of the dried landscape. Resolution of the challenges arising from tailing ponds remains a work in progress.

■ HOW WELL PREPARED ARE WE TO MANAGE THESE IMPACTS?

Current land policies do not deal well with rapid growth of production, cumulative effects, reclamation liabilities and landscape-scale impacts such as connectivity of wildlife populations. There is a need to not only better quantify land use, but to use this information to develop regional plans. There have been several attempts to develop such plans in the oil sands region, though none have been put into action. A previous initiative, for example, investigated a Triad land management approach.[12] This approach involves the delineation of three land use zones in the oil sands area: the Intensive zone would consist of oil sands operations, the Extensive zone would consist of forestry and the Protected zone would have no industrial activity. Other actions were recommended such as management of off-highway vehicle access, further work on refining the size of each zone, and a periodic revision of the framework. In 2009, the Government of Alberta released a new Land Use Framework. This framework divides Alberta into seven regions for which regional plans will be developed, one of which is the new Lower Athabasca regional plan to be implemented in the oil sands region. The importance of such approaches is that they allow policy-makers to build scenarios examining future outcomes related to landscape disturbance. The ultimate effectiveness of such initiatives depends on government commitment and the strength of the final plans. One ambiguity that remains is whether resources will be available at the end of a project to ensure that reclamation occurs. In recent years, this problem has been addressed by new rules that mandate oil sands surface mining companies to provide financial security for reclamation in the form of a bond posted to the Environmental Protection Security Fund.[7] By 2010, the total oil sands security fund was 946 million dollars (CAD).[46] The costs of reclamation may not be adequately represented in these funds, as upgraders and extraction plants are not included and security requirements for coal and hardrock mining have been chronically underestimated.[7] Financial security for in situ recovery is managed by the Energy Resources Conservation Board. The current system is in need of a systematic risk management approach to avoid financial liability to the public.

At an operational level, there are several proposed policies that could be of importance for public land decisions related to oil sands development, particularly tradable land use rights. In a tradable land use rights system, publicly owned resources are capped and traded between resource users.[47] The resource, in this case land, is then rationed through a pricing mechanism. If one company uses less land than their allocation, they can sell the right to another company requiring additional land. There are several ways a company can disturb less land than their allocation; for example, through better land use planning or using different technologies. Disturbance on an ecologically defined region can be limited by regulators to a certain percentage a year. Land conservation offsets can be used to compensate for the loss of biodiversity or natural areas by replacing or restoring lands or financial compensation. In 2006, for example, Albian oil sands committed $4 million over 10 years to partially offset the terrestrial effects associated with their Muskeg River Mine expansion project through acquiring and restoring private land.[48] In order to effectively implement these policies, the way in which the metrics are calculated should be transparent, if not standardized.

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Fragmentation can be reduced by integrated landscape management and access management. Integrated landscape mangement involves the coordination of industries to reduce land disturbance (e.g., sharing roads). Impacts extend may extend even farther as human access to natural areas increases with the development of linear features such as roads and pipelines. Linear features can become access points for recreation, hunting, and fishing.[47] Recreational use of linear features after their creation propagate their existence through time, such as hunting and off-road vehicle use. Such impacts can be reduced through the use of access management plans. Features such as access roads may also be transferred to other land uses, such as forestry.

Surface water use by oil sands currently appears to be well managed while water quality remains a contentious subject. Under Canadian law, provincial governments manage water within their borders. In Alberta, the Water Act sets out the regulations related to the allocation of all surface water and groundwater. The issue of low flows in the winter in rivers affected by oil sands operations by developing the Water Management Framework for the Lower Athabasca River.[49] This framework places a weekly cap on water use by oil sands companies that is based on the natural and seasonal changes in river flow. In the near time, no restrictions on water use from oil sands development are expected. In a high-growth scenario for surface mining, water use restrictions are expected in 2020 during seasonal low-flow times of the year, necessitating storage of up to 15% of total annual license volumes.[34] This scenario assumed 2.3 million barrels per day of bitumen will be produced using surface mining by 2020. Water markets have begun to emerge in Alberta due to water constraints in the south created by agricultural uses unrelated to oil sands. Once markets in Southern Alberta have become more mature, they may be used as a model for watersheds impacted by oil sands development if water becomes a constraint in the future. The Water Act, developed in 1999, made it possible to buy and sell water licenses in Alberta.[50] Data is very scarce on water pricing; however, one study reported that in 2001, the average trading price of water rights was \$98 per dam^3 and ranged from \$25 per dam^3 to \$173 per dam^3 (CAD).[51]

Current monitoring of water quality is in need of improvement and transparent reporting. A new governance model has been recommended that includes an independent scientific advisory committee, adequate resources, a newly designed monitoring system, a communication strategy for stakeholders, and a mechanism for dipute resolution.[40] A monitoring plan for water quality of the Athabasca River has been proposed to address the current shortcomings, which includes integrated ground and surface water approach.[37] Much like land use planning in the province, the ultimate strength of these plans depends on the financial and regulatory commitment of the provincial and federal governments. Tailings ponds are reportedly monitored and where seepage is detected, government requires a recapture system to return the tailings to the pond.[52] The Alberta government states that all of the leakage from tailings ponds is detected and captured by groundwater monitoring systems or ditches and that there are no impacts to surface water outside these sites,[53] yet no data are provided to verify this. It is unclear how much tailings ponds are seeping and how much is captured, indicating a need for improved reporting or independent monitoring. The level to which groundwater withdrawal affects surface water flows is uncertain. The nature and extent to which groundwater is contaminated or depleted is unclear and is in need of further investigation and improved reporting. To address the growing concerns around the possible impact of oil sands development on groundwater, Alberta Environment is developing the Groundwater Management Frameworks in several regions that may be impacted by oil sands operations.

■ CONCLUSIONS

Transitions to unconventional fossil fuels will ultimately change both the quality and availability of water and land resources. Without proper assessment, these transitions may not be managed adequately particularly if the growth is rapid, such as the case of oil sands. Technology is an important factor in the ultimate magnitude of land and water impacts. The land disturbance of surface mining is primarily on site while a significant portion of land disturbed by in situ recovery is displaced upstream. The upstream land disturbance of in situ recovery can be reduced by replacing natural gas with alternative energy sources and by making efficiency improvements. There is a need for systematic study of land use impacts and standardization of the calculation of metrics. There are a variety of temporal horizons one may consider, which is particularly important with respect to reclamation success. Once such metrics are agreed upon, comparisons of different energy sources can be better understood. With a standardized approach, analysts can move toward incorporating impacts such as biodiversity. Policies to reduce impacts, such as tradable land use rights, will subsequently be easier to implement. Experience from the oil sands indicates that regional planning for land is one method that should be used to minimize broader scale, cumulative impacts.

Water availability should play a crucial role in understanding impacts of oil sands operations to water resources. It is important to keep water use from oil sands development in perspective compared to water use in southern watersheds. Policies currently appear to be adequate and even forward thinking for surface water use in oil sands development. As oil sands development grows and climate changes, water availability may become more of a limitation and restrictions may be put in place for water withdrawals. Water storage is one way to meet restrictions. There is also opportunity to use the southern markets as a model to assist in the regulation of water use. While water use is currently well managed, water quality remains contentious. The most significant points of contention have grown from water quality where there is the lack of independent, transparent data and inadequate monitoring. To tease out real and perceived environmental risks and respond to public concerns, there is a need to perform independent scientific studies that are reported in a transparent manner. One way this could be accomplished is to develop an independent scientific advisory panel that monitors and disseminates information about the environmental impacts of oil sands development and provides recommendations on how to better manage these impacts.[54] Improving the monitoring of water quality remains a work in progress.

As we transition to unconventional fuels, our impacts to land and water resources will change. There are two current challenges that need to be addressed, one is the need to better quantify impacts and the other is to better address those that are not currently well managed. A better understanding of how well technologies and policies address these impacts can inform governance in other areas with rapidly expanding unconventional fossil fuel production that is analogous to the case of oil sands, such as shale gas.

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Biography

Sarah M. Jordaan is a Postdoctoral Fellow at the Energy Technology Innovation Policy research group at Harvard University. A portion of her research has been conducted with the Laboratory on International Law and Regulation at the University of California, San Diego. She earned her PhD in 2009 at the University of Calgary in Environmental Design with the Energy and Environmental Systems Group of ISEEE. Dr. Jordaan's primary research interests involve systems-level analysis of the environmental impacts of energy technologies. Her research has typically examined the impacts of technologies from a life cycle perspective, with the goal of informing policy and decision-making. To date, she has been involved with specific projects on oil sands development, shale gas extraction, ethical implications of biofuels, water consumption of alternative transportation fuel scenarios, and the development of quantitative tools for comparing the land use of energy extraction more broadly.

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