

Special Series

History, overview, and governance of environmental monitoring in the oil sands region of Alberta, Canada

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EDITOR'S NOTE:

This article is part of the special series “A Decade of Research and Monitoring in the Oil Sands Region of Alberta, Canada.” The series documents the history of monitoring in the region and critically reviews a synthesis of monitoring results published within key environmental theme areas to identify patterns of consistent responses or effects; significant gaps in knowledge; and recommendations for improved monitoring, assessment, and management of the region.

Abstract

Over the past decades, concerns regarding the local and cumulative impacts of oil sands development have been increasing. These concerns reflect the industry's emissions, land disturbance, water use, and the resulting impacts to Indigenous Rights. Effective environmental management is essential to address and ultimately manage these concerns. A series of ambient regional monitoring programs in the oil sands region (OSR) have struggled with scope and governance. In the last 10 years, monitoring has evolved from a regulatory-driven exercise implemented by industry into a focused, collaborative, multistakeholder program that attempts to integrate rigorous science from a multitude of disciplines and ways of knowing. Monitoring in the region continues to grapple with leadership, governance, data management, scope, and effective analysis and reporting. This special series, “A Decade of Research and Monitoring in the Oil Sands Region of Alberta, Canada,” provides a series of critical reviews that synthesize 10 years of published monitoring results to identify patterns of consistent ecological responses or effects, significant gaps in knowledge, and recommendations for improved monitoring, assessment, and management of the region. The special series considered over 300 peer-reviewed papers and represents the first integrated critical review of the published literature from the region. This introductory paper of the series introduces the history of ambient environmental monitoring in the OSR and discusses historic and ongoing challenges with the environmental monitoring effort. While significant progress has been made in areas of governance, expanded geographical scope, and inclusion of Indigenous communities in monitoring in the region, significant issues remain regarding a lack of integrated reporting on environmental conditions, public access to data, and continuity of monitoring efforts over time. *Integr Environ Assess Manag* 2022;18:319–332. © 2021 The Authors. *Integrated Environmental Assessment and Management* published by Wiley Periodicals LLC on behalf of Society of Environmental Toxicology & Chemistry (SETAC).

KEYWORDS: Alberta, Environmental monitoring and impact, Indigenous knowledge, Multistakeholder, Oil sands

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INTRODUCTION

Canada possesses 10% of the world's proven oil reserves, making Canada the holder of the third largest oil reserves globally, of which 97% lies in the oil sands deposits of northern Alberta (Natural Resources Canada, 2019). Proven reserves in the oil sands are approximately 166 billion barrels, distributed across three major oil sands deposits within Alberta: the Athabasca, Peace River, and Cold Lake deposits (Figure 1). The majority (81%) of total bitumen reserves are situated within the Lower Athabasca and Cold Lake deposits

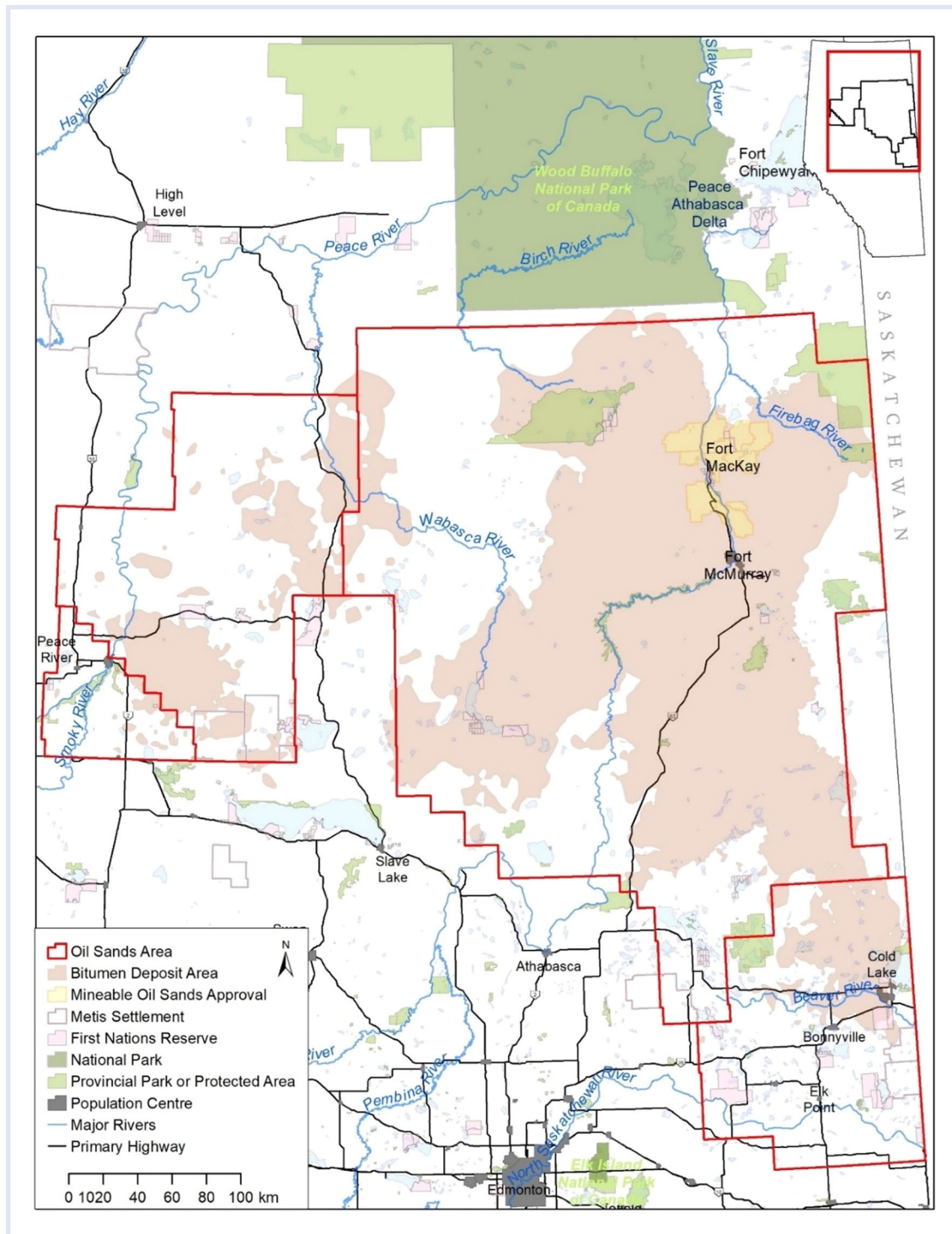


FIGURE 1 Map of the oil sands region, Alberta, Canada (Government of Alberta, 2019)

(Alberta Environmental Monitoring Panel [AEMP], 2011; Hopke et al., 2016). Together, the deposits underlie 140 200 km² of boreal forests, peatlands, and northern prairie ecozones spanning northern Alberta and part of Saskatchewan (Dowdeswell et al., 2010). The Athabasca River system and its intricate tributaries flow through the Athabasca oil sands area and bitumen deposits near Fort McMurray and drain into the Peace–Athabasca Delta and

Lake Athabasca, both sensitive ecosystems of World Heritage status. Several Indigenous communities call the region home and depend upon its resources for the exercise of their Rights and maintenance of their culture. Approximately 23 000 Indigenous people from 18 First Nations and 6 Métis settlements live in the oil sands regions (OSRs) of Alberta as described and illustrated in the Indigenous Community-Based Monitoring (ICBM) paper in this series (Beausoleil

et al., 2021). Some of these communities are surrounded by oil sands development and work with these operations in various and diverse capacities.

Before 2012, most regional monitoring was undertaken by a patchwork of regional, multistakeholder organizations (including the Wood Buffalo Environmental Association [WBEA], the Regional Aquatics Monitoring Program [RAMP], the Ecological Monitoring Committee for the Lower Athabasca [EMCLA], and the Lakeland Industry and Community Association [LICA]). These were “regional” monitoring organizations (in that they are not monitoring specific projects), but they were not all of the same “regional scale” or driven by the same questions or objectives with respect to the OSR. These organizations were essentially driven by a need to address local, Indigenous, and environmental concerns regarding cumulative environmental effects in the absence of a more comprehensive government monitoring or management framework (Ayles et al., 2004; Cronmiller & Noble, 2019). Industry participation in these organizations was commonly required in operator approval conditions as a mechanism to address concerns, particularly those identified in environmental assessments and those of local Indigenous communities. Governance of the organizations varied but typically included industry- and government-dominated governance committees, with limited representation from Indigenous communities and environmental nongovernmental organizations. Ongoing challenges in defining scope, funding, and coordination between organizations led to a patchwork of monitoring that, in many cases, was not designed to assess environmental change that spanned traditional media boundaries (AEMP, 2011; Ayles et al., 2004; Boothe, 2015; Cronmiller & Noble, 2019; Gosselin et al., 2010). Furthermore, environmental monitoring in the OSR was historically guided by regulatory considerations at an operation-specific level, which constrained the scope and rigor of the monitoring effort. The use of exclusive data access as an incentive to participation in some monitoring organizations generated mistrust and led to public accusations that the oil sands industry and regulatory authorities were either concealing or unaware of the environmental implications of oil sands development. Indigenous communities in particular felt that their concerns, including impacts to air quality, wildlife populations, ecosystem health, and water quality and quantity, were not adequately addressed by monitoring activities (Boothe, 2015; Dowdeswell et al., 2010). The accruing mistrust reached a critical point with the publication of two studies that concluded that oil sands development was associated with undocumented environmental contamination (Kelly et al., 2009, 2010), a finding that resonated with the experience of Indigenous community members.

The ensuing concern among Indigenous communities, academic researchers, and the general public catalyzed the commission of multiple Expert Panel Reviews. The Panels were mandated to assess available evidence of various environmental and health issues observed in the OSR, and to provide recommendations for a region-wide environmental

monitoring system (AEMP, 2011; Dowdeswell et al., 2010; Gosselin et al., 2010; Hopke et al., 2016). The outcome was a reframing of regional oil sands monitoring (OSM) with the intent of developing a more comprehensive, centrally coordinated effort initiated as the Joint Oil Sands Monitoring program (JOSM), coordinated by the Government of Canada and the Government of Alberta. After an initial 3-year period, JOSM transitioned into the regional OSM program.

More than 500 papers, reports, and other media examining potential environmental impacts of the oil sands industry have been produced from various sources, authors, and programs in the areas of air and atmospheric deposition, surface water, groundwater, wildlife, wetlands, cumulative effects, and Indigenous (community-based) monitoring. Integrated reporting of this information within an environmental theme area is limited and is almost nonexistent across theme areas. Despite hundreds of millions of dollars invested by a multitude of stakeholders including academics, industry, governments, and communities, an integrated understanding of the accumulated state of the environment has not been compiled, publicly released, and/or published (Cronmiller & Noble, 2019; Hopke et al., 2016). This places the industry, those who depend upon it, those who regulate it, and those affected by it in an increasingly serious position of uncertainty with respect to the potential risks of environmental effects from the industry and the potential opportunities for the industry to mitigate these risks.

This paper is the first of a six-paper series that reviews and integrates a decade of peer-reviewed literature in the OSR. The objective of this introductory paper is to outline how monitoring in the region moved from a collection of unrelated, regulatory-driven programs to a large, multistakeholder-driven program with a broad scope. Like many environmental monitoring programs, monitoring in the oil sands has struggled with defining scope, reporting and analysis, and inclusion of Indigenous perspectives (Cronmiller & Noble, 2019). This introduction sets the stage for other papers in the series that synthesize monitoring results published within each of the monitoring theme areas, and an integrated synthesis across monitoring themes to assess the condition of the environment in the region and remaining knowledge gaps. This series does not include an extensive review of raw data or gray literature, except in cases where is necessary to support interpretation of results.

OIL SANDS OPERATIONS

Operations differ in the chemical composition of the deposit and recovery technology, leading to differences in tailings profiles, emissions, landscape disturbance, and contaminant profiles of process waters. This makes understanding their cumulative impacts and attributing effects to specific processes or facilities very challenging. Understanding oil sands mining processes and operations is fundamental to understanding the existing and potential environmental effects associated with operations.

Technical details on oil sands operations can be found in Murray (2015).

Oil sands are a mixture of sand, clay, water, and bitumen. Bitumen is an extra-heavy crude oil with such high viscosity that mobilization with steam or diluent is required to enable flow. Large-scale commercial production of bitumen began in 1967 and has almost doubled since the 1980s (Poveda & Lipsett, 2013), exceeding 3 million barrels per day by 2018 (Alberta Energy Regulator, 2019). Approximately \$313 billion of capital has been invested in the oil sands to date (Statistics Canada, 2019), indicating the importance of this industry to Canada's economy.

The growth of the industry into the future has become difficult to project, given impacts of declining oil prices, divestment due to global warming and other environmental concerns, and the impacts of the COVID-19 pandemic, all of which have slowed investment (Millington, 2020). The extent of the impact that the health crisis will have on economic growth, employment, trade, social behavior, and capital investment remains unclear (Millington, 2020). Nonetheless, oil sands operations are designed for long-term production; thus, existing operations continue to extract bitumen, and environmental monitoring continues.

Bitumen from the region can be recovered and extracted by two methods: in situ or surface (open-pit) mining. The Athabasca deposit is the largest and only site where oil sands deposits are shallow enough to be accessible by open-pit mining (Canadian Association of Petroleum Producers [CAPP], 2018). The remaining reserves are too deep and are recovered by reducing the viscosity of the oil to a point where it can be pumped to the surface, primarily by steam injection. Future industry growth is projected to be dominated by in situ approaches. Technological innovation is constant in the oil sands and other methods are undergoing pilot testing, with the intent to improve the efficiency of extraction and minimize environmental impacts, for example, by reducing water use and greenhouse gas (GhG) emissions.

As of 2017, there were eight operating open-pit mines operated by four companies (Suncor, Syncrude, Canadian Natural Resources Limited, and Imperial), with a total active mining footprint of 953 km² (CAPP, 2018). Most mines have been operating for fewer than 18 years, with anticipated lifespans of between 40 and 80 years. Mine operations typically consist of five basic components: an open-pit mine, a bitumen production unit, tailings storage pond(s), a tank farm, and a utilities plant. Landscape disturbance for oil sands mining is similar to other forms of open-pit mining and currently is comparable to that of a large city such as New York (784 km²). Tailings management presents critical and pressing issues for the industry, including reclamation, emissions from containment ponds, seepage and other risks associated with tailings containment, and issues associated with bird landings and mortality. Other issues associated with mines include stack and fugitive atmospheric emissions, wastewater treatment and disposal, and water use. Tailings in this context include the remainder of the bitumen ore following bitumen extraction and

comprises water, sand, fine silts, clay, residual bitumen and lighter hydrocarbons, inorganic salts, and water-soluble organic compounds.

Deeper oil sands deposits can only be developed using in situ approaches, which uses heating of bitumen to increase its viscosity to allow it to be pumped to the surface. As of 2017, there were approximately 30 in situ projects in Alberta (OSIP, Government of Alberta, 2019). The first was established in 1985 (Imperial Oil Limited). However, the majority have been in operation less than 15 years, with a lifespan of approximately 40 years. Facilities typically include a series of well pads, a steam and power generation plant, a central processing plant, and a water treatment facility. The majority of future development will be in situ projects (Dowdeswell et al., 2010). In situ operations have a less dramatic footprint on the landscape than open-pit mines. However, individual operations can be quite large and the cumulative effect of multiple in situ operations is unknown. Exploration and pipelines associated with in situ operations have led to significant linear disturbance throughout the three oil sands deposits. Other issues include air emissions, water use and disposal, and potential impacts to groundwater.

Bitumen recovered through mining or in situ techniques requires upgrading to a lighter synthetic crude oil through removal of longer chain hydrocarbons (asphaltenes) and sulfur in an upgrader. Bitumen that is not upgraded at the production site must be prepared for pipeline transport by the addition of a diluent. There are currently four upgraders in the OSR including three on-site of mining operations (Canadian Natural Resource Limited's Horizon Mine, Syncrude's Mildred Lake Mine, and Suncor's Base Mine) and one independent upgrader located in Edmonton, AB, Canada (Scotford Upgrader).

EXPERT PANEL REVIEWS

Increased scrutiny of OSM resulted in the commissioning of several expert reviews. The Expert Panel reviews by the Royal Society of Canada (Gosselin et al., 2010), Environment Canada (Dowdeswell et al., 2010), and the Government of Alberta (AEMP, 2011) have directly influenced OSM in the OSR. These reviews identified deficiencies in previous approaches to OSM relating to the lack of integration and clear questions, the need for clearer governance, transparency and public accessibility of data, and the synthesis of knowledge to inform management of this important industry.

The need for a cohesive monitoring framework with clear questions

A lack of clear questions is a common failure for long-term monitoring programs (Lindenmayer & Likens, 2010). The monitoring organizations in the OSR developed their monitoring approaches based on regulatory requirements, but did not necessarily have an overarching framework with clear questions to inform long-term management (AEMP, 2011; Cronmiller & Noble, 2019; Dowdeswell et al., 2010). This was identified as a major deficiency, particularly in a

region of such dense industrial development (Gosselin et al., 2010). Impacts to groundwater (Gosselin et al., 2010) and surface water (Dowdeswell et al., 2010) were particular areas for which there was a lack of a cohesive framework for detecting change. The AEMP (2011) recommended that the program be transformed using an adaptive monitoring framework, with activities integrated across air, land, water, and biodiversity to ensure efficiency and consistency.

The unique challenge of monitoring in the OSR is the ability to detect effects and attribute cause in an area with dense industrial development and potentially significant cumulative effects. First Nations and Métis communities had long been raising concerns regarding impacts that were not always addressed through the existing regulatory programs. The monitoring organizations were often given the responsibility of addressing these issues, without a rigorous approach for detecting change on various spatial scales in a way that could inform management (Cronmiller & Noble, 2019). The Royal Society Panel identified that the regulatory system relied on impact assessments with key deficiencies and had not kept pace with the rapid development of the region, and that key regional cumulative impacts had not been adequately assessed (Gosselin et al., 2010). Finally, monitoring was largely focused on the oil sands mining sector. The in situ sector conducted monitoring on a project-specific basis, lacking consistency and coordination in monitoring design and methodology (Dowdeswell et al., 2010; Gosselin et al., 2010). In short, the existing programs were criticized as lacking rigor and being inadequate for the size of the issues, stating that “[a]lthough a significant amount of monitoring and research activity is occurring within the oil sands region, it is dwarfed by the level of activity that was expended on other major environmental issues of the last decades, such as the acid deposition problem in eastern Canada” (Dowdeswell et al., 2010). These findings highlighted the need for effective cumulative environmental assessment based on better environmental monitoring in the region.

Transparency

Effective environmental monitoring addresses not only a scientific or management need to assess impacts to the receiving environment but also a societal need to ensure public trust in resource management (Cronmiller & Noble, 2019). One of the primary means of achieving this is a rigorous program that provides publicly accessible data and data access that allows for independent validation and analysis. The patchwork of facility, ambient, and multistakeholder-driven monitoring in the OSR has resulted in nonintegrated data being warehoused in various sites. Transitions and discontinuation of programs have also affected integration, maintenance, and access to data. Apart from some regional air-quality data readily accessible from WBEA and federal National Pollutant Release Inventory databases, monitoring programs in the OSR lacked transparency, contributing to the perception that they were obscuring environmental impacts (Cronmiller & Noble, 2019). Data collected by the RAMP

were perceived to lack consistent collection and quality assurance protocols and were not readily accessible for public use until mounting criticism forced the program to respond (Ayles et al., 2004; Gosselin et al., 2010). All three expert panels recognized that the lack of coordinated and publicly available data was affecting assurance that regulatory decisions were being made on merits of scientific evidence, free from political and commercial interference (Cronmiller & Noble, 2019; Gosselin et al., 2010).

Inclusive and effective governance

Long-term monitoring is difficult to maintain over time, given competing financial and regulatory priorities. Changing governance and leadership, inconsistent funding, and lack of a clear mandate are common issues that can contribute to the failure of monitoring programs (Cronmiller & Noble, 2019; Lindenmayer & Likens, 2010). Long-term monitoring in the OSR has developed as a patchwork of different approaches with different governance and funding models. For example, RAMP, WBEA, and the Cumulative Effects Management Association (CEMA) were all multistakeholder organizations with mandates to oversee aquatic and air monitoring, and studies relating to cumulative effects management in the OSR. Governance of these programs included participation of Indigenous communities, some participation from the provincial government, and industry was required to participate as a condition of their operating approvals. These multistakeholder organizations provided a level of programmatic oversight to monitor environmental effects from oil sands development in the absence of a government framework (Cronmiller & Noble, 2019).

Once the government-led Joint Oil Sands Program was established, support for RAMP and CEMA declined, and the organizations dissolved. This left Indigenous communities concerned that there was no longer a monitoring system in the region to meaningfully address their concerns (Thurton, 2017). In addition, papers published by Kelly et al. (2009, 2010) suggested the prevalence of a previously neglected stressor in the OSR and concluded that existing monitoring was incapable of detecting key environmental changes. From the Indigenous point of view, these results validated their concerns. The three review panels that were convened in response to widespread criticism of the existing programs in the region recognized the importance of (a) addressing Indigenous concerns meaningfully and (b) including Indigenous knowledge in monitoring design and execution. The panels recommended a new governance arrangement that would more effectively guide monitoring decisions and integrate and analyze the data (AEMP, 2011; Cronmiller & Noble, 2019; Dowdeswell et al., 2010; Gosselin et al., 2010). The AEMP report delved deepest into issues of governance and management, concluding that the best way to ensure scientific oversight, organization, and integration was to establish an arm's length environmental monitoring commission, which would guide ambient monitoring while integrating data from existing compliance monitoring activities (AEMP, 2011).

Implementing the recommendations

In Canada, the federal government is responsible for environmental matters that transcend boundaries such as transboundary water issues, migratory birds, and GhGs, as well as impacts to Indigenous reserve lands and impacts to fish, fish-bearing, and navigable waters. Meanwhile provinces, such as Alberta, are responsible for natural resource management and environmental protection within the boundaries of their jurisdiction. Both levels of government bear a responsibility to consider impacts to Indigenous Rights, an issue that has gained renewed attention, given commitments to self-determination of Indigenous peoples in Canada, Canada's commitment to the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP), and commitments under Section 35 of Canada's *Constitution Act (1982)* (Government of Canada, 2017).

Recognizing the need for interjurisdictional coordination, provincial and federal governments collaborated to develop a more meaningful, rigorous, and systematic oil sands environmental monitoring program. The AEMP (2011) report recognized that environmental monitoring needed to be a component of an effective cumulative effects management system. The AEMP (2011) report suggested that Alberta's land-use approach (Government of Alberta, 2008) be the foundation for a new environmental monitoring and reporting system, beginning in the Lower Athabasca Region. The land-use framework was not yet finalized, but it was intended that OSM would become the regional monitoring system that would support the cumulative effects management system that was lacking in the OSR. It was intended to evaluate management effectiveness at the regional level and focus monitoring and management on high-risk areas through iterative, adaptive monitoring (AEMP, 2011). To date, the land-use framework for the Lower Athabasca Region is years behind in its reporting and has failed to effectively integrate with environmental monitoring programs in the region.

In response to the findings and recommendations of the Expert Panel Reviews, Environment Canada and Government of Alberta committed to develop a preliminary surface-water quality monitoring plan for the Lower Athabasca River and tributaries (Government of Canada, 2011). They then broadened their efforts to other environmental media including air and biodiversity, with the intention that the media-specific plans were integrated into a single holistic ecosystem-based approach. This second phase presented an integrated OSM program framework and a proposed sampling design that fulfilled the key principles identified by the Federal Oil Sands Advisory Panel for the design and implementation of a “world-class” monitoring program.

The JOSM program 2012–2015

In 2012, the Province of Alberta and the Canadian Government launched the JOSM program with the release of the Joint Canada-Alberta Implementation Plan (“Implementation Plan”) (Government of Alberta, Government of Canada, 2012). The intent was to phase implementation of the Plan over

3 years to consolidate existing, isolated monitoring initiatives into a single, transparent government-led approach with scientific underpinning (Cronmiller & Noble, 2019). The Implementation Plan also laid out a funding mechanism via the *Oil Sands Environmental Monitoring Program Regulation* (Government of Alberta, 2013) that enabled the annual collection of a fee from the oil sands sector. By convention, the value of the fee has been up to \$50 million/year. According to the “Implementation Plan,” the two governments would be responsible for engaging with industry, independent scientists, First Nations, Métis organizations, and other stakeholders (Government of Alberta, Government of Canada, 2012).

Indigenous communities welcomed the development of a new monitoring system, hoping that it would be a vehicle to address community concerns. However, initial attempts to build a governance system inclusive of Indigenous people were unsuccessful, with Indigenous people expressing concern that they would be leaving multistakeholder regional monitoring programs that, while facing difficulties, nonetheless had meaningful mechanisms for including Indigenous people in governance (Cronmiller & Noble, 2019; Thurton, 2017). The Implementation Plan also comprised a schedule of rigid commitments that left little room for adaptation in response to stakeholder concerns. After months of engagement, several Indigenous communities left the program due to a lack of progress in having their concerns addressed (Office of the Auditor General of Canada, 2014).

One lesson learned in the establishment of the Joint Oil Sands Program was the lack of a unifying monitoring framework or clear questions to guide monitoring (Cronmiller & Noble, 2019). The program was announced with a budget of \$50 million/year, concomitant with a planning process that effectively amounted to a call for proposals. The result was a collection of disparate monitoring and scientific initiatives that, while addressing some immediate gaps in knowledge, nonetheless reflected the scientific interests of individual researchers rather than a cohesive program supported by a clear conceptual model of potential causes and effects (Cronmiller & Noble, 2019; Hopke et al., 2016). A review of JOSM (Hopke et al., 2016) found that while improvements in regional monitoring had occurred, issues remained with respect to rigor, integration, quality assurance and control, transparency, and a clear articulation of goals for monitoring in the OSR. As stated by Boothe (2015), the JOSM agreement between the governments expired in March 2015 and was not renewed, “in part because of AEMERA's unwillingness to accept the federal government as an equal partner in oil sands monitoring.”

The Alberta Environmental Monitoring and Evaluation and Reporting Agency (AEMERA) 2014–2016

As proposed by AEMP (2011), in 2014, the Alberta Government formally launched an arm's length agency called AEMERA. AEMERA was created to take over implementation of JOSM and obtain credible and scientific data about the state of the environment in an open, transparent, and timely manner, independent of, but

accountable to, the Government of Alberta (Cronmiller & Noble, 2019; Hopke et al., 2016). As an arm's length organization with participation of both levels of government, AEMERA was intended to reduce potential conflict of interest and was unique in its use of a science advisory panel, which also included a Traditional Knowledge Panel. However, Indigenous communities remained cautious in their engagement with the new agency, given that a formal governance role for these communities was lacking.

Following a short period of operation, a review of AEMERA and its monitoring program was requested by the Alberta Minister of Environment and Parks in 2015. The review by Boothe (2015) encompassed the rationale for AEMERA, its organizational structure and governance model, and the outputs of the organization including implementation of JOSM. The review was scathing, concluding that AEMERA was a costly, “failed experiment in outsourcing core responsibility of government to an arms-length body. Three years and tens of millions of dollars later, the results are an organization that is still struggling to get established, dysfunctional relationships with its two key partners, AEP [Alberta Environment and Parks] and EC [Environment Canada], and a failure of all three parties to realize the promise of the transformational JOSM plan to bring critically-needed, world-class environmental monitoring to Alberta's oil sands” (Boothe, 2015). While the JOSM Implementation Plan had committed to a principle of inclusion of Traditional Knowledge involving members of local communities in monitoring activities (Government of Alberta, Government of Canada, 2012), inclusion remained lacking (Office of the Auditor General of Canada, 2014). Ross (2015) stated that, by failing to include Traditional Knowledge from Indigenous communities in the OSR, JOSM had failed to become a “world-class” monitoring program.

In April 2016, AEMERA dissolved and the Province of Alberta announced the newly formed Environmental Monitoring and Science Division within the Alberta Ministry of Environment and Parks, to take monitoring efforts back under the control of the Provincial Government (Cronmiller & Noble, 2019). AEMERA's Vice-President and Chief Scientist became the Chief Scientist and Assistant Deputy Minister responsible for environmental monitoring in the province including the OSM Program.

The OSM program

Migration of the monitoring program and responsibility in Alberta from within government, to a newly formed independent agency (AEMERA), and then back into a new department in government, albeit with the same Chief Scientist, disrupted administration, continuity, access to data and information, transparency, and integrated delivery of results as evidenced in the 2016–2017 and 2017–2018 Oil Sands Monitoring Annual Reports (Government of Alberta, Government of Canada, 2017, 2018) and summarized by Cronmiller and Noble (2019). Federal involvement in the program remained largely consistent through this period, in

contrast to ongoing political changes in Alberta. Exacerbating challenges in monitoring efforts further, on 1 May 2016, unprecedented wildfires swept through the OSR, forcing the largest wildfire evacuation in Alberta's history, destroying homes, infrastructure, and over 590 000 ha of boreal landscape.

In December 2017, the Government of Alberta and Environment and Climate Change Canada renewed their commitment to collaborative monitoring of the oil sands by establishing a revised memorandum of understanding (MOU) (Dubé et al., 2018). The effort was led by some of the original developers of the OSM Program in 2012 familiar with the history and learnings of previous efforts and programs. The MOU signified the mutual intentions of both governing parties to continue to collaborate and share accountability for the design and implementation of an integrated monitoring, evaluation, and reporting system for the Alberta oil sands through the OSM program (Government of Alberta, Government of Canada, 2019). Importantly, the MOU identified some significant shifts by formally recognizing and affirming the Treaty and Aboriginal Rights of Indigenous peoples under Section 35 of the *Constitution Act (1982)* (Dubé et al., 2018; Government of Canada, 2017). The acknowledgment of Section 35 Rights of Indigenous peoples marked a commitment to establish effective mechanisms for Indigenous participation in the design, implementation, and governance of the program.

With an overarching vision to establish baseline conditions and track environmental impacts from oil sands development, the MOU provides that the assessment of cumulative environmental effects must also include the tracking and identification of monitoring indicators that are relevant to Indigenous communities. Paving the way for greater Indigenous inclusion in monitoring programs, communities in the Alberta OSR were invited in the spring of 2018 to join the OSM Operational Framework Task Team to share responsibility for the development of the Operational Framework Agreement (OFA) that would guide governance of the Program into the future (Dubé et al., 2018). Working collaboratively with the Science Co-Leads of the Program representing Alberta Environment and Parks and Environment and Climate Change Canada, 18 Indigenous communities participated in the development of the OFA, aiming to further improve Indigenous participation and foster openness, transparency, and inclusion of Indigenous Knowledge in the environmental monitoring program (Dubé et al., 2018). Key to the success of the Task Team was the process of codevelopment and a willingness to share the pen, openly communicate key concerns and “pinch points,” test assumptions, and progress in iterative steps toward consensus. This allowed the Task Team to design a governance program learning from the failures of earlier multi-stakeholder programs. Industry and industry associations were not at the development table based upon the direction outlined in the MOU but were invited to review and comment on the final draft of the OFA with the Task Team. This invitation, however, was a serious point of discussion.

After much debate, it was decided that the path towards excellence in monitoring and management should involve industry, given their knowledge and expertise on their operations. Industry provided its full support for implementation of the framework. The OFA governance structure was completed in December 2018 following 8 months of discussions, and implementation began in January 2019.

OSM governance

Collaborative multistakeholder approaches to environmental problem-solving have emerged through the goal of shared decision making that includes individuals and groups most impacted by potential negative outcomes (von der Porten et al., 2015). In essence, this is a way of recognizing that extensive involvement is not the same thing as meaningful input (Gregory, 2000). A critical element of the multistakeholder approach is the recognition of and respect for differing world views and ways of knowing. Environmental literature has begun to acknowledge the significance of integrating local knowledge, Indigenous Knowledge, and western science (Failing et al., 2007; Lertzman, 2010; Spak, 2005; van Tol Smit et al., 2015).

As early as 1991, the Northern River Basins Study (NRBS) Board, a joint initiative of Alberta, Northwest Territories, and Canada that was designed to oversee the transboundary nature of the River Basins study, operated on a collaborative, consensus-driven basis, with representation from federal, provincial, First Nations and municipal governments, Métis communities, and other stakeholders including industry and environmental groups. The success of the Board was rooted in its programmatic structure and planning process (Gummer et al., 2000). Attempting to determine and quantify multiple environmental stressors in the Basin, the plan of action involved a “conceptual model” to guide the integration of various individual studies to support cumulative effects assessment (Gummer et al., 2000). As the first large Canadian study managed by a multiple stakeholder Board, First Nations and Métis peoples actively participated on the board as equal participants, playing a key role in setting the scientific objectives, which included the use of Indigenous Knowledge. Demonstrating the value of shared management, inclusive of consensus-based processes and independent science advisory committees with First Nations and Métis participation to oversee quality assurance, the success of the system paved the way for issue-specific multistakeholder processes in the region (Gummer et al., 2000). However, NRBS was a scientific research program with a limited 5-year scope.

Other Canadian management and monitoring programs where a multistakeholder governance approach had been implemented include management of the Great Bear Rainforest through the Regional Action Framework (Tiakiwai et al., 2017) and the Eastern Athabasca Regional Monitoring Program (EARMP, 2021). Both regions had seen conflict between the needs of Indigenous people and resource development: forestry in the Great Bear Rainforest in Northern

British Columbia, Canada, and uranium mining in Northern Saskatchewan, Canada. Both programs were based on agreements that include government, industry, and local Indigenous communities, and empower these various actors to collaboratively develop monitoring and support monitoring directly aimed at addressing community members' concerns. The Great Bear Rainforest case study, in particular, showed that the collaborative approach enabled an adaptive model capable of integrating multiple perspectives across government, First Nations, industries, and environmental groups, all with vested interests in the ecosystems of the North Pacific. This model represented a major turning point in resource management, successfully creating a workable solution after many years of conflict (Tiakiwai et al., 2017).

The many evolutions of monitoring and governance in the OSR over time made it clear that scientific success (including the contributions of different cultures and knowledge systems) and the resulting influence on decision making for environmental protection and cumulative effects management depended upon stability in governance (Cronmiller & Noble, 2019). Fundamentally, an approach was needed that empowered both more effective resource management and the ability of stakeholders and Indigenous Rights holders to participate more meaningfully in decision making. In the meantime, over \$300 million had been paid by industry for government-led regional monitoring (exclusive of an equivalent investment in on-site compliance monitoring), with few tangible results that informed or advanced management, and Indigenous communities' concerns remained unaddressed (AEMP, 2011; Boothe, 2015; Cronmiller & Noble, 2019; Gosselin et al., 2010; Government of Alberta, Government of Canada, 2019; Thurton, 2017).

The OFA was a landmark agreement for the region developed with the cooperation of two governments, 18 First Nation and Métis communities and organizations, and industry. While ultimate decision making and budget accountability rested with the governments, if decisions were made that altered the course of the multistakeholder consensus, documented and transparent rational for the change in decision was a requirement of the governance process. Despite criticisms by some external to the process who felt that the agreement went too far with respect to shared governance, the participating parties felt that it brought a level of coordination, transparency, and shared accountability that had not existed previously.

The OFA, supported by the MOU, was built on an Operational Framework Logic model to outline the vision, principles, objectives, and desired outcomes of monitoring under the OSM program, as well as actions, programs, and performance measures needed to support and achieve the outcomes (Dubé et al., 2018). This model defines the shared action and targeted outcomes that are critical to the success of the program. The importance of these elements is underscored by the knowledge that previous monitoring strategies in the region failed to establish credibility because they neglected the fundamental consideration of an inclusive governance arrangement that outlines the goals,

objectives, and values of the program (Cronmiller & Noble, 2019; Joly & Westman, 2017).

To understand the challenging and complex interactions of various stressors in Alberta's OSR, the governance structure of OSM reflects a collaborative multistakeholder approach involving actors with diverse backgrounds, significant history, and relationships, and acknowledges the need for identification of any environmental change(s) through the use of Traditional and local knowledge to help develop plausible hypotheses about cause–effect relationships (Failing et al., 2007; Moller et al., 2004). The organizational structure of the Oil Sands Monitoring Governance is shown in Figure 2.

The Co-Chairs of the OSM program (and their respective Deputy Ministers and Ministers) hold the ultimate decision-making authority after receiving recommendations from the Oversight Committee. Representatives on the Oversight Committee communicate the broader voice of their respective communities or organizations determined via Indigenous, industry, and government caucuses. This does not represent true co-governance with respect to Indigenous participation in the program, but was a necessary compromise, given the fiduciary responsibility of government. A requirement to provide written statements if Co-Chairs are required to make a decision contrary to a consensus recommendation provides transparency over decision making. The Oversight Committee is a strategic committee supported by the Science and Indigenous Knowledge Integration Committee (SIKIC), chaired by an Alberta Environment and Parks (AEP) Science Co-Lead and an ECCC Science Co-Lead. Together, the Co-Leads are accountable for the overall and the integrated science and knowledge of the OSM program. This committee was specifically developed to address concerns of the panel reviews that had identified the need for a mechanism to integrate monitoring efforts across the program (Hopke et al., 2016).

Various Technical Advisory Committees (TACs) oversee media-specific monitoring and report directly into SIKIC (Dubé et al., 2018). The Indigenous Community-Based Monitoring Advisory Committee oversees ICBM, develops Indigenous community capacity and ethics guidance for the program, and is comprised of Indigenous members, with an Indigenous and government Co-Chair. Capacity for meaningful participation at governance tables is funded by the program for nonindustry and nongovernment participants.

The OFA establishes a consensus-based decision-making approach throughout the organizational structure. The key elements guiding the consensus-based approach include inclusive, participatory, collaborative, agreement-seeking, and cooperative group discussions. It is understood that the committees will strive to achieve consensus and be responsible for the decision to identify and escalate non-consensus issues. The governance structure of the program is globally unique and was designed with the intent to increase accountability, coordination, and inclusivity for monitoring in the region.

The first year of implementation from January 2019 to January 2020 witnessed the majority of committees established and multistakeholder governance of funding decisions implemented. This included administrative processes to support the governance, renewed expectations for monitoring scientists for accountability, reporting, integration and data management, and revised funding models to provide monitoring organizations with multiyear commitments to build consistency for delivery. In early 2020, concurrent with a shift in political leadership in Alberta, and organizational changes at AEP, leadership of the monitoring program in Alberta was disrupted again. While the governance structure remains intact and the federal government remains consistent in its participation, the outcomes of this disruption concurrent with the global COVID pandemic remain uncertain. At the time this paper

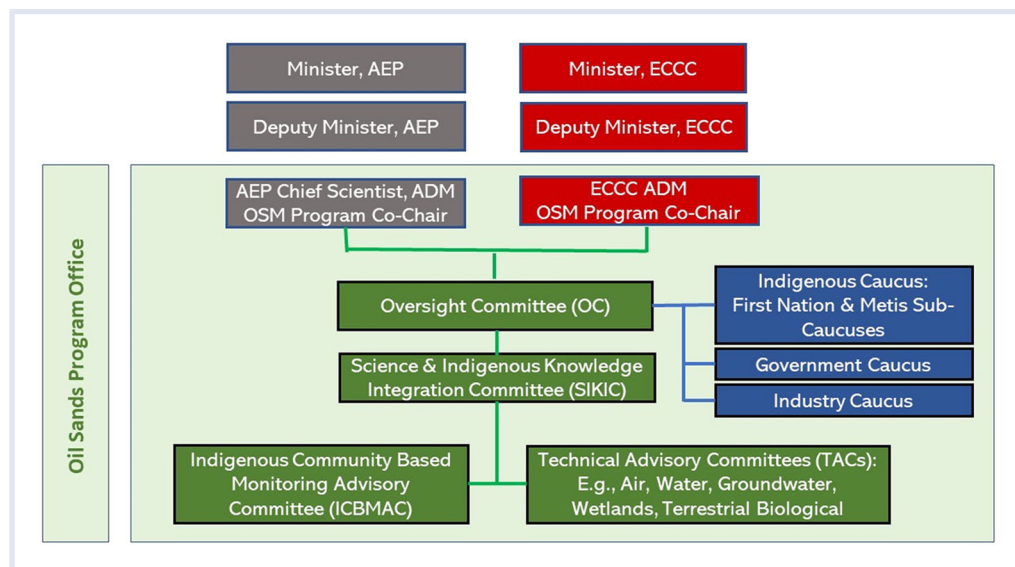


FIGURE 2 Organizational structure of Oil Sands Monitoring Governance. ADM, Assistant Deputy Minister; AEP, Alberta Environment and Parks; ECCC, Environment and Climate Change Canada; OSM, oil sands monitoring (Adapted from Dubé et al., 2018)

was written, the Annual Report for the 2019–2020 year was not available.

GLOBAL CONTEXT OF MONITORING IN THE OSR

The current monitoring program in the OSR is comparatively unique among large international, national, and/or regional monitoring programs specifically in how it includes monitoring across environmental theme areas, Indigenous participation and community-based monitoring, and the size of its annual budget. The OSR is also comparatively unique, given the (global) controversial nature of the resource development industry itself. Given this uniqueness, the opportunity exists for the monitoring program to make a significant contribution to understanding the environmental impacts in the OSR informed by different knowledge systems as well as advancing the discipline of environmental monitoring governance. If successful, it would be a significant case study for mobilizing knowledge and innovation demonstrating that you can have collaborative and coordinated monitoring programs in highly controversial resource sectors.

While it is globally unique, the OSM program does share some elements of large, national, or regional monitoring programs, such as the Terrestrial Ecosystem Research Network (TERN) in Australia and the Swedish Environmental Protection Agency (EPA) Monitoring Program. These are large, multimedia monitoring programs publishing annual reports on the condition of the environment (Swedish EPA, 2019; TERN, 2017). TERN has a similar governance structure to OSM with an Advisory Board and Science Advisory Committee and a separate central Executive Group that is responsible for ensuring communication among all governance levels. However, there is no formal mechanism to include Indigenous perspectives or participation. The Swedish program is run by two government agencies: the Swedish EPA and the Swedish Agency for Marine and Water Management. These programs in Sweden and Australia are not specifically tracking industrial impacts but rather assessing broad changes in the environment including climatic variables.

The UK Environmental Change Network (ECN) is a large national environmental monitoring and research program (UKECN, 2019). While it is similar to OSM in some respects, including a multicommittee governance structure, the ECN publishes annual newsletters and has produced one broader synthesis report—a special issue marking 20 years of environmental monitoring (Sier & Monteith, 2016).

Comparable monitoring programs that examine industrial activities include the McArthur River Mine (MRM) Monitoring Program in Australia (MRM, 2017) and the Independent Environmental Monitoring Program (IEMP) in Canada. The MRM program, however, is designed for regulatory compliance—it is part of MRM's commitment to the Australian and Territory regulatory authorities. In Canada, the IEMP is a planned environmental sampling initiative led by the Canadian Nuclear Safety Commission, designed to verify that public and environmental health around licensed nuclear facilities are protected. It is implemented for facilities in all segments of the

nuclear fuel cycle: uranium mines and mills, uranium and nuclear processing facilities, nuclear power plants, research and medical isotope production facilities, and waste management facilities (IEMP, 2019). Both of these programs are limited to local impacts of specific facilities.

The US National Council for Air and Stream Improvement (NCASI) is similar to OSM in that it is a long-term industry-focused monitoring program funded by industry (NCASI, 2019a). In this case, NCASI was established in 1943 by a consortium of pulp and paper companies. Unlike OSM and its \$50 million/year budget, NCASI receives \$100 K/year from members as well as unspecified amounts from the NCASI Foundation, a nonprofit industry corporation. Among their research programs is the Long-Term Receiving Water Study (LTRWS) that examines the influence of pulp mill effluent discharges on receiving water aquatic ecosystem health (NCASI, 2019b). This study, in particular, is comparable to many OSM studies in that the goal was to put the LTRWS into a watershed and regional context, including multiple sources, stressors, habitats, and assessment endpoints (Hall et al., 2009; Landis & Thomas, 2009). Unlike current monitoring in the OSR, Indigenous participation is not evident in study planning or in program governance.

One monitoring program with a moderately comparable budget to the OSM program is the US National Ecological Network (NEON). It is a continental-scale observation facility designed to collect long-term open access ecological data with a reported \$469 million budget over 30 years (Lindenmayer & Likens, 2018). This averages to \$16 million/year—more than the other monitoring programs discussed here, but still significantly lower than the annual \$50 million investment received by the OSM Program. However, the focus of NEON is data collection and sharing, and it does not have the funds to support analysis of the data that are gathered (Lindenmayer & Likens, 2018).

In the United States, the Southern California Coastal Water Research Project (SCCWRP) is a public research and development agency funded by wastewater and stormwater treatment agencies, water quality regulatory agencies, and federal agencies, foundations, and municipalities (Schiff et al., 2016). It is governed by a 14-member board, made up of senior managers from Southern California's largest wastewater and stormwater treatment agencies and water-quality regulatory agencies (SCCWRP, 2019). The SCCWRP in turn oversees and funds the Southern California Bight Regional Marine Monitoring Program. This is an integrated, collaborative program that provides large-scale assessments of the Southern California Bight on a 5-year cycle, looking at the impacts of human on the health of approximately 1500 square miles of Southern California's coastal waters.

The Ecosystem Health Monitoring Program (EHMP) for Moreton Bay in South East Queensland, Australia, is a program led by Healthy Lands and Water, an independent organization that works in partnership with Traditional Owners, government, industry, utilities, and communities (EHMP, 2019). EHMP has a similar model of Indigenous inclusion,

having signed an MOU in 2015 with the Quandamooka Yoolooburrabee Aboriginal Corporation. Despite this commonality, the EHMP does not have the budget, industrial activity focus, or the governance established in OSM.

NEXT STEPS

Evidence of progress

Environmental monitoring in the OSR of Alberta is arguably unmatched with respect to its history, investment, and level of public scrutiny at local to international scales. Concerns that have emerged over the past two decades include considerable discontinuity, eroded public trust, a lack of data access and management affecting transparency, a lack of integrated multitheme reporting on environmental condition including cumulative effects, and limited inclusion of effective mechanisms for Indigenous participation in the design, implementation, and governance of monitoring in the region (AEMP, 2011; Boothe, 2015; Cronmiller & Noble, 2019; Dowdeswell et al., 2010; Gosselin et al., 2010; Hopke et al., 2016; Swanson, 2019a, 2019b).

Some progress has been made toward addressing these concerns particularly since 2017 (Government of Alberta, Government of Canada, 2019). The scope of the program has expanded to be more inclusive of both mining and in situ operations, although emphasis remains on mining development with limited coverage of areas of concern to some First Nations and Métis communities (e.g., in the Cold Lake and Peace River Regions) (Swanson, 2019a, 2019b). Governments and communities downstream of operations in the Northwest Territories (to Alberta's north) have expressed some concerns with a lack of consideration by OSM programs (Swanson, 2019a, 2019b). However, monitoring by other programs, initiatives, and Indigenous communities downstream of the Athabasca region, including in Wood Buffalo National Park, a UNESCO World Heritage Site, and the Northwest Territories to Alberta's north, is increasing, given the widespread concern about cumulative effects from developments including oil sands, oil and gas, hydroelectric facilities, and climate change (Independent Environmental Consultants [IEC], 2018).

Monitoring in the region has made some steps toward moving to a cohesive adaptive monitoring program. This is evidenced by the conceptual models developed by participants in workshops in 2018 and 2019 (see articles in this special series). Conceptual models are organizational tools often used in ecological studies and risk assessment to generate hypotheses, build common and connected understanding of stressor-pathway-response linkages in systems under study, and to focus relevant research (Broszeit et al., 2019; Van den Brink et al., 2016). In 2018–2019, eight Integration Workshops were held to both develop conceptual models and begin the process of integrating the disparate monitoring projects (Government of Alberta, Government of Canada, 2019; Swanson, 2019a, 2019b). Eight separate workshops were held on terrestrial biological monitoring, groundwater, surface water and aquatic

biology, atmospheric deposition, geospatial science, mercury contamination, predictive modeling, and ICBM, with detailed reporting and recommendations for all workshops, except the ICBM workshop (Swanson, 2019a, 2019b).

These conceptual models followed a common stressor-pathway-response framework to support integration discussions at each workshop and also to provide a consistent basis for evaluation of the current status and future direction of monitoring in the region. The conceptual models were linked to the three desired core outcomes of monitoring in the region: (1) to assess accumulated environmental condition or state (have things changed?); (2) to determine relationships between oil sands-related stressors and effects (are there observed changes and are they caused by the oil sands industry?); and (3) to assess cumulative effects (what are the combined effects of oil sands stressors across regions and over time?) (Dubé et al., 2018). The conceptual models reflected where participating researchers' and organizations' work fit within the conceptual model and how it was contributing to the core outcomes. They also allowed for consolidation of existing research into a common frame to identify what work had been done and where there may be a conceptual understanding of the ecosystem, oil sands-related stressors, valued components, and indicators of concern to local Indigenous communities in the OSR. The workshops used the conceptual models to coordinate the opinions and perspectives, albeit qualitative and subjective, of those attending the workshops to assist with work planning under the OSM program for the 2019–2020 monitoring year (Swanson, 2019a, 2019b).

Given the shifting accountability for monitoring in Alberta over time (Cronmiller & Noble, 2019), one of the most significant developments toward increased stability was the renewal of the MOU and development and implementation of a landmark governance agreement in 2018 (Dubé et al., 2018; Government of Alberta, Government of Canada, 2019). The agreement fulfilled the intentions of the Ministers of Environment for Canada and Alberta at the time, outlining an inclusive and accountable multistakeholder, hierarchical governance structure to direct environmental monitoring in the region. Most importantly, the agreement provided the basis for stability and honored the requirement to increase participation of Indigenous communities in the governance and implementation of the program including increased investment in Indigenous-led community-based monitoring (Government of Alberta, Government of Canada, 2019). Given the agreement was in place and in the final stages of implementation when the latest shift in leadership occurred in the program in the winter of 2021, it remains to be seen if the significance of the agreement will be realized.

Finally, despite a lack of integrated reporting on environmental condition in the region, the number of oil sands-related peer-reviewed publications on air emissions, air quality and deposition, surface water, wildlife and biodiversity, and wetlands has grown considerably over the last

decade. Monitoring efforts have produced over 300 peer-reviewed publications over the last decade excluding reports and studies conducted by regional multistakeholder organizations that provide another large body of knowledge specific to the OSR. For this review paper series, we considered 377 unique publications from the 12-year period between 2009 and 2020 (Roberts et al., 2021a, 2021b) and summarized these by environmental theme area and over time. The number of annual publications within the scope of the review has climbed steadily over time. If not for this effort of solid individual scientific contributions, the ability to integrate and synthesize in this series would not have been possible.

Ongoing issues

Despite steps forward in governance, significant challenges remain with scientific integration, data management, public access to data, stable leadership, and a lack of integrated multitheme reporting on environmental conditions including cumulative effects (Boothe, 2015; Hopke et al., 2016; Swanson, 2019a, 2019b). These challenges are not necessarily unique to OSM and represent an issue observed in the ecological sciences more broadly (Van den Brink et al., 2016). A lack of integrated analysis and data collection is somewhat expected for monitoring conducted as independent efforts by independent researchers. However, when large, well funded, central programs are implemented in a region, coordination and reporting through a consistent framework relative to key questions of concern are expected. Furthermore, given the level of financial investment in this region and the level of global scrutiny, improved coordination, delivery of monitoring outcomes, and performance are expected. Various actors in the oil sands have attempted to produce integrative frameworks for monitoring coordination (Government of Canada, 2011; Hopke et al., 2016), but these frameworks have not succeeded in the implementation stage due to a combination of factors including changing leadership, program instability, a lack of clear questions and goals for the framework and program, and the challenges associated with moving diverse groups with diverse interests toward a common outcome (Boothe, 2015; Cronmiller & Noble, 2018, 2019; Hopke et al., 2016).

The development of conceptual models and efforts to integrate the monitoring projects began the process of moving toward a rigorous, adaptive monitoring program. However, challenges include pressures to maintain programs that may not fully meet the needs of an adaptive monitoring program and legacies of monitoring to meet regulatory requirements. For example, emphasis on common regulatory requirements such as monitoring for compounds with regulated ambient concentrations somewhat constrains monitoring and understanding complex mixtures such as atmospheric concentrations of total reduced sulfur compounds or total hydrocarbons, or chemical species such as alkylated polycyclic hydrocarbons and naphthenic acids that, while potentially toxic, are nonetheless hard to distinguish and identify. The

companion papers in this series summarize these challenges (Arciszewski et al., 2021; Horb et al., 2021; Roberts et al., 2021a, 2021b).

Finally, while the OFA was instrumental in bringing together government, industry, and Indigenous communities into a governance structure that is globally unique, maintaining the program requires constant work and vigilance. Cronmiller and Noble (2019) raised “the significant uncertainty about the stability of institutional arrangements to support long-term environmental monitoring, and the tensions between the need for scientific autonomy for credible science whilst ensuring the pursuit of monitoring questions that are relevant to the day to day needs of regulatory decision makers.” The impact of instability in political and program-level leadership, governance, and membership, particularly in Alberta, continues to create significant uncertainty that needs to be managed for the future of monitoring in the OSR.

CONDITION OF ENVIRONMENT REVIEW

Public reporting on the condition or state of environment is a foundational component of any environmental monitoring program. Transparency in this respect brings credibility to the monitoring and also provides a venue for scientific synthesis and understanding of accumulated knowledge addressing key questions. To date, much of the knowledge reporting from the OSR has been in the form of peer-reviewed papers in technical science journals. In this special series, we provide a comprehensive review of this peer-reviewed literature from the last decade, divided by environmental media (air, water, and land), with the objectives to (1) consolidate the knowledge gained to date; (2) highlight key commonalities and gaps in the reported literature; and (3) leverage this knowledge to assess the state of integration within environmental monitoring efforts in the OSR.

In the papers that follow, we organize knowledge based on a conceptual model approach, utilizing more detailed theme-level conceptual models in each of the main review papers, namely, for air and deposition (Horb et al., 2021), surface aquatics (Arciszewski et al., 2021), and terrestrial biology (Roberts et al., 2021a). We also present an overview of ICBM in the OSR (Beausoleil et al., 2021). To close this series, we consolidate knowledge gained from these reviews into a higher-level synthesis and present a larger summary based on a cross-media conceptual model (Roberts et al., 2021b) that advances understanding of the accumulated environmental state and identifies current gaps and future priorities. This integrated interpretation leans heavily on published Western science literature, a decision made to ensure feasibility of the task, given the extent of knowledge resources. We acknowledge that this synthesis is consequently incomplete, given that it omits some published and unpublished gray literature, published and unpublished data, and extensive knowledge from Indigenous communities.

True condition of environment reporting is a living process that will only be realized when the complete

breadth of monitoring knowledge, including published literature, unpublished work, and raw monitoring data, is subject to ongoing integrated interpretation, integrated analysis, adaptive decision making, and timely public reporting.

CONCLUSION

It is only through open and transparent reporting, peer-reviewed publication, and knowledge sharing with other knowledge holders in the region that the potential impacts of the oil sands operations on the environment and communities can be understood and managed. There is an arguably unmatched financial investment in monitoring in this region compared to other programs in the world. Sound science and integrated knowledge must drive evaluation of the sustainability of the oil sands industry, and this science must be regularly and accurately reported to the public. This special review series represents one step toward much-needed integrated reporting on the condition of the environment in the OSR.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

DATA AVAILABILITY STATEMENT

No raw data were used for this article.

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