Oil Sands Monitoring Program: Integration Workshop Reports (Part 1 of 2)

Oil Sands Monitoring Program
Technical Report Series 7.1

List of contributing experts to this report and their and affiliations:

Stella, Swanson[1]

[1]Swanson Environmental Strategies

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Comments, questions, or suggestions regarding the content of this document may be directed to:

Ministry of Environment and Parks, Environmental Monitoring and Science Division

Oil Sands Monitoring Program Office

10th Floor, 9888 Jasper Avenue NW, Edmonton, Alberta, T5J 5C6

Email: OSM-Info@gov.ab.ca

Website: environmentalmonitoring.alberta.ca

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The University of Calgary provided invaluable logistical support, including the management of all matters relating to venue, issuing of invitations and tracking responses, distribution of pre-workshop information packages, production of materials to be used at the workshops and detailed note-taking at the workshops. I would particularly like to acknowledge Maria Hoiss and Pam Hyde for their efficiency, attention to detail, and unflappability when faced with last-minute changes and requests.

I was very fortunate to have the assistance of three highly skilled facilitators – Karen Chown (Terrestrial Biological Monitoring Workshop) and Margo Purcell and Jolene Ondrik (for the remaining workshops). Karen, Margo and Jolene were instrumental in ensuring that all of the workshops were conducted in an open and inclusive manner, with opportunities for everyone to participate. Their expertise and ability to quickly adjust to workshop conditions were fundamental to the achievement of workshop objectives.

Each workshop was planned with the assistance of Workshop Leads who provided review and input to the Conceptual Framework and individual conceptual models for each Theme, reviewed workshop agendas, helped assemble pre-workshop information packages, and generated initial invitation lists for review by the Co-Chair and Science Co-Leads. Workshop Leads also presented reviews of the current status of their Theme, and provided feedback after each workshop.

Workshop Leads were:

Terrestrial Biological Monitoring: Dan Farr, Samantha Song, Bruce Pauli, Jeff Ball, Maureen Freemark

Groundwater: Cynthia McClean, Greg Bickerton

Surface Water and Aquatic Biology: John Orwin, Joseph Culp, Colin Cook

Atmospheric Deposition: Stewart Cober, Leiming Zhang, Greg Wentworth, Bob Myrick

Geospatial Science: Faye Wyatt, Colleen Mortimer, Daniel Peters, Donald Baird

Mercury: Bruce Pauli, John Chételat, Maureen Freemark

Predictive Modelling: Anil Gupta, Paul Makar, Greg Bickerton, Cynthia McClain, Bruce Pauli, Faye Wyatt, Dan Farr, John Orwin

Finally, I thank all of the workshop participants for their hard work, attention, and willingness to engage with each other.

Forward

In February 2018 work planning under the Oil Sands Monitoring (OSM) program for the 2018-2019 fiscal year occurred. This involved review of work plans submitted to the OSM Program by an OSM Interim Science Review Committee with representation from the Government of Alberta, Government of Canada, local First Nations and Métis communities, science experts, and industry including Canadian Association of Petroleum Producers (CAPP) and Canada's Oil Sands Innovation Alliance (COSIA). Work plans were evaluated using several criteria, including the inclusion of assessments of current environmental state, new and emerging priorities, and commitment to evaluating progress to date and integration across program areas. The objective of the OSM Program is to design and implement an integrated monitoring, evaluation, and reporting system that acquires and reports on baseline environmental conditions, tracks any environmental impacts due to oil sands development, and assesses cumulative environmental effects from oil sands development and operations. Work plans submitted to the OSM Program are required to demonstrate that they will contribute to meeting this objective.

Following review based on the above criteria, recommendations for funding were made to the OSM Science Co-Leads and Co-Chairs. The OSM Co-Chairs approved fifty-two (52) of seventy-three (73) projects submitted under the 2018-19 OSM work planning process. In many theme areas the Interim Science Review Committee recommended the program "take pause" to synthesize the work that has been completed and the path forward to support design and prioritization for 2019-2020 OSM work planning. A series of "Integration Workshops" was recommended.

In response to this recommendation, the OSM Program proceeded with planning and holding seven technical Integration Workshops in the 2018-2019 year. Each Workshop would focus on the objectives and required core results of the OSM Program and would provide answers to the following questions: (1) where are we?; (2) where do we need to go?; and (3) How are we going to get there?

A word about the content of this report

This report presents the core results of the Seven OSM Integration Workshops held between the end of October, 2018 and early February, 2019. It is derived from detailed notes taken by the University of Calgary. As such, it represents the best efforts of the note-takers in capturing technical discussions, as well as my judgement with respect to the important points raised by participants and the consensus achieved with respect to the answers to "where are we?", "where do we need to go?", and "how are we going to get there?". It has been prepared to provide as accurate a record as possible in order to help guide the deliberations of the committees within the Operational Framework Agreement Structure for the OSM Program. A separate report presents recommendations for the OSM Program.

Stella Swanson, Ph.D.

Executive Summary

Background

This report provides the results of seven technical Integration Workshops: Terrestrial Biological Monitoring; Groundwater; Surface Water and Aquatic Biology; Atmospheric Deposition, Geospatial Science, Mercury, and Predictive Modelling. The workshops were held between the end of October, 2018 and early February, 2019.

This report is a summary of detailed notes taken during each workshop. It represents as faithful a reflection of workshop discussions and consensus as possible; thus, it reflects the background and expertise of attendees. Opinions regarding issues such as governance, data management and data accessibility, are those of workshop participants. Confirmation of workshop consensus and conclusion items will require broader verification/validation with monitoring data and published or reported literature; actions which are currently underway. Governance and processes for dealing with issues such as data management and accessibility are being dealt with through the Operational Framework Agreement (OFA) for the OSM Program.

A maximum of 40 participants per workshop was established based on achieving balanced participation and manageable size. The process for development of invitation lists for each of the seven workshops was based upon a standard set of criteria, which are presented in the main body of this report.

Information provided in pre-workshop packages as well as presentations made during the workshops is available at https://albertagov.box.com/s/vdcrdzu7o750o7cctrceu8pdwmodq3wa. When reference is made to this information, the link to the site is provided.

A Conceptual Framework was developed prior to the Workshops to provide a consistent basis for evaluation of the current status and future direction of the OSM Program. The framework was developed to ensure a focus on the objective of the OSM Program. It provided the basis for the agendas of all seven workshops, a set of required elements for the design of OSM projects, and an approach for prioritization of future projects. It also included conceptual models of the linkages between stressor sources, pathways and mechanisms, and effects. These conceptual models provided an additional tool for evaluating the OSM Program.

According to the Memorandum of Understanding (2017) the Objective of the OSM Program is to design and implement an integrated monitoring, evaluation, and reporting system that includes the acquisition and reporting of regional data on baseline environmental conditions, tracking any environmental impacts, and the assessment of cumulative environmental effects from oil sands development. This objective translates to the Three

Core OSM Results: (1) assess accumulated environmental condition or state (have things changed?); (2) determine relationships between oil sands-related stressors and effects (are the observed changes caused by the oil sands industry?; and (3) assess cumulative effects (what are the combined effects of oil sands stressors across regions and over time?).

The objectives of each workshop were to: (1) determine current results for each of the OSM Theme areas relative to OSM Objectives and the Three Core OSM Results (**where are we?**); (2) identify priorities within and across theme areas which, when addressed, will advance the OSM Program towards achieving its objectives (**where do we need to go?**); and, (3) identify actions required to address the priorities (**how are we going to get there?**).

This report does not short-list the 36 priorities identified at the workshops. Further prioritization and integration is dealt with in the Recommendations Report, which presents a road-map to integration of the OSM Program and suggests the top priorities to be addressed in the near-term and in the first 5-year Strategic Plan.

State of the OSM Program Regarding Achieving the Three Core Outcomes

Current Environmental State or Condition

General

- The OSM Program has produced a substantial body of information regarding the spatial and temporal distribution of environmental stressors in the oil sands region (with emphasis on mineable oil sands areas).
- There has been a strong focus on contaminants except in the Terrestrial Biological Monitoring Theme, which has focused on landscape disturbance.
- There is still work to be done on establishing appropriate baselines in order to determine whether there have been spatial or temporal changes in state or condition.

Terrestrial

- Regional-scale habitat disturbance due to oil sands and non-oil sands stressors is well documented.
- The caribou population has declined substantially and strong shifts in bird communities have been observed; however, the relative contribution of oil sands development to these trends is uncertain.

- Some oil sands-related contaminants have been measured in some species (e.g., furbearers, semi-aquatic birds); however, the significance of measured levels to wildlife health and population metrics is poorly understood.
- Detection of change is highly dependent on spatial and temporal scale; there are mis-matches between the scale of habitat disturbance mapping and observed changes in species.
- Baseline information is lacking for certain stressors and the baseline is continuously changing at different rates in different areas.
- There is a disconnect between compliance monitoring (inside the fence) and OSM Program monitoring.

Groundwater

- Groundwater monitoring under the OSM Program is in the formative stage. Available groundwater data for the oil sands region were not collected to address the specific objectives of the OSM Program.
- Local-scale (primarily on-site) effects are understood, both in terms of groundwater quantity and quality, at least in terms of compliance with permit requirements.
- Access to all relevant groundwater data is a key requirement, followed by a synthesis report.
- There has been a substantial effort dedicated to groundwater modelling in support of environmental assessments (EAs), government policy and planning or academic research; however, there has been little collaboration and sharing of results. Validation of model predictions made in EAs is rare, particularly beyond the site scale

Surface Water and Aquatic Biology

- Most of the surface water and aquatic biology information is from oil sands mining areas.
- There are consistent flow-related seasonal water quality patterns in the lower Athabasca River that are caused either by dilution during high flows or association with suspended sediments. These patterns are not oil sands-related, although oil sands development is one source of chemicals measured in the river water.
- There is a spatial pattern of increasing concentrations (amount in a certain volume) and loads (amount per a period of time) upstream versus downstream in the Athabasca

mainstem for total vanadium, dissolved selenium and dissolved arsenic. It is unknown if this is a global pattern for rivers of this region.

- There is a temporal pattern of increasing concentrations of some dissolved and total metals in the Athabasca mainstem. Total phosphorus also showed an increased downstream of Fort McMurray, but this increase has levelled off over the last 15 years with improved Fort McMurray sewage treatment.
- Historic and current water flows are highly variable and future variability is predicted to be strongly affected by climate variability and change. Mean annual flow is predicted to increase with an overall shift to increased winter flow, earlier freshet and decreased summer flow.
- Modelling has shown that flows respond differently to climate and land cover changes. Flows decrease in response to land cover changes (because of changes in evapotranspiration) and increase in response to climate change (wetter and warmer conditions).
- Assessments indicate that ice-jam releases and the resulting energy waves in the water generate extreme erosive forces and suspended sediment concentrations. Spring breakup generates the highest total suspended solids loads for the year.
- The current status of benthic invertebrate communities in tributaries shows a difference between sites within oil sands development footprints and reference sites; however, the effects of natural bitumen deposits cannot be distinguished from the effects of oil sands development.
- Benthic invertebrate communities in the mainstem Athabasca River showed increases in the relative number of tolerant taxa, both in the area affected by Fort McMurray sewage discharges and adjacent to oil sands developments.
- Laboratory exposure of fathead minnows to natural oil sands sediment from the Steepbank and Ells Rivers was associated with some non-lethal deformities and changes to social behaviour and poor egg production. Exposure to undiluted melted snow from site near oil sands mines decreased larval fish survival, but exposure to spring runoff water did not affect survival. This shows that dilution may be sufficient to limit impacts to fish.
- The fish health response pattern in the mainstem Athabasca was indicative of nutrient enrichment. This pattern has declined with time, coincident with improved Fort McMurray sewage treatment.

- There is an absence of information on lakes. There has been a strong focus on erosional habitats in both the mainstream Athabasca and in tributaries versus habitats where sediments are deposited (e.g. back channels and pools). Wetland monitoring information has not been integrated with the surface water information.

Atmospheric Deposition

- Deposition is enhanced within ~10-100 km of surface mining depending upon the chemical of concern.
- Total sulphur deposition (<100 km) is dominated by dry and wet sulphur dioxide. There is a good understanding of seasonal patterns.
- Total nitrogen deposition is poorly understood in part because of the large number of reactive nitrogen species and confounding processes.
- Acidification of streams and lakes caused by the deposition of sulphur and nitrogen compounds has not been observed except in some streams during spring freshet. Some model simulations predict acidification, but these predictions have not been verified by field data.
- Base cation (calcium, magnesium, sodium and potassium) deposition is poorly understood because of the lack of measurement needed to calculate dry deposition. There is some evidence of alkalization (increase in pH) in shallow lakes less than 50 km from oil sands operations because of deposition of base cations. There is evidence that base cation deposition is neutralizing acidifying deposition near oil sands facilities. Effects of alkalization on vegetation are uncertain.
- Total mercury deposition is poorly understood. The contribution of oil sands operations to mercury deposition beyond ~30 km might be small. Mercury deposition decreases exponentially with distance from oil sands sources up to ~80 km. Mercury and methyl mercury in snow packs are predominantly bound to particles, which likely explains the higher deposition closer to oil sands operations.
- Total trace element deposition is poorly understood. The deposition of most of the trace elements decreases exponentially with distance from oil sands sources up to ~85 km.. However, there are some elements (e.g. cadmium and chromium) with no spatial gradients in deposition, which suggests the impact of local and regional sources rather than oil sands development. Trace elements are occasionally above guidelines for soil, snowmelt and water. Effects from these concentrations on aquatic or terrestrial biota have not been reported.

- PAC deposition is higher near major oil sands developments and declines exponentially with distance because most PACS are bound to particles that deposit near emissions sources. Alkylated PACs are the dominant PAC species in snow packs within 50 km of oil sands operations. The highest deposition to snow packs has been observed over the Athabasca River between the Muskeg and Steepbank Rivers where oil sands development is most intense. Higher deposition is also found along the north-south directions than east-west directions. Some parent polycyclic aromatic hydrocarbon (PAH) compounds exceed soil and sediment guidelines. There are no guidelines for alkylated PAHs or dibenzothiophenes (DBTs) which are predominantly associated with oil sands sources.
- Enhanced concentrations of PACs have been observed in wolves, moose, caribou and birds. Negative effects have been observed in otters, although not at the population level. No negative effects were observed in the aquatic invertebrate Daphnia (water flea).

Mercury

- There is no apparent oil sands-related pattern for:
  - Air (gaseous elemental Hg)
  - Lake water
  - Lake sediment
  - Lichen
  - Large-bodied fish
- Elevated mercury has been observed in:
  - Atmospheric deposition (local)
  - Snow (local)
  - Athabasca River water downstream of the Clearwater River
  - Small-bodied fish (very limited data)
  - Waterbird eggs (related to sediment transport – origin of mercury in sediment is subject to question)

Stressor-Response Relationships

General

- Effects on some terrestrial and aquatic biota have been observed and/or predicted; however, confirmed causal links between these effects and oil sands-related stressors have not been established

Terrestrial Biological Monitoring

- While changes in some populations and communities (particularly some land birds and caribou) have been observed relative to land disturbance, it is difficult to tease out the effects of oil sands-related disturbances from the effects of other habitat disturbances. Effects of some oil sands-related stressors on some land bird species can be discriminated from other stressors and synergistic effects must be considered; however, the spatial scale of such studies is important.
- While there is strength in understanding habitat loss, we need a better understanding of the effects of changes in habitat quality on valued species and rare species.
- The effects of increased human access require more study.
- Oil sands-related effects on food security have not been adequately addressed. Furthermore, information about effects on birds, furbearers, and vegetation, including culturally important plants, is lacking.

Groundwater

- Linkages between stressors and effects on groundwater resources are not well characterized, particularly beyond the local (site) scale
- The lack of sufficient baseline data and/or lack of access to relevant, synthesized baseline data limits the ability to discriminate the effects of oil sands-related, natural, and other anthropogenic stressors
- There are several knowledge gaps which prevent us from understanding oil sands-related effects on groundwater at the sub-regional and regional scales.

Surface Water and Aquatic Biology

- The strength of relationships between three primary stressor sources – municipal discharges, oil sands operations, and natural bitumen - and effects on benthic invertebrate communities and fish health in the mainstem Athabasca varies. There is strong evidence for the effect of municipal effluent on benthic invertebrates and fish health. There are fairly strong links between all three sources and water quality in the mainstem . Sediment quality reflects both natural bitumen and industry sources; however, discriminating between natural and industry effects on benthic and fish health is difficult.

- Causes of observed responses to stressors in tributaries are still uncertain. Benthic invertebrate communities show evidence of mild environmental stress; however, the relative role of natural bitumen versus industry-related stressors in causing observed decreases in sensitive taxa is still not clear. Similarly, increased liver size in slimy sculpin may be due to natural bitumen exposure, industry-related chemical releases, or both.
- Effects on physical habitat caused by water diversions, elimination of wetlands, ponds and lakes and portions of tributaries, and modifications to stream channels have not been a focus of past monitoring. Therefore, the relative effect of changes in quantity and quality of habitat versus contaminant-related effects is unknown

Atmospheric Deposition

- There is little evidence of widespread acidification due to nitrogen or sulphur deposition, likely due to the mitigating effect from concurrent base cation deposition. Several studies have observed deposition of base cations exceeding the sum of acidifying pollutants within tens of kilometres of oil sands facilities.
- There is evidence that base cation and nitrogen deposition within about 50 km of oil sands facilities are affecting terrestrial ecosystems. Observations include: (1) difference between soil microbial communities along the nitrogen + sulphur deposition gradient; (2) negative correlation between elevated nitrogen/sulphur/base cation deposition and moss/lichen cover and richness and (3) negative correlation between internode length and acidifying deposition.
- There is no evidence that enhanced nitrogen or phosphorus deposition has caused eutrophication in aquatic ecosystems.
- Experimental application of nitrogen to a bog near Mariana Lakes, AB stimulated nitrogen fixation up to 3.1 kg/ha but then progressively inhibited nitrogen fixation above this level. Increasing experimental nitrogen input led to a switch from new nitrogen being taken up primarily by *Sphagnum* to being taken up primarily by shrubs. As shrub growth and cover increase, *Sphagnum* abundance and NPP decrease. The results were use to derive a recommended nitrogen deposition critical load of 3 kg N per ha per year

Mercury

- There are few very stressor-response data regarding responses to oil sands-related mercury concentrations
- Mercury concentrations in waterbird eggs in the Athabasca River downstream of oil sands development have increased compared to the year of earliest collection. These concentrations are unrelated to forest fire events and long range transport of mercury, suggesting that oil sands development or local sources of mercury are affecting egg mercury levels or there are other factors which create conditions leading to methylation of mercury (and thus uptake into eggs). Some egg samples exceeded the lower limit of the threshold for effects on reproduction
- This is no evidence to date linking the oil sands industry to observed mercury concentrations in Lake Athabasca fish

Cumulative Effects Assessment

General

- Cumulative effects have received little attention to date in the OSM Program
- Integration among OSM Themes is required to address cumulative effects. Assessing the incremental contribution of oil sands-related stressors to cumulative effects will require methods for identifying specific activities responsible for habitat disturbances. It was noted that oil sands-related disturbance cannot be assessed in isolation of other disturbances and that climate change is an important contributor or modifier of cumulative effects
- Assessment of cumulative effects must address the interactions between oil sands-related activities and other sources of disturbance, notably forestry.
- Indigenous knowledge should play an important role in the assessment of cumulative effects. Knowledge can be applied at various spatial and temporal scales.

Terrestrial Biological Monitoring

- ABMI is now at a point where changes in species can be estimated in relation to cumulative habitat disturbance; however, these modelled predictions will require field verification. The time required for verification is an important consideration because by the time a predicted change is verified, it may be too late to prevent or mitigate the habitat disturbances.

Groundwater

- Knowledge of cumulative effects on groundwater beyond the local scale is very limited.
- Although regulatory permits stipulate that there be no discharges to groundwater by oil sands operations, releases due to seepage, landscape disturbance, spills and other malfunctions should be considered.
- Production of cumulative risk map can be a starting point. These maps would be developed using our existing understanding of sources and pathways and the relative vulnerability of the groundwater resources (both shallow and deep). The maps could include explicit recognition of uncertainty.
- There may be a better opportunity for understanding cumulative effects on groundwater quantity rather than quality because changes in quantity are easier to detect in the short-term and EAs may include more baseline data.

Surface Water and Aquatic Biology

- Nutrient-contaminant interactions are possible below Fort McMurray where municipal sewage effluent and oil sands-related exposure occurs; however, these interactions have not been investigated in detail. Interpretation of cumulative effects in tributaries is confounded by natural bitumen exposure.
- Assessment of the combined effects of fish habitat changes due to land disturbance, changes in groundwater discharge patterns and flows, and natural disturbances such as fire require integration among OSM Themes.
- Participants noted that there needs to be clarity regarding investigation of the cumulative effects of *multiple stressors* versus the assessment of cumulative effects of *several sources of a particular stressor* distributed over time and space. These two types of cumulative effects may both be important in the oil sands region

Atmospheric Deposition

- Multiple stressor effects from the combination of deposited contaminants is a topic requiring further study. Additive, synergistic or antagonistic relationships can occur among multiple stressors
- The combined effects of atmospheric deposition plus climate change or landscape disturbance were raised as a potential issue requiring assessment in all oil sands regions

Mercury

- The relative contribution of the oil sands industry to cumulative mercury loadings to air, water and sediments and subsequent concentrations in biota is still highly uncertain.

The Application of Geospatial Science and Predictive Modelling to the Three Core Outcomes

Geospatial Science and Predictive Modelling provide tools to achieve all three core outcomes. A summary of useful tools and approaches is presented below.

Geospatial Science

Geospatial science has been successfully applied to the assessment of environmental condition as well as detection of change (OSM Core Outcome #1). However, it has been less frequently used to evaluate stressor-response relationships (OSM Core Outcome #2) particularly with respect to specific oil sands-related stressors at appropriate spatial and temporal scales. Geospatial science is required for assessment of cumulative effects (Core Outcome #3) across theme areas.

- Tools such as LiDAR can be used for indicating current state as well as temporal change in features such as wetland extent, water level, canopy height, and vegetation condition in the oil sands region
- GIS pixel frequency maps can be used to provide baseline information, including baseline changes with time.
- ABMI geospatial data are available for application to the OSM Program objectives. Both downloadable static datasets and web applications of real-time and historical data are available.
- Remote sensing of the Peace Athabasca Delta is being used to build additional understanding of baselines through observations of spatial and temporal changes.
- Remote sensing has provided valuable baseline data over large spatial areas using a repeatable timeline.
- Remote sensing provides reference information from nearby natural regions for comparison to areas exposed to stressors such as water use/abstraction and landscape disturbance.

- Field data validation of remote sensing and modelling is required for a complex system such as the Peace Athabasca Delta. Community based monitoring will continue to play an important role in this validation.
- In some cases, cumulative effects can be mapped (OSM Core Outcome #3). However, distinguishing the effects of natural stressors from anthropogenic stressors is difficult
- Cumulative effects with respect to forest and wetland structural health have been mapped in the oil sands region. Comparisons between burned and non-burned wetlands as well as structural health as a function of distance and direction from active mining operations and atmospheric emissions have been conducted. These analyses have illustrated the importance of wildfire in the region and the challenge of separating natural and oil sands-related effects.

Predictive Modelling

Predictive modelling has been a central tool in establishing condition or state (Core Outcome #1). It has not been used as extensively to investigate stressor-response relationships (Core Outcome #2). Predictive modelling will be essential to the assessment of cumulative effects.

The contributions of modelling and further modelling needs include:

Atmospheric Deposition:

- Modelling has produced a relatively good set of estimates of the spatial distribution of atmospheric deposition; however, there are some gaps for specific stressors
- Connections between oil sands industry sources and deposition have been inferred from estimated spatial distribution patterns. More scenario simulations such as those run for mercury could address relative source contributions and other important questions
- Air modelling has focussed on source-pathway linkages. Stack emissions have been the primary source considered. Land disturbance sources have not been a specific focus
- Integration is required to address stressor-response relationships, interactions along exposure pathways, and cumulative effects. This has not yet occurred

Groundwater

- Most existing groundwater models were not developed specifically to address OSM objectives

- Regional -to-site level model scales are the most applicable to the OSM Program. Information relevant to OSM Program core outcomes has been produced by past and current modelling
- Sub-watershed, project scale models performed as part of most EIAs Project-are built for the purpose of comparing pre-development, current and full-build scenarios. Therefore, they inherently examine expected change in response to oil sands development
- Current groundwater models can be used to run sensitivity analyses for identification of the key drivers of oil sands-related effects. Scenario analyses can be used to compare and contrast effects on features such as groundwater level with various degrees of current and future surface disturbance and groundwater withdrawals
- There are some existing groundwater models which were designed to address cumulative effects
- The linkages between natural and oil sands-related factors and groundwater recharge and discharge have been addressed by past groundwater modelling. Taken together, the results of these modelling exercises can be evaluated for the relative importance of linkages with natural, oil sands and non-oil sands-related factors
- Past modelling results have indicated the importance of wetlands and precipitation to recharge, predicted local impacts on water level, identified high intrinsic vulnerability areas and predicted recovery times for aquifer heads

Surface Water

- Extensive hydrologic and surface water quality modelling has taken place to produce historic, current and projected future spatial and temporal variability of flow, sediment transport, water quality and sediment quality. Effects of climate change and land use have been modelled
- Historical baseline models provide reference levels against which current and future changes can be assessed. This baseline has been used to evaluate the impacts of climate change and land use change on hydrology, water quality or fish habitats
- Models can be used to investigate stressor-response relationships and causation through the use of scenario analysis which compare and contrast predicted effects from different combinations of stressors
- To date, water quality models have not been focussed on distinguishing among stressor sources or effects. Nor have they focussed on critical drivers of effects

- Progress has been made with respect to cumulative effects, particularly with respect to climate change plus land use change effects on hydrology
- Past and current modelling has identified the critical role of weather and climate on hydrology of the lower Athabasca system. Hydrology, in turn, drives pathways and mechanisms which can lead to effects
- Several linkages remain poorly understood, including linkages between natural bitumen and water or sediment quality and between atmospheric deposition and water quality

Terrestrial

- Terrestrial modelling has focused on evaluating and predicting relationships between stressors related to major land use categories (“footprint groups”) and responses in species or communities
- Footprint groups include agricultural, forestry, transportation, human-created waterbodies, urban, rural and industrial and energy (mines, wells and other energy features)
- The relative effects of “footprint groups” or “sectors” have been evaluated.
- Relationships between forest composition and structure and bird abundance have been assessed
    - Models are currently being updated for application to oil sands-related stressors
- While the modelling of bird responses is well developed, models for other taxa may not be as established
- Population dynamics modelling results are being compared among regions such as “western mineable”, “eastern mineable” and “All Lower Athabasca Production Region” for population parameters such as occupancy, colonization and extinction
- With increasing number of repeated field samples, modellers are getting better at testing whether local and regional changes in footprint are correlated with population parameters

Priority Uncertainties Associated with Achieving the Three Core Outcomes

Workshop participants identified and the short-listed uncertainties associated with establishing the current environmental status or condition, stressor-response relationships, and cumulative effects.

The top 6 uncertainties for Terrestrial Biological Monitoring are (in order of the number of votes received):

1. Quality, quantity, safety and availability of traditional resources
2. The levels of uncertainty related to predicted and observed effects on terrestrial biota, including rare species
3. The spatial and temporal scales required to define conditions and allow removal of ‘footprint’
4. State, trend and cause-effect relationships for mammal and plant communities
5. Effects of atmospheric deposition
6. Knowledge held by Indigenous communities

The top 5 uncertainties for Groundwater are (in order of the number of votes received):

1. Baseline and range of variability for groundwater quality and quantity
2. The location of critical groundwater-dependent ecosystems, groundwater/surface water interaction rates and mass flux.
3. Hydrogeological Conceptual Model
4. Effects of climate change on groundwater quantity and quality
5. Reclamation success.

The top 6 uncertainties for Surface Water and Aquatic Biology are (in order of the number of votes received):

1. Separation of different anthropogenic and natural stressors (in situ, surface mining, natural bitumen, forestry, sewage discharges etc). Includes cumulative effects.
2. The amount of atmospheric deposition of contaminants which reaches the Athabasca watershed. Quantification of emissions and loading distributions.
3. Fate of oil sand organic and inorganic contaminants in downstream receiving habitats and food webs.
4. Lack of knowledge of higher order ecological effects
5. Unsure that the selection of measurement endpoints reflects community concerns and values
6. Indicators of natural versus anthropogenic change.

The top 5 uncertainties for Atmospheric Deposition are (in order of the number of votes received):

1. Fugitive dust sources and pathways for base cations, trace elements. Includes spatial uncertainty and seasonality. Includes large particle modelling.

2. Long-term deposition trends for those constituents of concern which are produced by oil sands. Includes timescale to effects and temporal variability.
3. Sources and deposition of total nitrogen, including spatial distribution and critical loads.
4. Source attribution – oil sands versus non-oil sands. Mercury and trace elements, others as needed (PACs)
5. Ecological impacts of base cations – multiple interacting stressors (base cations, nitrogen, sulphur

The top 4 uncertainties for mercury are (in order of the number of votes received):

1. Oil sands industry mercury sources and speciation
2. Mercury in traditional foods and subsequent effects on traditional resources and human health
    a. Mercury concentrations in traditional foods compared to other regions. THEN if it is confirmed that the oil sand industry contributes to an incremental increase in mercury
    b. Effects of mercury
3. Quantify and understand natural vs anthropogenic sources (oil sands, compensation lakes, non oil sands anthropogenic such as forestry, hydroelectric)
4. Mercury mass balance and transport
    c. Methylmercury transport mechanisms
    d. Mass balance of total and methylmercury source contributions to the Athabasca River

Key Questions for Each of the Priority Uncertainties

Key questions developed for each of the priority uncertainties are presented in Appendix 3. The list of Key Questions is long; therefore, further prioritization will be required. The Recommendations Report includes suggestions for which key questions are near-term and medium-term priorities.

Key Questions or Critical Linkages Selected as Priorities for the Application of Geospatial Science and Predictive Modelling

Geospatial Science workshop participants identified the key questions where the application of geospatial science would be particularly useful in the near or medium-term and then short-listed those key questions for prioritization via a voting process (Appendix 4).

The top 5 key questions selected for the application of Geospatial Science in order of priority were:

1. Mapping community knowledge of the quality and quantity of traditional resources
2. The spatial and temporal variability in hydrologic connectivity between depositional areas and surface water bodies and the key drivers of this variability.
3. The location of groundwater-dependent ecosystems.
4. The species which are the most sensitive to habitat fragmentation.
5. The effects of enhanced N, S and base cation deposition on vegetation communities.

Predictive Modelling workshop participants based their prioritization on the identification of critical linkages in the conceptual models for terrestrial, groundwater, surface water and atmospheric deposition themes. They then short-listed the critical linkages (Appendix 4) and voted on the top priority linkages.

The top 5 critical pathways and processes for the application of Predictive Modelling in order of priority were:

1. Groundwater connectivity with surface water quality and baseflow inputs.
2. Natural, oil sands and non-oil sands stressors -> surface water quality, groundwater quality and sediment quality ->fish health and human health.
3. The causal linkage between surface water quality and ecological effects (monitored changes in benthic invertebrates and fish health). Coupled water quality-quantity. Link to air deposition.
4. Atmospheric deposition links to terrestrial effects and surface water quality
5. Contaminant exposure and effects on terrestrial species persistence, biodiversity, productivity. Includes comparison to habitat effects.

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Background

The Oil Sands Monitoring Program was formed in 2012 in response to stakeholder concerns regarding the state of the environment in the oil sands region of Alberta. It is one of the largest multi-media environmental monitoring programs in the world funded by industry through the Oil Sands Monitoring Program Regulation and co-managed by the Governments of Alberta and Canada. The program operates at $50 million dollars per year and is foundational to ensuring the balance between environmental protection and sustainable oil sands energy development.

Decisions on OSM Program direction are supported through a governance process involving Indigenous communities, governments, independent experts, industry and ENGOs. Ensuring the program, and those funded under it, are delivering to the program's mandate was the key driver resulting in seven Integration Workshops held in 2018-2019.

This report provides the key results of seven technical Integration Workshops: Terrestrial Biological Monitoring; Groundwater; Surface Water and Aquatic Biology; Atmospheric Deposition, Geospatial Science, Mercury, and Predictive Modelling. The workshops were held between the end of October, 2018 and early February, 2019.

A maximum of 40 participants per workshop was established based on achieving balanced participation and manageable size. The process for development of invitation lists for each of the seven workshops was based upon a standard set of criteria. Attendance Lists for each workshop are provided in Appendix 1.

The Oil Sands Monitoring Program was formed in 2012. It is one of the largest environmental monitoring programs in the world and is funded by industry through the Oil Sands Monitoring Program Regulation at $50M per year.

Decisions on OSM Program direction are supported through a governance process involving Indigenous communities, government, independent experts, industry and environmental non-government organizations.

This report provides the key results of 7 Technical Integration Workshops

A maximum of 40 participants per workshop was established based on achieving balanced participation and manageable size.

Invitation lists for each workshop were based upon standard criteria.

Invitation List Criteria

- **Balanced participation** among (1) current PIs (count Workshop Leads within this category), (2) Science Experts, (3) Indigenous representatives, (4) Industry representatives, and (5) representatives of other OSM Themes.
    - **(1) Principal Investigators:**
        - PIs to be selected from among current and “paused” projects
        - Balanced among participating organizations (ECCC, AEP, academia, other (e.g. Innotech, WBEA, etc.))
        - PIs already involved in projects which require integration with other Themes
    - **(2) Science Experts – select a cross-section based on:**
        - Experience in the oil sands region
        - No connection with oil sands to bring fresh perspective
        - Recognized integrator across disciplines
        - Expert in establishing that a change in status or condition has occurred
        - Expert in stressor-response patterns and causation
        - Expert in cumulative effects assessment
        - Strategic thinker
    - **(3) and (4) Indigenous/Industry:**
        - Indigenous participants to be selected by the OFA Task Team – up to 4 participants
        - Industry participants to be selected by COSIA – up to 4 participants
    - **(5) Representation from Other Themes (4-5 participants):**
        - Representatives relevant to the workshop outcomes, including policy and planning, among others

Flexibility in application of invitation criteria was necessary because of factors such as the lack of availability of science experts, and last-minute substitutions because of unexpected cancellations. In all cases, the most important consideration was achieving balance among participants.

A Conceptual Framework was developed to provide a consistent basis for the evaluation of current status and future direction of the OSM Program at all workshops.

The Conceptual Framework presented the OSM Program Objective, a set of required elements for the design of OSM projects, and an approach for prioritization of future projects. It also provided conceptual models which illustrated stressor-pathway-effect linkages.

- ***OSM Management*** was to be represented all workshops.
- ***OSM Secretariat members*** (at least one from ECCC and one from AEP) would provide support at all workshops.

Flexibility in application of these criteria was necessary because of factors such as the lack of availability of science experts, and last-minute substitutions because of unexpected cancellations. *In all cases, the most important consideration was achieving balance among participants.*

A Conceptual Framework was developed to provide a consistent basis for evaluation of the current status and future direction of the OSM Program. It provided the OSM Program objective, the basis for the agendas of all seven workshops, a set of required elements for the design of OSM projects, and an approach for prioritization of future projects. It also included conceptual models of the linkages between stressor sources, pathways and mechanisms, and effects. These conceptual models provided an additional tool for evaluating the OSM Program. Conceptual Frameworks for each workshop are in https://albertagov.box.com/s/vdcrdzu7o750o7cctrceu8pdwmodq3wa.

According to the Memorandum of Understanding (2017) the Objective of the OSM Program is to design and implement an integrated monitoring, evaluation, and reporting system that includes the acquisition and reporting of regional data on baseline environmental conditions, tracking any environmental impacts, and the assessment of cumulative environmental effects from oil sands development.(http://oilsandsmonitoringprogram.com/wp-content/uploads/2018/06/OSM-MOU-December-1-2017.pdf). This objective translates to the Three Core OSM Results: (1) assess accumulated environmental condition or state (have things changed?); (2) determine relationships between oil sands-related stressors and effects (are the observed changes caused by the oil sands industry?; and (3) assess cumulative effects (what are the combined effects of oil sands stressors across regions and over time?).

The objectives of each workshop were to: (1) determine current results for each of the OSM Theme areas relative to OSM Objectives and the Three Core OSM Results (**where are we?**); (2) identify priorities within and across theme areas which, when addressed, will advance the OSM Program towards achieving its objectives (**where do we need to go?**); and, (3) identify actions required to address the priorities (**how are we going to get there?**).

This report is based on the discussions and consensus among workshop participants; thus, it reflects the background and expertise of attendees. Confirmation of workshop results will require verification/validation with monitoring data and published or reported literature; actions which are currently underway.

This report does not short-list the 36 priorities identified at the workshops. Further prioritization and integration is dealt with in the Recommendations Report, which presents a road-map to integration of the OSM Program and suggests the top priorities to be addressed in the near-term and in the first 5-year Strategic Plan.

Three Core OSM Results

1. Assess accumulated environmental condition or state (**have things changed?)**

2. Determine relationships between oil sands-related stressors and effects (**are changes caused by the oil sands industry?**)

3. Assess cumulative effects (**what are the combined effects of oil sands stressors across regions and over time?**)

Terrestrial Biological Monitoring Workshop

“Where are We”: Current Status of Terrestrial Biological Monitoring

Accumulated Environmental Condition or State

Workshop participants generally agreed that:

- Many years of study by academic, government and industry researchers have produced a substantial amount of information for terrestrial habitats and species. The Alberta Biodiversity Monitoring Institute (ABMI) inventory and mapping of habitat disturbance accompanied by the monitoring of hundreds of species is an important example of such work.
- Regional-scale habitat disturbance due to oil sands and non-oil sands stressors is well documented; however, the spatial scale of the work may not be sufficient to allow for the resolution required to discriminate oil sands from non-oil sands stressor effects.
- The caribou population has declined substantially and strong shifts in bird communities have been observed; however, the relative contribution of oil sands development to these trends is uncertain.

Multiple years of study across many programs have yielded a large amount of information for many terrestrial habitats and species.

Habitat disturbance at the regional scale due to multiple oil sands and non-oil sands stressors is well documented, but this spatial scale may not be sufficient to allow for the resolution required to discriminate oil sands from non-oil sands stressor effects.

- Some oil sands-related contaminants have been measured in some species (e.g., furbearers, semi-aquatic birds); however, the significance of measured levels to wildlife health and population metrics is poorly understood.
- Detection of change is highly dependent on spatial and temporal scale; there are mis-matches between the scale of habitat disturbance mapping and observed changes in species.
- Baseline information is lacking for certain stressors and the baseline is continuously changing at different rates in different areas.
- There has been limited integration between scientific and Indigenous observations of change.
- There is a disconnect between compliance monitoring (inside the fence) and OSM Program monitoring.
- There has been very limited integration among OSM Themes.

The caribou population has declined substantially and there have been strong shifts in bird communities but the relative contribution of oil sands development to these trends is uncertain.

Some oil-sands related contaminants have been measured in furbearers and some bird species; however, the significance of measured levels to wildlife health and population metrics is poorly understood.

Detection of change is highly dependent on spatial scale and there are mis-matches between the scale of habitat disturbance mapping and observed changes in species.

Integration of Indigenous and western science knowledge has been very limited.

It is difficult to tease out the incremental effects of oil sands-related habitat disturbance and we need information on habitat quality, not just habitat loss.

Oil Sands-Related Stressor-Response Relationships

There was consensus that while changes in some populations and communities (particularly land birds and caribou) have been observed relative to land disturbance, it is difficult to tease out the effects of oil sands-related disturbances from the effects of other habitat disturbances. In the opinion of some participants, effects of some oil sands-related stressors on land birds can be discriminated from other stressors and synergistic effects must be considered; however, the spatial scale of such studies is important. Participants noted that while there is strength in understanding habitat loss, we need a better understanding of the effects of changes in habitat quality on valued species and rare species.

There was agreement that the effects of increased human access require more study. Increased access can increase hunting and fishing pressure and can cause further habitat disturbance via mechanisms such as erosion and disruption of animal movements.

The perspective of Indigenous communities is that oil sands-related effects on food security have not been adequately addressed. Furthermore, information about effects on birds, furbearers, and vegetation, including culturally important plants, is lacking.

The effects of increased human access due to oil sands development require more study.

Oil sands-related effects on food security have not been adequately addressed.

Indigenous communities would like to see increased information about effects on birds, furbearers and vegetation.

Cumulative Effects

ABMI is now at a point where changes in species can be estimated in relation to habitat disturbance; however, these modelled predictions will require field verification. The time required for verification is an important consideration because by the time a predicted change is verified, it may be too late to prevent or mitigate the habitat disturbances.

There was consensus that integration among OSM Themes is required to address cumulative effects. Assessing the incremental contribution of oil sands-related stressors to cumulative effects will require methods for identifying specific activities responsible for habitat disturbances. It was noted that oil sands-related disturbance cannot be assessed in isolation of other disturbances and that climate change is an important contributor or modifier of cumulative effects.

Assessment of cumulative effects must address interactions between oil sands activities and other sources of disturbance as well as with climate change

Indigenous participants emphasized that assessment of cumulative effects must address the interactions between oil sands-related activities and other sources of disturbance, notably forestry. They cautioned that management of cumulative effects cannot be industry-by-industry, but must be integrated across sectors.

Workshop participants agreed that future scenario evaluation is critical to the management of cumulative effects in the oil sands regions. Collaboration will be required to produce a realistic and useful suite of future scenarios with which to compare and contrast predicted cumulative effects.

“Where Do We Need to Go?”: Prioritization by Identification of Key Uncertainties

Because of the very large number of uncertainties, prioritization is necessary. Key uncertainties were identified and then short-listed by workshop participants using a set of prioritization criteria. A final list of the top 6 key uncertainties was determined through a voting process.

Key uncertainties are those where knowledge of stressor-pathway-effects relationships is imperfect or lacking.

A conceptual model of linkages among stressors, pathways and effects was used to assist in the identification of uncertainties (Figure 1).

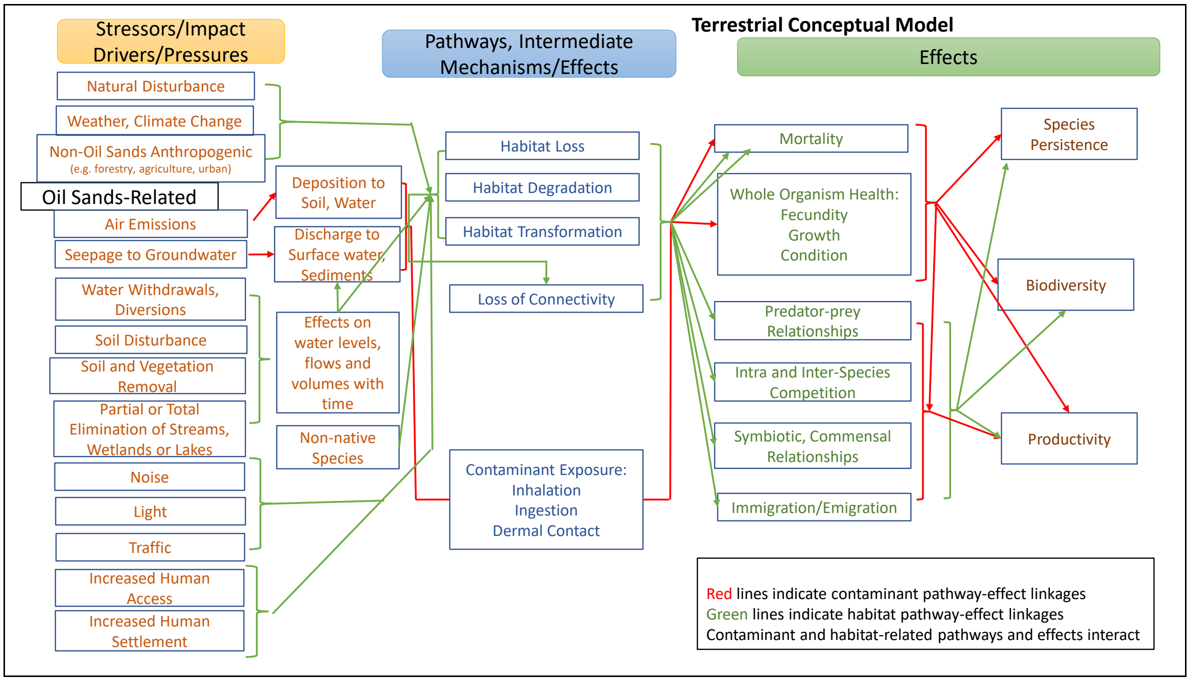


Figure 1. Terrestrial Conceptual Model Showing Linkages Among Stressors, Pathways and Effects

The top 6 uncertainties for Terrestrial Biological Monitoring are (in order of the number of votes received):

1. Quality, quantity, safety and availability of traditional resources
2. The levels of uncertainty related to predicted and observed effects on terrestrial biota, including rare species

3. The spatial and temporal scales required to define conditions and allow removal of ‘footprint’
4. State, trend and cause-effect relationships for mammal and plant communities
5. Effects of atmospheric deposition
6. Knowledge held by Indigenous communities

The complete list of uncertainties is presented in Appendix 2.

A conceptual model of stressor-pathway-effect linkages assisted in the identification of uncertainties.

Six key uncertainties were identified by workshop participants.

The key uncertainties determine “where we need to go”.

“How Are We Going to Get There?”

The six key uncertainties provide a “road map” for the Terrestrial Biological Monitoring component of the OSM Program. Every key uncertainty requires a set of key questions to be answered, just as in order to use a road map, we need to know our destination.

The key uncertainties provide a road map for future monitoring.

The key questions provide the destinations for the road map.

Workshop participants developed key questions for each of the six key uncertainties. These key questions are the starting point of monitoring design.

There was insufficient time for participants to produce other required elements of monitoring design. The required elements are provided in the Conceptual Framework for the OSM Program and are illustrated in Figure 2.

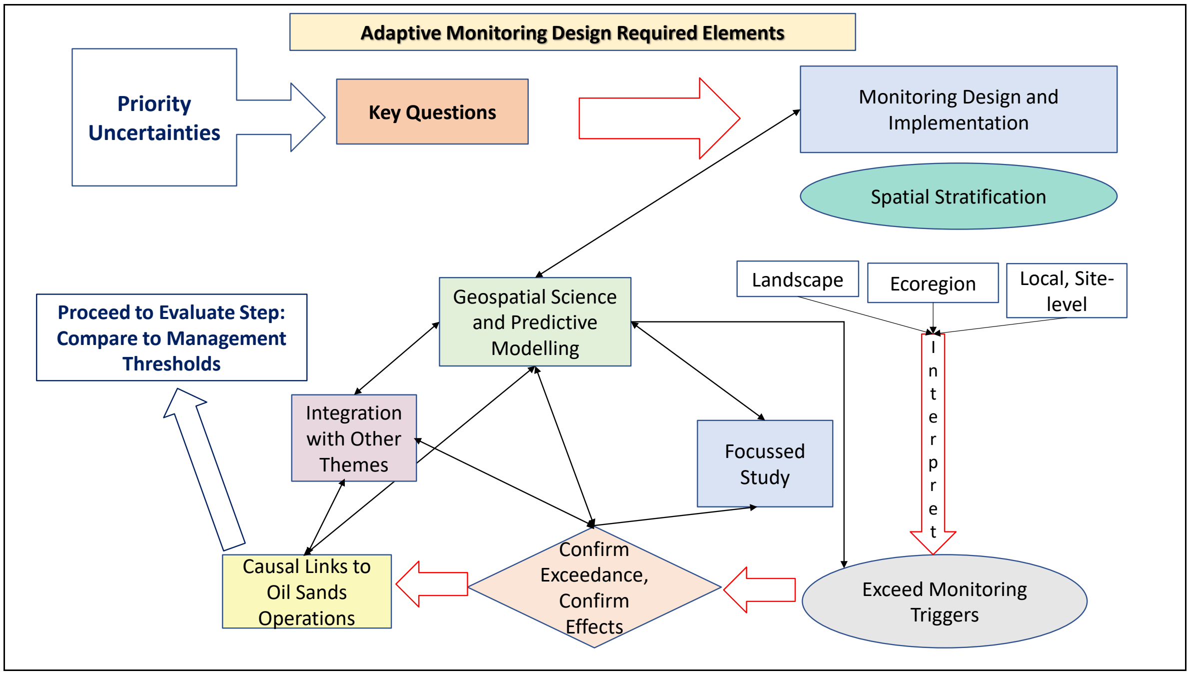


Figure 2. The Required Elements of the OSM Program Adaptive Monitoring Design.

The Key Questions associated with each of the key uncertainties are indented under each uncertainty below.

1. *Quality, quantity, safety and availability of traditional resources*
   - What species should we focus on?
   - How do we build trust in communities?
   - Do studies need to be done more regionally, reflecting concerns of several communities? Or should we work with individual communities?
   - Are we monitoring an appropriate range of spatial scales to answer communities' questions?
2. *Levels of uncertainty related to predicted versus observed effects on terrestrial biota including rare species*
   - Comparisons between observed vs predicted effects are required.
   - Measured effects must be accompanied by a stipulated level of acceptable uncertainty.

- Priority pathways for understanding effects on receptor species need to be identified (some taxonomic groups have less developed understanding)
- Is the current approach for setting priorities sufficient to predict future states? What approaches are needed to address this?

3. *What spatial and temporal scales are required to define conditions and allow removal of "footprint"*
    - Which species are the most sensitive to habitat fragmentation? (include habitat fragmentation from in situ oil sands operations)
    - What is the rate of spatial change in conditions which affect caribou populations and how much of this change is due to oil sands activities?
    - How do oil sands-related effects on terrestrial biota compare to effects from other anthropogenic stressors (at specific spatial or temporal scales)?
4. *State, trend, cause-effect relationships for mammal and plant communities.*
    - NOTE: the workshop notes did not contain recognizable key questions.
5. *Effects of atmospheric deposition*
    - What are the levels of mercury in foods consumed by Indigenous people?
    - What are the effects of enhanced nitrogen deposition on vegetation communities?

A set of key questions was developed by workshop participants for each key uncertainty.

Sets of key questions for each of the six key uncertainties are presented in the adjacent text.

For the most part, the key uncertainties identified by the Terrestrial Biological Monitoring workshop were quite broad. Thus, the key questions were not always specific enough to provide clear direction to the design.

More work on key questions is required. Ideally, key questions can support the development of hypotheses about the effects of oil sands-related stressors.

- What are the effects of sulphur deposition on vegetation communities?

6. *Knowledge held by Indigenous communities*
    - **Questions must be developed via engagement with communities**
        - Require integration of community knowledge and knowledge generated by others
        - Need to formalize entry point for people who want to work with communities and also need communication protocols
        - Opportunity to incorporate community based monitoring

Examples of more specific questions related to the uncertainty regarding effects of atmospheric deposition:

Does nitrogen and base cation deposition in wetlands within the local study area exceed monitoring triggers developed to indicate spatial and temporal change relative to baseline?

Is there a consistent relationship between nitrogen and base cation deposition and primary productivity of wetlands in the local study area?

Parking Lot

The following topics are important but could not be addressed during the Workshop. Some of these issues pertain to later stages of the adaptive management cycle. Others could be considered during the work planning process.

- Public information which is readily available and accessible
- Connections between monitoring results and policy or management decisions
- Trust of society
- The lack of environmental guidelines or objectives for many contaminants and/or environmental media
- Mechanisms to encourage integration and collaboration
- Lack of knowledge among scientists about the oil sands industry
- Effective collaboration with Indigenous communities

Groundwater Workshop

"Where are We": Current Status of Groundwater Monitoring

There was general agreement among workshop participants that groundwater monitoring under the OSM Program is in the formative stage. Available groundwater data for the oil sands region were not collected to address the specific objectives of the OSM Program. Data are from several sources including compliance monitoring conducted by industry, provincial groundwater monitoring networks, and federal groundwater investigations which focused on specific priority assessment and method development.

There was a strong consensus among participants that access to all relevant groundwater data is a key requirement, followed by a synthesis report. The synthesis report would provide a review of the current knowledge of groundwater in the oil sands regions in the context of OSM Program objectives. This report would form the basis for further planning of groundwater monitoring under the OSM Program.

Groundwater monitoring under the OSM Program is in the formative stage. Most of the existing data were not collected to address OSM objectives.

Access to and synthesis of relevant groundwater data were identified as keys to further planning of groundwater monitoring under OSM.

Local-scale monitoring has shown changes in ground water level and water quality.

There are several knowledge gaps preventing us from understanding oil sands-related effects on groundwater at the sub-regional and regional scales.

Accumulated Environmental Condition or State

Prediction of future effects on groundwater in reclaimed areas of oil sands regions requires further work and validation.

Groundwater modelling efforts have been substantial but have not been coordinated and validation is rare.

Alignment between agencies with respect to coordinated development of groundwater monitoring is an important issue, particularly with respect to avoidance of duplication and ensuring alignment with OSM Program objectives

Compliance monitoring done by industry provides local-scale data. In addition, there have been some specific local-scale studies; e.g. on seepage from a tailings facility. There was general agreement that local-scale (primarily on-site) effects are understood, both in terms of groundwater quantity and quality, at least in terms of compliance with permit requirements. For example, changes in water levels and increases in chloride levels have been observed.

Identified knowledge gaps included: pathways connecting local groundwater systems to regional systems; pathways from shallow versus deep groundwater to the surface environment; sub-regional and regional baseline data, understanding discharge and recharge zones; and future effects on groundwater systems in reclaimed areas.

There has been a substantial modelling effort dedicated to groundwater in support of environmental assessments (EAs), government policy and planning or academic research. However, there has been little collaboration and sharing of results. Validation of model predictions made in EAs is rare, particularly beyond the site scale.

Alignment between agencies with respect to coordinated development of groundwater monitoring frameworks was raised as an important issue, particularly given the effort and expense required for groundwater monitoring. In particular, participants noted that work being done under the Lower Athabasca Regional Plan (LARP) and work to be done under the OSM Program should be aligned to ensure that duplication is avoided, priority monitoring questions for the OSM Program are identified and distinguished from those addressed under the LARP, and both programs are optimized to address their respective objectives.

"*We are having a hard time with this exercise, which is instructive*" – Workshop Participant

Oil Sands-Related Stressor-Response Relationships

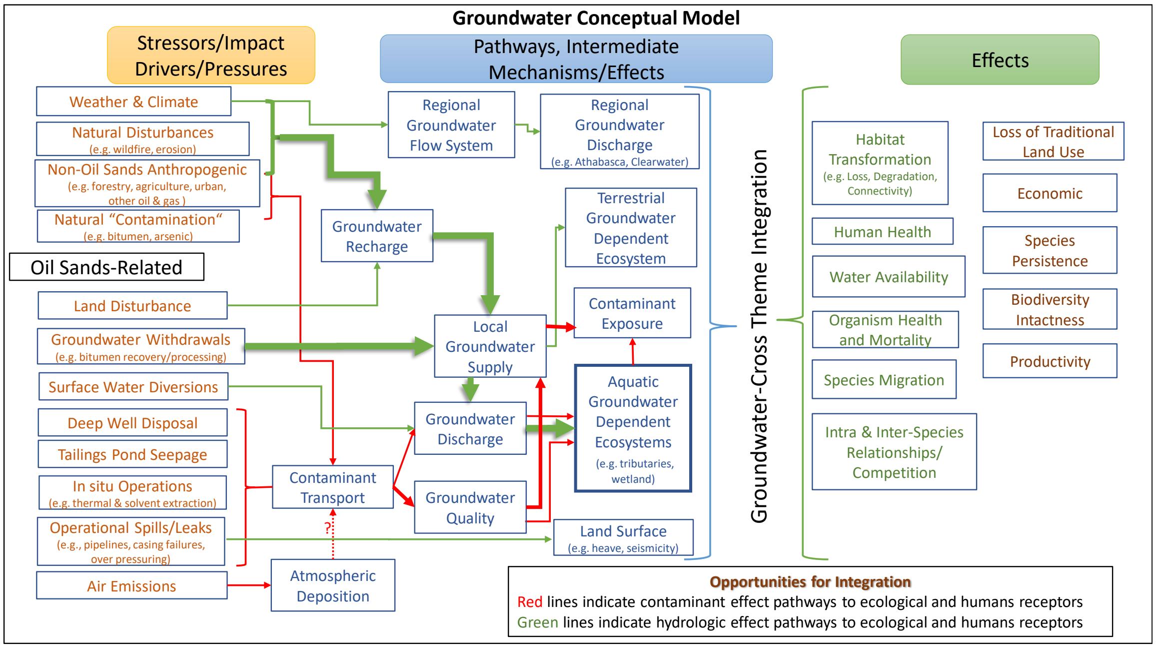


Figure 3. The Groundwater Conceptual Model Showing Linkages Among Stressors, Pathways and Effects

The Conceptual Model for groundwater (Figure 3) served as a tool for examining stressor-pathway-effects linkages and the current state of knowledge regarding those linkages.

There was broad consensus that linkages between stressors and effects on groundwater resources are not well characterized, particularly beyond the local (site) scale. For example, the effects of oil sands-related land disturbance on groundwater recharge at the sub-regional or regional scale are poorly understood. Effects that have been detected or predicted, e.g., changes in groundwater levels outside of project footprints, have not been investigated or validated in a systematic manner. It was noted by some participants that there are tools which allow discrimination of oil sands-related stressors (e.g. "fingerprinting" of oil sands-affected process water).

Stressor-response relationships are not well characterized, particularly beyond the site/local scale.

The lack of baseline data and/or the lack of access to relevant, synthesized baseline data limits the ability to discriminate among oil sands-related, natural, climate change-related, and other anthropogenic stressors.

The lack of sufficient baseline data and/or lack of access to relevant, synthesized baseline data limits the ability to discriminate the effects of oil sands-related, natural, and other anthropogenic stressors. At local scales, it is difficult to distinguish between oil sands and urban development effects. Participants noted that it will be increasingly important to factor climate change into assessments of current and future effects.

Cumulative Effects

There was consensus that knowledge of cumulative effects beyond the local scale is very limited and that integration with other OSM Themes will be required to increase this knowledge. Although it was recognized that regulatory permits stipulate that there be no discharges to groundwater by oil sands operations, participants noted that releases due to seepage, landscape disturbance, spills and other malfunctions should be considered.

Knowledge of cumulative effects on groundwater beyond the local scale is very limited.

Integration with other OSM Themes will be required for meaningful cumulative effects assessment.

Indigenous knowledge can play an important role in understanding cumulative effects and should be integrated with western science

There may be a better opportunity in the shorter-term for understanding cumulative effects on groundwater quantity rather than quality.

Production of cumulative risk maps was suggested as a starting point. These maps would be developed using our existing understanding of sources and pathways and the relative vulnerability of the groundwater resources (both shallow and deep). The maps could include explicit recognition of uncertainty.

The important role that Indigenous knowledge can play in the assessment of cumulative effects was highlighted by workshop participants. This knowledge can be applied at various spatial and temporal scales. It was noted that incorporation of Indigenous knowledge has not been sufficient.

Some participants suggested that there is a better opportunity for understanding cumulative effects on groundwater quantity rather than quality because changes in quantity are easier to detect in the short-term and EAs may include more baseline data. An effective regional program would be required to determine if effects are local only and are due to oil sands operations. Consideration of timescale would also be important; i.e., during active oil sands operations versus post-closure.

“Where Do We Need to Go?”: Prioritization by Identification of Key Uncertainties

Key uncertainties were identified, aided by the Conceptual Model (Figure 3). The identified uncertainties were then short-listed by workshop participants, using a set of prioritization criteria. A final list of the top 5 key uncertainties was determined through a voting process.

The complete list of uncertainties is presented in Appendix 2.

The top 5 uncertainties for Groundwater are (in order of the number of votes received):

1. Baseline and range of variability for groundwater quality and quantity
2. The location of critical groundwater-dependent ecosystems, groundwater/surface water interaction rates and mass flux.
3. Hydrogeological Conceptual Model
4. Effects of climate change on groundwater quantity and quality
5. Reclamation success.

Break-out groups identified and then short-listed key uncertainties associated with knowledge of stressors, pathways and effects on groundwater resources.

“How Are We Going to Get There?”

The Key Questions associated with each of the key uncertainties are indented under each uncertainty below.

1. Baseline and range of variability for groundwater quality and quantity

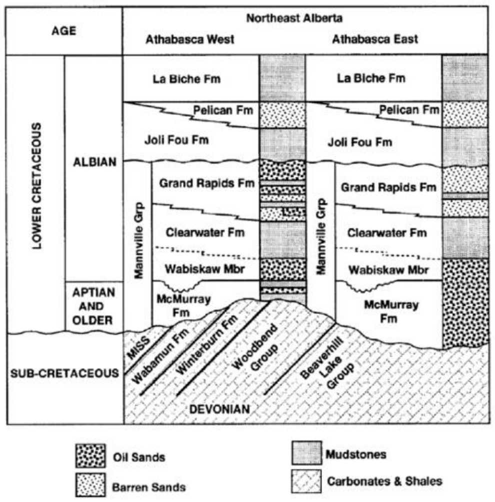
- What is the natural range of variability?
- Where would we expect to see water balance changes?
- How do monitored changes compare to model predictions?
- What is a suitable control or reference area?

- Can proxy data be used to help understand past conditions?

2. *Location of critical groundwater-dependent ecosystems, as well as groundwater/surface water interaction rates and mass flux*.

Key Questions associated with each Key Uncertainty are presented in the text.

- Where are the groundwater dependent ecosystems (GDEs)?
- Which ecosystems would be impacted most seriously by changes in groundwater quantity and quality? Which are most sensitive?
    - NOTE: Indigenous communities will have different answers to this question
    - A risk map might be the place to start



- How and to what extent does groundwater influence fens?
    - Chemistry? Water levels and timing?
- Has industry altered the rate of Devonian water discharge into the Athabasca River?
    - What is "critical"; i.e. high consequences to water balance?
    - Tributaries must be considered in definition of "critical"

3. *Hydrogeologial Conceptual Model*

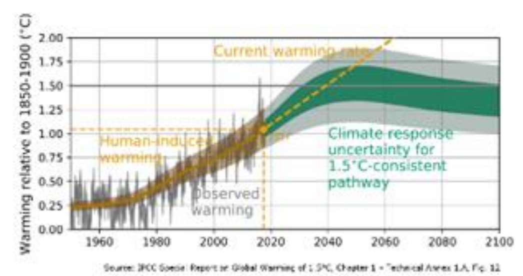
NOTE: Key Uncertainty #3 is more of a general requirement rather than an uncertainty. The following presents the thoughts of the break-out group regarding requirements for construction of the Conceptual Model

- Must understand the geology – need to establish sufficient level of confidence in the knowledge of the geological setting at the appropriate spatial scale for OSM
- Agreement that there are sufficient data spatially distributed to give a good picture of the hydrogeological framework

- Model would be for a disturbed landscape
- Focus should be shallow groundwater because ultimately, it's the shallower systems that concern the communities and affect ecosystems.
- In order to construct the model, knowledge of geology, geochemistry, fluid flow, flow patterns, recharge and discharge is required
- Clarity regarding stressors will be required
- The boundary condition for the model must be determined; e.g. groundwater divides
- The model can inform monitoring
- The model should be divided into mining and in situ
- Uncertainties include: water level or geochemistry data, sufficient identification of flow paths for a regional monitoring system and influence of surface water on groundwater.
- Could modelling done by oil sands operators be scaled up spatially and temporally?

4. *Effects of climate change on groundwater quantity and quality*

<u>Modelling</u>:



Source: IPCC Special Report on Global Warming of 1.5°C, Chapter 1 – Technical Annex 1.A, Fig. 12

- Do the time scales used in current climate change models predict changes in the oil sands region?
- Can predictive modelling be used to test the resiliency of reclamation scenarios given potential climate change impacts on groundwater flows?
- How does climate change affect the overall water balance in the oil sands region? Do climate models predict increased or decreased precipitation flux and groundwater discharge?
- How are changes in climate affecting location, timing, chemistry of groundwater systems?
- Does loading of salts change over time due to climate change?
- How would the impact of climate change on vegetation affect groundwater?

    - Compare existing vegetation with 50 year out reclamation plan
    - What should be measured on the ground to calibrate and verify models? (what is measurable – recharge isn't measurable)
    - NOTE: see the most recent EIA to check predictions made.

Spatial Trends:

- How far-reaching are climate-change related effects on groundwater systems? Do we see trends in water level change in a range of different locations inside and outside of the oil sands region and do those trends show a relationship with climate change?
- Can the effects of groundwater withdrawals be distinguished from climate change and at which spatial scale?

Addressing the key questions about reclamation success will require integration with other OSM themes.

Groundwater-Dependent Ecosystems:

- Where would we expect to see changes in water levels due to climate change?
- Would climate change cause effects on water temperatures in streams/wetlands with significant proportion of inflow coming from groundwater?

5. *Reclamation Success*

- Does the local reclaimed system fit with the surrounding system?
    - Key parameters include: interaction with regional system; interaction with GDEs; flow system; and, water quality.
- Is different monitoring required to understand sub-regional success vs local success (on lease)?

Parking Lot

The following topics are important but could not be addressed during the Workshop. Some of these issues pertain to later stages of the adaptive management cycle. Others could be considered during the work planning process.

- Mechanisms for moving information among agencies and industry
- Public information which is readily available and accessible
- Better use of groundwater data from all sources
- Demonstrate that management of impacts on groundwater is happening
- Standards for data quality
- Standard methods
- Trust of society
- Connections among groundwater management frameworks

Surface Water and Aquatic Biology Workshop

“Where are We”: Current Status of Surface Water and Aquatic Biology Monitoring

Accumulated Environmental Condition or State

Surface water and aquatic biology technical and synthesis reports (Workshop Information Package sub-folder in the Surface Water and Aquatic Biology folder https://albertagov.box.com/s/vdcrdzu7o750o7cctrceu8pdwmodq3wa) provided a valuable source of information regarding the current knowledge about the condition of water quantity, quality and aquatic biota in the oil sands region. These reports were provided in the pre-workshop information package. Key results from these reports are summarized below, supplemented by discussion during the workshop.

Recent reports on surface water quality, aquatic biota, and water quantity (hydrology) provided the basis for discussion of accumulated condition or state of the aquatic environment.

Most available surface water and aquatic biology data are from oil sands mining areas. There is very limited information from in situ oil sands production areas.

Workshop participants noted that most of the available surface water and aquatic biology monitoring data are from oil sands mining areas, with few data from in situ production areas. Therefore, the accumulated condition or state relative to stressor sources from in situ operations is largely unknown.

There are consistent flow-related seasonal water quality patterns in the lower Athabasca River that are caused either by dilution during high flows or association with suspended sediments. These patterns are not oil sands-related, although oil sands development is one source of chemicals measured in the river water. Dissolved constituents (such as metals) typically have maximum concentrations during low flow, under ice. Constituents associated with high suspended sediment have higher concentrations during high flow. Water quality guideline exceedances are associated with high flow and are frequently observed for aluminum, copper, iron and total suspended solids. Pyrene is the only polyaromatic compound (PAC) that occasionally exceeds guidelines. PACs are associated with natural bitumen deposits as well as with oil sands operations.

There is a spatial pattern of increasing concentrations (amount in a certain volume) and loads (amount per a period of time) upstream versus downstream in the Athabasca mainstem for total vanadium, dissolved selenium and dissolved arsenic. It is unknown if this is a global pattern for rivers of this region.

There is a temporal pattern of increasing concentrations of some dissolved and total metals in the Athabasca mainstem. Total phosphorus also showed an increased downstream of Fort McMurray, but this increase has levelled off over the last 15 years with improved Fort McMurray sewage treatment.

Historic and current water flows are highly variable and predicted future variability is predicted to be strongly affected by climate variability and change. Mean annual flow is predicted to increase with an overall shift to increased winter flow, earlier freshet and decreased summer flow.

Seasonal water quality patterns are related to water flow. Water quality guideline exceedances occur during high flow for elements typically associated with suspended sediment.

Some metals are higher downstream vs upstream in lower Athabasca River but it is not known whether this is a global pattern for rivers in the region.

There is a temporal pattern of increasing concentrations of some dissolved and total metals in the Athabasca River. Past increases in total phosphorus levelled off after improved Fort McMurray sewage treatment

Modelling of the Muskeg River Basin has shown that flows respond differently to climate and land cover changes. Flows decrease in response to land cover changes (because of changes in evapotranspiration) and increase in response to climate change (wetter and warmer conditions). In the near future, land cover change may play a much larger role than climate change, except for spring runoff which is affected by development on other tributaries in the region.

Modelling of the Muskeg River Basin indicates that flows respond differently to climate and land cover change.

Hypothetical increased chemical inflows from tributaries had decreased contribution to mainstream water quality with distance downstream.

Modelling indicates that the concentration of chemical constituents from all sources (natural and anthropogenic) in the bed sediments is the major factor in determining the state and variation of their concentration in the water column. Floodplain, back channels, and islands were the major areas where sediments were deposited. High flows transported the majority of sediment.

Hypothetical increased chemical inflows from tributaries were modelled and showed a decrease in the effect of tributary inflow contribution to the mainstem water quality with distance downstream due to dilution and mixing. Sediment entrapment (including sediment containing bitumen) within cobbles on the streambeds was found to be the main form of sediment and contaminant removal from the water column.

Models were unable to account for the highly dynamic processes and bed disturbances that occur during ice breakup with subsequent changes to sediment and contaminant dynamics. Assessments indicate that ice-jam releases and the resulting energy waves in the water generate extreme erosive forces and suspended sediment concentrations. Spring breakup generates the highest total suspended solids loads for the year.

Spring breakup generates the highest suspended sediment loads.

Benthic invertebrate communities show mild environmental stress at sites within oil sands development footprints.

The current status of benthic invertebrate communities and fish health in tributaries shows a difference between sites within oil sands development footprints and reference sites; however, the effects of natural bitumen deposits cannot be distinguished from the effects of oil sands development. Benthic communities have characteristics which indicate mild environmental stress.

Benthic invertebrate communities show mild environmental stress at sites within oil sands development footprints.

Slimy sculpin had increased liver and decreased gonad size at sites within development footprints.

Laboratory exposure of fathead minnows to natural oil sands sediment resulted in non-lethal deformities, changes in social behaviour and poor egg production.

Benthic invertebrate communities in the mainstem have a greater proportion of tolerant taxa.

Fish health condition in the mainstem Athabasca River has been indicative of nutrient enrichment.

Slimy sculpin (a small-bodied fish species) show increased liver and decreased gonad size – responses associated with exposure to contaminants (particularly PACS). Laboratory exposure of fathead minnows to natural oil sands sediment from the Steepbank and Ells Rivers was associated with some non-lethal deformities and changes to social behaviour and poor egg production. Exposure to undiluted melted snow from site near oil sands mines decreased larval fish survival, but exposure to spring runoff water did not affect survival. This shows that dilution may be sufficient to limit impacts to fish.

Benthic invertebrate communities in the mainstem Athabasca River showed increases in the relative number of tolerant taxa, both in the area affected by Fort McMurray sewage discharges and adjacent to oil sands developments. Historic benthic communities also had more tolerant species; however, this result may be an artifact of sampling methods used in the past.

The fish health response pattern in the mainstem Athabasca was indicative of nutrient enrichment. This pattern has declined with time, coincident with improved Fort McMurray sewage treatment.

Workshop participants identified several gaps in our current knowledge of condition and status of the aquatic environment in the oil sands region. There is an absence of information on lakes. There has been a strong focus on erosional habitats in both the mainstream Athabasca and in tributaries versus habitats where sediments are deposited (e.g. back channels and pools). Wetland monitoring information has not been integrated with the surface water information.

Some participants noted that elevated naphthenic acid concentrations have been observed at Beaver River and McLean Creek; however, impact on ecosystem health was limited and very localized.

Stressor-Response Relationships

Evidence is strong for benthic community response patterns associated with municipal discharges in the mainstem Athabasca. Benthic and fish health responses associated with the oil sands industry have not been established.

We cannot yet discriminate between natural bitumen and industry-related causes of observed benthic and fish health responses in tributaries.

Effects on physical habitat have not been a focus of monitoring to date.

The relative effect of changes in quantity and quality of habitat versus contaminant-related effects is unknown.

The strength of relationships between three primary stressor sources – municipal discharges, oil sands operations, and natural bitumen - and effects on benthic invertebrate communities and fish health in the mainstem Athabasca has been evaluated (Figures 4 and 5). There is strong evidence for the effect of nutrients released in municipal effluent, as shown by the ++ symbol in Figure 4. There are links between all three sources and water quality in the mainstem (the + symbols in Figure 4). Sediment quality reflects both natural bitumen and industry sources; however, discriminating between natural and industry effects on benthic and fish health is difficult.

Causes of observed responses to stressors in tributaries are still uncertain (Figure 5). Benthic invertebrate communities show evidence of mild environmental stress; however, the relative role of natural bitumen versus industry-related stressors in causing the observed decreases in sensitive taxa is still not clear. Similarly, increased liver size in slimy sculpin may be due to natural bitumen exposure, industry-related chemical releases, or both. Laboratory tests have shown that natural bitumen produces toxic responses in fish.

There was general agreement that more work is required on “fingerprinting” natural bitumen versus industry-related PACs. More integration with atmospheric deposition is required in order to more fully understand the relative role of deposition as a source (especially via snow melt). Integration with groundwater was also noted as a requirement, particularly with respect to groundwater/surface water interactions in tributaries.

Effects on physical habitat caused by water diversions, elimination of wetlands, ponds and lakes and portions of tributaries, and modifications to stream channels have not been a focus of past monitoring. Therefore, the relative effect of changes in quantity and quality of habitat versus contaminant-related effects is unknown.

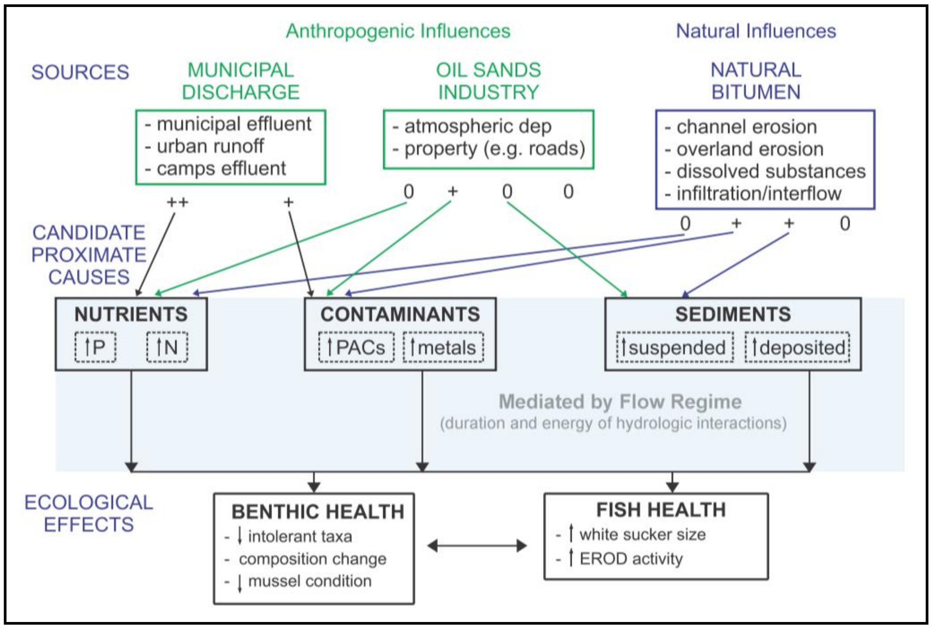


Figure 4 Stressor-Response Results to Date for the Athabasca River. (Culp et al. 2018. Water Data Synthesis report)

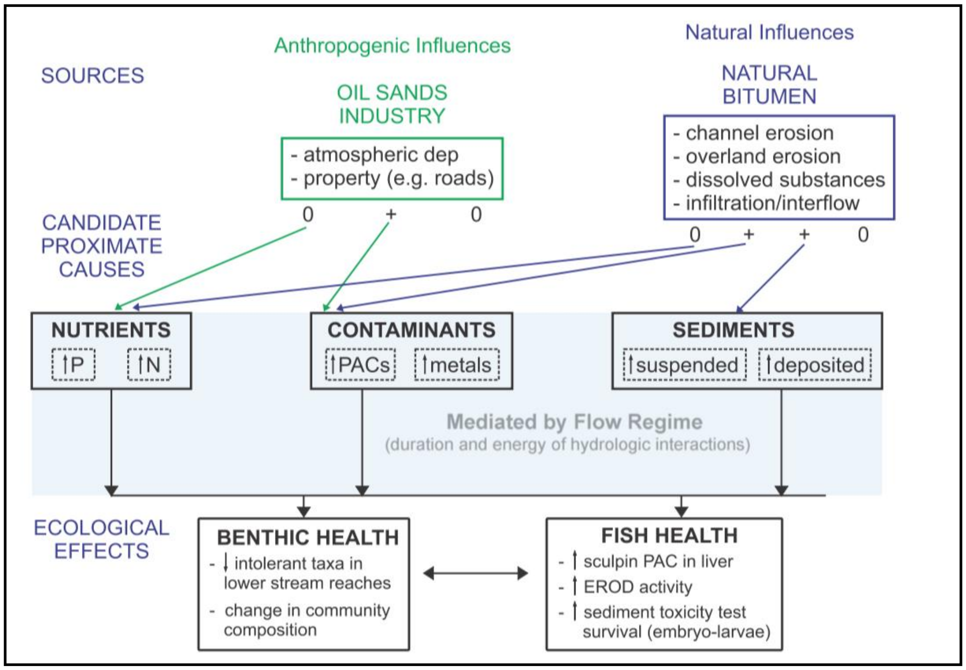


Figure 5 Stressor-Response Relationships Results to Date for Tributaries (Culp et al. 2018. Water Data Synthesis Report)

Cumulative Effects

Nutrient-contaminant interactions are possible below Fort McMurray where municipal sewage effluent and oil sands-related exposure occurs; however, these interactions have not been investigated in detail. Interpretation of cumulative effects in tributaries is confounded by natural bitumen exposure.

Some participants called attention to the importance of work in the Peace Athabasca Delta because of the potential cumulative effects of downstream transport of contaminants combined with substantial hydrologic changes caused by the WAC Bennett dam.

Assessment of the combined effects of fish habitat changes due to land disturbance, changes in groundwater discharge patterns and flows, and natural disturbances such as fire require integration among OSM Themes.

Participants noted that there needs to be clarity regarding investigation of the cumulative effects of *multiple stressors* versus the assessment of cumulative effects of several sources of a *particular stressor* distributed over time and space. These two types of cumulative effects may both be important in the oil sands region.

It is possible that nutrients from sewage effluent and contaminants from oil sands interact to produce cumulative effects but this has not been investigated in detail.

Interpretation of cumulative effects in tributaries is confounded by natural bitumen exposure.

Participants noted the importance of assessment of cumulative effects in the Peace Athabasca Delta.

Assessment of cumulative effects on fish habitat requires integration among OSM Themes.

Where Do We Need to Go?”: Prioritization by Identification of Key Uncertainties

The Conceptual Model for Surface Water and Aquatic Biology (Figure 6) served as a tool for examining stressor-pathway-effects linkages and identifying uncertainties associated with those linkages.

The identified uncertainties were then short-listed by workshop participants, using a set of prioritization criteria. A final list of the top 6 key uncertainties was determined through a voting process.

The complete list of uncertainties is presented in Appendix 2.

Break-out groups identified and then short-listed key uncertainties associated with knowledge of stressors, pathways and effects on surface water and aquatic biota.

The top 6 uncertainties for Surface Water and Aquatic Biota are (in order of the number of votes received):

1. Separation of different anthropogenic and natural stressors (in situ, surface mining, natural bitumen, forestry, sewage discharges etc). Includes cumulative effects.
2. The amount of atmospheric deposition of contaminants which reaches the Athabasca watershed. Quantification of emissions and loading distributions.
3. Fate of oil sand organic and inorganic contaminants in downstream receiving habitats and food webs.
4. Lack of knowledge of higher order ecological effects
5. Unsure that the selection of measurement endpoints reflects community concerns and values
6. Indicators of natural versus anthropogenic change.

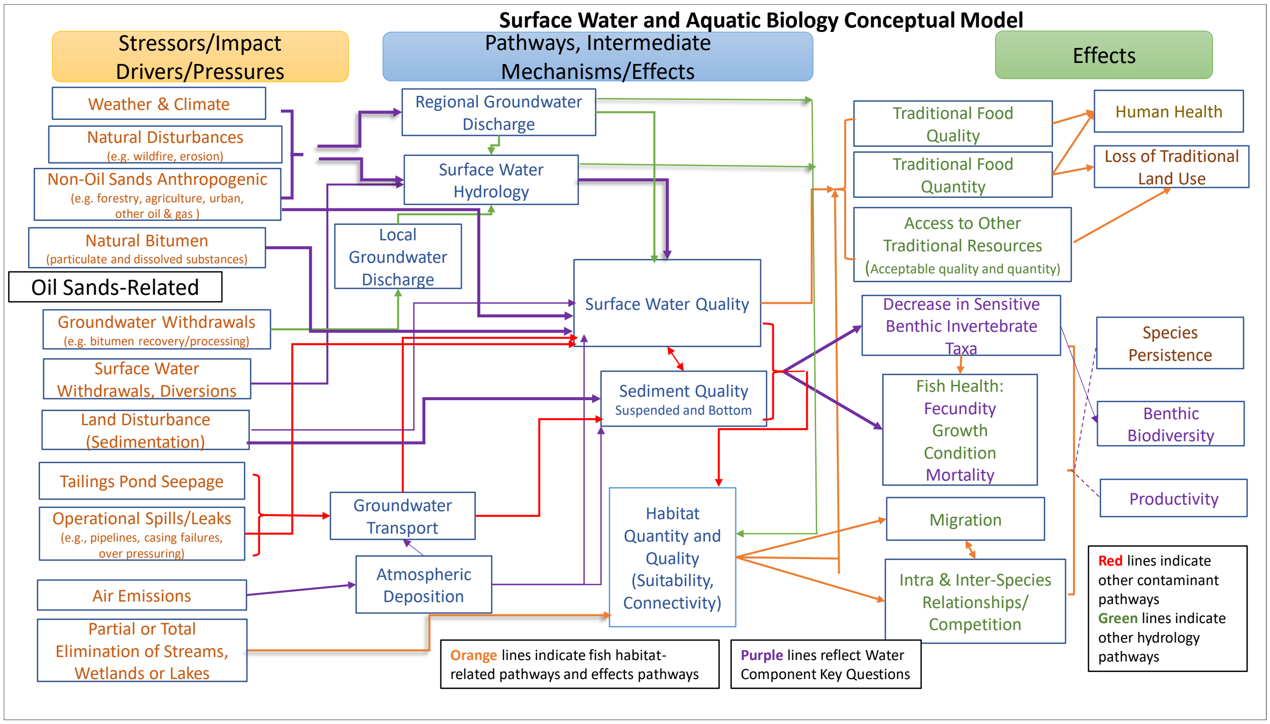


Figure 6 Surface Water and Aquatic Biology Conceptual Model

“How are We Going to Get There?”

Break-out groups were assigned one of the 6 key uncertainties and developed Key Questions for their assigned uncertainty. Some group developed hypotheses. The Key Questions and hypotheses are indented under each of the 6 key uncertainties below.

1. Separation of different anthropogenic and natural stressors

Null Hypotheses

i.- There are no observed differences in biological responses between different sites within a tributary (upstream, within, and downstream of the McMurray Formation and industrial development)

ii- There are no identifiable source inputs that could explain observed differences in biological responses within a tributary.

iiia- Isolated chemical mixtures from identified source

Key Questions associated with each Key Uncertainty are presented in the text. A Photo of Natural Bitumen is shown below.

Photo of Natural Bitumen

inputs of interest between sites in a tributary do not elicit responses in laboratory bioassays that are consistent with the original field observations.

iiib- Isolated chemical mixtures from identified source inputs of interest between sites in a tributary do not differ in chemical profile (qualitative and quantitative).

Photo of Laboratory Toxicity Testing

Key Questions

- What are the differences in contaminant signatures from upper reaches to lower reaches in tributaries (Firebag (reference) vs Steepbank)?
- What are the differences in source and loads of inputs among sites?
    - Groundwater and overland flow
    - Fugitive dust/ pet coke
    - Bank erosion
- What is the contribution of the source input differences to ecological effects?
    - Field observations
    - Toxicity tests (Effects Directed Analysis)
    - Interannual variation in key environmental drivers (e.g. flow)
    - Role of nutrient -contaminant interaction in modifying toxicity

Separation of natural and anthropogenic effects will require the use of both laboratory and field methods.

Differences in sources and loadings among sites need to be examined relative to observed responses.

What are the differences in contaminant signatures upstream to downstream in tributaries?

What is the role of nutrient-contaminant interaction in modifying toxicity?

NOTE: This break-out group recommended that a two-day workshop be held to develop focused studies on investigation of cause.

Remaining Issues:

- Gaps in field observations across tributaries – spatial extent
- Role of geology

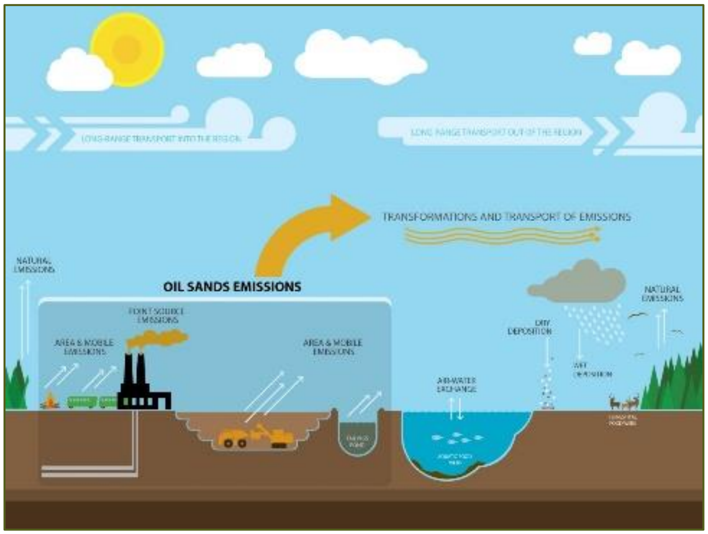
- Role and contributions of groundwater

2. *The amount of atmospheric deposition of contaminants which reaches the Athabasca watershed. Quantification of emissions and loading distributions.*

    - What is the temporal (seasonal, interannual) and spatial variability in contaminant “x” deposition across the landscape?
    - How does the type of land cover, topography, etc affect the mass of contaminant “x” deposited and accumulated?
    - What is the spatial and temporal variability in the hydrological connection between the depositional areas and regional waterbodies? What are the key drivers of spatial and temporal variability in the hydrological connection between depositional areas and the waterbody?
    - What is the fate of contaminant “x” once it is deposited to the landscape?
    - What proportion of contaminant “x”, once deposited, is delivered to the waterbody and how does this change seasonally, interannually and spatially?

How does the type of land cover, topography, etc, affect the mass of contaminants deposited and accumulated by biota?

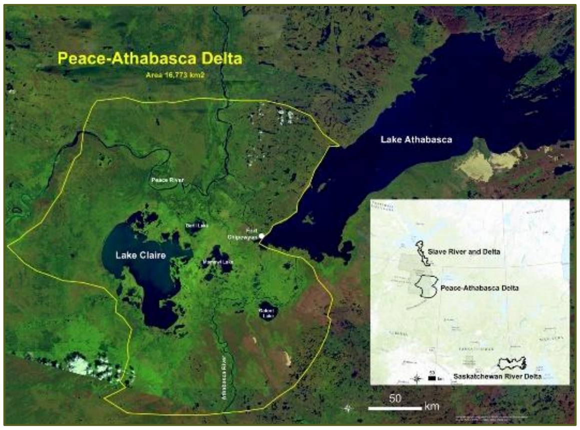
How do the connections between atmospheric deposition and surface water bodies vary spatially and temporally?



Atmospheric pathways to surface waters

NOTE: This break-out group recommended that a fully instrumented representative basin be established. The group also recommended that deposition monitoring be aligned with the National Atmospheric Deposition

3. *Fate of oil sands organic and inorganic contaminants in downstream receiving habitats and food webs.*



Null Hypothesis: oil sands inorganics and organic contaminants are not changing food webs in downstream receiving environments.

Approaches for addressing this hypothesis:

- Source attribution: spatial distribution of loads, mass balance, sediment finger printing, multi-variate statistics, chemical fingerprinting, isotope analysis
- Bioavailability in food web and uptake – tissue (plants) analysis, metal speciation, water chemistry, modelling tools, sediment chemistry, passive sampling
- Transport: high frequency turbidity data, suspended sediment sampling

Key Question: How does an altered food web impact bioaccumulation of contaminants (or vice versa)?

4. *Lack of knowledge of higher order ecological effects*

The Peace Athabasca Delta is the focus of concerns regarding downstream transport of contaminants and subsequent accumulation in food webs

What are the implications of current fish health results to populations of sensitive/valued fish species?

What are the impacts of oil sands development on aquatic habitat connectivity at large spatial scales?

- What are the impacts of oil sands development on aquatic habitat connectivity at large spatial scales?
- Focus on:

- How can we separate oil sands mining contribution from other development (forestry, urban etc)
- What are the implications to populations of sensitive/valued fish species?

- Require sufficient information to assess fish habitat quality, access and utilization at a large spatial scale

5. *Unsure that selection of measurement endpoints reflects community concerns and values.*

- What are the commonalities between existing OSM work and communities and how do you maximize exposure of OSM Programs in these communities in response to community needs?
- Can the existing OSM projects integrate with community-based monitoring?
    - Gaps:
        - Cold Lake area
        - Sites and indicators relevant to communities
    - Confirm that endpoints are relevant to communities
- What are some effective approaches to building capacity in the communities?
    - “Capacity can’t be bought, it must be built”

6. *Indicators of natural versus anthropogenic change?*

- Which indicators can be extrapolated from individual to population level?
- What indicators would show a response to natural and anthropogenic stressors? What focussed research is required to identify indicators of most utility with respect to distinguishing natural and anthropogenic stressors?
- What environmental markers can be used to identify the downstream Fort McMurray effects in order to allow for unconfounded assessment of oil sands activities on the mainstem Athabasca River?

Can existing OSM projects integrate with community based monitoring? Can alignment be achieved with respect to sites and indicators?

What are some effective approaches to building capacity in Indigenous communities?

Which indicators can be extrapolated from individual to population level effects?

What focused research is required to identify indicators of most utility with respect to distinguishing natural and anthropogenic stressors?

Parking Lot

The following topics are important but could not be addressed during the Workshop. Some of these issues pertain to later stages of the adaptive management cycle. Others could be considered during the work planning process.

- Need greater clarity on stressors – sources as well as linkages
- Communication of results in accessible language so there can be effective dialogue with communities
- Relationship between monitoring and management action
- Logistical challenges of getting people together so they can integrate their efforts
- The need to include Cold Lake and Peace regions\

Atmospheric Deposition Workshop

"Where are We": Current Status of Atmospheric Deposition Monitoring

Accumulated Environmental Condition or State

The summary of accumulated environmental condition or state provided in the following paragraphs is from the report "Summary, Evaluation and Integration of Atmospheric Deposition Monitoring in the Athabasca Oil Sands Region" (2018), which was provided to workshop participants in the pre-workshop information package (https://albertagov.box.com/s/vdcrdzu7o750o7cctrceu8pdwmodq3wa).

In general, atmospheric deposition is enhanced within ~10-100 km of surface oil sands mining depending upon the chemical of concern.

Total sulphur deposition is dominated by dry and wet sulphur dioxide. Total nitrogen deposition is poorly understood. Acidification of streams and lakes caused by sulphur and nitrogen deposition has not been observed except in some streams during spring freshet.

In general, monitoring and modelling of atmospheric deposition has indicated that deposition is enhanced within ~10-100 km of surface mining depending upon the chemical of concern. Sulphur and PAC deposition is well understood with significant monitoring and generally consistent findings. Deposition of nitrogen compounds, base cations and trace elements is poorly understood because of little or incomplete monitoring but findings have been generally consistent. Methyl mercury deposition is very poorly understood with a limited number of contradicting studies.

Total sulphur deposition (<100 km from oil sands operations) is dominated by dry and wet sulphur dioxide. There is a good understanding of seasonal patterns. Total nitrogen deposition is poorly understood in part because of the large number of reactive nitrogen species and confounding processes. There is still a limited understanding of key components of total nitrogen deposition including wet deposition, bi-directional ammonia exchange and contribution of other nitrogen species. Acidification of streams and lakes caused by the deposition of sulphur and nitrogen compounds has not been observed except in some streams during spring freshet. Some model simulations predict acidification, but these predictions have not been verified by field data.

Base cation deposition may be causing alkalization in shallow lakes within 50 km of oil sands operations and may be neutralizing acidifying deposition.

Increased nutrient concentrations in forests and wetlands have been observed within 50 km of oil sands operations.

Base cation (calcium, magnesium, sodium and potassium) deposition is poorly understood because of the lack of measurement needed to calculate dry deposition. There is some evidence of alkalization (increase in pH) in shallow lakes less than 50 km from oil sands operations because of deposition of base cations. There is evidence that base cation deposition is neutralizing acidifying deposition near oil sands facilities. Effects of alkalization on vegetation are uncertain.

Total mercury deposition is poorly understood and contribution of oil sands operations to mercury deposition beyond ~30 km might be small.

Total mercury deposition is poorly understood. The contribution of oil sands operations to mercury deposition beyond ~30 km might be small. Mercury deposition decreases exponentially with distance from oil sands sources up to ~80 km. Mercury and methyl mercury in snow packs are predominantly bound to particles, which likely explains the higher deposition closer to oil sands operations. Mercury concentrations in the Athabasca River near oil sands development and in tributaries affected by land disturbance are higher than upstream. Higher mercury concentrations are also found near the Athabasca Delta and Lake Athabasca; however, sediment cores collected in the Delta show that mercury concentrations have been declining since the beginning of oil sands development. Mercury concentrations in sediments in lakes are low and there is no spatial pattern relative to proximity to oil sands operations. Mercury concentrations in lichens in the are similar to those in background locations. More information on the implications of observed mercury concentrations will be available from the Mercury Workshop (see below).

Mercury concentrations in the Athabasca River near oil sands development and in tributaries affected by land disturbance are higher than upstream.

Deposition of most trace elements decreases exponentially with distance from oil sands sources. Trace elements are occasionally above guidelines for soil, and water but effects on aquatic or terrestrial biota have not been reported.

Total trace element deposition is poorly understood. The deposition of most of the trace elements decreases exponentially with distance from oil sands sources up to ~85 km.. However, there are some elements (e.g. cadmium and chromium) with no spatial gradients in deposition, which suggests the impact of local and regional sources rather than oil sands development. Trace elements are occasionally above guidelines for soil, snowmelt and water. Actual effects from these concentrations on aquatic or terrestrial biota have not been reported.

PAC deposition declines exponentially with distance.

PAC deposition is higher near major oil sands developments and declines exponentially with distance because most PACS are bound to particles that deposit near emissions sources. Alkylated PACs are the dominant PAC species in snow packs within 50 km of oil sands operations. The highest deposition to snow packs has been observed over the Athabasca River between the Muskeg and Steepbank Rivers where oil sands development is most intense. Higher deposition is also found along the north-south directions than east-west directions. Some parent polycyclic aromatic hydrocarbon (PAH) compounds exceed soil and sediment guidelines. There are no guidelines for alkylated PAHs or dibenzothiophenes (DBTs) which are predominantly associated with oil sands sources.

Enhanced concentrations of PACs have been observed in wolves, moose, caribou and birds. Negative effects have been observed in otters, although not at the population level. No negative effects were observed in the aquatic invertebrate *Daphnia* (water flea).

Workshop participants pointed out that:

- More monitoring and modelling for in situ production areas is needed
- More validation of model predictions is required; e.g. predicted acidification of lakes in the far-field
- More measurements along the entire spatial gradient from near-field to far-field are required
- Ammonia should be measured and monitored

Enhanced concentrations of PACs have been observed in wolves, moose, caribou and birds. Negative effects have been observed in otters but not in the aquatic invertebrate *Daphnia.*

- Deposition monitoring and modelling should be coordinated with biological monitoring
- Odour is a significant concern to communities
- There is a lot of underutilized (including older) data which could be valuable for trend detection
- Transport mechanisms and chemical transformations are significant sources of uncertainty
- There have been minimal links between deposition and human health
- Emissions inventory data needs to be linked with this Theme

Major gaps include monitoring and modelling for in situ production areas

Model predictions require validation (e.g. acidification of far-field lakes)

Odour is a significant concern to communities – should it be part of OSM?

An atmospheric deposition conceptual model (Figure 7) was used to support discussions of current state and condition as well as stressor-response relationships.

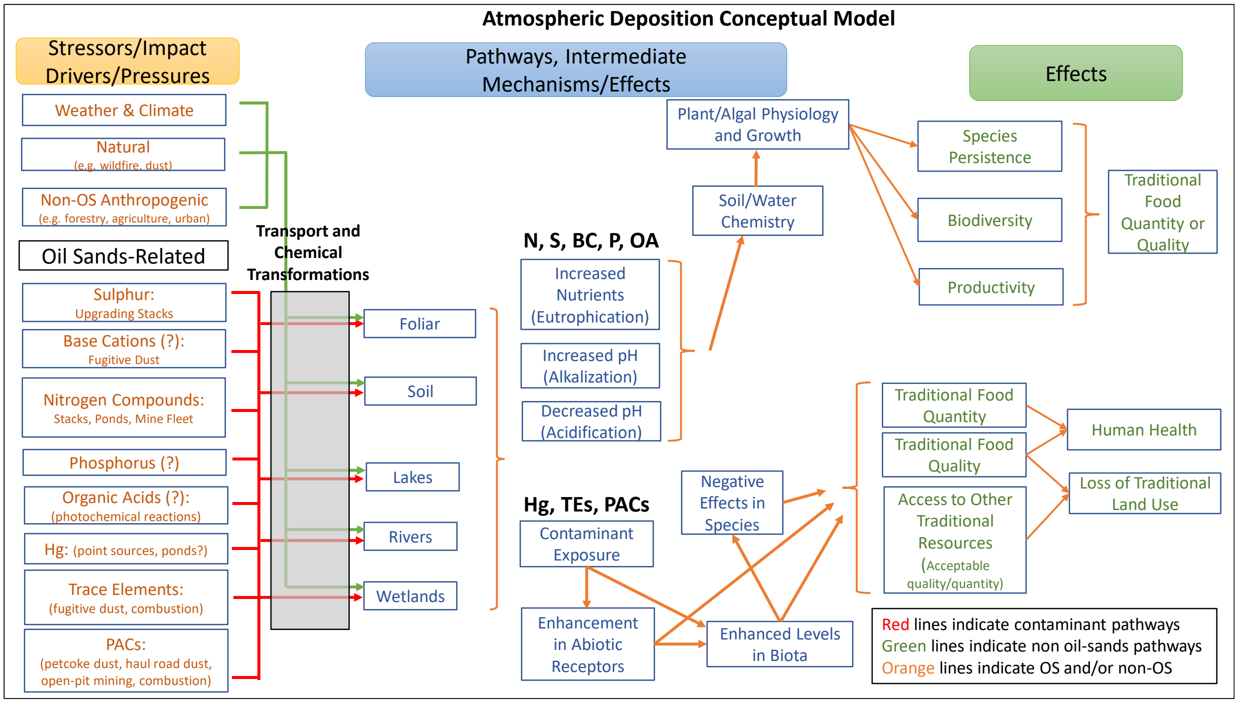


Figure 7 Conceptual Model for Atmospheric Deposition

Oil Sands-Related Stressor-Response Relationships

There is little evidence of widespread acidification due to nitrogen or sulphur deposition, likely because of the mitigating effect of concurrent base cation deposition.

Effects of base cation and nitrogen deposition on vegetation have been observed within ~50 km of oil sands operations

There is no evidence that enhanced nitrogen or phosphorus deposition has caused eutrophication.

Experimental applications of nitrogen to a sphagnum bog over 5 years resulted in inhibited nitrogen fixation at N application rates above 3 kg/ha/yr.

Sphagnum fuscum net primary production was inhibited after the first year of N application while dominant shrub and black spruce net primary production was stimulated.

As shrub growth and cover increased, Sphagnum abundance and net primary production decreased.

As noted above, there is little evidence of widespread acidification due to nitrogen or sulphur deposition, likely due to the mitigating effect from concurrent base cation deposition. Several studies have observed deposition of base cations exceeding the sum of acidifying pollutants within tens of kilometres of oil sands facilities.

There is evidence that base cation and nitrogen deposition within about 50 km of oil sands facilities are affecting terrestrial ecosystems. Observations include: (1) difference between soil microbial communities along the nitrogen + sulphur deposition gradient; (2) negative correlation between elevated nitrogen/sulphur/base cation deposition and moss/lichen cover and richness and (3) negative correlation between internode length and acidifying deposition.

There is no evidence that enhanced nitrogen or phosphorus deposition has caused eutrophication in aquatic ecosystems.

Dr. Kel Weider presented information on the effects of experimental application of nitrogen to a bog near Mariana Lakes, AB. Dr. Weider subsequently provided a manuscript (Weider et al. in press) which provided the information summarized below.

The applications were at rates of 0.5.10,15,20 and 25 kg N per ha per year plus controls. The applications occurred over five years. Nitrogen deposition near oil sands operations are up to 17 kg per ha per year. Regional background levels are less than 2 kg per ha per year.

Increasing experimental nitrogen addition stimulated nitrogen fixation at rates up to 3.1 kg per ha per year but then progressively inhibited nitrogen fixation above this level. *Sphagnum fuscum* net primary production (NPP) was inhibited after the first year while dominant shrub and black spruce NPP was stimulated with increasing abundance of shrub species and vascular plants in general. Increasing experimental nitrogen input led to a switch from new nitrogen being taken up primarily by *Sphagnum* to being taken up primarily by shrubs. As shrub growth and cover increase, *Sphagnum* abundance and NPP decrease. Weider et al. recommended a nitrogen deposition critical load of 3 kg N per ha per year because inhibition of nitrogen fixation caused by nitrogen deposition plays a key role in bog structural and functional responses.


Sphagnum Bog

Mercury in fish near oil sands development decreased from 1984-2011.

Mercury in fish collected in the Athabasca River near oil sands development decreased from 1984-2011. In Lake Athabasca, mercury in fish decreased or showed no trend. Mercury in fish from Nemur Lake near oil sands mining areas increased from 2000-2007 but the increase was similar to that at remote lakes elsewhere.

Mercury in waterbird eggs has increased and sometimes exceeds the threshold for reproductive effects.

Mercury concentrations in waterbird eggs in the Athabasca River downstream of oil sands development have increased compared to the year of earliest collection. These concentrations are unrelated to forest fire events and long range transport of mercury, suggesting that oil sands development or local sources of mercury are affecting egg mercury levels or there are other factors which create conditions leading leading to methylation of mercury (and thus uptake into eggs). Some egg samples exceeded the lower limit of the threshold for effects on reproduction.

Workshop participants observed that:

- Triggers, thresholds, or critical loads are often missing for contaminants; therefore, it is difficult to isolate; which contaminant is the cause of observed change

It can be difficult to isolate which stressor is the cause of an observed change.

Effects pathways (mechanisms) for some deposition indicators are unknown or poorly understood

Information on effects is biased to ecosystem types that have been highly studied

Collaboration with other disciplines will help ensure that deposition information matches the needs of effects-based studies.

- There is uncertainty with respect to effects pathways; e.g., how does altered soil chemistry affect forest growth?;
- Information on effects is biased to ecosystem types that have been highly studied (because they were assumed to be sensitive, rightly or wrongly);
- Atmospheric deposition scientists need to collaborate with other disciplines to ensure that deposition information is what is needed in order to understand effects on receptors;
- The spatial and temporal resolution of measurements must be commensurate with the scale of observed responses; and,
- Effects from concentrations of contaminants in biota have not been reported except for PACs in otters.

Cumulative Effects

Multiple stressor effects from the combination of deposited contaminants is a topic requiring further study.

Multiple stressor effects from the combination of deposited contaminants is a topic requiring further study. Additive, synergistic or antagonistic relationships can occur among multiple stressors. Antagonistic effects are apparent between acidifying deposition and base cation deposition where base cations neutralize the effects of acidifying compounds. Workshop participants noted that the benefits of such antagonistic effects may decline if in situ production increases and mining decreases, because the primary source of base cations is dust deposition. Some trace elements act in an additive manner while others may act synergistically to increase toxicity. Nutrient enrichment may increase methylation of mercury via stimulation of bacterial processes. On the other hand, nutrient enrichment may lead to “growth dilution” of mercury in fish.

The cumulative effects of deposition related to in situ operations has not received any significant attention in the OSM Program to date.

Workshop participants noted that the cumulative effects of in situ operations has not received any significant attention to date. While individual facilities may be small, the large number of them may produce significant cumulative effects.

The combined effects of atmospheric deposition plus climate change or landscape disturbance were raised as a potential issue requiring assessment in all oil sands regions.

"Where Do We Need to Go?": Prioritization by Identification of Key Uncertainties

The Conceptual Model for Atmospheric Deposition (Figure 6) served as a tool for examining stressor-pathway-effects linkages and identifying uncertainties associated with those linkages. The identified uncertainties were then short-listed by workshop participants, using a set of prioritization criteria. A final list of the top 6 key uncertainties was determined through a voting process.

Break-out groups identified and then short-listed uncertainties associated with atmospheric deposition.

The complete list of uncertainties is presented in Appendix 2.

The top 5 uncertainties for Atmospheric Deposition in order of priority were:

Five priority uncertainties were identified.

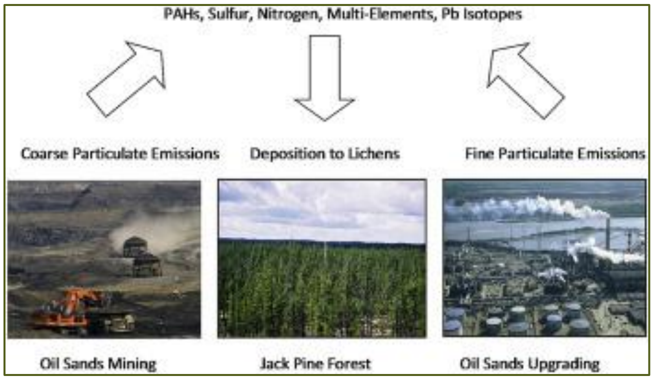
1. Fugitive dust sources and pathways for base cations, trace elements. Includes spatial uncertainty and seasonality. Includes large particle modelling.
2. Long-term deposition trends for those constituents of concern which are produced by oil sands. Includes timescale to effects and temporal variability.
3. Sources and deposition of total nitrogen, including spatial distribution and critical loads.
4. Source attribution – oil sands versus non-oil sands. Mercury and trace elements, others as needed (PACs)
5. Ecological impacts of base cations – multiple interacting stressors (base cations, nitrogen, sulphur)

"How Are We Going to Get There?"

Key Questions associated with each Key Uncertainty are presented in the text.

Break-out groups were assigned one of the 5 key uncertainties and developed Key Questions for their assigned uncertainty. Some group developed hypotheses. The Key Questions and hypotheses are indented under each of the 5 key uncertainties below.

1. *Fugitive dust sources and pathways for base cations, trace elements. Includes spatial uncertainty and seasonality. Includes large particle modelling.*



- What size fraction distribution dominates base cations? Where (distance and windspeed)?
- What is the speciation and size distribution of fugitive dust?
- What are the sources of fugitive dust and what is the magnitude and speciation of sources?

- What can vegetation data tell us about deposition of fugitive dust?
- What is the seasonal variability (e.g. with respect to snow)?
- What are the meteorological drivers for fugitive dust emissions? Vs mechanical sources. Wind-blown origin from pet coke?

Can aircraft and ground-based observations of fugitive dust be linked to source types?

What is the spatial distribution of fugitive dust and its components?

- Can the aircraft and ground-based observations of fugitive dust be linked to source types?
- What is the impact of reducing fugitive dust on human health versus neutralization benefits?
- What is the mobility of the base cations from terrestrial ecosystem deposition to aquatic ecosystems (e.g. lakes)?
- What are the chemical transformations affecting fugitive dust and how do they affect downwind deposition?

- What is the combined response to base cations, N and acidity on receptors (plants, surface waters)?
- What is the resulting spatial distribution of fugitive dust and its components?

What is the combined response to base cations, N and S in plants, surface waters?

- Can model-measurement fusion be used/improved to get better spatial maps?
- How will the in situ facilities and other projected emissions change fugitive dust and neutralization?

Design Issues:

How will in situ facilities and other projected emissions change fugitive dust and neutralization?

- Focused study for surface monitoring of fugitive dust
- PCA of aircraft fugitive dust linked to surface observations (and other means of source attribution)
- Need to choose sites on the surface carefully
- What is the size distribution of fugitive dust much further downwind (50-200 km)?

2. *Long-term deposition trends for those constituents of concern which are produced buy oil sands. Includes timescale to effects and temporal variability.*

   - On a chemical species by species basis, does the existing monitoring program adequately capture the spatial deposition?
   - How far out do we need to measure before we get to no effects or background levels?

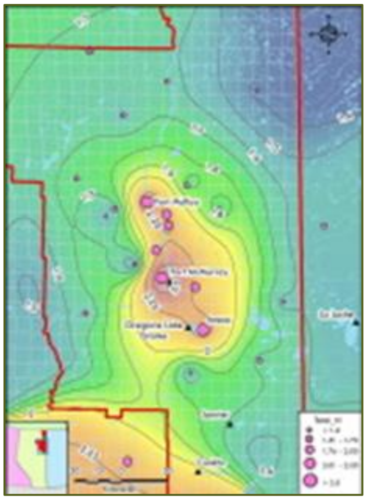
How far out do we need to measure before we get to no effects or background levels?

We need validations from communities to choose the chemical species to model

   - Are we adequately measuring other oil sands regions such as Peace River, Cold Lake.
     - Do we need to characterize these other regions in the same way we have done for surface mining operations?
   - Can we design a monitoring program that validates model predictions of long range deposition?
   - Are we monitoring the right things?

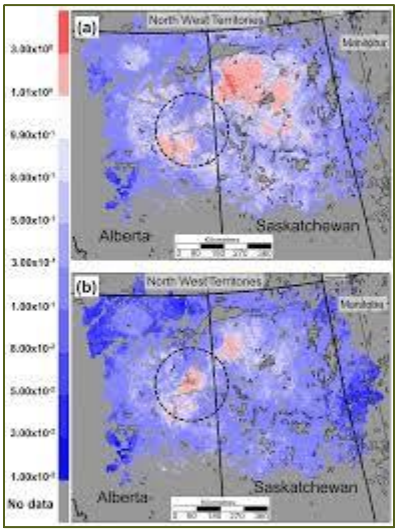
    - We need validations from communities to choose the chemical species to model
    - Uncertainty around temporal measurements – communities might specify requirements on what needs to be measured
- Do we need super sites?

3. *Sources and deposition of total nitrogen, including spatial distribution and critical loads.*
    - What are major sources of ammonia– oil sands vs non-oil sands (50 km from fenceline)?
    - What are major sinks of ammonia (50km from fenceline). At what distance negligible?
    - What fraction of total N deposition is attributable to oil sands?
        - What is the spatial variability: 0-50 km;50-100 km; > 100 km from facility fencelines



How do spatial trends like these change over time?

What are major sources and sinks of ammonia?



Are modelled critical loads for acidification confirmed by field observations?

- Are critical loads for acidification being exceeded (lakes/aquatic vs terrestrial)? Near, mid and far-field? What are the critical loads?
- What is the difference in total N deposition between in situ and mineable areas (near, mid and far-field)?
- What are the differences in effects in receiving environments?
- What is the spatial variability in critical loads (by receiving environment)?
- What are levels of unknown N species by receiving environment? Are these levels important?
- Is observed N deposition around oil sands mines within values predicted by EIAs?

- What spatial and temporal scale do we see impact from N deposition in receiving environments
    - In situ vs mining
    - Near, mid and far-field
- What distances are near, mid and far field? Is this dependent on oil sands type (in situ vs mining)? At what distances do oil sands emissions become negligible?
- What are the effects of different N species in different receiving environments? NH3 vs NO3 vs NH4

What are the differences in effects in receiving environments?

Is observed nitrogen deposition around oil sands mines within values predicted by environmental impact assessments?

Is the oil sands industry a significant source of mercury?

What are mercury emissions outside of the oil sands region?

Can we distinguish oil sands sources of trace elements from natural sources?

4. Source attribution – oil sands versus non-oil sands. Mercury and trace elements; others as needed (PACs)

Mercury:

- Is the oil sands industry a significant source of mercury?
- What are the oil sands processes that could contribute to methylation of mercury?
- What are the co-occurring pollutants with mercury? (there are tools available that measure this)
- What are the mercury emissions outside of the oil sands region?

Trace Metals/ PACs

- Can we distinguish oil sands sources of trace elements from natural sources?
- Do isotopes and co-contaminants (Rare Earth Elements) help identify the sources?

Passive samplers

Recommendations

- Ongoing monitoring of multiple pollutants in air (active/passive, snow), lichens, tree cores, lake sediments

- Need precipitation measurement of trace elements (should be combined with existing collections of PACs)
- Combine all of the various multi-contaminant geospatial data to understand current status.

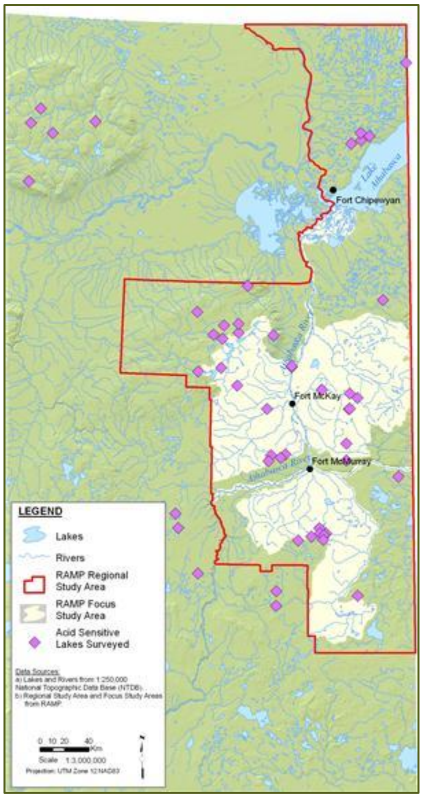
5. *Ecological impacts of base cation – multiple interacting stressors (base cations, nitrogen, sulphur)*

Hypotheses

H_1: There are differences in patterns of spatial distribution of base cations and S/N which leads to differences in how they combine across the landscape. This changes over time (e.g. emissions from in situ vs mining area in terms of dust/base cations vs N and perhaps S).

H_2: Ecosites will show a range of sensitivities.

- E.g. low Cation Exchange Capacity/base saturation site types will be most sensitive
- To verify ecological effects, need co-location of deposition monitoring and ecological effects monitoring



Acid sensitive lakes information (RAMP)

Issues and Opportunities

- Other data or samples (provincial soils database, ABMI soil samples)
- A reference from outside the region
- Scale and resolution must be suitable for terrestrial monitoring
- Controlled experiments might be useful (e.g. critical load questions)
- Deposition close to mining is mostly relevant for impacts on reclaimed ecosystems

Controlled experiments (such as those conducted by Weider et al) might be useful

Parking Lot

The issue of effective communication was raised by workshop participants but could not be addressed within the workshop scope. Communication among OSM Program Themes and with

Indigenous communities and the general public was identified as a key issue at all workshops. Specific communication suggestions included a focus on graphic or other forms of visual representation of results to facilitate exploration and discussion of the data and results by multi-disciplinary scientists as well as by lay persons.

The question of how a stressor such as odour gets “put on the list” was raised.

A question was asked about whose job it is to make links between deposition and human health.

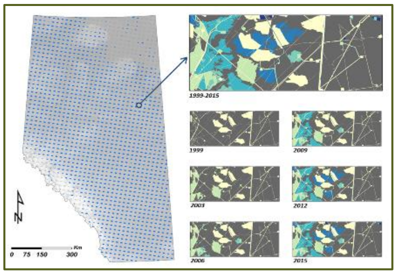
Geospatial Science Workshop

"Where are We": Current Status of the Application of Geospatial Science to Achieving the Three Core Outcomes of the OSM PROGRAM

What is Geospatial Science?

Geospatial science is a discipline that focuses on using information technology to understand natural and human patterns and processes. Remote Sensing, Geographic Information Systems (GIS) and Global Positioning Systems technologies are commonly used as measurement, observation, and analysis tools.

Geospatial science is a discipline that focuses on using information technology to understand natural and human patterns and processes.



Landcover with Time (ABMI)

The role of geospatial science includes defining and quantifying spatial and temporal data, overlaying data sets, identifying gaps in sample designs, and examining complex relationships among spatial data sets. Geospatial science can assist with identification of critical linkages within conceptual models as well as quantification of nodes or connections within the models.

Application of Geospatial Science to the OSM Program: Case Studies

Tools such as LiDAR can be used for indicating current state as well as temporal change in features such as wetland extent, water level, canopy height, and vegetation condition in the oil sands region.

The potential for application of geospatial science to achieving the three core outcomes of the OSM Program was demonstrated via case studies of wetlands, ABMI's examination of land use patterns and biodiversity, and remote sensing in the Peace Athabasca Delta.

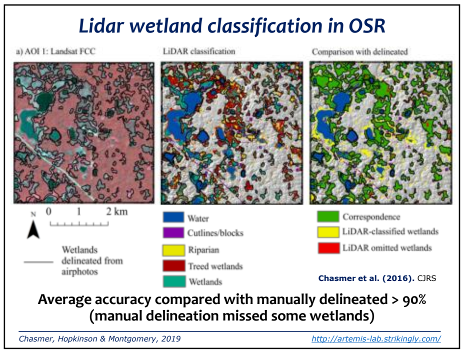
A workshop presentation by Colleen Mortimer presented selected results from a literature review of remote sensing of wetland features in Alberta (Presentation sub-folder in the Geospatial Science Folder https://albertagov.box.com/s/vdcrdzu7o750o7cctrceu8pdwmodq3wa.) A wide variety of geospatial data and measurement endpoints have been used with reasonable accuracy for some features such as landcover classification, wetland class, vegetation species composition, water level, and water flux.

There is significant potential for application of LiDAR to the assessment of accumulated environmental condition or state in oil sands regions. For example, wetland classification using LiDAR had high accuracy when compared with manually delineated classifications based on air photos. LiDAR can not only indicate the current state but also changes with time for features such as wetland extent and water level. LiDAR has been used to examine changes in canopy height in an active oil extraction area of the oil sands region north of Slave Lake. If there are multiple years of LiDAR data, changes in vegetation condition and community composition can be evaluated.

GIS pixel frequency maps can be used to provide baseline information, including baseline changes with time.

Satellite optical imagery can be used to indicate vegetation greenness at reclamation sites.

ABMI geospatial data are available for application to the OSM Program objectives. Both downloadable static datasets and web applications of real-time and historical data


Lidar wetland classification in OSR

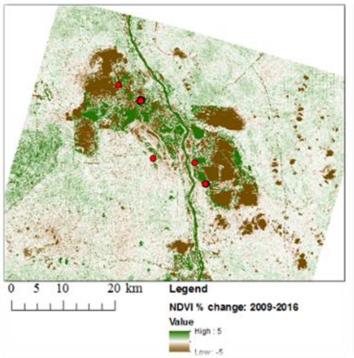
Chasmer et al. (2016). CJRS

Average accuracy compared with manually delineated > 90%
(manual delineation missed some wetlands)

Chasmer, Hopkinson & Montgomery, 2019 http://artemis-lab.strikingly.com/

From Workshop Presentation by C. Mortimer

An example of the use of GIS pixel frequency maps to indicate the spatial distribution of temporary, seasonal and semi-permanent water bodies illustrated how such analyses can provide baseline information (including baseline changes over time) as well as deviations from normal due to climate extremes or anthropogenic stressors.



Vegetation greenness change over 7 years. From Workshop Presentation by C. Mortimer

Satellite optical imagery has been used to indicate vegetation greenness over 7 years at four reclamation sites around Fort McMurray. This tool can also be used to analyse trends with time in relation to variables such as precipitation and the presence of wetlands.

Cumulative effects with respect to forest and wetland structural health have been mapped in the oil sands region (Chasmer et al 2019). Comparisons between burned and non-burned wetlands as well as structural health as a function of distance and direction from active mining operations and atmospheric emissions have been conducted. These analyses have illustrated the importance of wildfire in the region and the challenge of separating natural and oil sands-related effects.

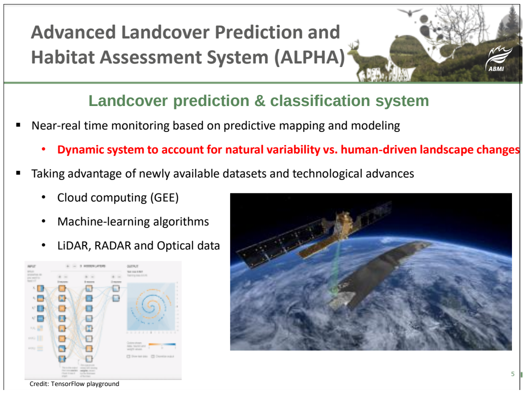
In a workshop presentation by Jahan Kariyeva (Presentation sub-folder in the Geospatial Science Folder https://albertagov.box.com/s/vdcrdzu7o750o7cctrceu8pdwmodq3wa), the application of ABMI geospatial data to the OSM PROGRAM objectives was discussed. Examples of downloadable static data sets include Alberta-wide wetlands extent, permanent water, and other landcover classes. Web applications of real-time and historical data include real-time water portal with water attributes, historical human footprint regeneration, and historical surface water trends and climate.

The Advanced Landcover Prediction and Habitat Assessment System (ALPHA) combines static, real-time and historical information for use in analysis of topics such as probabilistic identification of peatlands and wetlands in the boreal region and the monitoring of hydrologic variability.

A workshop presentation by Daniel Peters described remote sensing of the Peace Athabasca Delta (Presentation sub-folder in the Geospatial Science Folder https://albertagov.box.com/s/vdcrdzu7o750o7cctrceu8pdwmodq3wa.) Key questions include:

- Are oil sands stressor effects discernible in the wetlands of the PAD?
    - Via aerial deposition?
    - Via surface water pathways?
- Do we have sufficient baseline data?
    - Identify deltaic wetlands and lakes
    - High resolution bathymetry/surface elevations
    - Ecosystem status
- How can we monitor/assess change?
    - Traditional ground-based measurements
    - Aerial/satellite remotely sensed observations
    - Model of environmental change processes.

Cumulative effects: analysis of forest wetland structural health with distance from mining operations. From presentation by C.Mortimer



Advanced Landcover Prediction and Habitat Assessment System (ALPHA)

Landcover prediction & classification system

- Near-real time monitoring based on predictive mapping and modeling
    - Dynamic system to account for natural variability vs. human-driven landscape changes
- Taking advantage of newly available datasets and technological advances
    - Cloud computing (GEE)
    - Machine-learning algorithms
    - LiDAR, RADAR and Optical data

Credit: TensorFlow playground

The ALPHA system being used by ABMI.

Remote sensing has provided valuable baseline data over large spatial areas in the PAD using a repeatable timeline. For example, it generates information regarding seasonal and annual changes in wetland water levels seasonally and connectivity among wetland features. It is the only practical means to map extensive spatial areas.

Remote sensing provides reference information from nearby natural regions. This information can be used for comparison with information from areas exposed to specific stressors such changes in hydrologic regime due to hydroelectric dams, water use/abstraction by industry and landscape disturbance by multiple human uses.

Field data validation of remote sensing results and accompanying modelling is required for a complex system such as the PAD. Community based monitoring will continue to play an important role in this validation.

There are new remote sensing sensors to be launched soon (e.g. Radarsat Constellation) which may provide an opportunity to enhance the study of the PAD. Emerging drone technology may also contribute to the spatial coverage of data collection at relatively low cost.

Remote sensing of the Peace Athabasca Delta is being used to build additional understanding of baselines through observations of spatial and temporal changes.

Remote sensing has provided valuable baseline data over large spatial areas using a repeatable timeline.

Remote sensing provides reference information from nearby natural regions for comparison to areas exposed to stressors such as water use/abstraction and landscape disturbance.

Field data validation of remote sensing and modelling is required for a complex system such as the PAD. Community based monitoring will continue to play an important role in this validation.

Summary Based on Case Studies

Experience to date has shown that geospatial science has successfully been applied to the assessment of environmental condition or state as well as detection of change (OSM Core Outcome #1). This includes historic, current and predicted future states.

New remote sensing sensors and emerging drone technology may both provide opportunities to enhance the study of the PAD.

Geospatial science has not been as frequently applied to the evaluation of stressor-response relationships (OSM Core Outcome #2). In particular, the determination of the relative contribution of oil sands-related stressors to observed responses has proven to be challenging. In addition, the evaluation of stressor-response patterns has not always been at spatial or temporal scales which are appropriate to the known distribution of oil sands-related stressors (e.g. atmospheric deposition).

In some cases, cumulative effects can be mapped. However, stressor determination is challenging, as is distinguishing natural change from anthropogenic-related change. Furthermore, the relative contribution of oil sands-related stressors at far-field locations such as the PAD have not been distinguished from dominant factors such as natural hydrologic variability.

General Observations of Workshop Participants Regarding the Application of Geospatial Science within the OSM Program

In summary, geospatial science has been successfully applied to the assessment of environmental condition as well as detection of change (OSM Core Outcome #1). However, it has been less frequently used to evaluate stressor-response relationships (OSM Core Outcome #2) particularly with respect to specific oil sands-related stressors at appropriate spatial and temporal scales.

Workshop Leads noted that geospatial science can take a leadership role for some key questions and a support role for others. They also noted that geospatial science is key to achieving integration across OSM Themes. It was noted that over 500 publications have been produced from the OSM Program. Therefore, there are data to be used but there has not been integration in service of achieving OSM Program objectives.

Indigenous knowledge can be integrated with geospatial science in several ways. It can be incorporated into geospatial models. It can be used to validate remote sensing information. It can identify locations of important ecological features as well as areas of importance with respect to traditional resource use. Community-based monitoring data can contribute to calibration and

Geospatial science is key to integration across OSM Themes.

Indigenous knowledge can be integrated with geospatial science in several ways.

Geospatial scientists can provide data to predictive modellers and modellers can, in turn, provide outputs for geospatial analysis.

Geospatial science is required for assessment of cumulative effects across theme areas.

validation of spatial models of contaminant exposure and habitat change as well as confirming the areas where effects are being observed.

Geospatial scientists can provide data to predictive modellers and modellers can, in turn, provide outputs for geospatial analysis. GIS tools are integral to modelling.

Participants noted that geospatial science is required for assessment of cumulative effects across theme areas. For example, GIS can be used to produce layers depicting multiple stressors and ecosystem responses.

An open data policy is central to the successful application of geospatial science within the OSM Program. In some cases, data sets are acquired by private companies; in these cases data sharing agreements will be required. It was noted that there are mechanisms through the federal government to access data at no charge.

A key near-term requirement is to develop an operational program that uses remote sensing and earth observation in a systematic and routine way to develop datasets to support the quantification of stressors and responses across the oil sands region (spatially and temporally). Geospatial methods for quantification of cumulative effects in an integrative manner have not been widely used for the oil sands region, despite there being ample examples from other jurisdictions (see Hodgson and Halpern 2019 in the Workshop Information Package sub-folder in the Geospatial Science folder https://albertagov.box.com/s/vdcrdzu7o750o7cctrceu8pdwmodq3wa). This may be due to the limited amount of data at the spatial and temporal scales required for assessment of effects in the oil sands region.

Developing thresholds for change from baseline is also a limiting factor in the application and use of geospatial techniques. Beyond the human footprint analyses conducted at large landscape scales, spatial data are lacking. Pilot studies have demonstrated how remote sensing and earth observation can generate the data required, but in the absence of an operational program there hasn't been much progress in expanding these pilot studies across the oil sands region.

An open data policy is central to the successful application of geospatial science within the OSM Program.

Workshop participants noted that separation of the effects of different anthropogenic stressors will require the aggregation of data sets and then appropriate stratification by spatial and temporal scale and by stressor type.

Participants noted that geospatial analysis alone cannot answer key questions; however, it can pinpoint locations of different stressors and can also be used to stratify information. GIS-based data be used as a "gate process" for flagging changes in the receiving environment which require further monitoring and/or modelling.

A key near-term requirement is to develop an operational program that uses remote sensing and earth observation in a systematic and routine way to develop datasets to support the quantification of stressors and responses across the oil sands region (spatially and temporally).

Workshop Focus

The Geospatial Science Workshop had a different focus than previous workshops. Workshop participants were asked to consider how geospatial science can assist in addressing Key Questions identified during other workshops and if so, how geospatial science can be used to contribute to the 3 core OSM outcomes.

Which Key Questions Should Be the Focus of Near-term Geospatial Science?

Break-out groups considered a compiled list of key questions from previous workshops and identified the key questions that could be at least partially addressed using geospatial science in the relatively near future.

Developing thresholds for change from baseline is also a limiting factor in the application and use of geospatial techniques. Beyond the human footprint analyses conducted at large landscape scales, spatial data are lacking.

The quantity and quality of traditional resources was one of the questions most frequently identified by break-out groups for near-term geospatial analysis. Specific questions included:

- What species should we focus on?
- How do we build trust in communities?
- Do studies need to be done more regionally, reflecting concerns of several communities?
- Are we monitoring an appropriate range of spatial scales to answer communities' questions.

Separation of the effects of different anthropogenic stressors will require the aggregation of data sets and then appropriate stratification by spatial and temporal scale and by stressor type

Geospatial analysis alone cannot answer key questions; however, it can pinpoint locations of different stressors and can also be used to stratify information.

Workshop participants considered how geospatial science can assist in addressing Key Questions identified during earlier OSM workshops.

Discussion of this question included the comment that maps are a key communication and planning tool when working together with Indigenous communities because Indigenous knowledge is place-based. Maps of the distribution of traditional resources could contribute to building of trust with communities. These maps could incorporate information about Traditional Land Use in Environmental Impact Assessments.

Break-out groups also noted that explicit links between current Parks Canada work in the Peace Athabasca Delta (PAD) and OSM should be made in order to take advantage of knowledge being generated about muskrat abundance, macroinvertebrates in the PAD and amphibians.

The question from the Terrestrial Workshop regarding the **spatial and temporal scales required to define current condition and to allow removal of the "footprint" of habitat alteration or degradation caused by oil sands operations** generated considerable discussion. While some break-out groups agreed that this question can be addressed by geospatial science in the relatively near-term, the first requirement will be to develop an operational definition of "oil sands-related footprint" that is applicable to the OSM Program. The definition will vary depending upon the stressors and effects being examined because some stressor/effect relationships occur over wider spatial or temporal scales than others. This requirement is an example of the general need for operational definitions before geospatial science can effectively be applied to specific key questions.

The quantity and quality of traditional resources was one of the questions most frequently identified for near-term geospatial analysis

Maps are a key communication and planning tool for use with Indigenous communities

Once the definition of "footprint" has been established, there are geospatial techniques for analysis of trends and whether trends in footprint are correlated with specific effects. Geospatial analysis can also be used to help discriminate effects of natural variability from variability associated with the oil sands industry and other anthropogenic activities. For example, the Advanced Landcover Prediction and Habitat Assessment System (ALPHA) combines near real-time monitoring with predictive mapping and modelling for examination of natural variability vs anthropogenic landscape changes (J. Kariyeva presentation to the workshop).

An operational definition of "footprint" that is applicable to the OSM Program is required. The definition will vary depending upon the stressors and effects being examined.

Geospatial analysis combined with modelling can help discriminate between natural variability and anthropogenic effects

"Footprint"-related questions include which species are the most sensitive to habitat fragmentation and how oil sands-related effects compare to effects from other anthropogenic stressors (at specific spatial or temporal scales).

Questions related to "footprint" which can be explored using geospatial science are:

- What is the appropriate scale with respect to oil sands-related effects?
- How do temporal and spatial scales vary with respect to effects on ecosystem structure vs ecosystem function?
- When is a footprint no longer a footprint?

Specific questions related to footprint include:

- Which species are most sensitive to habitat fragmentation?
- What is the rate of spatial change in conditions which affect caribou populations?
- How do oil sands-related effects on terrestrial biota compare to effects from other anthropogenic stressors (at specific spatial or temporal scales)?

Location of groundwater-dependent ecosystems (GDEs) was identified as a near to medium-term question to be addressed by geospatial science. The first step is to develop a definition of GDEs.

The location of groundwater-dependent ecosystems (GDEs) was identified as a near to medium-term question to be addressed by geospatial science. The issue of definition was also raised for this question. It was pointed out that footprint could be based on multi-metric indicators or a pre-determined definition. It was also noted that certain terms might mean different things to different people; therefore, there is a need for a common lexicon with respect to the use of the term footprint.

Geospatial science can assist with the evaluation of spatial trends related to climate change.

A specific question was whether the effects of groundwater withdrawals can be distinguished from climate change effects and at which spatial scale.

Concerns regarding availability of information at the appropriate scale were raised with respect to the mapping of GDEs. It was noted that remote sensing tools can be used to identify discharge areas which, in turn, can be mapped and provided to groundwater specialists for further definition of GDEs.

One break-out group noted that geospatial science can assist with the **evaluation of spatial trends related to climate change.** Key questions included how far-reaching climate-change effects would be on groundwater systems and whether we see climate change-related trends in water level in a range of different locations inside and outside of the oils sands region. A specific question was whether the effects of groundwater withdrawals can be distinguished from climate change effects and at which spatial scale.

The effects of enhanced nitrogen and sulphur deposition on vegetation communities is a near-term opportunity for geospatial scientists to integrate with atmospheric deposition scientists and terrestrial ecologists.

Wetlands may be a logical focus of nearer-term geospatial analyses of the effects of N and S deposition.

Differences in spatial patterns of deposition, for N and S and base cations can be mapped and analysed using geospatial tools.

The examination of the **effects of enhanced nitrogen (N) and sulphur (S) deposition on vegetation communities** is a near-term opportunity for geospatial science to work with atmospheric deposition scientists and terrestrial ecologists. Field data collection and modelling of deposition have occurred, albeit with identified gaps. Furthermore, as explained in the Atmospheric Deposition section, there have been experimental studies of the effects of nitrogen deposition on bogs.

Wetlands may be a logical focus of nearer-term geospatial analyses of the effects of N and S deposition, since they can serve as proxies to study not only this question but also questions related to water balance, climate change, and how reclaimed systems fit within the surrounding system.

Differences in spatial patterns of deposition, not only for N and S but also for base cations can be mapped and analysed using geospatial tools. The answer to this question will contribute to a greater understanding of how N,S and base cations combine across the landscape and change over time (*e.g., emission from in situ facilities versus mining operations*). It was noted that there may be insufficient data for in situ production areas.

Several other atmospheric deposition key questions were identified as being amenable to near-term or medium-term geospatial analyses; however these questions were often identified by only one break-out group. The questions were:

- Where critical loads for acidification are predicted to be exceeded versus observed to be exceeded
- The range of sensitivity to acidifying deposition
- The scale at which impacts from N deposition are observed or predicted (mining vs in situ)
- Spatial distribution of fugitive dust and its components
- Major sources of ammonia within 50 km of oil sands operations
- Oil sands-related sources of mercury
- Where oil sands-related deposition (and associated effects) becomes negligible

> Temporal and spatial variability of contaminant deposition, the effect of land cover, topography, etc. on the mass of contaminants deposited and accumulated, and the spatial and temporal variability in hydrological connectivity between deposition areas and waterbodies are additional examples of near-term opportunities for integration of geospatial scientists with other disciplines.

Surface Water and Aquatic Biology workshop participants produced three broad key questions related to atmospheric deposition which are also a near-term opportunity for geospatial science. These questions are related to those noted above with respect to spatial patterns of deposition; therefore, it will be important to ensure that there is clarity regarding logical combinations of questions into integrated programs. These questions are: **what is the temporal and spatial variability in contaminant deposition across the landscape in order to guide the design of monitoring and assess vulnerability of the receiving environment**?; **how does the type of land cover, topography, etc. affect the mass of contaminants deposited and accumulated**?; and, **what is the spatial and temporal variability in the hydrological connectivity between deposition areas and regional waterbodies and what are the key drivers of that variability?** Integration across geospatial, atmospheric, hydrologic, water quality and aquatic biology disciplines will be required to address these questions.

> Geospatial science can contribute to the understanding of the groundwater baseline for all oil sands regions; however, while this work can begin immediately, it will take time to fully establish baseline conditions.

Which Key Questions Require More Time?

It was generally agreed that geospatial science can contribute to the understanding of the groundwater baseline for all of the oil sands regions, including the range of natural variability of groundwater quantity and quality. While this work can proceed immediately, it was noted that it will take time to fully establish baseline conditions.

Because the determination of baseline can be contentious, geospatial science can contribute lines of evidence via the use of a range of spatial tools and analysis approaches. Baseline can be determined from reference areas as well as via examination of spatial or temporal trends through the use of geospatial interpolation methods. Monique Dubé stated at the workshop that the appropriate spatial or temporal reference points will be subject to review by the OSM Program Oversight Committee.

Baseline can be determined from reference areas as well as via examination of spatial or temporal trends through the use of geospatial interpolation methods.

Geospatial science, combined with predictive modelling, can be used to predict if and where water balance changes may occur. It can also be used to examine the rate of change.

Workshop participants agreed that geospatial science can be used to predict **where to expect changes in water balance.** However, the data required for exploration of this question have not, to the knowledge of workshop participants, been assembled. It was noted that predictive modellers will need to work together with geospatial scientists to address this question.

The question of **whether reclaimed systems fit within surrounding systems** lends itself to geospatial analysis; however, there will be substantial data requirements in order to allow the assembly of layers related to geology, soils, topography, groundwater, and surface water interactions. Workshop participants suggested that wetlands be used as a proxy to study local reclaimed systems.

The question of whether reclaimed systems fit within surrounding systems lends itself to geospatial analysis; however, there will be substantial data requirements.

"Where Do We Need to Go?": Prioritization of Key Questions to be Addressed Using Geospatial Science

Break-out groups considered the Compiled List of Key Questions from previous workshops and then evaluated the questions using the following criteria:

- Current state of operation-ready tools and programs

- We are equipped to address the required spatial and temporal scales for this question
- There are current partnerships among existing programs which can be used in the near-to-medium term
- There are available datasets which are common to several Key Questions
- Relevant geospatial work has already been done or is underway

Break-out groups identified and then short-listed key questions produced at previous OSM integration workshops.

A list of the top 5 key questions was determined through a voting process. All of the top 5 key questions are to be addressed in the near-term.

A final list of the top 5 key questions to be addressed by geospatial science was determined through a voting process. All of the top 5 key questions are to be addressed in the near-term; however, it was noted that mapping of community knowledge of traditional resources should be ongoing.

The complete list of 10 short-listed key questions considered during voting is presented in Appendix 3.

The top 5 key questions in order of priority were:

1. Mapping community knowledge of the quality and quantity of traditional resources
2. The spatial and temporal variability in hydrologic connectivity between depositional areas and surface water bodies and the key drivers of this variability.
3. The location of groundwater-dependent ecosystems.
4. The species which are the most sensitive to habitat fragmentation.
5. The effects of enhanced N, S and base cation deposition on vegetation communities.

"How Are We Going to Get There?"

Five break-out groups were each assigned one of the top 5 key questions. Groups were asked to outline the steps required to apply geospatial science to their Key Question, in logical order and in accordance with the requirements of

Five break-out groups were each assigned one of the top 5 Key Questions

Groups were asked to outline the steps required to apply geospatial science to their Key Question, in logical order.

adaptive monitoring design. Groups were asked to pay particular attention to spatial and temporal scale and the definition of change relative to baseline, trend analysis or other tools.   In addition, groups were asked to identify:

- critical dependences (e.g. with specific Themes or agencies which have data required for use by geospatial scientists)
- processes which must be in place to ensure the required level of coordination and cooperation with respect to specific aspects of design (e.g. temporal and spatial scale, indicators, and endpoints)
- required partnerships.

Data requirements were the focus of all groups, as illustrated by the results presented below.

Key Question #1: Mapping Community Knowledge of Traditionally Accessed Resources

There are many sources of data relevant to the mapping of community knowledge of traditional resources.

Communities have done a lot of work with industry regarding traditional resources as part of environmental assessments; however, open access to this information is an issue.

A process for combining community knowledge with geospatial science is required.

Capacity in Indigenous communities to translate traditional knowledge into a form amenable to mapping is an issue. There will also be a need for geospatial scientists to spend a meaningful amount of time directly interacting with members of Indigenous communities.

Break-out group members noted that there many sources of data relevant to this question. For example, there are data on understory vegetation communities, including berries such as buffalo berry and blueberry. These data have been mapped in a format similar to ABMI products. The Cumulative Environmental Management Association (CEMA) collected information which may be applicable. However, CEMA is no longer in operation; therefore, access to the data needs to be clarified. Communities have done a lot of work with industry as part of environmental assessments; however, this information has not been assembled in one place, nor is there necessarily open access to this information.

A process for combining community knowledge with geospatial science is required. Effective communication will be necessary. Identification of geospatial tools which have immediate potential will be useful. For example, LiDAR data provides good information on terrain, which can be used in statistical analysis to predict landscape features associated with traditional resources. This has been demonstrated in the Cold Lake are, where a strong linkage has been found between LiDAR information and berry production. Maps produced by western science can be overlain on maps produced using Indigenous knowledge to illustrate commonalities, gaps, and discrepancies.

Capacity in Indigenous communities to translate traditional knowledge into a form amenable to mapping using geospatial science is an issue. There will be a need for individuals who are dedicated to this task. There will also be a need for geospatial specialists to spend a meaningful amount of time directly interacting with members of Indigenous communities.

Key Question #2: Spatial and Temporal Variability in Hydrological Connectivity Between Depositional Area and Waterbodies.

This question was interpreted as pertaining to both surface water and groundwater.

Data requirements include:

- high resolution surface elevation data (DEM) which are up-to-date
- subsurface hydrostratigraphy
- water body bathymetry
- footprint data with elevation for features such as bridges, berms and ditches
- hydrological and hydrogeological data
- covariates such as mobilization of sediments
- snow phenology
- LiDAR at 1x1 resolution would be ideal but may not be achievable
- Ground-based LiDAR for dense vegetation areas
- Blue LiDAR for bathmetry of wetlands
- Radar data for bathymetry
- Community based monitoring data for ground truthing

The hydrological connectivity questions was interpreted as pertaining to both surface water and groundwater.

There is a long list of data requirements.

Hydrologic data are currently held by the government of Alberta, ABMI and industry. Exploration of requirements to gain access to data will be required.

Data are currently held by the government of Alberta, ABMI and industry. There are different products for different purposes and some information is restricted. Exploration of requirements to gain access to data will be required.

Once data are acquired, data storage and management will be an issue.

Question #3: Where are Groundwater Dependent Ecosystems?

Definition of GDEs

Groundwater-dependent ecosystems include wetlands, streams and rivers. GDEs also include features such as mineral licks.

Wetlands are a broad category. Some fens are likely to be vulnerable to disruptions in groundwater flow. An understanding of how fens are connected to groundwater is required when looking for spatial distribution of vulnerable fens. It is also necessary to understand how anthropogenic disruption such as water withdrawals, deforestation or creating a large mound or depression might affect those connections. Bogs lack hydraulic connectivity; therefore, precipitation is the only water source. Groundwater inflow to streams and rivers is often vital in the winter when flow is low and overwintering habitat is scarce.

Group members also noted that changes in groundwater quality should also be considered. For example, salinized groundwater supplying a fen can alter the biologic communities in that fen.

Stressor sources associated with the oil sands industry include:

- Land disturbance
- Removal of forest cover
- Water withdrawals
- Surface water diversions
- Deep well disposal
- Seepage
- Spills and leaks

Groundwater-dependent ecosystems include wetlands, streams and rivers as well as features such as mineral licks.

Fens are likely to be vulnerable to disruptions in groundwater flow whereas bogs are not.

Groundwater inflow to streams and rivers is often vital in the winter when flow is low and overwintering habitat is scarce.

Group members noted that changes in groundwater quality should also be considered.

There are several sources of stressors associated with the oil sands industry which may have pathways which lead to GDEs.

- Air emissions.

Data Needs and Sources: Wetlands

There has been extensive work on wetland classification in Alberta; e.g., Ducks Unlimited, Alberta Geological Survey (AGS), ABMI, and academic research. However, the wetland classifications are at different levels and qualities. The group noted that data must be “fit for purpose” and because of the lack of consistency in methodology it will be difficult to confidently identify changes in wetlands with existing data. Furthermore, reference data will be needed.

The usability of existing data depends on the size of the GDE. The group commented that for streams and springs, the existing data are probably insufficient but are adequate for wetlands.

The first step may be to compare existing data and maps to see what is best suited to address this Key Question. It was noted that there are large time differences among individual studies. However, the data may be useful for training geospatial models.

An additional part of the first step will be to review existing classifications in terms of the required scale and detail required to address the Key Question. For example, effects from changes in water quality (notably salinity) will require data at the level of specific wetland attributes; i.e., there can be changes in wetlands that are not visible such as water chemistry.

There has been extensive work on wetland classification in Alberta; however, the classifications are at different levels and qualities.

Data must be “fit for purpose” for identifying GDEs in the oil sands region which are vulnerable to stressors from the oil sands industry.

Review of existing wetlands data will include identification of data suitable for training geospatial models. Requirements for data at the level of specific wetland attributes should also be considered (e.g. water quality).

Data Needs and Sources: Springs

Data for spring locations in Alberta have been collected by AGS, AEP, DFO, CEMA and academics. The quality and comparability of these data requires assessment.

Data for spring locations in Alberta have been collected by AGS, AEP fish and wildlife, DFO and academics. CEMA also produced map layers for spring locations based on traditional knowledge. There is a need to assess the quality of these data and compare the results.

There are topographic correlates for springs and AGS has published this information for the oil sands area. Springs along the Athabasca River have been mapped. Faults may indicate a preferential flow pathway. Geospatial imagery can identify discharge water that is warmer – this information can be used to locate springs.

Geospatial imagery can identify warmer discharge water which can be used to locate springs.

Available information for rivers include thermal data to identify groundwater discharging to rivers and surveys of electrical conductivity along riverbeds.

While remote sensing can be used for some water quality parameters in lakes, not all lake data are easily relatable to groundwater.

Data Needs and Sources: Rivers

Available information includes thermal data to identify groundwater discharging to surface water using infrared surveys. Surveys of electrical conductivity along riverbeds have been used to identify salinity (an indicator of groundwater discharge). The group noted that they did not have a geospatial scientists at their table who has worked on rivers; therefore, they didn't know what sort of geospatial data might be applicable.

Data Needs and Sources: Lakes

The group observed that while remote sensing data can be used for some water quality parameters such as suspended sediments and pH, not all lake data are easily relatable to groundwater. The challenge is to obtain information on shallow groundwater/lake water connectivity.

Data Needs and Sources: Pathways

Potentially applicable data for use in identifying groundwater-to-surface pathways include: pumping test data which also show salinity; AEP regional groundwater monitoring; groundwater model outputs (water elevations, directions and magnitudes); soil and surficial geology databases; and, topographic derivatives and water levels.

There are several sources of information which can be used for identifying groundwater-to-surface pathways.

Ideas for the Near-Term

- The following ideas for near-term work were discussed by group members:
- Use Digital Elevation Models (DEMs) or topographic and geologic predictors in areas where we have spatial geology to identify vulnerable GDEs
- If there are maps that show where there has been dewatering and there are cones of depression, look for intersections with fens, which would indicate vulnerability

  - In some cases there are EIA predictions and in some areas of the oil sands, groundwater models are calibrated to field data to show where water levels have been lowered
  - Withdrawal can cause the surface of the earth to decline
  - Industry/AER have data on impacts – these data take time to be made publicly available
- Take smaller-scale data and compile it to tell a geospatial-scale story
  - 5-6 research groups in the Fort McMurray area collecting data (ABMI, Boreal Ecosystem Recovery and Assessment (BERA), COSIA, University of Alberta, University of Lethbridge) but these data are not being shared
  - Use EIA data
- Build upon the work on effects of linear development on fens reported by Jahan Kariyeva during her presentation to the workshop

Several opportunities for near-term work on this Key Question were identified. All require integration with the groundwater Theme and all also require data sharing.


ABMI Geospatial Data:
example of data use/applications

Disturbed Fen
Near-real Time
(optical data)

From workshop presentation by J. Kariyeva

Key Question #4: Which Species are Most Sensitive to Habitat Fragmentation?

General Issues

The identification of sensitive species will require development of criteria which are appropriate to the scale of the analysis. A risk-based approach may be appropriate. However, there may be inadequate information on species distributions, especially for aquatic species. Terrestrial species could be selected based on criteria such as habitat-specific vs generalists, good vs poor dispersers, home range size, etc. Parks Canada’s approach is to “bin” species and then intentionally select a mix of species types.

The identification of sensitive species will require development of criteria which are appropriate to the scale of the analysis.

There will be issues regarding effects on species when they are outside of the study region. The solution to this will be to focus on the life stages which occur within the oil sands region.

Participants agreed that operationalizing the available data can be challenging. Data formats may not be standard and availability of data may not be consistent. Much data is held on private servers (e.g. with consultants). Approaches that allow the use of old/historic data while still being aware of limitations of these data will be required.

Applicable Data Sets

Landscape

- ABMI Human Footprint
- Oil sands and forestry operator-supplied data (may have to be purchased)
- Use Earth Observation/Remote Sensing to validate the disturbance layers – AER has done this and the alignment of observed and reported is quite good
- AER may have disposition data
- Canadian Wildlife Service human impact layer
- Basic land survey data, especially for validation of wetlands or the presence of small infrastructure such as culverts, fences, etc.

The group commented that landscape habitat layers need to be species-specific (in terms of scale), especially if the desired products are things like Species Distribution Models (SDMs) or Resource Selection Function (RSFs). The risk-based approach for oil sands-related stressor-responses may require a different focus (e.g. spatially-explicit exposure modelling based on home ranges and spatial distribution of the stressor).

Terrestrial Biota

- Boreal bird surveys – observational data of bird occurrences but most be requested piecemeal
- App: “ebird”

There will be issues regarding effects on species when they are outside of the study region. The solution to this will be to focus on the life stages which occur within the oil sands region.

Operationalizing the available data will be challenging. It may be more cost effective to collect new data.

A number of applicable datasets were identified regarding the assessment of the sensitivity to landscape disturbance.

Risk-based assessment will require information that supports spatially explicit exposure modelling.

Data for terrestrial biota are spread widely among a variety of sources. ABMI bird data with associated analysis of effects of landscape disturbance may be a logical place to start.

- ABMI and University of Alberta bird data
- COSIA camera data
- EIAs
- AEP

The above list is by no means a complete one. Given the widespread nature of data for terrestrial biota, the ABMI bird data with associated analysis of the effects of landscape disturbance may be a logical place to start.

Data for aquatic biota are primarily in two places – AEP (including RAMP) and ECCC. EIAs are another important data source.

Earth Observation/Remote Sensing data accessibility may be an issue (e.g. oil sands industry LiDAR data).

Aquatic Biota

- Location of culverts, stream crossings, bridges, weirs, and other barriers
- Stream diversion locations (EIAs, AER, AEP data)
- Streams or lakes which have been partially or totally eliminated (EIAs, AER, AEP, DFO (for habitat off-sets))
- Benthic invertebrate community composition and abundance (EIAs, RAMP, OSM Surface Water and Aquatic Biology Theme)
- Seasonal use of habitats by fish (EIAs, RAMP)
- Fish migration information (EIAs, RAMP, AEP, academics)

A challenge with much of the aquatic data is pseudo-absences caused by the lack of data. This applies to fish and amphibians.

Earth Observation/Remote Sensing Data

- High resolution RS data could be used for culverts, etc
- High resolution LiDAR – oil sands operators do this annually
- eDNA data
- Derived Ecosite Phase (available through open government) – combined NDVI and LiDAR data
- Canadian Wildlife Service –boreal disturbance layer – natural disturbance
- Historic air photos which go back to the 1930s

Question #5: Effects of Enhanced N, S and Base Cation Deposition Attributable to Oil Sands Operations on Vegetation Communities

The group noted that variations in soil affect vegetation communities; therefore, it is important to include soil data as a variable when addressing this Key Question.

Data Needs and Sources

- Soils - Government of Alberta
- Deposition of N,S, and base cations –AEP and ECCC (modelled), WBEA (measured); EIAs
- In situ vs surface mining (WBEA)
- Impacts of wildfires (Government of Alberta, ECCC, academics)
- Dustfall data and mapping
- Improved understanding and quantification of base cation and N sources/emissions (both oil sands industry and natural fires)
- Magnitude of sources of N, S and base cations
- Particle size distribution (to improve estimates of dry particle deposition)
- Leaf area index – can use airborne remote sensing
- Vegetation responses to deposition
- Soil inventory for the oil sands region

Variations in soil affect vegetation communities; therefore, it is important to include soil data as a variable when addressing this Key Question.

There is a long list of data needs for this Key Question.

The remote sensing network is not optimized.

Higher resolution information and analysis is required to address this Key Question.

Discrimination of cause of observed effects on vegetation communities will require careful study design which will likely require the use of reference areas or gradient-based approaches.

It was noted that the remote sensing network is not optimized. Limited resources are being spent in a relatively small area and do not necessarily measure deposition.

Design Issues

The group noted that higher resolution information and analysis is required to address this Key Question. The design should be based upon an understanding of the fate, transport, and effects of each of the stressors (which can be obtained via integration with the Atmospheric Deposition and Terrestrial Biological Monitoring Themes). Discrimination of cause of observed effects on vegetation communities will require careful study design which will likely require the use of reference areas or gradient-based approaches.

Geospatial Science Opportunities

Geospatial science can provide data capture and statistical techniques, but there is a need to obtain spatial continuous data combined with ground truthing. Historic remote sensing data may not have the required resolution. The ideal scenario described by the group would be to start collecting high resolution data of multiple sources now and continue incrementally over time.

There is an opportunity to use airborne remote sensing (LiDAR/hyperspectral) to confirm/observe changes in vegetation in jack pine forests and wetlands. Airborne remote sensing data can be compared to interpolated and simulated deposition maps. The data can help focus attention on areas requiring ground studies.

The ideal scenario described by the group would be to start collecting high resolution data of multiple sources now and continue incrementally over time.

There is an opportunity to use airborne remote sensing (LiDAR/hyperspectral) to confirm/observe changes in vegetation in jack pine forests and wetlands.

Geospatial science can provide a “wall-to-wall” map of ecoregion information (e.g. surface, soils) and can improve existing products.

Parking Lot

Communication was identified as a key issue, as it was at all previous workshops. Specific mention was made of the creation of “story maps”. These maps combine pictures together with spatial information. The story maps can go back in time and use aerial photos as well as traditional knowledge.

Some communities have a Community Knowledge Keeper databases that include interviews and traditional maps and information. Sharing this information is addressed under the OFA.

Provision of geospatial data as well as GIS models to predictive modellers will be required for integration to succeed.

Mercury Workshop

“Where are We”: Current Status of Mercury Monitoring

Accumulated Environmental Condition or State

The summary of accumulated environmental condition or state provided in the following paragraphs is based upon the workshop presentation by John Chételat, Craig Hebert, and Ashu Dastoor as well as subsequent discussion by workshop participants (Presentations sub-folder of the Mercury folder in https://albertagov.box.com/s/vdcrdzu7o750o7cctrceu8pdwmodq3wa).

The Global Environmental Multiscale-Modelling Air Quality and Chemistry-Mercury (GEM-MACH-Hg) model was used to simulate the geographical distributions of mercury concentrations in air as well as deposition of mercury in and outside of oil sands production regions from 2012-2015. Model simulations were compared with measurements of mercury in air and on the ground. The influences of other important sources of mercury in the region were investigated, including local biomass burning and global and regional anthropogenic emissions.

Mercury emissions from the oil sands industry contributed a small proportion of total mercury emissions in Canada. Total emissions were 25 kg compared 4.3 tonnes nation-wide. Biomass burning in Canada contributed 11.1 tonnes.

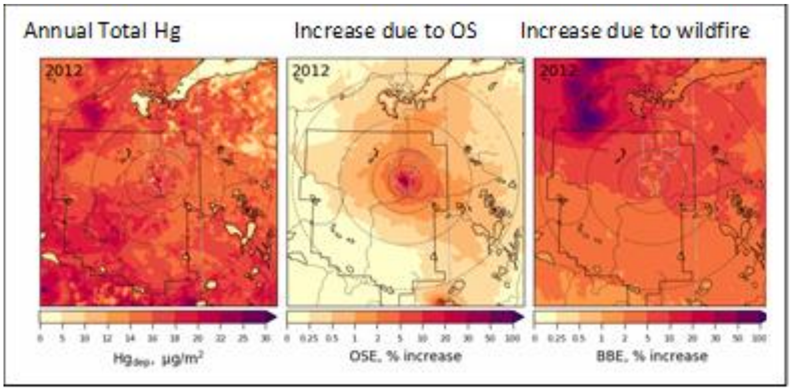
GEM-MACH-Hg model simulations were compared with measurements of mercury. The influences of other important mercury sources were also investigated, including wildfires.

Mercury emissions from the oil sands industry contributed a small proportion of total mercury emissions in Canada: 25 kg compared 4.3 tonnes nation-wide.

Modelled mercury deposition for 2012 showed increased mercury deposition (~30%->50%) in a localized area around oil sands operations. In comparison, wildfire emissions caused much more widespread (and higher overall) increases in mercury deposition.

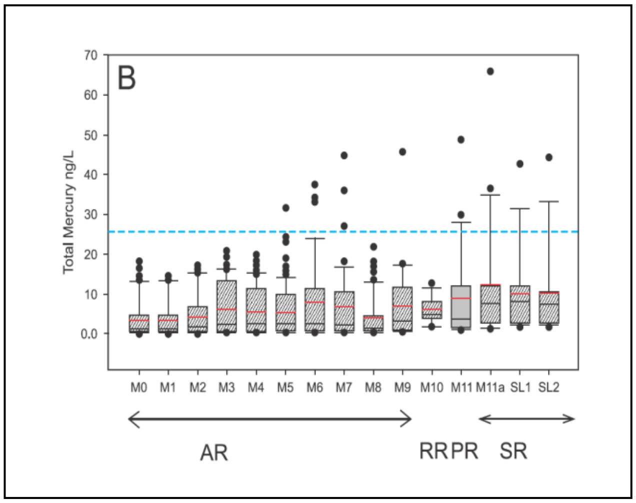
Oil sands operations produced an increase in oxidized mercury in air but not gaseous elemental mercury. Comparisons of modelled and measured mercury showed good model-measurement agreement. Measurements included gaseous elemental mercury concentrations at two oil sands sites (2010-2018) and at Fort McKay (2013-2018), oxidized mercury at Fort McKay (2013-2018) and snow mercury measurements (2012-2016).

Modelled mercury deposition for 2012 showed increased mercury deposition (~30%->50%) in a localized area around oil sands operations. In comparison, wildfire emissions caused much more widespread (and higher overall) increases in mercury deposition (see illustration below, from the workshop presentation).. Modelling predicted that total snow mercury loading increased. Snowpack measurements in 2012 and 2015 showed higher total and methylmercury close to operations. Maximum loadings occurred primarily between the Muskeg and Steepbank rivers.



There is conflicting information regarding mercury deposition. Total and methylmercury loadings were highly variable even within 8 km of oil sands industry sources. Therefore, long-distance transport likely influences total loadings. Methylmercury loadings in snowpacks at nearfield sites in 2015 were high due to high particle loadings, even though particles originating from oil sands activities were not enriched in methylmercury. Mercury concentrations in lichens in the oil sands region are similar to those in background locations (information from Atmospheric Deposition Workshop).

> Modelling predicted that total snow mercury loading increased. Snowpack mercury measurements showed higher total and methylmercury loadings close to operations.
>
> Mercury loadings were highly variable, including within 8 km of an oil sands industry source, indicating that long-distance transport likely influences loadings, even in the near-field.
>
> There is conflicting information regarding mercury deposition in the oil sands region.



Measured total mercury and methylmercury concentrations in the Athabasca River were higher downstream of the confluence with the Clearwater River (see illustration below, from the workshop presentation by Chételat and Hebert), although most total mercury concentrations remained below the CCME water quality guideline of 26 ng/L (indicated by the blue dotted line).

Total and methylmercury concentrations in the Athabasca River were higher downstream of the confluence with the Clearwater River; however, most total concentrations remained below the CCME water quality guideline of 26 ng/L.

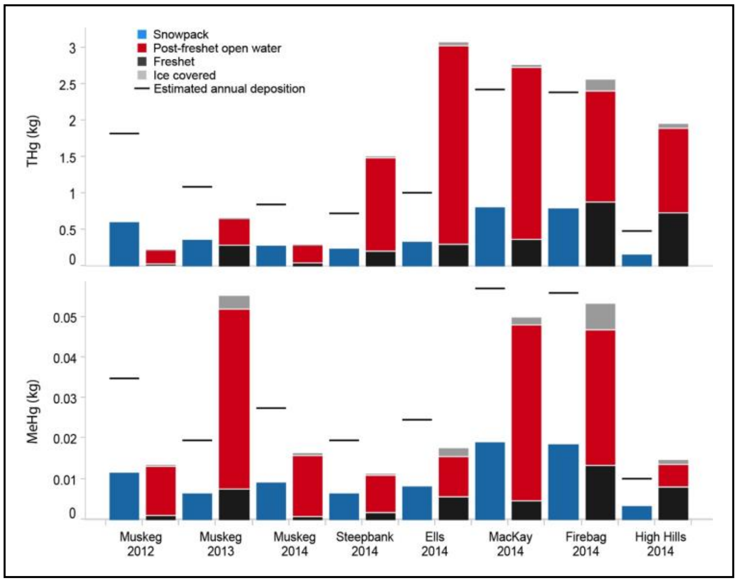
Total mercury concentrations in tributaries of the Athabasca River vary temporally and spatially within and among watersheds.

Total mercury in tributaries tracks water flow, with a springtime pulse during freshet.

Exports of total and methylmercury by tributaries exceeded estimated annual deposition to tributary watersheds in all tributaries except High Hills (the reference watershed).

Total and methylmercury concentrations in tributaries of the Athabasca River varied temporally and spatially with and among watersheds. In general, total mercury concentrations were correlated with water flow in both the reference watershed (with no development) and watersheds in oil sands production areas, showing a springtime pulse during freshet.

Exports of total and methylmercury by tributaries exceeded estimated annual deposition to the watersheds in all tributaries except High Hills (the reference watershed) (see illustration below, from the workshop presentation https://albertagov.box.com/s/vdcrdzu7o750o7cctrceu8pdwmodq3wa). Snowpack mercury and methylmercury loads equaled or exceeded the amount of freshet exports except High Hills.



Measured total and methylmercury concentrations in water from 50 lakes in the oil sands region were similar to other boreal lakes. Mean total mercury concentrations ranged from 0.4-5.3 ng/L. Mean methylmercury concentrations ranged from 0.01 to 0.34 ng/L.   The highest concentrations of total mercury occurred in lakes >100 km away from oil sands activities. Modelling estimated that <2% of mercury directly deposited to the sampled lakes originated from oil sands activities.

Lake sediment records from 20 lakes in the oil sands region showed no evidence of an influence from oil sands operations. The trends in sediment mercury concentrations reflected a global-scale pattern of mercury emissions.

Monitoring of mercury concentrations in water and frogs from wetlands locations within the oil sands region showed no spatial pattern.

Mean whole-body mercury concentrations in small-bodied fish (spottail shiner and emerald shiner) were higher downstream of oil sands operations than upstream locations or the PAD (see the workshop presentation https://albertagov.box.com/s/vdcrdzu7o750o7cctrceu8pdwmodq3wa).

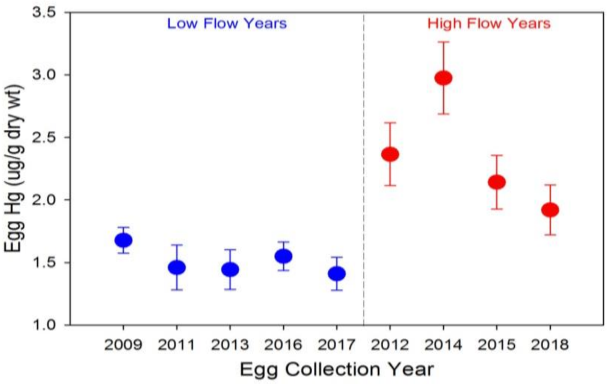
Mercury concentrations in walleye downstream of Fort McMurray were similar at all five sites sampled. There have been no temporal trends in mercury concentrations in walleye, lake trout, northern pike and burbot monitored since 2008 in western Lake Athabasca. There is no evidence of increasing trends in mercury concentration, which is in contract to trends observed for burbot and lake grout in Great Slave Lake.

Total and methylmercury concentrations in water from 50 lakes in the oil sands region are similar to other boreal lakes.

Lake sediments in the oil sands region show no evidence of an influence from oil sands operations. The trends in sediment mercury concentrations reflect a global-scale pattern of mercury emissions

Mercury concentrations in water and frogs from wetland locations in the oil sands region show no spatial pattern.

Mercury concentrations in waterbird eggs were higher in the Athabasca region than in southern or northern areas. Temporal variability in waterbird eggs from 2009-2017 was largely driven by flow of the Athabasca River (see illustration below, from the workshop presentation by Chételat and Hebert). Athabasca River flow is highly variable and influences mercury concentrations in the river. High flows transport high suspended sediment loads into Lake Athabasca. When June egg



Egg Island Caspian Tern

concentrations were related to concentrations from the year before, it was apparent that birds accumulate contaminants where they spend the breeding season. No data were presented regarding the relative contribution of oil sands industry operations versus natural sources to mercury in suspended sediments.

Mean whole-body mercury concentrations in two small-bodied fish species were higher at locations in the Athabasca River downstream of oil sands operations.

Available data do not indicate any spatial or temporal trends in large-bodied fish mercury concentrations.

The mercury concentrations in waterbird eggs (especially Caspian terns) may exceed thresholds for mercury toxicity during high-flow years. However, as noted above, the origin of mercury in waterbird eggs located in far-field locations is subject to question.

Mean total and methylmercury concentrations measured in river otters from 6 regions (Swan Hills, In Situ oil sands area, mining oil sands area, Birch Mountains, PAD and Aklavik) were highest in otters from the PAD and Aklavik. This pattern is more consistent with global mercury deposition.

Mercury concentrations in waterbird eggs were higher in the Athabasca region than in southern or northern areas. Temporal variability in waterbird eggs from 2009-2017 was largely driven by flow of the Athabasca River.

The pattern of mean total and methylmercury in river otters in 6 regions, including the oil sands region was more consistent with global mercury deposition.

Summary of Current Condition With Respect to Mercury

No oil sands-related pattern for:

- Air (gaseous elemental Hg)
- Lake water
- Lake sediment
- Lichen
- Large-bodied fish

Elevated mercury in:

- Atmospheric deposition (local)
- Snow (local)
- Athabasca River water downstream of the Clearwater River
- Small-bodied fish (very limited data)

- Waterbird eggs (related to sediment transport – origin of mercury in sediment is subject to question)

While we may have some understanding of how mercury deposition patterns have changed, there is a need to examine the causes of those changes. For example variability in weather, oil sands-related emissions, frequency and severity of wildfires, and landscape disturbances (both oil sands-related and caused by other activities) may all play a role

Participants noted that while we may have some understanding of how mercury deposition patterns have changed, there is a need to examine the causes of those changes. For example, variability in weather, oil sands-related emissions, frequency and severity of wildfires, and landscape disturbances (both oil sands-related and caused by other activities) may all play a role. A participant pointed out that oxidized, particulate and elemental mercury will show up differently in the measurements of deposition; therefore, we need to understand how those percentages change with source. This information would help discriminate among sources.

Participants also noted that while there is information on mercury deposition, we have insufficient understanding of fate and transport after mercury has been deposited to snow, soil, vegetation or surface water.

Several participants expressed concerns about the accuracy of National Pollutant Release Inventory (NPRI) mercury emissions data. Questions included whether there is a standard method for calculating emissions reported to the NPRI. The speciation of mercury emissions was raised as an information need; NPRI reporting does not include mercury speciation. Speciation information is important because of the different behaviour of mercury species with respect to partitioning to particles.

There is insufficient understanding of fate and transport after mercury has been deposited to snow, soil, vegetation or surface water.

There are about the accuracy of NPRI mercury emissions data. Mercury speciation information is needed. Partitioning to particulate matter is an important issue.

Apart from stack emissions, other oil sands-related mercury sources may include fugitive dust from mining operations. The relative contribution of fugitive dust to measured mercury concentrations is unknown. Tailings ponds have not been shown to be mercury sources.

The high spatial variability in annual deposition was noted by workshop participants. Data needed to help explain this variability and distinguish sources include wet deposition, mercury speciation, and year-round sampling (not just snowpack).

The OSM Program must first establish whether the oil sands industry is a significant source of mercury. Information needed to improve understanding of mercury sources includes:

- Detailed and validated stack emissions data
- Mercury speciation data
- Mercury isotopes data
- Stack emissions vs fugitive dust data
- Effect of land disturbances on erosion and transport of soils into waterbodies
    - Discriminating mercury sources in soils
- Primary locations of methylation of mercury

The relative contribution of fugitive dust originating from oil sands operations to mercury deposition is unknown.

If the oil sands industry is confirmed as a significant source of mercury, then the OSM Program can proceed with improving the understanding of mercury pathways (fate and transport). Information requirements would include:

- Combined effects of contaminants in emissions which may influence mercury speciation and transport (e.g. acidifying emissions, nutrients such as N)
- Location of mercury methylation in the Athabasca River watershed (wetlands, lakes, compensation lakes) and the connectivity between these methylmercury sources and the river.
- Natural and oil sands-related factors which
- Effects of overland flooding on release and transport of mercury to tributaries and the Athabasca River
- Erosional processes contributing to mercury transport
    - Related to land disturbance
    - Dust generation and deposition
    - Waterborne mercury
- Greater understanding of what happens to mercury after it is deposited to the landscape

Evaluation of the causes of high spatial variability in annual deposition requires year-round data.

There are several information needs to improve understanding of mercury sources and pathways.

Oil Sands-Related Stressor-Response Relationships

There are few very stressor-response data regarding responses to oil sands-related mercury concentrations.

Mercury concentrations in waterbird eggs exceed toxicity thresholds during high-flow years. These concentrations are unrelated to forest fire events and long-range transport of mercury, suggesting that oil sands development or local sources of mercury are affecting egg mercury levels or there are other factors which create conditions leading to methylation of mercury (and thus uptake into eggs)

Alberta Health has issued consumption advisories for lake trout and northern pike larger than 6 lbs and walleye larger than 3 lbs taken from Lake Athabasca.

There was general agreement among workshop participants that there are very few stressor-response data regarding responses to oil sands-related mercury concentrations. Mercury concentrations in waterbird eggs exceed toxicity thresholds during high-flow years. These concentrations are unrelated to forest fire events and long-range transport of mercury, suggesting that oil sands development or local sources of mercury are affecting egg mercury levels or there are other factors which create conditions leading to methylation of mercury (and thus uptake into eggs).

Mercury is a priority concern for Indigenous communities given the history of exposure of Indigenous people to mercury produced by processes used in industries such as pulp and paper. The mercury produced by these processes was discharged to waterbodies and then biomagnified in food chains leading to fish eaten by people.

Alberta Health has issued consumption advisories for lake trout and northern pike larger than 6 lbs and walleye larger than 3 lbs taken from Lake Athabasca. These advisories suggest a limit of 1 serving/week for children < 4 years of age, 2 servings/week for children between 5 and 11 years of age, and 5 servings/week for women between 15 and 49 years of age. There are no limits for anyone else and no limits for smaller fish.

Alberta Health does not report data for mercury in fish for the lower Athabasca River, nor for any of the tributaries to the river on its website.

As noted above, the mercury concentrations in fish from Lake Athabasca do not show any temporal or spatial trends. Therefore, there is no evidence to date that the oil sands industry has contributed to the observed mercury concentrations in Lake Athabasca fish.

Workshop participants noted that the relative contribution of the oil sands industry to predicted and observed mercury concentrations need to be better understood before investigations of stressor-response relationships can be warranted.

There was some debate regarding whether mercury is too complex for establishing stressor-response relationships because of its biogeochemical behaviour. Interpretation of patterns in methylmercury in biota can be very difficult. Furthermore, climate change is producing a changing baseline. After considerable discussion, workshop participants came back to the point that study of stressor-response relationships and causation requires teasing apart natural processes and a solid understanding of the oil sands industry as a source.

Cumulative Effects

Cumulative loadings of mercury to suspended sediments in the Athabasca River may be contributing to risk to waterbirds such as Caspian Tern. However, as noted above, the relative contribution of the oil sands industry to these cumulative loadings is still highly uncertain.

There are no spatial or temporal trends in mercury concentrations in Lake Athabasca fish. Therefore, there is no evidence to date linking the oil sands industry to observed mercury concentrations in Lake Athabasca fish.

Study of stressor-response requires teasing apart natural processes as well as a solid understanding of the oil sands industry as a source.

The relative contribution of the oil sands industry to mercury-response relationships and cumulative effects is highly uncertain.

“Where Do We Need to Go?”: Prioritization by Identification of Key Uncertainties

The Conceptual Model for Mercury (Figure 8) served as a tool for examining source-pathway-effects linkages and identifying uncertainties associated with those linkages. Workshop Leads also produced a draft list of uncertainties for consideration by participants. The draft uncertainties were:

- <u>Sources</u>
    - Knowledge of all Hg sources and the relative role of oil sands sources (level, speciation, trend)
- <u>Pathways/Mechanisms</u>
    - Hg deposition fluxes (especially summertime)

  - Soil, litter, dry deposition fluxes of Hg
  - Effect of local and regional drivers (climate change, changes in emissions, further expansion of OS mining, land-use disturbances) on Hg dynamics
  - Hg pathways in the Peace Athabasca Delta (PAD)
  - Hg pathways in Lake Athabasca
  - Hg/MeHg mechanisms in the PAD
  - Mass-balance
  - Terrestrial pathways (transformation and transport) of Hg
  - Hg pathway from air to bioaccumulation in aquatic food chain
- Effects
  - Downwind vulnerable (low pH) lakes south of Fort McMurray
  - Athabasca River flood plain lakes (Potential Fish nursery areas and methylation spots)
  - Cumulative effects of all pollutants on environmental/wildlife health
- Knowledge on key species/areas (community value)
  - Fish from Birch Mountain lakes
  - Sport fish

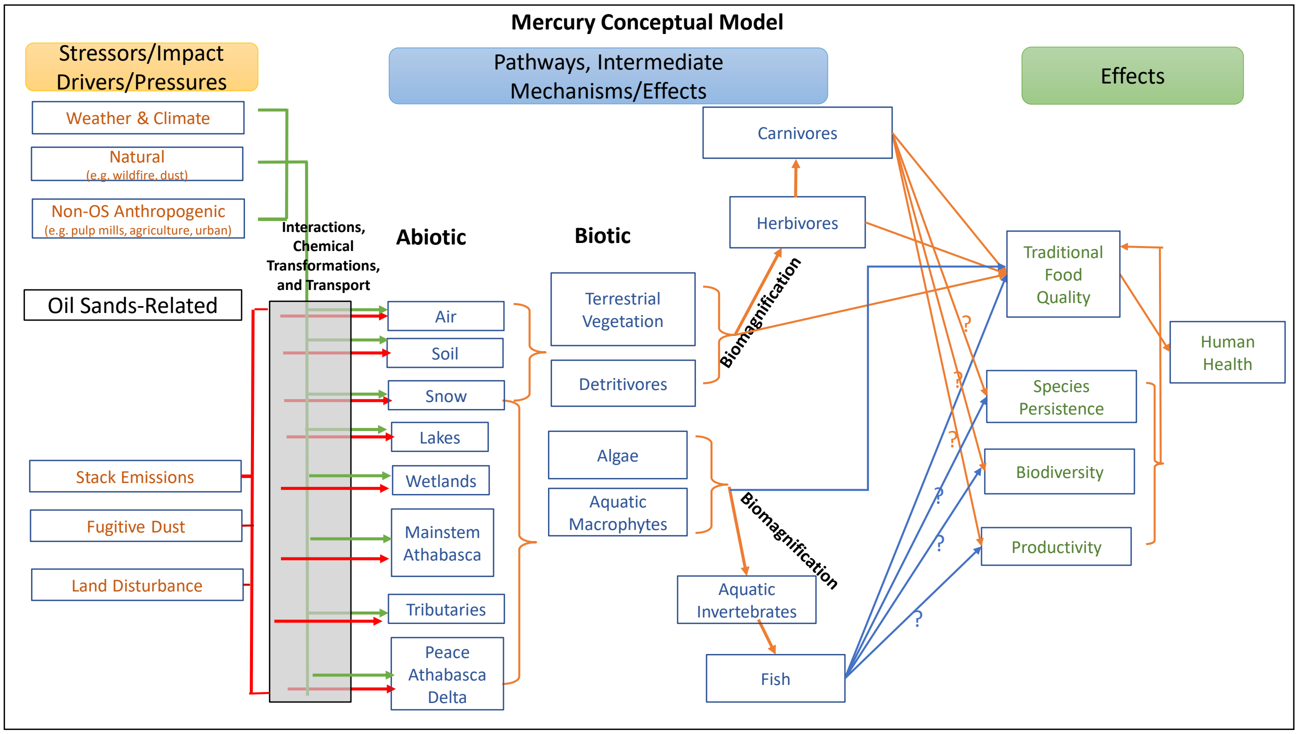


Figure 8. Mercury Conceptual Model

A final list of the top 4 key uncertainties was determined through a voting process.   The complete list of uncertainties assembled and considered by workshop participants is presented in Appendix 2.

The top 4 uncertainties for mercury (in order of the number of votes received):

1. Oil sands industry mercury sources and speciation
2. Mercury in traditional foods and subsequent effects on traditional resources and human health
    - Mercury concentrations in traditional foods compared to other regions. THEN if it is confirmed that the oil sand industry contributes to an incremental increase in mercury
    - Effects of mercury
3. Quantify and understand natural vs anthropogenic sources (oil sands, compensation lakes, non oil sands anthropogenic such as forestry, hydroelectric)
4. Mercury mass balance and transport
    - Methylmercury transport mechanisms
    - Mass balance of total and methylmercury source contributions to the Athabasca River

“How are We Going to Get There?”

Break-out groups were assigned one of the 4 key uncertainties and developed Key Questions for their assigned uncertainty. The Key Questions are indented under each of the 5 key uncertainties below.

Break-out groups were assigned to one of the 4 Key Uncertainties. Each group then developed Key Questions for their specific Key Uncertainty.

What is the characterization of mercury emissions from stacks as well as from land disturbance (dust)?

What emissions other than mercury affect mercury deposition and accumulation?

1. *Oil sands mercury sources and speciation.* **This uncertainty, together with Uncertainty #3, must be addressed prior to work on the remaining uncertainties.**

   - What is the characterization of mercury emissions from stacks and land disturbance (including speciation)?
   - What emissions other than mercury impact mercury accumulation and methylation?
   - Can we collect fugitive dust and understands its characteristics in order to understand its relative contribution to mercury deposition and transformation?
   - What is the level of mercury deposition in the oil sands region during the rest of the year (outside of snow seasons)?

   This group noted that it would be useful to conduct deposition sampling during shutdowns of upgraders.

2. *Mercury in Traditional Foods and Subsequent Effects on Traditional Resources and Human Health*

   Does the oil sands industry contribute to an incremental increase of mercury in traditional foods?

   - What has been done to date to measure mercury in traditional foods? Where? How?
   - Do the food items that have been measured encompass the full range of subsistence foods? Are the sampled at the right place and time?

What has been done to date to measure mercury in traditional foods? Do the food items encompass the full range of subsistence foods and were they sampled at the right place and time?

- How are the traditional foods prepared and what is eaten?
- Are mercury concentrations now and in the past higher in the oil sands regions than elsewhere (near and far?)
- Can we attribute mercury present in subsistence foods to oil sands sources?
- What has/is changing in the environment that affects mercury biogeochemistry, methylation and biomagnification?
- Are there historical samples which could be accessed and analysed for mercury?

Are there effects from mercury on traditional resources and human health?

- Does the perception of pollution from oil sands development affect use of subsistence foods?
- Are mercury concentrations above threshold levels that would result in consumption advisories?
- What advisories have been issued?
- Do the advisories affect use of subsistence foods?
- Have there been direct effects of mercury on health (humans and fish/wildlife)?
- Have there been indirect effects on human health?

This group emphasized the need to compile all existing information on mercury in traditional foods. Specific reference was made to work by Phil Thomas from the University of Ottawa, who is one of the researchers involved in the First Nations Food, Nutrition and Environment Study (FNFNES) (fnfnes.ca), which is funded by Health Canada.

Are mercury concentrations now and in the past higher in the oil sands regions than elsewhere?

What has/is changing in the environment that affects mercury fate, transport, and biomagnification?

Are there historical samples which could be analysed for mercury?

Does the perception of mercury from oil sands development affect use of subsistence foods?

Have there been direct or indirect effects on human health? On fish or wildlife?

What are all of the natural versus anthropogenic sources of mercury in the oil sands region?

What is the relative contribution of natural vs anthropogenic sources in the Athabasca River and the PAD?

3. *Quantify and understand mercury inputs from natural and anthropogenic sources (oil sands, compensation lakes, non-oil sands such as hydroelectric dams)*

- What are the natural versus anthropogenic sources of mercury in the oil sands region?
- What is the relative contribution of natural and anthropogenic sources in the Athabasca River and the PAD?
- What is the spatial and temporal variation of source contributions?

What is the spatial and temporal variation of sources

This group raised some of the same questions as the group working on Key Uncertainty #1 above. They recommended work on dust vs. stack emission effects on local mercury deposition. They also suggested studies of different dust types; e.g., dust from soil disturbance, coke, and dry tailings. They echoed the call for speciation of emissions. The group also noted that the compilation of data requires completion so that there can be a gap analysis regarding mercury sources.

Where are mercury methylation sites in the oil sands region up to and including the PAD? What conditions are required for methylation? Are these conditions changing over time?

4. *a. Mechanisms of transport of methylmercury from near-field to far-field downstream systems.*
   b. Mass balance of mercury and methylmercury source contributions to the Athabasca River.

- Where are mercury methylation sites within the oil sands region all the way to the PAD? (riverine wetlands, lakes, tributaries)
- Can we model sites and conditions that lead to methylmercury in order to understand its spatial and temporal distribution?
- What conditions are required for methylation? Mercury load? Effect of other emissions? Are these conditions changing over time?
- What are mercury sediment concentrations in the Athabasca River upstream and downstream of the oil sands region?
  - How does this sediment mobilize if it contains mercury?

What are mercury concentrations in sediments upstream and downstream of the oil sands region? Which sediments contain mercury? Why?

What are the relative contributions of overland flow, groundwater, tributaries and the mainstem to mercury mass balance?

What proportion of deposited mercury is transported vs retained/accumulated?

  - Which sediments contain mercury? Which horizons? What is the range and scale of mercury with respect to source?
- What are non-atmospheric mercury sources? Sediments? Soils? Other?
- What are non-atmospheric transport mechanisms? Model these?
  - Overland flow
  - Groundwater
  - Tributaries
  - Mainstem
- What is the fate of mercury deposited on the land surface? What is transported vs retained/accumulated?
- What is the fate of mercury deposited/transported in the Athabasca River?
  - How much is bioaccumulated?
  - How much settles in depositional areas?
    - Where are the depositional areas?
    - Are these sites of methylation
    - How do these change temporally and spatially?
- Are there spatial or temporal patterns in total and methylmercury concentrations in biota?
  - Have any spatial trends been confirmed with abiotic and biotic samples? With source-tracking tools such as stable isotopes?

Are there spatial or temporal patterns in total and methylmercury concentrations in biota and if so, have these been confirmed using source-tracking tools such as stable isotopes?

The need for an integrated “super site” approach was noted.

Community-based Monitoring can contribute to answering these Key Questions.

Two groups worked on this uncertainty and produced similar recommendations for Key Questions. Both groups emphasized the need for data compilation across disciplines followed by integration of study designs. The need for a “super site” approach was raised (as it was during the Atmospheric Deposition and Geospatial Science workshops).

It was noted that mercury sources to the PAD from the Peace River system should be examined, particularly with respect to waterbirds and other biota which range throughout the delta.

Group members suggested that there is a potential for community-based monitoring to contribute to answering the above key questions.

Parking Lot

Communication was identified as a key issue, as it was at all previous workshops. A specific question was asked about OSM Program deliverables other than scientific publications. Information pamphlets? Community updates?

Databases were once again raised as a critical issue.

It was noted that the workshops were driven by scientific questions. This raises the question of how Indigenous questions can be “bolted on” to the scientific questions. A participant asked how the committees within the OFA Governance Structure will address community drivers and prioritize activities. This participant wondered if there is clear alignment between Indigenous community concerns and scientific studies.

A participant recommended annual meetings to discuss finding so that integration can happen.

Predictive Modelling Workshop

Where are We”: Current Status of Predictive Modelling

The predictive modelling workshop focused on the five OSM conceptual models produced for Terrestrial Biological Monitoring, Groundwater, Surface Water and Aquatic Biology, Atmospheric Deposition and Mercury. The conceptual models provided the framework for discussion of the role that predictive modelling should play within the OSM Program going forward.

The four primary discussion points with respect to “where are we” with predictive modelling were:

- How has predictive modelling contributed to the three core OSM outcomes
- Where are we with respect to identifying the critical source-pathway-effects linkages which drive oil sands-related effects?
- Which Key Questions have been addressed by modelling to date? To what extent?
- What specific model integration has taken place?

The predictive modelling workshops used the 5 conceptual models produced for OSM Themes as a framework for discussion of the role modelling should play going forward.

The “Where are We” discussion examined how modelling has contributed to the 3 Core Outcomes, identification of critical source-pathway-effect linkages and Key Questions. The degree of model integration was also reviewed.

Modelling Contributions to the Three Core OSM Outcomes

Presentations on the current status of modelling were made for air, groundwater, surface water, and terrestrial biology. Each presenter was asked to address the above questions (See Presentations sub-folder in Predictive Modelling folder https://albertagov.box.com/s/vdcrdzu7o750o7cctrceu8pdwmodq3wa). Workshop participants then added their own knowledge and perspectives.

Air

Current Condition or State

Air quality and deposition modelling has used data for natural stressors, non oil-sands anthropogenic stressors and oil sands stressors to estimate atmospheric deposition of contaminants of concern to soil, snow, and water. The modelling estimates are then analyzed for spatial patterns of deposition in the oil sands region and beyond. The estimated contaminant loadings have been compared to critical loads. Some critical loads have been predicted to be exceeded, primarily in the near-field. However, critical loads of acidifying emissions to aquatic systems have been predicted to be exceeded over a fairly substantial area, extending into Saskatchewan. However, these predictions are now somewhat outdated, since they were based on 2013 emissions levels.

Air modelling has produced estimates of the spatial distribution of deposition of contaminants of concern.

Most air modelling has focused on mining areas.

A summary of the current environmental condition with respect to atmospheric deposition is presented in the report “Summary, Evaluation and Integration of Atmospheric Deposition Monitoring in the Athabasca Oil Sands Region” https://albertagov.box.com/s/vdcrdzu7o750o7cctrceu8pdwmodq3wa which was provided to the Atmospheric Deposition workshop participants in the pre-workshop information package. Most air modelling has focused on oil sands mining with much less attention paid to in situ production. Participants noted that with the predicted shift to more in situ production relative to mining, more modelling effort aimed at in situ sources is required.

Workshop participants were satisfied that the available models such as GEM-MACH were sufficiently capable and applicable. There was consensus that air modelling has produced a relatively good set of estimates of the spatial distribution of atmospheric deposition of contaminants of concern; however, there are some gaps for specific stressors such as base cations.

Air modelling has produced estimates of the spatial distribution of deposition of contaminants of concern.

Most air modelling has focused on mining areas.

Workshop participants were satisfied that the available models such as GEM-MACH were sufficiently capable and applicable.

There was general consensus that air modelling has produced a relatively good set of estimates of the spatial distribution of atmospheric deposition; however, there are some gaps for specific stressors.

Connections between oil sands industry sources and contaminant deposition have been inferred primarily by interpretation of the estimated spatial distribution of deposition. In some cases, air modelling has been used to estimate the relative contribution of natural stressors such as forest fires (for mercury) and non oil sands-related sources (again for mercury). Models such as GEM-MACH are capable of running scenario simulations aimed at questions such as relative contribution from specific sources, effects of implementation of a new control technology, a shift to more in situ production, and the effects of climate change.

Participants noted the need for more coordinated model/measurement work. Some examples of model/measurement work which has improved model performance include comparison of modelled N deposition with aircraft and satellite observations and the use of aircraft volatile organic compounds (VOC) observations to improve model emissions inputs. Field monitoring which is designed specifically to calibrate and validate model predictions is needed. At present, field data are often collected without explicit reference to the spatial and temporal scales addressed by models. For example, there has been a focused effort on measuring mercury in the snowpack but mercury data for other seasons are lacking.

Stressor-Response Relationships

Air modelling has focused on the source-pathway linkages in the conceptual models, with a strong emphasis on deposition to soil and water. The primary sources considered by air modelling have been oil sands emissions from stacks, with some effort devoted to wildlife sources and global atmospheric transport (in the case of mercury). Land disturbance sources (which in turn create fugitive dust) have not been a specific focus of air modelling, whether for the oil sands industry, natural wind erosion, or other anthropogenic disturbances such as forestry and linear developments.

Connections between oil sands industry sources and deposition have been inferred from estimated spatial distribution patterns. More scenario simulations such as those run for mercury could address relative source contributions and other important questions.

Participants noted the need for more coordinated model/measurement work.

Air modelling has focused on source-pathway linkages. Stack emissions have been the primary source considered. Land disturbance sources have not been a specific focus.

Air modelling is needed to understand the relative contribution of other oil sands-related sources (especially dust) as well as other anthropogenic and natural sources.

Although air modelling can be used to evaluate "cumulative air quality stressors" on the landscape, it has not been used for this purpose to date.

Workshop participants agreed that air modelling is needed to understand the relative contribution of other oil sands-related sources (specifically dust) as well as other anthropogenic and natural sources to deposition of contaminants of concern. As noted above, models such as GEM-MACH can be used to address questions related to other sources via comparisons among different model scenarios.

Cumulative Effects

Air modelling can contribute to the understanding of cumulative effects via scenario analysis.

Most Key Questions directly addressed by air modelling are those related to understanding sources and pathways.

Air modelling can be used to evaluated "cumulative air quality stressors" on the landscape; however, modelling to date has focused on estimating deposition for individual stressors or stressor categories. Integration with other disciplines could inform air modelers about what estimates of cumulative stress are needed.

Workshop participants noted that there are opportunities for air modelling to contribute to the understanding of cumulative effects via scenario analysis. Alternative future scenarios with varying levels of emissions combined with important co-variables such as climate change and land use change could be compared. For example, scenarios where there is more base cation deposition and less acidifying deposition because of the shift to more in situ production could be compared using 2-3 different climate change and land use scenarios.

Critical Linkages Identified by Air Modelling

Integration with other modelling efforts is required to address stressor-response relationships, interactions along exposure pathways, and cumulative effects. This has not yet occurred.

The air emissions- deposition linkage has been treated as a critical linkage. However, critical linkages are those linkages which drive *effects*. Participants at all previous workshops noted the current high level of uncertainty associated with establishing oil sands-related effects. Furthermore, as noted above, modelling has focused on stack emissions; other sources such as fugitive dust associated with land disturbances have received less attention.

Key Questions Addressed by Air Modelling

The presentation on air modelling indicated where modelling provides direct information related to Key Questions and where it provides ancillary information related to Key Questions via the use of symbols on each of the five conceptual models (see the Presentations sub-folder in the Predictive Modelling workshop folder https://albertagov.box.com/s/vdcrdzu7o750o7cctrceu8pdwmodq3wa).As expected, most of the Atmospheric Key Questions have been, at least in part, addressed by past and current modelling. However, Key Questions which require integration between air modelling and other disciplines have not been addressed, except for the provision of ancillary information which can form the basis for further work.

The air emissions- deposition linkage with groundwater has been treated as a critical linkage, but there is uncertainty regarding whether deposition has caused effects.

Integration With Other Modelling

Most existing groundwater models were not developed specifically to address OSM objectives.

Integration with other modelling efforts is required to address stressor-response relationships as well as interactions along exposure pathways, and cumulative effects of multiple stressors at various spatial and temporal scales. This has not yet occurred, as was noted at other workshops. In order to achieve OSM outcomes, required model integration includes, but is not limited to:

- Air modelling combined with geospatial modelling and analysis; and,
- Deposition modelling combined with water quality modelling and risk modelling, including risk to human health and ecological receptors.

Groundwater

Current Condition or State

Most existing groundwater models were not developed specifically to address OSM objectives. There are models at various spatial scales ranging from the entire Athabasca River Basin to regional (northern(NAOS) and southern oil sands (SAOS) regions) to watersheds/sub watersheds to sites.

Regional -to-site level model scales are the most applicable to the OSM Program. Information relevant to OSM Program core outcomes has been produced by past and current modelling. Available models can be used to establish the current level of understanding of the groundwater system in the oil sands regions, including the current state. For example, the objectives of models used within the Alberta Groundwater Management Framework (NAOS, SAOS and Cold Lake-Beaver River) included enhanced understanding of the regional hydrogeology and system dynamics under natural conditions and with development activity. Sub-watershed, project scale models performed as part of most EIAs are built for the purpose of comparing pre-development, current and full-build scenarios. Therefore, they inherently examine expected change in response to oil sands development. Predictions produced by these models can be compared to monitoring data for indicators such as water level. Site-scale modelling of Tar Island Dyke was used to estimate groundwater movement to the Athabasca River. These predictions could then be compared to field measurements.

Regional -to-site level model scales are the most applicable to the OSM Program.

Sub-watershed, project scale models performed as part of most EIAs Project-are built for the purpose of comparing pre-development, current and full-build scenarios. Therefore, they inherently examine expected change in response to oil sands development.

Current groundwater models can be used to run sensitivity analyses for identification of the key drivers of oil sands-related effects. Scenario analyses can be used to compare and contrast effects on features such as groundwater level with various degrees of current and future surface disturbance and groundwater withdrawals.

Stressor-response Relationships

Assembly of groundwater model results (including models supporting EIAs) and subsequent analysis of predicted effects on groundwater quantity and quality may provide a start with respect to this OSM Core Outcome. This was a priority recommendation coming out of the Groundwater workshop. The review of modelling conducted to date compiled for the workshop (see Workshop Information sub-folder in the Predictive Modelling folder https://albertagov.box.com/s/vdcrdzu7o750o7cctrceu8pdwmodq3wa) included predicted responses to water withdrawals. Current groundwater models can be used to run sensitivity analyses for identification of the key drivers of oil sands-related effects. Scenario analyses can be used to compare and contrast effects on features such as groundwater level with various degrees of current and future surface disturbance and groundwater withdrawals.

Cumulative Effects

There are some existing groundwater models which were designed to address cumulative effects. The MacKay River watershed model was designed to quantify the potential cumulative effects of groundwater diversions on groundwater levels in aquifers underlying the MacKay River watershed and on groundwater discharge to streams. The study also considered the potential cumulative impacts of the diversions and surface activities on the MacKay River and its tributaries during low flow periods and determined whether the full build conditions could adversely affect the frequency, duration and severity of low flows in the system, thereby impairing traditional uses.

There are some existing groundwater models which were designed to address cumulative effects.

Critical Linkages Identified by Groundwater Modelling

The linkages between natural and oil sands-related factors and groundwater recharge and discharge have been addressed by past groundwater modelling. Taken together, the results of these modelling exercises can be evaluated for the relative importance of linkages with natural, oil sands and non-oil sands-related factors.

Past modelling results have indicated the importance of wetlands and precipitation to recharge, predicted local impacts on water level, identified high intrinsic vulnerability areas and predicted recovery times for aquifer heads.

The linkages between natural and oil sands-related factors and groundwater recharge and discharge have been addressed by past groundwater modelling, including models run in support of EIAs, industry models, and academic and government models. Taken together, the results of these modelling exercises can be evaluated for the relative importance of linkages with natural, oil sands and non-oil sands-related factors.

The summary of key findings for groundwater modelling provided in the workshop Information Package (https://albertagov.box.com/s/vdcrdzu7o750o7cctrceu8pdwmodq3wa) included the following:

- In general, results from models suggested that the majority of water entering the groundwater system would be derived from recharge due to infiltration from wetlands or precipitation while minor amounts would be provided by leakage from lakes. Modelling conducted by industry and Alberta Innovates;
- Water level fluctuations are more variable under climate change;

- EIA models did not consider impacts to the frequency and duration of low water events;
- Future groundwater diversions at full build will likely create localized impacts that are not sustainable with respect to drawdown and streamflow thresholds;
- High intrinsic vulnerability areas are mainly in the northern portion of the lower Athabasca region;
- Most major river valleys are more vulnerable than adjacent areas; and,
- Recovery of available head in the aquifers impacted by groundwater withdrawals is relatively rapid – within 20 years for major effects and 80 years for almost full dissipation.

The only groundwater Key Questions addressed by past and current modelling have been related to climate change.

There are some coupled models at the watershed scale; e.g., a groundwater-surface water model.

Key Questions Addressed by Groundwater Modelling

The only groundwater Key Questions addressed by past and current modelling have been related to the effects of climate change on groundwater quantity and quality.

Integration

There are some available coupled models at the watershed-scale which provide the opportunity to provide an integrated assessment of oil sands-related effects. For example, a coupled groundwater-surface water model was described at the workshop which indicated that riparian peatlands are one of the major controlling factors for lake-groundwater interactions in order to maintain surface water on permeable landscapes such as oil sands.

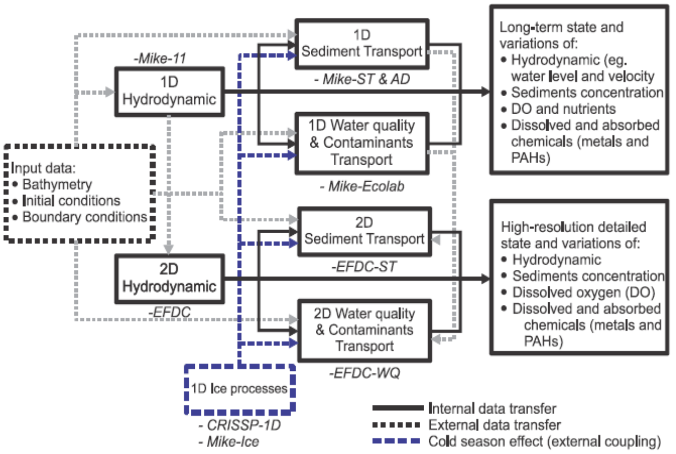
Surface Water and Aquatic Biology

Current Condition or State

Past and current modelling has produced information on historic, current and project future spatial and temporal variability of water flow and sediment transport into and through the lower Athabasca River and its tributaries. Water and sediment budgets for the lower Athabasca River and tributaries have been produced. Water quality modelling has addressed the fate and transport of nutrients, metals and PACs. The

Extensive hydrologic and surface water quality modelling has taken place to produce historic, current and projected future spatial and temporal variability of flow, sediment transport, water quality and sediment quality. Effects of climate change and land use have been modelled.

effects of climate change and land use/land cover changes have been modelled. Impacts from tailings management (seepage from tailings ponds and potential treated releases of oil sands-affected process water (OSPW) on water and sediment quality have been predicted.



From workshop presentation by A. Gupta

Historical baseline models provide reference levels against which current and future changes can be assessed. This baseline has been used to evaluate the impacts of climate change and land use change on hydrology, water quality or fish habitats.

Modelling has been performed by federal and provincial government agencies, industry and academia.

Almost all of the effort regarding stressor-response has been devoted to field-based effects monitoring at a site or reach level.

Models can be used to investigate stressor-response relationships and causation through the use of scenario analysis which compare and contrast predicted effects from different combinations of stressors.

Technical and synthesis reports provide a summary of the condition of water quantity, quality and aquatic biota in the oil sands region. These reports were provided in the Surface Water and Aquatic Biology pre-workshop information package.

Stressor-Response Relationships

Almost all of the effort regarding stressor-response has been devoted to field-based effects monitoring at a site or reach level. While responses have been observed (see the Surface Water and Aquatic Biology section), causation with respect to oil sands industry stressors versus other stressors has not been reported.

Historical baseline models provide reference levels against which current and future changes can be assessed. This baseline has been used to evaluate the impacts of climate change and land use change on hydrology, water quality or fish habitats.

To date, water quality models have not been focused on distinguishing among stressor sources or effects. Nor have they focused on critical drivers of effects.

Models can be used to investigate stressor-response relationships and causation through the use of scenario analysis which compare and contrast predicted effects from different combinations of stressors. For example, natural, non-oil sands and oil sands-related changes in land use can be modelled in separate scenarios as well as in combination. Water quality impacts due to natural bitumen versus loadings from atmospheric deposition could be compared separately and in combination.

To date, water quality models have not been focused on distinguishing among stressor sources or effects. Nor have they focused on critical drivers of effects.

Cumulative Effects

Progress has been made with respect to cumulative effects, particularly with respect to climate change plus land use change effects on hydrology.

Progress has been made with respect to cumulative effects, particularly with respect to climate change plus land use change effects on hydrology.

Past and current modelling has identified the critical role of weather and climate on hydrology of the lower Athabasca system. Hydrology, in turn, drives pathways and mechanisms which can lead to effects.

Several linkages remain poorly understood, including linkages between natural bitumen and water or sediment quality and between atmospheric deposition and water quality.

Critical Linkages Addressed by Surface Water Modelling

Modelling has identified the critical role of weather and climate on hydrology of the lower Athabasca system. Hydrology, in turn, drives pathways and mechanisms which can lead to effects; e.g., sediment transport and deposition.

Several linkages remain poorly understood, including linkages between natural bitumen and water or sediment quality and between atmospheric deposition and water quality.

Key Questions Addressed by Surface Water Modelling

Some of the Surface Water and Aquatic Biology questions are at least partially addressed by modelling; however, current modelling is not sufficient to evaluate differences in sources and loads among receiving environment sites. Nor has there been sufficient

Some Key Questions are partially addressed by current modelling; however, there are substantial gaps.

For the most part, surface water modelling integration has been internal to the Theme.

modelling in support of identifying critical drivers of effects on aquatic biota. Sediment transport models have partially addressed the question of contaminants in food webs in downstream environments but the model results are for suspended sediments only and not specific contaminants. There has been no modelling of effects of oil sands development on aquatic habitat connectivity, with the exception of project-level assessment within EIAs.

Integration

As noted above, there has been a limited amount of model integration between groundwater and surface water models; however, for the most part, surface water modelling integration has been internal to the Theme.

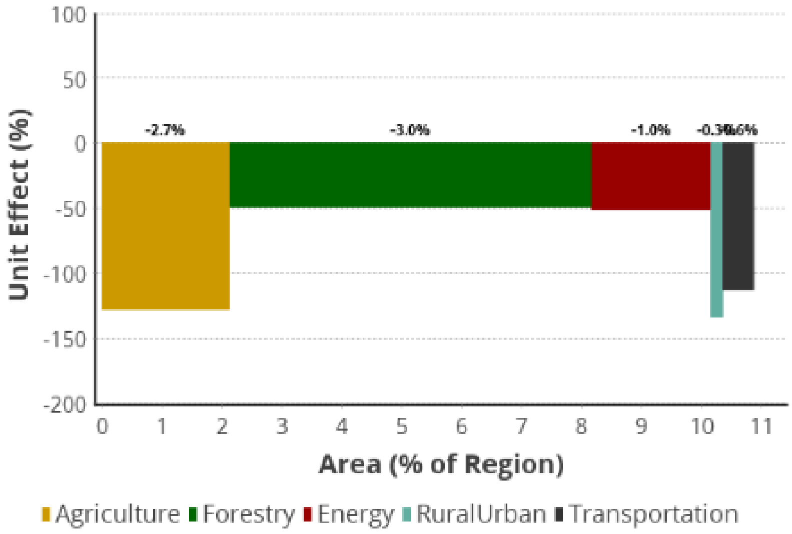
Terrestrial Models

Terrestrial modelling has focused on evaluating and predicting relationships between stressors related to major land use categories ("footprint groups") and responses in species or communities. Footprint groups include agricultural, forestry, transportation, human-created waterbodies, urban, rural and industrial and energy (mines, wells and other energy features). Predictions of regional population abundance are made for 1x1km cells under different footprint conditions, as was discussed at the Terrestrial Biological Monitoring workshop. The relative effects of "footprint groups" or "sectors" can then be evaluated. For example, the percent effect of agriculture, forestry, energy, rural/urban and transportation can be compared relative to the footprint areas for each sector, as shown below.

Terrestrial modelling has focused on evaluating and predicting relationships between stressors related to major land use categories ("footprint groups") and responses in species or communities.

Footprint groups include agricultural, forestry, transportation, human-created waterbodies, urban, rural and industrial and energy (mines, wells and other energy features).

The relative effects of "footprint groups" or "sectors" have been evaluated.



From workshop presentation by E. Bayne.

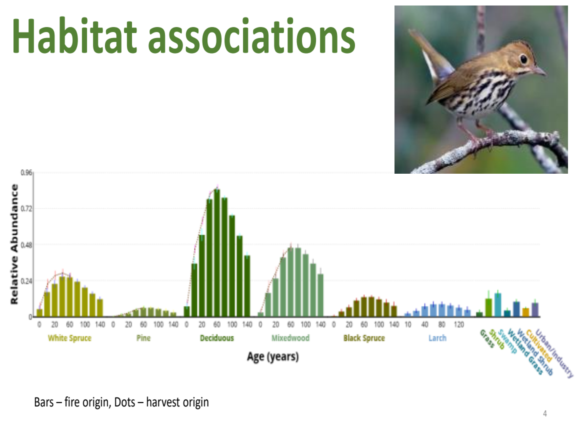
Relationships between forest composition and structure and bird abundance have been assessed.

Regression-based models are used to describe how natural and human-caused variation in environmental descriptors influences average bird abundance.

Scale and level of detail with respect to stressors is important when evaluating current state of terrestrial species.

Models are currently being updated for application to oil sands-related stressors.

An example of terrestrial modelling was presented by E. Bayne which focused on the relationship between forest composition and structure and bird abundance. Regression-based models are used to describe how natural and human-caused variation in environmental descriptors influences average abundance of species. Results can be portrayed by individual bird species, as illustrated below.


Habitat associations

Bars – fire origin, Dots – harvest origin

From workshop presentation by E. Bayne.

Scale and level of detail with respect to stressors is important when evaluating current state of terrestrial species. Models are currently being updated for application to oil sands-related stressors. For example, linear development is being split into seismic, transmission (pipe, power line), roads and wells. There are plans to add noise, light, traffic level, contaminant level and regeneration state of vegetated linear features.

While the modelling of bird responses is well developed, models for other taxa may not be as established.

Workshop participants commented that while the modelling of bird responses is well developed, models for other taxa may not be as established.

Stressor-Response Relationships

As noted above, regression models are being used to examine relationships between changes in environmental variables and bird species. In addition, population dynamics modelling results are being compared among regions such as “western mineable”, “eastern mineable” and “All Lower Athabasca Production Region” for population parameters such as occupancy, colonization and extinction. According to E. Bayne, there are good data for 150+ bird and amphibian species to estimate these population parameters. The paradigm used will be the same for all taxa but details will vary spending on the scale at which the species functions, the “nuisance” variables, and the amount of data available to test covariate combinations.

With increasing number of repeated field samples, modelers are getting better at testing whether local and regional changes in footprint are correlated with population parameters such as extinction and colonization rates (E. Bayne, workshop presentation).

Population dynamics modelling results are being compared among regions such as “western mineable”, “eastern mineable” and “All Lower Athabasca Production Region” for population parameters such as occupancy, colonization and extinction.

With increasing number of repeated field samples, modelers are getting better at testing whether local and regional changes in footprint are correlated with population parameters.

Although links between species models and cumulative effects simulators are possible, this has not yet been done

Cumulative Effects

Species models for estimation of occupancy and abundance can be linked to models such as ALCES (Landscape Cumulative Effects Simulator), BurnP3 fire growth model, Patchworks forest management optimization model, SpaDES(spatially explicit discrete

Terrestrial modelling has dealt with linkages across the entire conceptual model from source through pathways to effects (for the effects of landscape disturbance at large scales).

Terrestrial modelling has not addressed contaminant-stressors.

event simulation) models and Tardis (visual environment for exploring landscape patterns and changes to patterns with time). All of these tools can be used to construct and compare scenarios for examination of cumulative effects. However, this has not yet been done.

Critical Linkages Addressed by Current Modelling

Current modelling addresses the Terrestrial Conceptual model linkages between stressors such as soil disturbance, soil and vegetation removal, and partial or total elimination of streams, wetlands or lakes, intermediate effects such as habitat loss, degradation, transformation and loss of connectivity and effects on species persistence and biodiversity. Thus, terrestrial modelling is the only modelling which has dealt with linkages from stressor source (land disturbance at larges scales) through pathways to effects. However, as noted during the Terrestrial Biological Monitoring workshop, the modelling may not be sufficient to discriminate the relative contribution of oil sands-related stressors to observed effects in a given spatial area – particularly at the sub-regional or regional scale.

Current modelling addresses, in part, the Key Question about species which are the most sensitive to habitat fragmentation.

Finer spatial resolution will be required to discriminate oil sands-related stressors from other stressors.

There is a separate Key Question regarding appropriate spatial and temporal scales for terrestrial modelling. The answer will vary according to source-pathway-effect linkages.

Terrestrial modelling has not addressed contaminant-stressors. As noted above, there are plans to extend modelling to consideration of noise, light, traffic and regeneration state of revegetated linear features.

Key Questions Addressed by Current Modelling

Predictive modelling of intactness and effects on biodiversity in response to human footprint addresses, at least in part, the Key Question regarding the species which are most sensitive to habitat fragmentation. However, the spatial resolution of the modelling may be insufficient with respect to discrimination of oil sands industry-related contributions to habitat fragmentation. Furthermore, the use of intactness as an indicator requires review and verification.

The Key Question regarding oil sands industry-related effects versus other anthropogenic stressors is partially addressed by current modelling of responses to “footprint groups”. However, finer spatial resolution will be required.

The appropriate spatial and temporal scale with respect to oil sands industry-related effects is a separate Key Question. The answer will vary according to the source-pathway-effect linkages.

Integration

Integration with air, groundwater and surface water models or model results has not occurred, at least to the knowledge of workshop participants. The effects of hydrological variability (called Hydro-Temporal Variability) is presented as a key topic by ABMI; however, it is unclear whether there have been explicit links between current hydrologic models used by provincial agencies and ABMI modelling.

To the knowledge of workshop participants, there has been no integration with air, groundwater or surface water models.

"Where Do We Need to Go?": Prioritization of Critical Linkages and Processes

Workshop participants were asked to produce lists of critical linkages and processes in the five conceptual models which, in their opinion, should be prioritized for modelling. Critical pathways and processes are those which drive oil sands-related effects on biological receptors, human health and traditional resource use.

Key Questions developed by previous workshops provided another basis for prioritization.

Prioritization criteria were:

- The pathways or processes already have Key Questions
- There are applicable existing models
- Data are available at required spatial or temporal scales
- Baseline data are sufficient
- We have sufficient understanding of the processes to construct numeric models
- The pathways and processes have plausible links to effects on biota or humans

Critical pathways and processes are those which drive oil sands-related effects on biological receptors, human health and traditional resource use.

Break-out groups identified and then short-listed critical pathways and processes using a set of prioritization criteria.

- We can construct alternative scenarios sufficient to discriminate the effects of these pathways or processes.

The final list of the top 5 critical pathways to be addressed by modelling was determined through a voting process. The complete list of short-listed critical pathways considered during voting is presented in Appendix 4.

The top 5 critical pathways and processes in order of priority were:

1. Groundwater connectivity with surface water quality and base flow inputs.
2. Natural, oil sands and non-oil sands stressors -> surface water quality, groundwater quality and sediment quality ->fish health and human health.
3. The causal linkage between surface water quality and ecological effects (monitored changes in benthic invertebrates and fish health). Coupled water quality-quantity. Link to air deposition.
4. Atmospheric deposition links to terrestrial effects and surface water quality
5. Contaminant exposure and effects on terrestrial species persistence, biodiversity, productivity. Includes comparison to habitat effects.

"How Are We Going to Get There?"

Five break-out groups were each assigned one of the top 5 Critical Linkages or Processes. Groups were asked to answer as many of the following questions as possible:

- Are there applicable datasets and where are they?
- What spatial and temporal scales are appropriate?
- How will we address natural variability vs oil sands-related effects?
- Can we use modelling to test the relative role of other anthropogenic stressor vs oil sands-related stressors with respect to this pathway or process?
- Which environmental co-variables must be included for this pathway or process?
- What is required to integrate modelling and create model interfaces?
- What alternate scenarios should be tested to address this priority?

Five break-out groups were each assigned one of the top 5 Key Question.

Groups were asked to outline the steps required to apply geospatial science to their Key Question, in logical order.

- What partnerships are required to ensure effective model integration?

Critical Pathway #1: Groundwater Connectivity with Surface Water and Base flow Inputs

Data sources:

- AER, AEP, AGS, ECCC, industry, geospatial firms, consultancies
- Some data will be proprietary

Considerations for “model spin-up” include:

- Baseflow versus surface water modelling occurs at different scales
  - Baseflow is coarse and regional
  - Water quality is finer-scaled
- Regional scale is quite well-known
- Problems will occur at smaller scales
- Need tighter grid in the major tributaries, especially when considering ecological impacts

Model platforms include”

- Surface water: HSPF, SWAT
- Groundwater: GSFlow, Parflow

Issues:

- Point versus non-point sources
- Sediment transport
- Landscape changes
- Potentially different issues in minable versus in situ

There are many sources of data relevant to the mapping of community knowledge of traditional resources.

Data management and accessibility are being dealt with through the Operational Framework Agreement (OFA) for the OSM Program.

Communities have done a lot of work with industry regarding traditional resources as part of environmental assessments; however, open access to this information is an issue.

A process for combining community knowledge with geospatial science is required.

Capacity in Indigenous communities to translate traditional knowledge into a form amenable to mapping is an issue. There will also be a need for geospatial scientists to spend a meaningful amount of time directly interacting with members of Indigenous communities.

- Shallow Quaternary, Cretaceous, and Devonian all interact with the Athabasca River but this is not the case for the tributaries
- Quaternary is likely the issue with wetlands – requires a finer scale of analysis – may not be possible for the entire region
    - Need to define sub-watershed and sub-catchments
    - Nested modelling approaches maybe appropriate
- To start with – figure out where and when groundwater inputs are relevant
- More realistic climate models should be used

Temporal scale issues identified by the group were:

- Time steps versus time period
- Nesting in time – need to define what the nested scales are
- Time lags in effects in groundwater – duration of flow paths
- Climate change temporal scale:
    - Climate models tend to converge up toe the 2050s and then diverge
- Should consider including changes to mine plans

The hydrological connectivity questions was interpreted as pertaining to both surface water and groundwater.

There is a long list of data requirements.

Data are currently held by the government of Alberta, ABMI and industry. Data sharing agreements will likely be required with industry.

Requirements for model integration were:

- Surface geology
- Smooth and "massage" data for other users
- Non-numeric interfaces
- Figure out ways to incorporate field monitoring results on effects

Group members noted that some models already link surface water and groundwater (Mike-She, Par flow, GS-Flow, HGS).

Passing data between models externally will require building temporally variable boundary conditions.

Critical Pathway #2: Natural, Oil Sands and Non-oil Sands Stressors and Their Links with Surface and Groundwater Quality, Sediment Quality, Aquatic Biota and Human Health

The key regarding groundwater data will be to link different spatial scales and depths.

Sediment data are limited in quality and quantity. There is a need for a bed load dataset for upstream and downstream of the oil sands to the PAD as well as for tributaries.

Data needs include regional and watershed-scale groundwater data, surface water quality data for the lower Athabasca to the PAD and sediment data from upstream of the oil sands to the PD plus tributaries

The key regarding groundwater data will be to link different spatial scales and depths. Groundwater datasets are robust but limited and are assembled for specific purposes. A geological model produced by the Alberta Geological Survey (AGS) is becoming more available. Industry data (collected twice per year) are clustered around facilities. Regional models built for EIAs were compiled over time and focused on mineable and in situ area. There is a need for local scale data to supplement the regional models. There is also a need for watershed-level data.

Sediment data are limited in quality and quantity. The sediment dataset is temporally inconsistent. There is a need for a bed load dataset for upstream and downstream of the oil sands to the PAD as well as for tributaries. Sediment depth data are needed for the sediment transport model. It was noted that sediment depth can change by 5 meters in some areas of the Athabasca River.

The spatial scale of data requirements are as follows:

- Regional-scale and watershed-scale groundwater data
- Lower Athabasca River to the PAD for surface water quality
- Upstream of oil sands all the way to the PAD for sediment as well as tributaries.

A temporal baseline has to be established.

The ability to predict into the future will depend upon scale, data availability, computational demands, and information about future water release limits.

A temporal baseline has to be established. The definition of baseline should consider all stressors to groundwater, surface water and sediments. For example, the influence of upstream pulp mill discharges was detectable in the PAD. If a pre-oil sands development baseline is established, there will still need to be consideration of the influence of natural bitumen.

Group members recommended that the time-period for model predictions extend for no further than 100 years and should be scenario-based. The ability to predict into the future will depend upon scale, data availability and computational demands. Future water release limits and future development will be an important considerations that must be incorporated into the model scenarios.

Spatial and temporal scale integration of models will be required and contaminants of concern should be consistent and oil sands-related.

Group members noted that 2D models are good for open water but are not good for winter. Since the Athabasca River runs for a long period (Nov-Apr) under ice, there will be a need for annual accuracy for both open water and under ice.

Integration among groundwater, surface water and sediment models will depend upon spatial and temporal scale integration. Ideally, models would be dynamically coupled. Contaminants of concern should be consistent and oil sands-related.

Critical Pathway #3: The causal linkage between surface water quality and ecological effects (monitored changes in benthic invertebrates and fish health). Coupled water quantity-quality. Link to air deposition.

Applicable hydrology datasets exist and are well established. Water quality data are spotty for longer time series. Sediment data are very limited. Data for the PAD is an unknown. There is a need for bathymetry data upstream of Fort McMurray. There is a need for point source and non-point source data.

Applicable datasets for water quantity exist for current hydrological models. These datasets are easily adjusted and well established.

Surface water and sediment quality data are less available (particularly for sediment). There are long-term datasets but fewer upstream. There are very few data at the appropriate temporal scale. Bed sediment data are “horribly outdated”.

Data sources include academic, industry (EIAs and compliance) and government (EMSD, AER). Comments on the data include:

- Hydrological data are available over a longer time series.
- Water quality data is spotty for longer time series.
- Group members were not sure about available data for the PAD.
- Bathymetry upstream of Fort McMurray is a gap.

A fine temporal scale is needed.

The baseline temporal scale should extend back to the 1970s and early 1980s if possible but late 1980s or early 1990s would be acceptable. Upstream baseline data are required.

There is a need for point source vs non-point source data (composition and concentration).

Group members agreed that there is a need for a fine temporal scale for the hydrology/water quality modelling, with a minimum frequency of weekly. The baseline temporal scale should extend back to the 1970s-early 1980s; however late 1980s or early 1990s would be acceptable. Upstream baseline data are required. Some EIAs may have relevant baseline data but these data exist in PDF format or hard copy and detection limits have changed. The same applies to earlier data collected by AEP (e.g. as part of synoptic surveys of the Athabasca River) or data collected for the Northern River Basins Study.

High-resolution spatial scale (75 m grid) is required for the river model. A 5-10 km grid was suggested as an initial spatial scale for the PAD.

At the basin scale, upstream data are required. Then local contaminants loads can be fed into the models, allowing us to potentially pull out impacts.

Two types of model integration are required: (1) numeric; and, (2) interdisciplinary knowledge.

"….integration will be difficult but it has to be done".

High resolution spatial scale (75m grid) for the river model is critical because islands affect sediment transport. The PAD is a dynamic environment with lots of morphological change – a 5-10 km grid was suggested as a place to start. The sub-basin scale is ideal for hydrological modelling.

At the basin scale, upstream data are required. Then local contaminants loads can be fed into the models, allowing us to potentially pull out impacts. An issue that there are very few gauging stations upstream. Using a combination of LiDAR data for the banks and geo-swath data for bathymetry was suggested.

Group members agreed that integration is the most difficult aspect of addressing this critical pathway and that there will be criticism of integrated models. There are existing integrated hydrological/water quality models which can be used; however, we still need to integrate with atmospheric deposition and groundwater models and biological models.

Two types of integration are required: (1) numeric modelling; and (2) interdisciplinary knowledge. A first step will be to acknowledge and understand deficiencies. Models can be used to identify deficiencies and key uncertainties. Iterative model runs and collection of critical data will contribute to both numeric and knowledge integration.

Critical Pathway #4: Atmospheric Deposition Links to Terrestrial Effects and Surface Water Quality.

The group divided deposition into terrestrial and aquatic categories. Group members stated that the terrestrial contaminants of concern are nitrogen compounds, phosphorus and sulphur (all forms) because these contaminants affect vegetation. Aquatic contaminants of concern are nitrogen, phosphorus, sulphur, and trace metals. There are good datasets for these contaminants except for phosphorus which is difficult to measure. Group members were less certain about base cations and noted that there are fewer good data for PACs.

Current spatial resolution for deposition modelling is 2.5 km. An increase in resolution is desirable because terrestrial modelling requires very high resolution (~150m); however, computational needs may limit the ability to accomplish this. Methods to downscale need to be developed. A combination of nested models, on-the-ground measurements and off-line calculations using modelled concentrations and local land data may provide higher resolution. The group stated that such a combination may be possible with MODIS, Landsat, and Sentinel.

Bathymetry data are needed for lakes and rivers for modelling of effects of deposition on water quality. The resolution can be more coarse for water quality. Group members stated that LandSat could provide a 30m resolution.

> The group divided deposition into terrestrial and aquatic categories.
>
> Terrestrial contaminants of concern are nitrogen compounds, phosphorus and sulphur. Aquatic contaminants of concern are nitrogen, phosphorus, sulphur, and trace metals. There are good datasets for these contaminants except for phosphorus.
>
> Current spatial resolution for deposition modelling is 2.5 km. Terrestrial modelling requires very high resolution (~150m). A combination of nested models, on-the-ground measurements and off-line calculations using modelled concentrations and local land data may provide higher resolution

A large spatial scale (>1000 km) is needed to link predicted exceedances of critical loads of acidifying deposition with effects. Emissions from outside of the oil sands would have to be accounted for at the acid-sensitive water locations.

Bathymetry data are needed for lakes and rivers for modelling of effects of deposition on water quality. LandSat could provide a 30m

The group discussed the very large spatial scale of sulphur and nitrogen deposition (>1000km) and whether the scale of water quality modelling should also extend that far. It was agreed that emissions from outside of the oil sands would have to be accounted for at the water locations which might be acid-sensitive (northern Saskatchewan). Fourth-generation atmospheric models can provide this

Temporal scales to investigate the link between deposition and effects would need to go back at least 10+ years and forward 10 years. This means that 10+ years of deposition data will be needed for aquatic and terrestrial modelling. Currently, there is 1 year of deposition data, with plans to hindcast back 10 years and then project forward 10 years with additions of new emission sources.

Temporal scales to investigate the link between deposition and effects would need to go back at least 10+ years and forward 10 years.

Integration requires linking deposition to empirical information on land use/land cover for local concentrations and then to take this to the regional scale.

It was noted that the effects of acidifying emissions in waterbodies can take years to be discernible but once acidification has taken place, it may take decades or centuries to recover. Therefore, critical load exceedances give a warning but do not provide time-to-effect. The potential antagonistic effect of increasing base cation deposition is an additional important consideration, particularly given the expected shift to more in situ production with higher base cation loadings and lower acidifying emissions.

There is a need for terrestrial effects modelling (e.g. for vegetation health). Model runs could then be done for changes in land use and land cover. Vegetation health data could be acquired via Earth Observation tools.

Integration requirements for terrestrial deposition include very local land use information. There is a need to link deposition field to empirical information on land use/land cover for local concentrations and then to take this to the regional scale.

There is a need for terrestrial effects modelling (e.g. for vegetation health). Model runs could then be done for changes in land use and land cover. A lot of data on vegetation health will be required. Earth observation tools may be useful for acquiring vegetation health data. These data can then guide model integration and linkages.

Aquatic integration will require higher resolution deposition and/or very good downscaling. A possible approach is to achieve 250m resolution in restricted time windows in areas of high concern/priority.

Integration with geospatial science is required. High-resolution DEM is required and it must include bathymetry.   A common geomatics/geospatial database is needed for ALL models. Integration is then achieved via common input data. It will then be up to the modellers to smooth the data as required.

Aquatic integration will require higher resolution deposition and/or very good downscaling.

A common geomatics/geospatial database is needed for ALL models. Integration is then achieved via common input data.

Critical Pathway #5: Contaminant Exposure Linked to Terrestrial Species Persistence, Biodiversity and Productivity. Includes Comparison to Habitat Effects.

There are many applicable datasets for contaminants; however access to these data is an issue.

Post-hoc use of deposition models at finer temporal or spatial scales was suggested to investigate instances where effects have been observed.

Response data on abundance are available but there is a need to identify species which are most likely to be sensitive to contaminants (e.g. aquatic or semi-aquatic species). There is also the need to consider culturally important species.

There are many applicable datasets for contaminants; however access to these data by terrestrial researchers is an issue. Group members noted that it may be necessary to consider atmospheric deposition and aquatic contamination separately.

Post-hoc use of deposition models at finer temporal or spatial scales was suggested to investigate instances where effects have been observed. A challenge is that there can be a high correlation between contaminant concentrations and habitat change.

Response data on abundance are available but there is a need to identify species which are most likely to be sensitive to contaminants (e.g. aquatic or semi-aquatic species). There is also the need to consider culturally important species. Data for other response metrics may be available; e.g., Indigenous community information on berry production.

A comprehensive scan of potential data sources is required. Contaminant data sources include ECCC, WBEA, AEP and OSM. Response data sources include WBEA, Kel Weider (wetlands) and ABMI.

Temporal scales will primarily be retrospective. For example, there are 20 years of bird data and about 10 years of contaminant data (lichens).

The group noted that the usefulness of any new data used in terrestrial models depends on detectability of effects and the indicators.   Empirical modelling can be used to assess potential contaminant-response relationships and compare these to other drivers such as wildfire. It will be important to define what constitutes a “change” because terrestrial systems are inherently “noisy”. It will also be important to identify the most appropriate indicators using criteria such as signal-to-noise ratios, sensitivity, specificity of response, and intrinsic importance.

Temporal scales will primarily be retrospective.

The usefulness of any new data used in terrestrial models depends on detectability of effects and the indicators.

Empirical modelling can be used to assess potential contaminant-response relationships and compare these to other drivers such as wildfire.

A baseline (pre-disturbance) approach can be used to distinguish natural variability from oil sands impacts.

The group suggested that a baseline (pre-disturbance) approach can be used to distinguish natural variability from oil sands impacts. Examples of data which could be useful include: lichen samples and other archived samples; Alberta-Pacific tree measurement data; and, long-term plot data for natural and reclaimed areas (COSIA). The Integrated Terrestrial Biological Monitoring workplan was noted (COSIA (?)).

Where existing data are insufficient, the group suggested that experiments be conducted to generate new data to be used in models.

A baseline (pre-disturbance) approach can be used to distinguish natural variability from oil sands impacts.

Where existing data are insufficient, the group suggested that experiments be conducted to generate new data to be used in models. Kel Weider’s experiments with nitrogen addition to wetlands is an example. Such experiments could help compare critical loads with “observable effects loads”.

This group differed from the group discussing Critical Pathway #4 regarding terrestrial scale requirements. While Group #4 stated that terrestrial modelling required fine resolution, Group #5 stated that resolution can be coarser than that used for atmospheric deposition. This difference may be due to different scales required for vegetation health (Group #4) versus terrestrial fauna such as birds (Group #5). Notwithstanding the cause of this disparity, it will need to be addressed because effects on vegetation are, in turn, linked to effects on terrestrial fauna.

Requirements for integration include data exchange formats which must address scale, resolution, file type, geospatial coordinates, and units of measurement. Questions related to raster vs vector, projection of spatial data and embedded attributes must be addressed. Spatial analysis of plumes versus footprint is required – it was noted that this should be included in the Geospatial workplan.

Opinions differed between Groups #4 and #5 regarding terrestrial spatial resolution; Group #4 called for fine-scale and Group #5 stated that resolution can be coarser than for deposition modelling. This disparity needs to be addressed because effects on vegetation are, in turn, linked to effects on terrestrial fauna.

Requirements for integration include data exchange formats which must address scale, resolution, file type, geospatial coordinates, and units of measurement.

Environmental co-variables which must be included climate, geology, hydrologic setting, edaphic (surface, soil terrain), fire, and distance to other land uses such as agriculture.

Additional Suggestions and Ideas

Participants were asked to write their additional suggestions and ideas regarding the critical pathways on flip charts. These are listed below.

<u>Which environmental co-variables must be included?</u>

- Comment 1:
  - Hydrology from upland to lowland
  - Climate to snow
  - Land use-land cover
  - Soil
  - Landscape (wetlands)

  - Ice/glacier
  - Geology
  - Sediment
- Comment 2: Variability not just means
- Comment 3:
  - Climate
  - Terrain
  - Forest fires
  - Ecoregion change
  - Climate and fire effects on vegetation types with time
- Comment 4:
  - Climate
  - Natural disturbance
  - Edaphic (surface, soil, terrain)
  - Hydrologic setting
- Comment 5:
  - Vapor flux from land makes precipitation and guides thermal and vice versa
  - Link climate models to water models – dynamic feedback should be 2-way
- Comment 6
  - Distance to agriculture
- Comment 7 – depends on the research question
- Comment 8
  - Precipitation

Participants suggested a high resolution and locally adapted regional model vs a small-scale local model for addressing natural variability vs oil sands-related effects for Critical Pathway #3. Integration of upstream hydrology/water quality models with downstream and delta models was also suggested.

Isotope and chemical fingerprinting plus air modelling which shuts off oil sands emissions were suggested for Critical Pathway #4.

Data from experiments that control for natural variability or a high quantity of data across a gradient of oil sands exposure were suggested for Critical Pathway #5. Model integration and stochastic modelling were also suggested for this pathway.

  - Snow pack

How Will We Address Natural Variability vs Oil Sands Effects?

- For Critical Pathway #3:
  - a high resolution and locally adapted “regional” model versus a local-small scale and single-objective driven model. This required integration of existing models and data in a “Model Framework”
  - Integration of upstream hydrology-water quality models to downstream hydrodynamic and delta models
- For Critical Pathway #4:
  - Isotope work and chemical fingerprinting for contaminants.
  - Air: shut off oil sands emissions as a scenario and what’s left is natural variability plus other non-oil sands sources
- For Critical Pathway #5:
  - either new data from experiments that control for natural variability OR by high quantity of data across a gradient of oil sands exposure to enable post-hoc/retrospective analysis to detect oil sands signals
  - Use stochastic models to capture variability in projections
  - Integrate NRCan Burn P3 model with land use scenario (i.e., ALCES, Patchworks) with set climate scenarios. Hydrology models need to link to fens etc. more explicitly.
- Spatial analysis and trends – regional vs local oil sands

There was general agreement that modelling can be used to test the relative role of other anthropogenic stressors vs oil sands-related stressors.

Comparison of scenarios which add or remove stressors could be used to discriminate among anthropogenic stressors.

The importance of baseline was reiterated with respect to discriminating among anthropogenic stressors

A key question is at what resolution are we content with the answer

Removing oil sands emissions from the modelling, and stochastic modelling, were again suggested for this question.

Can we use modelling to test the relative role of other anthropogenic stressors vs oil sands-related stressors?

- Yes- with different scenarios, adding or removing stressors to the models
- Yes – we do to some extent already; however, we need to ensure models are parameterized with data that are not confounded (i.e., need to make sure we have data from sites that are not impacts by oil sands)
- Yes – there are a variety of different methods and models which can be used to detect non-oil sands vs oil sands stressors. These are “regional” integrated modelling systems that combine hydrology+river+delta+experimental studies of fish sensitivity
- Yes, but the key question is to what resolution are we content with the answer?.
- Yes, at least for relative contribution to atmospheric deposition (provided the emissions inventories are good enough)
- To some extent, but need to determine the baseline
- Yes but need to include non-oil sands processes in the models and scenarios
- Zero-out the oil sands emissions – easy to do for the air site and keep the other anthropogenic emissions and compare the two simulations
- Variable importance/partitioning using ML/stochastic modelling

What partnerships are required to ensure efficient model integration?

- Industry has considerable Ph.D.-level water modelling expertise – use this
    - Fully integrated and dynamic surface water-groundwater interaction models have already been built – don’t reinvent the wheel
- Partnerships with Indigenous communities
- Two-year secondment of subject matter experts and modelers into physically co-located teams to build the structure for integration
- Maintain the momentum that exists plus what has been created by the workshop series
    - Ongoing working group conference calls and occasional in-person meetings

> Partnerships with industry were recommended to take advantage of models which have already been built.
>
> Partnerships with Indigenous communities are required.
>
> Several suggestions were made for maintaining the momentum created by the workshop series.

- Monthly webinar series to present/share recent results and planned work
- Leader charged with ensuring integration of groups is absolutely required – a “quarterback” to coordinate the team and make sure all players are working and communicating towards a common goal
- Communities of Practice

Need stronger partnerships between western scientists and Indigenous community members to design modelling and identify receptors of interest

What alternate scenarios should be tested?

- Long-term effects to human health from oil sands-related contaminants
- Alternate reference state/natural range of variability (at least for terrestrial biodiversity)
- Future developments of oil sands and non-oil sands plus climate change effects
- Long-term effects at the community level on traditional foods
- Reclamation to land uses that support Indigenous economies
- Air scenario with no oil sands emissions to give relative impact of oil sands on concentrations and deposition
- Future projected emission scenarios e.g., more in situ, new surface mines (e.g. Teck), decommissioned surface mines.
- Alternate future scenarios such as “business as usual”, “clean technology”, “expansion open pit”, “in situ future development”

Suggested alternate scenarios included future oil sands and non-oil sands developments plus climate change.

Reclamation to land uses that support Indigenous economies was suggested as a scenario.

Future projected emissions scenarios could include more in situ, more surface mines, decommissioned surface mines.

“Business as usual”, “Clean Technology”, “Expansion open pit” and “in situ future development” were 4 suggested alternate future scenarios.

Conclusions Regarding the State of the OSM Program With Respect to Achieving the Three Core Outcomes

The conclusions arising from the seven workshops, together with the Key Uncertainties and Key Questions, form the basis for the Recommendations Report.

The conclusions from the Terrestrial Biological Monitoring, Groundwater, Surface Water and Aquatic Biology, Atmospheric Deposition and Mercury workshops with respect to the Three Core Outcomes of the OSM Program are presented below.

Current Environmental State or Condition

General

- The OSM Program has produced a substantial body of information regarding the spatial and temporal distribution of environmental stressors in the oil sands region (with emphasis on mineable oil sands areas); this information has been generated through a combination of field monitoring and predictive modelling.
- With the exception of Terrestrial Biological Monitoring, stressor information is focused on contaminants.
- There is still work to be done on establishing appropriate baselines in order to determine whether there have been spatial or temporal changes in state or condition.

Terrestrial

- Regional-scale habitat disturbance due to oil sands and non-oil sands stressors is well documented.
- The caribou population has declined substantially and strong shifts in bird communities have been observed; however, the relative contribution of oil sands development to these trends is uncertain.
- Some oil sands-related contaminants have been measured in some species (e.g., furbearers, semi-aquatic birds); however, the significance of measured levels to wildlife health and population metrics is poorly understood.

- Detection of change is highly dependent on spatial and temporal scale; there are mis-matches between the scale of habitat disturbance mapping and observed changes in species.
- Baseline information is lacking for certain stressors and the baseline is continuously changing at different rates in different areas.
- There is a disconnect between compliance monitoring (inside the fence) and OSM Program monitoring.

Groundwater

- Groundwater monitoring under the OSM Program is in the formative stage. Available groundwater data for the oil sands region were not collected to address the specific objectives of the OSM Program. Data are from several sources including compliance monitoring conducted by industry, provincial groundwater monitoring networks, and federal groundwater investigations which focussed on specific priority assessment and method development
- Local-scale (primarily on-site) effects are understood, both in terms of groundwater quantity and quality, at least in terms of compliance with permit requirements.
- Access to all relevant groundwater data is a key requirement, followed by a synthesis report.
- There has been a substantial effort dedicated to groundwater modelling in support of environmental assessments (EAs), government policy and planning or academic research. However, there has been little collaboration and sharing of results. Validation of model predictions made in EAs is rare, particularly beyond the site scale

Surface Water and Aquatic Biology

- Most of the surface water and aquatic biology information is from oil sands mining areas.
- There are consistent flow-related seasonal water quality patterns in the lower Athabasca River that are caused either by dilution during high flows or association with suspended sediments. These patterns are not oil sands-related, although oil sands development is one source of chemicals measured in the river water.
- There is a spatial pattern of increasing concentrations (amount in a certain volume) and loads (amount per a period of time) upstream versus downstream in the Athabasca

mainstem for total vanadium, dissolved selenium and dissolved arsenic. It is unknown if this is a global pattern for rivers of this region.

- There is a temporal pattern of increasing concentrations of some dissolved and total metals in the Athabasca mainstem. Total phosphorus also showed an increased downstream of Fort McMurray, but this increase has levelled off over the last 15 years with improved Fort McMurray sewage treatment.
- Historic and current water flows are highly variable and future variability is predicted to be strongly affected by climate variability and change. Mean annual flow is predicted to increase with an overall shift to increased winter flow, earlier freshet and decreased summer flow.
- Modelling of the Muskeg River Basin has shown that flows respond differently to climate and land cover changes. Flows decrease in response to land cover changes (because of changes in evapotranspiration) and increase in response to climate change (wetter and warmer conditions).
- Assessments indicate that ice-jam releases and the resulting energy waves in the water generate extreme erosive forces and suspended sediment concentrations. Spring breakup generates the highest total suspended solids loads for the year.
- The current status of benthic invertebrate communities in tributaries shows a difference between sites within oil sands development footprints and reference sites; however, the effects of natural bitumen deposits cannot be distinguished from the effects of oil sands development.
- Benthic invertebrate communities in the mainstem Athabasca River showed increases in the relative number of tolerant taxa, both in the area affected by Fort McMurray sewage discharges and adjacent to oil sands developments.
- Laboratory exposure of fathead minnows to natural oil sands sediment from the Steepbank and Ells Rivers was associated with some non-lethal deformities and changes to social behaviour and poor egg production. Exposure to undiluted melted snow from site near oil sands mines decreased larval fish survival, but exposure to spring runoff water did not affect survival. This shows that dilution may be sufficient to limit impacts to fish.
- The fish health response pattern in the mainstem Athabasca was indicative of nutrient enrichment. This pattern has declined with time, coincident with improved Fort McMurray sewage treatment.

- There is an absence of information on lakes. There has been a strong focus on erosional habitats in both the mainstream Athabasca and in tributaries versus habitats where sediments are deposited (e.g. back channels and pools). Wetland monitoring information has not been integrated with the surface water information.

Atmospheric Deposition

- In general, monitoring and modelling of atmospheric deposition has indicated that deposition is enhanced within ~10-100 km of surface mining depending upon the chemical of concern.
- Total sulphur deposition in the oil sands region (<100 km) is dominated by dry and wet sulphur dioxide. There is a good understanding of seasonal patterns.
- Total nitrogen deposition is poorly understood in part because of the large number of reactive nitrogen species and confounding processes. There is still a limited understanding of key components of total nitrogen deposition including wet deposition, bi-directional ammonia exchange and contribution of other nitrogen species.
- Acidification of streams and lakes caused by the deposition of sulphur and nitrogen compounds has not been observed except in some streams during spring freshet. Some model simulations predict acidification, but these predictions have not been verified by field data.
- Base cation (calcium, magnesium, sodium and potassium) deposition is poorly understood because of the lack of measurement needed to calculate dry deposition. There is some evidence of alkalization (increase in pH) in shallow lakes less than 50 km from oil sands operations because of deposition of base cations. There is evidence that base cation deposition is neutralizing acidifying deposition near oil sands facilities. Effects of alkalization on vegetation are uncertain.
- Total mercury deposition is poorly understood. The contribution of oil sands operations to mercury deposition beyond ~30 km might be small. Mercury deposition decreases exponentially with distance from oil sands sources up to ~80 km. Mercury and methyl mercury in snow packs are predominantly bound to particles, which likely explains the higher deposition closer to oil sands operations.
- Total trace element deposition is poorly understood. The deposition of most of the trace elements decreases exponentially with distance from oil sands sources up to ~85 km.. However, there are some elements (e.g. cadmium and chromium) with no spatial gradients in deposition, which suggests the impact of local and regional sources rather

than oil sands development. Trace elements are occasionally above guidelines for soil, snowmelt and water. Actual effects from these concentrations on aquatic or terrestrial biota have not been reported.

- PAC deposition is higher near major oil sands developments and declines exponentially with distance because most PACS are bound to particles that deposit near emissions sources. Alkylated PACs are the dominant PAC species in snow packs within 50 km of oil sands operations. The highest deposition to snow packs has been observed over the Athabasca River between the Muskeg and Steepbank Rivers where oil sands development is most intense. Higher deposition is also found along the north-south directions than east-west directions.   Some parent polycyclic aromatic hydrocarbon (PAH) compounds exceed soil and sediment guidelines. There are no guidelines for alkylated PAHs or dibenzothiophenes (DBTs) which are predominantly associated with oil sands sources.
- Enhanced concentrations of PACs have been observed in wolves, moose, caribou and birds. Negative effects have been observed in otters, although not at the population level. No negative effects were observed in the aquatic invertebrate *Daphnia* (water flea).

Mercury

- There is no apparent oil sands-related pattern for:
    - Air (gaseous elemental Hg)
    - Lake water
    - Lake sediment
    - Lichen
    - Large-bodied fish
- Elevated mercury has been observed in:
    - Atmospheric deposition (local)
    - Snow (local)
    - Athabasca River water downstream of the Clearwater River
    - Small-bodied fish (very limited data)

    - Waterbird eggs (related to sediment transport – origin of mercury in sediment is subject to question)

Stressor-Response Relationships

General

- Effects on some terrestrial and aquatic biota have been observed and/or predicted; however, confirmed causal links between effects and oil sands-related stressors have not been established

Terrestrial Biological Monitoring

- While changes in some populations and communities (particularly land birds and caribou) have been observed relative to land disturbance, it is difficult to tease out the effects of oil sands-related disturbances from the effects of other habitat disturbances. Effects of some oil sands-related stressors on some land bird species can be discriminated from other stressors and synergistic effects must be considered; however, the spatial scale of such studies is important.
- While there is strength in understanding habitat loss, we need a better understanding of the effects of changes in habitat quality on valued species and rare species.
- The effects of increased human access require more study.
- Oil sands-related effects on food security have not been adequately addressed. Furthermore, information about effects on birds, furbearers, and vegetation, including culturally important plants, is lacking.

Groundwater

- Linkages between stressors and effects on groundwater resources are not well characterized, particularly beyond the local (site) scale
- The lack of sufficient baseline data and/or lack of access to relevant, synthesized baseline data limits the ability to discriminate the effects of oil sands-related, natural, and other anthropogenic stressors
- There are several knowledge gaps which prevent us from understanding oil sands-related effects on groundwater at the sub-regional and regional scales.

Surface Water and Aquatic Biology

- The strength of relationships between three primary stressor sources – municipal discharges, oil sands operations, and natural bitumen - and effects on benthic invertebrate communities and fish health in the mainstem Athabasca varies. There is strong evidence for the effect of municipal effluent on benthic invertebrates and fish health. There are fairly strong links between all three sources and water quality in the mainstem . Sediment quality reflects both natural bitumen and industry sources; however, discriminating between natural and industry effects on benthic and fish health is difficult.

- Causes of observed responses to stressors in tributaries are still uncertain. Benthic invertebrate communities show evidence of mild environmental stress; however, the relative role of natural bitumen versus industry-related stressors in causing observed decreases in sensitive taxa is still not clear. Similarly, increased liver size in slimy sculpin may be due to natural bitumen exposure, industry-related chemical releases, or both.

- Effects on physical habitat caused by water diversions, elimination of wetlands, ponds and lakes and portions of tributaries, and modifications to stream channels have not been a focus of past monitoring. Therefore, the relative effect of changes in quantity and quality of habitat versus contaminant-related effects is unknown

Atmospheric Deposition

- There is little evidence of widespread acidification due to nitrogen or sulphur deposition, likely due to the mitigating effect from concurrent base cation deposition. Several studies have observed deposition of base cations exceeding the sum of acidifying pollutants within tens of kilometres of oil sands facilities.

- There is evidence that base cation and nitrogen deposition within about 50 km of oil sands facilities are affecting terrestrial ecosystems. Observations include: (1) difference between soil microbial communities along the nitrogen + sulphur deposition gradient; (2) negative correlation between elevated nitrogen/sulphur/base cation deposition and moss/lichen cover and richness and (3) negative correlation between internode length and acidifying deposition.

- There is no evidence that enhanced nitrogen or phosphorus deposition has caused eutrophication in aquatic ecosystems.

- Experimental application of nitrogen to a bog near Mariana Lakes, AB stimulated nitrogen fixation up to 3.1 kg/ha but then progressively inhibited nitrogen fixation above this level. Increasing experimental nitrogen input led to a switch from new nitrogen being taken up primarily by *Sphagnum* to being taken up primarily by shrubs. As shrub growth and cover increase, *Sphagnum* abundance and NPP decrease. The results were use to derive a recommended nitrogen deposition critical load of 3 kg N per ha per year

Mercury

- There are few very stressor-response data regarding responses to oil sands-related mercury concentrations
- Mercury concentrations in waterbird eggs in the Athabasca River downstream of oil sands development have increased compared to the year of earliest collection. These concentrations are unrelated to forest fire events and long range transport of mercury, suggesting that oil sands development or local sources of mercury are affecting egg mercury levels or there are other factors which create conditions leading to methylation of mercury (and thus uptake into eggs). Some egg samples exceeded the lower limit of the threshold for effects on reproduction
- This is no evidence to date linking the oil sands industry to observed mercury concentrations in Lake Athabasca fish

Cumulative Effects Assessment

General

- Cumulative effects have received little attention to date in the OSM Program
- Integration among OSM Themes is required to address cumulative effects. Assessing the incremental contribution of oil sands-related stressors to cumulative effects will require methods for identifying specific activities responsible for habitat disturbances. It was noted that oil sands-related disturbance cannot be assessed in isolation of other disturbances and that climate change is an important contributor or modifier of cumulative effects
- Assessment of cumulative effects must address the interactions between oil sands-related activities and other sources of disturbance, notably forestry.
- Indigenous knowledge should play an important role in the assessment of cumulative effects. Knowledge can be applied at various spatial and temporal scales.

Terrestrial Biological Monitoring

- ABMI is now at a point where changes in species can be estimated in relation to cumulative habitat disturbance; however, these modelled predictions will require field verification. The time required for verification is an important consideration because by the time a predicted change is verified, it may be too late to prevent or mitigate the habitat disturbances.

Groundwater

- Knowledge of cumulative effects on groundwater beyond the local scale is very limited.
- Although regulatory permits stipulate that there be no discharges to groundwater by oil sands operations, releases due to seepage, landscape disturbance, spills and other malfunctions should be considered.
- Production of cumulative risk map can be a starting point. These maps would be developed using our existing understanding of sources and pathways and the relative vulnerability of the groundwater resources (both shallow and deep). The maps could include explicit recognition of uncertainty.
- There may be a better opportunity for understanding cumulative effects on groundwater quantity rather than quality because changes in quantity are easier to detect in the short-term and EAs may include more baseline data.

Surface Water and Aquatic Biology

- Nutrient-contaminant interactions are possible below Fort McMurray where municipal sewage effluent and oil sands-related exposure occurs; however, these interactions have not been investigated in detail. Interpretation of cumulative effects in tributaries is confounded by natural bitumen exposure.
- Assessment of the combined effects of fish habitat changes due to land disturbance, changes in groundwater discharge patterns and flows, and natural disturbances such as fire require integration among OSM Themes.
- Participants noted that there needs to be clarity regarding investigation of the cumulative effects of *multiple stressors* versus the assessment of cumulative effects of *several sources of a particular stressor* distributed over time and space. These two types of cumulative effects may both be important in the oil sands region

Atmospheric Deposition

- Multiple stressor effects from the combination of deposited contaminants is a topic requiring further study. Additive, synergistic or antagonistic relationships can occur among multiple stressors
- The combined effects of atmospheric deposition plus climate change or landscape disturbance were raised as a potential issue requiring assessment in all oil sands regions

Mercury

- The relative contribution of the oil sands industry to cumulative mercury loadings to air, water and sediments and subsequent concentrations in biota is still highly uncertain.

The Application of Geospatial Science and Predictive Modelling to the Three Core Outcomes

Geospatial Science and Predictive Modelling provide tools to achieve all three core outcomes. A summary of useful tools and approaches is presented below.

Geospatial Science

Geospatial science has been successfully applied to the assessment of environmental condition as well as detection of change (OSM Core Outcome #1). However, it has been less frequently used to evaluate stressor-response relationships (OSM Core Outcome #2) particularly with respect to specific oil sands-related stressors at appropriate spatial and temporal scales. Geospatial science is required for assessment of cumulative effects across theme areas.

- Tools such as LiDAR can be used for indicating current state as well as temporal change in features such as wetland extent, water level, canopy height, and vegetation condition in the oil sands region
- GIS pixel frequency maps can be used to provide baseline information, including baseline changes with time.
- GIS pixel frequency maps can be used to provide baseline information, including baseline changes with time.
- ABMI geospatial data are available for application to the OSM Program objectives. Both downloadable static datasets and web applications of real-time and historical data are available.

- Remote sensing of the Peace Athabasca Delta is being used to build additional understanding of baselines through observations of spatial and temporal changes.
- Remote sensing has provided valuable baseline data over large spatial areas using a repeatable timeline.
- Remote sensing provides reference information from nearby natural regions for comparison to areas exposed to stressors such as water use/abstraction and landscape disturbance.
- Field data validation of remote sensing and modelling is required for a complex system such as the PAD. Community based monitoring will continue to play an important role in this validation.
- In some cases, cumulative effects can be mapped (OSM Core Outcome #3). However, distinguishing the effects of natural stressors from anthropogenic stressors is difficult
- Cumulative effects with respect to forest and wetland structural health have been mapped in the oil sands region. Comparisons between burned and non-burned wetlands as well as structural health as a function of distance and direction from active mining operations and atmospheric emissions have been conducted. These analyses have illustrated the importance of wildfire in the region and the challenge of separating natural and oil sands-related effects.

Predictive Modelling

Predictive modelling has been a central tool in establishing condition or state Core Outcome #1). It has not been used as extensively to investigate stressor-response relationships. Predictive modelling will be essential to the assessment of cumulative effects.

The contributions of modelling and further modelling needs include:

Atmospheric Deposition

- Modelling has produced a relatively good set of estimates of the spatial distribution of atmospheric deposition; however, there are some gaps for specific stressors
- Connections between oil sands industry sources and deposition have been inferred from estimated spatial distribution patterns. More scenario simulations such as those run for mercury could address relative source contributions and other important questions
- Air modelling has focussed on source-pathway linkages. Stack emissions have been the primary source considered. Land disturbance sources have not been a specific focus

- Integration is required to address stressor-response relationships, interactions along exposure pathways, and cumulative effects. This has not yet occurred

Groundwater

- Most existing groundwater models were not developed specifically to address OSM objectives
- Regional -to-site level model scales are the most applicable to the OSM Program. Information relevant to OSM Program core outcomes has been produced by past and current modelling
- Sub-watershed, project scale models performed as part of most EIAs Project-are built for the purpose of comparing pre-development, current and full-build scenarios.   Therefore, they inherently examine expected change in response to oil sands development
- Current groundwater models can be used to run sensitivity analyses for identification of the key drivers of oil sands-related effects. Scenario analyses can be used to compare and contrast effects on features such as groundwater level with various degrees of current and future surface disturbance and groundwater withdrawals
- There are some existing groundwater models which were designed to address cumulative effects
- The linkages between natural and oil sands-related factors and groundwater recharge and discharge have been addressed by past groundwater modelling. Taken together, the results of these modelling exercises can be evaluated for the relative importance of linkages with natural, oil sands and non-oil sands-related factors
- Past modelling results have indicated the importance of wetlands and precipitation to recharge, predicted local impacts on water level, identified high intrinsic vulnerability areas and predicted recovery times for aquifer heads

Surface Water

- Extensive hydrologic and surface water quality modelling has taken place to produce historic, current and projected future spatial and temporal variability of flow, sediment transport, water quality and sediment quality. Effects of climate change and land use have been modelled

- Historical baseline models provide reference levels against which current and future changes can be assessed. This baseline has been used to evaluate the impacts of climate change and land use change on hydrology, water quality or fish habitats
- Models can be used to investigate stressor-response relationships and causation through the use of scenario analysis which compare and contrast predicted effects from different combinations of stressors
- To date, water quality models have not been focussed on distinguishing among stressor sources or effects. Nor have they focussed on critical drivers of effects
- Progress has been made with respect to cumulative effects, particularly with respect to climate change plus land use change effects on hydrology
- Past and current modelling has identified the critical role of weather and climate on hydrology of the lower Athabasca system. Hydrology, in turn, drives pathways and mechanisms which can lead to effects
- Several linkages remain poorly understood, including linkages between natural bitumen and water or sediment quality and between atmospheric deposition and water quality

Terrestrial

- Terrestrial modelling has focussed on evaluating and predicting relationships between stressors related to major land use categories (“footprint groups”) and responses in species or communities
- Footprint groups include agricultural, forestry, transportation, human-created waterbodies, urban, rural and industrial and energy (mines, wells and other energy features)
- The relative effects of “footprint groups” or “sectors” have been evaluated.
- Relationships between forest composition and structure and bird abundance have been assessed
    - Models are currently being updated for application to oil sands-related stressors
- While the modelling of bird responses is well developed, models for other taxa may not be as established

- Population dynamics modelling results are being compared among regions such as “western mineable”, “eastern mineable” and “All Lower Athabasca Production Region” for population parameters such as occupancy, colonization and extinction

With increasing number of repeated field samples, modellers are getting better at testing whether local and regional changes in footprint are correlated with population parameters

Appendix 1: Workshop Attendees

Terrestrial Biological Monitoring

Name	Organization
Dan Farr	Workshop Lead AEP
Samantha Song	Workshop Lead ECCC
Bruce Pauli	Workshop Lead ECCC
Jeff Ball	Workshop Lead ECCC
Maureen Freemark	Workshop Lead ECCC
Principal Investigators	
Erin Bayne	University of Alberta
Judith Toms	ECCC
Shannon White	Alberta Biodiversity Monitoring Institute
Stephen Lougheed	Alberta Biodiversity Monitoring Institute
Tara Narwani	Alberta Biodiversity Monitoring Institute
Sara Depoe	AEP
Stephanie Connor	AEP
External Experts	
Jason Fisher	Innotech Alberta.
Carolyn Campbell	Alberta Wilderness Association

Rhona Kindopp	Parks Canada Agency
Joseph Culp	ECCC
Allen Legge	Biosphere Solutions
Garry Scrimgeour	AEP and University of Alberta
Indigenous Representatives	
Carla Davidson	OFA Task Team
Eddison Lee-Johnson	OFA Task Team
Gillian Donald	OFA Task Team
Cameron Johnson	OFA Task Team
Ave Dersch	OFA Task Team
Industry Representatives	
Ole Mrklas	COSIA Director of Monitoring
Tyler Colberg	COSIA, Imperial
Janice Lineham	COSIA, Suncor
Ted Johnson	COSIA, Cenovus
Other OSM Program Theme Representatives	
Faye Wyatt (Geospatial Science)	AEP
Greg Wentworth (Atmospheric Science)	AEP
OSM Program Leadership and Secretariat	

Monique Dubé	Science Co-Lead
Kevin Cash	Science Co-Lead
Fred Wrona	Program Co-Chair
Jaime Dawson	Secretariat: ECCC
Tim Arciszewski	Secretariat: AEP
Yemi Ilesanmi	Secretariat: AEP

Groundwater (New OSM Program Theme)

Name	Organization
Cynthia McClain	Workshop Lead, AEP, EMSD
Greg Bickerton	Workshop Lead, ECCC
Laura Smith	AEP, EMSD
Colin Cooke	AEP, EMSD
James Roy	Environment and Climate Change Canada
John Spoelstra	Environment and Climate Change Canada
Steve Wallace	AEP, Policy and Planning
Alex Oiffer	AEP, Policy and Planning
Tomislav Renic	AEP, Operations
External Experts	

Jean Birks	Innotech
Steve Grasby	Natural Resources Canada, GSC
Rich Petrone	U of Waterloo
Dan Palombi	AGS
Brian Smerdon	AGS
Matthew Elmes	University of Waterloo
Jon Fennell	University of Alberta/Integrated Sustainability
Industry Representatives	
David Edwards	COSIA, CNOOC International
James Guthrie	COSIA, Imperial
Brian Tsang	COSIA, Suncor
Dallas Heisler	COSIA, Syncrude
Indigenous Representatives	
Sanil Sivarajan	Fort McKay Métis
Other OSM Program Theme Representatives	
Dan Farr (Terrestrial Biological Monitoring)	AEP, EMSD
Colin Cooke (Surface Water)	AEP, EMSD
Craig Mahoney (Wetlands)	AEP, EMSD

Anil Gupta (Surface Water; Predictive Modelling)	AEP, EMSD
Faye Wyatt (Geospatial Science)	AEP, EMSD
OSM Program Leadership and Secretariat	
Monique Dubé	Science Co-Lead
Fred Wrona	Program Co-Chair
Tim Arciszewski	Secretariat: AEP

Surface Water and Aquatic Biology

Name	Organization
Joseph Culp	Workshop Lead, ECCC
Colin Cooke	Workshop Lead, AEP
John Orwin	Workshop Lead, AEP
Principal Investigators	
Alexa Alexander-Trusiak	ECCC
Donald Baird	ECCC
Robert Brua	ECCC
Ian Droppo	ECCC
Rick Frank	ECCC
Nancy Glozier	ECCC

Yamini Gopalapillai	ECCC
Mark McMaster	ECCC
Anil Gupta	AEP EMSD
Keegan Hicks	AEP
Paul Drevnick	AEP
External Experts	
Queenie Gray	Parks Canada
Rod Hazelwinkel	AEP EMSD
Jan Ciborowski	University of Windsor
Jordan Musetta-Lambert	ECCC
Carolyn Campbell	Alberta Wilderness Association
Shannon White	ABMI
Jason Kerr	AEP
Mark Poesch	University of Alberta
Indigenous Representatives	
Findlay MacDermid	Dene Ni Nenne Manager
Carla Davidson	Athabasca Region First Nations
Jesse Sinclair	LGL Ltd
Sanil Sivarajan	Fort McKay Métis

Industry Representatives	
Joanne Hogg	COSIA, CNRL
James Guthrie	COSIA, Imperial
Ole Mrklas	COSIA, Director of Monitoring
Carla Wytrykush	COSIA, Syncrude
Other OSM Program Theme Representatives	
Faye Wyatt (Geospatial Science)	AEP
Cynthia McClain (Groundwater)	AEP
Leming Zhang (Atmospheric Science)	ECCC
OSM Program Leadership and Secretariat	
Monique Dubé	Science Co-Lead
Tim Arciszewski	Secretariat, AEP
Kevin Cash	Science Co-Lead, ECCC
David Roberts	Secretariat, AEP

Atmospheric Deposition

Name	Organization
Stewart Cober	Workshop Lead, ECCC
Gregory Wentworth	Workshop Lead AEP, EMSD

Leiming Zhang	Workshop Lead ECCC
Principal Investigators	
Bob Myrick	AEP, EMSD
Ewa Dabek	Environment and Climate Change Canada
Tom Harner	Environment and Climate Change Canada
Yamini Gopalapillai	Environment and Climate Change Canada
Paul Makar	Environment and Climate Change Canada
Jean-Pierre Charland	Environment and Climate Change Canada
Michael Bisaga	LICA
Sanjay Prasad	WBEA
Eric Edgerton	ARA Inc., on behalf of WBEA
Ellen MacDonald	University of Alberta, on behalf of WBEA
Kel Wieder	Villanova University
External Experts	
Jason Ahad	NRCAN
D. Court Sandau	Chemistry Matters
Julien Aherne	Trent University
Shaun Watmough	Trent University
David Spink	Fort McKay First Nations

Allan Legge	Consultatnt
Indigenous Representatives	
Fin MacDermid	Cold Lake First Nations
Adi Adiele	Fort McKay Métis
Carla Davidson	Athabasca Region First Nations
Industry Representatives	
Tyler Colberg	COSIA, Imperial
Rekha Nambiar	COSIA, Suncor
Chris Fordham	COSIA
Ole Mrklas	COSIA
Policy and Planning	
Aaron Petty	AEP, Policy
Wally Qiu	Alberta Energy Regulator
Other OSM Program Theme Representatives	
Dan Farr (Terrestrial Biological Monitoring)	AEP, EMSD
Ian Droppo (Surface Water)	Environment and Climate Change Canada
Faye Wyatt (Geospatial Science)	AEP, EMSD
OSM Program Leadership and Secretariat	
Monique Dubé	Science Co-Lead AEP, EMSD

Laird Shutt	Director General, Atmospheric Science and Technology. ECCC
Kevin Cash	Science Co-Lead ECCC
Tim Arciszewski	Secretariat AEP, EMSD
Cassie Rauert	Secretariat, ECCC

Geospatial Science

Name	Organization
Faye Wyatt	Workshop Lead, AEP
Colleen Mortimer	Workshop Lead, AEP
Daniel Peters	Workshop Lead, ECCC
Donald Baird	Workshop Lead, ECCC
Geospatial Science Practitioners	
Jason Duffe	ECCC
Paul Zorn	Parks Canada
Jahan Kariyeva	ABMI
Chris McLinden	ECCC
Wendy Monk	ECCC
Shane Patterson	AEP
Craig Mahoney	AEP

External Experts	
Chris Bater	Alberta Agriculture and Forestry
Rhona Kindopp	Parks Canada
Kristin Eccles	University of Ottawa
Matt Landis	Integrated Atmospheric Solutions, LLC
Olaf Niemann	University of Victoria
Mir Mustafizur	University of Calgary
Dennis Chao	Alberta Geological Society
Indigenous Representatives	
Adi Adele	Fort McKay Métis
Maxwell Zhira	Owl River Métis Local #1949
Sanil Sivarajan	Fort McKay Métis
Industry Representatives	
Alison Blackstock	COSIA, Sncrude
Tyler Colbert	COSIA, Imperial
Calvin Duane	COSIA, CNRL
Rodney Guest	COSIA, Suncor
Other OSM Program Theme Representatives	

Anil Gupta (Surface Water, Predictive Modelling)	AEP
Cynthia McClain (Groundwater)	AEP
John Orwin (Surface Water)	AEP
Greg Wentworth (Atmospheric Science)	AEP
Dan Farr	AEP
OSM Program Leadership and Secretariat	
Monique Dubé	Science Co-Lead: AEP
Jaime Dawson	Secretariat: ECCC
Tim Ariszewski	Secretariat: AEP
David Roberts	Secretariat: AEP

Mercury

Name	Organization
Bruce Pauli	Workshop Lead: ECCC
John Chételat	Workshop Lead: ECCC
Maureen Freemark	Workshop Lead: ECCC
Principal Investigators	
Alexandra Steffan	ECCC
Ashu Dastoor	ECCC

Yamini Gopalapillai	ECCC
Craig Hebert	ECCC
Philippe Thomas	ECCC
Colin Cooke	AEP
Paul Drevnick	AEP
External Experts	
Kristin Eccles	University of Ottawa
Christina Suzanne	University of Calgary
Queenie Gray	Parks Canada
Indigenous Representatives	
Maxwell Zhira	Owl River Métis Local #1949
Adi Adiele	Fort McKay Métis
Brenda Miskimmin	Fort McKay First Nation
Carla Davidson	Athabasca Region First Nations
Industry Representatives	
Joanne Hogg	COSIA, CNRL
Ole Mrklas	COSIA, Director of Monitoring
Janice Linehan	COSIA, Suncor
Carla Wytrykush	COSIA, Syncrude

Other OSM Program Theme Representatives	
Leiming Zhang (Atmospheric Science)	ECCC
Roderick Hazewinkel (Surface Water and Aquatic Biology)	AEP, EMSD
Alexa Alexander-Trusiak (Surface Water and Aquatic Biology)	ECCC
Mark McMaster (Surface Water and Aquatic Biology)	ECCC
Faye Wyatt (Geospatial Science)	AEP, EMSD
Anil Gupta (Surface Water, Predictive Modelling)	AEP, EMSD
OSM Program Leadership and Secretariat	
Monique Dubé	Science Co-Lead, AEP
David Roberts	Secretariat: AEP
Tim Arciszewski	Secretariat: AEP
Judy Smith	OSMP Stakeholder Liaison

Predictive Modelling

Name	Organization
Anil Gupta (Surface Water)	Workshop Lead: AEP
Paul Makar (Atmospheric Deposition)	Workshop Lead: ECCC

Greg Bickerton (Groundwater)	Workshop Lead: AEP
Bruce Pauli (Mercury, Terrestrial Biological Monitoring)	Workshop Lead: ECCC
Faye Wyatt (Geospatial Science)	Workshop Lead: AEP
Dan Farr (Terrestrial Biological Monitoring)	Workshop Lead: AEP
John Orwin (Surface Water)	Workshop Lead: AEP
Principal Investigators	
Brandi Newton	AEP
Erin Bayne	University of Alberta
Babak Farjad	AEP
External Experts	
David Sauchyn	University of Regina
Greg Goss	University of Alberta
Monireh Faramarzi	University of Alberta
Xinzhong Du	University of Alberta
Shannon White	ABMI
Mike Nemeth	WaterSMART Solutions Ltd
Indigenous Representatives	
Adi Adiele	Fort McKay Métis
Colin Daniel	Fort McKay Métis

Carla Davidson	Athabasca Region First Nations
Maxwell Zhira	Owl River Métis Local 1949
Hansee Dai	Owl River Métis Local 1949
Diane Scoville	Lakeland Métis Local 1909
Industry Representatives	
Calvin Duane	COSIA, CNRL
Ole Mrklas	COSIA, Director of Monitoring
Craig Farnden	COSIA, Syncrude
Jon Jones	COSIA, Suncor
Policy and Planning	
Shalini Kashyap	AEP
Aaron Petty	AEP
OSM Program Leadership and Secretariat	
Kevin Cash	Science Co-Lead, ECCC
Tim Arciszewski	Secretariat: AEP
David Roberts	Secretariat: AEP

Appendix 2: All Uncertainties Identified at the Workshops

Terrestrial Biological Monitoring Workshop List of Uncertainties

This list compiles the “top 3” uncertainties of the 5 break-out groups. One group identified their “top 4”. Highlighted uncertainties are those which were selected as the Top Six via a voting process.

1. Knowledge held by FN communities – high area of concern – could be reduced with focused research
2. State trend and cause-effect on mammal and plant communities – could be reduced with focused
3. What are the levels of uncertainty related to predicted and observe effects on terrestrial biota including rare species?
4. The levels of uncertainty related to predicted and observed effects on terrestrial biota, including rare species
5. Quality, quantity, safety and availability of Traditional Resources
6. Persistence and impact of recovery of vulnerable species
7. Relative attribution for oilsands activities – life cycle of activities -exploration to construction extraction and recovery – maybe not high impact for FN but v important in terms of, identifying impacts of high consequence
8. Rates of recovery, physical land disturbance, important in context of land sensitivity
9. Loss of ecosystem, provision of clean water, pollination, requires research
10. Lack of information on quality and abundance of wild food
11. Effects of atmospheric deposition
12. Spatial and temporal scales to define reference and removal of footprint
13. Predictive modelling – need to validate – build trust and reduce uncertainties
14. Uncertainty on what is a cause and what is an effect
15. Are berries safe and available to eat – quality and quantity – berries here signify all Traditional Resource food
16. How are data used in management decision and evaluation EIA predictions for residual effects

Groundwater Workshop List of Uncertainties

This list compiles the “top 3” uncertainties of the 5 break-out groups. One group identified their Highlighted uncertainties are those which were selected as the Top 5 via a voting process.

1. Baseline conditions and range of variability for groundwater quantity and quality
2. Groundwater/surface water interactions rates and magnitude and mass flux at various flow system scales (combined with #8)
3. Tailings pond seepage (beyond Pond 1) rates and magnitude to Athabasca River and tributaries
4. Effects of climate change on groundwater quantity and quality
5. Effects of groundwater diversion on groundwater-dependent ecosystems
6. Land disturbance effects on groundwater quality and quantity
7. Understanding the geological framework
8. Where are the critical groundwater-dependent ecosystems? [combined with #2)
9. What is the timescale along pathways?
10. Reclamation success
11. Sensitivity of pathways to changing drivers/stressors
12. Effects and source attribution of multiple contaminants
13. Groundwater contributions to tributaries
14. Groundwater contributions to wetlands
15. Hydrogeological conceptual model – sub-regional – flow paths, geochemistry

Surface Water and Aquatic Biology Workshop List of Uncertainties

This list compiles the “top 3” uncertainties of the 5 break-out groups. One group identified their Highlighted uncertainties are those which were selected as the Top 6 via a voting process (6 because of a tie vote). The list incorporates changes made to address repetitions and overlaps.

1. Spatial variability in groundwater discharge to surface water (quantity and quality)
2. Separate the different anthropogenic and natural stressors (in situ, mining, natural bitumen, forestry, sewage treatment, fire, etc.). Include consideration of natural variability. Consider stressor-response relationships, relevance of measured endpoints re ecological effects and adequacy of reference characterization.
3. How much atmospheric deposition of contaminants is reaching the Athabasca watershed? Quantification of emissions and loading distribution to surface water
4. Fate of oil sands organic and inorganic contaminants in downstream receiving habitat/food webs

5. Influence of hydroclimatic variability and extreme event on surface water quality and biotic response
6. Lack of knowledge of higher order ecological effects
7. Land disturbance impacts on hydrology across the oil sands regions including wetlands; e.g. dewatering and dust.
8. Uncertainty that the selection of measurement endpoints reflects community concerns and values
9. Do we have the correct effects indicators to determine natural and anthropogenic effects?

Atmospheric Deposition Workshop List of Uncertainties

This list compiles the “top 3” uncertainties of the 5 break-out groups. Highlighted uncertainties are those which were selected as the Top 6 via a voting process (6 because of a tie vote). The list incorporates changes made to address repetitions and overlaps.

1. Transformation and fate of N and species; total deposition; spatial trends
2. Source attribution (oil sans development vs non-os). As needed
3. Toxicity and measurement of known and unknown PACs
4. Fugitive dust sources and pathways for base cations, trace elements. Includes spatial uncertainty and seasonality. Includes large particle modelling.
5. Sources and deposition of total nitrogen, including spatial distribution and critical loads.
6. Source attribution – oil sands versus non-oil sands. Mercury and trace elements, others as needed (PACs)
7. Ecological impacts of base cations – multiple interacting stressors (base cations, nitrogen, sulphur)
8. Source apportionment (Hg and Trace elements)
9. Deposition trends (long-term monitoring wet and dry)
10. Uncertainty in sources and deposition of total N (including Ammonia)
11. Fugitive dust spatial and temporal deposition patterns (inorganic and organic)
12. Fugitive dust (base cations as a component of this)
13. Nitrogen deposition-critical loads S and N and emissions location
14. Long-term deposition trends for those constituents of concern which are produced by oil sands. Includes timescale to effects and temporal variability.
15. Speciation of different sources
16. Base cation – requires: IER data, model, farfield
17. N deposition – requires: IER data, model, farfield
18. Fugitive dust – requires: large particle model, chem speciation

Mercury Workshop List of Uncertainties

This list compiles the “top 3” uncertainties of the 5 break-out groups. Highlighted uncertainties are those which were selected as the Top 6 via a voting process. The top 6 were reduced to the top 4 through combination of closely related uncertainties which received tie votes. The list incorporates changes made to address repetitions and overlaps.

1. Oil sands total and methyl mercury sources and speciation (dust, gaseous emissions, land disturbance)
2. Difference in mercury source emissions – in situ vs mining (regional differences)
3. Identify sensitive ecosystems in landscapes (e.g. understand methylation processes in wetlands). Include consideration of traditional foods.
4. Terrestrial-Aquatic pathways, transformations and transport
5. What are mercury concentrations in traditional foods (fish, berries etc) compared to other regions?
6. What are the effects of mercury on traditional resources and human health

    - 5 and 6 combined into one

7. Land disturbance from oil sands operations and relationship with erosion and dust
8. Summertime atmospheric wet/dry deposition
9. Inputs for mass balance/process-based model for catchment mercury transport
10. Mechanisms of transport of methylmercury from near-field to far-field downstream ecosystems
11. Mass balance of mercury and methyl mercury source contributions to the Athabasca River

    - 10 and 11 combined into one

12. Understand model uncertainties related to mercury speciation and emission quantification from NPRI
13. Quantify/understand mercury inputs from natural sources and anthropogenic sources (e.g. oil sands, compensation lakes, non oil-sands such as hydroelectric dams)

Appendix 3. Compiled List of Key Uncertainties and Key Questions

Introduction

This Appendix presents the key uncertainties (in order of priority) and associated key questions developed at the Terrestrial Biological Monitoring, Groundwater, Surface Water and Aquatic Biology, Atmospheric Deposition and Mercury workshops. Key uncertainties were identified at each workshop using a prioritization process which produced 5-6 key uncertainties. A set of key questions was then developed for each of the key uncertainties.

Terrestrial Biological Monitoring

Key Uncertainty: Quality/ quantity/safety, availability of traditional resources

Key Questions:

- General: all questions relate to quantity and quality of things you eat
- What species should we focus on?
- How do we build trust in communities?
- Do studies need to be done more regionally, reflecting concerns of several communities? Or should we work with individual communities?(regional approach could be challenging because concerns vary among communities)
- Are we monitoring an appropriate range of spatial scales to answer communities' questions? (e.g. localized depletion of mammals)

Key Uncertainty: What are the levels of uncertainty related to predicted (and observed) effects on terrestrial biota including rare species

Key Questions

- What is an acceptable level of uncertainty when evaluating species (this is a science-informed policy decision)?
- What pathways should be priorities for understanding effects on receptor species? (some taxonomic groups have less developed understanding)
- Is the current approach for setting priorities sufficient to predict future states? What approaches needed to address this?

Key Uncertainty: What spatial and temporal scales are required to define conditions and allow removal of "footprint"

Key Questions

- General Questions:
    - What is the appropriate scale with respect to oil sands-related effects?
    - How do temporal and spatial scales vary with respect to effects on ecosystem structure versus ecosystem function?
    - When is a footprint no longer a footprint? Need to consider and define temporal scale – historic and future
- Specific Questions:
    - Which species are most sensitive to habitat fragmentation?
        - Include habitat fragmentation from in situ oil sands operations
    - What is the rate of spatial change in conditions which affect caribou populations?
        - And how much of this change is due to oil sands activities?
    - How do oil sands-related effects on terrestrial biota compare to effects from other anthropogenic stressors (at specific spatial or temporal scales)?

Key Uncertainty: State, trend, cause-effect relationship for mammal and plant communities

Key Questions:

- **Raw Workshop notes do not contain recognizable key questions.**

Key Uncertainty: Effects of atmospheric deposition

Key Questions

- Divide AD into key classes that manifest themselves differently in terms of effects
    - PACs, Hg, Metals
    - Acidifying and nitrifying
- What are the levels of mercury in foods consumed by Indigenous people?
- What are the effects of enhanced nitrogen deposition on vegetation communities?
- What are the effects of sulphur deposition on vegetation communities?

Key Uncertainty: Knowledge held by Indigenous communities

Key Questions

- **NOTE: Questions must be developed via engagement with communities**
- In general, the concerns focus on impacts of oil sands development on quality and quantity of traditional resources
- Need alignment regarding what is “safe” or “healthy” and what is not
- Require integration of community knowledge and knowledge generated by others (e.g. Parks Canada)
- Explicit links between Parks Canada work (which includes working with communities) and OSM include:
    - Abundance of muskrat – link to fur-bearers and contaminants in fur-bearers
    - Macroinvertebrates in delta areas
    - Amphibians – Parks Canada scientist is in the community and working with community members
- Need to formalize entry point for people who want to work with communities and also need communication protocols
- Work with communities has to be long-term, reciprocal and beneficial

Groundwater

Key Uncertainty: Baseline and range of variability for groundwater quality and quantity

Key Questions

- What is the natural range of variability?
  - Seasonal variability
  - Long-term trends aren’t easy to demonstrate
- Where would we expect to see water balance changes?
  - System scale
  - Vulnerability
- How do monitored changes compare to model predictions?
  - Need conceptual model for baseline (outside area of impact)
- What is a suitable control or reference area?
- Can proxy data be used to help understand past conditions?

Key Uncertainty: What are critical GDEs, GW/SW Interaction rates, mass flux?

Key Questions

- Where are the Groundwater Dependent Ecosystems?
  - Modelling effort to map the GDEs and the connectivity
- Which ecosystems would be impacted most seriously by changes in GW quantity & quality? Which are most sensitive?
  - First Nations will have different answers to this question
  - McKay River – potential flow reversals – important to FN

  - Studies estimate GW input to various tributaries – those with minimal GW input are a lower risk (from dewatering?) – working at the watershed scale

- Has industry altered the rate of Devonian water discharge into the Athabasca River?
  - What is “critical”? Susceptible to change? High consequence from change (to water balance)? Timing aspect as GW input into e.g. tribs must be considered in definition of critical, even though overall GW input in SW is minimal.

- How and to what extent does GW influence Fens?
  - Timing? Chemistry?
  - Influence = hydro function

Key Uncertainty: Hydrogeological Conceptual Model: Subregional; flow paths

NOTE: this is more of a general requirement rather than an uncertainty. Therefore, the following presents the thoughts of the break-out group regarding requirements for construction of the Conceptual Model

- **Must understand the geology** – need to establish sufficient level of confidence in the knowledge of the geological setting at the appropriate spatial scale for OSM

- agreement that there are sufficient data spatially distributed to give a good picture of the hydrogeological framework

- **Model would be for a disturbed landscape**
  - Would be a different model. Need to understand the predevelopment
  - What is the model post development?
  - Have we sufficiently considered the implications of land disturbances on flow system dynamics?
  - Do we know enough about what we are doing on the land now that alter the flow systems to affect the future

- **Focus should be shallow groundwater**
  - Some debate about this:

    - Ultimately, it’s the shallower systems that concern the communities, and affect the ecosystems
    - We need to know the fluxes into shallow systems. Which means you have to understand the deeper system as well
    - Structural influences on deeper water on the system. It is a big concern for the communities.
        - How does that concern the community, because of the high water level and the quantity?

- **Hydrogeological model: need knowledge of:**
  - geology
  - geochemistry
  - fluid flow
  - flow patterns
  - recharge and discharge
- **Be clear about the stressors**
- **Determine the boundary condition**. Design some monitoring to determine the boundary positions; e.g. groundwater divides. Is there a long-term divide?
- **use the model to inform monitoring**
  - including geophysics
- **divide the model into mine and *in situ***
- **Uncertainties:**
  - Water level data or geochemistry data
  - Have we sufficiently identified the flow paths, structurally to support a regional monitoring system?
  - Influence of surface water on groundwater
- **Could modelling done by oil sands operators be scaled up spatially and temporally?**

Key Uncertainty: Effects of climate change on groundwater quantity and quality

Key Questions:

- Modelling:
  - Do the time scales used in current climate change models predict changes in the oil sands region?
  - Can predictive modelling be used to test the resiliency of reclamation scenarios given potential climate change impacts on groundwater flows?
  - How does climate change affect the overall water balance in the oil sands region? Do climate models predict increased or decreased precipitation flux and groundwater discharge?
  - How are changes in climate affecting location, timing, chemistry of groundwater systems?
    - Does loading of salts change over time due to climate change?
  - How would impact of climate change on vegetation affect groundwater?
    - Compare existing vegetation with 50 year out reclamation plan
  - What should be measured on the ground to calibrate and verify models? (what is measurable – recharge isn't measurable)
  - NOTE: see the most recent EIA to check predictions made.
- Spatial Trends:
  - How far-reaching are climate-change related effects on groundwater systems? Do we see trends in water level change in a range of different locations inside and outside of the oil sands region and do those trends show a relationship with climate change?
  - Can the effects of groundwater withdrawals be distinguished from climate change and at which spatial scale?
- Groundwater-Dependent Ecosystems:
  - Where would we expect to see changes in water levels due to climate change?

  - Would climate change cause effects on water temperatures in streams/wetlands with significant proportion of inflow coming from groundwater?

Key Uncertainty: Reclamation Success

Key Questions

- Does the local reclaimed system fit with the surrounding system?
  - Key parameters:
    - interaction with regional system
    - interaction with GDE (scale (time), Steady state, transition)
    - Flow system
    - Water quality
- Is different monitoring required to understand subregional success vs local success (on lease)?
- Integration need with surface water, geospatial, diversity

Surface Water Quality and Aquatic Biology

Key Uncertainty: Separation of different anthropogenic and natural stressors (in situ, surface mining, natural bitumen, forestry sewage treatment, etc). Includes cumulative effects.

Key Questions:

Null Hypotheses

i.- There are no observed differences in biological responses between different sites within a tributary (upstream, within, and downstream of the McMurray Formation and industrial development)

ii- There are no identifiable source inputs that could explain observed differences in biological responses within a tributary.

iiia- Isolated chemical mixtures from identified source inputs of interest between sites in a tributary do not elicit responses in laboratory bioassays that are consistent with the original field observations.

iiib- Isolated chemical mixtures from identified source inputs of interest between sites in a tributary do not differ in chemical profile (qualitative and quantitative). What are the differences in contaminant signatures from upper reaches to lower reaches in tributaries (Firebag (reference) vs Steepbank). Design based on JOSM observations.

- What are the differences in source and loads of inputs among sites?
    - Groundwater and overland flow
    - Fugitive dust/ pet coke
    - Bank erosion
- What is the contribution of the source input differences to ecological effects?
    - Field observations (JOSM)
    - Toxicity tests (Effects Directed Analysis)
    - Interannual variation in key environmental drivers (e.g. flow)
    - Role of nutrient -contaminant interaction in modifying toxicity
- Remaining Issues:
    - Gaps in field observations across tributaries – spatial extent
    - Role of geology
    - Role and contributions of groundwater
- **Recommendation:**
    - 2-day workshop to develop focused studies on investigation of cause

Key Uncertainty: How much atmospheric deposition of contaminants reaches the Athabasca watershed. Quantification of emissions and loading distributions.

Key Questions:

- What is the temporal (seasonal, interannual) and spatial variability in contaminant “x” deposition across the landscape?
- How does the type of land cover, topography, etc affect the mass of contaminant “x” deposited and accumulated?
- What is the spatial and temporal variability in the hydrological connection between the depositional areas and regional waterbodies? What are the key drivers of spatial and temporal variability in the hydrological connection between depositional areas and the waterbody?
- What is the fate of contaminant “x” once it is deposited to the landscape?
- What proportion of contaminant “x”, once deposited, is delivered to the waterbody and how does this change seasonally, interannually and spatially?
- **Recommendation:**
    - a fully instrumented representative basin (s)
    - align deposition monitoring with NADP protocol

Key Uncertainty: Fate of oil sands organic and inorganic contaminants in downstream receiving habitats/food webs

Key Questions:

- H_0: Oil sands inorganic and organic contaminants are not changing food webs in downstream receiving environments
    - Approaches for addressing this hypothesis:
    - Source attribution: spatial distribution of loads, mass balance, sediment finger printing, multi-variate statistics, chemical fingerprinting, isotope analysis
    - Bioavailability in food web and uptake – tissue (plants) analysis, metal speciation, water chemistry, modelling tools, sediment chemistry, passive sampling
    - Transport: high frequency turbidity data, suspended sediment sampling
  - Increase longitudinal spatial assessment from M1 to PAD with respect to:
    - contaminant sources (air, overland, groundwater)

        - Transport, deposition, remobilization, transformation, uptake
    - Include wetlands
- How does an altered food web impact bioaccumulation of contaminants (or vice versa)?

Key Uncertainty: Lack of knowledge of higher order ecological effects

Key Questions:

- What are the impacts of oil sands development on aquatic habitat connectivity at large spatial scales?
    - Focus on:
        - How can we separate oil sands mining contribution from other development (forestry, urban etc)
        - What are the implications to populations of sensitive/valued fish species?
- Require sufficient information to assess fish habitat quality, access and utilization at a large spatial scale

Key Uncertainty: Uncertainty that selection of measurement endpoints reflects community concerns and values

Key Questions:

- What are the commonalities between existing OSM work and communities and how do you maximize exposure of OSM Programs in these communities in response to community needs?
- Can the existing OSM Program integrate with community-based monitoring?
    - Gaps:
        - Cold Lake area
        - sites and indicators relevant to communities
    - Confirm that endpoints are relevant to communities
- What are some effective approaches to building capacity in the communities?

  - Capacity can’t be bought, it must be built

Key Uncertainty: Do we have the correct indicators of natural versus anthropogenic change?

Key Questions:

- Indicators must be sensitive and scaleable and must provide a signal early enough to prevent irreversible harm
- Which indicators can be extrapolated from individual to population level?
- What indicators would show a response to natural and anthropogenic stressors? What focussed research is required to identify indicators of most utility with respect to distinguishing natural and anthropogenic stressors?
- Metabolomics: for both long-term and short-term – can be used for fitness, reproduction, survival – linked as an early warning indicators
  - How do you make metabolomics relevant?
  - Would need focussed studies in references areas
  - See if metabolomics works to distinguish upstream vs downstream
- What environmental markers can be used to identify the downstream Fort McMurray effects in order to allow for unconfounded assessment of oilsands activities on the mainstem Athabasca River?

Atmospheric Deposition

Key Uncertainty: Fugitive dust sources and pathways for base cations, trace elements. Includes spatial uncertainty and seasonality. Includes large particle modelling.

Key Questions:

- What size fraction distribution dominates base cations? Where (distance and windspeed)?
- What is the speciation and size distribution of fugitive dust?

- What are the sources of fugitive dust and what is the magnitude and speciation of sources?
- What can vegetation data tell us about deposition of fugitive dust?
- What is the seasonal variability (e.g. with respect to snow)?
- What are the meteorological drivers for fugitive dust emissions? Vs mechanical sources. Wind-blown origin from pet coke?
- Can the aircraft and ground-based observations of fugitive dust be linked to source types?
- What is the impact of reducing fugitive dust on human health versus neutralization benefits?
- What is the mobility of the base cations from terrestrial ecosystem deposition to aquatic ecosystems (e.g. lakes)?
- What are the chemical transformations affecting fugitive dust and how do they affect downwind deposition?
- What is the combined response of base cations, N and acidity on receptors (plants, surface waters)?
- What is the resulting spatial distribution of fugitive dust and its components?
- Can model-measurement fusion be used/improved to get better spatial maps?
- How will the in situ facilities and other projected emissions change fugitive dust and neutralization?
- **Design Issues**
    - Focused study for surface monitoring of fugitive dust
    - PCA of aircraft fugitive dust linked to surface observations (and other means of
    - source attribution)
    - Need to choose sites on the surface carefully
    - What is the size distribution of fugitive dust much further downwind (50-200 km)?

Key Uncertainty: Deposition trends: long-term, for those constituents of concern which are produced by oil sands. Includes timescale to effects and temporal variability.

Key Questions:

- On a chemical species by species basis, does the existing monitoring program adequately capture the spatial deposition?
    - How far out do we need to measure before we get to no effects or background levels?
    - Are we adequately measuring other oil sands regions such as Peace River, Cold Lake, CHOPS
    - Do we need to characterize these other regions in the same way we have done for surface mining operations?
    - Can we design a monitoring program that validates model predictions of long range deposition?
    - Are we monitoring the right things?
    - We need validations from all stakeholders to choose the chemical species to model
    - Uncertainty around temporal measurements – stakeholders might specify requirements on what needs to be measured
- Designs equal super sites?
    - New monitoring approach
    - Passive
    - Models

Key Uncertainty: Sources and deposition of total nitrogen, including spatial distribution and critical loads

Key Questions:

- What are major sources of NH3 – oil sands vs non-oil sands (50 km from fenceline)?

- What are major sinks of NH3 (50km from fenceline). At what distance negligible?
- What fraction of total N deposition is attributable to oil sands?
    - What is the spatial variability: 0-50 km;50-100 km; > 100 km from facility fencelines
- Are critical loads for acidification begin exceeded (lakes/aquatic vs terrestrial)? Near, mid and far-field? What are the critical loads?
- What is the difference in total N deposition between in situ and mineable areas (near, mid and far-field)?
- What are the differences in effects in receiving environments?
- What is the spatial variability in critical loads (by receiving environment)?
- What are levels of unknown N species by receiving environment? Are these levels important?
- Is observed N deposition around oil sands mines within values predicted by EIAs?
- What spatial and temporal scale do we see impact from N deposition in receiving environments
    - In situ vs mining
    - Near, mid and far-field
- What distances are near. Mid and far field? Is this dependent on oil sands type (in situ vs mining)? At what distances do oil sands emissions become negligible?
- What are the effects of different N species in different receiving environments? NH3 vs NO3 vs NH4

Key Uncertainty: Source attribution – oil sands vs non-oil sands. Mercury and trace elements; others as needed (PACS)

Key Questions:

- **Mercury:**
    - Is the oil sands industry a source of mercury?
    - What are the oil sands processes that could contribute to methylation of mercury?

  - What are the co-occurring pollutants with mercury? (there are tools available that measure this)
  - What are the mercury emissions outside of the oil sands region?
- **Trace Metals/ PACs**
  - Can we distinguish oil sands sources of trace elements from natural sources?
  - Do isotopes and con-contaminants (REEs) help identify the sources?
- **Recommendations:**
  - Ongoing monitoring of multiple pollutants in air (active/passive, snow), lichens, tree cores, lake sediments
  - Need precipitation measurement of trace elements (should be combined with existing collections of PACs)
  - Combine all of the various multi-contaminant geospatial data to understand current status

Key Uncertainty: Ecological impacts of base cations – multiple interacting stressors (Base cations/N/S)

Key Questions:

- H_1: There are differences in patterns of spatial distribution of base cations and S/N.
  - which leads to differences in how they combine across the landscape and this changes over time (e.g. emissions from in in situ vs mining area in terms of dust/base cations vs N and perhaps S.
- H_2: Ecosites will show a range of sensitivities.
  - E.g. low CEC/base saturation site types will be most sensitive.
  - To verify ecological effects need co-location of deposition monitoring and ecological effects monitoring
- **Issues and Opportunities**
  - Other data or samples (provincial soils data base, ABMI soil samples)

- A reference from outside the region
- Scale and resolution needs to be suitable for developing a terrestrial monitoring program (township scale won’t work)
- Controlled experiments might be useful (e.g. critical load questions)
- Deposition close to mining is mostly relevant for impacts on reclaimed ecosystems

Mercury

Key Uncertainty: Oil sands mercury sources and speciation.

Key Questions

- What is the characterization of mercury emissions from stacks and land disturbance (including speciation)?
- What emissions other than mercury impact mercury accumulation and methylation?
- Can we collect fugitive dust and understands its characteristics in order to understand its relative contribution to mercury deposition and transformation?
- What is the level of mercury deposition in the oil sands region during the rest of the year (outside of snow seasons)?

Key Uncertainty: Mercury in Traditional Foods and Subsequent Effects on Traditional Resources and Human Health

Key Questions

Does the oil sands industry contribute to an incremental increase of mercury in traditional foods?

- What has been done to date to measure mercury in traditional foods? Where? How?
- Do the food items that have been measured encompass the full range of subsistence foods? Are the sampled at the right place and time?
- How are the traditional foods prepared and what is eaten?
- Are mercury concentrations now and in the past higher in the oil sands regions than elsewhere (near and far?)

- Can we attribute mercury present in subsistence foods to oil sands sources?
- What has/is changing in the environment that affects mercury biogeochemistry, methylation and biomagnification?
- Are there historical samples which could be accessed and analysed for mercury?

Are there effects from mercury on traditional resources and human health?

- Does the perception of pollution from oil sands development affect use of subsistence foods?
- Are mercury concentrations above threshold levels that would result in consumption advisories?
- What advisories have been issued?
- Do the advisories affect use of subsistence foods?
- Have there been direct effects of mercury on health (humans and fish/wildlife)?
- Have there been indirect effects on human health?

Key Uncertainty: Quantify and understand mercury inputs from natural and anthropogenic sources (oil sands, compensation lakes, non-oil sands such as hydroelectric dams)

Key Questions

- What are the natural versus anthropogenic sources of mercury in the oil sands region?
- What is the relative contribution of natural and anthropogenic sources in the Athabasca River and the PAD?
- What is the spatial and temporal variation of source contributions?

Key Uncertainty: (a) Mechanisms of transport of methylmercury from near-field to far-field downstream systems (b) Mass balance of mercury and methylmercury source contributions to the Athabasca River.

Key Questions

- Where are mercury methylation sites in aquatic environments downstream of oil sands operations up to and including the PAD? (riverine wetlands, lakes, tributaries)
- Can we model sites and conditions that lead to methylmercury in order to understand its spatial and temporal distribution?
- What conditions are required for methylation? Mercury load? Effect of other emissions? Are these conditions changing over time?
- What are mercury sediment concentrations in the Athabasca River upstream and downstream of the oil sands region?
    - How does this sediment mobilize if it contains mercury?
    - Which sediments contain mercury? Which horizons? What is the range and scale of mercury with respect to source?
- What are non-atmospheric mercury sources? Sediments? Soils? Other?
- What are non-atmospheric transport mechanisms? Model these?
    - Overland flow
    - Groundwater
    - Tributaries
    - Mainstem
- What is the fate of mercury deposited on the land surface? What is transported vs retained/accumulated?
- What is the fate of mercury deposited/transported in the Athabasca River?
    - How much is bioaccumulated?
    - How much settles in depositional areas?
        - Where are the depositional areas?
        - Are these sites of methylation
        - How do these change temporally and spatially?

- Are there spatial or temporal patterns in total and methylmercury concentrations in biota?
    - Have any spatial trends been confirmed with abiotic and biotic samples? With source-tracking tools such as stable isotopes?

Appendix 4. Short-Listed Key Questions and Critical Pathways Produced at the Geospatial and Predictive Modelling Workshops

Short-Listed Key Questions Voted on by Geospatial Workshop Participants

- Changes in the oil sands region due to climate change (at various scales)
- Impacts of oil sands development on aquatic habitat connectivity
- Effects of enhanced N, S and base cation deposition on vegetative communities
- Species which are the most sensitive to habitat fragmentation
- Role of spatial changes in conditions which affect caribou
- Where are the groundwater dependent ecosystems?
- Mapping community knowledge of traditionally accessed resources
- How do oil sands effects on biota compare to other natural and anthropogenic effects?
- What is the spatial and temporal variability of contaminants deposition (S, N, base cations, some PACs and trace elements)?

Short-Listed Critical Pathways Voted on by Predictive Modelling Participants

- Groundwater connectivity with surface water (water quality and seepage, baseflow inputs; need groundwater velocity field; need geology)
- The causal linkage between surface water quality and ecological effects (monitored changes in benthic invertebrates and fish health). Coupled water quality-quantity. Link to air deposition.
- Atmospheric deposition links to terrestrial effects and surface water quality

- Contaminant exposure and effects on terrestrial species persistence, biodiversity, productivity. Includes comparison to habitat effects.
- Pathways ending at food items consumed by people (human health); includes effects on food supply due to habitat loss.
- Oil sands and non-oil sands stressors -to surface water/groundwater/sediment -to fish health – to human health
- Spatial distribution of acid and nutrient critical loads – to eutrophication, acidification, alkalization – to soil and water chemistry – to vegetation changes
- Surface water quality (coupled with quantity) – to aquatic ecological effects (fine temporal resolution)
- Standardized scenarios for integrating stressors across landscape and subsequent effects on biota
- Sediment quality and quantity for transport model