

Oil Sands Monitoring

Technical Report 2024/25

Core Biodiversity Monitoring - Benthic Macroinvertebrates

Sample and Data Summary Report: 2011-2024



Project: OSM Surface Water Monitoring

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Core Biodiversity Monitoring- Benthic Macroinvertebrates Sampling and Data Summary Report 2011-2024.

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Executive Summary

Benthic macroinvertebrates (BMI) are key components of riverine food webs, are comprised of insects, crustaceans, molluscs and worms, and exist in intricate communities of individuals called “assemblages”. By sampling BMI along with water and sediment chemistry, habitat measurements, and other environmental variables the core Oil Sands Monitoring (OSM) Benthic Macroinvertebrate Monitoring Program objectives include determining if changes in BMI communities are occurring, if there are linkages with oil sands development, and the extent of cumulative effects along the river course.

This report is provided as a summary of the data and sampling that has occurred under the OSM benthic monitoring program since the initial sampling in 2011. The intent is to update the data summary tables in this report on an annual basis as tool for various stakeholders of the program as a succinct and accessible introduction to the BMI sampling regime. The report provides a detailed summary of how, where and when sampling has occurred. Although the Introduction and Study Design sections describe the objectives and the study design in a general context, there is no analysis or interpretation included herein. Sampling methods are briefly described with links to Standard Operating Protocols. Data characteristics, processes and timelines are described and links to data available online are provided.

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1. Introduction

Benthic macroinvertebrates (BMI) are key components of riverine food webs, are comprised of insects, crustaceans, molluscs and worms, and exist in intricate communities of individuals called “assemblages”. Changes in benthic invertebrate assemblages are used world-wide in environmental monitoring programs of aquatic ecosystem health because they are 1) reliable short- and long-term indicators of human disturbance, 2) have limited mobility and thus integrate the effects of exposure to stressors, and 3) are easy to collect. By sampling BMI along with water and sediment chemistry, habitat measurements, and other environmental variables the core Oil Sands Monitoring (OSM) Benthic Macroinvertebrate Monitoring Program can relate Pressures/Stressors of the existing OSM conceptual model to determine: 1) whether changes in BMI communities are occurring; 2) if there are linkages with oil sands development; and 3) the extent of cumulative effects along the river course.

For consistency we have chosen to refer to current environmental condition as the “Accumulated State” and current environmental condition in pre-defined reference sites as “Reference State” as defined in the Water Quality Monitoring Plan (Environment Canada, 2011a).

The objectives of ongoing annual benthic data and sample summary reports are to provide a summary of how, where and when sampling has occurred in succinct and easily digestible format. Although the Introduction and Study Design sections describe the objectives and the study design in a general context, there is no analysis or interpretation included herein. Sampling methods are briefly described with links to Standard Operating Protocols. Data characteristics and processes are described and links to data available online are provided. Annual sampling efforts by region and site from 2011-2024 are summarized and provided in tables (updated annually).

With respect to data and sample collection in 2023 and 2024, these objectives included:

- o In the Mainstem Athabasca River, benthic macroinvertebrate samples and associated supporting variables were collected at 11 sites, including 6 surveillance sites (M0, M2A, M3, M3B, M4 and M9) and 5 sites (Northland, Sun-Up, Sun-Dn, M3C and M7B) which were sampled within the reach where greatest change in benthic macroinvertebrate assemblages has been observed.
- o In the Athabasca River tributaries, collect benthic macroinvertebrate samples were collected at up to 30 existing long-term core surveillance sites in the tributaries to track temporal changes in reference and test areas. In 2023, sampling was conducted at 23 sites in the Steepbank River with a focus on increasing site replication within the lower test areas (i.e., test areas 2,3 and 4) where greatest change in benthic macroinvertebrate assemblages has been observed. Similarly, in 2024, sampling was conducted at 15 sites in the Ells River with increased replication in the areas of greatest change (i.e., test areas 1, 2 and 3). This rotation design is planned for the Mackay and Firebag rivers in 2025, thus, completing the planned rotation among these major tributaries.
- o In the In Situ portions of the southern Athabasca Oil Sands Region (Christina River Mainstem and tributaries, Hangingstone and Horse rivers) and Cold Lake Oil Sands Area, sample up to 40 sites to establish Reference and Accumulated State of benthic macroinvertebrate assemblages in reference and downstream areas.

2. Study Design

The current OSM BMI adaptive monitoring design is based on the recommendations from the peer-reviewed 2018 Technical Report (Culp et al., 2018) findings and as reviewed through the annual work planning process. The current adaptive monitoring design was updated from the original design published in the 2011 Integrated Monitoring Plan for the Oil Sands (Environment Canada 2011a and b). From the initiation of the program, in both the Athabasca River and its major tributaries, sampling has been based on a gradient design from upstream to downstream to allow detection of change and assessment of cumulative effects of multiple stressors. Factors considered in the design included whether the river reach is within a reference area (both outside and inside areas with exposure to natural bitumen), and location relative to municipal effluent inputs, oil sands activities, and other stressors (e.g., outfalls) that may contribute to cumulative effects.

The program continues to be adaptive in nature, establishing core-sampling sites with rotational sites sampled on a less frequent basis. Of importance, the design currently reflects a focus of effort on areas where changes in benthic invertebrate assemblages have been observed, and subsequent evaluation of potential drivers (natural and anthropogenic) of these changes. This allows assessments of change relative to reference conditions and evaluation of cumulative effects.

The BMI program is not designed to identify or monitor specific point source releases, but rather the overall aquatic ecosystem health and cumulative effects of the Athabasca River and its major tributaries relative to Reference and Accumulated States (Environment Canada 2011a). However, benthic invertebrate community assessments can detect changes resulting from periodic short or long-term exposure to low-level contaminants not necessarily detected through routine water quality programs. These gradient designs are robust in nature so that if additional stressors are introduced in future, minimal adaptation of the design would be required.

A description of the sampling designs and current monitoring phase for each subproject is provided for context of the data and sampling summaries provided below.

Athabasca River Mainstem (Fig. 1) - The gradient style design used by the Mainstem Benthos biomonitoring program is based on accepted Environmental Effects Monitoring (EEM) study designs. ECCO has established 19 BMI sites including Reference sites outside exposure to natural bitumen, Reference sites exposed to natural bitumen, Municipal Sewage Effluent (MSE) exposure sites, sites adjacent to Oil Sands Development activities, and sites located downstream of all human activities and considered Recovery areas. Not all sites are sampled in each year, but a core set of sites are sampled annually with other sites sampled on a rotational basis. These areas have been sampled since 2011 to establish Reference and Accumulated State for indicators of BMI assemblage and structural change. Design of the Mainstem BMI monitoring program is similar to those for water quality and fish health, if significant change is detected, investigation of drivers are used to identify associations of change.

Lower Athabasca River (LAR) Tributaries (Fig. 2) - Within four of the major tributaries (Steepbank, Ells, Mackay and Firebag rivers), an EEM gradient style design of 15-20 sites was used with replicate sites within river reaches with similar human disturbance, reference outside natural bitumen, reference inside natural bitumen, and up to 4 areas

within a tributary with increasing percentage of land disturbance (test groups). The OSM tributary program, initiated in 2011, has established 128 sites distributed among the different reference and exposure areas, with up to 50% sampled on an annual basis. The sampling to date establishes Reference State as well as Accumulated State in the exposure areas against which current and future change will be assessed. Several other tributaries including Alice Creek and the McIvor River entering the Peace Athabasca Delta in and around Wood Buffalo National Park have also been sampled since 2012.

In Situ OSM Regions (Fig. 3 and 4) – The Peace River, Christina River and Cold Lake In Situ Regions are in earlier stages of biomonitoring. Reconnaissance and limited sampling has occurred in these regions from 2016 – 2024. Building on work done to date, the program currently is focused on establishing Reference and Accumulated State for the Christina River Region, while sampling in the Peace River Oil Sands Region was paused. Sampling in the Cold Lake Oil Sands Region started in the fall of 2023. In the Christina River watershed sampling continued in 2024 to establish Reference and Accumulated State, while sampling proposed for 2025 will focus on sites with fewer than 4 years of sampling. Four sampling locations in the Cold Lake Region were sampled in 2023 and this was expanded to 7 sites in 2024.

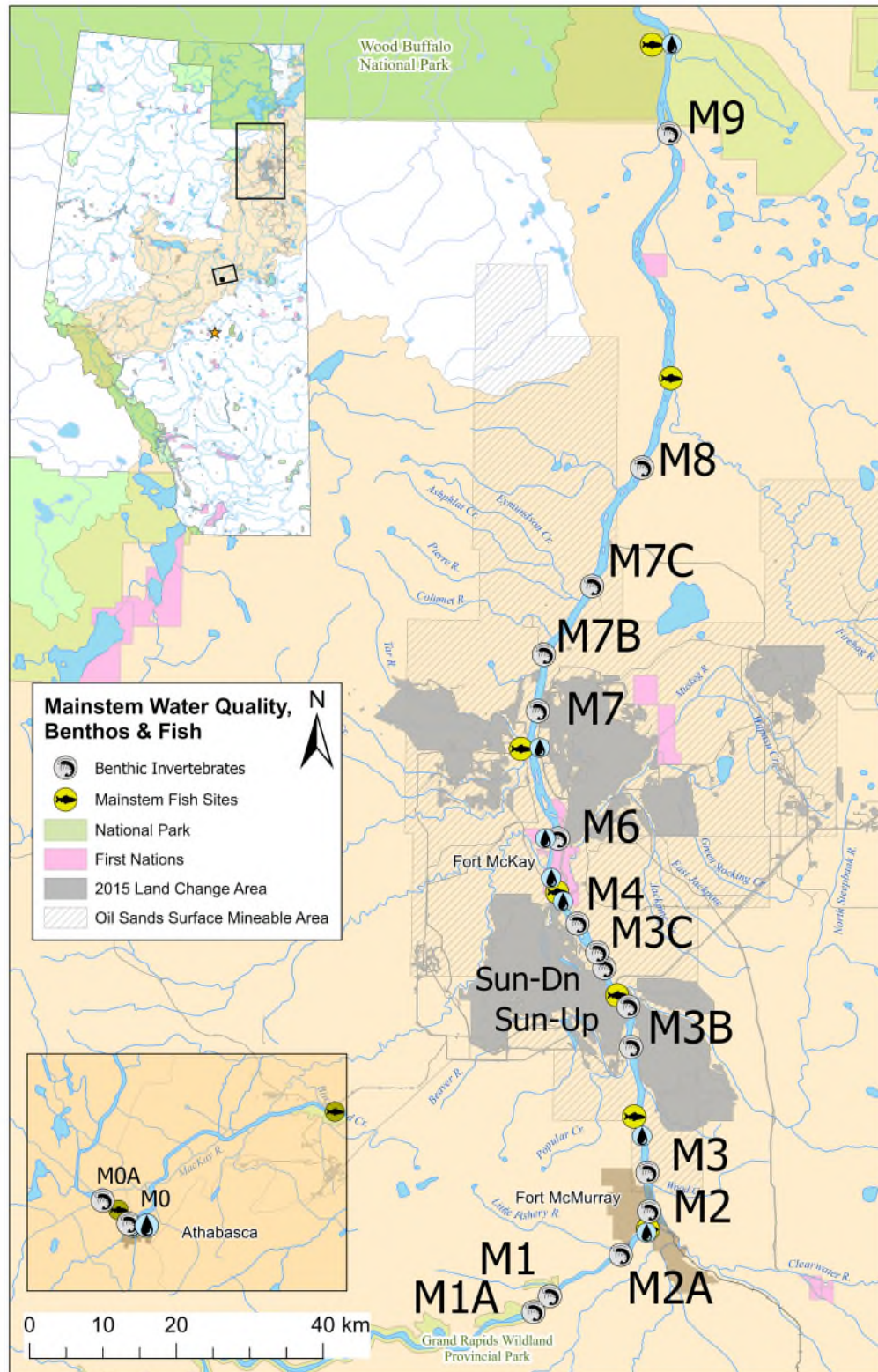


Figure 1. Map of current benthic macroinvertebrate monitoring sites in the mainstem of the Athabasca River of the surface mineable area of Athabasca Oil Sands Region. WQ and Fish sampling locations are also indicated.

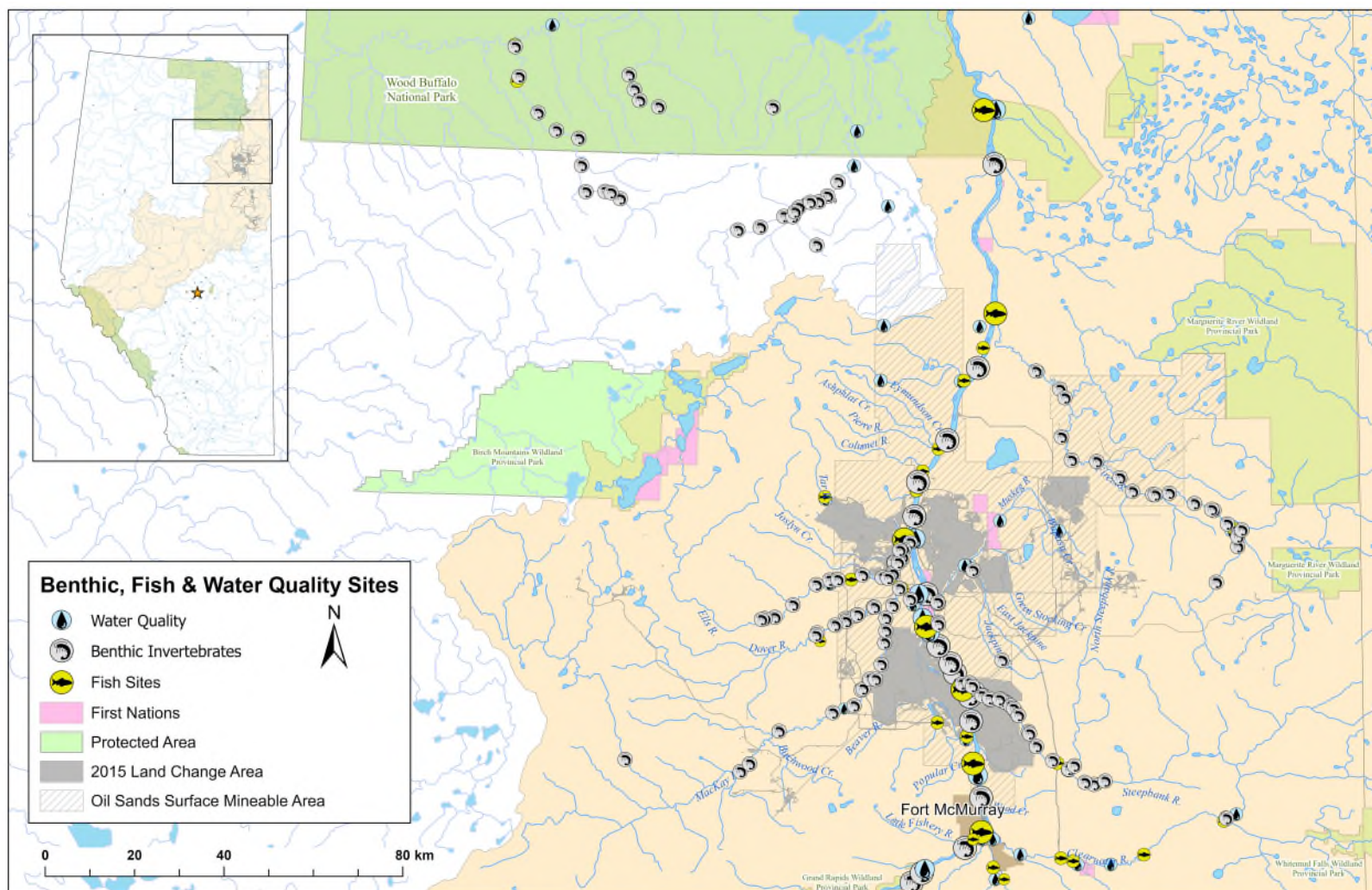


Figure 2. Map of current benthic macroinvertebrate monitoring sites in tributaries of the Athabasca River and Birch Mountains in the surface mineable area of Athabasca Oil Sands Region. WQ and Fish sampling locations are also indicated.

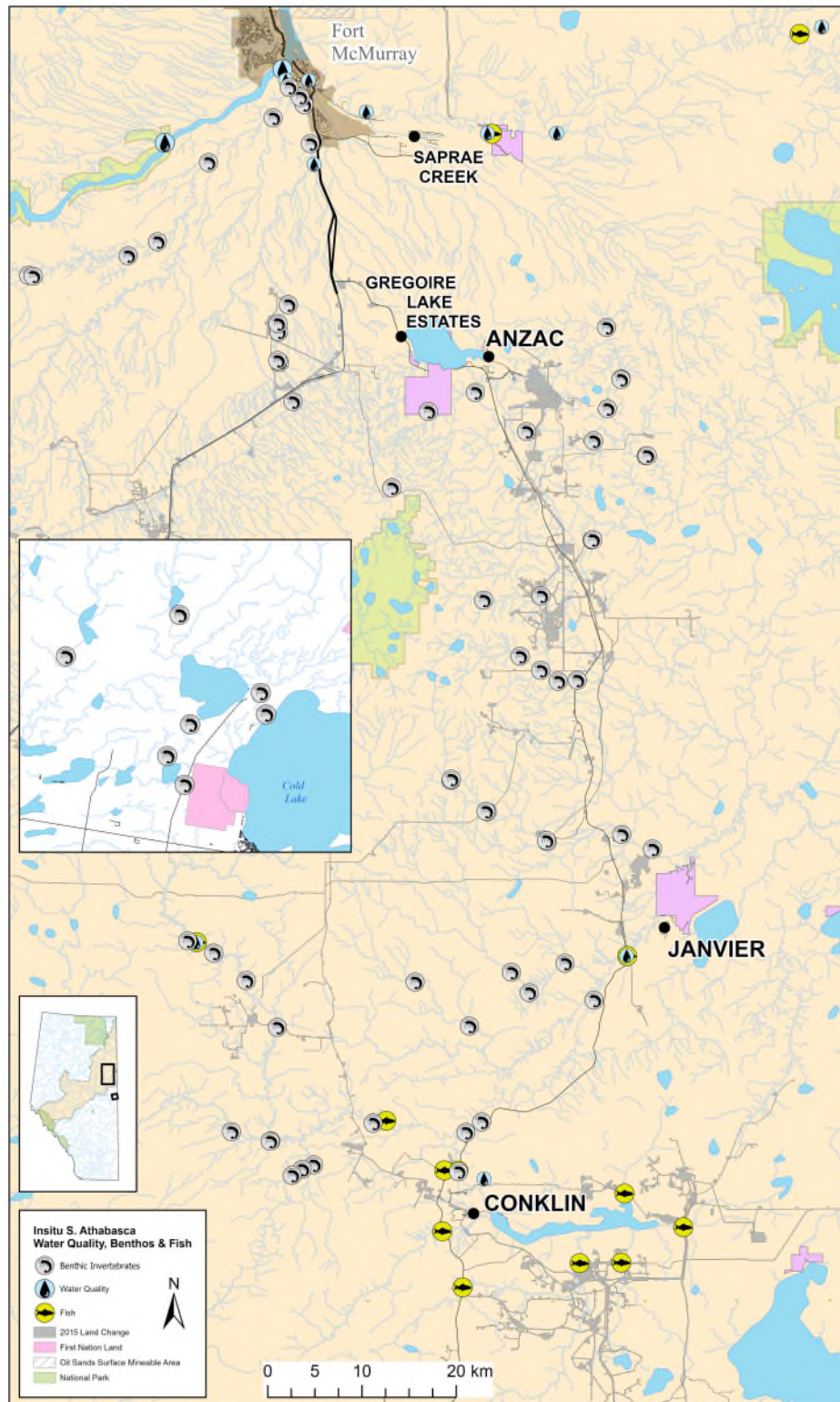


Figure 3. Map of current benthic macroinvertebrate monitoring sites within the In Situ areas of Athabasca Oil Sands Region in the Christina, Hangingstone, Horse rivers and in the Cold Lake Area. WQ and fish sampling location are also indicated.

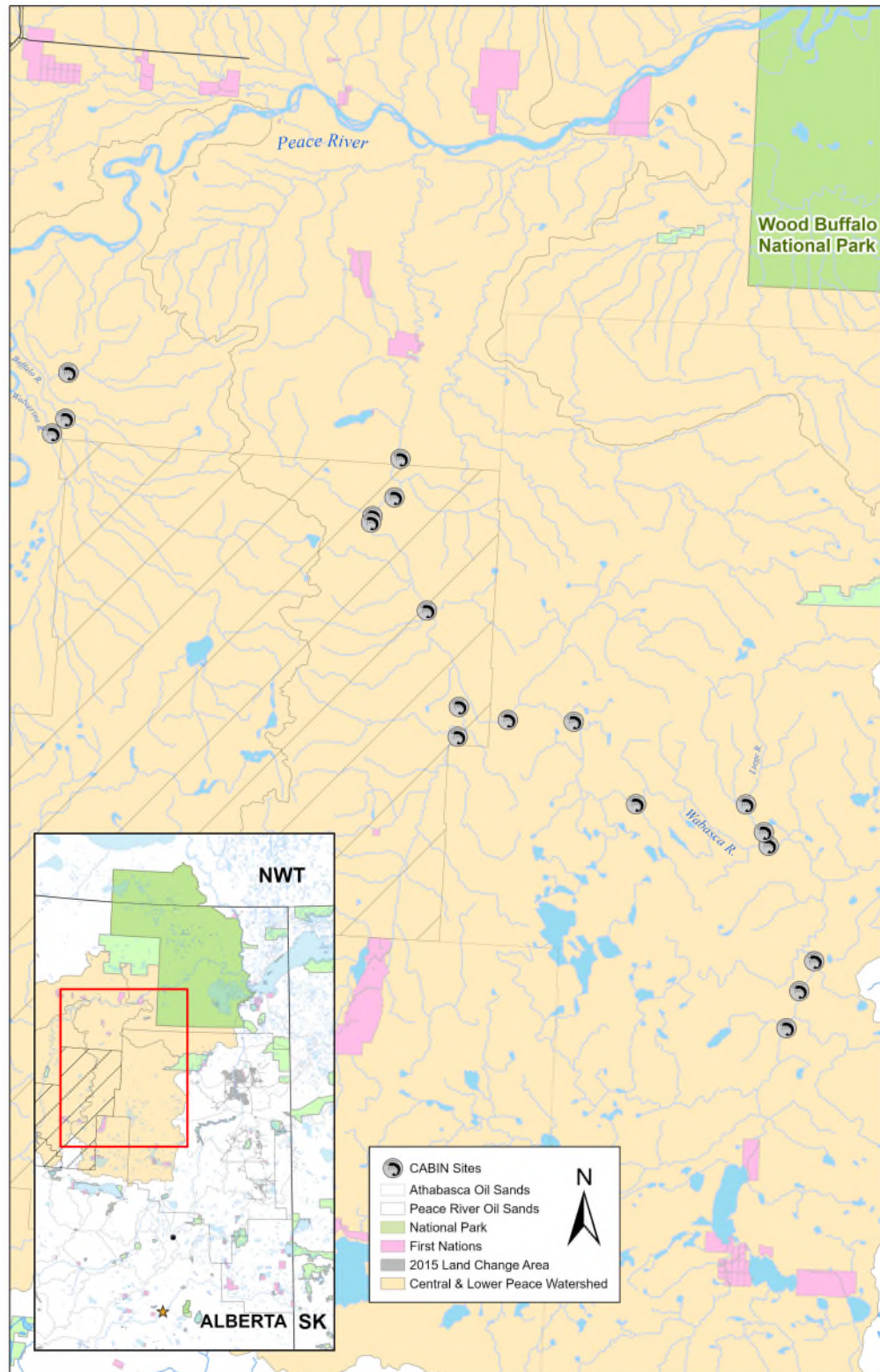


Figure 4. Map of benthic macroinvertebrate monitoring sites sampled between 2016-2019 in rivers within the Peace River Oil Sands Region.

3. Methods

Sampling is conducted once per year in the fall when water flows have stabilized, and benthic invertebrate communities are at their most diverse and sensitive to disturbance. Sampling includes the collection of benthic invertebrates using the kick sampling approach as described in the National CABIN methodology as well as habitat measures, such as slope, depth, velocity, periphyton (algal) biomass, and water and sediment quality as appropriate to the habitat and study specific objectives.

Water quality parameters routinely measured are based on the OSM recommended list in Appendix B of the Phase 1 water quality monitoring plan (Environment Canada 2011a) and include metals, nutrients, major ions, polycyclic aromatic compounds (PACs), mercury and PACs in sediment, and general parameters, such as turbidity, oxygen, and temperature.

Semi-permeable membrane devices (SPMDs) are deployed at multiple sites in the Athabasca River and its tributaries in mid-August, a month prior to BMI sampling. SPMDs measure time-integrated dissolved PACs and provide critical data of chronic exposure concentrations to aquatic organisms during the critical fall life cycle for many benthic macroinvertebrates. Discrete water quality samples do not provide this type of exposure information.

The OSM benthic program generally follows CABIN field and laboratory protocols which can be found at the following link:

[Canadian Aquatic Biomonitoring Network resources - Canada.ca](#)

The Mainstem Athabasca River benthic program follows a modified CABIN approach; details and protocols can be found here:

[Benthic Macroinvertebrate Biomonitoring Program: Mainstem Athabasca River - Federal Open Science Repository of Canada](#)

In addition, both OSM BMI programs collect additional supporting measures relevant to benthic macroinvertebrate communities. The manual at the link below describes these additional protocols that are completed depending on the objectives of the adaptive monitoring program/sites for OSM:

[Standard Operating Procedures for Benthic Invertebrate Monitoring in Wadeable Streams of the Athabasca Oil Sands Region; additions to the national CABIN protocol - Datasets - Oil Sands Monitoring \(alberta.ca\)](#)

Additional relevant SOPs can be found at the following links:

[Standard Operating Procedures for Water Quality Sampling - Datasets - Oil Sands Monitoring \(alberta.ca\)](#)

[Standard Operating Procedures for Water Quality Data Management and Database Procedures - Datasets - Oil Sands Monitoring \(alberta.ca\)](#)

[Standard Operating Procedures for Field Water Quality Sampling using Semi-permeable Membrane Devices \(SPMDs\) - Datasets - Oil Sands Monitoring \(alberta.ca\)](#)

4. Data Characteristics and Availability

All data collected through the OSM BMI programs are uploaded, verified, and managed in ECCC water quality and biomonitoring relational databases. Database protocols are provided at the links above and include routine back up processes on secure servers. These databases are considered the authoritative and originating source for OSM BMI data. Any updates, additions or QA/QC processes which occur within these databases are tracked. The most recent data files are uploaded and replace previous files on ECCC's Open data as described below. As such, users of the data should extract the most recent data files available.

Currently samples are processed and analyzed at the following laboratories:

- Water quality samples are analyzed at several laboratories including ECCC NLET laboratories for nutrients (Saskatoon), dissolved and total metals, major ions and physicals (Burlington). Polycyclic aromatic compounds (PACs) are analyzed at SGS AXYS laboratories in Victoria.
- Bed sediment samples are analyzed at NLET (Burlington) for extractable metals, mercury, carbon, nitrogen, and moisture and for PACs at SGS AXYS laboratories in Victoria.
- Benthic macroinvertebrate sample processing and identification are completed under contract by Society of Freshwater Science certified taxonomists. As per the CABIN National program and laboratory manual, a subset of samples are verified by the ECCC National CABIN taxonomist.

Data available on ECCC Open Data Portal at this link:

<http://donnees.ec.gc.ca/data/substances/monitor/benthic-invertebrates-oil-sands-region/> and is current to all data available.

Data is uploaded to the ECCC Open Data portal as data becomes available in the respective databases. The schedule for data upload to the ECCC Open Data Portal for the BMI is between June – December for samples collected the previous fall (see Fig. 5). This schedule is based on the expected date of receiving the data from the specific laboratory. In some cases, there have been data delays from the laboratories. However, each new data upload to the Open Data portal has all that is currently held in the database.

Specific data requests for unverified data or specific data formats are filled upon request. Over 45 such individual requests since 2021 have been provided for OSM related data to Provincial and Territorial partners, consultants, universities, and communities.

Data Sharing and Data Management Continued

13.1 Has there, or will there be, a Data Sharing agreement established through this Project? *

YES

13.2 Type of Quantitative Data Variables:

Both

13.3 Frequency of Collection:

Other

13.4 Estimated Data Collection Start Date:

2023-08-14

13.5 Estimated Data Collection End Date:

2023-10-31

13.6 Estimated Timeline For Upload Start Date:

2024-06-03

13.7 Estimated Timeline For Upload End Date:

2024-12-31

13.8 Will the data include traditional knowledge as defined by and provided by an Indigenous representative, Community or Organization?

NO

TABLE 13.9 Please describe below the Location of Data and Data Type:

Add a Data Source by clicking on the table and then clicking on the blue "+" symbol on the bottom right side of table

Name of Dataset	Location of Dataset (E.g.: Path, Website, Database, etc.)	Data File Formats (E.g.: csv, txt, API, accdb, xlsx, etc.)	Security Classification
Mainstem and Tributary Biomonitoring	ECCC Data Portal	Various including CSV	Open by Default
AEP Water Quality Data	AEP Data Portal	Various including CSF	Open by Default

Figure 5. Schedule of data upload to the Environment and Climate Change Canada Open Data Portal from the Benthos Monitoring work plan section 13.1.

5. Project Sampling Summaries 2011-2024

Sampling approaches for the OSM Benthic Macroinvertebrate (BMI) monitoring program from 2011–2024 have been adapted on an annual basis and were originally derived from the recommendations in the integrated monitoring plan document (Environment Canada, 2011), and revised based on the recommendations after a comprehensive peer-review of the program and results (Culp et. al, 2018). As well, on an annual basis, a detailed monitoring schedule with a list of the planned sites to be sampled has been developed, reviewed, and approved through the OSM work planning process.

In all years, the sites that were planned for the Athabasca River have been successfully sampled. In the tributary areas, for most years, all sites planned have been sampled. However, depending on conditions and access at the time of sampling (e.g., high water, beaver dam activity, anchor ice on stream bed, etc.) some sites may not have been sampled or nearby sites in the same reach area may have been sampled as an alternative. Sampling has occurred consistently within a 4-week period, between mid-September to mid-October. Samples were not collected in 2020 due to the suspension of sampling because of the global pandemic.

Over the 12 years of the OSM macroinvertebrate biomonitoring program a total of 1757 BMI and supporting water and sediment quality samples were collected from 245 sites in 12 distinct basins, rivers, or areas (Table 1, Appendix Tables A1a-d). On average, over 190 samples were collected each year. Sampling in the Athabasca River and its major tributaries (Steepbank, MacKay, Muskeg, Ells and Firebag rivers) was the priority in the earlier years, starting with 30 sites sampled as a pre-OSM pilot project in 2011. In 2012, an additional 20 sites were established and sampling in the Birch Mountains area was initiated as pre-development reference sites. During the first 2-4 years of sampling, further sites were established to fill study design gaps. As well, several sampling approaches (i.e., mesh size, sampling device, and artificial substrates), and additional response variables including periphyton and sestonic algal biomass, environmental 'omics', stable isotopes and ecosystem function measures were or are currently being evaluated (Table 4 in Environment Canada, 2011; Culp et. al., 2018; Culp et. al., 2021). Since 2017 (i.e., after the water rationalization exercise was completed during a workshop in November of 2016, Cooke et. al., 2018) sampling effort and approaches have remained consistent. In a typical year, 11 of the 19 sites are sampled in the Athabasca River and 45 of the 128 sites established in the tributaries.

For the Athabasca River and its major tributaries, reference and exposure categories have been defined as in Culp et. al., (2018). In the Athabasca River (Table 1, Appendix Table A1a), sites are categorized in a gradient from upstream to downstream as, 1) Reference Outside Exposure to Natural Bitumen, 2) Reference Inside Exposure to Natural Bitumen, 3) Municipal Sewage Effluent (MSE) site with Inside Exposure to Natural Bitumen + high exposure to Municipal Sewage Effluent (MSE), but no oil sands development exposure, 4) Oil Sands Development sites with Inside Exposure to Natural Bitumen + moderate MSE + high exposure to OS Development activities, and 5) Recovery sites with Inside Exposure to Natural Bitumen + moderate MSE + low exposure to OS Development activities. Sites have been added or relocated based on new information and not all sites are sampled every year, but since 2012 at least one site from each category has been sampled annually for assessment of cumulative effects (Appendix Table A1a). Additionally, during 2011-2015, as part of the investigation of sampling available benthic macroinvertebrate habitats, sand habitats were sampled at 10 sites in conjunction with the gravel cobble areas in the Mainstem of the Athabasca River (Table 1, Appendix Table A1a).

Table 1. Oil Sands Monitoring Program – Field sampling summary for all sampling areas from 2011-2024.

Sampling Summary: 2011-2023							Exposure Categories Present					
	Sampling Area	Total # Sites	Year of First Sampling	# Years Sampled	Total # Samples	Avg # Samples / Year (excluding 2011 & 2020)	Reference Outside Nat BR	Reference Inside Nat BR	Inside Natural BR + MSE	Inside Natural BR + MSE + OS Dev Activities	Inside Natural BR + OS Dev Activities	Inside Natural BR + Reduced OS Dev Activities (i.e., Recovery)
Athabasca River Mainstem	Lower Athabasca River Gravel Site	19	2011	13	700	55	✓	✓	✓	✓	na	✓
	Lower Athabasca River Sand Sites	10	2011	9 (to 2015)	230	49	na	✓	✓	✓	na	✓
Athabasca River & PAD Tributaries	Steepbank River	27	2011	14	155	11	✓	na	na	na	✓	na
	Mackay /Dover River	26	2011	14	131	9	✓	✓	na	na	✓	na
	Muskeg and Jack/Pine	6	2011	14	31	2	na	✓	na	na	✓	na
	Ells River	22	2011	14	120	9	✓	✓	na	na	✓	na
	Firebag River	20	2011	14	93	7	✓	✓	na	na	✓	na
	Birch Mountains	27	2012	11	87	8	✓	na	na	na	na	na
In Situ/SAGD Areas	Horse River	7	2016	7	21	3	na - not yet classified					
	Hangingstone River	9	2016	8	30	4						
	Christina River Watershed	46	2018	6	129	22						
	Cold Lake Oil Sands Area	7	2023	2	11	6						
	Peace River Oil Sands Area	19	2016	3	19	6						
	Total	245	na	na	1757	190						

In the LAR tributaries, sites are similarly categorized as, 1) Reference Outside Exposure to Natural Bitumen, 2) Reference Inside Exposure to Natural Bitumen, and 3) Inside Exposure to Natural Bitumen + Exposure to increasing OS Development activities. Sites with exposure to OS Development activities are further identified as distinct test categories (1-4) depending on levels of exposure as defined by % land disturbance, % active lease, and location relative to the Oil Sands Mineable Area, and OS development footprint/activities in the upstream catchment (Glozier and Ritcey 2023). Depending on level of OS development, not all categories of sites are present in all basins (Table 1). The sampling effort for the study has been stratified equally between reference (51%) and exposure (49%) areas (Table 2). Within a stream, samples have been stratified as close to proportional to the available river distance and accessible sampling sites within a category as feasible. Low and high-water years have made sampling some sites inaccessible in some years, but a focus was placed on ensuring at least several sites within each category were sampled each year for assessment of cumulative effects along the river gradient (Appendix Table A1b).

Table 2. Oils Sands Monitoring Program – Field sampling summary for tributaries to the Athabasca River and Peace Athabasca Delta by exposure category from 2011-2024.

	Total number of samples by Tributary and Exposure Category									
	Birch Mtns	Dover	Mackay	Ells	Firebag	Steepbank	Musk/Jack*	Total	%	
Reference - Outside Exposed Deposit	87	9	40	25	39	46	—	246	40%	51%
Reference - Inside Exposed Deposit	—	19	—	20	24	—	6*	69	11%	
Inside Exp Dep + OSM Test Group 1	—	—	23	29	30	24	6*	112	18%	49%
Inside Exp Dep + OSM Test Group 2	—	—	40	23	—	25	19	107	17%	
Inside Exp Dep + OSM Test Group 3	—	—	—	23	—	35	—	53	9%	
Inside Exp Dep + OSM Test Group 4	—	—	—	—	—	25	—	25	4%	
Total number of samples	87	28	103	120	93	155	31	617	100%	

In 2016 standardized OSM CABIN sampling was expanded to several In Situ Oil Sands Regions including in the Peace River Oil Sands Region and the Horse and Hangingstone rivers near Fort McMurray (Table 1, Appendix Table A1c and d). A total of 19 sites were sampled once in the Peace River Region over a 3-year period. Although sites sampled were in gravel/cobble streams and rivers, the dominant habitats adjacent to operating facilities are slow flowing streams with fine sediments and wetlands. Sampling was suspended in the Peace River Region after 2019 to allow information to be gathered, such as land use, land disturbance, and aquatic habitat characteristics to allow appropriate sampling designs and study objectives to be developed. Once clear objectives and priority areas are established, sampling was planned to resume upon work plan approval. The Horse and Hangingstone rivers were first sampled in the fall of 2016, post Fort McMurray Wildfire, and sampling has continued in these two basins in a gradient design upstream and downstream of In Situ operations.

In 2018 (Table 1, Appendix Table A1c) after work plan approvals, sampling in the Christina River Watershed was initiated to expand the OSM biomonitoring program to the In Situ Regions south of Fort McMurray. The initial design was based on resampling sites from five streams that have historic BMI and water quality (WQ) data through a previous study focused on effects of forestry in the mid to late 1990s. The TROLS (Terrestrial and Riparian Organisms, Lakes, and Streams) stream component was led by ECCC and included sampling of 4 sites in an upstream/downstream gradient design from each of the five major tributaries to the Christina River (Meadow, Cottonwood, Pony and Waddell creeks and the Kettle River). At the time of the TROLS study, there was minimal oil sands related activity in these basins, thus making the TROLS data set a unique opportunity to compare pre-OSM “Historic State” within this In Situ Region with current conditions. With the objective of establishing Reference and Accumulated State (Environment Canada 2011a) for this Region, in 2018 and 2019, a total of 20 sites were re-established among the five TROLS streams and additional sites in the Gregoire and upper Christina rivers. No sampling occurred in 2020 due to the global pandemic but since then an additional 26 sites have been established: the number of samples per site ranges from 1-6. As of 2024, 23 sites have 3 or more samples (i.e., at least 3 years of data). Thus, establishing Reference and Accumulated State in the Christina River Watershed is still underway with the focus of 2025 sampling being a focus on site with < 3 years of sampling.

6. Reporting - Primary publication list and select presentations (see Appendix B for representative presentations from 2020 and 2023)

Since the start of OSM, presentations and publications from the benthic macroinvertebrate OSM program have been produced and shared through peer-reviewed journal publications, technical reports, workshops and conferences. A list of these reporting products is provided below with links to online sources where available. As well, copies of key presentations provided by the study team at the 2020 and 2023 OSM work planning and Surface Water Technical Advisory Committee meetings have been provided in PDF form in Appendix B.

Publications

- LAU, D.C.P, R.B. BRUA, W. GOEDKOOP, & J.M. CULP. 2023. Fatty-acid based assessment of benthic food-web responses to multiple stressors in a large river system. *Environmental Pollution* 337: 122598 <https://doi.org/10.1016/j.envpol.2023.122598>
- KLEMT, W.H., R.B. BRUA, J.M. CULP, K. HICKS, B.B. WOLFE, & R.I. HALL. 2021. Evaluating Lower Athabasca River sediment metal concentrations from Alberta Oil Sands Monitoring programs using pre-development baselines. *Environmental Science & Technology* 55: 8817-8828 <https://doi.org/10.1021/acs.est.1c01761>
- CULP, J.M., DROPPA, I.G., DI CENZO, P.D., ALEXANDER-TRUSIAK, A., BAIRD, D.J., BICKERTON, G., BELTAOS, S., BONSAI, B., BRUA, R.B., CHAMBERS, P.A., DIBIKE, Y., GLOZIER, N.E., KIRK, J., LEVESQUE, L., MCMASTER, M., MUIR, D., PARROTT, J., PETERS, D.L., PIPPY, K. & J.W. ROY. 2021. Ecological effects and causal synthesis of oil sands activity impacts on river ecosystems: water synthesis review. *Environmental Reviews* 29: 315-327. <https://doi.org/10.1139/er-2020-0082>
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Appendix A

Appendix Table A1a. Oil Sands Monitoring Program 2011-2023: Detailed annual sampling summary for Mainstem Lower Athabasca River benthic macroinvertebrate monitoring program. Five replicate BMI samples taken at each site. X= Sampled in gravel substrate; XX = sampled in both gravel and sand substrates. *Exposure categories as in Culp et al., (2018).

Region	Site Name	Exposure to *	Latitude	Longitude	Surveillance (S) / Intensive Investigation (I)	Years Sampled															Σ
						2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024		
Athabasca River Mainstem	M0A	Reference Outside Nat Bit	54.7545	-113.3783	S								X	X		X	X			4	
	M0	Reference Outside Nat Bit	54.7265	-113.3006	S & I		X	X	X	X	X	X	X	X		X	X	X	X	12	
	M1A	Reference Inside Nat Bit	56.6219	-111.6552	S						X	X	X	X		X	X			6	
	M1	Reference Inside Nat Bit	56.6416	-111.6191	S	XX	XX	XX	XX	XX	X									6	
	M2A	Reference Inside Nat Bit	56.6927	-111.4626	S & I						X	X	X	X		X	X	X	X	8	
	M2	Reference Inside Nat Bit	56.7431	-111.3895	S	XX	XX	XX	X	XX	X									6	
	M3	Nat Bit & HIGH MSE	56.7938	-111.4042	S & I	XX	XX	XX	XX	XX	X	X	X	X		X	X	X	X	13	
	Northland	Nat Bit & HIGH MSE & MOD OSM	56.8792	-111.4328	I													X	X	2	
	M3B	Nat Bit & HIGH MSE & HIGH OSM	56.9473	-111.4427	S & I		XX	XX	XX	XX	X	X	X	X		X	X	X	X	12	
	Sun-Up	Nat Bit & MOD MSE & HIGH OSM	56.9968	-111.4490	I					X								X	X	3	
	Sun-Dn	Nat Bit & MOD MSE & HIGH OSM	57.0438	-111.5037	I					X								X	X	3	
	M3C	Nat Bit & MOD MSE & HIGH OSM	57.0629	-111.5198	I													X	X	2	
	M4	Nat Bit & MOD MSE & HIGH OSM	57.098	-111.5649	S & I	XX	XX	XX	XX	XX	X	X	X	X		X	X	X	X	13	
	M6	Nat Bit & MOD MSE & HIGH OSM	57.202	-111.6104	S	XX	XX	XX	XX	XX	X	X	X	X		X	X			11	
	M7	Nat Bit & MOD MSE & HIGH OSM	57.3579	-111.6586	S		XX	XX	XX	XX			X							5	
	M7B	Nat Bit & MOD MSE & HIGH OSM	57.4247	-111.6417	I													X	X	2	
	M7C	Nat Bit & MOD MSE & MOD OSM	57.5114	-111.538	S		XX	XX	XX	XX		X			X		X	X		8	
M8	Nat Bit & MOD MSE & MOD OSM	57.657	-111.4259	S	XX	XX	XX	XX	XX	X	X	X	X		X	X			11		
M9	Nat Bit & MOD MSE & MOD OSM	58.0666	-111.3681	S & I	XX	XX	XX	XX	XX	X	X	X	X		X	X	X	X	13		
					Σ	7	11	11	11	13	11	10	11	11	0	11	11	11	11	140	

Appendix Table A1b. Oil Sands Monitoring Program 2011-2023: Detailed annual sampling summary for Lower Athabasca River Tributary benthic macroinvertebrate monitoring program that includes: Steepbank, MacKay, Ells, Muskeg, Firebag rivers and Birch Mountain region. *Exposure categories as in Culp et al., (2018).

Region	Major Tributary	Site Name	Exposure To*	Latitude	Longitude	Surveillance (S) / IntenSive InveStigation (I) / Rotational (R)	Years Sampled																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
							2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Σ																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
Lower Athabasca River Tributaries	STEEPBANK RIVER	STERIFF15	Reference - Outside Exposed Deposit	56.82783	-110.95035	I																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																					</

Appendix Table A1b (con't). Oil Sands Monitoring Program 2011-2023: Detailed annual sampling summary for Lower Athabasca River Tributary benthic macroinvertebrate monitoring program that includes: Steepbank, MacKay, Ells, Muskeg, Firebag rivers and Birch Mountain region.

***Exposure categories as in Culp et al., (2018).**

Region	Major Tributary	Site Name	Exposure To*	Latitude	Longitude	Surveillance (S) / IntenSive InveStigation (I) / Rotational (R)	Years Sampled																			
							2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Σ					
Lower Athabasca River Tributaries	MACKAY AND DOVER RIVERS	DUNIFF01	Reference - Outside Exposed Deposit	56.85961	-112.7115	R			x	x	x	x											4			
		DOVNIFF04A	Reference - Outside Exposed Deposit	57.11634	-112.01776	S				x	x			x									3			
		DOVNIFF04	Reference - Outside Exposed Deposit	57.12142	-112.01329	R		x																1		
		DOVNIFF07	Reference - Outside Exposed Deposit	57.1375	-111.94786	R								x										1		
		DOVNIFF03	Reference - Inside Exposed Deposit	57.14531	-111.90717	R							x					x						2		
		DOVNIFF01	Reference - Inside Exposed Deposit	57.15042	-111.91114	R		x																1		
		DOVNIFF02	Reference - Inside Exposed Deposit	57.15603	-111.87492	R		x	x	x	x	x		x										5		
		DOVNIFF06	Reference - Inside Exposed Deposit	57.15908	-111.86431	R			x															1		
		DOVNIFF06	Reference - Inside Exposed Deposit	57.17437	-111.80713	S			x	x	x	x	x											x	6	
		DOVNIFF05A	Reference - Inside Exposed Deposit	57.17433	-111.80335	R									x				x	x					4	
		MCKNIFF01	Reference - Outside Exposed Deposit	56.84018	-112.28838	R									x	x									2	
		MCKNIFF07	Reference - Outside Exposed Deposit	56.85613	-112.25451	R		x	x	x															3	
		MCKNIFF05	Reference - Outside Exposed Deposit	56.92269	-112.1485	S		x	x	x	x	x	x		x	x	x			x	x				11	
		MCKNIFF02	Reference - Outside Exposed Deposit	56.96139	-111.95167	S		x	x	x	x				x	x				x	x	x	x		10	
		MCKNIFF10	Reference - Outside Exposed Deposit	56.9763	-111.87386	R									x										1	
		MCKNIFF09	Reference - Outside Exposed Deposit	57.00797	-111.84817	S		x	x	x	x	x			x	x	x			x	x	x	x		12	
		MCKNIFF05A	Reference - Outside Exposed Deposit	57.01038	-111.84216	R							x												1	
		MCKNIFF11	Inside Exp Dep + OSM Test Group 1	57.02982	-111.81715	R										x									1	
		MCKNIFF13	Inside Exp Dep + OSM Test Group 1	57.02967	-111.7958	R															x				1	
		MCKNIFF04	Inside Exp Dep + OSM Test Group 1	57.05986	-111.77587	S				x	x	x	x				x	x			x	x			x	9
		MCKNIFF06	Inside Exp Dep + OSM Test Group 1	57.10314	-111.76397	S				x	x	x	x	x				x			x	x	x	x		11
		MCKNIFF16	Inside Exp Dep + OSM Test Group 1	57.12735	-111.76013	R															x					1
		MCKNIFF08	Inside Exp Dep + Test Group 2	57.15265	-111.76068	S					x		x	x	x	x	x				x	x	x	x		10
		MCKNIFF03	Inside Exp Dep + Test Group 2	57.17767	-111.73501	S					x	x	x	x	x						x	x			x	11
		MCKNIFF15	Inside Exp Dep + Test Group 2	57.21261	-111.71044	R					x	x	x	x												6
		MCKNIFF12	Inside Exp Dep + Test Group 2	57.19111	-111.67056	S					x	x	x	x	x	x	x				x	x	x	x		13
						Σ	6	14	14	12	10	10	10	15	8	8	0	10	10	6	8		131			

Appendix Table A1b (con't). Oil Sands Monitoring Program 2011-2023: Detailed annual sampling summary for Lower Athabasca River Tributary benthic macroinvertebrate monitoring program that includes: Steepbank, MacKay, Ells, Muskeg, Firebag rivers and Birch Mountain region.

***Exposure categories as in Culp et al., (2018).**

Region	Major Tributary	Site Name	Exposure To*	Latitude	Longitude	Surveillance (S) / IntenSive InveStigation (I) / Rotational (R)	Years Sampled																			
							2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Σ					
Lower Athabasca River Tributaries	ELLS RIVER	ELLSRIF17	Reference - Outside Exposed Deposit	57.14661	-112.22033	I																		x	1	
		ELLSRIF15	Reference - Outside Exposed Deposit	57.14829	-112.20782	I								x	x										2	
		ELLSRIF09	Reference - Outside Exposed Deposit	57.15129	-112.17081	S & I			x	x	x	x	x						x	x						7
		ELLSRIF10	Reference - Outside Exposed Deposit	57.17689	-112.10476	I				x	x										x				x	4
		ELLSRIF06	Reference - Outside Exposed Deposit	57.21833	-112.01964	S & I			x	x	x	x	x	x					x	x	x	x				11
		ELLS RIF05A	Reference - Inside Exposed Deposit	57.22782	-111.97022	I						x							x							3
		ELLSRIF05	Reference - Inside Exposed Deposit	57.22767	-111.95897	S & I			x	x	x				x	x					x	x	x	x		9
		ELLSRIF13	Reference - Inside Exposed Deposit	57.22909	-111.9399	S & I			x					x	x	x	x				x	x			x	8
		ELLSRIF11	Inside Exp Dep + OSM Test Group 1	57.23883	-111.84849	S & I				x	x	x	x	x			x	x			x	x	x	x		11
		ELLSRIF14	Inside Exp Dep + OSM Test Group 1	57.2341	-111.77515	I								x	x						x					4
		ELLSRIF16	Inside Exp Dep + OSM Test Group 1	57.23273	-111.75417	I																			x	1
		ELLSRIF02A	Inside Exp Dep + OSM Test Group 1	57.2418	-111.73469	R							x													1
		ELLSRIF02	Inside Exp Dep + OSM Test Group 1	57.24456	-111.73656	S & I			x	x	x	x			x	x	x	x			x	x	x	x		12
		ELLSRIF01	Inside Exp Dep + Test Group 2	57.26467	-111.73319	I			x								x								x	4
		ELLSRIF01A	Inside Exp Dep + Test Group 2	57.2648	-111.73097	R				x																1
		ELLSRIF12	Inside Exp Dep + Test Group 2	57.2645	-111.71644	S & I								x	x					x		x	x	x		7
		ELLSRIF04A	Inside Exp Dep + Test Group 2	57.27579	-111.70131	I									x								x			3
		ELLSRIF04	Inside Exp Dep + Test Group 2	57.28007	-111.70496	S & I				x	x	x	x			x	x	x			x					8
		ELLSRIF07	Inside Exp Dep + Test Group 3	57.28983	-111.70944	S & I				x	x	x	x											x		6
		ELLSRIF03A	Inside Exp Dep + Test Group 3	57.2914	-111.69764	S & I					x	x	x	x	x	x	x				x	x	x	x		11
		ELLSRIF03	Inside Exp Dep + Test Group 3	57.30519	-111.67292	I			x																	1
		JOSRIF01	na - not classified but within Test Group 3	57.28964	-111.71122	I			x	x	x	x	x													5
Σ						4	10	11	10	10	9	9	7	8	0	10	11	6	15	120						

Appendix Table A1b (con't). Oil Sands Monitoring Program 2011-2023: Detailed annual sampling summary for Lower Athabasca River Tributary benthic macroinvertebrate monitoring program that includes: Steepbank, MacKay, Ells, Muskeg, Firebag rivers and Birch Mountain region.

***Exposure categories as in Culp et al., (2018).**

Region	Major Tributary	Site Name	Exposure To*	Latitude	Longitude	Surveillance (S) / Intensive Investigation (I) / Rotational (R)	Years Sampled																
							2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Σ		
Lower Athabasca River Tributaries	FIREBAG RIVER	FIRTRB04	Reference - Outside Exposed Deposit - INSITU/SAGD upstream	57.22648	-110.53746	R					x	x	x			x						4	
		FIRTRB03	Reference - Outside Exposed Deposit - INSITU/SAGD upstream	57.29755	-110.45716	R					x			x	x	x						4	
		FIRTRB05	Reference - Outside Exposed Deposit - INSITU/SAGD upstream	57.40966	-110.84743	R									x							1	
		FIRTRB02	Reference - Outside Exposed Deposit - INSITU/SAGD upstream	57.32131	-110.45741	R				x	x	x	x									4	
		FIRUPPER	Reference - Outside Exposed Deposit	57.33123	-110.44138	S	x	x	x	x	x	x	x	x				x				10	
		FIRUPPER01	Reference - Outside Exposed Deposit	57.34333	-110.49489	S				x					x			x	x	x		5	
		FIRUPPER02	Reference - Outside Exposed Deposit	57.3707	-110.54433	R								x								1	
		FIRUPPER03	Reference - Outside Exposed Deposit	57.37268	-110.55278	R										x						1	
		FIRMD03	Reference - Outside Exposed Deposit	57.38493	-110.61674	S				x	x	x	x		x	x			x	x	x	9	
		FIRMD06	Reference - Inside Exposed Deposit	57.4061	-110.71046	S									x	x			x	x	x	5	
		FIRMD09	Reference - Inside Exposed Deposit	57.4025	-110.7625	R										x						1	
		FIRMD04	Reference - Inside Exposed Deposit	57.40337	-110.77177	R					x				x			x	x			4	
		FIRMD05	Reference - Inside Exposed Deposit	57.40966	-110.84743	R									x	x						2	
		FIRMD	Reference - Inside Exposed Deposit	57.43718	-110.89437	S		x	x	x	x	x	x	x	x	x		x	x	x	x	12	
		FIRMD02	Inside Exp Dep + OSM Test Group 1	57.4698	-110.98098	R				x	x	x	x		x	x			x	x		8	
		FIRMD08	Inside Exp Dep + OSM Test Group 1	57.47267	-111.07496	R									x	x				x		3	
		FIRLOWER	Inside Exp Dep + OSM Test Group 1	57.51906	-111.11241	S		x	x	x	x	x	x	x	x	x		x	x	x	x	12	
		FIRMD07	Inside Exp Dep + OSM Test Group 1	57.59783	-111.09939	R									x							1	
		FIRLOWER01	Inside Exp Dep + OSM Test Group 1	57.6152	-111.11869	R					x											1	
		FIRLOWER02	Inside Exp Dep + OSM Test Group 1	57.65123	-111.20847	S					x	x			x	x			x			5	
Σ						1	3	6	12	8	7	5	12	15	0	5	8	7	4	93			

Appendix Table A1b (con't). Oil Sands Monitoring Program 2011-2023: Detailed annual sampling summary for Lower Athabasca River Tributary benthic macroinvertebrate monitoring program that includes: Steepbank, MacKay, Ells, Muskeg, Firebag rivers and Birch Mountain region.

***Exposure categories as in Culp et al., (2018).**

Region	Major Tributary	Site Name	Exposure To*	Latitude	Longitude	Surveillance (S) / IntenSive InveStigation (I) / Rotational (R)	Years Sampled																
							2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Σ		
Birch Mountains	ALICE CREEK TRIB	JALICARIFF03	Reference - Outside Exposed Deposit	57.98515	-112.78322	R						✖										1	
		JALICARIFF04	Reference - Outside Exposed Deposit	57.99693	-112.8185	R						✖										1	
		JALICARIFF02	Reference - Outside Exposed Deposit	57.99908	-112.84158	R					✖											1	
		JALICARIFF01	Reference - Outside Exposed Deposit	57.99739	-112.91344	S					✖	✖						✖				3	
	ALICE CREEK	EBRT0807	Reference - Outside Exposed Deposit	58.05002	-112.93325	S				✖	✖	✖	✖							✖		5	
		EBRT0808	Reference - Outside Exposed Deposit	58.10421	-112.94599	R				✖									✖			2	
		EBRT0806	Reference - Outside Exposed Deposit	58.11858	-113.03207	R				✖												1	
		EBRT0803	Reference - Outside Exposed Deposit	58.15297	-113.10387	R			✖	✖	✖	✖							✖	✖		6	
		EBRT0802	Reference - Outside Exposed Deposit	58.22433	-113.18031	S			✖	✖	✖		✖	✖					✖			6	
		EBRT0801	Reference - Outside Exposed Deposit	58.28433	-113.19906	R			✖	✖												2	
	BIRCH TRIBUTARIES	EBRT0813	Reference - Outside Exposed Deposit	58.1716	-112.6463	R				✖	✖	✖	✖									4	
		EBRT0814	Reference - Outside Exposed Deposit	58.18341	-112.71924	R				✖												1	
		EBRT0812	Reference - Outside Exposed Deposit	58.20528	-112.74071	R				✖	✖	✖										3	
		EBRT0804	Reference - Outside Exposed Deposit	58.23417	-112.76192	R				✖		✖	✖									3	
		EBRT0805	Reference - Outside Exposed Deposit	58.1755	-112.21115	R				✖	✖											2	
	MCMOR RIVER	EBRT0815	Reference - Outside Exposed Deposit	57.92786	-112.33569	R					✖											1	
		EBRT0816	Reference - Outside Exposed Deposit	57.93419	-112.25136	R					✖	✖	✖	✖	✖	✖		✖	✖			7	
		EBRT0817	Reference - Outside Exposed Deposit	57.95675	-112.16294	R					✖					✖						2	
		EBRT0819	Reference - Outside Exposed Deposit	57.90002	-112.03741	R						✖				✖						2	
		EBRT0818	Reference - Outside Exposed Deposit	57.95641	-112.12891	R						✖										1	
		EBRT0821	Reference - Outside Exposed Deposit	57.96626	-112.12144	R						✖				✖		✖				3	
		EBRT0809	Reference - Outside Exposed Deposit	57.97546	-112.10649	S				✖	✖	✖	✖	✖	✖	✖		✖	✖	✖		9	
		EBRT0822	Reference - Outside Exposed Deposit	57.98605	-112.06411	R										✖		✖				2	
		EBRT0820	Reference - Outside Exposed Deposit	57.98728	-112.03197	R						✖						✖				2	
		EBRT0810	Reference - Outside Exposed Deposit	57.99934	-111.99959	S				✖	✖	✖	✖	✖	✖	✖		✖			✖	8	
		EBRT0811	Reference - Outside Exposed Deposit	58.02798	-111.96023	S				✖	✖	✖	✖	✖	✖	✖		✖	✖	✖		9	
						Σ	0	2	3	13	13	17	8	4	8	0	7	7	5	0	87		

Appendix Table A1c. Oil Sands Monitoring Program 2011-2023: Detailed annual sampling summary for oil sands in situ regions including the Clearwater/ Christina, Horse and Hanginstone rivers, and the Cold Lake OSM Region.

Region	Major Tributary	Site Name	Latitude	Longitude	On Going Surveillance (S) / Intensive Investigation (I) / Establishing Baseline (B)	Years Sampled																
						2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Σ		
Clearwater/ Christina River Watershed	HIGH HILLS	HIGHHILLS	56.75160	-110.50624	na			X	X	X										3		
	Christina River	CHRIFF01	55.87844	-111.51339	B									X			X	X	X	X	5	
		CHRIFF02	55.80815	-111.40489	B									X			X	X	X	X	5	
		CHRCBM01	55.83460	-110.86852	B													X	X	X	3	
		CHRIFF03	55.70009	-111.41476	B													X	X	X	3	
		CHRIFF42	55.71734	-111.24197	B														X	X	2	
		CHRIFF04	55.718760	-111.058700	B														X	X	2	
		CHRIFF06	55.85252	-111.45782	B														X	X	2	
		CHRIFF05	55.889850	-111.557760	B														X	X	2	
	Christina River Tributary	CHRTIB01	55.699688	-111.415970	B										X				X	X	3	
		CHRTIB02	55.708536	-111.481110	B										X			X	X	X	4	
	Cottonwood Creek	COTRIFF01	56.163428	-110.99320	B									X	X		X	X			4	
		COTRIFF02	56.14862	-110.95838	B									X				X	X		3	
		COTRIFF03	56.13821	-110.92860	B									X	X		X				3	
		COTRIFF04	56.13929	-110.89603	B													X	X		2	
	Gregoire River	GRERIFF01	56.47501	-110.84477	B									X	X		X	X	X	X	6	
		GRERIFF02	56.37618	-110.98261	B									X	X		X	X	X	X	6	
		GRERIFF03	56.36715	-110.86732	B									X	X		X	X	X	X	6	
		GRERIFF04	56.42600	-110.81981	B									X	X		X	X	X	X	6	
		GRERIFF05	56.3527	-110.77705	B														X	X	2	
		GRERIFF06	56.39774	-110.84361	B														X	X	2	
		GRERIFF07	56.41328	-111.07066	B														X		1	
	Kettle River	KETRIFF01	56.013942	-111.049673	B										X		X	X			3	
		KETRIFF02	56.044036	-111.111108	B											X					1	
		KETRIFF02A	56.045060	-111.110820	B													X	X		2	
		KETRIFF03	56.014440	-111.051730	B														X		1	
		KETCBM01	55.985444	-110.947139	B														X		1	
		KETCBM01A	55.986669	-110.949098	B															X	1	
		KETCBM02	55.992402	-110.820889	B															X	1	
		KETCBM04	55.978358	-110.768563	B															X	1	
	Meadow Creek	MEDRIFF01	56.27282	-110.87046	B									X	X		X	X			4	
		MEDRIFF01A	56.27313	-110.86900	B														X	X	2	
		MEDRIFF02	56.21559	-111.05604	B									X	X		X				3	
		MEDRIFF03	56.21954	-110.95766	B									X			X	X	X	X	5	
	Pony Creek	PONYRIFF01	55.861305	-111.007768	B										X		X	X			3	
		PONYRIFF02	55.869856	-110.917633	B										X		X	X			3	
		PONYRIFF03	55.671360	-111.097760	B													X			1	
	Waddell Creek	WADRIFF01	55.809975	-111.079566	B										X		X	X	X	X	5	
		WADRIFF02	55.851870	-111.171628	B										X		X	X	X		4	
	Jackfish River	JACCBM01	55.671360	-111.097760	B													X	X	X	3	
		JACRIFF01	55.70879	-111.08534	B														X	X	2	
	May River	MAYCBM01	55.5007.4	-111.5208.8	B														X	X	2	
		MAYRIFF37	55.66731	-111.3784	B														X	X	2	
		MAYRIFF35	55.67312	-111.36151	B															X	2	
	Summont Creek	SURWLMN01	56.32211	-111.21383	B																1	
		SURWLMN02	56.3951	-111.15147	B																1	
					Σ	0	0	1	1	1	0	0	12	16	0	16	22	31	29	129		

Appendix Table A1c (con't). Oil Sands Monitoring Program 2011-2023: Detailed annual sampling summary for oil sands in situ regions including the Clearwater/ Christina, Horse and Hanginstone rivers, and the Cold Lake OSM Region.

Region	Major Tributary	Site Name	Latitude	Longitude	On Going Surveillance (S) / Intensive Investigation (I) / Establishing Baseline (B)	Years Sampled																
						2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Σ		
Additional InSitu/ SAGD Streams near Fort McMurray	HORSE RIVER	HRSRIF03	56.52191	-111.84133	B								✖							1		
		HRSRIF04	56.52122	-111.83347	B								✖							1		
		HRSRIF05	56.54162	-111.67006	B									✖						1		
		HRSRIF06	56.55526	-111.61945	S									✖				✖		2		
		HRSRIF07	56.63106	-111.53275	B									✖			✖		✖	3		
		HRSRIF02	56.67395	-111.42126	B						✖	✖	✖	✖			✖		✖	6		
		HRSRIF01	56.70308	-111.39368	S						✖	✖	✖	✖			✖	✖	✖	7		
	Σ					0	0	0	0	0	2	2	4	5	0	0	3	2	3	21		
	HANGINGSTONE RIVER	HNGRIF03	56.40374	-111.38506	B									✖	✖		✖	✖	✖	✖	6	
		HNGRIF04	56.47027	-111.40951	B									✖			✖	✖	✖	✖	5	
		HNGRIF02	56.64968	-111.35655	B						✖	✖		✖			✖	✖			5	
		HNGRIF01	56.68684	-111.36779	B						✖	✖	✖	✖				✖	✖		6	
		HNGRIF05	56.69155	-111.37210	B									✖			✖				2	
		HNGRIF06	56.49626	-111.39308	B												✖		✖		2	
		HNGRIF07	56.44112	-111.40761	B												✖		✖		2	
		HNGRIF07A	56.44294	-111.41087	B														✖		1	
		HNGRIF08	56.47811	-111.41071	B													✖			1	
Σ					0	0	0	0	0	2	2	3	4	0	2	7	5	5	30			
COLD LAKE OIL SANDS AREA	MEDCLFN01	54.63053	-110.20893	B														✖	✖	2		
	JFCCLFN01	54.63472222	-110.571611	B														✖	✖	2		
	MARCLFN01	54.69647222	-110.378583	B														✖	✖	2		
	MARCLFN02	54.58413	-110.32768	B															✖	1		
	MARCLFN04	54.547108	-110.359516	B															✖	1		
	MARCLFN05	54.52003	-110.31976	B															✖	1		
	MEDCLFN02	54.60736111	-110.194111	B														✖	✖	2		
Σ					0	0	0	0	0	0	0	0	0	0	0	0	4	7	11			

Appendix Table A1d. Oil Sands Monitoring Program 2011-2023: Detailed annual sampling summary for the Peace River Oil Sands Region.

Region	Site Name	Latitude	Longitude	On Going Surveillance (S) / Intensive Investigation (I) / Establishing Baseline (B)	Years Sampled														
					2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Σ
Peace River Oil Sands Area	LOON01	57.116444	-115.096607	B									X						1
	LOON02	57.050408	-115.09407	B									X						1
	MUD01	57.525233	-115.497391	B									X						1
	WAB18	57.65564	-115.398305	B									X						1
	WAB21B	57.569642	-115.412011	B									X						1
	WAB22D	57.510839	-115.501561	B									X						1
	WAB23B	57.32441	-115.249926	B									X						1
	WAB30B	57.093828	-114.894992	B									X						1
	WAB32	57.098171	-114.627831	B									X						1
	WAB44B	56.592859	-113.615738	B									X						1
	WAB45B	56.525485	-113.671009	B									X						1
	WAB48B	56.442527	-113.716196	B									X						1
	LGERIFF01	56.84407	-113.81746	B						X									1
	LGERIFF02	56.87355	-113.83864	B						X									1
	LGERIFF03	56.93326	-113.91513	B						X									1
	PEATRIB01	57.79074	-116.79022	B							X								1
	PEATRIB02	57.68879	-116.78632	B							X								1
	PEATRIB03	57.65348	-116.83546	B							X								1
	WABTRIB01	56.923	-114.35859	B						X									1
				Σ	0	0	0	0	0	4	3	0	12	0	0	0	0	19	

Appendix B

Appendix B: Representative Examples of Presentations provided to the OSM and Surface Water TAC members in 2020 and 2023. Other presentations listed in report are available upon request.

- 1) GLOZIER*, N.E., R.B. BRUA*, A. RITCEY, J. HANISCH*, & K. HYNES. 2023. Oil Sands Monitoring: Benthic macroinvertebrates – Thoughts on limits of change. Surface Water Technical Advisory Committee Meeting, 22-24 August 2023, Calgary, Alberta. * Co-presenters
- 2) GLOZIER*, N.E., R.B. BRUA*, A. RITCEY, L. LEVESQUE, J. HANISCH, & K. HYNES. 2023. Oil Sands Monitoring: Benthic macroinvertebrate Communities 2012 to 2023. Water Technical Advisory Committee Meeting, 24-25 July 2023, Calgary, Alberta. * Co-presenters
- 3) BRUA*, R.B., J.M. CULP, & N.E. GLOZIER. 2020. Aquatic ecosystem health monitoring: Benthic macroinvertebrates. Oil Sands Monitoring Program Aquatic Ecosystem Health Monitoring Workplan Workshop, 8-9 January 2020, Calgary, Alberta. * Presenter
- 4) Glozier*, N.E. A. Ritcey, K. Hynes and J. Hanisch 2020. Aquatic Ecosystem Health Monitoring – Benthic Macroinvertebrates. OSM Area – FMM Tributaries; SAGD Areas, South of FMM, Peace River and Cold Lake. Oil Sands Monitoring Program Aquatic Ecosystem Health Monitoring Workplan Workshop, 8-9 January 2020, Calgary, Alberta. * Presenter

OSM SURFACE WATER QUALITY & BENTHIC INVERTEBRATES

THOUGHTS ON LIMITS OF CHANGE

WQ - Nancy Glozier, Kerry Pippy, Lucie Levesque (ECCC),
Angela Sun AEPA
BMI - Nancy Glozier, Robert Brua, Allison Ritcey, (ECCC), Justin
Hanisch, Kristin Hynes (AEPA)

SW TAC Meeting Aug 22-24 2023 Calgary Alberta



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1

Limits of Change - Questions

Questions for Consideration

- How and where in the Adaptive Monitoring Framework will LoC be applied?
- Which indicators? How to evaluate indicators, what are the key attributes of an OSM Indicator?
- Will approaches to LoC be Indicator specific?
- **Objective today – to review the Limits of Change that have been applied in the WQ and BMI programs to date to adapt the monitoring design**



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2

Limits of Change - CES Lit Review

- Critical Effect Size (CES) is typically defined for a monitoring endpoint using reference or baseline data and includes a natural range of variation or values "expected" in a system in the absence of a potential impact that is being monitored
- Google Scholar results (comprising 500 individual records) were reviewed for the search term: critical "effect size." Each was briefly examined and excluded if; it did not pertain to ecology, was *strictly* a lab study, did not discuss "critical" effect size, was published before 1990,
 - 66 papers were retained and reviewed in more detail
 - 21 (32%) were general discussion papers
 - 45 papers (68%) explicitly discussed CES and provided examples

Type of Critical Effect Size	Number of Papers	Percent
Percentage around control metric	29	43.9%
General discussion of CES	21	31.8%
Confidence interval or multiplier of SD	12	18.2%
Other (within group variation, min/max of control value, Coen's D)	4	6.1%



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3

Limits of Change - CES Lit Review

- Percentages around means used for CES ranged from 10% - 100% in papers, depending on desired effect sizes and response being studied
- Confidence interval-based CESs were typically 90% or 95% CIs. Multipliers of a standard deviation (e.g., 1.96 x SD) were also reported in some papers, assuming data were normally distributed.
- Alternative CESs included a min/max range of control values, an unspecified measure of "within group variation," and Coen's d.
- When choosing a critical effect size for a program, careful consideration and analyses of reference/baseline data are required
- A single "one size fits all" CES for all monitoring metrics/endpoints may not always be possible in a program, as the nature of the variation can be different between metrics (e.g., richness vs. abundance of a taxonomic group).



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4

Indicator Characteristics

Indicator Attributes for Consideration

1. Ecologically Relevant
2. Easy to Communicate
3. Easily measured and reported
4. Scientifically Rigorous
5. Responsive to changes in the environment
6. Can show changes through time and/or space
7. Scale appropriate, regional, site specific
8. Thresholds can be developed



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5

Limits of Change - Assumptions

Assumptions of current LoC Discussion

- Current Indicators evaluated in the SOER, but other indicators remain under evaluation
 - Change in WQ can be **temporal, spatial or comparative to guideline**
 - Change in BMI is focused on effects on Aquatic Ecosystems, and specifically effects on **BMI communities** including NMDS, Bray Curtis, % Trichoptera
- **First level LoC** is a statistical difference at $p < 0.10$ and has been used to adapt the monitoring programs

Table 2. Decision Framework and Monitoring Response for various Levels of Water Changes

Level	Trigger	Response	Decision
1	There is a statistically significant change	Monitor presence in indicator	OK
2	There is a statistically significant change that suggests a deterioration in water quality or quantity	Monitor presence in indicator	OK
3	There is a statistically significant change that suggests a deterioration in water quality or quantity	Monitor presence in indicator	OK
Action Level	There is a statistically significant change that suggests a deterioration in water quality or quantity	Monitor presence in indicator	OK

Table 3. Decision "Triggers" for invertebrate monitoring program

Level	Trigger	Magnitude	Consequence
1	Effect detected	Statistical change	Seek confirmation
2	Confirmation of effect	Statistical change in time, abundance and direction	Increase spatial and temporal resolution around site of interest, add higher tier response variables
3	Exceeds critical effect size	Exceeds 100% for benthic invertebrate community endpoints or divergent from reference community in RCA models	Investigate potential source and cause of effect
Action Level	Exceeds critical effect size and is getting worse	Prolonged exceedence of critical effect size	Possible change in management actions warranted

6

Limits of Change - Assumptions

Assumptions of current LoC Discussion

- Where statistical difference at $p < 0.10$ has been observed, confirmed, in a consistent direction, with the extent and magnitude known, the monitoring programs have been adapted, for example:
 - WQ – stations suspended, frequency changed, some stations added, etc., (Optimization Exercise)
 - BMI – As previously reported, significant differences determine between reference/OS activity areas, areas of greatest change identified and is the current focus of monitoring
- WQ and BMI program are now at the stage of determining if change observed is related to Oil Sands Activities as approved through the 2023 scoping documents and work plans
- Options for **Second** level LoC (current discussion) applied if effects are related to OS activities.



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7

OSM Benthic invertebrates

Thoughts on Limits of change

BMI - Nancy Glozier, Robert Brua, Allison Ritcey, (ECCC),
Justin Hanisch, Kristin Hynes (AEPA)

SW TAC Meeting Aug 22-24 2023 Calgary Alberta



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8

Ecological vs Statistical Significance

"There is a widespread fallacy in environmental assessment that an effect that is small in magnitude relative to natural variation is of no ecological consequence."



"It is the difference in mean level of the variable that matters and there are no adequate grounds for valuing a species less if it is more variable than another."



Peterson 1993. Aust. J. Ecol. 18:21-52



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Limits of Change (Effect Size) Approaches

"The ... minimum effect size to be detectable in a monitoring study should be an absolute number (e.g., a decline in species richness from 50 to 30 per sample) or a proportional amount (e.g., a 25% decline in filter-feeders), but NOT a multiple of variance at the reference sites."



Green 1989. Aust. J. Ecol. 18:21-52



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Limits of Change - BMI

Proposed Indicators in draft SOER (Nov 2020)

1. Aquatic Invertebrate Assemblages – Two Indicators:

- ❑ **NMDS Ordination:** Non-metric multidimensional scaling (NMDS) is an ordination technique commonly used in the analysis of aquatic invertebrate assemblages by biomonitoring programs worldwide. The NMDS ordination incorporates both the diversity of invertebrates and their abundance in the sample analysis, hence making this a more comprehensive analysis.
- ❑ **Bray-Curtis (B-C) Index:** B-C Index reports values between 0 and 1 that indicate the extent of dissimilarity between two samples (i.e., how much their assemblages differ). Just like the NMDS ordination explained above, this single number results from an analysis of all the aquatic invertebrates present in a sample—both the diversity of invertebrates and their relative abundance.

2. Aquatic Invertebrate Structure – Three Indicators to date:

- ❑ **Family Richness:** The total number of all families of aquatic invertebrates collected at a site. This number could go up, down, or stay the same depending on the type of impact.
- ❑ **Total Abundance:** The total number of all individual aquatic invertebrates from all families collected at a site. This number could go up, down, or stay the same depending on the type of impact.
- ❑ **% Trichoptera:** The percentage of the order Trichoptera (caddisflies) in a sample. Some filter-feeding caddisflies are particularly sensitive to pollutants.



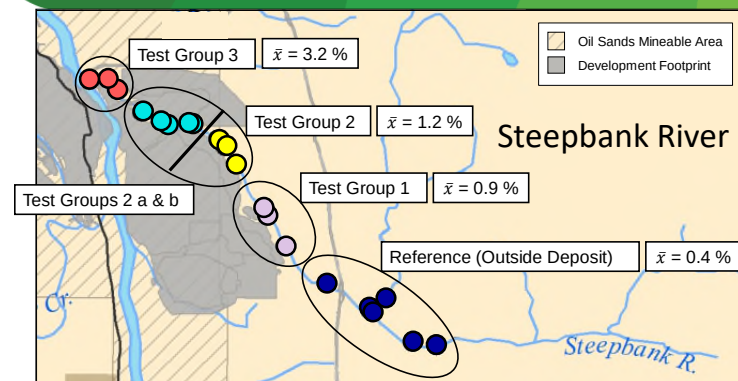
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Results – Gradient Assessments Steepbank River



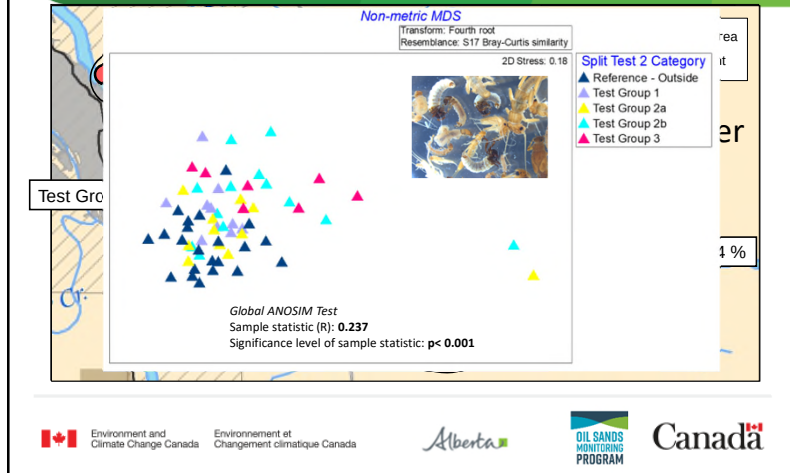
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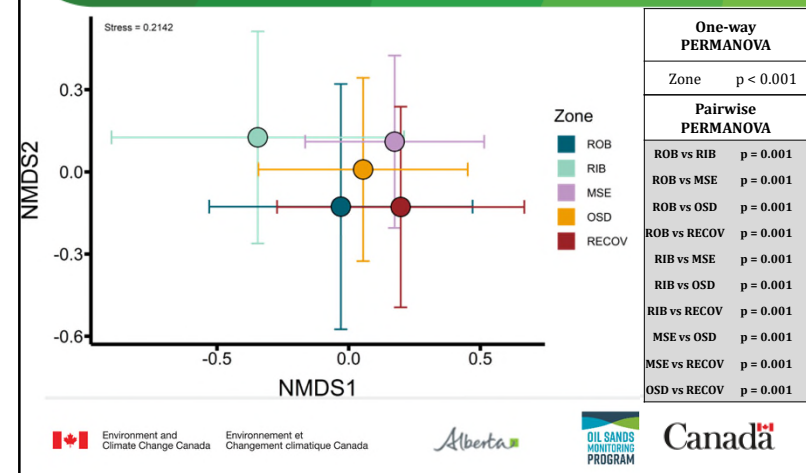
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Results – Gradient Assessments Steepbank River



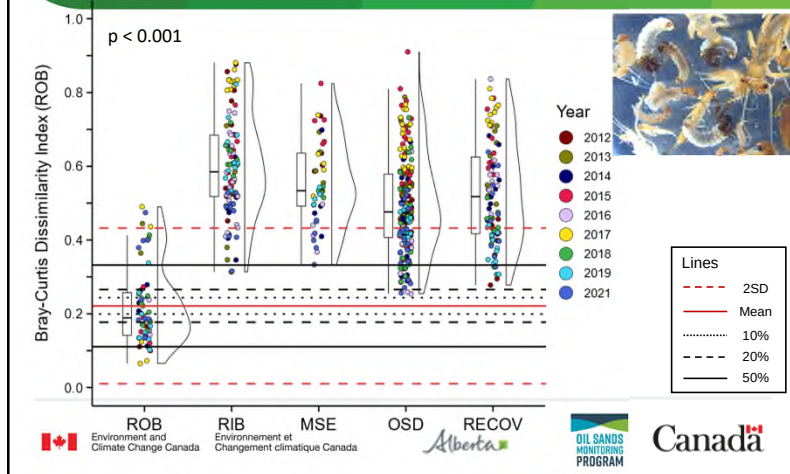
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Results – Mainstem



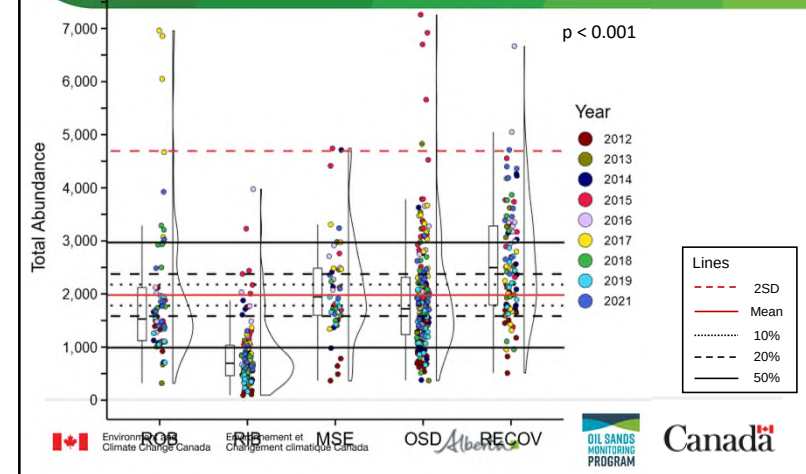
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Results – Mainstem



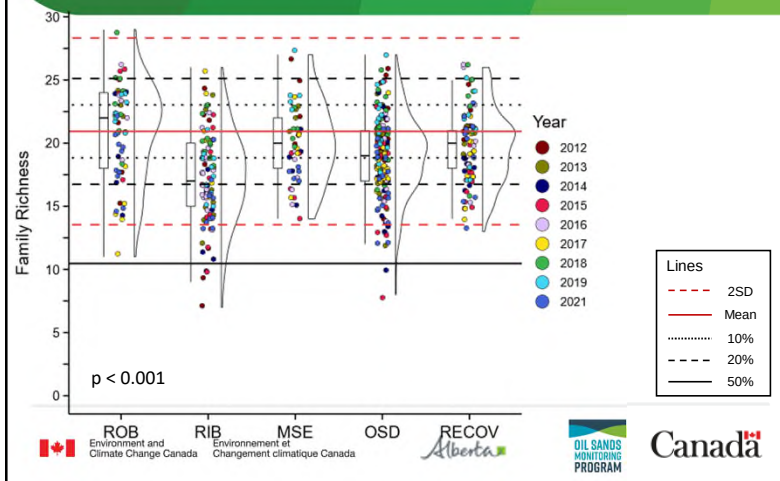
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Results – Mainstem



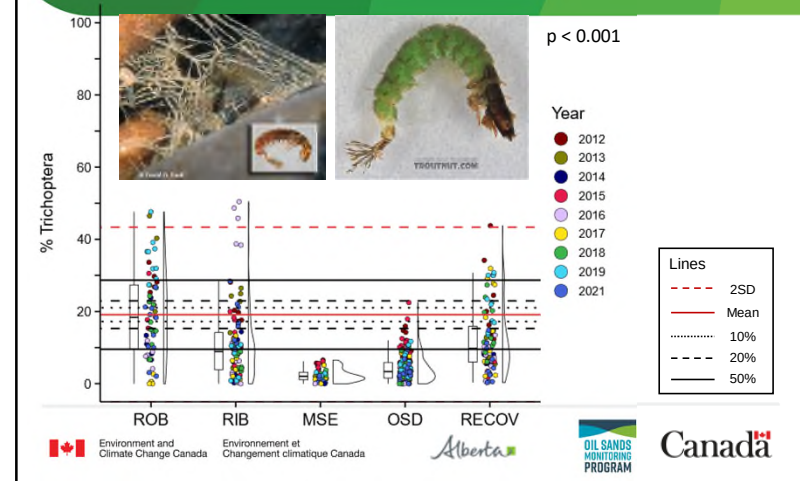
16

Results – Mainstem



17

Results – Mainstem



18

BMI Summary

- 1) Baseline conditions have been established for reference and accumulated state in exposure areas
- 2) Differences are consistently detected among reference areas and areas with increasing gradient of human activities; i.e., **confirmation of effects**
- 3) Changes in BMI communities in downstream areas are related to **increases** in pollution-tolerant taxa along with **decreases** in pollution sensitive taxa;
- 4) Program is continuing with **Surveillance Monitoring** to track changes related to ongoing mining activities, while continuing to **establish indicators and investigation if changes are linked to OS Activities**.



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LoC BMI Summary

1. **First** level LoC is a statistical change between sites at $p < 0.10$ and has been applied to Adapt the Monitoring Program
2. Program is current assessing if changes are related to OSM Activities
3. **Second** level LoC (current discussion) applied once determined if the change is related to OS activities. I.e., is the change of significant magnitude to warrant some type of action? Options include;
 1. NMDS - % Difference in Similarity between communities
 2. Metrics - % Difference from the reference mean metric, % LoC dependent on metric, could range from > 25% - 50? TBD
 3. Variance based, e.g., 2SD, poor estimate of limit of change, not recommended



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QUESTIONS?



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OSM BENTHIC INVERTEBRATE COMMUNITIES 2012 TO 2023

Nancy E. Glozier, Robert Brua, Allison Ritcey, Lucie Levesque
ECCC,
Justin Hanish, Kristin Hynes AEPA
SW TAC Meeting July 25 2023 Calgary Alberta



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1

OUTLINE & OBJECTIVES



2

Key Objectives: Benthic Invertebrates

Assess efficacy of JOSM (Phase 2) biomonitoring design to address:

Ecosystem Health:

- What is the current status of mainstem fish & benthos?
 - Establish a baseline against which future change can be assessed
 - Assess potential change since historical studies
- Are there reference vs. impact site differences in the biota?

Cumulative Effects:

- Is there evidence of cumulative effects of development on mainstem biota?
- Do predictive relationships exist that link system drivers to biotic responses?



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3

Key Objectives: Benthic Invertebrates

Assess efficacy of JOSM (Phase 2) biomonitoring design to address:

Ecosystem Health:

- What is the current status of mainstem fish & benthos?
 - Establish a baseline again
 - Assess potential change
- Are there reference vs. impact site differences in the biota?

Cumulative Effects:

- Is there evidence of cumulative effects on mainstem biota?
- Do predictive relationships exist that link system drivers to biotic responses?

Table 3. Decision "Triggers" for invertebrate monitoring program

Level	Trigger	Magnitude	Consequence
1	Effect detected	Statistical change	See confirmation
2	Confirmation of effects	Statistical change in same endpoints and direction	Increase spatial and temporal resolution around site of interest; add higher tier response variables
3	Exceeds critical effect size	Exceeds BBOD20 for benthic invertebrate community endpoints or divergent from reference community in RCA models	Investigate potential source and cause of effect
Action Level	Exceeds critical effect size and is getting worse	Prolonged exceedence of critical effect size	Possible change in management actions warranted



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Objectives of OSM: Benthic Invertebrates

1. Determine if changes in indicators are occurring in the oil sands region
2. Determine if the changes are caused by oil sands development activities
3. Determine the contribution in context of cumulative effects



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OSM Benthic Macroinvertebrate Endpoints

Preliminary Evaluation of Potential Endpoints as described in Phase 2 Document (ECCC 2011). As with EEM endpoints, each of these provide unique information on potential effects of stressors on BMI communities

- 1) Change in Benthic Macroinvertebrate Assemblage
 - a) nMDS Ordination
 - b) Bray-Curtis (B-C) Index
- 2) Change in Benthic Macroinvertebrate Structure
 - a) Family Richness
 - b) Total Abundance
 - c) %Trichoptera
- 3) Change in the Metabolome
 - a) Dragonfly (*Ophiogomphus* spp.)
- 4) Still evaluating numerous potential endpoints
 - a) Functional endpoints (FFG, decomposition, etc.)



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JOSM Study Design Considerations Tributaries

- 1) Priority Areas Defined by JOSM: major tributaries & least disturbed areas
- 2) Habitat Considerations – Define habitat; erosional (riffle/run);
- 3) Evaluate Study Designs – BACI, RCA, Gradient
- 4) Co-occurring Natural OS geology and Industrial gradients & habitat transitions
- 5) Definition of reference types: Outside & Inside OS geology
- 6) Definition of Exposure Areas



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JOSM Study Design Considerations Tributaries

	Reference Site (Outside Deposit)	Reference Site (Inside Deposit)	Test Site	
Has bitumen been observed and confirmed at the site (or at an upstream site)?	N	Y	Y	
Is the site within the oil sands mineable area (OSMA) or within 1 km of the OSMA?	N	Y	Y	
Is the site within the oil sands open pit mining development footprint?	N	N	Y	
Does the site have > 10% active lease AND > 1% land disturbance in the upstream catchment?	N	N	Y	



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Standardized Sampling Methods

Canadian Aquatic Biomonitoring Network (CABIN) protocol for wadeable streams (with other protocols for additional habitat/chemistry samples)



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Standardized Sampling Methods

Canadian Aquatic Biomonitoring Network (CABIN) protocol for wadeable streams (with other protocols for additional habitat/chemistry samples)



Water Quality

- Major ions
- Nutrients
- PAHs

Sediment Quality

- Metals
- PAHs

Physical Habitat

- Substrate particle size
- Embeddedness
- Water velocity

Periphyton biomass

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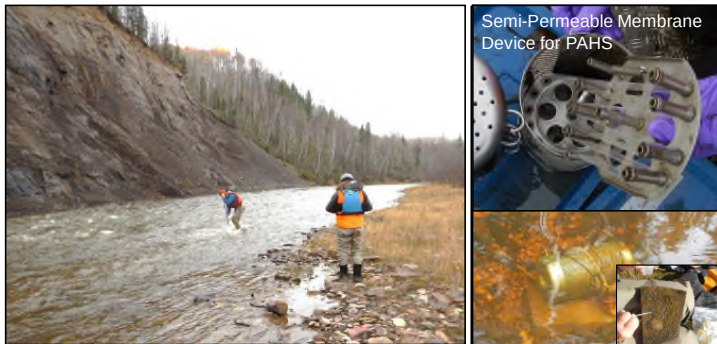
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10

Standardized Sampling Methods

Canadian Aquatic Biomonitoring Network (CABIN) protocol for wadeable streams (with other protocols for additional habitat/chemistry samples)



Semi-Permeable Membrane
Device for PAHs

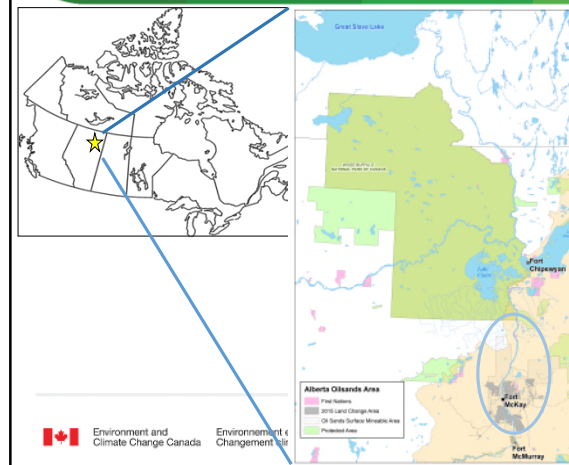
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Oil Sands Area, Monitoring & Features



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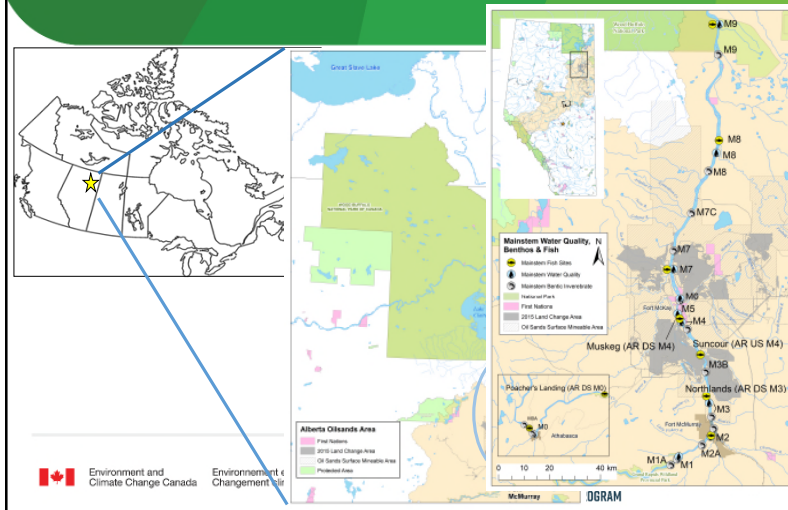
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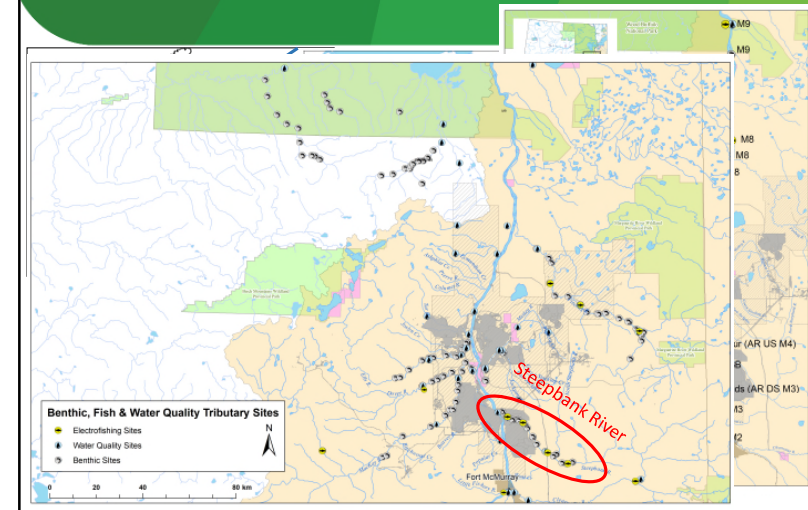
12

Oil Sands Area, Monitoring & Features



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Oil Sands Area, Monitoring & Features



14

SUMMARY Tributaries

- 1) Baseline conditions have been established for reference and accumulated state in exposure areas; Tributaries continue to exhibit good ecological condition with intolerant taxa, such as EPT, found at all locations;
- 2) Differences are consistently detected among reference areas and areas with increasing gradient of human activities; i.e., **confirmation of effects**
- 3) Changes in BMI communities in downstream areas are related to **increases** in tolerant taxa along with **decreases** in intolerant taxa;
- 4) Current analyses (BIO-ENV) are examining drivers of these changes within each watershed including habitat, hydrologic indices, WQ & Sediment chemistry, dissolved PAC concentrations (SPMDs)
- 5) Program is continuing with **Surveillance Monitoring** to track changes related to ongoing mining activities, while continuing to **establish indicators and investigation if changes are linked to OS Activities**.

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Oil sands Monitoring: Benthic Macroinvertebrates – Mainstem Athabasca River

Robert B. Brua¹ & Kristin Hynes²

¹Environment and Climate Change Canada

²Alberta Environment & Protected Areas



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Mainstem Benthic Sampling Design

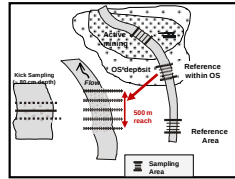


Outside McMurray formation

- M0 & M0A Reference outside OS geology

Inside McMurray formation

- M1A, M2A Reference inside OS geology (natural bitumen exposure, no development)
- M3: D/S Fort McMurray MSE, outside central OS development
- M3B-M7C: OS development activity
- M8-M9: Recovery sites



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Mainstem Benthic Sampling Methods



Kick net sampling



Hand net collections



Seston/Water/SPMD sampling



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Oil Sands Monitoring– Benthic Macroinvertebrate Endpoints

- 1) Change in Benthic Macroinvertebrate Assemblage
 - a) nMDS Ordination
 - b) Bray-Curtis (B-C) Index
- 2) Change in Benthic Macroinvertebrate Structure
 - a) Family Richness
 - b) Total Abundance
 - c) %Trichoptera
- 3) Still evaluating numerous potential endpoints
 - a) Functional endpoints (FFG, decomposition, etc.)



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Oil Sands Monitoring– Benthic Macroinvertebrate Endpoints

All endpoints being used or evaluated were identified in the original “Integrated Monitoring Plan for the Oil Sands”



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Biomonitoring Results – Mainstem Athabasca River

- 1) Created a comprehensive, rigorous, adaptive, and robust monitoring design that:
 - a) establishes baseline
 - b) detects change in benthic macroinvertebrate assemblages
 - c) evaluates cumulative effects, and
 - d) determines drivers of changes in benthic macroinvertebrate assemblages
- 2) Athabasca River tended to have abundant pollution sensitive taxa, such as EPT (mayflies, stoneflies, & caddisflies)
- 3) However, middle reaches of the Athabasca River associated with OS and MSE show signs of ecological change:
 - a) Increased abundance of pollution tolerant taxa compared to Reference and Recovery sites
 - b) Likely a cumulative response to nutrient enrichment and contaminant exposure



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JOSM Recommendations Implemented – Benthos

- 1) Develop and test additional biological metrics for benthos
- 2) Evaluate critical effect size approaches, including 2 SD (standard deviations), as tools to set protective effect thresholds
- 3) More specific to the mainstem Athabasca River
 - 1) Establish a set of core sites to be measured annually
 - 2) Ensure continued collection of sediment chemistry and SPMD
 - 3) Add references between M0 and M2



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JOSM Recommendations Implemented – Benthos

- 1) By adopting these recommendations, we have a replicated, rigorous, and adaptive biomonitoring framework
- 2) It improves assessment of ecological state, natural variability, and detection of environmental change in the oil sands region



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Objectives of OSM – Benthic Macroinvertebrates

1. Determine if changes in indicators are occurring in the oil sands region
2. Determine if the changes are caused by oil sands development activities
3. Determine the contribution in context of cumulative effects



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Objectives of OSM: Benthic Invertebrates

1. Determine if changes in indicators are occurring in the oil sands region – **Completed & Ongoing**
2. Determine if the changes are caused by oil sands development activities – **Ongoing, complex but investigating drivers**
3. Determine the contribution in context of cumulative effects – **Ongoing - gradient design specifically included to address CE**



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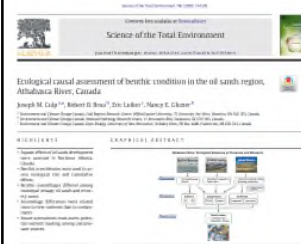


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Summary & Next Steps

Objectives for Aquatic Ecosystem Health:

1. What is the current status?
2. Are changes in indicators occurring in the oil sand region?
3. Is there evidence of cumulative effects on biota?
4. Do predictive relationships exist that link drivers to biotic responses?



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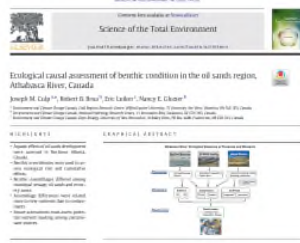


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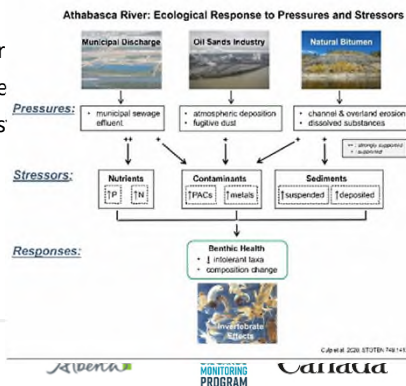
Summary & Next Steps

Objectives for Aquatic Ecosystem Health:

1. What is the current status?
2. Are changes in indicators occur
3. Is there evidence of cumulative
4. Do predictive relationships exist



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CAPRI 2018 STUDY 748/14302

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Aquatic Ecosystem Health Monitoring – Benthic Macroinvertebrates

Robert B. Brua, Joseph M. Culp and Nancy E. Glozier



8-9 January 2020
Aquatic Ecosystem Health Monitoring
Workplan Workshop
Calgary, Alberta



Canada

1

Key Objectives: Benthic Invertebrates

Assess efficacy of JOSM (Phase 2) biomonitoring design to address:

Ecosystem Health:

- What is the current status of mainstem fish & benthos?
 - Establish a baseline against which future change can be assessed
 - Assess potential change since historical studies
- Are there reference vs. impact site differences in the biota?

Cumulative Effects:

- Is there evidence of cumulative effects of development on mainstem biota?
- Do predictive relationships exist that link system drivers to biotic responses?

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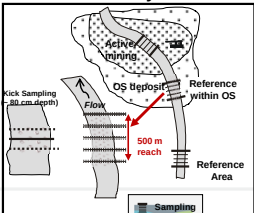
Mainstem Benthic Design

Outside McMurray formation

- M0 reference

Inside McMurray formation

- M1A, M2A reference outside OS development
- M3: D/S Fort McMurray MSE, outside central OS development
- M3B-M7C: OS activity
- M8-M9: Recovery sites

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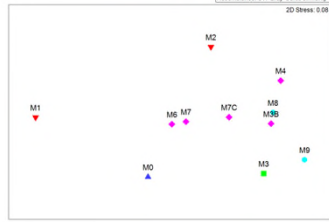
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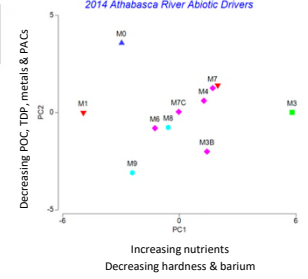
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2014 Athabasca River BMI Results

2014 Athabasca River BMI Data
Non-metric MDS



2014 Athabasca River Abiotic Drivers



Human Activity

- Ref/Out
- Ref/In
- MSE
- OS
- Recovery

Decreasing POC, TDP, metals & PACs

Increasing nutrients

Decreasing hardness & barium

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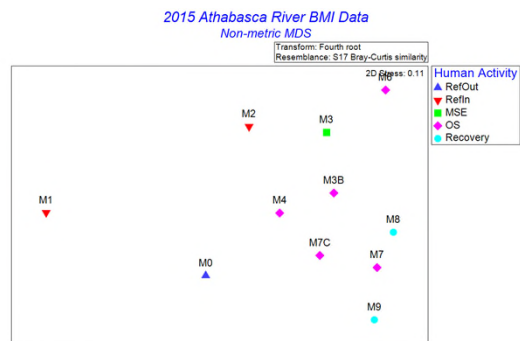
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2015 Athabasca River BMI Results



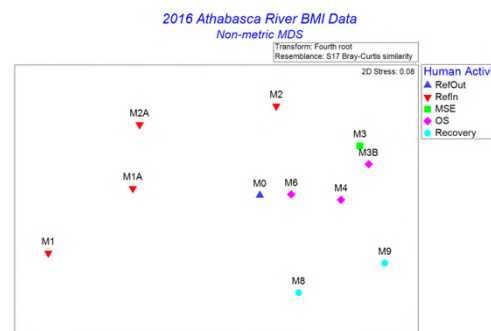
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2016 Athabasca River BMI Results



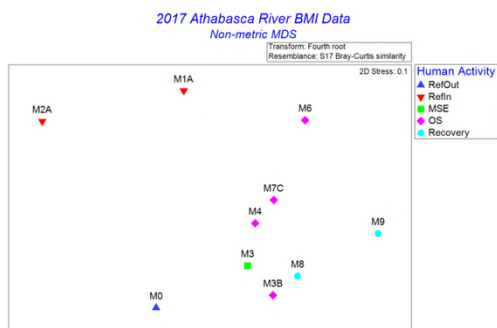
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2017 Athabasca River BMI Results



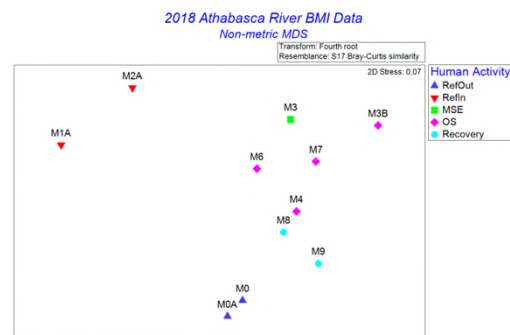
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2018 Athabasca River BMI Results



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Athabasca River BMI Drivers

2015: Increasing pollution tolerant taxa at MSE and OS compared to Reference and Recovery sites

Taxa associated with increasing nutrient-contaminant pattern; increasing total dissolved phosphorus and decreasing metals, such as vanadium

Pattern is similar to results from the JOSM 2012-14 results

2017: Increasing pollution tolerant taxa at MSE and OS compared to Reference and Recovery sites

Taxa associated with increasing nutrient-contaminant pattern; increasing total dissolved nitrogen and decreasing Total PACs; a similar model included decreasing total mercury

Pattern is similar to results from the JOSM 2012-14 results

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Benthic Macroinvertebrate Composition

2015: Increasing pollution tolerant taxa at MSE and OS compared to Reference and Recovery sites

MSE vs OS: OS had more Perlodidae, Heptageniidae, Gomphidae, Hydropsychidae, fewer pollution tolerant taxa

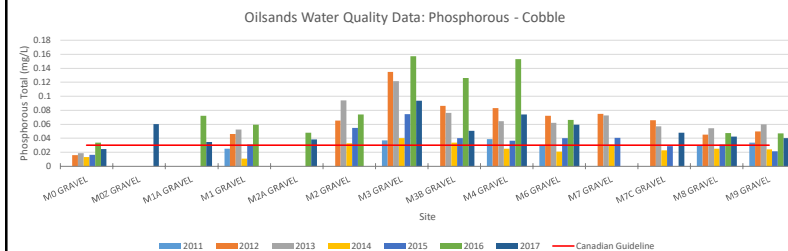
2017: Increasing pollution tolerant taxa at MSE and OS compared to Reference and Recovery sites

MSE vs OS: Top 3 taxa shared; 7 of 9 shared taxa comprised 70% of the sampled population; 40% & 33% of taxa at MSE and OS sites, respectively, were pollution tolerant taxa, however more pollution intolerant taxa were found in 2017

2018: MSE vs OS: Top 5 taxa shared; 8 of 10 shared taxa comprised ~70% 40% & 30% of taxa at MSE and OS sites were pollution tolerant taxa

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Total Phosphorus Concentrations



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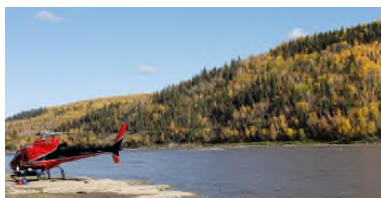
Conclusions

- 1) Continued detection of differences among human activities; Reference vs Impact
- 2) Lower Athabasca River continues to exhibit good ecological condition with intolerant taxa, such as EPT, found at all locations
- 3) However, the middle reaches (MSE & OS development sites) now pattern out together with an increased abundance of tolerant taxa
- 4) Similar nutrient-contaminant pattern related to benthic macroinvertebrate assemblages as found previously

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JOSM Recommendations Installed

- 1) Incorporated the recommendations from the JOSM report in the current biomonitoring program
 - 1) New reference sites outside and inside McMurray formation
 - 2) Biomonitoring program focused exclusively on cobble habitat
 - 3) Continue to collect sediment chemistry and SPMD data



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Key Questions of Benthic OSM Program

- 1) Are changes occurring in biological health?
 - i. There are changes in benthic macroinvertebrate assemblages in the mainstem Athabasca River
 - ii. Changes are associated with an increase in pollution tolerant taxa
- 2) What degree are changes attributable to oil sands activities?
 - i. Difficult to assess
 - ii. Nutrient-contaminant association with the benthic macroinvertebrate assemblage
- 3) What is the contribution in the context of cumulative effects?
 - i. Study design should be able to evaluate cumulative effects
 - ii. Benthic macroinvertebrate assemblages associated with nutrients and contaminants (from natural exposure to bitumen or OS activities?)



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Key Questions of Benthic OSM Program cont.

- 4) Are changes in biological health informing Indigenous concerns and health?
 - i. Unsure
 - ii. Benthic macroinvertebrate assemblages associated with nutrients and contaminants; information that can be used by Indigenous communities

More Importantly

- 1) We are very interested in feedback from Indigenous communities on our results
- 2) We are very interested in knowledge about the importance or lack thereof of our sampling sites to Indigenous communities
- 3) Are there other areas of the mainstem Athabasca that Indigenous communities feel we should be investigating; areas of cultural significance?
- 4) Are there other benthic invertebrate taxa, e.g. mussels, of concern to Indigenous communities that we should be sampling or could be sampled by communities?



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Acknowledgments

The authors acknowledge the financial support of the Oil Sands Monitoring Program and ECCC

We appreciate the extensive field assistance provided by Daryl Halliwell, Eric Luiker, Erica Keet, Jen Maines, Allison Ritcey, Mike Trudeau, Terava Groff, Samantha Matheson, and Kristin Hynes



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Aquatic Ecosystem Health Monitoring – Benthic Macroinvertebrates

OSM Area - FMM tributaries;
SAGD Areas: South of FMM, Peace River, Cold Lake

Nancy E. Glozier and Allison Ritcey ECCC
Kristin Hynes and Justin Hanisch AEP

8-9 January 2020

Aquatic Ecosystem Health Monitoring Workplan Workshop
Calgary, Alberta



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Key Objectives: Benthic Invertebrates

Assess efficacy of JOSM (Phase 2) biomonitoring design to address:

Ecosystem Health:

1. What is the current status of mainstem fish & benthos?
 - Establish a baseline against which future change can be assessed
 - Assess potential change since historical studies
2. Are there reference vs. impact site differences in the biota?

Cumulative Effects:

1. Is there evidence of cumulative effects of development on mainstem biota?
2. Do predictive relationships exist that link system drivers to biotic responses?



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2

FMM Tributary Benthic Design – Phase 2 JOSM Recommendations

The program should be **Effects-based** – *Benthic Invertebrate Communities*
Standardized sampling **protocols** needed

Definition of Reference Areas

Revise sampling design for tributaries to focus on:

- **clearly defined habitat** – helping to reduce the signal to noise ratio and thus increasing statistical power
- modified sampling design approaches to allow **more robust statistical** assessments of biological differences between reference and test reaches
- the development of analytical frameworks/models to provide a benchmark against which test sites can be evaluated



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3

Standardized Sampling Methods

Canadian Aquatic Biomonitoring Network (CABIN) protocol for wadeable streams (with other protocols for additional habitat/chemistry samples)



Semi-Permeable Membrane
Device for PAHS



Note – evaluate current & historic approaches for use in future long term assessments



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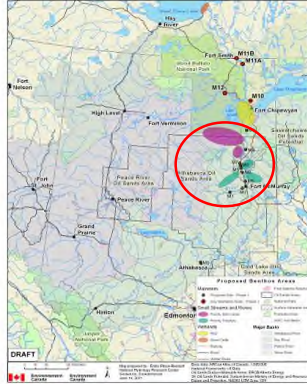


4

Study Design Considerations

CABIN Field sampling – Tributaries

- 1) Priority Areas Defined by JOSM: major tributaries & least disturbed areas
- 2) Habitat Considerations – Define habitat; erosional (riffle/run); evaluate deposition habitats
- 3) Evaluate Study Designs – BACI, RCA, Gradient
- 4) Definition of reference types: Outside & Inside OS geology
- 5) Definition of Exposure Areas
- 6) Co-occurring Natural OS geology and Industrial gradients & habitat transitions



5

Study Design Considerations

CABIN Field sampling – Tributaries

	Reference Site (Outside Deposit)	Reference Site (Inside Deposit)	Test Site
Has bitumen been observed and confirmed at the site (or at an upstream site)?	N	Y	Y
Is the site within the oil sands mineable area (OSMA) or within 1 km of the OSMA?	N	Y	Y
Is the site within the oil sands open pit mining development footprint?	N	N	Y
Does the site have > 10% active lease AND > 1% land disturbance in the upstream catchment?	N	N	Y



6

Study Design Considerations

CABIN Field sampling – Tributaries

- 6) Co-occurring Natural OS geology and Industrial gradients & habitat transitions
 - Natural co-occurring gradients/conditions
 - o Slope, bankful width,
 - o Groundwater inputs.
 - o Nutrients (bogs/fens in upper catchment)
 - o Natural bitumen seepage and presence in substrate
 - Industrial co-occurring gradients
 - o OS development (open pit, SAGD)
 - o Forestry in some watersheds
 - o Roads/other development

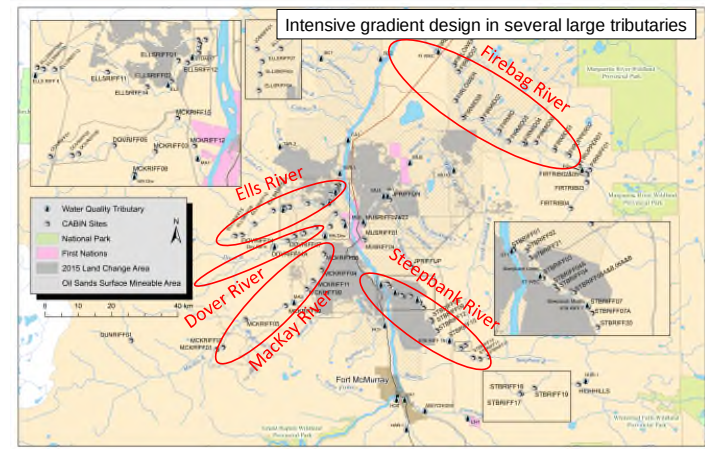


Natural bitumen exposure



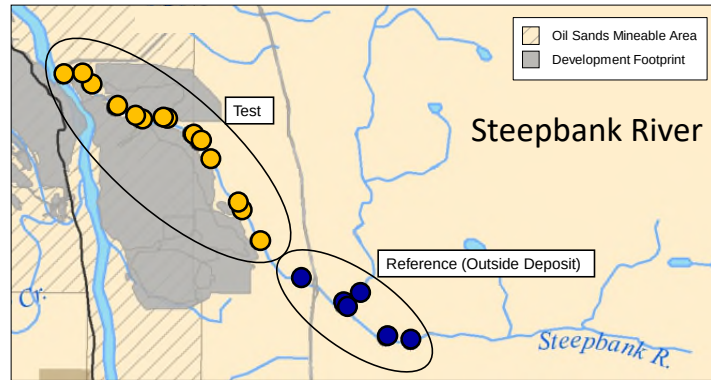
2018

Results – Gradient Assessments



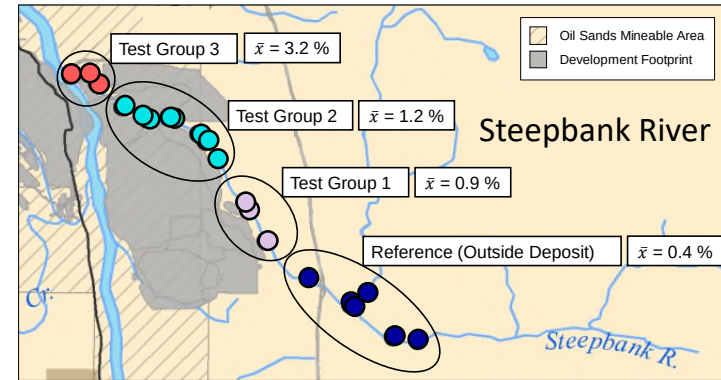
8

Results – Gradient Assessments Steepbank River



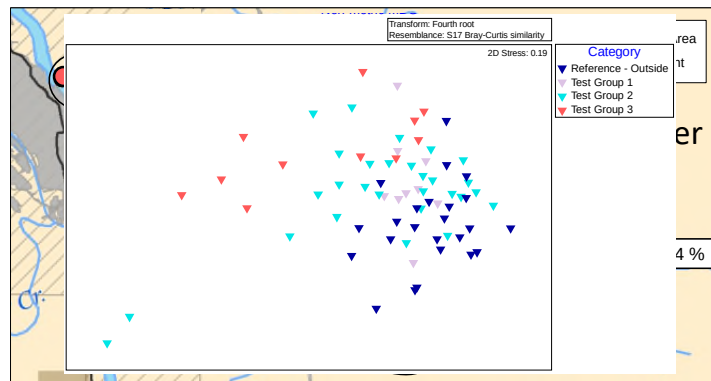
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Results – Gradient Assessments Steepbank River



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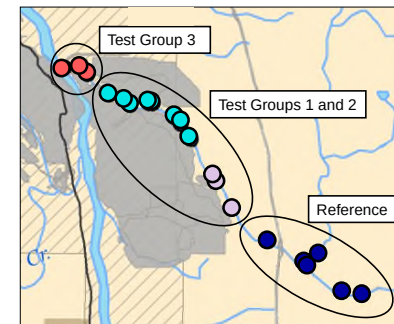
Results – Gradient Assessments Steepbank River



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Results – Gradient Assessments Steepbank River

PERMANOVA (Permutational ANOVA; PRIMER v.7)



PERMANOVA p values				
	Ref	Test 1	Test 2	Test 3
Ref		0.0031*	0.0002*	0.0001*
Test 1			0.2863	0.0004*
Test 2				0.0104*
Test 3				

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Results – Gradient Assessments MacKay, Ells, Dover, Firebag rivers

PERMANOVA (Permutational ANOVA; PRIMER v.7)

- 1) Permanova Gradient Analyses completed for other Priority Tributaries –
 - o Similar trends
 - o upstream references similar & first test area,
 - o greater differences downstream
 - o further detailed analyses pending

MacKay River			
	Ref Out	Test 1	Test 2
Ref Out		0.3102	0.0001*
Test 1			0.0041*
Test 2			

Dover River			
	Ref Out	Ref In	
Ref Out		0.223	
Ref In			

Ells River				
	Ref Out	Ref In	Test 1	Test 2
Ref Out		0.72	0.054*	0.002*
Ref In			0.071	0.001*
Test 1				0.023*
Test 2				
Test 3				0.642

Firebag River			
	Ref Out	Ref In	Test 1
Ref Out		0.0004*	0.0001*
Ref In			0.0667
Test 1			

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Summary

- 1) **Current status** of (BMI) communities? BMI communities in reference and test sites had typical riverine invertebrates, dominated by insects and worms. Shifts in community structure occurred by category and catchment.
- 2) **Differences** in BMI communities between **reference sites inside and outside** OS bitumen geology? No difference, overall, between reference sites inside and outside OS geology; however not all tributaries have both reference categories (e.g., Steepbank River); differences among reference sites in major tributaries documented.
- 3) **Differences** in BMI communities between **reference and potentially impacted (test) sites**? In the Steepbank River, assemblages from all 3 test groups were significantly different from reference assemblages; Test groups 1& 2 were similar but different from Test group 3 (furthest downstream); Differences were driven primarily by several families of Trichoptera, Plecoptera and Ephemeroptera and Naididae worms.

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NEXT STEPS

- 1) **Evaluate** the longitudinal changes in habitat and water quality (sediment & water chemistry, PAC profiles, etc.) as potential drivers of biological change in the Steepbank River and other large tributaries (Ells River showed similar longitudinal patterns). Investigate other measures (NMR)?
- 2) **Enhance linkages** with other programs being carried out in the tributaries (groundwater, water quality) and oil sands area (air quality)
- 3) **Recommendations for ongoing monitoring** – e.g., reduced list of core sites for continued annual sampling with semi-annual and rotational sites, program will be adaptable if further changes occur.

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Expanded Biomonitoring into SAGD Areas: South FMM; Peace River & Cold Lake

South of FMM (Christina & tributaries)

- o Sampling started in 2018; 20 sites

Peace River Oil Sands Area

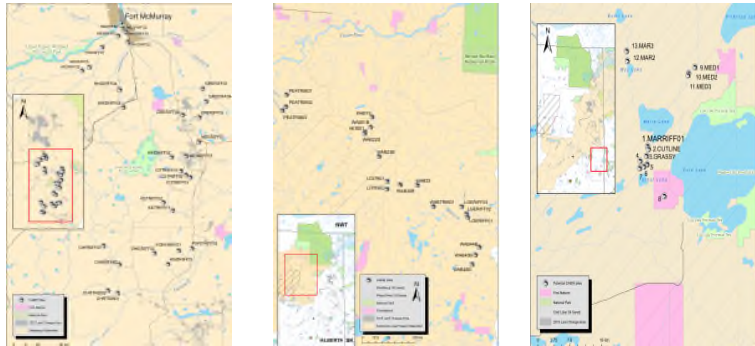
- o sampling started in 2016; 23 sites
- o GIS for activity gradient underway

Cold Lake Oil Sands Area

- o Recon 2019; >10 potential sites identified
- o Potential Sampling in 2020

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Expanded Biomonitoring into SAGD Areas: South FMM; Peace River & Cold Lake



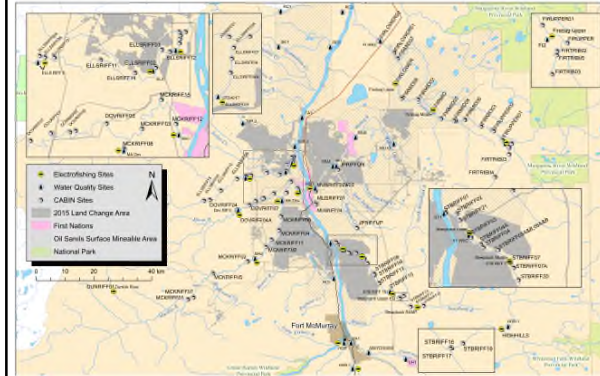
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Aquatic Ecosystem Health Monitoring: Integration



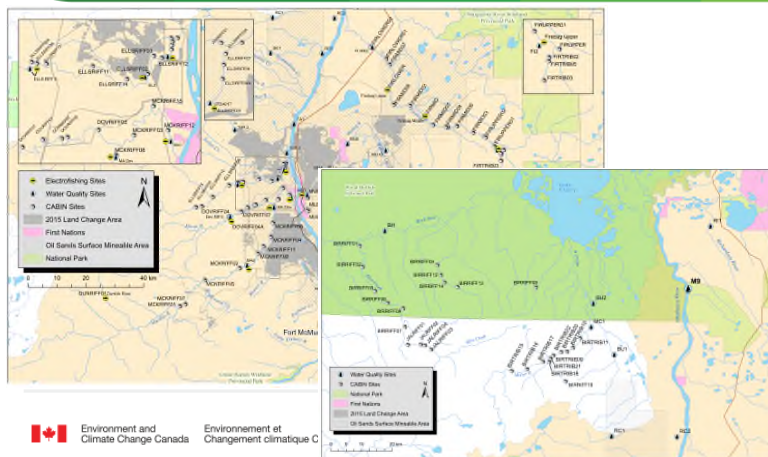
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Aquatic Ecosystem Health Monitoring: Integration



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Vancouver
Parks Canada
Cordillera Consulting
stREAMS Laboratory (Adam Yates)
Wood Buffalo and Mustang Helicopters
Environment Canada Scientific, Technical Staff and Students

Reports available: <https://www.canada.ca/en/environment-climate-change/services/oil-sands-monitoring/documents-reports.html>

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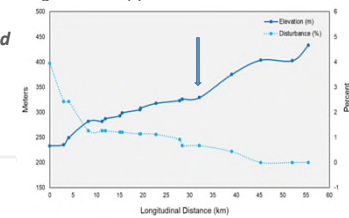
Appendix

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FMM Tributary Benthic Design – Challenges with Assessments

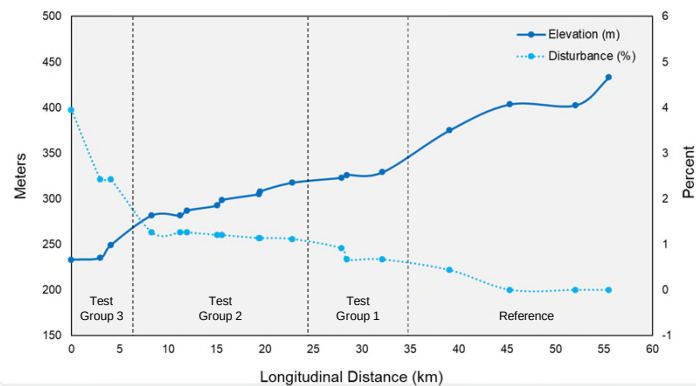
1. High year-to-year variability in discharge patterns, some years sampling was not possible with Hess/Neill due to depths.
2. Tributary headwaters arise in lower slope, muskeg type areas; transitions through a mid section that then rapidly cuts down and ultimately through the OS Clearwater and McMurray formations.
3. Nature of many tributaries - few smaller tributaries resulting in reaches accessible/available for sampling being limited to only higher stream orders (e.g., sites sampled in Mackay, Firebag rivers - Stream orders 4-6; Steepbank 4-5; Ells 5; see table 3.1 in report) thus difficult to design a RCA approach.

Resulting in co-occurring Natural OS geology and multiple Industrial gradients as well as changes in habitat.



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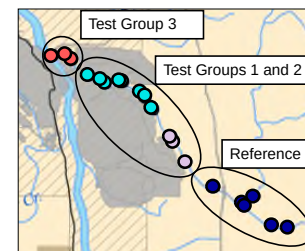
Steepbank River



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Steepbank River Invertebrates

SIMPER (Similarity Percentages; PRIMER v.7)



Reference vs. Test Groups

Plecoptera	Nemouridae	↑ Ref
Trichoptera	Brachycentridae	↑ Ref
	Hydropsychidae	↑ Ref
	Lepidostomatidae	↑ Ref
Annelida	Naididae	↑ Test 3

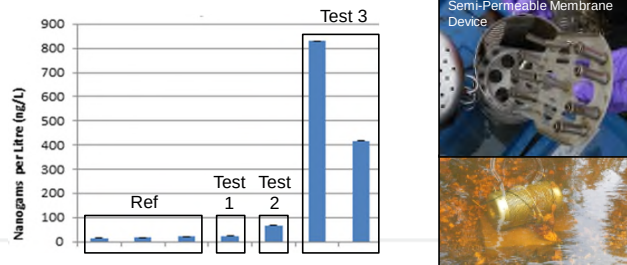
Test Groups 1 and 2 vs. Test Group 3

Ephemeroptera	Baetidae	↑ Test 1 and 2
Trichoptera	Lepidostomatidae	↑ Test 1 and 2
	Hydropsychidae	↑ Test 1 and 2
	Glossosomatidae	↑ Test 1 and 2
	Brachycentridae	↑ Test 1 and 2

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Steepbank River Habitat / WQ

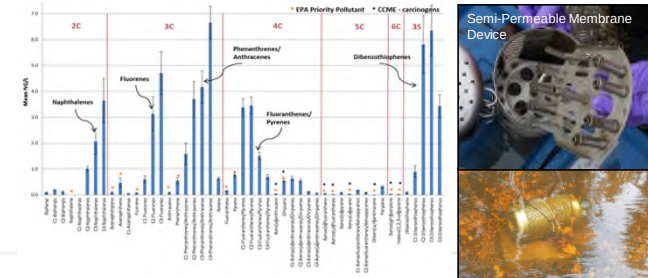
- Total polycyclic aromatic compounds (PACs) as measured with semi-permeable membrane devices (SPMDs)
- Increasing pattern from upstream to downstream (may be associated with increasing natural bitumen sources or anthropogenic sources)
- Next step: examine PAC profiles in reference and test sites



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Steepbank River Habitat / WQ

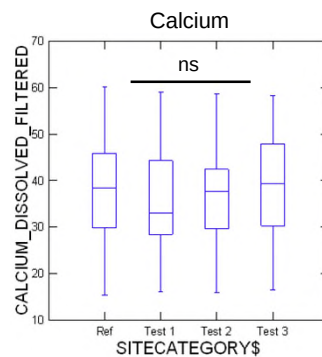
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Steepbank River Habitat / WQ

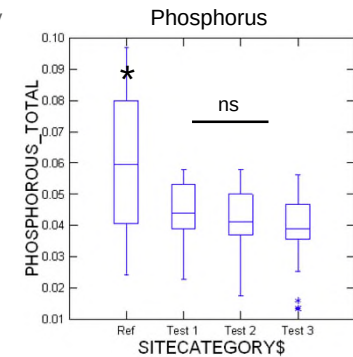
- Majority of habitat and water quality parameters were similar along stream gradient (e.g. Ca, Na, dissolved metals, TDS, N)
- Phosphorus (total and dissolved) was higher in reference areas but similar across all test categories – may be linked to bogs in headwaters
- Several parameters showed a continuous increasing pattern from upstream to downstream (e.g. chloride, sulphate) – may be linked to ground water or seepage



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Steepbank River Habitat / WQ

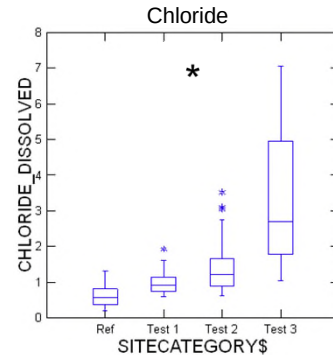
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Steepbank River Habitat / WQ

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Results – Successes

Tributary CABIN Field sampling Reference Sites



Potential RCA – highly influenced by yearly discharge variability

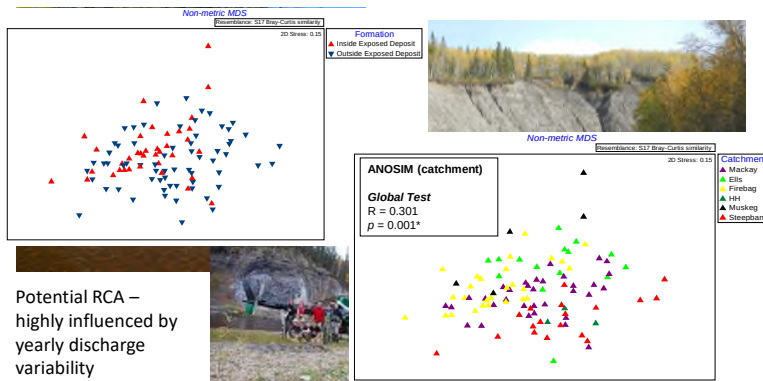
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Results – Successes

Tributary CABIN Field sampling Reference Sites



Potential RCA – highly influenced by yearly discharge variability

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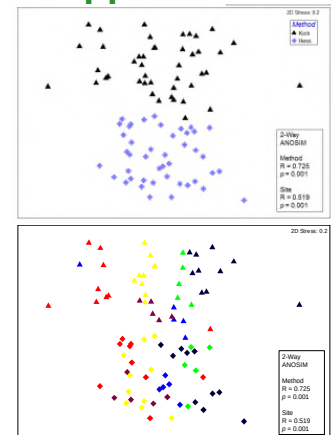
Evaluation of Historical Approaches

Hess/Neill – Kick & 400 vs 250

Two comparative Studies @ > 40 reaches

- 400 μ m Kick & 210 μ m Hess
- 400 μ m Kick & 250 μ m Kick (not shown)

- Kick and Hess samples different
- Sites generally align in similar pattern
- Kick sampling produced greater distinction among sites and less variability in metrics
- Taxon differences predictable and similar to mesh size effects
- Approach for incorporating historic data under development



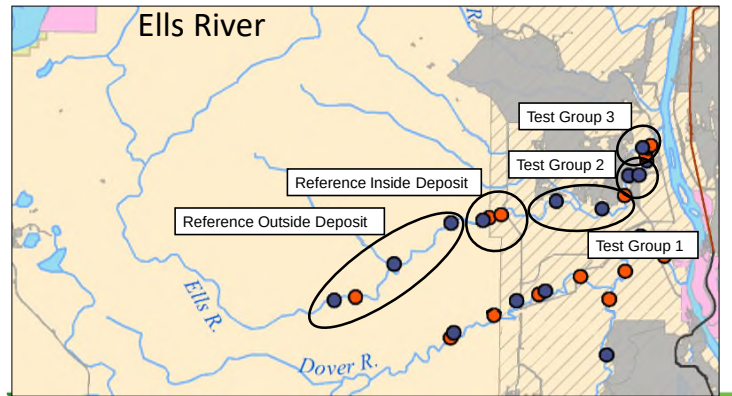
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Results – Successes

Tributary CABIN Field sampling with Gradient Design



Demonic Intrusion: 2016 Wildfire ("The Beast")

