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Revised Annotated Bibliography:

Literature Review on Biological Monitoring and Biological Indicators in the Hay and Slave Rivers for the Alberta–Northwest Territories Bilateral Water Management Agreement

Northwest Territories

August 2, 2017

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Government of the Northwest Territories
Environment and Natural Resources
600, 5102-50th Avenue
Yellowknife, NT, X1A 3S8

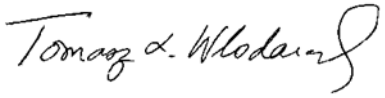
Attention: Annie Levasseur

RE: Revised Annotated Bibliography: Literature Review on Biological Monitoring and Biological Indicators in the Hay and Slave Rivers for the Alberta-Northwest Territories Bilateral Water Management Agreement

SLR Consulting (Canada) Ltd. is pleased to provide you with a revised annotated bibliography. This document includes additions made during the preparation of the Synthesis and Recommendations report.

We trust this document meets the requirements of the Government of the Northwest Territories (GNWT). I would like to thank the GNWT for selecting SLR for this work. It has been a gratifying piece of work.

Yours sincerely,
SLR Consulting (Canada) Ltd.



Tomasz Wlodarczyk, M.E.S
Principal Consultant,
National Manager, Environmental and Social Impact Assessment

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ACKNOWLEDGEMENTS

This work was prepared for the Government of the Northwest Territories – Water Resources Division. SLR and its research team gratefully acknowledge the input and direction of the following members of staff: Annie Levasseur, Rick Walbourne, Juanetta Sanderson, and Meghan Beveridge.

This annotated bibliography was compiled by Heidi Klein, Joan Eamer, Misty Lockhart, and Théo Charette.

1.0 INTRODUCTION

The Government of Northwest Territories (GNWT), in commitment to the Alberta-Northwest Territories Bilateral Water Management Agreement (the Agreement), has commissioned the preparation of an annotated bibliography in relation to biological monitoring and indicators for the Hay and Slave River basins, consistent with Appendix G of the Agreement. The purpose of the annotated bibliography is to provide a foundation for the synthesis of the monitoring literature and a recommendations report to be prepared in the next phase of this project. This report is the first deliverable.

2.0 METHODOLOGY

The literature search methodology consisted of four approaches, as follows.

1. ***Snowball Research Method:*** The literature considered for the annotation began with the documents supplied by the GNWT – Water Resources. Using these documents as a starting point, a snowball research methodology was utilized. Snowball methodology requires examining the references within documents that are then used to help identify others of relevance (Bernard 2006: 192-193[1]). Titles and authors encountered in the references of pertinent documents were investigated in Google, Google Scholar, or university library search engines and databases. Titles that referenced or were referenced by these documents were also identified and reviewed.

2. ***Broad Literature Search:*** Search terms listed in Table 1 were used in Google and Google Scholar, university library databases, and governmental agency online document repositories (see Table 2) in order to source a variety of publicly available documents (academic journal articles, government reports, and other grey literature). Sources that were not available electronically were not examined due to time constraints. The investigators also pursued literature prepared by researchers named by GNWT staff and its own team members.

3. ***Review of Established Monitoring Programs:*** Established monitoring programs were identified and information associated with these programs was examined through the review of web pages. As many of these projects did not have completed reports that were easily available, the names of lead researchers and project team members were used to further pursue relevant literature via other internet and library databases.

4. ***Expert Input:*** Throughout the collection of the literature and information on databases, Environment and Natural Resources (ENR) and staff at the Government of Alberta recommended documents for review.

In order to focus the research, specific search terms were identified and applied to the Hay and Slave River Basins (Figure 1). The research also included non-biological terms, such as water

[1] Bernard, H. Russell. 2006. *Research Methods in Anthropology: Qualitative and Quantitative Approaches*. Fourth Edition. Toronto: Altamira Press.

quality and quantity, as it may have focused on biological indicators. The search terms are in Table 1. Table 2 lists the databases and research portals investigated.

Given the frequency website addresses change, links to some of the websites might not be functioning at the time of reading.

Figure 1. Location of Hay River and Slave River Basins

Table 1. Search Terms

Topic	Search Terms
Amphibian(s)	Amphibian(s) Amphibian(s) + indicator + Northwest Territories Amphibian(s) + indicator + Slave River Amphibian(s) + indicator + Hay River
Aquatic Vegetation	Aquatic vegetation Aquatic vegetation + indicator Aquatic vegetation + indicator + Slave River Aquatic vegetation + indicator + Hay River
Beaver	Beaver Beaver + indicator + Northwest Territories Beaver + indicator + Slave River Beaver + indicator + Hay River
Benthic Invertebrates	Benthic invertebrates Benthic invertebrates + indicator + Northwest Territories Benthic invertebrates + indicator + Slave River Benthic invertebrates + indicator + Hay River
Ducks	Ducks Ducks + indicator Ducks + indicator + Slave River Ducks + indicator + Hay River
Fish	Fish Fish + indicator + Hay River Fish + indicator + Slave River
Hay River	Hay River Hay River + indicator Hay River + aquatic Hay River + aquatic + indicator Hay River + monitoring
Mink	Mink Mink + indicator Mink + indicator + Slave River Mink + indicator + Hay River
Muskrat	Muskrat Muskrat + indicator Muskrat + indicator + Slave River Muskrat + indicator + Hay River
Plants	Plant Plant + indicator + Slave River

Topic	Search Terms
	Plant + indicator + Hay River
River Otter	River Otter River Otter + indicator River Otter + indicator + Slave River River Otter + indicator + Hay River
Semi-aquatic Mammal	Semi-aquatic mammal Semi-aquatic mammal + indicator + Slave River Semi-aquatic mammal + indicator + Hay River
Slave River	Slave River Slave River + indicator Slave River + aquatic Slave River + aquatic + indicator Slave River + aquatic + monitoring
Vegetation	Vegetation + indicator + Northwest Territories Vegetation + indicator + Slave River
Waterfowl	Waterfowl Waterfowl + indicator + Northwest Territories Waterfowl + indicator + Slave River Waterfowl + indicator + Hay River
Water quality and quantity including sediment	Slave River + indicator Slave River + monitoring Hay River + indicator Hay River + monitoring

Table 2. Internet Databases and Research Portals

Database/Research Portal	URL Address
Alberta Biodiversity Monitoring Institute	http://www.abmi.ca/home/publications.html
Alberta Environmental Network	https://aenweb.ca/
Alberta Environment & Parks	http://aep.alberta.ca/
Alberta Environment & Parks Species at Risk	http://aep.alberta.ca/fish-wildlife/species-at-risk/default.aspx
Alberta Wildlife Status Reports	http://www.ab-conservation.com/publications/alberta-wildlife-status-reports/

Database/Research Portal	URL Address
Canada-Alberta Oil Sands Environmental Monitoring Information Portal	http://jointoilsandsmonitoring.ca/
Canadian Rivers Institute	http://www.canadianriversinstitute.com[1]
Canadian Water Network	http://www.cwn-rce.ca/
Cumulative Environmental Management Association (CEMA)	http://cemaonline.ca/
Fisheries and Oceans Canada WAVES Library Catalogue[2]	http://waves-vagues.dfo-mpo.gc.ca/waves-vagues/
Google	https://www.google.ca
Google Scholar	https://scholar.google.ca/
NWT Cumulative Impact Monitoring Program	http://www.enr.gov.nt.ca/programs/nwt-cimp
NWT Environment and Natural Resources Publications	http://www.enr.gov.nt.ca/publications
NWT Discovery Portal	http://nwtdiscoveryportal.enr.gov.nt.ca
NWT Research Database	http://data.nwtresearch.com/
NWT Species at Risk	http://www.nwtspeciesatrisk.ca/content/documents
NWT Water Stewardship	http://www.nwtwaterstewardship.ca
Peace-Athabasca Delta Ecological Monitoring Program	http://www.pademp.com
Regional Aquatics Monitoring Program (RAMP)	http://www.ramp-alberta.org
Repository of the Athabasca Basin	http://www.barbau.ca/
University libraries (University of British Columbia, University of Alberta, University of Alberta Education & Research Archive, University of Saskatchewan, Wilfred Laurier University)	http://www.library.ubc.ca/; https://library.ualberta.ca/; https://era.library.ualberta.ca/ http://www.usask.ca/toxicology/research_%20publications/toxicology-group.php http://libguides.usask.ca/FindingTheses https://nwtwlu.com/ http://scholars.wlu.ca/

[1] Interactive map under development. RAMP better source.

[2] The Federal Science Library Catalogue (http://science-libraries.canada.ca/eng/home/) which WAVES was migrated into was not operational until the week of March 6th, 2017. Unfortunately this resource was not available for investigation for the annotated bibliography literature review.

3.0 RESULTS

Over 348 documents, as well as on-line data sources (Table 2), were identified and summarized into Mendeley. Of these, relevant documents were annotated and are included in this report. Annotated titles include sources of information relevant to aquatic biological monitoring; reports on indicator development, and summary and synthesis reports judged to be directly relevant to project objectives; and a selection of reports on water and sediment studies. Other sources of information were reviewed as they were encountered. Reports and other information sources that may be useful in developing and interpreting indicators and monitoring programs related to aquatic biological monitoring were added to the reference library.

The most relevant information sources were entered into Mendeley (www.mendeley.com), an online bibliographic service. The references were sorted by indicator, with additional topics being added (e.g., review and methodology papers). Note that not all documents in Mendeley are publicly available. If the document is behind a paywall, SLR made a note of this.

As mentioned, the Mendeley library for this project contains 348 documents and sources categorized according to themes of biological indicators and other relevant categories (Table 3). Documents are sometimes referenced in more than one category when they cover more than one topic or indicator. This was especially the case with fish and water quality.

Table 3. Organization of Mendeley Folders

Category / Classification	Number of sources
Large Fish	53
Small Fish	14
Invertebrates	19
Aquatic mammals	24
Waterbirds	6
Amphibians	13
Algae, Vegetation and Aquatic Ecosystems	13
Water Quality and Quantity, and Sediment	47
Reviews, Summaries, State of Environment Reporting	24
Indicator Development and Assessment	26
Research and Methods	31
Online Databases/Report collections/Major program plans and reports	17
Reference documents (outside of the scope of the bibliography, but retained for interest and potential future use): not included in this report	61

4.0 BIBLIOGRAPHY

The annotations were organized by potential indicator and related subject matters. Some annotated documents are featured more than once as several studies included information on two or more indicators.

The "Supplementary Resources" categories are documents and on-line sources that have not been annotated but that provide additional information on an annotated reference, or that may be relevant to the development of the synthesis and recommendations report. Within Mendeley, notes were kept on the potential value of these reports. For example, numerous documents featured water quality and quantity. This information will be useful for setting the environmental context for indicators.

4.1 Large Fish

Aboriginal Affairs and Northern Development Canada, and Department of Environment and Natural Resources GNWT. 2012. *Our water, our life: Building partnerships to assess the health of the Slave River and Slave River Delta. Summary report for the Community Workshop convened in Fort Smith, NWT on March 1 and 2, 2011*. Yellowknife, Northwest Territories: Aboriginal Affairs and Northern Development Canada and Department of Environment and Natural Resources, Government of the Northwest Territories. Available at: http://www.nwtwaterstewardship.ca/sites/default/files/Slave%20River%20March%202011%20Workshop%20Report%20Final.pdf

Purpose/scope: Multi-party workshop discussing issues regarding upstream development, aquatic monitoring programs, identifying and evaluating potential indicators, and options for community-based monitoring in the Slave River and Delta.

Author Information: Multi-party workshop including representatives from Aboriginal organizations, Elders, water treatment operators from several communities, Aboriginal Affairs and Northern Development Canada (AANDC), ENR, Environment Canada, Parks Canada, and the Aurora Research Institute.

Location: Fort Smith

Findings: Information on expectations of Aboriginal organizations and community members for aquatic health and monitoring. Identification of potential indicators. Appendices include a summary of upstream human activity and associated impacts, and a list of potential ecosystem health indicators.

Relevance: Identification of potential biological and physical indicators.

Arens, C.J., J.C. Arens, N.S. Hogan, R.J. Kavanagh, F. Berrue, G.J. Van Der Kraak, and M.R. van den Heuvel. 2017. Population impacts in white sucker (*Catostomus commersonii*) exposed to oil sands-derived contaminants in the Athabasca River. *Environmental Toxicology and Chemistry* 9999 (9999): 1–10. DOI: 10.1002/etc.3735

Purpose/scope: "Biological and chemical endpoints were measured in white sucker collected downstream of Athabasca oil sands developments (AB, Canada) and compared with those at Calling Lake (AB, Canada), a reference location upstream of the Athabasca oil sands deposit."

Author Information: Researchers from several canadian universities, and from Canadian Natural Resources.

Location: Athabasca watershed, specifically Calling Lake and around the oil sands deposits on the Athabasca River.

Findings: "Concentrations of naphthenic acids were elevated in tributaries adjacent to oil sands mining developments. Tributary naphthenic acid profiles were more similar to aged oil sands process water than samples from the Athabasca River, suggesting an influence of tailings in the tributaries. White sucker showed higher energy storage in the Athabasca River as indicated by significantly higher condition and liver size. White sucker were not investing that energy into reproductive effort as measured by gonad size and fecundity, which were significantly reduced relative to the reference location." Exposed fishes also had higher levels of polycyclic aromatic hydrocarbons and heavy metals (Cd, Cu, Ni, Se) in their tissues.

Relevance: Indicates that fish exposed to oil sands deposits and development have elevated levels of pollutants and decreased reproductive potential - these tissue metrics can be potential indicators of fish and ecosystem health.

Features: Metal and trace element data (mean +/- Standard Error(SE)) reported for white sucker liver tissue samples from the Muskeg River and Calling Lake.

Baldwin, C., L. Bradford, M.K. Carr, L.E. Doig, T.D. Jardine, P.D. Jones, L. Bharadwaj, and K.-E. Lindenschmidt. 2017. Ecological patterns of fish distribution in the Slave River Delta region, Northwest Territories, Canada, as relayed by Traditional Knowledge and Western science. *International Journal of Water Resources Development* 627 (May). Routledge: 1–20. DOI: 10.1080/07900627.2017.1298516

Purpose/scope: Use TK and science results as a dual knowledge system (through a collaborative research partnership) about spawning and migration in Slave River and Delta; improve monitoring programs by extending beyond the confines of the present or recent past.

Author Information: University of Saskatchewan researchers

Location: Slave River and Delta

Findings: The paper provides a synthesis of information on seasonal fish distribution and spawning locations for resident and migratory fish based on literature review and 11 interviews of selected experts from Fort Smith and Fort Resolution. A key question for communities is safety of fish for consumption. Common species of interest (identified in the science literature and through interviews): burbot, goldeye, inconnu, lake whitefish, northern pike, trout-perch, and walleye. Flow changes and sediment changes are considered to have led to habitat fragmentation through changes in channel depth and

sandbar formation (especially in the delta). Some species appear to have altered their spawning areas (e.g. inconnu).

Relevance: Provides information and recommendations pertinent to fish and habitat indicators.

Bond, W.A., and D.K. Berry. 1980. *Fishery resources of the Athabasca River downstream of Fort McMurray, Alberta. Volume II*. Report AF 4.3.2. Alberta Oil Sands Environmental Research Program (AOSERP). Available at: https://era.library.ualberta.ca/items/182756a6-1542-4fef-a318-c6ffa6455795

Purpose/scope: "This report presents the results of work done in 1976, the first year of a two-year study intended to evaluate and describe the baseline state of the fish resources of the Athabasca River downstream of Fort McMurray."

Author Information: Researchers from the Department of Fisheries and Oceans Canada and the Department of Environment (Government of Alberta)

Location: Athabasca River, from Fort McMurray downstream to the mouth of the Firebag River.

Findings: 25 fish species were detected within the study area. "Preliminary tag return data indicate some movement of suckers, goldeye, lake whitefish, and walleye between the study area and Lake Athabasca. The fry of many species appear in the Athabasca River appear during June and July. Most of these fry do not remain in the study area but are carried downstream to nursery areas in the lower Athabasca River or Lake Athabasca."

Relevance: Provides historical reference of fish population data for sections of the Athabasca River downstream of oil sands operations. Fish migration patterns may be similar elsewhere in the Athabasca River, which may inform the spatial scale of monitoring studies. Disruptions to fish movement could have far-reaching effects downstream.

Features: Detailed life history descriptions for 11 fish species studied in the Athabasca River (specifically downstream of the oil sands mines) are presented.

Cash, K.J., W.N. Gibbons, K.R. Munkittrick, S.B. Brown, and J. Carey. 2000. Fish health in the Peace, Athabasca and Slave river systems. *Journal of Aquatic Ecosystem Stress and Recovery* 8 (1): 77–86. DOI: 10.1023/A:1011495823504

Purpose/scope: Assess the fish health in Peace, Slave and Athabasca river basins as it relates to exposure to pulp mill contaminants.

Author Information: University researchers and consultants (University of New Brunswick. National Water Research Institute and Golder Associates)

Location: Peace, Athabasca and Slave rivers

Findings: Dioxins and furans occur in the food web at low levels across the basins. Highest frequencies detected in vicinity of pulp mills. However, decline in concentrations of dioxins and furans in fish commensurate with changes in pulp mill treatment

technologies. "There is evidence of polychlorinated biphenyl (PCB) contamination in both the Athabasca and Peace river systems, Dioxins and furans (PCDD/Fs), rather than PCBs or organo-chlorine pesticides, are the chemicals of concern for human exposure." Sex hormone levels in burbot and longnose sucker near pulp-mill locations were significantly depressed, and that numbers of immature fish in these same locations were unexpectedly high. There is evidence of significant impacts that should be studied further.

Relevance: NRBS funded research paper on fish health

Features: Peer reviewed paper.

Dagg, J. 2016. *State of the Knowledge of the Slave River and Slave River Delta. A component of the vulnerability assessment of the Slave River and Delta. Final report April 2016*. The Pembina Institute. Available at: http://www.nwtwaterstewardship.ca/sites/default/files/FINAL_APRIL%2716_FINAL_Slave River State of the Knowledge Report.pdf

Purpose/scope: Literature review of the aquatic and riparian ecosystem of the Slave River and Delta. Focus on hydrology and sediment; water quality; metals and contaminants in water; sediment and fish; fish and insect/benthic communities; terrestrial wildlife species; vegetation; and air and climate.

Author Information: Pembina Institute employee

Location: Slave River and Delta

Findings: Literature search found large volume of information on hydrology and sediment load; water quality; metals and contaminants in water; sediments and fish; and muskrats. Moderate information about fish community, moose, beaver, and vegetation. Little information on benthic invertebrates and insects, mink, otter, aquatic birds, and air quality.

Relevance: Recent literature review for a portion of the study area

Features: Traditional knowledge and scientific knowledge

Dagg, J. 2016. *Vulnerability assessment of the Slave River and Delta. Summary report for the community workshop convened in Fort Smith, January 24-26, 2012. Final report April 2016*. Fort Smith: The Pembina Institute and Government of Northwest Territories. Available at: http://www.nwtwaterstewardship.ca/sites/default/files/FINAL_April'16_FINAL_SRDP_VulnerabilityAssessment.pdf

Purpose/scope: Fort Smith and Fort Resolution workshops to assess vulnerability of the Slave River and Delta ecosystem, and establish monitoring priorities.

Author Information: Local and traditional knowledge holders, Aboriginal governments' representatives, western scientists and government agencies

Location: Slave River and Delta

Findings: Monitoring priorities for six ecosystem components: hydrology and sediment load; water quality, fish and insect/benthic communities; wildlife; vegetation; air; and climate. Identification of potential indicator species.

Relevance: Monitoring and research requirements

Features: Traditional knowledge, western science

Donald, D.B., and A.H. Kooyman. 1977. Food, feeding habits, and growth of *goldeye Hiodon alosoides* (Rafinesque), in waters of the Peace-Athabasca Delta. *Canadian Journal of Zoology* 55: 1038–47

Purpose/scope: "The feeding habits of goldeye were determined by examining the food items found in 1785 stomachs collected from the Peace-Athabasca Delta, Alberta, in 1971, 1972, and 1973".

Author Information: From an environmental consulting firm and the Canadian Wildlife Service

Location: Lake Claire - Mamawi Lake area of the Peace Athabasca Delta in Wood Buffalo National Park

Findings: "Larval goldeye fed primarily on Calanoida and Cladocera. Post-larval goldeye fed mainly on Cladocera, Corixidae, and aerial insects but few Calanoida. These young fish selected the larger Cladocera and Calanoida from the plankton community. Growth was continuous from June to early September. Yearling and older goldeye had similar feeding habits with Corixidae being the most frequent food item present. They also fed on other aquatic and terrestrial invertebrates and small vertebrates. The food consumed on a given day reflected local as well as seasonal and yearly differences in abundance of the various organisms. Stomachs of these goldeye contained the least amounts of food during July and August. Yearling and fish at least up to age III showed appreciable growth only during June and July."

Relevance: Goldeye are an important food for predatory fish such as Walleye; changes in the abundance of invertebrate food sources due to environmental change may affect fish populations as well.

Donald, D.B., and G.D. Sardella. 2010. Mercury and other metals in muscle and ovaries of goldeye (*Hiodon alosoides*). *Environmental Toxicology and Chemistry* 29 (2): 373–79. DOI: 10.1002/etc.39

Purpose/scope: To assess the concentrations and accumulation of 24 trace metals (including mercury (Hg)) in the ovaries and muscle tissues of juvenile and adult female Goldeyes, a fish with both low annual growth and a long lifespan.

Author Information: Researchers from Environment Canada

Location: Mamawi Lake and Lake Claire, Peace-Athabasca Delta, AB

Findings: "Goldeye from the Delta were selected for the study because this population has a long life span, slow growth, and feeds at the same trophic level throughout life." Hg

accumulation in goldeye muscle was greater than for other long-lived species (e.g., lake trout, pike, walleye), and the Hg present in older goldeye from the Delta population could cause adverse biological effects to those individuals. Concentrations of metals in ovaries relative to muscle varied for each metal, though Hg was notably lower in ovaries (mean 21.1 ng/g wet wt vs. mean 288.6 ng/g wet wt), indicating that "developing embryos were not exposed to the constantly increasing and potentially toxic concentrations of Hg that occurred in female muscle." "In general, these results suggest that concentrations of many metals may be regulated and maintained in tissues of goldeye".

Relevance: Goldeye appear to be reliable indicators of Hg accumulation in the Peace-Athabasca Delta and associated systems; Goldeye contribute to the commercial fisheries of both Goldeye and Walleye in the region, and so these results have human health implications as well.

Features: Mean concentration (+/- Standard Deviation(SD)) of total trace metals in Goldeye muscle tissues and ovaries.

Evans, M.S., L. Lockhart, and J. Klaverkamp. 1998. *Metal studies of water, sediments and fish from the Resolution Bay area of Great Slave Lake: studies related to the decommissioned Pine Point Mine*. N.W.R.I. Contribution Series: 98-87. Saskatoon and Winnipeg: National Hydrology Institute and Freshwater Institute

Purpose/scope: To investigate metal concentrations in water, sediments and fish in Great Slave Lake due to the decommissioned Pine Point Mine.

Author Information: Government researchers

Location: Fort Resolution, Slave River

Findings: The study found that there was no evidence that fish in the Resolution Bay area, including the Little Buffalo and Slave Rivers were contaminated with metals by the decommissioned Pine Point Mine. Concentrations of metals in fish collected from the Slave and Little Buffalo River were similar to concentrations in fish collected from Resolution Bay in summer 1996, and in the general study area during the early 1970s. Only mercury concentrations in the liver of large pike and inconnu approached or exceeded consumption guidelines.

Relevance: Water, sediment, and fish baseline conditions in the Resolution Bay area in the late 1990s.

Features: Data reported as means ± SE

Evans, M.S., and D. Muir. 2006. Spatial and long-term trends in persistent organic contaminants and metals in lake trout and burbot in Great Slave Lake, NT. In *Synopsis of Research conducted under the 2005-2006 Northern Contaminants Program*, edited by S. Smith and J. Stow, 101–8. Ottawa: Indian and Northern Affairs, Northern Contaminants Program. Public Works and Government Services Canada

Purpose/scope: "This study is part of Northern Contaminants Program's Trend Monitoring Program whose overall objective is to measure contaminant trends in animals

that are important to traditional diets. The study focuses on lake trout and burbot harvested from Great Slave Lake in the Northwest Territories."

Author Information: Researchers from Environment and Climate Change Canada, with collaborators from NWT local governments, First Nations, and Fisheries and Oceans Canada

Location: Great Slave Lake and Slave River Delta at Fort Resolution

Findings: Project is ongoing. No results as of 29 March 2017. Lake trout and burbot will be harvested and chemical analyses (focused on mercury and other metal trends) will be performed on their tissues. Tissues will be archived for other potential analyses (e.g., organic contaminants) at a later date.

Relevance: Contaminant trends will be examined, providing information on bioaccumulation and suitability for human consumption.

Features: Great Slave Lake ongoing work. Information will be in previous yearly synopses.

Evans, M.S., and D.C.G. Muir. 2004. Contaminant biomagnification in specific reaches of the Peace-Athabasca River ecosystem - study highlights. In *Northern Rivers Ecosystem Initiative: Collective Findings (CD-ROM)*, edited by Environment Canada. Compiled by F.M. Conly, Saskatoon, SK (With Alberta Environment)

Purpose: To determine whether the high concentrations of organic contaminants in burbot liver downstream of pulp mills (relative to fish at less impacted diluted downstream sites or upstream control sites) is related to the trophic level at which the fish feed at the various sites

Author Information: Researchers from the National Water Institute (Environment Canada)

Location: Athabasca River from Emerson Lakes to Calling River and Wapiti River (tributary of Peace River) from Hwy 40 to Hwy 34 on Smoky River

Findings: "Coarse detritus and periphyton did not appear to be important food sources for the benthos and forage fish examined; fine organic matter probably was the more important food source. Summed PCB (ΣPCB) levels in benthos and forage fish followed the same spatial pattern observed in burbot liver in earlier years, indicating that ΣPCB levels in burbot liver are related to higher ΣPCB levels in their food sources. We hypothesize that ΣPCB are retained more strongly in the periphyton-rich reaches of the Wapiti, Smoky, and Athabasca Rivers, leading to greater ΣPCB uptake by the benthos and ultimately forage fish and burbot."

Relevance: Industrial development may affect river habitat quality by influencing whether contaminants are retained in biota and accumulated up the food chain.

Evans, M.S., and A. Talbot. 2012. Investigations of mercury concentrations in walleye and other fish in the Athabasca River ecosystem with increasing oil sands developments. *Journal of Environmental Monitoring* 14 (7). DOI: 10.1039/c2em30132f

Purpose/scope: This study is a follow-up to work that showed a short-term increase in mercury in walleye and related it to oil sands development. This study compiles database from previous monitoring to look at trends of several species of large bodied fish.

Author Information: Environment Canada research scientists

Location: Athabasca River

Findings: Species studied were walleye, lake whitefish, northern pike, and lake trout. In the oil sands area, mercury concentrations decreased in walleye and lake whitefish from 1984 to 2011. In western Lake Athabasca and its delta, mercury concentrations decreased in northern pike (1981-2009), and there was no trend for walleye (1981-2005) and lake trout (1978-2009). Mercury in lake trout in Namur Lake, west of the oil sands area, increased from 2000 to 2007. Similar increases in mercury have been observed in lake trout from similar sized lakes in the NWT. There is no evidence that mercury is increased in fish as a result of oil sands development.

Relevance: Baseline information on mercury in fish in the Athabasca River

Features: Journal paper with fish length, weight and mercury concentrations presented as means with standard deviations

Evans, M.S., and D. Muir. 2016. "Spatial and long-term trends in persistent organic contaminants and metals in lake trout and burbot from the Northwest Territories". *Profiles.science.gc.ca - Environmental Monitoring and Research*. http://www.science.gc.ca/eic/site/063.nsf/eng/h_97393.html. Consulted on 27 February 2017

Great Slave Lake ongoing work. Information will be in previous yearly synopses. **Purpose/scope:** "This study is part of Northern Contaminants Program's Trend Monitoring Program whose overall objective is to measure contaminant trends in animals that are important to traditional diets. The study focuses on lake trout and burbot harvested from Great Slave Lake in the Northwest Territories."

Author Information: Researchers from Environment and Climate Change Canada, with collaborators from NWT local governments, First Nations, and Fisheries and Oceans Canada

Location: Great Slave Lake and Slave River Delta at Fort Resolution

Findings: Project is ongoing. No results as of 29 March 2017. Lake trout and burbot will be harvested and chemical analyses (focused on mercury and other metal trends) will be performed on their tissues. Tissues will be archived for other potential analyses (e.g., organic contaminants) at a later date.

Relevance: Contaminant trends will be examined, providing information on bioaccumulation and suitability for human consumption.

Features: N/A.

Evans, M.S., and D.C.G. Muir. 2016. Persistent organic contaminants in sediments and biota of Great Slave Lake, Canada: Slave River and long-range atmospheric source influences. *Journal of Great Lakes Research* 42: 233–47. DOI: 10.1016/j.jglr.2015.12.001

Purpose/scope: Evaluate legacy persistent organic and polynuclear aromatic hydrocarbons pollutants in the West Basin and East Arm of Great Slave Lake.

Author Information: Environment Canada researchers

Location: West Basin and East Arm of Great Slave Lake, Slave River

Findings: Contaminant concentrations in surface sediments were generally higher in the West Basin than East Arm reflecting Slave River influence. Lipid distribution in fish bodies influenced findings. Lake size, available habitat, and productivity are contributing factors to concentrations in fish and invertebrates. Small fish had similar persistent organic pollutant (POP) concentrations as invertebrates. Food web key to finding outcomes.

Relevance: Historical data from mid-1990s. Synthesis included influence of the Slave River in contaminant loading in the Great Slave Lake and POP concentrations in fish, invertebrates and sediment. Synthesis and discussion contains comparative findings with other northern lakes.

Features: Peer-reviewed journal paper with data reported as means ± S.E.

Evans, M., D. Muir, R.B. Brua, J. Keating, and X. Wang. 2013. Mercury trends in predatory fish in Great Slave Lake: The influence of temperature and other climate drivers. *Environmental Science & Technology* 47 (22): 12793–801. DOI: 10.1021/es402645x

Golder Associates Ltd. 2004. *Review of historical fisheries information for tributaries of the Athabasca River in the oil sands region*. Submitted to: Regional Aquatic Monitoring Program (RAMP) Steering Committee

Purpose/scope: "The objectives of the historical data review for Athabasca River tributaries were: to construct a database containing fisheries information from past fisheries reports; to produce fish species distribution maps for the tributary watersheds; to synthesize the existing data and to provide an overview of fish communities and fish habitats in the tributary watersheds; to provide data for comparison with current and future RAMP monitoring data for trend analysis; and to identify knowledge gaps and provide recommendations for future work to improve RAMP."

Author Information: Environmental consultants

Location: Tributary watersheds of the Athabasca River from just upstream of Fort McMurray northward to the confluence with the Firebag River

Findings: Fifty tributaries within the specified stretch of the Athabasca were identified but fisheries reports were available for only 32 of these (22 names, 10 unnamed watercourses). Historical fisheries reports from various sources were synthesized and summarized for each of these 32 tributary watersheds, with sections on watercourse location, water quality, habitat description, habitat use, and fish summary included where applicable. Data gaps are also identified.

Relevance: Historical data may be used as baselines for future assessments of aquatic ecosystems in this area.

Features: Detailed historic fisheries summaries for tributaries along the Athabasca River; distribution maps for 27 species of fish.

Grey, B.J., S.M. Harbicht, and G.R. Stephens. 1995. *Mercury in fish from rivers and lakes in southwestern Northwest Territories*. Northern Water Resources Studies. Indian and Northern Affairs Canada. Available at: http://pubs.aina.ucalgary.ca/misc/38317.pdf. ISBN: 0662232208

Purpose/scope: Mercury studies in fish to address concerns about potential transboundary pollution

Author Information: Federal government study

Location: Hay River (at mouth), Slave River at Fort Smith, and Leland Lake (in Slave drainage) as a control

Findings: Lake whitefish, northern pike and walleye were sampled over a three-year period. Mercury levels were similar in all three locations, varying with species and age. The study concluded that the levels found showed no evidence of basin-related anthropogenic influence.

Relevance: A good baseline study as sample sizes are adequate for follow-up comparative work; methodology and rationale are solid and full data are in the report.

Features: Data appendix with all data

Jacobson, T.-L., and T.D. Boag. 1995. *Fish collections: Peace, Athabasca and Slave river basins, September to December, 1994*. Vol. 1994. Northern River Basins Study Project Report No. 61. Edmonton, Alberta: Prepared by EnviRsource Consulting Ltd. for the Northern River Basins Study. ISBN: 066224916X

Purpose/scope: "The purpose of this project was to collect and prepare fish from 23 sites on the Peace, Athabasca and Slave River drainages for conducting physical, physiological, contaminant and biophysical analyses."

Author Information: Environmental consultants and community contributors from Fort Chipewyan and Fort Resolution

Location: Peace River, Athabasca, and Slave River Basins (including Great Slave Lake)

Findings: "A total of 535 fish and 13 species were caught [...] Most fish examined externally and internally for gross pathological abnormalities and deformities appeared normal (84%). Of the abnormalities observed, tumours and lesions of longnose suckers were the most common."

Features: Morphological and pathological data for fish caught during this study.

Jantzie, T.D. 1976. *A synopsis of the physical and biological limnology and fishery programs within the Alberta Oil Sands Area*. Project AF 3.1.1. Alberta Oil Sands Environmental Research Program

Purpose/scope: "The major objectives were defined as follows: 1. to review existing data [as of 1976] relative to the aquatic resources of the AOSERP region; 2. to indicate the type and level of detail of information available on the physical and chemical limnology of lakes, rivers, and streams in the AOSERP region; and 3. to indicate the type and level of detail of existing information on the biology of fish inhabiting lakes, rivers, and streams in the AOSERP region."

Author Information: Environmental consultant

Location: Alberta Oil Sands Environmental Research Program study area: Athabasca River from the Clearwater River to confluence with Slave River

Findings: Describes the extent of limnology and fisheries research of waterbodies in the area, but does not elaborate on the findings of the research.

Relevance: Limited - no original research is presented nor summarized, and the state of research knowledge has changed considerably since publication.

Features: No original data, but provides a good bibliographic listing of limnological and fish information sources for the study region.

Johnson, P., E. Plate, D. Robichaud, and L. Renzetti. 2012. *Winter ecology in the Athabasca River: Mesohabitat species associations. Final Technical Report*. Report Prepared for CEMA Surface Water Working Group and Monitoring Technical Task Group. Sidney, British Columbia: LGL Limited

Purpose/scope: "A field study was carried out on the Lower Athabasca River to aid in assessing whether changes in relative abundance of five mesohabitats in winter due to water withdrawals would reduce aquatic ecological health in Segment 1 (delta) of the Athabasca River. The primary management question addressed was to determine whether there are significant negative biological impacts associated with predicted changes in mesohabitats in the Athabasca River delta due to Phase 2 water withdrawals."

Author Information: Research scientists from LGL Limited (consulting firm), commissioned by CEMA

Location: "Segment 2 of the Lower Athabasca River between 168 and 174 km north of Ft. McMurray"

Findings: "A total of 151 individuals, representing 23 taxa were identified in the benthic macroinvertebrate samples. The majority of individuals (91%) and the greatest number of genera (14) were members of the Chironomidae family of insects. [...] In general, mesohabitats characterized with slow velocity displayed the greatest number and variety of taxa. Macroinvertebrate community abundance appeared to be strongly related to water velocity with observed abundance being an order of magnitude lower in the medium velocity mesohabitat types but data were insufficient to statistically test these relationships. No fish were caught by angling or trapping methods, and video data

processing yielded no images of fish. Overall, gillnet catches were low, with 10 fish caught in 22 sets. [...] Analysis of the gill net data indicated that the data were too sparse to infer habitat association relationships. [...] Occupancy analyses showed that the probability of an area being occupied by small fish varied among mesohabitats and depths, but not between velocity categories. No habitat differences in occupancy could be detected for medium-sized or large fish. Results should be viewed as preliminary at this stage and more data are required to further analyze the observed patterns."

Relevance: Indicates which sampling methods may be effective or not for characterizing aquatic indicators (i.e., fish and macroinvertebrates) in northern streams.

Features: Raw environmental (streamflow and chemistry) and fish occupancy data from 2012.

Johnson, P., E. Plate, D. Robichaud, L. Renzetti, R. Bocking, and M. Gaboury. 2013. *Winter ecology in the Athabasca River 2012-2013 : Mesohabitat species Associations. Final draft technical report*. Report Prepared for CEMA Water Working Group and Surface Water Technical Group. Sidney, British Columbia: LGL Limited. Available at: http://library.cemaonline.ca/ckan/dataset/a014e3c2-8a16-4c0e-923e-90e254b96969/resource/2e4650c7-07b3-457e-88e9-6f84411f4b2a/download/winterecologyintheathabascariver20122013.pdf

Purpose/scope: "A field study was carried out on the Lower Athabasca River to aid in assessing whether changes in relative abundance of five mesohabitats in winter due to water withdrawals would reduce aquatic ecological health in the delta of the river. The primary management question addressed was to determine whether there are significant negative biological impacts associated with predicted changes in mesohabitats in the Athabasca River delta due to recommended water allocation limits." This report also covers the occupancy data from the 2012 report.

Author Information: Research scientists from LGL Limited (consulting firm), commissioned by CEMA

Location: "Segment 2 of the Lower Athabasca River between approximately 162 and 186 km north of Ft. McMurray (immediately upstream of the delta)"

Findings: "Environmental parameters, invertebrates and fish were sampled along 24 transects in 2012 and 60 transects in 2013. Invertebrate and fish associations were assessed across five mesohabitat types as defined by Paul and Locke (2009): deep, medium velocity; deep, slow velocity; moderate depth, medium velocity; moderate depth, slow velocity; and shallow, slow velocity. [...] Results from the fish and benthic habitat association analyses suggest that among physical habitat parameters velocity has a strong effect on habitat use whereas depth is less certain. However, differences in detection probability for small fish using the DIDSON among habitat types could potentially explain observed patterns in CPUE. Regardless, our results suggest decreased availability of mesohabitats with high velocities (>0.3 m/s) during winter would not result in decreased benthic invertebrate diversity or density, or reduced fish density."

Relevance: Indicates that the likelihood of observing fish or invertebrates varies according to mesohabitat type, implying that monitoring programs using these taxa must account for habitat preferences in sampling design if the indicators are to be reliable.

Features: Raw environmental (streamflow and chemistry) and fish occupancy data from 2013.

Jones, P.D., B. Tendler, E. Ohiozebau, A. Hill, G. Codling, J.P. Giesy, E. Kelly, P. Hodson, and J. Short. 2012. Health status and biomarker responses in fish from the Athabasca and Slave rivers in relation to potential exposure to contaminants from oilsands operations. In *Society of Environmental Toxicology and Chemistry (SETAC) North America 33rd Annual Meeting, Long Beach California*. Available at: https://www.usask.ca/toxicology/jgiesy/SETAC%202010/SETAC%202012/SETAC%20North%20America%20Nov%202012/Jones%20et%20al%202012-JPG.pdf

Purpose/scope: "The aim of the study was to investigate the health status of fish populations in the Athabasca and Slave rivers as related to environmental contaminants potentially originating from oil sands development."

Author Information: Researchers from the University of Saskatchewan, City University of Hong Kong, Environment and Natural Resources GNWT, Queens University, and a consulting firm from Juneau Alaska.

Location: Eight sites on the Athabasca and Slave Rivers (from upstream of Fort McMurray, AB to Fort Resolution, NWT)

Findings: "Assessment of condition and health during 4 seasons suggests that currently, conditions of fishes are relatively stable over the length of the river system [...] Morphometric measures as indicators of health of fish do not indicate major effects on fish based on current contaminant loadings to the river system [...] Chemical exposure data demonstrate increased exposure to PAHs in the vicinity of oil sands operations while the concentrations of some metals (i.e., Ti, Se) are greater in the Slave River than in the Athabasca."

Relevance: Morphometric measures of fish health may be inadequate to indicate fish and ecosystem health; chemical tissue analysis may be more appropriate for use as indicators of stress.

Kristensen, J., O. B.S., and A.D. Sekerak. 1976. *Walleye and goldeye fisheries investigations in the Peace-Athabasca Delta - 1975*. Project AF 4.1.1. Prepared by LGL for Aquatic Fauna Technical Research Committee, Alberta Oil Sands Environmental Research Program. Available at: https://era.library.ualberta.ca/items/9fdea349-73ae-4e0a-8fb3-994a5e4a4163

Purpose/scope: Report on fisheries studies in the lower Peace and Athabasca conducted as part of aquatic assessment related to the oil sands

Author Information: Consultant biologists contracted by an intergovernmental research program

Location: Peace-Athabasca Delta region: Richardson Lake, Lake Athabasca, Lake Claire, Mamawi Lake, Rivière des Rochers

Findings: Fish survey results including distribution, movement, abundance and distribution of juveniles, and biological and population characteristics. Species surveyed: walleye and goldeye.

Relevance: Potential baseline data for indicator development for large-bodied fish

Features: This report is scanned and made available by the University of Alberta Education and Research Archive.

Kristensen, J., and S.A. Summers. 1981. *Fish populations in the Peace-Athabasca Delta and the effects of water control structures on fish movements: data*. Fisheries and Marine Service Data Report No. 61. Winnipeg, Manitoba: Department of Fisheriesa nd the Environment, Fisheries and Marine Service, Western Region. Available at: http://www.dfo-mpo.gc.ca/Library/22285.pdf

Purpose/scope: Baseline information on fish in the Peace-Athabasca Delta in relation to concerns about flow changes from the Bennett Dam

Author Information: Consultant report for Department of Fisheries and Oceans Canada

Location: Peace-Athabasca Delta

Findings: Results of an extensive mark-recapture program on goldeye, lake whitefish, longnose sucker, northern pike, walleye, and white sucker in the Peace-Athabasca Delta in 1976. Part of the study is related to weirs and fishways in the outflows of Lake Athabasca (constructed not long before the study) and their impact on fish movements.

Relevance: Provides baseline information on major large fishes in the study area, including distribution, movements, age structure, abundance and population estimates.

Features: Scanned data report

Lafontaine, C. 1997. *Fort Resolution Fish Monitoring Program (1992-1993): Concentrations of metals and trace elements in muscle and liver of fish collected from Great Slave Lake, Fort Resolution area, NWT. Final Report*. Yellowknife, NWT: Prepared for Department of Indian Affairs and Northern Development Water Resources Division. Available at: http://www.reviewboard.ca/upload/project_document/EA0607-002_Document__Fort_Resolution_Fish_Monitoring_Program__1992-3_.pdf

Purpose/scope: Analyze muscle and liver of fish near Fort Resolution for metals including arsenic, cadmium, copper, lead, mercury, nickel and zinc

Author Information: Water quality specialist in Yellowknife

Location: Fort Resolution, NWT

Findings: Forty-eight fish (walleye, pike, whitefish, burbot and longnose sucker) were sampled for metal concentrations. Sampling location was selected because they are consumed by the residents of Fort Resolution. Metal concentrations were low and posed no consumption hazards.

Relevance: Baseline metal levels in fish near Fort Resolution to the west of the Slave River delta. Although outside of area, may provide reference information.

Features: Data reported as means ± S.E.

Little, A.S. 1997. *Food and habitat use within fish assemblages of the lower Slave River, Northwest Territories.* MSc Thesis. Available at: http://www.collectionscanada.gc.ca/obj/s4/f2/dsk2/ftp04/mq21185.pdf

Purpose/scope: Document spatial and temporal patterns of food and habitat use at three locations along the Slave River system to assess trophic and habitat relationships within the assemblages.

Author Information: Graduate student

Location: Slave River

Findings: Distinct habitat use due to differences in discharge and the amounts of vegetation. Finer-scaled differences also observed among individual species. Dietary overlap was also generally low.

Relevance: Status of fish species and habitat in 1997. Discussion of unique habitat requirements of fish.

Features: Peer-reviewed journal paper with data reported as means ± S.E.

Lockhart, W.L., G.A. Stern, G. Low, M. Hendzel, G. Boila, P. Roach, M.S. Evans, et al. 2005. A history of total mercury in edible muscle of fish from lakes in northern Canada. *Science of the Total Environment* 351–352: 427–63. DOI: 10.1016/j.scitotenv.2004.11.027

Lutz, A., and M. Hendzel. 1976. *Survey of baseline levels of contaminants in aquatic biota of the AOSERP study area*. Project AF 2.1.1. Alberta Oil Sands Environmental Research Program Aquatic Fauna Sector. Winnipeg, Manitoba: Fisheries and the Environment Canada Freshwater Institute. Available at: https://era.library.ualberta.ca/files/m613mx66b/AF 2.1.1June 1977.pdf

Purpose/scope: “To determine background levels of contaminants in aquatic fauna, water and sediments [in the oil sands region]” Specifically, “1. determine background levels of contaminants in fish, water, sediments, and invertebrates; 2. define the relationship between level of contaminant and size of fish; 3. identify natural sources of contamination; 4. provide baseline biological information on a number of potential sites for further experimental work.”

Author Information: Researchers from the Freshwater Institute (Fisheries and Oceans Canada (DFO) and Environment Canada), for the Alberta Oil Sands Environmental Research Program

Location: AOSERP study area: Athabasca River from the Clearwater River to confluence with Slave River

Findings: No evidence found for metal accumulation up the food chain (based on invertebrate data). All metal concentrations in water were within accepted values (except Fe and Mn, but these exceedances were related to aesthetic objectives). Freshwater plankton appear to accumulate metals. No natural source of contamination in water was identified.

Relevance: Baseline metal concentration data from mid-1970's

Features: Metal concentrations in water, sediment, fish, invertebrates, and plankton (means +/- SD).

Machniak, K., and W.A. Bond. 1979. *An intensive study of the fish fauna of the Steepbank River watershed of northern Alberta*. Project AF 4.5.2. Alberta Oil Sands Environmental Research Program

Purpose/scope: "To describe the baseline states of the fish resources and the aquatic habitat of the Steepbank River watershed, and to provide a quantitative estimate of the significance of this watershed to the fisheries of the Athabasca River system."

Author Information: Researchers from the Freshwater Institute (Fisheries and Oceans Canada, and Environment Canada)

Location: Steepbank River watershed, a tributary of the Athabasca that is upstream of Fort McMurray

Findings: 23 fish species were documented in this study. "Northern pike demonstrated little tendency to move around while walleye and suckers moved great distances. The resident fish fauna of the Steepbank River consists largely of pearl dace, brook stickleback, lake chub, longnose dace and slimy sculpin."

Relevance: Fish migration patterns may be similar elsewhere in the Athabasca River, which may inform the spatial scale of monitoring studies. Disruptions to fish movement could have far-reaching effects downstream. Also provides upstream reference population survey data.

Features: Detailed life history descriptions for 14 fish species studied in the Athabasca (specifically Steepbank) River are presented.

Machniak, K., W.A. Bond, M.R. Orr, D. Rudy, and D. Miller. 1980. *Fisheries and aquatic habitat investigations in the MacKay River watershed of northeastern Alberta*. Project WS 1.3.1. Alberta Oil Sands Environmental Research Program and Syncrude Canada. Available at: https://era.library.ualberta.ca/files/g445cd77v/WS 1.3.1 June 1980.pdf

Purpose/scope: "To describe the baseline states of the fish resources and the aquatic habitat of the MacKay River watershed, and to provide a quantitative estimate of the significance of this watershed to the fisheries of the Athabasca River system."

Author Information: Researchers from the Freshwater Institute (Fisheries and Oceans Canada, and Environment Canada)

Location: MacKay River watershed, a tributary of the Athabasca

Findings: 20 fish species were detected in the MacKay river watershed. "The resident fish fauna of the MacKay River watershed consists largely of brook stickleback, pearl dace, finescale dace, longnose dace, and slimy sculpin. A resident northern pike population appears to be present in the vicinity of the confluence of the Dunkirk and MacKay rivers."

Relevance: Fish migration patterns may be similar elsewhere in the Athabasca River, which may inform the spatial scale of monitoring studies. Disruptions to fish movement could have far-reaching effects downstream. Also provides reference information for oil sands region waterbodies prior to intense development.

Features: Detailed life history descriptions for 14 fish species studied in the Athabasca (specifically MacKay) River are presented.

McCarthy, L.H., G.R. Stephens, D.M. Whittle, J. Peddle, S. Harbicht, C. LaFontaine, and D.J. Gregor. 1997. Baseline studies in the Slave River, NWT, 1990–1994: Part II. Body burden contaminants in whole fish tissue and livers. *Science of The Total Environment* 197 (1–3): 55–86. DOI: 10.1016/S0048-9697(96)05420-4

Purpose/scope: Establish if Slave River contaminant levels in fish tissues are suitable for human consumption.

Author Information: Government and university researchers

Location: Slave River

Findings: Fish muscle tissue is fit for human consumption. Using late 1980s / early 1990s state of art methodologies, persistent low concentrations of organochlorine (OC) pesticides, PCBs, dioxin and furan isomers, Polycyclic aromatic hydrocarbons (PAHs), chlorinated phenolics, and heavy metals were identified. Toxaphene levels should be continued to be monitored.

Relevance: Baseline dataset for the early 1990s and contaminant level findings against human consumption standards. Large fish as indicators and bioavailability of contaminants.

Features: Peer-reviewed journal paper with data reported as means ± S.E.

Mill, T.A., P. Sparrow-Clark, and R.S. Brown. 1997. *Fish distribution, movement and gross external pathology information for the Peace, Athabasca and Slave river basins*. Report No. 147. Northern River Basins Study. Edmonton, Alberta: Northern River Basins Study. Available at: http://www.barbau.ca/sites/www.barbau.ca/files/0-662-24831-7.pdf

Muir, D., and C. Fraikin. 2004. Spatial and temporal trends of organochlorine contaminants in fish from Alberta's northern rivers. In *Northern Rivers Ecosystem Initiative: Collective Findings (CD-ROM)*, edited by Environment Canada. Compiled by F.M. Conly, Saskatoon, SK (With Alberta Environment)

Purpose/scope: "Temporal and spatial trends of polychlorinated biphenyls (PCBs), organochlorine (OC) pesticides, other industrial related OCs (chlorobenzenes, chloroveratroles), as well as polychlorinated dibenzo- p-dioxins and –dibenzofurans (PCDD/PCDFs) were studied in fish" downstream of pulp mills; long-range OC transport was also considered.

Author Information: Researchers from the National Water Research Institute (Environment Canada) and Golder Associates

Location: Athabasca and Wapiti/Smoky/Peace river systems in Northern Alberta. Note that the study is conducted in the mid to upper reaches in both river systems, but looks more broadly across the watershed, referencing data at the Slave Delta (i.e., Great Slave Lake).

Findings: Concentrations of TCDD, TCDF, and PCBs in water were highest downstream of municipal and bleached kraft pulp mills. However, major declines of TCDD and TCDF were observed for burbot, mountain whitefish, and longnose suckers at several sites, reflecting the success of effluent reduction programs by the pulp mills... "Semi-volatile OCs [...] were present at low levels in all fish with generally higher levels at upstream sites on the Athabasca River implying an atmospheric and/or snow and glacial meltwater pathway".

Relevance: Industrial contaminants vary spatially and temporally - baseline data on contaminants in these river systems is essential to know whether fish are continually accumulating toxins or have residual amounts from past effluents.

Features: Mean (with SD) concentrations of various OC contaminants in fish liver and muscle tissues from the Wapiti, Athabasca, Lesser Slave, and Peace river systems.

Northern River Basins Study Board. 1996. *Northern River Basins Study report to the ministers*. Edmonton: Environment Canada and Alberta Environment. Available at: https://www.ceaa.gc.ca/050/documents_staticpost/63919/96375/3-1996-Northern_River_Basins_Study-Report_to_the_Ministers.pdf

Purpose/scope: Peace, Athabasca, and Slave Rivers state of the environment (SOE) for fish, drinking water quality, and flow rate with greatest focus on Athabasca

Author Information: Scientific work was completed by private companies, individuals, government agencies, and educational institutions. The research was overseen by a seven-member Science Advisory Committee.

Location: Peace, Athabasca and Slave Rivers

Findings: Summary of findings from 150 "mini" studies benchmarking key aspects of the SOE. In fish, dioxin and furans declined during the study, except in fish near pulp mills where levels of toxic dioxins, furans and mercury still exist. Levels of PCBs appeared to be within generally accepted consumption guidelines. Fish near pulp mills had lower sex hormones, tumours and growths. Drinking water quality was good for the majority of basin residents. 25% of the residents get water directly from water sources that should be treated for bacteria. Flow rate is being affected by upstream dams that have changed patterns in flow and ice patterns drying out Peace-Athabasca delta and affecting the growth rate of Slave River delta. Cumulative effects are summarized on a river reach by river reach basis.

Relevance: SOE conditions 1996. Implemented recommendations can be checked for effectiveness.

Features: Plain language report with peer reviewed data

Ohiozebau, E., P.D. Jones, B. Tendler, A. Hill, G. Codling, J.P. Giesy, E. Kelly, P. Hodson, and J. Short. 2012. Exposure of fish in the Athabasca and Slave Rivers to PAHs potentially derived from Oilsands operations. In *Society of Environmental Toxicology and Chemistry (SETAC) North America 33rd Annual Meeting, Long Beach California*. Available at: http://www.enr.gov.nt.ca/sites/enr/files/fish_health_study_pahs.pdf

Purpose/scope: To investigate the exposure of fish populations in the Athabasca and Slave rivers to PAHs; to describe the spatial and temporal distribution of concentrations of PAHs in fish bile, liver, and muscle tissue; and to translate the data to estimates risk for human consumers.

Author Information: University researchers

Location: Athabasca and Slave Rivers

Findings: Bile concentrations of PAHs reflect recent exposure and may not reflect edible tissue concentrations.

Relevance: Poster indicates there may be relevant research on PAH up-take.

Features: Peer-reviewed journal paper with data reported as means ± S.E. Research is also summarized as a poster with same authors, title and year.

Ohiozebau, E., B. Tendler, G. Codling, E. Kelly, J.P. Giesy, and P.D. Jones. 2016. Potential health risks posed by polycyclic aromatic hydrocarbons in muscle tissues of fishes from the Athabasca and Slave Rivers, Canada. *Environmental Geochemistry and Health*, no. Di. Springer Netherlands: 1–22. DOI: 10.1007/s10653-016-9815-3

Purpose/scope: To determine the concentrations of PAHs in goldeye, whitefish, pike, walleye, and burbot caught in the oil sands region, and to determine whether PAH concentrations are high enough to pose human health risks

Author Information: Researchers from the Universities of Saskatchewan and Hong Kong, and the Department of Environment and Natural Resources, Government of NWT.

Location: Athabasca and Slave Rivers, specifically, near Fort McMurray, Fort McKay, Fort Chipewyan, Fort Smith, and Fort Resolution.

Findings: All PAH concentrations were multiplied by a Toxic Equivalency Factor to determine their potential toxicity. “Species with a preference for benthic habitats are more likely to have greater exposures to PAH in a polluted environment than those with a preference for pelagic environments.” While concerns of First Nations communities around the societal and cultural values of fish resources are not to be diminished, this study found no evidence that consuming major food fishes in the Athabasca and Slave Rivers contributes to immediate and direct health impacts.

Relevance: Fishes and other biota integrate much information about their immediate environment and can be effective ecological indicators. “It is desirable therefore that a monitoring program in water, sediments and biota be in place and extend to the entire Athabasca/Slave basin to detect the presence of contaminants and mitigate their potential human and ecological effects”.

Features: PAH concentrations in muscle tissue are presented as mean +/- SD (assumed; not indicated whether SD or SE) for 5 species x 16 PAHs x 3 sampling seasons.

Ohiozebau, E., B. Tendler, A. Hill, G. Codling, E. Kelly, J.P. Giesy, and P.D. Jones. 2016. Products of biotransformation of polycyclic aromatic hydrocarbons in fishes of the Athabasca/Slave river system, Canada. *Environmental Geochemistry and Health* 38 (2). Springer Netherlands: 577–91. DOI: 10.1007/s10653-015-9744-6

Purpose/scope: To measure concentrations of biotransformed polycyclic aromatic hydrocarbons (PBPAH) in nutritionally, culturally, and ecologically important fish.

Author Information: University and government based researchers

Location: Athabasca River and Slave River

Findings: Spatial and seasonal trends in bile concentrations of PBPAHs coincided with fishes in locations proximate to oil sands operations. Fish trophic level and habitat preference found to be important factors in accounting for the concentrations of PBPAHs. PBPAH levels in fish can be a good indicator of trends and spatial distribution of PAHs. Follow-up work of PBPAH levels in fish tissue is required.

Relevance: PBPAHs in bile may be a reference point for discharge decision-making.

Features: Peer-reviewed journal paper with data reported as means ± S.E.

Ohlson, D., G. Long, and T. Hatfield. 2010. *Phase 2 Framework Committee Report*. Compass Resource Management and Solander Ecological Research. Available at: https://albertawilderness.ca/wordpress/wp-content/uploads/2015/12/20100131_rp_athabasca_p2fc.pdf

Purpose/scope: Outcome of Phase 2 Water Management Framework that will prescribe when, and how much, water can be withdrawn from the Lower Athabasca River for cumulative oil sands mining water use.

Author Information: Committee report prepared by consultants

Findings: Insights gained from technical analyses and modelling. Ecosystem health focused on fish core to evaluation.

Relevance: May be useful for synthesis report for modelling and recommendations.

Features: Modelling of water levels

RAMP. 2016. "Fish inventory data". Regional Aquatics Monitoring Program. http://www.ramp-alberta.org/data/Fisheries/Inventory/default.aspx. Consulted on 16 March 2017

Purpose/scope: “Fish inventory studies are conducted by RAMP to examine trends in abundance and population variables for key indicator fish species. The inventory focuses on sections of the Athabasca River that are adjacent to oil sands development or near tributaries with development within their watershed. An inventory is also conducted on the

Clearwater River to provide some perspective on fish communities of a river without development." This dataset contains historical (1987-2014) fish inventory data.

Author Information: Regional Aquatics Monitoring Program

Location: Various reaches of the Athabasca River system in Alberta, including tributaries near oil sands and other developments; Clearwater River

Findings: Data for 28 species of fish are presented (length, weight, stage, sex, maturity, age), as well as catch date (1987-2014) and location

Relevance: Historical demographic and morphological data for fish from the Athabasca (impacted) and Clearwater (reference) rivers.

Features: Searchable database with raw fish data from 1987-2014

RAMP. 2016. "Fish pilot study data". Regional Aquatics Monitoring Program. http://www.ramp-alberta.org/data/Fisheries/PilotStudy/default.aspx. Consulted on 16 March 2017

Purpose/scope: "Fish inventory studies are conducted by RAMP to examine trends in abundance and population variables for key indicator fish species. The inventory focuses on sections of the Athabasca River that are adjacent to oil sands development or near tributaries with development within their watershed. An inventory is also conducted on the Clearwater River to provide some perspective on fish communities of a river without development." This dataset contains current (August 2015) fish inventory data.

Author Information: Regional Aquatics Monitoring Program

Location: Various reaches of the Athabasca River system in Alberta, including tributaries near oil sands and other developments; Clearwater River

Findings: Data for 13 species of fish are presented (length, weight, stage, sex, maturity, age) as well as catch date (August 22-27 2015) and location

Relevance: Current (2015) demographic and morphological data for fish from the Athabasca (impacted) and Clearwater (reference) rivers

Features: Searchable database with raw fish data from 2015

RAMP. 2016. "Sentinel species program data". Regional Aquatics Monitoring Program. http://www.ramp-alberta.org/data/Fisheries/Sentinel/default.aspx

Purpose/scope: "Sentinel species monitoring evaluates the health of a representative fish species in the Athabasca River, and in smaller tributaries of the Athabasca River that have oil sands development. The approach compares characteristics such as growth, survival, body size, and reproduction of a sentinel species caught downstream of oil sands development to fish that reside upstream of the development, or to data collected prior to development."

Author Information: Regional Aquatics Monitoring Program

Location: Various reaches of the Athabasca River system in Alberta, including tributaries near oil sands and other developments; Clearwater River

Findings: Demographic and morphological data for 6 species of mid-trophic, sentinel fish are presented (length, weight, stage, sex, maturity, age, organ weights), as well as catch date (1999-2015) and location

Relevance: Historical demographic and morphological data for mid-trophic fish from the Athabasca (impacted) and Clearwater (reference) Rivers

Features: Searchable database with raw fish data from 1999-2015

RAMP. 2016. "Fish tissue program data". Regional Aquatics Monitoring Program. http://www.ramp-alberta.org/data/Fisheries/Tissue/default.aspx

Purpose/scope: "Fish tissue is analyzed for chemicals in order to assess the suitability for human consumption and the implications for fish health. Fish tissue monitoring is conducted on the Athabasca and Clearwater rivers as well as on several regional lakes throughout the RAMP focus study area." This monitoring has been ongoing since 1998.

Author Information: Regional Aquatics Monitoring Program, in collaboration with Alberta Sustainable Resource Development

Location: Athabasca and Clearwater Rivers, and several lakes within the oil sands region

Findings: Tissue data for various fish species analysed (6 species total), including data on mercury concentrations, external and internal pathologies, organ characteristics, and other demographic and morphological data. Different species are sampled each year and at different locations, providing some temporal and spatial representation of fish condition within the region.

Relevance: Indicates the health status of economically and ecologically important fish species, which can be used as both a reference for future monitoring and as an indication of which species may be appropriate as indicators.

Features: Extensive database of raw fish tissue data for several species from 1998-2014

RL & L/EMA Slave River Joint Venture. 1985. *Fall fish spawning habitat survey 1983-1985. Final report*. Edmonton, Alberta: Prepared for the Slave River Hydro Study Group, Slave River Hydro Study Pre-Investment Phase

Sanderson, J. (Peddle), C. Lafontaine, and K. Robertson. 1998. *Slave River environmental quality monitoring program: summary report*. Yellowknife, NWT: Water Resources Division, Indian and Northern Affairs Canada and Department of Resources, Wildlife and Economic Development, Government of the Northwest Territories. Available at: http://www.enr.gov.nt.ca/sites/enr/files/slave_river_environmental_quality_monitoring_program_-_report_summary_1998.pdf

Purpose/scope: The Slave River Environmental Quality Monitoring Program (SREQMP) was a five-year multimedia sampling program operating from 1990 to 1995, to characterize

baseline conditions of the aquatic ecosystem in the Slave River at Fort Smith, NWT, Canada. This report provides a summary of the Slave River Environmental Quality Monitoring Program Final Five Year Report (Sanderson et al., 1997).

Author Information: Authors are from the Water Resources Division of Indian and Northern Affairs Canada and the Department of Resources, Wildlife and Economic Development of the Government of NWT.

Location: The Slave River at Fort Smith, NWT

Findings: Same as the full SREQMP report.

Relevance: A higher-level summary of the precedent ecosystem-scale monitoring that has preciously occurred.

Features: A more condensed version of the full SREQMP report (Sanderson et al., 1997).

Sanderson, J. (Peddle), C. Lafontaine, and K. Robertson. 1997. *Slave River Environmental Quality Monitoring Program: Final five year study report, 1990-1995*. Yellowknife, NWT: Indian and Northern Affairs Canada, Water Resources Division, and Government of the Northwest Territories, Department of Resources, Wildlife and Economic Development

Purpose/scope: "The Slave River Environmental Quality Monitoring Program (SREQMP) was a five year multimedia sampling program operating from- 1990 to 1995, to characterize baseline conditions of the aquatic ecosystem in the Slave River at Fort Smith, Northwest Territories (NWT), Canada. The comprehensive nature of the program made it the first of its kind in the Northwest Territories."

Author Information: Authors are from the Water Resources Division of Indian and Northern Affairs Canada and the Department of Resources, Wildlife and Economic Development of the Government of NWT.

Location: The Slave River at Fort Smith, NWT

Findings: Sampling included water, suspended sediment and fish. The focus was contaminants. Fish were analyzed for tissue contaminant levels and enzyme activity biomarkers (hepatic MFO enzyme activity). "In general, the results of the study indicate that many parameters are at extremely low levels or were not detected even with state of the art analytical techniques. Of those compounds which were found, metals and PAHs are most likely from natural sources, while the presence of pesticides and PCBs indicates atmospheric transport. The detection of chlorinated phenolics, dioxins and furans, although at low levels, could be a result of downstream transport. While some findings may warrant further study, overall the levels of contaminants measured in the aquatic environment at Fort Smith are not likely to cause adverse effects."

Relevance: Provides a precedent water, sediment, and fish quality monitoring program, including field and analytical methods, to guide the development of subsequent multimedia monitoring programs.

Features: "This detailed report provides the study design, detailed field methods, complete documentation of analytical methods, and analysis of results, in order to document the vast background information associated with the study."

Schwalb, A.N., A.C. Alexander, A.J. Paul, K. Cottenie, and J.B. Rasmussen. 2015. Changes in migratory fish communities and their health, hydrology, and water chemistry in rivers of the Athabasca oil sands region: A review of historical and current data. *Environmental Reviews* 23 (2): 133–50. DOI: 10.1139/er-2014-0065

Purpose/scope: "We reviewed existing data to examine whether community composition and health of migratory fish (such as northern pike, walleye, and suckers) in the lower Athabasca region have changed over the past 40 years and whether these could be explained by changes in hydrology or water chemistry."

Author Information: Researchers from the University of Lethbridge, the Canada Centre for Inland Waters, Alberta Environment and Sustainable Resource Development, and the University of Guelph

Location: Athabasca oil sands region, specifically the Muskeg River watershed on the Lower Athabasca and the mainstem Athabasca and Clearwater Rivers

Findings: Existing data were analysed, including data from RAMP's fish fence program. Strong correlation were found between TSS and average daily discharge in 5 of the 7 rivers examined. Incidences of fin erosion in the lower Athabasca region were higher than reported for most studies at non-polluted sites. "Declines of 53%–100% in the abundance of three migratory fish species were detected in the Muskeg watershed (15% land change). Significant changes in fish health were detected. The largest decreases in body condition of fish in the region occurred in the late 1990s and coincided with elevated levels of fin erosion, the most frequently occurring external abnormality, and with extreme discharge conditions"

Relevance: Migratory fishes can be used as bioindicators over a large spatial scale, though they may be particularly sensitive to hydrological disruptions

Stapanian, M.A., C.P. Madenjian, P.A. Cott, R.R. Rediske, and J.P. O'Keefe. 2014. Polychlorinated biphenyl congener distributions in burbot: Evidence for a latitude effect. *Environmental Toxicology and Chemistry* 33 (11): 2448–54. DOI: 10.1002/etc.2703

Stewart, D.B. 1999. *A review of information on fish stocks and harvests in the South Slave area, Northwest Territories*. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2493. Winnipeg, Manitoba: Central and Arctic Region, Department of Fisheries and Oceans. Available at: http://www.dfo-mpo.gc.ca/Library/251225.pdf

Purpose/scope: "This document was prepared to assist the Department of Fisheries and Oceans (DFO) and the Renewable Resources Board(s), which may be appointed in the future, to co-manage fisheries in the South Slave area. It reviews information on stocks of fishes that are harvested for subsistence, commerce and sport in the area south and east of Great Slave Lake. The information is current to February 1998."

Author Information: Biological consultant, report prepared for the Department of Fisheries and Oceans Canada.

Location: South Slave Area of NWT (excluding Great Slave Lake)

Findings: Difficult to generalize from reviews of individual waterbodies, species and communities. Generally, "four main fishery management issues stand out in the South Slave area: 1) the potential for overharvesting by subsistence and sport fisheries, 2) potential for overharvesting of migratory stocks by the Great Slave Lake commercial fishery, 3) the potential for adverse impacts from hydroelectric and industrial developments in the region and upstream, and 4) the quality of fishery information on which to base resource management decisions [...] The existing knowledge of fisheries resources in the South Slave area is not sufficient to ensure effective long term fishery management."

Relevance: Indicates information gaps regarding sustainable fisheries management in this region. May help quantify the angling demand on fish populations, and determine the suitability of different species in different areas to serve as ecological indicators.

Features: Tabular summary of fish harvests and stocks from the South Slave Area, by community and waterbody

Tendler, B., E. Ohiozebau, A. Hill, G. Codling, J.P. Giesy, E. Kelly, P. Hodson, J. Short, and P. D. Jones. 2012. *Exposure of fish in the Athabasca and Slave rivers to metals potentially derived from oilsands operations*. Poster presented at Society of Environmental Toxicology and Chemistry (SETAC) North America 33rd Annual Meeting, Long Beach California. Available at: http://www.nwtwaterstewardship.ca/sites/default/files/Fish_Health_Study_-Metals-Oilsands_0.pdf

This poster summarizes the research performed by Tendler et al. (2012) under the same title.

Tripp, D.B., P.J. McCart, R.D. Saunders, and G.W. Hughes. 1981. *Fisheries studies in the Slave River Delta, NWT. Final report*. Calgary, Alberta: Aquatic Environments Limited

Purpose/scope: To obtain baseline information of the life histories of 23 fish populations in the Slave River delta through a two-year field study.

Author Information: Consultants. No other information provided.

Location: Slave River delta (fish and benthos); Slave River (fish)

Findings: Life fish history data includes habitat, invertebrate consumption, and water quality data. The researchers also documented fishing practices and use of fish.

Relevance: Data on the delta in the early 1980s

Features: Some data reported as means ± S.E.

Williams, T.G., W.L. Lockhart, D.A. Metner, and S. Harbicht. 1997. Baseline studies in the Slave River, NWT, 1990-1994: Part III. MFO enzyme activity in fish. *Science of the Total Environment* 197 (1–3): 87–109. DOI: 10.1016/S0048-9697(96)05421-6

Purpose/scope: Establish background levels of fish enzymes that are indicators of exposure to pollutants. This study is part of the Slave River Environmental Quality Monitoring Program.

Author Information: Scientists from University of Waterloo and federal departments of Fisheries and Environment.

Location: NWT portion of the Slave River. Sampling sites were Fort Smith, Leland Lake and Alexie Lake.

Findings: Hepatic (liver) mixed function oxygenase (MFO) analyses, as well as fish weight, length and age measurements were conducted. Some differences were found between enzyme activity levels in Slave River fish and enzyme activity levels in fish from background/reference sites. The main conclusion, however, is that the results indicate that the NWT portion of the Slave River is a relatively pristine environment.

Relevance: Baseline data for a potential indicator using fish liver enzyme activity for large-bodied fish (walleye, northern pike, lake whitefish, and burbot). Sampling also provided baseline data for a potential indicator on fish condition, including weight in relation to age, and hepatosomatic and gonadosomatic indices.

Features: Peer-reviewed journal paper with data reported as means ± S.E.

4.1.1 Supplementary Resources: Large Fishes

Evans, M.S., and D. Muir. 2006. Spatial and long-term trends in persistent organic contaminants and metals in lake trout and burbot in Great Slave Lake, NT. In *Synopsis of Research conducted under the 2005-2006 Northern Contaminants Program*, edited by S. Smith and J. Stow, 101–8. Ottawa: Indian and Northern Affairs, Northern Contaminants Program. Public Works and Government Services Canada

Evans, M., D. Muir, R.B. Brua, J. Keating, and X. Wang. 2013. Mercury trends in predatory fish in Great Slave Lake: The influence of temperature and other climate drivers. *Environmental Science & Technology* 47 (22): 12793–801. DOI: 10.1021/es402645x

Landrum, P. n.d. *Literature review of fish contamination in the Slave River and Great Slave Lake. Draft Report*

May be useful to use the relevant annotations that are present at the end of the report.

Lockhart, W.L., G.A. Stern, G. Low, M. Hendzel, G. Boila, P. Roach, M.S. Evans, et al. 2005. A history of total mercury in edible muscle of fish from lakes in northern Canada. *Science of the Total Environment* 351–352: 427–63. DOI: 10.1016/j.scitotenv.2004.11.027

Mill, T.A., P. Sparrow-Clark, and R.S. Brown. 1997. *Fish distribution, movement and gross external pathology information for the Peace, Athabasca and Slave river basins*. Report No. 147. Northern River Basins Study. Edmonton, Alberta: Northern River Basins Study. Available at: http://www.barbau.ca/sites/www.barbau.ca/files/0-662-24831-7.pdf

RL & L/EMA Slave River Joint Venture. 1985. *Fall fish spawning habitat survey 1983-1985. Final report*. Edmonton, Alberta: Prepared for the Slave River Hydro Study Group, Slave River Hydro Study Pre-Investment Phase

Note that only the executive summary and part of the introduction sections are included.

Stapanian, M.A., C.P. Madenjian, P.A. Cott, R.R. Rediske, and J.P. O'Keefe. 2014. Polychlorinated biphenyl congener distributions in burbot: Evidence for a latitude effect. *Environmental Toxicology and Chemistry* 33 (11): 2448–54. DOI: 10.1002/etc.2703

Tendler, B., E. Ohiozebau, A. Hill, G. Codling, J.P. Giesy, E. Kelly, P. Hodson, J. Short, and P. D. Jones. 2012. *Exposure of fish in the Athabasca and Slave rivers to metals potentially derived from oilsands operations*. Poster presented at Society of Environmental Toxicology and Chemistry (SETAC) North America 33rd Annual Meeting, Long Beach California. Available at: http://www.nwtwaterstewardship.ca/sites/default/files/Fish_Health_Study_-Metals-Oilsands_0.pdf

This poster summarizes the research performed by Tendler et al. (2012) under the same title.

4.2 Small Fish

Aboriginal Affairs and Northern Development Canada, and Department of Environment and Natural Resources GNWT. 2012. *Our water, our life: Building partnerships to assess the health of the Slave River and Slave River Delta. Summary report for the Community Workshop convened in Fort Smith, NWT on March 1 and 2, 2011*. Yellowknife, Northwest Territories: Aboriginal Affairs and Northern Development Canada and Department of Environment and Natural Resources, Government of the Northwest Territories. Available at: http://www.nwtwaterstewardship.ca/sites/default/files/Slave_River_March_2011_Workshop_Report_Final.pdf

Purpose/scope: Multi-party workshop discussing issues regarding upstream development; aquatic monitoring programs; identifying and evaluating potential indicators; and options for community-based monitoring in the Slave River and Delta

Author Information: Multi-party workshop including representatives from Aboriginal organizations, Elders, water treatment operators from several communities, AANDC, ENR, Environment Canada, Parks Canada, and the Aurora Research Institute.

Location: Fort Smith

Findings: Information on expectations of Aboriginal organizations and community members for aquatic health and monitoring. Identification of potential indicators. Data summaries in appendices on water quality and quantity in the Slave River Basin. Summary of upstream human activity and associated impacts.

Relevance: Identification of potential biological and physical indicators

Dagg, J. 2016. *Vulnerability assessment of the Slave River and Delta. Summary report for the community workshop convened in Fort Smith, January 24-26, 2012. Final report April 2016*. Final. Fort Smith: The Pembina Institute and Government of Northwest Territories. Available at:

http://www.nwtwaterstewardship.ca/sites/default/files/FINAL_April%2716_%20FINAL_SRDP_VulnerabilityAssessment.pdf

Purpose/scope: Fort Smith and Fort Resolution workshops to assess vulnerability of the Slave River and Delta ecosystem, and establish monitoring priorities.

Author Information: Local and traditional knowledge holders; Aboriginal governments representatives; western scientists; and government agencies

Location: Slave River and Delta

Findings: Monitoring priorities for six ecosystem components: hydrology and sediment load; water quality; fish and insect/benthic communities; wildlife; vegetation; air and climate. Identification of potential indicator species.

Relevance: Monitoring and research requirements

Features: Traditional knowledge, western science

Dagg, J. 2016. *State of the Knowledge of the Slave River and Slave River Delta. A component of the vulnerability assessment of the Slave River and Delta. Final report April 2016*. The Pembina Institute. Available at: http://www.nwtwaterstewardship.ca/sites/default/files/FINAL_APRIL%2716_FINAL_Slave River State of the Knowledge Report.pdf

Purpose/scope: Literature review of the aquatic and riparian ecosystem of the Slave River and Delta. Focus on hydrology and sediment; water quality; metals and contaminants in water; sediment and fish; fish and insect/benthic communities; terrestrial wildlife species; vegetation; and air and climate.

Author Information: Pembina Institute employee

Location: Slave River and Delta

Findings: Literature search found a large volume of information on hydrology and sediment load; water quality; metals and contaminants in water; sediments and fish; and muskrats. Moderate information about fish community, moose, beaver, and vegetation. Little information on benthic invertebrates and insects; mink; otter and aquatic birds; and air quality.

Relevance: Recent literature review for a portion of the study area

Features: Traditional knowledge and scientific knowledge

Evans, M.S., and D.C.G. Muir. 2016. Persistent organic contaminants in sediments and biota of Great Slave Lake, Canada: Slave River and long-range atmospheric source influences. *Journal of Great Lakes Research* 42: 233–47. DOI: 10.1016/j.jglr.2015.12.001

Purpose/scope: Evaluate legacy persistent organic and polynuclear aromatic hydrocarbons pollutants in the West Basin and East Arm of Great Slave Lake.

Author Information: Environment Canada researchers

Location: West Basin and East Arm of Great Slave Lake, Slave River

Findings: Contaminant concentrations in surface sediments were generally higher in the West Basin than East Arm reflecting Slave River influence. Lipid distribution in fish bodies influenced findings. Lake size, available habitat, and productivity contributing factor to concentrations in fish and invertebrates. Small fish had similar POP concentrations as invertebrates. Food web key to finding outcomes.

Relevance: Historical data from mid-1990s. Synthesis included influence of the Slave River in contaminant loading in the Great Slave Lake and POP concentrations in fish, invertebrates and sediment. Synthesis and discussion contains comparative findings with other northern lakes.

Features: Peer-reviewed journal paper with data reported as means ± S.E.

Golder Associates Ltd. 2004. *Review of historical fisheries information for tributaries of the Athabasca River in the oil sands region*. Submitted to: Regional Aquatic Monitoring Program (RAMP) Steering Committee

Purpose/scope: "The objectives of the historical data review for Athabasca River tributaries were: to construct a database containing fisheries information from past fisheries reports; to produce fish species distribution maps for the tributary watersheds; to synthesize the existing data and to provide an overview of fish communities and fish habitats in the tributary watersheds; to provide data for comparison with current and future RAMP monitoring data for trend analysis; and, to identify knowledge gaps and provide recommendations for future work to improve RAMP."

Author Information: Environmental consultants

Location: Tributary watersheds of the Athabasca River from just upstream of Fort McMurray northward to the confluence with the Firebag River

Findings: Fifty tributaries within the specified stretch of the Athabasca were identified but fisheries reports were available for only 32 of these (22 names, 10 unnamed watercourses). Historical fisheries reports from various sources were synthesized and summarized for each of these 32 tributary watersheds, with sections on watercourse location, water quality, habitat description, habitat use, and fish summary included where applicable. Data gaps are also identified.

Relevance: Historical data may be used as baselines for future assessments of aquatic ecosystems in this area.

Features: Detailed historic fisheries summaries for tributaries along the Athabasca River; distribution maps for 27 species of fish.

Little, A.S. 1997. *Food and habitat use within fish assemblages of the lower Slave River, Northwest Territories.* MSc Thesis. Available at: http://www.collectionscanada.gc.ca/obj/s4/f2/dsk2/ftp04/mq21185.pdf

Purpose/scope: Document spatial and temporal patterns of food and habitat use at three locations along the Slave River system to assess trophic and habitat relationships within the assemblages.

Author Information: Graduate student

Location: Slave River

Findings: Distinct habitat use due to differences in discharge and the amounts of vegetation. Finer-scaled differences also observed among individual species. Dietary overlap was also generally low.

Relevance: Status of fish species and habitat in 1997. Discussion of unique habitat requirements of fish.

Features: Peer-reviewed journal paper with data reported as means ± S.E.

Little, A.S., W.M. Tonn, R.F. Tallman, and J.D. Reist. 1998. Seasonal variation in diet and trophic relationships within the fish communities of the lower Slave River, Northwest Territories, Canada. *Environmental Biology of Fishes* 53 (4). Kluwer Academic Publishers: 429–45. DOI: 10.1023/A:1007433400648

Purpose/scope: To examine spatial and temporal patterns of diet for nine fish species from three different types of habitat along the lower Slave River.

Author Information: University, government and consulting researchers

Location: Slave River

Findings: All fish species exhibited seasonal variations in diet within and among the study areas. Dietary overlap was generally low throughout all seasons and locations. Benthic feeders exhibited moderate degrees of diet overlap during spring and summer. Few fish fed in the fall. Most fishes in the lower Slave River system are generalist, opportunistic feeders, consuming a number of different prey.

Relevance: Fish species and behaviour in the Slave River

Features: Peer-reviewed journal paper with data reported as means ± S.E.

McMaster, M.E., L.M. Hewitt, G. R. Tetreault, J.L. Parrott, G.J. Van Der Kraak, C.B. Portt, and N. Denslow. 2004. Detailed endocrine assessments in wild fish within the northern river basins. In *Northern Rivers Ecosystem Initiative: Collective Findings (CD-ROM)*, edited by Environment Canada. Compiled by F.M. Conly, Saskatoon, SK (With Alberta Environment)

Purpose/scope: Highly detailed report concerning endocrine levels in fish exposed to sewage and kraft pulp mill effluent. “Our objective was to compare endocrine function in fish with other measures of overall fish performance such as growth, energy storage and age structure.”

Author Information: Researchers from the National Water Research Institute (Environment Canada), University of Guelph, a consulting firm, and the University of Florida

Location: The mainstream of the Athabasca River near Whitecourt, AB, and the Wapiti-Smoky river systems near Grande Prairie, AB

Findings: "As these northern rivers are nutrient limited, fish responded to effluent addition (increased nutrients) by showing signs of increased growth and development relative to the upstream reference fish specifically at the Grande Prairie location. Evidence of eutrophication at the Whitecourt sites was not as evident, as the reference location was also nutrient saturated. Some signs of altered reproductive function were observed downstream of the mill sites, however additional responses were observed downstream of the municipal sewage treatment plants from the neighbouring communities. These responses were minimal compared to earlier studies at other older pulp and paper facilities."

Relevance: Multiple pulp mills and sources of sewage in these rivers may disrupt the normal functioning and reproductive capacity of fish downstream, such as in the Slave or Hay rivers.

Northern River Basins Study Board. 1996. *Northern River Basins Study report to the ministers*. Edmonton: Environment Canada and Alberta Environment. Available at: http://www.barbau.ca/content/northern-river-basins-study-project

Purpose/scope: Peace, Athabasca and Slave rivers SOE for fish, drinking water quality, and flow rate with greatest focus on Athabasca.

Author Information: Scientific work was completed by private companies, individuals, government agencies and educational institutions. The research was overseen by a seven-member Science Advisory Committee.

Location: Peace, Athabasca and Slave rivers

Findings: Summary of findings from 150 "mini" studies benchmarking key aspects of the SOE. In fish, dioxin and furans declined during the study, except in fish near pulp mills where levels of toxic dioxins, furans and mercury still exist. Levels of PCBs appeared to be within generally accepted consumption guidelines. Fish near pulp mills had lower sex hormones, tumours and growths. Drinking water quality was good for the majority of basin residents. 25% of the residents get water directly from water sources that should be treated for bacteria. Flow rate is being affected by upstream dams that have changed patterns in flow and ice patterns drying out Peace-Athabasca delta and affecting the growth rate of Slave River delta. Cumulative effects are summarized on a river reach by river reach basis.

Relevance: State of the environment conditions 1996. Implemented recommendations can be checked for effectiveness.

Features: Plain language report with peer reviewed data

RAMP. 2016. "Sentinel species program data". Regional Aquatics Monitoring Program. http://www.ramp-alberta.org/data/Fisheries/Sentinel/default.aspx

Purpose/scope: "Sentinel species monitoring evaluates the health of a representative fish species in the Athabasca River, and in smaller tributaries of the Athabasca River that have oil sands development. The approach compares characteristics such as growth, survival, body size, and reproduction of a sentinel species caught downstream of oil sands development to fish that reside upstream of the development, or to data collected prior to development."

Author Information: Regional Aquatics Monitoring Program

Location: Various reaches of the Athabasca River system in Alberta, including tributaries near oil sands and other developments; Clearwater River

Findings: Demographic and morphological data for 6 species of mid-trophic, sentinel fish are presented (length, weight, stage, sex, maturity, age, organ weights) as well as catch date (1999-2015) and location

Relevance: Historical demographic and morphological data for mid-trophic fish from the Athabasca (impacted) and Clearwater (reference) rivers

Features: Searchable database with raw fish data from 1999-2015.

Spafford, M.D. 1999. Trout-perch *Percopsis omiscomaycus* (Walbaum) and lake chub *Couesius plumbeus* (Agassiz) as sentinel monitoring species in the Athabasca River, Alberta. University of Alberta. University of Alberta

Purpose/scope: "Life histories and biology of two small-bodied fish, the trout-perch and the lake chub, were investigated to determine their suitability as sentinel species to monitor the effects of pulp mill effluents on ecosystem health."

Author Information: Graduate student

Location: Athabasca River, central Alberta

Findings: The study concluded that trout-perch are much better than lake chub as sentinel species for monitoring the health of aquatic ecosystems, based on low variance of key parameters and biomarkers (including liver somatic index and gonado-somatic index), and hence high potential to detect effects.

Relevance: Provides baseline information and rationale on these two species as potential indicators.

Features: Scanned document

Tetreault, G.R., M.E. McMaster, D.G. Dixon, and J.L. Parrott. 2003. Using reproductive endpoints in small forage fish species to evaluate the effects of Athabasca Oil Sands activities. *Environmental toxicology and chemistry* 22 (11): 2775–82. DOI: 10.1897/03-7

Purpose/scope: Evaluate the influence of naturally occurring oil sands-related compounds on reproductive function in fish.

Author Information: University researchers

Location: Athabasca basin, oil sands region

Findings: Species studied were slimy sculpin and pearl dace, collected from the Steepbank and Ells rivers. Parameters assessed included gonado-somatic index, fecundity and gonadal steroid production. Results showed elevated liver enzyme activity in fish exposed to naturally occurring compounds, and, to a greater degree, in fish exposed to development-related oil sands-related compounds.

Relevance: Provides baseline and two treatment levels for assessing bio-markers in small-bodied fish, in relation to oil sands development.

Tripp, D.B., P.J. McCart, R.D. Saunders, and G.W. Hughes. 1981. *Fisheries studies in the Slave River Delta, NWT. Final report*. Calgary, Alberta: Aquatic Environments Limited

Purpose/scope: To obtain baseline information of the life histories of 23 fish populations in the Slave River delta through a two-year field study.

Author Information: Consultants. No other information provided.

Location: Slave River delta (fish and benthos); Slave River (fish)

Findings: Life fish history data includes habitat, invertebrate consumption, and water quality data. The researchers also documented fishing practices and use of fish.

Relevance: Data on the delta in the early 1980s.

Features: Some data reported as means ± S.E.

Wallace, R.R., and P.J. McCart. 1984. *The fish and fisheries of the Athabasca River basin: Their status and environmental requirements*. Dominion Ecological Consulting Ltd. and Aquatic Environments Ltd. for Alberta Environment Planning Division. Available at: https://era.library.ualberta.ca/files/cc08hg78m/1984 - Wallace - Athabasca River Fish & Fisheries.pdf

Purpose/scope: Provide a review of state of knowledge on fish in the Athabasca River basin.

Author Information: Fisheries biologists (consultants); report prepared for government

Location: Entire Athabasca River basin

Findings: The report reviews current (1984) knowledge on fish ecology and production in the Athabasca Basin. It is management oriented, with discussion on fisheries and management objectives. Findings are presented by sub-basin.

Relevance: Baseline information on large- and small-bodied fish – on ecology, socio-economic significance and distribution

Features: The report was digitized by the Oil Sands Research and Information Network, University of Alberta.

4.3 Invertebrates

Aboriginal Affairs and Northern Development Canada, and Department of Environment and Natural Resources GNWT. 2012. *Our water, our life: Building partnerships to assess the health of the Slave River and Slave River Delta. Summary report for the Community Workshop convened in Fort Smith, NWT on March 1 and 2, 2011*. Yellowknife, Northwest Territories: Aboriginal Affairs and Northern Development Canada and Department of Environment and Natural Resources, Government of the Northwest Territories. Available at: http://www.nwtwaterstewardship.ca/sites/default/files/Slave River March 2011 Workshop Report Final.pdf

Purpose/scope: Multi-party workshop discussing issues regarding upstream development; aquatic monitoring programs; identifying and evaluating potential indicators; and options for community-based monitoring in the Slave River and Delta.

Author Information: Multi-party workshop including representatives from Aboriginal organizations, Elders, water treatment operators from several communities, AANDC, ENR, Environment Canada, Parks Canada, and the Aurora Research Institute.

Location: Fort Smith

Findings: Information on expectations of Aboriginal organizations and community members for aquatic health and monitoring. Identification of potential indicators. Appendices include a summary of upstream human activity and associated impacts and a list of potential ecosystem health indicators.

Relevance: Identification of potential biological and physical indicators

Barton, D.R., and R.R. Wallace. 1980. *Ecological studies of the aquatic invertebrates of the Alberta Oil Sands Research Program study area of northeastern Alberta*. Alberta Oil Sands Environmental Research Program. AOSERP Report 88. Edmonton, Alberta: Fisheries and Environment Canada Freshwater Institute. Available at: https://era.library.ualberta.ca/files/xw42n813d/AF 2.0.1 Apr 1980.pdf

Purpose/scope: Document baseline conditions of invertebrate fauna in the Athabasca River and its tributaries

Author Information: Government and university researchers

Location: Steepbank and Athabasca rivers

Findings: The study includes information on habitats in tributaries to the Athabasca River. Substrate conditions were also sampled for variations in conditions and the substrate was found to be influenced by direction and magnitude of river currents as discharge

fluctuates. Finally, the study tested responses of benthic communities to specific impacts, including oil spills and substrate alterations. Findings showed that benthic invertebrates are dependent upon the development of a microbial film on the surface of the stone and that this process is, to a large extent, light dependent.

Relevance: Baseline conditions in the early 1980s including invertebrates and substrate conditions. Conditions needed to recolonize substrate in diversion channels.

Features: Peer-reviewed research study with data reported as means ± S.E.

Boerger, H. 1983. *Distribution and abundance of macrobenthos in the Athabasca River near Fort McMurray.* Alberta Environment, Research Management Division. Available at: https://era.library.ualberta.ca/files/dv13zv41w/OF-53 Feb 1983.pdf

Purpose/scope: "During 1981, macrobenthos was collected at 16 stations along an 85 km stretch of the Athabasca River from just upstream of Fort McMurray to just downstream of the Ells River. The major objective was to determine if effluents from the Suncor tar sands operations have had a significant impact on the macrobenthos. A second objective was to determine seasonal variations in abundance and size of the macrobenthos. Such information will be useful in planning future monitoring studies."

Author Information: Researcher from the University of Calgary, report prepared for Alberta Environment

Location: 85-km stretch of the Athabasca River between Fort McMurray and the Ells River

Findings: In total, 348 samples were collected containing 27,229 specimens belonging to 68 taxonomic groups (53% of specimens were in *Chironomidae*). Average size and densities were highest in early June. "The density of invertebrates downstream from the Suncor Tar Sands Mining and Extraction Plant was 31% lower than at sites upstream from the plant. There were no site-specific differences with regard to number of taxa or Shannon-Weaver diversity. Abundance and composition of invertebrates upstream of the Suncor plant were influenced by the confluence of the Clearwater River and by the effluent from the Fort McMurray Sewage Treatment Plant."

Relevance: Baseline (early 80's) invertebrate community data can be compared to contemporary samples to determine whether changes over time have occurred on this stretch of the Athabasca.

Features: Appendix containing macroinvertebrate and fish density data for each of the sampling stations. Results from this work are also reported in Walder and Mayhood 1985.

Dagg, J. 2016. *State of the Knowledge of the Slave River and Slave River Delta. A component of the vulnerability assessment of the Slave River and Delta. Final report April 2016*. The Pembina Institute. Available at: http://www.nwtwaterstewardship.ca/sites/default/files/FINAL_APRIL%2716_FINAL_Slave River State of the Knowledge Report.pdf

Purpose/scope: Literature review of the aquatic and riparian ecosystem of the Slave River and Delta. Focus on hydrology and sediment, water quality, metals and contaminants in water, sediment and fish, fish and insect/benthic communities, terrestrial wildlife species, vegetation, and air and climate

Author Information: Pembina Institute employee

Location: Slave River and Delta

Findings: Literature search found large volume of information on hydrology and sediment load; water quality; metals and contaminants in water; sediments and fish; and muskrats. Moderate information was found about fish community, moose, beaver and vegetation. Little information on benthic invertebrates and insects, mink, otter, aquatic birds, and air quality.

Relevance: Recent literature review for a portion of the study area

Features: Traditional knowledge and scientific knowledge.

Dagg, J. 2016. *Vulnerability assessment of the Slave River and Delta. Summary report for the community workshop convened in Fort Smith, January 24-26, 2012. Final report April 2016*. Fort Smith: The Pembina Institute and Government of Northwest Territories. Available at: http://www.nwtwaterstewardship.ca/sites/default/files/FINAL_April%2716_%20FINAL_SRDP_VulnerabilityAssessment.pdf

Purpose/scope: Fort Smith and Fort Resolution workshops to assess vulnerability of the Slave River and Delta ecosystem, and establish monitoring priorities.

Author Information: Local and traditional knowledge holders; Aboriginal governments representatives; western scientists and government agencies

Location: Slave River and Delta

Findings: Monitoring priorities for six ecosystem components: hydrology and sediment load; water quality; fish and insect/benthic communities; wildlife; vegetation; air and climate. Identification of potential indicator species

Relevance: Monitoring and research requirements

Features: Traditional knowledge, western science

Evans, M.S., and D.C.G. Muir. 2016. Persistent organic contaminants in sediments and biota of Great Slave Lake, Canada: Slave River and long-range atmospheric source influences. *Journal of Great Lakes Research* 42: 233–47. DOI: 10.1016/j.jglr.2015.12.001

Purpose/scope: Evaluate legacy persistent organic and polynuclear aromatic hydrocarbons pollutants in the West Basin and East Arm of Great Slave Lake.

Author Information: Environment Canada researchers

Location: West Basin and East Arm of Great Slave Lake, Slave River

Findings: Contaminant concentrations in surface sediments were generally higher in the West Basin than East Arm reflecting Slave River influence. Lipid distribution in fish bodies influenced findings. Lake size, available habitat, and productivity are contributing factors to concentrations in fish and invertebrates. Small fish had similar POP concentrations as invertebrates. Food web key to finding outcomes.

Relevance: Historical data from mid-1990s. Synthesis included influence of the Slave River in contaminant loading in the Great Slave Lake and POP concentrations in fish, invertebrates, and sediment. Synthesis and discussion contains comparative findings with other northern lakes.

Features: Peer-reviewed journal paper with data reported as means ± S.E.

Golder Associates Ltd. 2003. *Review of historical benthic invertebrate data for rivers and streams in the oil sands region*. Submitted to: Regional Aquatic Monitoring Program (RAMP) Steering Committee

Purpose/scope: "The objective of this report is to provide an overview of the available historical benthic invertebrate data (up to and including the 2001 RAMP survey), with an emphasis on the Athabasca River, its major tributaries and small streams."

Author Information: Environmental consultants

Location: Athabasca River near the Oil Sands region, including the MacKay River, Muskeg River, Steepbank River, and small streams north and south of Fort McMurray

Findings: "This review provided an overview of historical benthic invertebrate data in the Oil Sands Region and described the benthic fauna of major rivers and small streams in the Oil Sands Region. The amount of potentially useful historical data is considerable, despite losses of the raw data collected by some of the early studies. Most of the historical data appear to be of acceptable quality and were collected using standard benthic sampling devices that are still widely used. The quantity and quality of supporting data (e.g., physical habitat data) varies by survey and compilation of a consistent supporting data set would require a large additional effort."

Relevance: Historical data may be used as baselines for future assessments of aquatic ecosystems in this area.

Features: Summary of the amount and type of historical benthic invertebrate data in the oil sands region by river and lake (1974-2001)

Johnson, P., E. Plate, D. Robichaud, and L. Renzetti. 2012. *Winter ecology in the Athabasca River: Mesohabitat species associations. Final Technical Report*. Report Prepared for CEMA Surface Water Working Group and Monitoring Technical Task Group. Sidney, British Columbia: LGL Limited

Purpose/scope: "A field study was carried out on the Lower Athabasca River to aid in assessing whether changes in relative abundance of five mesohabitats in winter due to water withdrawals would reduce aquatic ecological health in Segment 1 (delta) of the

Athabasca River. The primary management question addressed was to determine whether there are significant negative biological impacts associated with predicted changes in mesohabitats in the Athabasca River delta due to Phase 2 water withdrawals."

Author Information: Research scientists from LGL Limited (consulting firm), commissioned by CEMA

Location: Segment 2 of the Lower Athabasca River between 168 and 174 km north of Ft. McMurray

Findings: "A total of 151 individuals, representing 23 taxa were identified in the benthic macroinvertebrate samples. The majority of individuals (91%) and the greatest number of genera (14) were members of the Chironomidae family of insects. [...] In general, mesohabitats characterized with slow velocity displayed the greatest number and variety of taxa. Macroinvertebrate community abundance appeared to be strongly related to water velocity with observed abundance being an order of magnitude lower in the medium velocity mesohabitat types but data were insufficient to statistically test these relationships. No fish were caught by angling or trapping methods, and video data processing yielded no images of fish. Overall, gillnet catches were low, with 10 fish caught in 22 sets. [...] Analysis of the gill net data indicated that the data were too sparse to infer habitat association relationships. [...] Occupancy analyses showed that the probability of an area being occupied by small fish varied among mesohabitats and depths, but not between velocity categories. No habitat differences in occupancy could be detected for medium-sized or large fish. Results should be viewed as preliminary at this stage and more data are required to further analyze the observed patterns."

Relevance: Indicates which sampling methods may be effective or not for characterizing aquatic indicators (i.e., fish and macroinvertebrates) in northern streams

Features: Raw environmental (streamflow and chemistry) and fish occupancy data from 2012

Johnson, P., E. Plate, D. Robichaud, L. Renzetti, R. Bocking, and M. Gaboury. 2013. *Winter ecology in the Athabasca River 2012-2013 : Mesohabitat species Associations. Final draft technical report*. Report Prepared for CEMA Water Working Group and Surface Water Technical Group. Sidney, British Columbia: LGL Limited. Available at: http://library.cemaonline.ca/ckan/dataset/a014e3c2-8a16-4c0e-923e-90e254b96969/resource/2e4650c7-07b3-457e-88e9-6f84411f4b2a/download/winterecologyintheathabascariver20122013.pdf

Purpose/scope: "A field study was carried out on the Lower Athabasca River to aid in assessing whether changes in relative abundance of five mesohabitats in winter due to water withdrawals would reduce aquatic ecological health in the delta of the river. The primary management question addressed was to determine whether there are significant negative biological impacts associated with predicted changes in mesohabitats in the Athabasca River delta due to recommended water allocation limits." This report also covers the occupancy data from the 2012 report.

Author Information: Research scientists from LGL Limited (consulting firm), commissioned by CEMA

Location: Segment 2 of the Lower Athabasca River between approximately 162 and 186 km north of Ft. McMurray (immediately upstream of the delta)

Findings: "Environmental parameters, invertebrates and fish were sampled along 24 transects in 2012 and 60 transects in 2013. Invertebrate and fish associations were assessed across five mesohabitat types as defined by Paul and Locke (2009): deep, medium velocity; deep, slow velocity; moderate depth, medium velocity; moderate depth, slow velocity; and shallow, slow velocity. [...] Results from the fish and benthic habitat association analyses suggest that among physical habitat parameters velocity has a strong effect on habitat use whereas depth is less certain. However, differences in detection probability for small fish using the DIDSON among habitat types could potentially explain observed patterns in CPUE. Regardless, our results suggest decreased availability of mesohabitats with high velocities (>0.3 m/s) during winter would not result in decreased benthic invertebrate diversity or density, or reduced fish density."

Relevance: Indicates that the likelihood of observing fish or invertebrates varies according to mesohabitat type, implying that monitoring programs using these taxa must account for habitat preferences in sampling design if the indicators are to be reliable.

Features: Raw environmental (streamflow and chemistry) and fish occupancy data from 2013

Liu, Q. 2016. *Diversity of wetland non-biting midges (Diptera: Chironomidae) and their responses to environmental factors in Alberta*. MSc Thesis. University of Alberta, Department of Biological Sciences. Available at: https://era.library.ualberta.ca/files/cbr86b3584

A thesis on chironomid diversity in Alberta wetlands and value to biological monitoring. Not specific to the project area.

Lutz, A., and M. Hendzel. 1976. *Survey of baseline levels of contaminants in aquatic biota of the AOSERP study area*. Project AF 2.1.1. Alberta Oil Sands Environmental Research Program Aquatic Fauna Sector. Winnipeg, Manitoba: Fisheries and the Environment Canada Freshwater Institute. Available at: https://era.library.ualberta.ca/files/m613mx66b/AF 2.1.1June 1977.pdf

Purpose/scope: "To determine background levels of contaminants in aquatic fauna, water and sediments [in the oil sands region]" Specifically, "1. determine background levels of contaminants in fish, water, sediments, and invertebrates; 2. define the relationship between level of contaminant and size of fish; 3. identify natural sources of contamination; 4. provide baseline biological information on a number of potential sites for further experimental work."

Author Information: Researchers from the Freshwater Institute (Fisheries and Oceans Canada, and Environment Canada), for the Alberta Oil Sands Environmental Research Program

Location: AOSERP study area: Athabasca River from the Clearwater River to confluence with Slave River

Findings: No evidence found for metal accumulation up the food chain (based on invertebrate data). All metal concentrations in water were within accepted values (except Fe and Mn, but these exceedances were related to aesthetic objectives). Freshwater plankton appear to accumulate metals. No natural source of contamination in water was identified.

Relevance: Baseline metal concentration data from mid-1970's.

Features: Metal concentrations in water, sediment, fish, invertebrates and plankton a (means +/- SD).

McCarthy, L.H., K. Robertson, R.H. Hesslein, and T.G. Williams. 1997. Baseline studies in the Slave River, NWT, 1990-1994: Part IV. Evaluation of benthic invertebrate populations and stable isotope analyses. *Science of the Total Environment* 197 (1–3): 111–25. DOI: 10.1016/S0048-9697(96)05422-8

Purpose/scope: A five-year monitoring program was established to evaluate suspended sediment and water quality, fish health, and benthic invertebrates in the territorial portion of the Slave River. As part of the monitoring program, this report focuses on a benthic invertebrate survey and stable isotope fish diet analysis.

Author Information: Researchers from the Canada Centre for Inland Waters, Dept. of Renewable Resources GNWT, Department of Fisheries and Oceans Canada, and the University of Waterloo.

Location: The portion of the Slave River within NWT (Fort Smith downstream to the confluence of the Slave and Salt Rivers).

Findings: "The majority of benthic invertebrates occurred at very low levels in the Slave River and organisms that had previously been used in biomonitoring studies (e.g. bivalve molluscs, large oligochaetes) were rare or absent. Over 90% of the invertebrates collected from the Slave River were chironomids or small oligochaetes and comparisons of benthic invertebrate communities in the Slave River Delta indicated that few changes in percent composition or diversity had occurred over a 10-year period. At least two significant food sources are indicated by the stable isotope of sulphur. One source is probably from Great Slave Lake, while the other is probably upstream of Fort Smith (Athabasca and Peace Rivers). Also, the stable isotope of carbon indicates that the food source is via different pathways and may include benthic as well as pelagic origins."

Relevance: The benthic invertebrate survey provides a baseline for future population analysis, specific to the NWT portion of the Slave River; indicates that both Great Slave Lake, and the Athabasca and Peace Rivers are influential for fish diets, so changes to those waterbodies may incite a trophic cascade involving fish.

Features: S, C, N stable isotope and morphological data for walleye, goldeye, northern pike, lake whitefish, longnose suckers, and burbot. See Peddle et al. (1997) for an extensive historical perspective, detailed overview of the entire monitoring program, and all data results.

Namayandeh, A., and J.M. Culp. 2016. Chironomidae larvae from the lower Athabasca River, AB, Canada and its tributaries including macroscopic subfamily and tribe keys, indices for

environmental tolerance and trait-based information for biomonitoring. *Journal of Entomological and Acarological Research* 48 (2): 201–32. DOI: 10.4081/jear.2016.6075

Purpose/scope: To develop a simple taxonomic key for Chironomidae larvae that can be used by non-specialists and specialists for biomonitoring programs.

Author Information: Government and university researcher

Location: Invertebrates, Athabasca River

Findings: A key for identifying Chironomidae larvae based on morphology and habitat.

Relevance: A revised key for identifying Chironomidae larvae.

Paterson, M., M. Lawrence, and A. Sekerak. 1990. *Benthic invertebrates and biomonitoring in the Slave River, N.W.T.: A pilot survey*. Winnipeg and Yellowknife: North/South Consultants Inc. and Applied Environmental Services

Purpose/scope: The objectives were to: 1) provide a baseline description of benthic habitats and associated invertebrate communities; 2) compare results with previous invertebrate collections made in the Slave River delta; and 3) assess the suitability of benthic invertebrates as biomonitors of ecosystem health in the Slave River.

Author Information: Environmental consultants

Location: Slave River, Slave River delta, Salt River

Findings: A total of 53 sites representing a variety of habitats were sampled in the Slave and Salt rivers. A total of 69 benthic taxa were identified in samples from the Slave and Salt rivers. The benthic community was dominated by chironomid larvae (midges) and oligochaetes (aquatic worms). The majority of taxa were rare and only 10 occurred at 10 or more sites. Chironomids were identified as possible biomonitoring indicators; however, chironomids are difficult to classify and samples may make population level analysis inappropriate. Note that the results of this study are reported in McCarthy et al. 1997.

Relevance: Pros and cons of chironomids as bio-indicators

Features: Data reported as means ± S.E.

Paterson, M., M. Lawrence, and A. Sekerak. 1991. *Benthic invertebrates and biomonitoring in the Slave River, N.W.T.: 1991*. Winnipeg and Yellowknife: North/South Consultants Inc. and Applied Environmental Services

RAMP. 2016. "Benthic invertebrate communities data availability report". Regional Aquatics Monitoring Program. http://www.ramp-alberta.org/data/Benthic/OutputBenthicDataAvailability.aspx. Consulted on 16 March 2017

Purpose/scope: “The objectives of the RAMP Benthic Invertebrate component are to: 1. collected baseline data to characterize the natural variability of benthic invertebrate communities in the oil sands region; 2. monitor benthic invertebrate communities to identify any changes potentially linked to oil sands development, as well as cumulative

effects and regional trends; and 3. collect data against which predictions documented in EIAs can be assessed." This dataset contains historical (1998-2015) invertebrate inventory data.

Author Information: Regional Aquatics Monitoring Program

Location: Athabasca and Clearwater Rivers, and several lakes within the oil sands region

Findings: Abundance data for 142 taxa of invertebrates are presented, sorted by taxonomy, location, and sampling method

Relevance: Historical abundance data for benthic invertebrates from the Athabasca (impacted) and Clearwater (reference) rivers

Features: Searchable database with raw invertebrate data from 1998-2015

Rosenberg, D.M. 1992. Freshwater biomonitoring and Chironomidae. *Netherlands Journal of Aquatic Ecology* 26 (2–4): 101–22. DOI: 10.1007/BF02255231

A review paper, not related to the study area.

Tripp, D.B., P.J. McCart, R.D. Saunders, and G.W. Hughes. 1981. *Fisheries studies in the Slave River Delta, NWT. Final report*. Calgary, Alberta: Aquatic Environments Limited

Purpose/scope: To obtain baseline information of the life histories of 23 fish populations in the Slave River delta through a two-year field study.

Author Information: Consultants. No other information provided.

Location: Slave River delta (fish and benthos); Slave River (fish)

Findings: Life fish history data includes habitat, invertebrate consumption, and water quality data. The researchers also documented fishing practices and use of fish.

Relevance: Data on the delta in the early 1980s

Features: Some data reported as means ± S.E.

Walder, G.L., and D.W. Mayhood. 1985. *An analysis of benthic invertebrate and water quality monitoring data from the Athabasca River*. RMD Report: L-91. Edmonton, Alberta: Prepared for Alberta Environment, Research Management Division by Sigma Biometrics and FWR Freshwater Research Limited. Available at: https://era.library.ualberta.ca/files/4q77fr76d/RMD_L-91_Walder_Benthic_Invertebrate_1985.pdf

Purpose/scope: This report presents a detailed statistical analysis of water quality and benthic invertebrate data from previous studies on the Athabasca River.

Author Information: Consultants preparing report for the Alberta Government (Sigma Biometrics and FWR Freshwater Research Ltd., commissioned by the Research Management Division of Alberta Environment.)

Location: Athabasca Oil Sands Area, AB

Findings: Most major ions were correlated with each other and filterable residue; potassium concentrations were independent of other ion concentrations; all metals except lead and mercury associated with non-filterable residue and total phosphate. Marked differences in water quality and benthic invertebrates between left and right shores of the Athabasca River, possibly due to influences of Clearwater River and other tributaries. Benthic invertebrate communities were analyzed but results are non-conclusive due to non-random sampling design. If measuring both water quality and benthic invertebrates for a study, it is recommended to sample water some period of time (e.g., one year) prior to invertebrate sampling, rather than at the same time, for maximum ecological relevance.

Relevance: Historical data from 1980s comparing water quality and invertebrate communities up- and downstream of oil sands plants

Features: Many principal component analysis ordination plots representing water quality and invertebrate community patterns among Athabasca River study sites

4.3.1 Supplementary Resources: Invertebrates

Liu, Q. 2016. *Diversity of wetland non-biting midges (Diptera: Chironomidae) and their responses to environmental factors in Alberta*. MSc Thesis. University of Alberta, Department of Biological Sciences. Available at: https://era.library.ualberta.ca/files/cbr86b3584

A thesis on chironomid diversity in Alberta wetlands and value to biological monitoring. Not specific to the project area.

Paterson, M., M. Lawrence, and A. Sekerak. 1991. *Benthic invertebrates and biomonitoring in the Slave River, N.W.T.: 1991*. Winnipeg and Yellowknife: North/South Consultants Inc. and Applied Environmental Services

Rosenberg, D.M. 1992. Freshwater biomonitoring and Chironomidae. *Netherlands Journal of Aquatic Ecology* 26 (2–4): 101–22. DOI: 10.1007/BF02255231

A review paper, not related to the study area.

4.4 Aquatic Mammals

Aboriginal Affairs and Northern Development Canada, and Department of Environment and Natural Resources GNWT. 2012. *Our water, our life: Building partnerships to assess the health of the Slave River and Slave River Delta. Summary report for the Community Workshop convened in Fort Smith, NWT on March 1 and 2, 2011*. Yellowknife, Northwest Territories: Aboriginal Affairs and Northern Development Canada and Department of Environment and Natural Resources, Government of the Northwest Territories. Available at: http://www.nwtwaterstewardship.ca/sites/default/files/Slave River March 2011 Workshop Report Final.pdf

Purpose/scope: Multi-party workshop discussing issues regarding upstream development; aquatic monitoring programs; identifying and evaluating potential indicators; and options for community-based monitoring in the Slave River and Delta.

Author Information: Multi-party workshop including representatives from Aboriginal organizations, Elders, water treatment operators from several communities, AANDC, ENR, Environment Canada, Parks Canada, and the Aurora Research Institute.

Location: Fort Smith

Findings: Information on expectations of Aboriginal organizations and community members for aquatic health and monitoring. Identification of potential indicators. Data summaries in Appendices on water quality and quantity in the Slave River Basin. Summary of upstream human activity and associated impacts.

Relevance: Identification of potential biological and physical indicators

Addison, E.M., G.A. Fox, and M. Gilbertson, ed. 1991. *Proceedings of the expert consultation meeting on mink and otter, Windsor Ontario March 5 and 6, 1991*. Windsor, Ontario: International Joint Commission: United States and Canada. Available at: http://www.ijc.org/files/publications/E19.pdf

Purpose/scope: Roundtable on mink and river otter reporting on, among other things, the usefulness of mink and otter as biological indicators of ecosystem health particularly in shoreline wetlands and to assess the usefulness of mink and otter as reliable indicators of improvement in the water quality.

Author Information: Scientists, researchers, government

Location: Great Lakes

Findings: Before mink and otter could be used as an indicator more information would be needed about populations, diet, habitat, etc.

Relevance: Provides an indication of the data that needs to be collected to allow mink and otter to serve as ecosystem quality indicators.

Features: Peer reviewed papers

Basu, N., A.M. Scheuhammer, S.J. Bursian, J. Elliott, K. Rouvinen-Watt, and H.M. Chan. 2007. Mink as a sentinel species in environmental health. *Environmental Research* 103 (1): 130–44. DOI: 10.1016/j.envres.2006.04.005

Purpose/scope: “Here we discuss the use of mink (Mustela vison) as a sentinel organism by reviewing the pertinent literature from exposure- and effects-based studies. The review focuses on mercury (Hg) and polychlorinated biphenyls (PCBs)…”

Author Information: Government and university research scientists

Findings: This review paper addresses the characteristics of mink that make this animal a good indicator species: widely distributed, abundant, fish-eating (and thus accumulate contaminants in fish), sensitive to toxic effects with known quantitative dose-effect relationships. References NWT studies (Poole et al. 1998) and BC (Elliott et al. 2004), but no studies in Alberta.

Relevance: Relevant to indicator selection for semi-aquatic mammals and contaminants measures

Boutin, S. Birkenholz, D.E. 1987. Boutin and Birkenholz 1987 muskrat furbearer chapter.pdf. In *Wild furbearer management and conservation in North America*, 315–25

Carmichael, D. 2014. Surveyors see increase in delta muskrat pushups. *Northern Journal*, 28July. Available at: https://norj.ca/2014/07/surveyors-see-increase-in-delta-muskrat-pushups/

The Peace-Athabasca Delta Ecological Monitoring Program (PADEMP) monitoring programs have few publications relating to their activities, so we have included this newspaper article about the muskrat monitoring.

Cott, P., S. Goodman, and R. Gregory. 2016. Concentrations of mercury and other heavy metals in furbearers from the Slave River. *NWT Environmental Research Bulletin (NERB)* 1 (3): 2. DOI: http://www.enr.gov.nt.ca/sites/enr/files/128-cimp_bulletin_v1i3-proof.pdf

Purpose/scope: This study considered carcasses of muskrat, snowshoe hare, mink, and beaver collected by trappers in the Slave River Delta. Muscle tissues were tested for mercury, cadmium, arsenic, lead, and chromium. Stomach contents were also examined for heavy metals.

Author Information: Government employees

Location: Fort Fitzgerald and Slave River Delta

Findings: Heavy metals were very low in the muscle of mink, beaver, snowshoe hare, and muskrat. 2013 average mercury concentrations in the livers of mink and snowshoe hare had decreased studies conducted in the early 1990s. Cadmium was highest in beaver and snowshoe hare. Arsenic highest in muskrats. Higher lead concentrations are found in beaver and muskrat. Chromium concentrations were low and relatively consistent among furbearers.

Relevance: This Bulletin provides information on heavy metal analysis completed in 2013. Peer-reviewed papers are referenced in the summary.

Features: The Research Bulletin relied on peer reviewed information, and new data.

Cott, P., S. Goodman, and N. Mair. 2016. *Muskrat pushup abundance along the Slave River*. *NWT Environmental Research Bulletin (NERB)*. Vol. 1. Available at: https://www.enr.gov.nt.ca/sites/enr/files/muskrat_pushup.pdf

Purpose/scope: “This project was designed to address community concerns about declining muskrat populations in the watershed. Establishing a baseline for muskrat pushup [mud and vegetation shelter] densities will contribute towards developing repeatable and standardized survey methods that can assist in monitoring cumulative environmental change over time.”

Author Information: Individuals from the Government of NWT's Cumulative Impact Monitoring Program. Project is an initiative led by the Slave River and Delta Partnership.

Location: Slave River, from just north of Fort Chipewyan to Great Slave Lake

Findings: Based on aerial surveys, pushup densities and abundances were both greatest in the Slave River Delta. Higher densities were found (and expected) in areas with more wetland habitats, such as the east side of the River.

Relevance: "This survey provides a baseline of information [about muskrat pushup densities] that can be compared to future surveys, and enables environmental change to be tracked over time."

Features: Plain language summary; raw density data

Dagg, J. 2016. *State of the Knowledge of the Slave River and Slave River Delta. A component of the vulnerability assessment of the Slave River and Delta. Final report April 2016*. The Pembina Institute. Available at: http://www.nwtwaterstewardship.ca/sites/default/files/FINAL_April%2716_%20FINAL_SRDP_VulnerabilityAssessment.pdf

Purpose/scope: Literature review of the aquatic and riparian ecosystem of the Slave River and Delta. Focus on hydrology and sediment; water quality; metals and contaminants in water; sediment and fish; fish and insect/benthic communities; terrestrial wildlife species; vegetation; and air and climate.

Author Information: Pembina Institute employee

Location: Slave River and Delta

Findings: Literature search found large volume of information on hydrology and sediment load; water quality; metals and contaminants in water; sediments and fish; and muskrats. Moderate information about fish community, moose, beaver and vegetation. Little information on benthic invertebrates and insects; mink; otter; aquatic birds; and air quality.

Relevance: Recent literature review for a portion of the study area

Features: Traditional knowledge and scientific knowledge

Dagg, J. 2016. *Vulnerability assessment of the Slave River and Delta. Summary report for the community workshop convened in Fort Smith, January 24-26, 2012. Final report April 2016*. Final. Fort Smith: The Pembina Institute and Government of Northwest Territories. Available at: https://www.nwtwaterstewardship.ca/sites/default/files/FINAL_April%2716_%20FINAL_SRDP_VulnerabilityAssessment.pdf

Purpose/scope: Fort Smith and Fort Resolution workshops to assess vulnerability of the Slave River and Delta ecosystem, and establish monitoring priorities.

Author Information: Local and traditional knowledge holders; Aboriginal governments representatives; western scientists, and government agencies

Location: Slave River and Delta

Findings: Monitoring priorities for six ecosystem components: hydrology and sediment load; water quality; fish and insect/benthic communities; wildlife; vegetation; air and climate. Identification of potential indicator species.

Relevance: Monitoring and research requirements

Features: Traditional knowledge, western science

ENR, ed. 2013. 2013 summary. In *2013 Annual report of wildlife research in the NWT*. Environment and Natural Resources, Government of the Northwest Territories

Environmental Management Associates. 1984. *Beaver and muskrat investigations - Fall 1983*. Calgary, Alberta: Prepared for the Slave River Hydro Study Group

Did not acquire a copy of this report and were not able to find more information on it.

Geddes, F.E. 1981. *Productivity and habitat selection of muskrats in the Slave River Delta*. Edmonton, Alberta: Mackenzie River Basin Task Force, Northwest Territories Wildlife Service

Purpose/scope: The study, part of the Mackenzie River Basin Study, was initiated in 1978 to gather baseline data on muskrat habitat selection and productivity in the Slave River Delta.

Author Information: Contractor preparing report for the Northwest Territories Wildlife Service

Location: Slave River delta

Findings: The report is on a study started in 1978. Three annual aerial surveys, along with ground-truthing, were conducted to record distribution and abundance of muskrat houses and pushups. Water levels, and snow and ice thickness were also monitored to help understand the relationships with muskrat ecology. Conclusions: suitable habitat for muskrat houses is mainly in the bays in the outer delta, and the few lakes or perched basins; water levels, and snow and ice conditions are important influences.

Relevance: Baseline information on muskrats and information pertinent for using muskrat as a climate-change related indicator as it looks at relationships of muskrat ecology and water discharge and climate variables.

Features: This is a scanned report from the Indian and Northern Affairs library in Yellowknife. Presents only total counts per year, not details of methods.

Gilbert, F.F. 1979. *Interim report on semi-aquatic mammal studies 1977-1978*. Project TF 3.1. Alberta Oil Sands Environmental Research Program. Guelph, Ontario: Department of Zoology, University of Guelph. Available at: https://era.library.ualberta.ca/files/5138jg26f

This is an interim report - we have annotated the final report (Gilbert 1982). Semi-aquatic mammal census in the oil sands.

Gilbert, F.F., and E.G. Nancekivell. 1982. Food habits of mink (Mustela vison) and otter (Lutra canadensis) in northeastern Alberta. *Canadian Journal of Zoology* 60 (6): 1282–88. DOI: 10.1139/z82-172

Purpose/scope: Determine food habits of mink and otter in contrasting habitat types (one lake-dominated and one stream-dominated) in a region of the Athabasca basin with potential for future impacts from oil sands.

Author Information: Researchers from the University of Guelph

Location: Athabasca river basin, oil sands region: Muskeg, Dover and Snipe river basins

Findings: Fish (mainly brook stickleback) was most frequently eaten by mink in the lake-dominated study area and by otter in both study areas. The mink diet was more based on mammals (hares) in the stream-dominated basin. Otter scats contained more fish and invertebrates and fewer mammals and birds than mink scats.

Relevance: This baseline data on what foods are eaten by these two species provides information for selecting indicators and for interpreting measurements of contaminants or bio-indicators.

Features: Peer-reviewed journal article with full data – prey species occurrence in scats

Hood, G., C. Bromley, and N.T. Kur. 2009. *A review of existing models and potential effects of water withdrawals on semi-aquatic mammals in the Lower Athabasca River*. Camrose, Alberta: University of Alberta, Augustana Campus, Department of Science. Report prepared for Cumulative Environmental Management Association, Surface Water Working Group. Available at: http://library.cemaonline.ca/ckan/dataset/c3a76e19-71de-4381-ab91-67456749de6d/resource/2707d011-9f32-4299-a929-e20d51ea8a38/download/cemareporthoodfinalreportdec2009.pdf

Purpose/scope: Review the scientific and unpublished literature to determine the potential effects of varying river flows on habitat for semi-aquatic mammals and applicability for future model development. The study included interviews with trappers, elders, and other local experts.

Author Information: University of Alberta researchers

Location: Lower Athabasca River

Findings: Beavers and muskrat were the main species of focus, but the study also looked at mink and otter. The literature review is comprehensive, including historical reports, review of key ecology and population information on all species; and review of the extensive body of information on the effects of flow regulation on muskrat and beaver in the Peace-Athabasca Delta.

“Both in the literature and during the interviews it became apparent that all four species were highly dependent on adequate water supplies, particularly during the winter months

when they are most vulnerable. Once under the ice for the winter, any increase or decrease in water levels could result in the direct mortality of beavers and muskrats. A significant decrease in summer flows can directly influence foraging resources and increase the risk of predation. The loss of wetland habitat in the Peace-Athabasca Delta (PAD) following the establishment of the Bennett Dam provided important insights into the role that periodic flooding plays in the viability of these species (particularly muskrats). During the interviews, many participants also mentioned the decreasing water levels within the Athabasca River and its associated water bodies. Perched basins and neighbouring tributaries and wetlands play a critical role in the persistence of beavers and muskrats. Although both species can live in larger rivers, they survive best in areas with more predictable water levels. Several elders and active trappers spoke to the increased dependence of all these species on the main rivers as the perched basins and adjacent habitats dry out."

Relevance: This report is a very useful resource for indicator development for semi-aquatic mammals in relation to flow variation and habitat change from river regulation and from climate change.

Features: Appendix A contains the interview results from 14 interviews in the form of questions and grouped responses. Appendix B contains the data listings from previous studies (beaver and muskrat survey results from the 1970s to the 2000s, in the oil sands region). The report has an associated database of all current and historical aerial photographs from Fort McMurray downstream to the Delta.

Kennedy, D., B. Boucher, B. Elkin, and Aboriginal Wildlife Harvesters Committee (Fort Resolution). 1999. Metals and organic contaminants in Beaver and Muskrat in the Slave River delta area, NWT. In *Synopsis of research conducted under the 1998/1999 Northern Contaminants Program*, edited by S. Kalhok. Ottawa: Indian Affairs and Northern Development

No electronic copy are available.

PADEMP. n.d. "Muskrat monitoring". *Peace-Athabasca Delta Ecological Monitoring Program*. http://www.pademp.com/research-and-monitoring/muskrat-monitoring/

Purpose/scope: "To determine: 1) the trend in relative abundance of muskrats within the Peace-Athabasca Delta over time; 2) whether there is a difference in muskrat abundance between basins receiving water from the Athabasca and Birch Rivers; 3) whether there is a difference in water quality between productive and unproductive basins; and 4) how long it takes for muskrats to re-establish after average to above-average snowfall years, or after flood events."

Author Information: Project lead is an ecologist from Parks Canada (Wood Buffalo National Park (WBNP))

Location: Basins within the Birch and Athabasca Deltas (including WBNP and Athabasca Chipewyan First Nation Reserve lands)

Findings: "The first survey occurred in February of 2012. Surveys will be conducted annually. Muskrat push-ups and houses are counted and measured within 15 basins. At each basin, habitat measurements (snow depth, ice thickness, water depth, physical water

quality parameters) are recorded and water quality samples taken". No data or findings are presented at this URL.

Relevance: Study results may provide a good baseline for muskrat habitat quality within the Peace-Athabasca Delta; however, no associated reports or summaries were presented.

Peterson, E.K., and B.A. Schulte. 2016. Impacts of pollutants on beavers and otters with implications for ecosystem ramifications. *Journal of Contemporary Water Research & Education* 157 (1): 33–45. DOI: 10.1111/j.1936-704X.2016.03212.x

Purpose/scope: "To review published evidence on the toxicological impacts of pollutants in beavers and river otters and discuss the implications of exposure to their behavioural systems, conservation, and surrounding ecosystems."

Author Information: University researchers

Location: No specified location, but the North American Beaver and River Otter (species found in the Slave River) are discussed in detail.

Findings: Both beavers and otters are ecologically important aquatic mammals, serving as ecosystem engineers and keystone species, respectively. Together, they may have value as indicators of potential toxin threats to humans. Populations may be affected when exposed to lethal or even sub-lethal contaminant concentrations, which may have additional consequences for aquatic communities and ecosystems.

Relevance: Beavers and otters may have value as indicators of aquatic contamination in the Slave River, as trophic cascades may result when ecosystem engineers (beavers) or keystone species (otters) are affected by water pollution.

Features: Detailed review paper, covering natural history, historical conservation, exposure to anthropogenic pollutants, and potential behavioural and ecological ramifications.

Poole, K.G., B.T. Elkin, and R.W. Bethke. 1998. Organochlorine and heavy metal contaminants in wild mink in western Northwest Territories, Canada. *Archives of Environmental Contamination and Toxicology* 34 (4): 406–13. DOI: 10.1007/s002449900337

Purpose/scope: Determine tissue levels of metals and organochlorines in mink in NWT, using that species as an indicator of ecosystem health (final report).

Author Information: Government of the Northwest Territories biologists

Location: NWT, including Slave River Basin

Findings: This paper reports on a four-year study (with sampling occurring in winters from 1991-1995). Interim results were reported in Poole et al. 1995. "All groups of organochlorines were detected in mink livers at relatively low levels…. There was a general trend of decreasing organochlorine burdens along a northerly or westerly gradient for some groups of compounds, primarily DDT, PCB, chlordane and dieldrin. Toxic equivalents (TEQs) of mink liver tissue were low…. Levels of heavy metal burdens in liver

and kidney tissues were found to be relatively low, with the exception of Hg, which was found at moderate levels. There was no obvious geographic trend to the pattern of heavy metal burdens. The available evidence suggests that long-range atmospheric transport is the main source of the organochlorine contaminants observed. Local conditions (geology, water and soil chemistry, diet, etc.) may determine heavy metal burdens. Levels of contaminants in NWT mink appear to be one to two orders of magnitude lower than levels observed to cause reproductive impairment, reduced survival of kits, or lethality in adult mink."

Relevance: The samples are based on mink submitted by trappers, and one of the collection locations is Fort Smith. The data are relevant as baseline data for mink as an indicator species. This paper includes a review of mink as an indicator species (accumulating contaminants through both aquatic and terrestrial food webs).

Features: Peer-reviewed paper. Data presented for each sampling location as means with standard errors. Organochlorine data are presented as sums of congeners.

Poole, K.G., B.T. Elkin, and R.W. Bethke. 1995. Environmental contaminants in wild mink in the Northwest Territories, Canada. *Science of The Total Environment* 160–161 (January): 473–86. DOI: 10.1016/0048-9697(95)04381-A

Reid, D.G., T.E. Code, A.C.H. Reid, and S.M. Herrero. 1994. Spacing, movements, and habitat selection of the river otter in boreal Alberta. *Canadian Journal of Zoology* 72 (7): 1314–24. DOI: 10.1139/z94-175

Purpose/scope: Examination of spacing, home ranges and movements of river otters in boreal Alberta

Author Information: University researchers (University of British Columbia)

Location: Winefred Lake, Athabasca River

Findings: The findings are pertinent to otter ecology, especially factors affecting habitat selection and relationship to winter ice.

Relevance: May provide insight into potential for otters as indicators related to climate change.

Features: Journal paper with summarized data, on size of home ranges and habitat preferences.

Searing, G.F. 1979. *Distribution, abundance and habitat associations of beavers, muskrats, mink and river otters in the AOSERP study area, Northeastern Alberta*. Alberta Oil Sands Environmental Research Program. Project LS 23.2. LGL Limited

Purpose/scope: Literature review of information on habitat preferences of beavers, muskrat, mink and otter, augmented with field studies, primarily on beaver lodge and muskrat house locations within the oil sands region.

Author Information: Consultant reporting to the Alberta Oil Sands Environmental Research Program

Location: oil sands region, Athabasca River

Findings: The literature review covers ecology of beaver, muskrat, mink, river otter, Field program: "Beavers avoided locating their lodges in jack pine and black spruce-tamarack habitats. Tracks of mink were found to occur in greater numbers in willow and aspen vegetation types than would be expected by the availability of these habitats. Habitat preferences of muskrats and river otters could not be determined because too few data were collected on these species." Field studies did not include the Peace-Athabasca Delta.

Relevance: May provide useful background information for selection of indicators, as well as some information on density and distribution of aquatic mammals.

Features: The report includes data appendices and location data for surveys.

Slave River Delta Partnership. 2016. *Results from 2013 Slave River Furbearer Study. Slave River Partnership Meeting, Fort Smith, NWT January 2016*. Fort Smith, NWT: Northwest Territories Department of Environment and Natural Resources

Purpose/scope: Addresses community concern about the health of the Slave River watershed ecosystem, specifically furbearers.

Author Information: Names of contributors are listed, but not affiliations. Includes government scientists and community experts.

Location: Slave River watershed

Findings: (1) study of muskrats: Aerial survey in 2013 found that muskrat push-up densities were highest in the Slave River Delta (60% of all observed); (2) Study on concentrations of heavy metals in mink, muskrat, hare and beaver (muscle tissue analyzed for mercury, cadmium, arsenic, lead, and chromium) concluded that concentrations are very low. Mercury in livers of mink and hare were lower than in samples from the 1990s.

Relevance: The study establishes baseline densities and repeatable survey methods for muskrat push-up counts in the Alberta and NWT portions of the Slave River. The metals study provides 2013 data and comparison with 1990s data, which can be repeated for indicator species.

Features: Maps included that show sampling locations (and survey blocks and pathways for aerial surveys). Push-up count full results included. Contaminants data are presented graphically as means and standard errors.

4.4.1 Supplementary Resources: Aquatic Mammals

Carmichael, D. 2014. Surveyors see increase in delta muskrat pushups. *Northern Journal*, 28July. Available at: https://norj.ca/2014/07/surveyors-see-increase-in-delta-muskrat-pushups/

The PADEMP monitoring programs have few publications relating to their activities, so we have included this newspaper article about the muskrat monitoring.

ENR, ed. 2013. 2013 summary. In *2013 Annual report of wildlife research in the NWT*. Environment and Natural Resources, Government of the Northwest Territories

Environmental Management Associates. 1984. *Beaver and muskrat investigations - Fall 1983*. Calgary, Alberta: Prepared for the Slave River Hydro Study Group

We do not have a copy of this report and are not able to find more information on it.

Gilbert, F.F. 1979. *Interim report on semi-aquatic mammal studies 1977-1978*. Project TF 3.1. Alberta Oil Sands Environmental Research Program. Guelph, Ontario: Department of Zoology, University of Guelph. Available at: https://era.library.ualberta.ca/files/5138jq26f

This is an interim report - we have annotated the final report (Gilbert 1982). Semi-aquatic mammal census in the oil sands.

Poole, K.G., B.T. Elkin, and R.W. Bethke. 1995. Environmental contaminants in wild mink in the Northwest Territories, Canada. *Science of The Total Environment* 160–161 (January): 473–86. DOI: 10.1016/0048-9697(95)04381-A

Whitson, A. 2012. Lack of muskrat push-ups causing alarm. *Northern Journal*, 28February.

4.5 Waterbirds

Butterworth, E., A. Leach, M. Gendron, B. Pollard, G.R. Stewart, and Ducks Unlimited Canada. 2004. Peace-Athabasca Delta waterbird inventory program: 1998-2001 Final report. Ducks Unlimited Canada. September 2002. In *Northern Rivers Ecosystem Initiative: Collective Findings (CD-ROM)*, edited by Environment Canada. Compiled by F.M. Conly, Saskatoon, SK (With Alberta Environment).

Purpose/scope: To document Ducks Unlimited Canada's (DUC) waterfowl monitoring efforts from 1998-2001 and to explore the possible effect of basin flooding (due to a flood from an ice jam in 1996-1997) on waterfowl breeding pair abundance.

Author Information: Ducks Unlimited Canada

Location: Peace-Athabasca Delta, AB

Findings: "While the response of waterbirds to the flood of 1996/1997 and subsequent decline in water levels (as indicated by the number of dry basins) support the hypothesis that flood events are crucial to waterfowl use of the delta, the PAD continues to host substantial numbers of moulting and staging waterbirds from all four North American migratory flyways, exceeding numbers reported from other reputable staging areas."

Relevance: Natural climatic cycles affecting waterbodies (e.g., flooding events) can considerably affect estimates of aquatic biota population sizes, and this variability should be considered when monitoring affected species. Dewatering of the PAD due to climate or other anthropogenic factors may be detrimental to waterfowl and other aquatic life (e.g., muskrats, fish).

Features: Data indicating waterfowl breeding pair numbers for 20+ species within the PAD from 1998-2001.

Canada and Alberta. 2016. "Wild bird health and contaminants". *Canada-Alberta Oil Sands Environmental Monitoring Portal*.

This reference links to the data in multiple spreadsheets. There are the data from Hebert et al. (2011) and Hebert et al. (2013).

Church, M. 2013. "Slave River pelican population has “good” year". Northern Journal. https://norj.ca/2013/11/slave-river-pelican-population-has-good-year/. Consulted on 10 July 2017

Purpose/scope: Long-term monitoring of pelican nests and fledglings at their nesting site near Fort Smith

Author Information: Northern Journal report on the program and 2013 results

Location: Nesting grounds are located on several islands on the Slave River near the Mountain Portage peninsula, southeast of Fort Smith.

Findings: Arial photographs from 2,000 feet above nesting grounds. Adults, chicks, and nests are counted and survival rate is estimated. This 2013 article reports on the recovery of numbers, with increases since 1974 when recording began.

Relevance: Ongoing citizen science monitoring program on Slave River

Features: Short journal article

Hebert, C.E., D. Campbell, R. Kindopp, S. Macmillan, P. Martin, E. Neugebauer, L. Patterson, and J. Shatford. 2013. Mercury trends in colonial waterbird eggs downstream of the oil sands region of Alberta, Canada. *Environmental Science and Technology* 47 (20): 11785–92. DOI: 10.1021/es402542w

Purpose/scope: To determine potential mercury (Hg) accumulation in tern and gull eggs indicating potential dietary contamination from oil sands activities and recent forest fires.

Author Information: Researchers from Parks Canada and Environment Canada

Location: Peace-Athabasca Delta and Lake Athabasca, also one site near Calgary

Findings: For two gull species at the northern sites, statistically significant increases in Hg over time occurred, and Hg increased non-significantly for two species of terns. Stable isotope analysis indicated that bird dietary change was not responsible for these trends, nor were egg Hg trends related to recent forest fires. Conversely, Hg concentrations significantly decreased at the southern Alberta site suggest the importance of local Hg sources in regulating regional Hg trends.

Relevance: Indicates for populations downstream of the oil sands region that waterbird eggs appear to accumulate Hg over time and should be continually monitored.

Features: Annual mean delta-15-N values (+/- SD) isotope data from gull and tern eggs; mean concentrations of dioxins and furans in eggs before/after 2011 wildfire.

Hebert, C.E., D.V.C. Weseloh, S. Macmillan, D. Campbell, and W. Nordstrom. 2011. Metals and polycyclic aromatic hydrocarbons in colonial waterbird eggs from Lake Athabasca and the

Peace-Athabasca Delta, Canada. *Environmental Toxicology and Chemistry* 30 (5): 1178–83. DOI: 10.1002/etc.489

Purpose/scope: This study investigates how contaminant levels (i.e., metals, polycyclic aromatic hydrocarbons (PACs)) in eggs collected in the oil sands region might be affected by and reflect the location of collection.

Author Information: Scientists from Environment Canada, Parks Canada, and Alberta Parks

Location: Receiving waters of the Athabasca River (downstream of oil sands), Lake Athabasca, and the Peace River

Findings: "Egg Hg levels increased with delta-15-N values (a proxy of food web trophic position); however, some eggs exhibited Hg levels greater than expected based on trophic position. There eggs were from sites in receiving waters of the Athabasca River. Levels of Hg in egg pools were correlated with naphthalene levels..." Hg concentrations in California Gull eggs increased 40% from 1977-2009.

Relevance: Provides baseline data for contaminant levels in eggs of colonial waterbirds breeding in Northern Alberta, and emphasizes the need to include higher trophic level species in monitoring plans.

Features: Mean Hg, As, PAC concentration and delta-15-N isotope level data for waterbird eggs

4.5.1 Supplementary Resources: Waterbirds

Canada and Alberta. 2016. Wild bird health and contaminants. *Canada-Alberta Oil Sands Environmental Monitoring Portal*.

This reference links to the data in multiple spreadsheets. There are the data from Hebert et al. (2011) and Hebert et al. (2013).

PADEMP. n.d. Assessing impacts of oil sands development on fish-eating birds. Peace-Athabasca Delta Ecological Monitoring Program. http://www.pademp.com/research-and-monitoring/assessing-impacts-of-oil-sands-development-on-fish-eating-birds/.. Consulted on 15 March 2017

Detailed descriptions of this work can be found in Hebert et al. (2011) and Hebert et al. (2013).

4.6 Amphibians

Bayne, E., and T. Muhly. 2014. *EMCLA amphibian monitoring: Using wildlife acoutsics SM2 detector*. Environmental Monitoring Committee of the Lower Athabasca, Alberta Biodiversity Monitoring Institute. Available at: http://ftp.public.abmi.ca//home/publications/documents/74_Bayne_etal_2014_AmphibiansReport2012_ABMI.pdf

This report contains some preliminary data on distribution and habitat relationships, but it is primarily an assessment of a potential methodology for amphibian monitoring.

Conference of Management Authorities. 2017. *Management plan for amphibians in the Northwest Territories*. Species at Risk (NWT) Act Management Plan and Recovery Strategy Series. Yellowknife, Northwest Territories: Environment and Natural Resources, Government of the Northwest Territories. Available at: http://www.nwtspeciesatrisk.ca/sites/default/files/amphibian_management_plan_for_the_nwt_draft_for_public_review_july2016.pdf. ISBN: 9780770802509

Environment and Climate Change Canada. 2016. Amphibian health, toxicology, and contaminants. *Canada-Alberta Oil Sands Environmental Monitoring Portal*.

Purpose/scope: To make publicly available raw toxicology data collected 2011-2013 from wood frogs at oil sands-region aquatic habitats.

Author Information: Researchers from the federal government and from Keyano College (Fort McMurray)

Location: Athabasca Oil Sands region, near Fort McMurray, Fort Chipewyan, Fort Resolution and Fort Smith

Findings: The concentrations of 25 metals in the tissues of wood frog tadpoles, “recent metas” and adults are presented for samples collected 2011-2013. No summaries or analyses of the data are presented here.

Relevance: Provides a reference for metal accumulation in frogs up and downstream of major oil sands developments; permits data analyses.

Features: Raw toxicology dataset containing detected metal concentrations in wood frog tissues.

GNWT. 2016. *Management plan for amphibians in the Northwest Territories. Draft for public review*. Yellowknife, NT: Government of the Northwest Territories, Environment and Natural Resources. Available at: http://www.nwtspeciesatrisk.ca/sites/default/files/amphibian_management_plan_for_the_nwt_draft_for_public_review_july2016.pdf

Melvin, S.D., and V.L. Trudeau. 2012. Toxicity of Naphthenic Acids to Wood Frog Tadpoles (*Lithobates sylvaticus*). *Journal of Toxicology and Environmental Health, Part A* 75 (3). Taylor & Francis Group: 170–73. DOI: 10.1080/15287394.2012.640092

Northwest Territories Species at Risk Committee. 2013. *Species status report: Northern leopard frog (Lithobates pipiens) in the Northwest Territories*. Yellowknife, NT: Northwest Territories Species at Risk Committee. Available at: http://www.nwtspeciesatrisk.ca/sites/default/files/northern_leopard_frog_nwt_status_report_dec_2013_final2_0.pdf

PADEMP. n.d. "Health of amphibian populations". Peace-Athabasca Delta Ecological Monitoring Program. http://www.pademp.com/research-and-monitoring/health-of-amphibian-populations/ . Consulted on 15 March 2017

Pollet, I., and L.I. Bendell-Young. 2000. Amphibians as indicators of wetland quality in wetlands formed from oil sands effluent. *Environmental Toxicology and Chemistry* 19 (10): 2589. DOI: 10.1897/1551-5028(2000)019

Purpose/scope: Assess impacts of oil sands effluents on amphibians

Author Information: University researchers

Location: Oil sands region

Findings: This is a lab study testing growth and survival of tadpoles in waters from five wetlands in the oil sands area. "Amphibians such as Bufo boreas and Rana sylvatica were sensitive indicators of effluent quality. Based on the effluents used in this study, wetlands formed from oil sands effluent will not support viable amphibian populations." Specific impacts differed among species and populations and included reduced growth and survival rates.

Relevance: This study is process-affected waters, but may provide some guidance for assessing potential downstream impacts.

Features: N/A.

Schock, D.M. 2013. Health of amphibian populations as indictors of ecosystem health. In *2013 Annual report of wildlife research in the NWT*, edited by Environment and Natural Resources, 126–29. Northwest Territories, Environment and Natural Resources. Available at: https://www.enr.gov.nt.ca/sites/enr/files/2013_nwt_wildlife_research_permits_annual_report.pdf . ISBN: 9780770802141

Purpose/scope: Monitor wood frog health in relation to impacts from oil sands, with comparable methods to Alberta studies; concern is spread of PAHs (PACs) into ponds via snowmelt.

Author Information: Keyano College wildlife pathologist

Location: Sites near Hay River, Fort Smith and Fort Resolution

Findings: Unable to find results – this is a description of the work prior to it being undertaken. Dates for project are listed as June 28, 2012 to June 27, 2013.

Relevance: Potential indicator.

Features: Detailed summary of project plans only

Schock, D.M. 2009. *Amphibian population and pathogen surveys in the Dehcho and Sahtu, Northwest Territories, 2007 and 2008*. Manuscript Report 206. Yellowknife, Northwest Territories: Government of Northwest Territories, Department of Environment and Natural Resources. Available at: https://www.enr.gov.nt.ca/sites/enr/files/206_manuscript.pdf.

Though the report discusses western Dehcho, it may be of use to identify lack of studies done in the project area.

Shank, C., and A. Nixon. 2014. *Climate change vulnerability of Alberta's terrestrial biodiversity: A preliminary assessment*. Available at: http://www.natureserve.org/sites/default/files/shankandnixon_2014_climatechangevulnerabilityofalbertasterrestrialbiodiversity_abmi.pdf

Useful for indicator development. "Amphibians were consistently found to be the taxonomic group having the greatest vulnerability to climate change of the six taxonomic groups assessed. Amphibians are vulnerable to climate change largely as a result of anthropogenic barriers to dispersal, narrow thermal and hydrological niches, and dependence on specific moisture conditions."

Simpson, L., and L. Andrusiak. 2009. *Peace River Site C Hydro Project Stage 2: Baseline vegetation and wildlife report*. Keystone Wildlife Research Ltd., prepared for BC Hydro Site C Project 2008-2009. ISBN: 9780321606785

Contains information on amphibian surveys in the Peace River corridor.

The Nature Conservancy. 2013. *Amphibian and reptile sightings in the NWT*.

Purpose/scope: To depict the spatial distribution of 6 amphibian and 2 reptile species within NWT

Author Information: Nature Conservancy (non-profit group)

Location: All of NWT, plus Wood Buffalo NP in Alberta

Findings: N/A

Relevance: Indicates known (as of 2013) locations of amphibian and reptile species within NWT; baseline distribution map

Features: Map

4.6.1 Supplementary Resources: Amphibians

Bayne, E., and T. Muhly. 2014. *EMCLA amphibian monitoring: Using wildlife acoustics SM2 detector*. Environmental Monitoring Committee of the Lower Athabasca, Alberta Biodiversity Monitoring Institute. Available at: http://ftp.public.abmi.ca//home/publications/documents/74_Bayne_etal_2014_AmphibiansReport2012_ABMI.pdf

This report contains some preliminary data on distribution and habitat relationships, but it is primarily an assessment of a potential methodology for amphibian monitoring.

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GNWT. 2016. *Management plan for amphibians in the Northwest Territories. Draft for public review*. Yellowknife, NT: Government of the Northwest Territories, Environment and Natural Resources. Available at: http://www.nwtspeciesatrisk.ca/sites/default/files/amphibian_management_plan_for_the_nwt_draft_for_public_review_july2016.pdf

Melvin, S.D., and V.L. Trudeau. 2012. Toxicity of Naphthenic Acids to Wood Frog Tadpoles (*Lithobates sylvaticus*). *Journal of Toxicology and Environmental Health, Part A* 75 (3). Taylor & Francis Group: 170–73. DOI: 10.1080/15287394.2012.640092

Northwest Territories Species at Risk Committee. 2013. *Species status report: Northern leopard frog (Lithobates pipiens) in the Northwest Territories*. Yellowknife, NT: Northwest Territories Species at Risk Committee. Available at: http://www.nwtspeciesatrisk.ca/sites/default/files/northern_leopard_frog_nwt_status_report_dec_2013_final2_0.pdf

PADEMP. n.d. "Health of amphibian populations." Peace-Athabasca Delta Ecological Monitoring Program. http://www.pademp.com/research-and-monitoring/health-of-amphibian-populations/. Consulted on 15 March 2017

Shank, C., and A. Nixon. 2014. *Climate change vulnerability of Alberta's terrestrial biodiversity: A preliminary assessment*. Available at: http://www.natureserve.org/sites/default/files/shankandnixon_2014_climatechangevulnerabilityofalbertasterrestrialbiodiversity_abmi.pdf

Useful for indicator development. "Amphibians were consistently found to be the taxonomic group having the greatest vulnerability to climate change of the six taxonomic groups assessed. Amphibians are vulnerable to climate change largely as a result of anthropogenic barriers to dispersal, narrow thermal and hydrological niches, and dependence on specific moisture conditions."

Simpson, L., and L. Andrusiak. 2009. *Peace River Site C Hydro Project Stage 2: Baseline vegetation and wildlife report*. Keystone Wildlife Research Ltd., prepared for BC Hydro Site C Project 2008-2009. ISBN: 9780321606785

Contains information on amphibian surveys in the Peace River corridor.

4.7 Algae, Vegetation, Aquatic Ecosystems

Connor, S.J., D.J. Baird, J.F. Gibson, M. Hajibabaei, and S. Shokralla. 2015. Diversity patterns of benthic diatoms in wetlands of the Peace-Athabasca Delta, Alberta, Canada. Conference poster. In *9th Use of Algae for monitoring rivers and comparable habitats (UAMRIch) and international workshop on benthic algae taxonomy (InBAT)*. Trento, Italy

Purpose/scope: "The objective of this study is to observe diversity patterns of benthic and epiphytic diatoms in wetlands of the Peace-Athabasca Delta, and to determine their suitability for biomonitoring."

Author Information: Research scientists with Environment Canada

Location: Peace-Athabasca Delta, Dog River (Slave R. tributary)

Findings: Benthic diatoms were sampled by collecting the biofilm rom submerged stalks of macrophytes in wetlands. The preliminary data analysis is on diversity and temporal variation. Further work will compare with benthic invertebrate sampling.

Relevance: Potential information for indicator development

Features: This is a conference poster outlining the program and providing some preliminary results.

English, M.C., R.B. Hill, M. a. Stone, and R. Ormson. 1997. Geomorphological and botanical change on the Outer Slave River Delta, NWT, before and after impoundment of the Peace River. *Hydrological Processes* 11 (13): 1707–24. DOI: 10.1002/(SICI)1099-1085(19971030)11:13<1707::AID-HYP600>3.0.CO;2-O

Purpose/scope: Document changes in the outer Slave River Delta before and after impoundment of Peace River at Hudson's Hope, BC using aerial photographs

Author Information: University based researchers

Location: Slave River Delta, Peace River

Findings: Reduction in growth rate in cleavage bar islands from 1946 to 1994. The reduction between 1977 and1994 is thought to be a result of reduced sediment load after impoundment.

Relevance: State of the environment information

Features: References include muskrats and information on aquatic species

Kramer Anderson, N., and E.E. Wohl. 2013. *Driftcretions: A study of land growth from driftwood, Great Slave Lake, Canada*. Geological Society of America

Kramer, N., and E. Wohl. 2014. Estimating fluvial wood discharge using time-lapse photography with varying sampling intervals. *Earth Surface Processes and Landforms* 39 (6): 844–52. DOI: DOI: 10.1002/esp.3540

Peterson, G. 1998. *The distribution of vegetation in the perched basins of the Peace-Athabasca Delta*. MSc Thesis. Available at: http://www.collectionscanada.gc.ca/obj/s4/f2/dsk2/ftp04/mq28976.pdf

Purpose/scope: "This study was conducted to assess the general pattern of the distribution of vegetation in the perched basins of the Peace-Athabasca Delta."

Author Information: Thesis

Location: Peace-Athabasca Delta

Findings: A wet-to-dry gradient among vegetation species was evident, and water-related variables were highly correlated with the primary axes of variation. A secondary trend among species also existed that was mainly related to small-scale bison disturbance... "These results show that the distribution of vegetation in the perched basins is dependent on variables besides elevation and water table. Small and large-scale disturbance characteristics, pre-emption of resources, wave action, wind-driven seiches and longer-term water-related variables all may be important, but shift in importance from region to region within the PAD."

Relevance: If vegetation is used as indicators of ecosystem integrity, the region-specific environmental covariates must be understood to help select meaningful indicators. Section 1.2.4 discusses historical studies. Conclusion chapter talks about monitoring recommendations.

Features: Vegetation presence/absence and environmental covariate data from transects

Pietroniro, A., and J. Töyrä. 2004. Monitoring Delta Ecosystem Response to Water-Level Restoration. In *Northern Rivers Ecosystem Initiative: Collective Findings (CD-ROM)*, edited by Environment Canada. Compiled by F.M. Conly, Saskatoon, SK (With Alberta Environment)

Purpose/scope: "This paper attempts to present a geomatics based approach for monitoring the spatio-temporal [ecosystem] changes that occur within [the Peace-Athabasca Delta]."

Author Information: Researchers from the National Water Research Institute (Environment Canada)

Location: Peace-Athabasca Delta, AB

Findings: Various types of remotely sensed data and imagery were used to produce flood, flood duration, topography (Digital Elevation Model from LiDAR), and vegetation maps of the PAD with about 85% accuracy. Comparing these maps revealed that a relationship exists between vegetation patterns and both flood duration and topography. "Because of the usefulness of these spatial databases, it is recommended that flood maps and vegetation maps are generated annually to monitor the changes that occur in the delta.

Relevance: Natural flooding patterns (in space and through time) change the distribution and composition of ecological communities; selected indicators should be robust to this variability.

Features: Vegetation and flood duration maps of the PAD (circa early 2000s)

Sokal, M.A., R.I. Hall, and B.B. Wolfe. 2008. Relationships between hydrological and limnological conditions in lakes of the Slave River Delta (NWT, Canada) and quantification of their roles on sedimentary diatom assemblages. *Journal of Paleolimnology* 39 (4): 533–50. DOI: 10.1007/s10933-007-9128-8

Purpose/scope: "Water chemistry and surface sediments were analyzed from 41 shallow lakes representing three previously-defined hydrological categories in the Slave River Delta, Northwest Territories, Canada, in order to identify relationships between hydrological and limnological conditions and their associations with recently deposited diatom assemblages"

Author Information: University researchers

Location: Lakes in the Slave River Delta, NWT

Findings: "Evaporation-dominated lakes are associated with high relative abundance of common epiphytic diatom taxa, while diatoms indicative of flood- and exchange-dominated lakes span a wide range of habitat types (epiphytic, benthic) but also include unique planktonic diatoms (Stephanodiscus and Cyclostephanos taxa) that were not found in surface sediments of evaporation- dominated lakes. The planktonic diatom taxa originate from the Slave River, and thus are indicative of river influence."

Relevance: "Knowledge gained from this formative study is being used in biomonitoring and paleolimnological investigations of the Slave River Delta to further understanding of the complex interactions among hydrology, limnology, and aqua- tic ecology in this freshwater ecosystem."

Features: Hydrological, physical, chemical characteristics of lakes and rivers in the study area (means + SD) See also Sokal 2007 (thesis upon which this paper is based).

Sokal, M.A. 2007. *Assessment of hydroecological changes at the Slave River Delta, NWT, using diatoms in seasonal, inter-annual and paleolimnological experiments*. PhD Thesis. University of Waterloo, Department of Biology. Available at: https://uwspace.uwaterloo.ca/bitstream/handle/10012/3364/Michael A Sokal - PhD Thesis.pdf?sequence=1&isAllowed=y

Purpose/scope: To evaluate relationships between hydrology, limnology, and ecology of water bodies in the Slave River Delta (at a variety of spatial and temporal scales) using diatoms as indicators.

Author Information: PhD candidate from the University of Waterloo

Location: Lakes in the Slave River Delta, NWT

Findings: Specific diatom "indicator" taxa were identified for each of evaporation-, flood-, and exchange-dominated lakes. "Results indicate that river flooding is the dominant hydrological process controlling the temporal dynamics of limnological and ecological conditions in lakes of the Slave River Delta."

Relevance: Diatoms show strong potential for use as indicators of waterbody hydrological and limnological conditions, and may be especially useful in a paleolimnological context to establish baselines and understand past trajectories of lakes in this area.

Features: Diatom percent abundance data. The second chapter of this thesis forms the basis of the annotated journal paper Sokal et al. 2008.

Timoney, K. 2008. Rates of vegetation change in the Peace-Athabasca Delta. *Wetlands* 28 (2): 513–20. DOI: 10.1672/07-88.1

Purpose/scope: Landscape changes (between open water, marshes and meadows, shrub communities, and forest cover classes) were examined in the Peace-Athabasca Delta for the period 1945-2001.

Author Information: Researcher from independent environmental consulting company

Location: Peace-Athabasca Delta

Findings: Vegetation dynamics, particularly between wetlands and open water, and forest communities, are characteristic of the Delta. Succession from open water to marsh and marsh to willows were common, and oscillatory changes were common. At centennial scales, succession from open water to marsh to willow to forest communities are expected.

Relevance: Indicates that vegetation community change is typical in the PAD, and a change in community type may be part of a natural cycle rather than indicative of anthropogenic change.

Timoney, K. 2008. Factors influencing wetland plant communities during a flood-drawdown cycle in the Peace-Athabasca Delta, Northern Alberta, Canada. *Wetlands* 28 (2). Springer Netherlands: 450–63. DOI: 10.1672/07-45.1

Purpose/scope: "To examine the relationships between environmental and biological factors and wetland community changes over a flood-drawdown cycle," using existing vegetation and environmental data from the Peace-Athabasca Delta."

Author Information: Researcher from independent environmental consulting company

Location: Peace-Athabasca Delta

Findings: Multiple factors influenced vegetation variation, including water regime, bison grazing, and landscape attributes such as distance to the nearest major river, relative elevation, and geographic location within the PAD. Both physical and biological factors were influential, and these regimes were integrated with each other. Persisting hot and dry conditions in the PAD may favour the establishment dominance of weeds - "altered community composition may slow the recovery from natural and anthropogenic stresses and decrease the predictability of an already complex ecosystem"

Relevance: Provides a baseline (1993 and 2001) for vegetation community composition for the PAD, which may be useful for vegetation-based monitoring in this area.

Features: Cluster analysis and environmental/biological covariates for 25 vegetation community clusters

Timoney, K.P., and G. Argus. 2006. Willows, water regime, and recent cover change in the Peace–Athabasca Delta. *Ecoscience* 13 (3): 308–17. DOI: 10.2980/i1195-6860-13-3-308.1

Purpose/scope: This study examines the relationships between water level changes and willow cover in the Peace-Athabasca Delta (vegetation cover and its temporal response to flooding and drying were assessed for five common willow species in relation to water levels).

Author Information: An environmental consultant and a researcher emeritus from the Canadian Museum of Nature

Location: Peace-Athabasca Delta

Findings: "Willow cover declined over the period 1993-2001, but cover changes differed among species. Willow cover decreased the most on the wetter transects, while drier

transects increased in willow cover [...] Willow dieback was correlated with water depth, duration of flooding, and time since flooding. Large, old willows were more tolerant of flooding than small, young willows. A pulse of willow establishment occurred during the early 1980s that coincided with a drying period in the delta, increased regional wildfire activity, a decline in river discharge, and a decline in the level of Lake Athabasca. An increase in willow cover followed and reached a peak ca. 1993. Flooding in the mid- to late 1990s resulted in a decline in willow cover."

Relevance: Increased willow cover may result from delta-wide desiccation, leading to a change in the natural vegetation community baseline of the region.

Wiklund, J.A. 2012. *Lakes of the Peace-Athabasca Delta: Controls on nutrients, chemistry, phytoplankton, epiphyton and deposition of polycyclic aromatic compounds (PACs)*. PhD Thesis. University of Waterloo, Department of Biology. Available at: https://uwspace.uwaterloo.ca/bitstream/handle/10012/6543/Wiklund_Johan.pdf?sequence=1

Purpose/scope: "This thesis examines the effects of river flooding (and the lack of) on water clarity, nutrients, chemistry, phytoplankton abundance, epiphyton community composition and the deposition of polycyclic aromatic compounds (PACs) in lakes of the Peace-Athabasca Delta. "

Author Information: PhD candidate from the University of Waterloo

Location: Peace-Athabasca Delta

Findings: Three main experiments were performed, examining the role of flooding on contemporary epiphytic diatom communities, characterizing the hydrolimnological responses of PAD lakes to flooding, and determining the roles of the Athabasca River and atmospheric transport as vectors for the deposition of PACs in the PAD. "Overall, results of this research identify that river flooding exerts strong control on physical, chemical and biological conditions of lakes within the PAD [...] natural processes continue to dominate the delivery of water and contaminants to the delta. Regular and frequent flooding is not essential to maintain the supply of nutrients and the productivity of delta lakes..."

Relevance: Identifies sampling methods for periphyton suitable for aquatic biomonitoring; quantifies natural vs. industrial water, and nutrient and contaminant contributions to the PAD.

Features: Table containing chemical and physical characteristics of study lakes and rivers (individual in situ measurements over several years and seasons) This thesis contains chapters that will become scientific papers, specifically, Wiklund et al. 2010 (Journal of Paleolimnology), Wiklund et al. 2012 (Science of the Total Environment), Hall et al. 2012 (PLoS ONE). See these sources for further information on their respective topics.

Wolfe, B.B., R.I. Hall, T.W.D. Edwards, and J.W. Johnston. 2012. Developing temporal hydroecological perspectives to inform stewardship of a northern floodplain landscape subject to multiple stressors: paleolimnological investigations of the Peace– Athabasca Delta. *Environmental Reviews* 20: 191–210. DOI: 10.1139/A2012-008

4.7.1 Supplementary Resources: Algae, Vegetation, Aquatic Ecosystems

Kramer Anderson, N., and E.E. Wohl. 2013. *Driftcretions: A study of land growth from driftwood, Great Slave Lake, Canada*. Geological Society of America

Kramer, N., and E. Wohl. 2014. Estimating fluvial wood discharge using time-lapse photography with varying sampling intervals. *Earth Surface Processes and Landforms* 39 (6): 844–52. DOI: 10.1002/esp.3540

Prowse, T.D., and M. Conly. 1996. *Impacts of flow regulation on the aquatic ecosystem of the Peace and Slave rivers*. Synthesis Report No.1. Northern River Basin Study. Edmonton, Alberta: Northern River Basins Study. Available at: http://www.barbau.ca/sites/www.barbau.ca/files/0-662-24697-7-bw_0.pdf

Wolfe, B.B., R.I. Hall, T.W.D. Edwards, and J.W. Johnston. 2012. Developing temporal hydroecological perspectives to inform stewardship of a northern floodplain landscape subject to multiple stressors: paleolimnological investigations of the Peace– Athabasca Delta. *Environmental Reviews* 20: 191–210. DOI: 10.1139/A2012-008

4.8 Water Quality and Quantity, and Sediment

Abdul Aziz, O.I., and D.H. Burn. 2006. Trends and variability in the hydrological regime of the Mackenzie River Basin. *Journal of Hydrology* 319 (1–4): 282–94. DOI: 10.1016/j.jhydrol.2005.06.039

Purpose/scope: Hydrological trends and variability analysis for 19 stations along the Mackenzie River Basin from Edmonton to Inuvik

Author Information: Scientists in the Department of Civil Engineering, University of Waterloo

Location: Mackenzie River Basin

Findings: Winter month (i.e., December to April) flows showed strongly increasing trends. Slightly decreasing late spring and fall months. Earlier onset of spring freshet. Warming trend in winter and spring months. Patterns most pronounced for central and southern parts of basin.

Relevance: Recommendations for improved sampling and modelling

Features: Peer-reviewed journal article

Aboriginal Affairs and Northern Development Canada. 2012. *Report summary: Slave River*. Aboriginal Affairs and Northern Development Canada. Available at: https://www.aadnc-aandc.gc.ca/DAM/DAM-INTER-NWT/STAGING/texte-text/slaveRiverReport2012_1367957032853_eng.pdf. ISBN: 9781100215396

Purpose/scope: Long-term trends in water and sediment quality, and flow in the Slave River watershed. Report includes findings from over 200 water samples and 27 suspended sediment samples and analysis for over 500 different substances. Samples were compared to the Guidelines for Canadian Drinking Water Quality and Recreational Water Quality, and Canadian Council of Ministers of the Environment (CCME) Guidelines for the protection of freshwater aquatic life.

Author Information: Government employees from Water Resources Division of Aboriginal Affairs and Northern Development Canada

Location: Slave River watershed including NWT, Saskatchewan, Alberta, and British Columbia

Findings: Increasing trends in phosphorus, sulphate, and sodium. Cadmium, chromium, copper, iron, and lead were higher than the aquatic life guidelines more than 25% of the time. Other metals did not exceed the guidelines or exceedances were less than 25% of the time. 11 pesticides detected in water samples, all below guidelines. Naturally occurring dissolved solvent patterns may be altered by upstream dams.

Relevance: Limited. Water quality and quantity affect the suitability of aquatic ecosystems to support biota, and so may indirectly affect biological indicators. Report based on 35 years of water quality data.

Features: Government reviewed and prepared report

Aboriginal Affairs and Northern Development Canada. 2014. *The Hay River: Water monitoring activities in the Hay River region*. Aboriginal Affairs and Northern Development Canada. Available at: https://www.enr.gov.nt.ca/sites/enr/files/hay_river_report_2013.pdf. ISBN: 1800567960

Purpose/scope: Information handout on water quality and quantity, and information on water monitoring initiatives

Author Information: Aboriginal Affairs and Northern Development Canada

Location: Hay River

Findings: Water volume in the Hay River has remained relatively stable since monitoring began in 1963. Only a slight increasing trend in winter flow was revealed. Water quality changes have been found with increasing trends in phosphorus and decreasing trends in calcium, magnesium and sulphate. These levels have changed since sampling began in 1988. Hydrocarbons were also found in water and sediment samples.

Relevance: State of the environment information on water quality and quantity in the Hay River.

Aboriginal Affairs and Northern Development Canada. 2013. Water Quality and Quantity Monitoring Sites in the Northwest Territories. Available at: http://www.nwtwaterstewardship.ca/sites/default/files/WaterQualityAnnie8x11_4.pdf

Purpose/scope: A map depicting water quality and quantity monitoring sites in the NWT, broken down by the agency responsible for each monitoring effort

Author Information: Federal government

Location: NWT, especially the Mackenzie River Basin

Relevance: Provides a spatial representation of existing water quality/quantity monitoring initiatives in the NWT.

Features: Map

Aboriginal Affairs and Northern Development Canada, and Department of Environment and Natural Resources GNWT. 2012. *Our water, our life: Building partnerships to assess the health of the Slave River and Slave River Delta. Summary report for the Community Workshop convened in Fort Smith, NWT on March 1 and 2, 2011*. Yellowknife, Northwest Territories: Aboriginal Affairs and Northern Development Canada and Department of Environment and Natural Resources, Government of the Northwest Territories. Available at: http://www.nwtwaterstewardship.ca/sites/default/files/Slave River March 2011 Workshop Report Final.pdf

Purpose/scope: Multi-party workshop discussing issues regarding upstream development; aquatic monitoring programs; identifying and evaluating potential indicators, and options for community-based monitoring in the Slave River and Delta

Author Information: Multi-party workshop including representatives from Aboriginal organizations, Elders, water treatment operators from several communities, AANDC, ENR, Environment Canada, Parks Canada, and the Aurora Research Institute

Location: Fort Smith

Findings: Information on expectations of Aboriginal organizations and community members for aquatic health and monitoring. Identification of potential indicators. Data summaries in Appendices on water quality and quantity in the Slave River Basin. Summary of upstream human activity and associated impacts.

Relevance: Identification of potential biological and physical indicators

Beltaos, S. 2014. Comparing the impacts of regulation and climate on ice-jam flooding of the Peace-Athabasca Delta. *Cold Regions Science and Technology* 108: 49–58. DOI: 10.1016/j.coldregions.2014.08.006

Purpose/scope: Understanding implications / relative contribution of 1) water regulation and 2) climate change on ice-jam flooding of the Pease-Athabasca Delta.

Author Information: Canadian government research scientist and professional engineer

Location: Peace-Athabasca delta

Findings: Quantified relative impacts of regulation and climate change where regulation is dominant force contributing two-thirds to the reduction in ice-jam flooding frequency. Freezeup level is the “dominant resistance variable that influences ice-jam flood frequency”.

Relevance: Contributing factors to changes in the Slave River watershed

Features: Peer-reviewed paper

Bourbonniere, R.A., S.L. Telford, L.A. Ziolkowski, J. Lee, M.S. Evans, and P.A. Meyers. 1997. Biogeochemical marker profiles in cores of dated sediments from large North American lakes. In *Molecular markers in environmental geochemistry*, edited by R.P. Eganhouse, Symposium, 133–50. Washington, D.C.: American Chemical Society

Brock, B.E., M.E. Martin, C.L. Mongeon, M.A. Sokal, S.D. Wesche, D. Armitage, B.B. Wolfe, R.I. Hall, and T.W.D. Edwards. 2010. Flood frequency variability during the past 80 years in the Slave River Delta, NWT, as determined from multi-proxy paleolimnological analysis. *Canadian Water Resources Journal* 35 (3): 281–300. DOI: 10.4296/cwrj3503281

Brock, B.E., B.B. Wolfe, and T.W.D. Edwards. 2007. Characterizing the Hydrology of Shallow Floodplain Lakes in the Slave River Delta, NWT, Canada, Using Water Isotope Tracers. *Arctic, Antarctic, and Alpine Research* 39 (3). The Institute of Arctic and Alpine Research UCB 450, University of Colorado, Boulder, Colorado 80309-0450, U.S.A: 388–401. DOI: 10.1657/1523-0430(06-026)[BROCK]2.0.CO;2

Dagg, J. 2016. *State of the Knowledge of the Slave River and Slave River Delta. A component of the vulnerability assessment of the Slave River and Delta. Final report April 2016*. The Pembina Institute. Available at: http://www.nwtwaterstewardship.ca/sites/default/files/FINAL_APRIL%2716_FINAL_Slave River State of the Knowledge Report.pdf

Purpose/scope: Literature review of the aquatic and riparian ecosystem of the Slave River and Delta. Focused on hydrology and sediment; water quality; metals and contaminants in water; sediment and fish; fish and insect/benthic communities; terrestrial wildlife species; vegetation; and air and climate

Author Information: Pembina Institute employee

Location: Slave River and Delta

Findings: Literature search found large volume of information on hydrology and sediment load; water quality; metals and contaminants in water; sediments and fish; and muskrats. Moderate information about fish community, moose, beaver, and vegetation. Little information on benthic invertebrates and insects, mink, otter and aquatic birds, and air quality.

Relevance: Recent literature review for a portion of the study area

Features: Traditional knowledge and scientific knowledge

Dagg, J. 2016. *Vulnerability assessment of the Slave River and Delta. Summary report for the community workshop convened in Fort Smith, January 24-26, 2012. Final report April 2016*. Final. Fort Smith: The Pembina Institute and Government of Northwest Territories. Available at: https://www.nwtwaterstewardship.ca/sites/default/files/FINAL_April%2716_%20FINAL_SRDP_VulnerabilityAssessment.pdf

Purpose/scope: Fort Smith and Fort Resolution workshops to assess vulnerability of the Slave River and Delta ecosystem, and establish monitoring priorities.

Author Information: Local and traditional knowledge holders; Aboriginal governments representatives; western scientists and government agencies

Location: Slave River and Delta

Findings: Monitoring priorities for six ecosystem components: hydrology and sediment load; water quality; fish and insect/benthic communities; wildlife, vegetation; and air and climate. Identification of potential indicator species.

Relevance: Monitoring and research requirements

Features: Traditional knowledge, western science

Dubé, M.G., and J.E. Wilson. 2013. Accumulated state assessment of the Peace-Athabasca-Slave River system. *Integrated environmental assessment and management* 9 (3): 405–25. DOI: 10.1002/ieam.1354

Purpose/scope: Effects-based water quality and quantity cumulative effects assessment

Author Information: University researchers

Location: Peace-Athabasca-Slave

Findings: This study assessed seasonal changes in 1) Peace River water quality and quantity before and after dam development, 2) Athabasca Riverwater quality and quantity before and after oil sands developments, 3) tributary inputs from the Peace and Athabasca Rivers to the Slave River, and 4) upstream to downstream differences in water quality in the Slave River. In addition, seasonal benchmarks were calculated for each river based on pre- perturbation post-perturbation data for future cumulative effects assessments.

Relevance: State of the environment information across three periods with focus on effect of dams

Features: Peer-reviewed journal paper with data reported as means ± S.E.

Elmes, M.C., J.A. Wiklund, S.R. Van Opstal, B.B. Wolfe, and R.I. Hall. 2016. Characterizing baseline concentrations, proportions, and processes controlling deposition of river-transported bitumen-associated polycyclic aromatic compounds at a floodplain lake (Slave River Delta, Northwest Territories, Canada). *Environmental Monitoring and Assessment* 188 (5): 1–15. DOI: 10.1007/s10661-016-5277-4

Purpose/scope: Characterizing baseline concentrations, proportions, and processes driving deposition of bitumen-associated PACs in the Slave River Delta through sediment core analysis.

Author Information: University based researchers

Location: Slave River Delta, Athabasca Delta

Findings: Sediment core in the Slave River Delta revealed that the deposition of river-transported bitumen-associated indicator PACs decades before oil sands development, owing to natural erosion along upstream riverbanks and fluvial entrainment of these contaminants. The sediment core analysis concentrations and proportions of river-transported bitumen-associated PACs establish new baseline conditions. The analysis did not find significant differences in concentrations and proportions of river-transported, bitumen-associated indicator PACs in sediments deposited during periods of high flood influence before oil sands and after oil sands development.

Relevance: Baseline information for Slave River Delta

Features: PAH data

English, M.C., R.B. Hill, M. a. Stone, and R. Ormson. 1997. Geomorphological and botanical change on the Outer Slave River Delta, NWT, before and after impoundment of the Peace River. *Hydrological Processes* 11 (13): 1707–24. DOI: 10.1002/(SICI)1099-1085(19971030)11:13<1707::AID-HYP600>3.0.CO;2-O

Purpose/scope: Document changes in the outer Slave River Delta before and after impoundment of Peace River at Hudson's Hope, BC using aerial photographs

Author Information: University based researchers

Location: Slave River Delta, Peace River

Findings: Reduction in growth rate in cleavage bar islands from 1946 to 1994. The reduction between 1977 and1994 is thought to be a result of reduced sediment load after impoundment.

Relevance: State of the environment information

Features: References include muskrats and information on aquatic species.

Environ EC (Canada) Inc. 2012. *Status and trends of hydrology, water quality and suspended sediment quality of the Hay River*. Mississauga, ON: Environ EC Canada Inc. Available at: http://sdw.enr.gov.nt.ca/nwtdp_upload/Hay River Complete -2(compressed).pdf

Purpose/scope: Describe status and trends of hydrology, water quality, and suspended sediment quality of the Hay River.

Author Information: Consultant scientists prepared the report for the federal government (AANDC)

Location: Hay River

Findings: Information from water quality and quantity monitoring was analysed. Results are presented for each component of water quality, comparing results with guidelines and assessing trends where relevant. Water flows at the Hay River station (17 km from the mouth of the river, active since 1963) are described in terms of seasonality, flow trends and extreme events.

Relevance: Recent synthesis of water quality, quantity and suspended sediment data that is relevant to work on aquatic life indicators. Includes an overview of the basin, such as current activity, water allocation, geology, and climate. Also contains information on sampling stations.

Evans, M.S., B. Billeck, L. Lockhart, J.P. Bechtold, M.B. Yunker, and G. Stern. 2002. PAH sediment studies in Lake Athabasca and the Athabasca River ecosystem related to the Fort McMurray oil sands operations: sources and trends. In *Oil and Hydrocarbon Spills III*, edited by C.A. Brebbia, 365–74. Southampton, UK: WIT Press. Available at: https://www.witpress.com/Secure/elibrary/papers/OIL02/OIL02034FU.pdf. ISBN: 1-85312-922-4

Examination of sediment cores. Provides information on downstream contaminants (PAHs) from oil sands operations in relation to natural sources. Part of the RAMP monitoring program.

Evans, M.S., D.C.G. Muir, W.L. Lockhart, and R.A. Bourbonniere. 1997. Organic contaminants in the Great Slave Lake ecosystem: Slave River influences on contaminant loading and biomagnification. In *The AMAP international symposium on environmental pollution in the arctic, June 1-5, 1997. Extended abstracts*, 137–39. Tromso, Norway: Arctic Monitoring and Assessment Program

Glozier, N.E., D.B. Donald, and D. Halliwell. 2009. *Wood Buffalo National Park water quality: Status and trends from 1989-2006 in three major rivers; Athabasca, Peace and Slave*. Prairie and Northern Office, Water Quality Monitoring and Surveillance Division, Water Science and Technology Directorate, Environment Canada. Available at: http://donnees.ec.gc.ca/data/substances/monitor/surface-water-quality-oil-sands-region/expanded-geographic-extent-oil-sands-region/WBNP_Water_Quality_Eng.pdf

Purpose/scope: “In this report we have presented and interpreted water quality data collected on the Athabasca, Peace, and Slave rivers at the boundaries of Wood Buffalo National Park between August 1989 and December 2006.”

Author Information: Water quality scientists from Environment Canada

Location: Athabasca (@27 Baseline), Peace (@ Peace Point), Slave (@ Fitzgerald) rivers within Wood Buffalo NP

Findings: The Bennett Dam has led to a change in Peace and Slave discharge patterns and thus affected seasonal patterns of several dissolved parameters. “Trends in major ion concentrations were inconsistent among sites and parameters [...] Oxygen concentrations increased over time largely in winter, which is not a concern for aquatic biota [...] Exceedances to CCME guidelines for total metal [and TP and TN] concentrations were frequent but found to be directly related to the naturally high sediment loads in these rivers and probably have no negative effect on aquatic life [...] Increasing nutrients along with decreasing river discharge appears to be the largest concern for the study reaches of the Athabasca and Slave rivers and those downstream.”

Relevance: Significant upward or downward water quality trends may be matched by changes in aquatic invertebrates or fishes responding to the altered habitat conditions.

Features: Water quality data are summarized with detailed statistical summaries and trend analyses in Appendices 2-3.

Golder Associates. 2012. *Appendix 3.4: Peace-Athabasca Delta assessment*. Available at: http://ceaa.gc.ca/050/documents_staticpost/59540/56367/A34-Peace-Athabasca_Delta_Assessment.pdf

This report is part of the CEAA review of the Jackpine Mine Expansion (Shell). It addresses potential incremental and cumulative effects on the PAD and contains data on hydrology and water quality.

Hall, R.I., B.B. Wolfe, J.A. Wiklund, T.W.D. Edwards, A.J. Farwell, and D.G. Dixon. 2012. Has Alberta oil sands development altered delivery of polycyclic aromatic compounds to the Peace-Athabasca delta? Edited by Caroline P. Slomp. *PLoS ONE* 7 (9). Public Library of Science: e46089. DOI: 10.1371/journal.pone.0046089

Hebben, T. 2009. *Analysis of water quality conditions and trends for the long-term river network: Athabasca River, 1960-2007*. Edmonton, Alberta: Water Quality Branch, Alberta Environment. Available at: https://open.alberta.ca/dataset/5418bce4-f0ff-4e41-9f72-f019a9ebd2fb/resource/3b3369bd-0ccf-41d6-adf6-4a1df2369949/download/8142.pdf

Purpose/scope: "The purpose of this report is to provide both a general overview of water quality conditions in the Athabasca River, in the form of summary statistics and time series graphs for all four [Long Term River Network] sites, and more in-depth statistical trend analyses on long-term data for the Athabasca and Old Fort monitoring stations."

Author Information: Limnologist from Alberta Environment

Location: Monitoring sites along the Athabasca River in AB; specifically, Hinton, Athabasca, Fort McMurray and Old Fort

Findings: "Monotonic trend analyses of water quality data revealed trends in several variables at both the Athabasca and Old Fort sites. Stream flow at both locations was found to be decreasing since 1960. At the same time, turbidity, a number of nutrients, and some metals described significant increasing trends at the Old Fort (downstream) station. Relatively high turbidity, in association with high nutrients and metals, is characteristic of the lower Athabasca River and its tributaries and has resulted in frequent water quality guideline exceedances for several variables. Increasing trends in these parameters, however, suggest an additional influence on water quality in the river. Decreasing flows and, hence, a reduced dilution capacity for point source effluents may be partly responsible. However, anthropogenic disturbance in the watershed may also be a contributor."

Relevance: Significant upward or downward water quality trends may be matched by changes in aquatic invertebrates or fishes responding to the altered habitat conditions.

Features: Water quality summary statistics for all four sites and trend analysis for two sites for the 1957-2007 period.

Kelly, E.N., D.W. Schindler, P. V. Hodson, J.W. Short, R. Radmanovich, and C.C. Nielsen. 2010. Oil sands development contributes elements toxic at low concentrations to the Athabasca River and its tributaries. *Proceedings of the National Academy of Sciences* 107 (37): 16178–83. DOI: 10.1073/pnas.1008754107

Kelly, E.N., J.W. Short, D.W. Schindler, P. V. Hodson, M. Ma, A.K. Kwan, and B.L. Fortin. 2009. Oil sands development contributes polycyclic aromatic compounds to the Athabasca River and its tributaries. *Proceedings of the National Academy of Sciences of the United States of America* 106 (52): 22346–51. DOI: 10.1073/pnas.0912050106

Purpose/scope: The purpose of this study was to highlight the extent of pollution (specifically polycyclic aromatic compounds (PACs)) from oil sands mining and processing on the Athabasca River and local snow deposits.

Author Information: Researchers from the University of Alberta and Queen's University, and from Oceana (non-profit ocean environmental advocacy group).

Location: Alberta oil sands region (specifically the Athabasca River and tributaries from south of Fort McMurray to Fort Chipewyan, Athabasca Delta, and Lake Athabasca)

Findings: Waterbody contamination associated with oil sands production is greater than previously reported. Airborne PACs deposit into snowpacks, which represent a significant source of loading into waterbodies upon snowmelt and may be at concentrations harmful to aquatic life. Existing monitoring programs (i.e., RAMP) did not detect this due to inconsistent sampling design, inadequate statistical power, and monitoring-insensitive responses.

Relevance: Water quality downstream of oil sands facilities may be poorer than previously reported. This article highlights changes required for water quality monitoring downstream of the oil sands to be effective.

Features: A separate document with supporting information is available

MacDonald, L.A., J.A. Wiklund, M.C. Elmes, B.B. Wolfe, and R.I. Hall. 2016. Paleolimnological assessment of riverine and atmospheric pathways and sources of metal deposition at a floodplain lake (Slave River Delta, Northwest Territories, Canada). *Science of the Total Environment* 544 (February): 811–23. DOI: 10.1016/j.scitotenv.2015.11.173

Purpose/scope: This study used a detailed flood-pulse record of a lake in the Slave River Delta to improve knowledge of metal deposition via fluvial processes. This established baseline concentrations of metals to determine whether there is evidence of pollution associated with resource development.

Author Information: Researchers from the University of Waterloo and Wilfred Laurier University (both in Waterloo, ON)

Location: A lake in the Slave River Delta, NWT (downstream of Alberta oil sands, down wind of a former gold mine near Yellowknife)

Findings: Sediments deposited since the onset of oil sands development do not have elevated levels of metals relative to pre-development conditions (once levels were

adjusted for historic flood condition and sediment deposition processes). Knowledge of paleohydrological conditions (e.g., historic flooding conditions) is important to understand contaminant deposition pathways in these lakes.

Relevance: Past hydrological conditions should be accounted for in long-term water quality monitoring studies to prevent the detection of false trends or attributing these trends to other factors.

Features: Detailed stratigraphic profiles of sediment cores depicting concentrations of pollutant metals

McCarthy, L.H., T.G. Williams, G.R. Stephens, J. Peddle, K. Robertson, and D.J. Gregor. 1997. Baseline studies in the Slave River, NWT, 1990–1994: Part I. Evaluation of the chemical quality of water and suspended sediment from the Slave River (NWT). *Science of The Total Environment* 197 (1–3): 21–53. DOI: 10.1016/S0048-9697(96)05419-8

Purpose/scope: To create a baseline water and suspended sediment quality dataset for the Slave River Watershed to compare present and future effects from upstream activities and long-range contaminant transport.

Author Information: Researchers from the Canada Centre for Inland Waters; the Department of Earth Sciences at the University of Waterloo; the Water Resources Division of Indian and Northern Affairs Canada; and the Department of Renewable Resources of the Government of the Northwest Territories

Location: Fort Smith, NWT, on the Slave River

Findings: Few positive detections of PAHs, PCBs, CPs, or pesticides (indicating unlikely adverse effects); metals often exceeded water quality guidelines but not by significant amounts, and may be from natural sources.

Relevance: Provides a baseline description of water quality in the Slave River, against which future monitoring results may be compared.

Features: Summary of physical water parameters correlated with discharge

Milburn, D., M. Stone, M. English, and T. Prowse. 2000. Observations on sediment chemistry of the Slave River Delta, Northwest Territories, Canada. In *The role of erosion and sediment transport in nutrient and contaminant transfer. Proceedings of a symposium held at Waterloo, Ontario, Canada in July 2000*, edited by M. Stone, Internatio, 203–9. Wallingford: IAHS Press

Neill, C.R., and B.J. Evans. 1981. *Circulation of water and sediment in the Athabasca Delta area*. AOSERP Project WS 3.3.1. Alberta Oil Sands Environmental Research Program

Contains information on inflows and outflows from the delta area and Athabasca Lake which is essential for understanding sources of pollution to the Slave River.

Nilsson, C., and K. Berggren. 2000. Alterations of riparian ecosystems caused by river regulation. *BioScience* 50 (9): 783. DOI: 10.1641/0006-3568(2000)050[0783:AORECB]2.0.CO;2

Purpose/scope: A literature review on the effects of dams and river regulations on riparian ecosystems

Author Information: Landscape ecology researchers from Umea University in Sweden

Location: This review is global in scope, though there is mention of some major dammed rivers and reservoirs in Canada (notably, the Slave River delta of Great Slave Lake, Northwest Territories, Canada, was markedly reduced after impoundment of the Peace River by the Bennett Dam near Hudson's Hope, British Columbia.)

Findings: Generally, upstream effects of dams involve terrestrial and riparian ecosystems inundation (resulting in erosion, habitat loss, greenhouse gas release, and changes to community composition). Downstream effects include reduced flood peaks, sedimentation rates and smaller extent of the active floodplain, as well as replacement of native riparian species with exotics and salinization.

Relevance: The Peace River, a major tributary of the Slave River, is dammed (by the Bennett Dam in BC) before it enters the NWT, and up- and downstream riparian ecosystems may be altered as described here. See English et al. (1997, Hydrological Processes 11:1707-1724) for a more detailed account

Features: Figure 5 provides an overview of riparian succession following a reduced flooding regime downstream from dams.

Northern River Basins Study Board. 1996. *Northern River Basins Study report to the ministers*. Edmonton: Environment Canada and Alberta Environment. Available at: http://www.barbau.ca/sites/www.barbau.ca/files/0-662-24768-X_0.pdf

Purpose/scope: Peace, Athabasca, and Slave Rivers SOE for fish, drinking water quality, and flow rate with greatest focus on Athabasca.

Author Information: Scientific work was completed by private companies, individuals, government agencies, and educational institutions. The research was overseen by a seven-member Science Advisory Committee.

Location: Peace, Athabasca, and Slave Rivers

Findings: Summary of findings from 150 "mini" studies benchmarking key aspects of the SOE. In fish, dioxin and furans declined during the study, except in fish near pulp mills where levels of toxic dioxins, furans and mercury still exist. Levels of polychlorinated biphenyls (PCBs) appeared to be within generally accepted consumption guidelines. Fish near pulp mills had lower sex hormones, tumours and growths. Drinking water quality good for majority of basin residents. 25% residents get water directly from water sources that should be treated for bacteria Flow rate is being affected by upstream dams that have changed patterns in flow and ice patterns drying out Peace-Athabasca delta and affecting the growth rate of Slave River delta. Cumulative effects are summarized on a river reach by river reach basis.

Relevance: State of the environment conditions in 1996. Implemented recommendations can be checked for effectiveness.

Features: Plain language report with peer reviewed data

Northwest Territories. 2013. *Northwest Territories Water Monitoring Inventory*. Version 1. Available at: http://www.nwtwaterstewardship.ca/sites/default/files/YELLOWKN-%23599863-v1-water_strategy_-_water_monitoring_inventory_-_updated_December2013.PDF

Purpose/scope: "The NWT Water Monitoring Inventory includes information on current water monitoring programs led by Aboriginal, federal and territorial governments, communities, industry, and others."

Author Information: Government of the NWT, and Aboriginal Affairs and Northern Development Canada.

Location: Throughout NWT

Findings: A comprehensive overview of water quality and quantity monitoring initiatives (to 2013) by federal, territorial, and Aboriginal governments, as well as resource management boards, communities, industry, and academia.

Relevance: Provides an excellent summary of existing monitoring, which can be consulted to establish baseline water conditions for future monitoring efforts.

Features: Majority of the report is a large table that provides a comprehensive overview on monitoring initiatives to date (known to 2013).

Ohlson, D., G. Long, and T. Hatfield. 2010. *Phase 2 Framework Committee Report*. Compass Resource Management and Solander Ecological Research. Available at: https://albertawilderness.ca/wordpress/wp-content/uploads/2015/12/20100131_rp_athabasca_p2fc.pdf

Purpose/scope: Outcome of Phase 2 Water Management Framework that will prescribe when and how much water can be withdrawn from the Lower Athabasca River for cumulative oil sands mining water use.

Author Information: Committee report prepared by consultants

Findings: Insights gained from technical analyses and modelling. Ecosystem health focused on fish core to evaluation.

Relevance: May be useful for synthesis report for modelling and recommendations.

Features: Modelling of water levels

Reid, R. 2010. *Baseline Water Monitoring Programs in the Northwest Territories. Laurier CALIBER Workshop Yellowknife, Northwest Territories 13-14 July, 2010*. Yellowknife, Northwest Territories: DIAND Water Resources Division.

Rood, S.B., G.W. Stupple, and K.M. Gill. 2015. Century-long records reveal slight, ecoregion-localized changes in Athabasca River flows. *Hydrological Processes* 29 (5): 805–16. DOI: 10.1002/hyp.10194

Sanderson, J. (Peddle), C. Lafontaine, and K. Robertson. 1998. *Slave River environmental quality monitoring program: summary report*. Yellowknife, NWT: Water Resources Division, Indian and Northern Affairs Canada and Department of Resources, Wildlife and Economic Development, Government of the Northwest Territories. Available at: http://www.enr.gov.nt.ca/sites/enr/files/slave_river_environmental_quality_monitoring_program_-_report_summary_1998.pdf

Purpose/scope: The SREQMP was a five-year multimedia sampling program operating from 1990 to 1995, to characterize baseline conditions of the aquatic ecosystem in the Slave River at Fort Smith, NWT, Canada. This report provides a summary of the Slave River Environmental Quality Monitoring Program Final Five Year Report (Sanderson et al., 1997).

Author Information: Authors are from the Water Resources Division of Indian and Northern Affairs Canada and the Department of Resources, Wildlife and Economic Development of the Government of NWT.

Location: The Slave River at Fort Smith, NWT

Findings: Same as the full SREQMP report

Relevance: A higher-level summary of the precedent ecosystem-scale monitoring that has preciously occurred

Features: A more condensed version of the full SREQMP report (Sanderson et al., 1997)

Sanderson, J. (Peddle), C. Lafontaine, and K. Robertson. 1997. *Slave River Environmental Quality Monitoring Program: Final five year study report, 1990-1995*. Yellowknife, NWT: Indian and Northern Affairs Canada, Water Resources Division, and Government of the Northwest Territories, Department of Resources, Wildlife and Economic Development

Purpose/scope: "The Slave River Environmental Quality Monitoring Program (SREQMP) was a five year multimedia sampling program operating from- 1990 to 1995, to characterize baseline conditions of the aquatic ecosystem in the Slave River at Fort Smith, Northwest Territories (NWT), Canada. The comprehensive nature of the program made it the first of its kind in the Northwest Territories."

Author Information: Authors are from the Water Resources Division of Indian and Northern Affairs Canada, and the Department of Resources, Wildlife and Economic Development of the Government of NWT.

Location: The Slave River at Fort Smith, NWT

Findings: Sampling included water, suspended sediment and fish. The focus was contaminants. Fish were analyzed for tissue contaminant levels and enzyme activity biomarkers (hepatic MFO enzyme activity). "In general, the results of the study indicate that many parameters are at extremely low levels or were not detected even with state of

the art analytical techniques. Of those compounds which were found, metals and PAHs are most likely from natural sources, while the presence of pesticides and PCBs indicates atmospheric transport. The detection of chlorinated phenolics, dioxins and furans, although at low levels, could be a result of downstream transport. While some findings may warrant further study, overall the levels of contaminants measured in the aquatic environment at Fort Smith are not likely to cause adverse effects."

Relevance: Provides a precedent water, sediment and fish quality monitoring program, including field and analytical methods, to guide the development of subsequent multimedia monitoring programs.

Features: "This detailed report provides the study design, detailed field methods, complete documentation of analytical methods, and analysis of results, in order to document the vast background information associated with the study."

Sanderson, J., A. Czarnecki, and D. Faria. 2012. *Water and suspended sediment quality of the transboundary reach of the Slave River, Northwest Territories*. Yellowknife, Northwest Territories: Indian and Northern Affairs Canada, Water Resources Division, and Government of the Northwest Territories, Department of Resources, Wildlife and Economic Development. Available at: http://www.nwtwaterstewardship.ca/sites/default/files/YELLOWKN-%23555560-v1-SLAVE_RIVER_REPORT_WITH_APPENDICES_-_FINAL (2).PDF

Purpose/scope: "This report describes the water and suspended sediment quality conditions in the Slave River at Fort Smith. The status and long-term trends in water quality from the Slave River at Fitzgerald are also examined. Additionally, seasonal flow patterns and long- term temporal hydrological trends for the Slave River at Fitzgerald are assessed. A summary of the geology and upstream activities in the Slave River Catchment is also provided. Current monitoring efforts are assessed and recommendations are made for future monitoring."

Author Information: Water quality specialists and hydrologists from the Water Resources Division, Renewable Resources and Environment Directorate, NWT Region, Aboriginal Affairs and Northern Development Canada.

Location: The Slave River at Fort Smith and Fitzgerald, NWT

Findings: Significant changes in the timing of flows, caused by upstream regulation of the Peace River in BC for hydropower. Total metals (e.g., Cd, Cr, Cu, Fe, Pb, Hg) exceeded their respective CCME Canadian Water Quality Guidelines for the Protection of Freshwater Aquatic Life CPFAL guidelines in greater than 25% of cases, while other metals (e.g., As, Ba, Mn, Ni, Se, Ar, V, Zn) exceed these less than 25% of the time, though these guidelines are national in scope and may not be appropriate to compare Slave River values against. Physical parameters, nutrients and major ions did not exceed their respective guidelines, nor did pollutants such as PAHs, PCDD/Fs organochlorine pesticides, chlorinated benzenes or chlorinated phenolics.

Relevance: An updated description of the hydrology and water, and suspended sediment quality of the Slave River given natural and anthropogenic contaminant sources

Features: Provides an updated description of water and sediment quality compared to the 1997 SREQMP report, as well as long-term trend analyses.

Schindler, D.W. 2013. Water quality issues in the oil sands region of the Lower Athabasca River, Alberta. *Geoscience Canada* 40 (Special Issue: Environmental Management of the Alberta Oil Sands): 202–14. DOI: 10.12789/geocanj.2013.40.012

Purpose/scope: "The purpose of this paper is to describe the state of water quality in the lower Athabasca River, how it has been affected by the oil sands industry, and what is necessary to improve our understanding of the present and future impacts of industry on the river."

Author Information: Limnologist from the University of Alberta

Location: Oil sands region of the Lower Athabasca River, AB

Findings: The RAMP was a monitoring regime that was largely ineffective at detecting and reporting cumulative environmental degradation associated with oil sands development. Concentrations of compounds such as mercury and PACs have increased due to oil sands development, and have had documented effects on fish and other aquatic life in the Athabasca River. 170 km^2 of tailings ponds are also a potential environmental concern. Better monitoring and reporting initiatives are necessary.

Relevance: Emphasizes the need for independent, transparent, science-based monitoring of waterbodies downstream from major developments.

Features: Excellent review of oil sands environmental problems over the past century and current water quality concerns.

Squires, A.J., C.J. Westbrook, and M.G. Dubé. 2010. An approach for assessing cumulative effects in a model river, the Athabasca River Basin. *Integrated Environmental Assessment and Management* 6 (1): 119–34

Purpose/scope: "The main objectives of this paper were to 1) quantify spatial and temporal changes in water quantity and quality over the entire Athabasca River mainstem across historical (1966-1976) and current day (1996-2006) time periods and 2) to evaluate the significance of any changes relative to existing benchmarks (e.g. water quality guidelines)."

Author Information: Researchers from the University of Saskatchewan

Location: Mainstem Athabasca River, AB; from the headwaters to the mouth at Lake Athabasca

Findings: "Our results show that significant changes have occurred in both water quantity and quality between the historical and current day Athabasca River basin [specifically, decrease in discharge and increase in dissolved Na, SO4, Cl, TP concentrations in the second time period]. It is known that in addition to climatic changes, rivers which undergo increased agricultural, urban and industrial development can experience significant changes in water quantity and quality due to increased water use, discharge of effluents and surface run-off."

Relevance: Cumulative effects assessment approach can be applied to any river system; data for the Athabasca in particular can help to quantify natural and anthropogenic stressors and put the magnitude of local changes in regional context.

Stone, M., and M.C. English. 1988. *Geochemistry of sediments in the Slave River delta, NWT*. Yellowknife, NWT: Report submitted to Department of Indian Affairs and Northern Development Canada

Tri-Star Environmental Consulting. 2011. *Approaches to the development of transboundary surface water quality objectives for the Hay and Slave rivers*. Yellowknife, Northwest Territories: Report Prepared for Water Resources Division, Aboriginal and Northern Affairs Canada

Purpose/scope: To update site- and parameter-specific water quality objectives for the transboundary Slave and Hay Rivers for Alberta and NWT for a variety of flow conditions using a range of generally-accepted statistical methods.

Author Information: Environmental consulting company, prepared for the Water Resources Division of Aboriginal Affairs and Northern Development Canada

Location: Slave and Hay Rivers, between AB and NWT

Findings: National/provincial water quality guidelines are typically too generic to be meaningfully applied to individual waterbodies; instead site-specific monitoring objectives should be established based on the historical data set and local environmental conditions (including variable hydrologic and seasonal conditions). The transboundary rivers should be monitored using objectives, alert levels, and trigger levels based on the 95th percentile statistic. Objectives, alert levels, and trigger levels are established for multiple routine, nutrient, and metal variables for each river, often with different values for each of winter baseflow, spring freshet, summer recession, and fall recession.

Relevance: Water quality monitoring target levels that are set specific to each river will support the delineation of specific biological monitoring objectives if a similar approach is taken (e.g., invertebrate communities that are characteristic of good water quality in the Slave River in AB/NWT rather than generic nation-wide indicators).

Features: Table E1 summarizes proposed water quality objectives, and alert and trigger levels for each of the Slave and Hay Rivers.

Walder, G.L., and D.W. Mayhood. 1985. *An analysis of benthic invertebrate and water quality monitoring data from the Athabasca River*. RMD Report: L-91. Edmonton, Alberta: Prepared for Alberta Environment, Research Management Division by Sigma Biometrics and FWR Freshwater Research Limited. Available at: https://era.library.ualberta.ca/files/4q77fr76d/RMD_L-91_Walder_Benthic_Invertebrate_1985.pdf

Purpose/scope: This report presents a detailed statistical analysis of water quality and benthic invertebrate data from previous studies on the Athabasca River.

Author Information: Consultants preparing report for the Alberta Government (Sigma Biometrics and FWR Freshwater Research Ltd., commissioned by the Research Management Division of Alberta Environment.)

Location: Athabasca Oil Sands Area, AB

Findings: Most major ions were correlated with each other and filterable residue; potassium concentrations were independent of other ion concentrations; all metals except lead and mercury were associated with non-filterable residue and total phosphate. Marked differences in water quality and benthic invertebrates between left and right shores of the Athabasca River, possibly due to influences of Clearwater River and other tributaries. Benthic invertebrate communities were analyzed but results are non-conclusive due to non-random sampling design. If measuring both water quality and benthic invertebrates for a study, it is recommended to sample water some period of time (e.g., one year) prior to invertebrate sampling, rather than at the same time, for maximum ecological relevance.

Relevance: Historical data from 1980s comparing water quality and invertebrate communities up- and downstream of oil sands plants.

Features: Many principal component analysis ordination plots representing water quality and invertebrate community patterns among Athabasca River study sites.

W-E-R AGRA Ltd. 1993. *Data review water quality monitoring at the Alberta-Northwest Territories boundary*. Edmonton, AB: Report Prepared for Alberta Environmental Protection, Environmental Assessment Division

Wiklund, J.A., R.I. Hall, and B.B. Wolfe. 2012. Timescales of hydrolimnological change in floodplain lakes of the Peace-Athabasca Delta, northern Alberta, Canada. *Ecohydrology* 5 (3): 351–67. DOI: 10.1002/eco.226

This paper is based on Wiklund 2012 (PhD thesis), which also includes data on epiphytic diatoms and plankton.

Wiklund, J.A., R.I. Hall, B.B. Wolfe, T.W.D. Edwards, A.J. Farwell, and D.G. Dixon. 2012. Has Alberta oil sands development increased far-field delivery of airborne contaminants to the Peace–Athabasca Delta? *Science of The Total Environment* 433 (September): 379–82. DOI: 10.1016/j.scitotenv.2012.06.074

Study of dispersal of contaminants, based on sediment cores.

Wiklund, J.A., R.I. Hall, B.B. Wolfe, T.W.D. Edwards, A.J. Farwell, and D. George Dixon. 2014. Use of pre-industrial floodplain lake sediments to establish baseline river metal concentrations downstream of Alberta oil sands: a new approach for detecting pollution of rivers. *Environmental Research Letters* 9 (12). IOP Publishing: 124019. DOI: 10.1088/1748-9326/9/12/124019

Wolfe, B.B., R.I. Hall, T.W.D. Edwards, S.R. Vardy, M.D. Falcone, C. Sjunneskog, F. Sylvestre, S. McGowan, P.R. Leavitt, and P. van Driel. 2008. Hydroecological responses of the Athabasca Delta, Canada, to changes in river flow and climate during the 20th century. *Ecohydrology* 1: 131–48. DOI: 10.1002/eco.13

Possibly of use for synthesis report re methodologies - isotopic tracers for measuring hydroecological resilience. The work is based on sediment cores in the Athabasca Delta.

Wolfe, B.B., T.L. Karst-Riddoch, S.R. Vardy, and M.D. Falcone. 2005. Impacts of climate and river flooding on the hydro-ecology of a floodplain basin, Peace-Athabasca Delta, Canada since A.D. 1700. *Quaternary Research* 64 (2): 147–62

4.8.1 Supplementary Resources: Water Quality and Quantity, and Sediment

Bourbonniere, R.A., S.L. Telford, L.A. Ziolkowski, J. Lee, M.S. Evans, and P.A. Meyers. 1997. Biogeochemical marker profiles in cores of dated sediments from large North American lakes. In *Molecular markers in environmental geochemistry*, edited by R.P. Eganhouse, Symposium, 133–50. Washington, D.C.: American Chemical Society

Brock, B.E., M.E. Martin, C.L. Mongeon, M.A. Sokal, S.D. Wesche, D. Armitage, B.B. Wolfe, R.I. Hall, and T.W.D. Edwards. 2010. Flood frequency variability during the past 80 years in the Slave River Delta, NWT, as determined from multi-proxy paleolimnological analysis. *Canadian Water Resources Journal* 35 (3): 281–300. DOI: 10.4296/cwrj3503281

Brock, B.E., B.B. Wolfe, and T.W.D. Edwards. 2007. Characterizing the Hydrology of Shallow Floodplain Lakes in the Slave River Delta, NWT, Canada, Using Water Isotope Tracers. *Arctic, Antarctic, and Alpine Research* 39 (3). The Institute of Arctic and Alpine Research UCB 450, University of Colorado, Boulder, Colorado 80309-0450, U.S.A: 388–401. DOI: 10.1657/1523-0430(06-026)[BROCK]2.0.CO;2

Evans, M.S., B. Billeck, L. Lockhart, J.P. Bechtold, M.B. Yunker, and G. Stern. 2002. PAH sediment studies in Lake Athabasca and the Athabasca River ecosystem related to the Fort McMurray oil sands operations: sources and trends. In *Oil and Hydrocarbon Spills III*, edited by C.A. Brebbia, 365–74. Southampton, UK: WIT Press. Available at: https://www.witpress.com/Secure/elibrary/papers/OIL02/OIL02034FU.pdf

Examination of sediment cores. Provides information on downstream contaminants (PAHs) from oil sands operations in relation to natural sources. Part of the RAMP monitoring program.

Evans, M.S., D.C.G. Muir, W.L. Lockhart, and R.A. Bourbonniere. 1997. Organic contaminants in the Great Slave Lake ecosystem: Slave River influences on contaminant loading and biomagnification. In *The AMAP international symposium on environmental pollution in the arctic, June 1-5, 1997. Extended abstracts*, 137–39. Tromsø, Norway: Arctic Monitoring and Assessment Program

Golder Associates. 2012. *Appendix 3.4: Peace-Athabasca Delta assessment*. Available at: http://ceaa.gc.ca/050/documents_staticpost/59540/56367/A34-Peace-Athabasca_Delta_Assessment.pdf

This report is part of the CEAA review of the Jackpine Mine Expansion (Shell). It addresses potential incremental and cumulative effects on the PAD and contains data on hydrology and water quality.

Hall, R.I., B.B. Wolfe, J.A. Wiklund, T.W.D. Edwards, A.J. Farwell, and D.G. Dixon. 2012. Has Alberta oil sands development altered delivery of polycyclic aromatic compounds to the Peace-Athabasca delta? Edited by Caroline P. Slomp. *PLoS ONE* 7 (9). Public Library of Science: e46089. DOI: 10.1371/journal.pone.0046089

Kelly, E.N., D.W. Schindler, P. V. Hodson, J.W. Short, R. Radmanovich, and C.C. Nielsen. 2010. Oil sands development contributes elements toxic at low concentrations to the

Athabasca River and its tributaries. *Proceedings of the National Academy of Sciences* 107 (37): 16178–83. DOI: 10.1073/pnas.1008754107

Milburn, D., M. Stone, M. English, and T. Prowse. 2000. Observations on sediment chemistry of the Slave River Delta, Northwest Territories, Canada. In *The role of erosion and sediment transport in nutrient and contaminant transfer. Proceedings of a symposium held at Waterloo, Ontario, Canada in July 2000*, edited by M. Stone, Internatio, 203–9. Wallingford: IAHS Press

Neill, C.R., and B.J. Evans. 1981. *Circulation of water and sediment in the Athabasca Delta area*. AOSERP Project WS 3.3.1. Alberta Oil Sands Environmental Research Program

Contains information on inflows and outflows from the delta area and Athabasca Lake - which is essential for understanding sources of pollution to the Slave River.

Ohlson, D., G. Long, and T. Hatfield. 2010. *Phase 2 Framework Committee Report*. Compass Resource Management and Solander Ecological Research. Available at: https://albertawilderness.ca/wordpress/wp-content/uploads/2015/12/20100131_rp_athabasca_p2fc.pdf

Rood, S.B., G.W. Stupple, and K.M. Gill. 2015. Century-long records reveal slight, ecoregion-localized changes in Athabasca River flows. *Hydrological Processes* 29 (5): 805–16. DOI: 10.1002/hyp.10194

Stone, M., and M.C. English. 1988. *Geochemistry of sediments in the Slave River delta, NWT*. Yellowknife, NWT: Report submitted to Department of Indian Affairs and Northern Development Canada

W-E-R AGRA Ltd. 1993. *Data review water quality monitoring at the Alberta-Northwest Territories boundary*. Edmonton, AB: Report Prepared for Alberta Environmental Protection, Environmental Assessment Division

Wiklund, J.A., R.I. Hall, and B.B. Wolfe. 2012. Timescales of hydrolimnological change in floodplain lakes of the Peace-Athabasca Delta, northern Alberta, Canada. *Ecohydrology* 5 (3): 351–67. DOI: 10.1002/eco.226

This paper is based on Wiklund 2012 (PhD thesis), which also includes data on epiphytic diatoms and plankton.

Wiklund, J.A., R.I. Hall, B.B. Wolfe, T.W.D. Edwards, A.J. Farwell, and D.G. Dixon. 2012. Has Alberta oil sands development increased far-field delivery of airborne contaminants to the Peace–Athabasca Delta? *Science of The Total Environment* 433 (September): 379–82. DOI: 10.1016/j.scitotenv.2012.06.074

Study of dispersal of contaminants, based on sediment cores.

Wiklund, J.A., R.I. Hall, B.B. Wolfe, T.W.D. Edwards, A.J. Farwell, and D. George Dixon. 2014. Use of pre-industrial floodplain lake sediments to establish baseline river metal concentrations downstream of Alberta oil sands: a new approach for detecting pollution of rivers. *Environmental Research Letters* 9 (12). IOP Publishing: 124019. DOI: 10.1088/1748-9326/9/12/124019

Wolfe, B.B., R.I. Hall, T.W.D. Edwards, S.R. Vardy, M.D. Falcone, C. Sjunneskog, F. Sylvestre, S. McGowan, P.R. Leavitt, and P. van Driel. 2008. Hydroecological responses of the Athabasca Delta, Canada, to changes in river flow and climate during the 20th century. *Ecohydrology* 1: 131–48. DOI: 10.1002/eco.13

Possibly of use for synthesis report re methodologies - isotopic tracers for measuring hydroecological resilience. The work is based on sediment cores in the Athabasca Delta.

Wolfe, B.B., T.L. Karst-Riddoch, S.R. Vardy, and M.D. Falcone. 2005. Impacts of climate and river flooding on the hydro-ecology of a floodplain basin, Peace-Athabasca Delta, Canada since A.D. 1700. *Quaternary Research* 64 (2): 147–62

4.9 Reviews, Summaries, State of Environment Reports

Aboriginal Affairs and Northern Development Canada. 2012. *Report summary: Slave River*. Aboriginal Affairs and Northern Development Canada. Available at: https://www.nwtwaterstewardship.ca/sites/default/files/SlaveRiverReportSummary.pdf. ISBN: 9781100215396

Purpose/scope: Long-term trends in water and sediment quality, and flow in the Slave River watershed. Report includes findings from over 200 water samples and 27 suspended sediment samples, and analysis for over 500 different substances. Samples were compared to the Guidelines for Canadian Drinking Water Quality and Recreational Water Quality, and CCME Guidelines for the protection of freshwater aquatic life.

Author Information: Government employees from Water Resources Division of Aboriginal Affairs and Northern Development Canada

Location: Slave River watershed including NWT, Saskatchewan, Alberta, and British Columbia

Findings: Increasing trends in phosphorus, sulphate, and sodium. Cadmium, chromium, copper, iron, and lead were higher than the aquatic life guidelines more than 25% of the time. Other metals did not exceed the guidelines or exceedances were less than 25% of the time. 11 pesticides detected in water samples, all below guidelines. Naturally occurring dissolved solvent patterns may be altered by upstream dams.

Relevance: Limited. Water quality and quantity affect the suitability of aquatic ecosystems to support biota, and so may indirectly affect biological indicators. Report based on 35 years of water quality data.

Features: Government reviewed and prepared report.

AECOM Canada Ltd. 2010. *Synthesis of ecological information related to the Peace-Athabasca Delta*. Fort Smith, Northwest Territories: Prepared for Peace-Athabasca Delta Ecological Monitoring Program (PADEMP). Available at:

Discussion of Key Indicators of Ecological Integrity. Appendix A is a listing of the monitoring programs for the region.

AEMERA, and ECC. 2015. *2014-2015 technical results summary*. Prepared by Alberta Environmental Monitoring Evaluation and Reporting Agency and Environment and Climate Change Canada. Joint Canada Alberta Implementation Plan for Oil Sands Monitoring [JOSM]. Available at: http://aemera.org/wp-content/uploads/2015/08/JOSM-Technical-Results-Summary-2014-2015.pdf

Results report for 2014-2015 for all JOSM monitoring program. The report focuses on non-technical results summaries.

CharettePellPoscente Environmental Corp, and Hutchinson Environmental Sciences Ltd. 2012. *Aquatic ecosystem health of the Peace watershed project. Final Report, June 2012*. Mighty Peace Watershed Alliance. Available at: https://www.ceaa.gc.ca/050/documents/p63919/98130E.pdf

Purpose/scope: "The objective of this report is to present issues affecting aquatic health [in the Peace River Watershed], to identify key information gaps and to suggest strategies to resolve these, in preparation of the State of the Watershed report."

Author Information: Environmental consultants, prepared for the Mighty Peace Watershed Alliance (ENGO)

Location: Peace River Watershed, AB

Findings: Relevant and up-to-date studies and summaries were reviewed to outline the state of aquatic ecosystem health and the extent of current knowledge within each of the six sub-watersheds. 11 high-priority data and knowledge gaps relating to aquatic ecosystem structure and function, and stressor-effect relationships were identified to support future assessment and management of aquatic ecosystem health in the Peace River Basin.

Relevance: Precursor to state-of-watershed report; provides a preliminary (but still informative) assessment of watershed and aquatic ecosystem health.

Features: Detailed overview of land use and biophysical features of aquatic ecosystems within the 6 sub-watersheds of the Peace River.

Collister, D.M., J.L. Kansas, T. Antoniuk, and B.J. Power. 2003. *Review and assessment of environmental effects information for wildlife and fish indicators in the Regional Sustainable Development Strategy (RSDS) study area within the Athabasca Oil Sands Region (AOSR). Final Report*. Fort McMurray, AB: Cumulative Environmental Management Association. Available at: http://library.cemaonline.ca/ckan/dataset/4043d7a4-a6c2-49fd-a4e3-6ec1d5dd3451/resource/814467d9-7f11-40b0-b3bf-b2eaf5145b87/download/reviewandassessenvironeffectsinfoforwildlifeandfish.pdf

Dagg, J. 2016. *State of the Knowledge of the Slave River and Slave River Delta. A component of the vulnerability assessment of the Slave River and Delta. Final report April 2016*. The Pembina Institute. Available at: http://www.nwtwaterstewardship.ca/sites/default/files/FINAL_APRIL%2716_FINAL_Slave River State of the Knowledge Report.pdf

Purpose/scope: Literature review of the aquatic and riparian ecosystem of the Slave River and Delta. Focus on hydrology and sediment; water quality; metals and contaminants in water; sediment and fish; fish and insect/benthic communities; terrestrial wildlife species; vegetation; and air and climate

Author Information: Pembina Institute employee

Location: Slave River and Delta

Findings: Literature search found large volume of information on hydrology and sediment load; water quality; metals and contaminants in water; sediments and fish; and muskrats. Moderate information about fish community, moose, beaver, and vegetation. Little information on benthic invertebrates and insects; mink; otter and aquatic birds; and air quality.

Relevance: Recent literature review for a portion of the study area

Features: Traditional knowledge and scientific knowledge

Dagg, J. 2016. *Vulnerability assessment of the Slave River and Delta. Summary report for the community workshop convened in Fort Smith, January 24-26, 2012. Final report April 2016*. Final. Fort Smith: The Pembina Institute and Government of Northwest Territories. Available at: https://www.nwtwaterstewardship.ca/sites/default/files/FINAL_April%2716_%20FINAL_SRDP_VulnerabilityAssessment.pdf

Purpose/scope: Fort Smith and Fort Resolution workshops to assess vulnerability of the Slave River and Delta ecosystem, and establish monitoring priorities.

Author Information: Local and traditional knowledge holders; Aboriginal governments representatives; western scientists and government agencies

Location: Slave River and Delta

Findings: Monitoring priorities for six ecosystem components: hydrology and sediment load; water quality; fish and insect/benthic communities; wildlife, vegetation; air and climate. Identification of potential indicator species

Relevance: Monitoring and research requirements

Features: Traditional knowledge, western science

Donald, D.B., W. Aitken, J. Syrgiannis, N.E. Glozier, F.G. Hunter, and M.R. Gilchrist. 2004. State of the aquatic environment Peace-Athabasca delta - 2002. In *Northern Rivers Ecosystem Initiative: Collective Findings (CD-ROM)*, edited by Environment Canada. Compiled by F.M. Conly, Saskatoon, SK (With Alberta Environment)

Dubé, M.G., and J.E. Wilson. 2013. Accumulated state assessment of the Peace-Athabasca-Slave River system. *Integrated environmental assessment and management* 9 (3): 405–25. DOI: 10.1002/ieam.1354

Purpose/scope: Effects-based water quality and quantity cumulative effects assessment

Author Information: University researchers

Location: Peace-Athabasca-Slave

Findings: This study assessed seasonal changes in 1) Peace River water quality and quantity before and after dam development, 2) Athabasca Riverwater quality and quantity before and after oil sands developments, 3) tributary inputs from the Peace and

Athabasca Rivers to the Slave River, and 4) upstream to downstream differences in water quality in the Slave River. In addition, seasonal benchmarks were calculated for each river based on pre- perturbation post-perturbation data for future cumulative effects assessments.

Relevance: State of the environment information across three periods with focus on effect of dams

Features: Peer-reviewed journal paper with data reported as means ± S.E.

Eaton, B., and T. Charette. 2016. *Drivers, stressors, and indicators of wetland change in Alberta's Oil Sands Region – potential for use in wetland monitoring*. Cold Lake, Athabasca, Peace River: Alberta Innovates - Technology Futures and CPP Environmental Corp. Available at: http://ftp.public.abmi.ca/home/publications/documents/455_Eaton_etal_2017_DriversStressorsIndicatorsofWetlandChangeinAlbertaOSR_ABMI.pdf

Purpose/scope: Summary of features needed to develop a wetland monitoring program for northeastern Alberta. Focus on measuring cumulative effects of natural and anthropogenic factors on wetlands (i.e., detect an impact); and detecting changes in wetlands associated with specific anthropogenic activities (i.e., diagnose what caused an impact).

Author Information: Consultants, prepared for Alberta Innovates

Location: Cold Lake, Athabasca, and Peace River

Findings: Based on human footprint evaluation in the oil sands region and the identification of wetland indicators, the research considered the best diagnostic medium for change. The report recommends indicators, and multi-level sampling considerations.

Relevance: Summary of the influence of upstream and oil sands anthropogenic activities on wetlands

Features: Extensive literature search, sampling and research recommendations

Environment Canada, and Alberta Environment. 2004. *Northern Rivers Ecosystem Initiative 1998-2003. Final report 2004*. Edmonton: Environment Canada and Alberta Environment. Available at: http://www.barbau.ca/sites/www.barbau.ca/files/northern%20rivers%20ecosystem%20initiative%201998-2003,%20first%20progress%20report%20november,%201999.pdf

Purpose/scope: This report contains "the recommendations from the Northern River Basins Study (1996; a 5-year initiative launched by governments in 1991 to obtain further scientific information regarding the existing conditions in, and the effects of development on, the aquatic ecosystem of the Peace-Athabasca-Slave river basins), the response to those recommendations by the governments of Canada, Alberta and the Northwest Territories (1997), and a summary of Northern Rivers Ecosystem Initiative (NREI) Progress Reports from 1999, 2001 and NREI activities up to March 31, 2003."

Author Information: Representatives from the governments of Canada, Alberta and the NWT

Location: Peace-Athabasca-Slave River basins. Note that the relevant areas are mostly in Alberta, though the Slave River watershed up to Fort Resolution (NWT) is included. Basins in BC, Saskatchewan, and Nunavut were excluded.

Findings: Multiple recommendations for aquatic ecosystem management were made to the three governments between 1996 and2004. These ranged from pollution prevention and management to fish consumption policies to Peace-Athabasca Delta reclamation requirements to First Nations consultation and involvement. The response of government to these recommendations, including any legislative actions and other progress, are detailed chronologically.

Relevance: Summary of the regulatory recommendations and actions taken (up to 2004) to improve aquatic ecosystem health in the Peace-Athabasca-Slave river basins

Features: Appendix 1 (p. 83) features a cross-reference table linking NRBS recommendations with government actions in the report. Appendix 2 (pg 86) features a list of NREI project reports.

ESTR Secretariat. 2013. *Taiga Plains Ecozone evidence for key findings summary*. Evidence for Key Findings Summary Report No.13. Canadian Biodiversity: Ecosystem Status and Trends 2010. Ottawa, ON: Canadian Councils of Resource Ministers. Available at: http://www.biodivcanada.ca/99361C1A-F46F-4A64-8366-51A6CA6EEAF5/No.13_Taiga_Plains_EKFS_July2013_E.pdf

Summary of ecosystem status and trends reporting for Canada for this ecozone.

Golder Associates Ltd. 2010. *Government of the Northwest Territories final report: Aquatic ecosystem health - report on state of knowledge*. Yellowknife: Golder Associates Ltd.

Purpose/scope: This report provides a review of the current (2010) state of knowledge of aquatic ecosystem health in the NWT portion of transboundary waters crossing the NWT-AB border, and identifies both critical information gaps and priority items for future research.

Author Information: Environmental consulting firm, contracted by the Government of NWT

Location: Water bodies crossing the AB-NWT border, particularly the Slave River from Fort Smith to its delta at Great Slave Lake, Hay River from the AB-NWT border, to its delta at Great Slave Lake, and Great Slave Lake.

Findings: The review included information on aquatic habitat and vegetation, lower trophic communities (periphyton, phyto- and zooplankton, benthic invertebrates); fish (populations, health, tissue chemistry); and fur-bearing aquatic mammals and aquatic birds (water and suspended sediment reviewed in a different report). The extent of available and relevant data varied between these groups, but baseline information is lacking in nearly all cases. Following a comprehensive review, a monitoring program should focus on the Slave and Hay Rivers

Relevance: Identifies critical information gaps and priority areas for more aquatic ecosystem research, specific to major NWT waterbodies.

Features: Tables 1, 2, 3 summarize the known (to 2010) studies of aquatic ecosystem and biota health for the Slave River, Hay River, and Great Slave Lake, respectively. Table 4 similarly includes this information for several secondary priority transboundary water bodies.

Goodwin, R., L. Howard, L. Howard, and B. Latham, ed. 1998. *An annotated bibliography of the Northwest Territories Action on Water component of the Arctic Environmental Strategy*. Arctic Science and Technology Information System, Arctic Institute of North America, University of Calgary. Available at: http://publications.gc.ca/collections/Collection/R32-220-1998E.pdf. ISBN: 8676692661

Purpose/scope: An annotated bibliography and review of 215 publications which examined various aspects of the NWT hydrosphere, including water flow; evaporation and snow data; fish and sediment samples; and inorganic and organic water quality sampling.

Author Information: Multiple contributors, but edited by individuals from the Arctic Science and Technology Information System of the Arctic Institute of North America at the University of Calgary and from the Water Resources Division of Indian and Northern Affairs Canada.

Location: NWT broadly, but individual studies focus on specific regions and water bodies.

Relevance: Annotated summary of over 200 publications relating to NWT water quality and hydrology

Features: Excellent summary of NWT water quality and hydrology studies conducted from 1991-1997, with supporting citation information for each study.

Hutchinson Environmental Sciences Ltd. 2014. *Background report on aquatic ecosystem health for the Peace River watershed*. Mighty Peace Watershed Alliance. Available at: http://mightypeacesow.org/pdf/MPWA_Aquatic_Ecosystems_Background_Report.pdf

Indian and Northern Affairs Canada. 2007. *A preliminary State of Knowledge Report of Valued Components for the NWT Cumulative Impact Monitoring Program (NWT CIMP) and audit. Final draft. Updated June 2007.* Yellowknife, NT: Indian and Northern Affairs Canada, NWT Cumulative Impact Monitoring Program

Purpose/scope: "The purpose of this report is to provide an initial state of knowledge for identified Valued Components (VCs) under the NWT Cumulative Impact Monitoring Program (NWT CIMP) and Audit."

Author Information: Department of Indian and Northern Affairs Canada, prepared for the NWT Cumulative Impacts Program and Audit Working Group

Location: Multiple regions within the NWT

Findings: A starting point for the CIMP was to identify valued components (VC), which is "any part of the environment considered important based on economic, social, cultural, community, ecological, legal or political concern". VCs identified were as follows: water and sediment quality; water quantity; snow, ground ice and permafrost; fish habitat, population and harvest; fish quality; caribou; moose; other terrestrial mammals; other avian wildlife; marine mammals; vegetation; climate; air quality; and human health and community wellness. The preliminary state of knowledge of each of these VCs was reviewed and summarized, with a focus on key monitoring indicators, current monitoring, and monitoring gaps and recommendations.

Relevance: Defining VCs allows specific indicators and thresholds to be identified for NWT monitoring initiatives.

Features: Reviews of VCs in Part B, with key monitoring activities and documents outlined.

Jones, P., University of Saskatchewan, and Slave River and Delta Partnership. 2017. *Slave Watershed Environmental Effects Program*. Canadian Water Network

Purpose/scope: Hydrological trends and variability analysis for 19 stations along the Mackenzie River Basin from Edmonton to Inuvik

Author Information: Scientists in the Department of Civil Engineering, University of Waterloo

Location: Mackenzie River Basin

Findings: Winter month (i.e., December to April) flows showed strongly increasing trends. Slightly decreasing late spring and fall months. Earlier onset of spring freshet. Warming trend in winter and spring months. Patterns most pronounced for central and southern parts of basin.

Relevance: Recommendations for improved sampling and modelling

Features: Peer-reviewed journal article

Mackenzie River Basin Board. 2003. *Mackenzie River Basin State of the Aquatic Ecosystem Report 2003*. Fort Smith, NT: Mackenzie River Basin Board Secretariat. Available at: http://www.mrbb.ca/information/34/index.html

Mighty Peace Watershed Alliance. 2015. *State of the Watershed*. McLennon, AB: Mighty Peace Watershed Alliance. Available at: http://www.mightypeacesow.org/pdf/MPWA-SoW_Full.pdf. ISBN: 7803243355

Purpose/scope: A first attempt at documenting the state of the Peace and Slave Watershed, including the status of water quantity, quality, and aquatic ecosystems.

Author Information: Mighty Peace Watershed Alliance, a multi-sector, not-for-profit society composed of stakeholders and communities and the designated Watershed Planning and Advisory Council for this watershed.

Location: Literature review - covers the Alberta portion of the Peace/Slave River watershed.

Findings: Identifies six categories of watershed health indicators and summarizes each to give an assessment of the state of the watershed. Impacts to each of these indicators from existing or future human development are described. Historical trends are placed in context with current conditions, and knowledge gaps are identified.

Relevance: Outlines the current (as of 2015) state of the watershed and suggests indicators for watershed health monitoring programs.

Features: Six categories of watershed health indicators identified (landscape, biological community, surface water quantity, surface water quality, groundwater quantity, groundwater quality), with multiple potential indicators in each. Appendix 2 provides a summary of findings.

Mitchell, P., and E. Prepas, ed. 1990. *Atlas of Alberta lakes*. University of Alberta Press. Available at: http://albertalakes.ualberta.ca/?page=home

Purpose/scope: Reference book. A comprehensive, but dated, source of information on selected lakes.

Author Information: University and government scientists (many authors and contributors)

Location: About 100 lakes throughout Alberta, including over 20 lakes in the Peace and Athabasca watersheds, such as Lake Athabasca.

Findings: Includes an introduction to the Peace-Athabasca watersheds and descriptions of selected lakes, including drainage and lake basin characteristics, water quality, and biology. The book summarizes research and monitoring conducted up to the late 1980s, including unpublished government studies of limnology, fish, invertebrates and waterfowl.

Relevance: Provides good descriptions of water basin and lake characteristics, and is a source of information about older aquatic biology studies that are likely no longer available. Many of the references are to unpublished government data.

Features: The URL points to a searchable web version of the original book (not updated), linked to Google Maps to show locations.

North/South Consultants Inc. 2007. *Summary report on the initial assessment of ecological health of aquatic ecosystems in Alberta: Water quality, sediment quality and non-fish biota*. Water for Life: Healthy Aquatic Ecosystems. Edmonton, Alberta: Alberta Environment. Available at: https://open.alberta.ca/publications/9780778567479

Brief mention of Hay River, as well as Slave. Recommendations for interprovincial monitoring programs.

North/South Consultants Inc. 2007. *Information synthesis and initial assessment of the status and health of aquatic ecosystems in Alberta: Surface water quality, sediment quality and non-fish-biota*. Water for Life: Healthy Aquatic Ecosystems. Technical Report # 278/279-

01. Edmonton, Alberta: Alberta Environment. Available at: https://open.alberta.ca/publications/9780778567479

Discusses Hay and Slave River systems. Includes discussion of indicators for aquatic ecosystem health and associated frameworks. Section 2 discusses the methodology for their annotated bibliography.

Timoney, K.P. 2009. Three centuries of change in the Peace--Athabasca Delta, Canada. *Climatic Change* 93 (3): 485–515. DOI: 10.1007/s10584-008-9536-4

Wallace, R.R., and P.J. McCart. 1984. *The fish and fisheries of the Athabasca River basin: Their status and environmental requirements*. Dominion Ecological Consulting Ltd. and Aquatic Environments Ltd. for Alberta Environment Planning Division. Available at: https://era.library.ualberta.ca/files/cc08hg78m/1984 - Wallace - Athabasca River Fish & Fisheries.pdf

Purpose/scope: Provide a review of state of knowledge on fish in the Athabasca River basin.

Author Information: Fisheries biologists (consultants); report prepared for government

Location: Entire Athabasca River basin

Findings: The report reviews current (1984) knowledge on fish ecology and production in the Athabasca Basin. It is management oriented, with discussion on fisheries and management objectives. Findings are presented by sub-basin.

Relevance: Baseline information on large- and small-bodied fish – on ecology, socio-economic significance, and distribution.

Features: The report was digitized by the Oil Sands Research and Information Network, University of Alberta.

4.9.1 Supplementary Resources: Reviews, Summaries, State of Environment Reports

AECOM Canada Ltd. 2010. *Synthesis of ecological information related to the Peace-Athabasca Delta*. Fort Smith, Northwest Territories: Prepared for Peace-Athabasca Delta Ecological Monitoring Program (PADEMP).

Discussion of Key Indicators of Ecological Integrity. Appendix A is a listing of the monitoring programs for the region. May want to examine the references for the report in more detail.

AEMERA, and ECC. 2015. *2014-2015 technical results summary*. Prepared by Alberta Environmental Monitoring Evaluation and Reporting Agency and Environment and Climate Change Canada. Joint Canada Alberta Implementation Plan for Oil Sands Monitoring [JOSM]. Available at: http://aemera.org/wp-content/uploads/2015/08/JOSM-Technical-Results-Summary-2014-2015.pdf

Results report for 2014-2015 for all JOSM monitoring program. The report focuses on non-technical results summaries.

Collister, D.M., J.L. Kansas, T. Antoniuk, and B.J. Power. 2003. *Review and assessment of environmental effects information for wildlife and fish indicators in the Regional Sustainable*

Development Strategy (RSDS) study area within the Athabasca Oil Sands Region (AOSR). Final Report. Fort McMurray, AB: Cumulative Environmental Management Association. Available at: http://library.cemaonline.ca/ckan/dataset/4043d7a4-a6c2-49fd-a4e3-6ec1d5dd3451/resource/814467d9-7f11-40b0-b3bf-b2eaf5145b87/download/reviewandassessenvironeffectsinfoforwildlifeandfish.pdf

Donald, D.B., W. Aitken, J. Syrgiannis, N.E. Glozier, F.G. Hunter, and M.R. Gilchrist. 2004. State of the aquatic environment Peace-Athabasca delta - 2002. In *Northern Rivers Ecosystem Initiative: Collective Findings (CD-ROM)*, edited by Environment Canada. Compiled by F.M. Conly, Saskatoon, SK (With Alberta Environment)

ESTR Secretariat. 2013. *Taiga Plains Ecozone evidence for key findings summary*. Evidence for Key Findings Summary Report No.13. Canadian Biodiversity: Ecosystem Status and Trends 2010. Ottawa, ON: Canadian Councils of Resource Ministers. Available at: http://www.biodivcanada.ca/99361C1A-F46F-4A64-8366-51A6CA6EEAF5/No.13_Taiga_Plains_EKFS_July2013_E.pdf

Summary of ecosystem status and trends reporting for Canada for this ecozone.

Hutchinson Environmental Sciences Ltd. 2014. *Background report on aquatic ecosystem health for the Peace River watershed*. Mighty Peace Watershed Alliance. Available at: http://mightypeacesow.org/pdf/MPWA_Aquatic_Ecosystems_Background_Report.pdf

Discusses Hay and Slave River systems. Includes discussion of indicators for aquatic ecosystem health and associated frameworks. Section 2 discusses the methodology for their annotated bibliography.

Timoney, K.P. 2009. Three centuries of change in the Peace--Athabasca Delta, Canada. *Climatic Change* 93 (3): 485–515. DOI: 10.1007/s10584-008-9536-4

4.10 Indicator Development and Assessment

AEMERA, and ECC. 2015. *2014-2015 technical results summary*. Prepared by Alberta Environmental Monitoring Evaluation and Reporting Agency and Environment and Climate Change Canada. Joint Canada Alberta Implementation Plan for Oil Sands Monitoring [JOSM]. Available at: http://aemera.org/wp-content/uploads/2015/08/JOSM-Technical-Results-Summary-2014-2015.pdf

Results report for 2014-2015 for all JOSM monitoring program. The report focuses on non-technical results summaries.

AEMERA, and ECCC. 2014. *Joint Implementation plan for oil sands monitoring: Results report: 2013-2014*. Prepared by Alberta Environmental Monitoring Evaluation and Reporting Agency and Environment and Climate Change Canada. Joint Canada Alberta Implementation Plan for Oil Sands Monitoring [JOSM]. Available at: https://www.canada.ca/en/environment-climate-change/services/oil-sands-monitoring/results-report-2013-2014.html

Report for 2013-2014 for all JOSM monitoring programs, including information on what was sampled where and any changes in plans and commitments.

Ayles, G.B., M. Dubé, and D. Rosenberg. 2004. *Oil sands regional aquatic monitoring program (RAMP) scientific peer review of the five year report (1997-2001)*. Fort McMurray, AB:

Regional Aquatics Monitoring Program. Available at: www.andrewnikiforuk.com/Dirty_Oil_PDFs/RAMP Peer review.pdf

A more up-to-date peer review of RAMP, which includes many of the findings presented here (excluding evaluation of aquatic vegetation component), is in Main (2011).

Brown, J., D.D. Macdonald, K.J. Cash, and J.M. Culp. 2004. An annotated bibliography on cumulative effects assessment in northern river ecosystems. In *Northern Rivers Ecosystem Initiative: Collective Findings (CD-ROM)*, edited by Environment Canada. Compiled by F.M. Conly, Saskatoon, SK (With Alberta Environment)

Canada and Alberta. 2012. *Joint Canada/Alberta implementation plan for oil sands monitoring*. Government of Canada. Available at: http://publications.gc.ca/collections/collection_2013/ec/En84-89-2013-eng.pdf. ISBN: 9781100216300

Purpose/scope: This document presents the federal/Alberta plan for integrated monitoring of oil sands impacts—it brings together other programs, including RAMP, into one plan with separate monitoring programs and commitments to 2015.

Author Information: Federal/provincial committee personnel

Location: Athabasca River, oil sands area

Findings: "The Implementation Plan builds on a foundation of monitoring that is already in place, and is intended to enhance existing monitoring activities. It reflects the Integrated Monitoring Plan for the Oil Sands released by Environment Canada on July 21, 2011, and will be consistent with the Government of Alberta's plans for a province- wide environmental monitoring system, including the oil sands region."

Department of Indian Affairs and Northern Development. 1995. *The development of ecosystem maintenance indicators for the Slave, Liard and Peel Rivers. Background information*. Experts Workshop, September 12-14, 1995. Saskatoon, Saskatchewan

Information from a workshop on indicator development, including the Slave River

Eaton, B., and T. Charette. 2016. *Drivers, stressors, and indicators of wetland change in Alberta's Oil Sands Region – potential for use in wetland monitoring*. Cold Lake, Athabasca, Peace River: Alberta Innovates - Technology Futures and CPP Environmental Corp. Available at: http://ftp.public.abmi.ca/home/publications/documents/455_Eaton_etal_2017_DriversStressorsIndicatorsofWetlandChangeinAlbertaOSR_ABMI.pdf

Purpose/scope: Summary of features needed to develop a wetland monitoring program for northeastern Alberta. Focus on measuring cumulative effects of natural and anthropogenic factors on wetlands (i.e. detect an impact); and detecting changes in wetlands associated with specific anthropogenic activities (i.e. diagnose what caused an impact).

Author Information: Consultants, prepared for Alberta Innovates

Location: Cold Lake, Athabasca, and Peace River

Findings: Based on human footprint evaluation in the oil sands region and the identification of wetland indicators, the research considered the best diagnostic medium for change. The report recommends indicators and multi-level sampling considerations.

Relevance: Summary of the influence of upstream and oil sands anthropogenic activities on wetlands

Features: Extensive literature search, sampling, and research recommendations

Environment Canada. 2011. *Integrated monitoring plan for the oil sands: terrestrial biodiversity component*. Government of Canada. Available at: http://publications.gc.ca/site/eng/396865/publication.html. ISBN: 9781100189383, 1100189386

Plans for bird and amphibian monitoring for the oil sands region and downstream. This report provides more detail than is in the Joint Canada/Alberta implementation plan (Canada and Government of Alberta 2012).

GNWT. 2016. *A review of potential aquatic ecosystem indicators for the Slave River and the Slave River Delta, Northwest Territories. Draft report*

Hardi, P., and M. Roy. 2005. *Inventory of ecosystem indicators in Canada's North for the Northern Ecosystem Initiative*. International Institute for Sustainable Development. Available at: http://caid.ca/NorEcoSysIni2005.pdf

Hatfield Consultants. 2014. *Indicators of aquatic ecosystem integrity for the Mackenzie River Basin: Workshop summary*. North Vancouver, British Columbia: Hatfield Consultants

Purpose/scope: Summary of a 2013 workshop held to recommend indicators of aquatic ecosystem health for the 2017 State of Aquatic Ecosystems Report (SOAER), "and to apply both science-based and traditional knowledge (TK)-based approaches to indicator selection, to ensure that TK is most effectively identified and used by the Mackenzie River Basin Board in the SOAER process."

Author Information: Environmental consultants from Vancouver, contracted by the Mackenzie River Basin Board (MRBB). Report summarizes the input of 26 workshop participants.

Location: Workshop discussed the Mackenzie River Basin (parts of BC, AB, SK, YT, NWT) but the workshop itself was held in Edmonton, AB.

Findings: Six important elements: cumulative state of water quality (particular attention to effects of anthropogenic facilities), aquatic biology, water quantity, human access to land and water, land use and habitat fragmentation, and spiritual/cultural aspects of land and water. "To best capture both science-based and TK-based perspectives on ecosystem health, indicators should be chosen that span a range of scales and levels of detail or integration."

Relevance: No specific indicators outlined, but combines TK and science to inform what indicators should be selected based on consensus of workshop participants.

Features: Promotes integration of TK- and science-based approaches for selection of indicators (e.g., Table 2.1). Recommendations made for 2017 SOAER document.

Lindeman, D.H., E. Ritson-Bennett, and S. Hall, ed. 2011. Saskatoon, Saskatchewan: Prepared by Environment Canada. Available at: http://publications.gc.ca/collections/collection_2013/ec/En84-95-2-2013-eng.pdf.

Comprehensive summary of all of the monitoring studies (historical and current) in oil sands Phase 2 expansion area.

MacDonald Environmental Sciences Ltd. 1995. *Expert's workshop on the development of ecosystem maintenance indicators for the transboundary river systems within the Mackenzie River Basin: Workshop summary report*. Ladysmith, BC

MacDonald Environmental Sciences Ltd. 2009. *Conceptual Site Model Slave River Basin*. Yellowknife, NT: Prepared for Water Resources Division, Indian and Northern Affairs Canada

MacDonald Environmental Sciences Ltd. 1995. *Development of ecosystem maintenance indicators for the Slave, Liard, and Peel Rivers. Supporting documentation for Experts Workshop*. Ladysmith, BC: MacDonald Environmental Sciences Ltd.

MacDonald, D.D. 1990. *A discussion paper on the development of ecosystem guidelines for the Slave River, Northwest Territories*. Ladysmith, BC: MacDonald Environmental Sciences Ltd.

MacDonald, D.D. 1994. *A discussion paper on the development of ecosystem maintenance indicators for the transboundary river systems within the Mackenzie River Basin: Slave, Liard, and Peel rivers*. Ladysmith, BC: MacDonald Environmental Sciences Ltd.

MacDonald, D.D., and S.L. Smith. 1990. *An approach to monitoring ambient environmental quality in the Slave River Basin, Northwest Territories: Toward a consensus*. Yellowknife, Northwest Territories: Indian and Northern Affairs Canada, NWT Region Renewable Resources & Environment

Results of a workshop on planning monitoring for environmental quality. Includes biotic monitoring.

Main, C. 2011. *2010 regional aquatics monitoring program (RAMP) scientific review*. Calgary, AB: Integrated Water Management Program, Alberta Innovates - Technology Futures. Available at: http://ramp-alberta.org/UserFiles/File/RAMP_2010_Scientific_Peer_Review_Report.pdf

Purpose/scope: "The purpose of the 2010 RAMP review is to evaluate the methods presently used by RAMP to evaluate aquatic ecosystems and suggest changes to update the existing program where warranted [...] The overall goal of the RAMP program review is to answer three key questions as they pertain to each of the aforementioned areas of

concern: 1. Can the present Program detect changes if they occur? 2. Can the source of any potential changes be identified by the present Program? 3. Are the appropriate questions being asked by the Program and are the appropriate criteria being monitored to answer those questions?"

Author Information: Report authored by the program leader from the Integrated Water Management Program from Alberta Innovates-technology Futures, but the review itself was performed by nine researchers and scientists from universities, government, or unaffiliated industry.

Location: RAMP area of interest (Athabasca Oil Sands region, AB)

Findings: In general, the review panel concluded that the RAMP was not successful at meeting several of its own objectives, or insufficient data were available to assess this. The reviewers focused on climate and hydrology, water quality, benthos and sediment quality, fish populations, and acid-sensitive lake components of RAMP, and provided specific science-based recommendations to improve each.

Relevance: Highlights shortcomings of existing aquatic ecosystem monitoring and includes guidance and recommendations for strengthening future initiatives in this area.

Features: Detailed reviews/critiques of RAMP by each reviewer are provided in the appendices.

Patterson, L., and J. Shatford. 2013. *Making connections: Ecological monitoring in the Peace-Athabasca delta. Summary report of the forum hosted by the Peace-Athabasca Delta Ecological Monitoring Program (PADEMP) in Fort Chipewyan, Alberta, November 6-7, 2012*

Purpose/scope: "The primary objectives of this forum were to determine the extent to which the research and monitoring questions identified in the draft PAD Vulnerability Assessment (PADEMP 2013) are being addressed by current or planned monitoring projects and to discuss opportunities for cooperation, collaboration, information sharing and further inclusion of Traditional Knowledge."

Author Information: Report prepared by employees of Wood Buffalo NP. Forum participants in cluded Traditional Knowledge holders, community members and scientists.

Location: Fort Chipewyan, AB

Findings: "Of the 56 questions discussed, 19 (34%) are addressed by current or planned monitoring, 30 (54%) are partially addressed (either addressing part of the question, or addressing it in the region but not in the PAD), and 7 (13%) are not addressed. Key recommendations include: • Continue to explore opportunities for collaboration between and among monitoring project leads, Traditional Knowledge holders and community members at all stages of monitoring program development (planning, implementation, results interpretation and communication); • Communicate monitoring efforts and results on a regular basis to PAD community members. Tailor communication products to the needs of community members. Develop a variety of communication tools (Open Houses, newsletters, videos, reports, web-sites, etc.) and use plain, non-technical language that is suitable for a wide range of audiences. • Ensure monitoring results are used to support

management action required to maintain the ecological integrity of the delta. Don't monitor without action. Monitoring must be meaningful and lead towards effective management."

Relevance: Outlines what steps must be taken to ensure monitoring is properly directed to support TK, community, and scientific interests. Also highlights which ecosystem features (e.g., air quality, water quality, plants, animals, fish) are perceived to be inadequately monitored.

Features: List of questions of concern from community members regarding monitoring efforts

Prowse, T.D., F.M. Conly, M. Church, and M.C. English. 2002. A review of hydroecological results of the Northern River Basins Study, Canada. Part 1. Peace and Slave rivers. *River Research and Applications* 18 (5): 429–46. DOI: 10.1002/rra.681

Sokal, M.A. 2007. *Assessment of hydroecological changes at the Slave River Delta, NWT, using diatoms in seasonal, inter-annual and paleolimnological experiments*. PhD Thesis. University of Waterloo, Department of Biology. Available at: https://uwspace.uwaterloo.ca/bitstream/handle/10012/3364/Michael A Sokal - PhD Thesis.pdf?sequence=1&isAllowed=y

Purpose/scope: To evaluate relationships between hydrology, limnology, and ecology of water bodies in the Slave River Delta (at a variety of spatial and temporal scales) using diatoms as indicators.

Author Information: PhD candidate from the University of Waterloo

Location: Lakes in the Slave River Delta, NWT

Findings: Specific diatom "indicator" taxa were identified for each of evaporation-, flood-, and exchange-dominated lakes. "Results indicate that river flooding is the dominant hydrological process controlling the temporal dynamics of limnological and ecological conditions in lakes of the Slave River Delta."

Relevance: Diatoms show strong potential for use as indicators of waterbody hydrological and limnological conditions, and may be especially useful in a paleolimnological context to establish baselines and understand past trajectories of lakes in this area.

Features: Diatom percent abundance data. The second chapter of this thesis forms the basis of the annotated journal paper Sokal et al. 2008.

Squires, A.J., C.J. Westbrook, and M.G. Dubé. 2010. An approach for assessing cumulative effects in a model river, the Athabasca River Basin. *Integrated Environmental Assessment and Management* 6 (1): 119–34

Purpose/scope: "The main objectives of this paper were to 1) quantify spatial and temporal changes in water quantity and quality over the entire Athabasca River mainstem across historical (1966-1976) and current day (1996-2006) time periods and 2) to evaluate the significance of any changes relative to existing benchmarks (e.g. water quality guidelines)."

Author Information: Researchers from the University of Saskatchewan

Location: Mainstem Athabasca River, AB, from the headwaters to the mouth at Lake Athabasca

Findings: "Our results show that significant changes have occurred in both water quantity and quality between the historical and current day Athabasca River basin [specifically, decrease in discharge and increase in dissolved Na, SO4, Cl, TP concentrations in the second time period]. It is known that in addition to climatic changes, rivers which undergo increased agricultural, urban and industrial development can experience significant changes in water quantity and quality due to increased water use, discharge of effluents and surface run-off."

Relevance: Cumulative effects assessment approach can be applied to any river system; data for the Athabasca in particular can help to quantify natural and anthropogenic stressors, and put the magnitude of local changes in regional context.

Stantec Consulting Ltd. 2016. *State of Aquatic Knowledge for the Hay River Basin*. Yellowknife, NT: Stantec Consulting Ltd. Available at: https://www.enr.gov.nt.ca/sites/enr/files/aquatic_knowledge_hay_river_basin.pdf.

Two fish contaminant studies are summarized. Grey et al. 1995; Bujold 1995 as summarized in Hatfield 2009. None of these reports are available.

Tri-Star Environmental Consulting. 2011. *Approaches to the development of transboundary surface water quality objectives for the Hay and Slave rivers*. Yellowknife, Northwest Territories: Report Prepared for Water Resources Division, Aboriginal and Northern Affairs Canada

Purpose/scope: To update site- and parameter-specific water quality objectives for the transboundary Slave and Hay Rivers for Alberta and NWT for a variety of flow conditions using a range of generally-accepted statistical methods.

Author Information: Environmental consulting company, prepared for the Water Resources Division of Aboriginal Affairs and Northern Development Canada

Location: Slave and Hay Rivers, between AB and NWT

Findings: National/provincial water quality guidelines are typically too generic to be meaningfully applied to individual waterbodies; instead site-specific monitoring objectives should be established based on the historical data set and local environmental conditions (including variable hydrologic and seasonal conditions). The transboundary rivers should be monitored using objectives, alert levels, and trigger levels based on the 95th percentile statistic. Objectives, alert levels, and trigger levels are established for multiple routine, nutrient, and metal variables for each river often with different values for each of winter baseflow, spring freshet, summer recession and fall recession.

Relevance: Water quality monitoring target levels that are set specific to each river will support the delineation of specific biological monitoring objectives if a similar approach is taken (e.g., invertebrate communities that are characteristic of good water quality in the Slave River in AB/NWT rather than generic nation-wide indicators)

Features: Table E1 summarizes proposed water quality objectives, alert, and trigger levels for each of the Slave and Hay Rivers.

Wiklund, J.A., N. Bozinovski, R.I. Hall, and B.B. Wolfe. 2010. Epiphytic diatoms as flood indicators. *Journal of Paleolimnology* 44 (1): 25–42. DOI: 10.1007/s10933-009-9383-y

4.10.1 Supplementary Resources: Indicator Development and Assessment

AEMERA, and ECC. 2015. *2014-2015 technical results summary*. Prepared by Alberta Environmental Monitoring Evaluation and Reporting Agency and Environment and Climate Change Canada. Joint Canada Alberta Implementation Plan for Oil Sands Monitoring [JOSM]. Available at: http://aemera.org/wp-content/uploads/2015/08/JOSM-Technical-Results-Summary-2014-2015.pdf

Results report for 2014-2015 for all JOSM monitoring program. The report focuses on non-technical results summaries.

AEMERA, and ECCC. 2014. *Joint Implementation plan for oil sands monitoring: Results report: 2013-2014*. Prepared by Alberta Environmental Monitoring Evaluation and Reporting Agency and Environment and Climate Change Canada. Joint Canada Alberta Implementation Plan for Oil Sands Monitoring [JOSM]. Available at: https://www.canada.ca/en/environment-climate-change/services/oil-sands-monitoring/results-report-2013-2014.html

Report for 2013-2014 for all JOSM monitoring programs, including information on what was sampled where and any changes in plans and commitments.

Ayles, G.B., M. Dubé, and D. Rosenberg. 2004. *Oil sands regional aquatic monitoring program (RAMP) scientific peer review of the five year report (1997-2001)*. Fort McMurray, AB: Regional Aquatics Monitoring Program. Available at: www.andrewnikiforuk.com/Dirty_Oil_PDFs/RAMP Peer review.pdf

A more up-to-date peer review of RAMP, which includes many of the findings presented here (excluding evaluation of aquatic vegetation component), is in Main (2011).

Brown, J., D.D. Macdonald, K.J. Cash, and J.M. Culp. 2004. An annotated bibliography on cumulative effects assessment in northern river ecosystems. In *Northern Rivers Ecosystem Initiative: Collective Findings (CD-ROM)*, edited by Environment Canada. Compiled by F.M. Conly, Saskatoon, SK (With Alberta Environment)

Department of Indian Affairs and Northern Development. 1995. *The development of ecosystem maintenance indicators for the Slave, Liard and Peel Rivers. Background information*. Experts Workshop, September 12-14, 1995. Saskatoon, Saskatchewan

Information from a workshop on indicator development, including the Slave River.

Environment Canada. 2011. *Integrated monitoring plan for the oil sands: terrestrial biodiversity component*. Government of Canada. Available at: http://publications.gc.ca/site/eng/396865/publication.html

Plans for bird and amphibian monitoring for the oil sands region and downstream. This report provides more detail than is in the Joint Canada/Alberta implementation plan (Canada and Government of Alberta 2012).

GNWT. 2016. *A review of potential aquatic ecosystem indicators for the Slave River and the Slave River Delta, Northwest Territories. Draft report*

Hardi, P., and M. Roy. 2005. *Inventory of ecosystem indicators in Canada's North for the Northern Ecosystem Initiative*. International Institute for Sustainable Development. Available at: http://caid.ca/NorEcoSysIni2005.pdf

Lindeman, D.H., E. Ritson-Bennett, and S. Hall, ed. 2011. *Existing and historical water monitoring in the Phase 2 geographic expansion area, to 2011*. Saskatoon, Saskatchewan: Prepared by Environment Canada. Available at: http://publications.gc.ca/collections/collection_2013/ec/En84-95-2-2013-eng.pdf

Comprehensive summary of all of the monitoring studies (historical and current) in oil sands Phase 2 expansion area.

MacDonald Environmental Sciences Ltd. 2009. *Conceptual Site Model Slave River Basin*. Yellowknife, NT: Prepared for Water Resources Division, Indian and Northern Affairs Canada

MacDonald Environmental Sciences Ltd. 1995. *Expert's workshop on the development of ecosystem maintenance indicators for the transboundary river systems within the Mackenzie River Basin: Workshop summary report*. Ladysmith, BC

MacDonald Environmental Sciences Ltd. 1995. *Development of ecosystem maintenance indicators for the Slave, Liard, and Peel Rivers. Supporting documentation for Experts Workshop*. Ladysmith, BC: MacDonald Environmental Sciences Ltd.

MacDonald, D.D. 1990. *A discussion paper on the development of ecosystem guidelines for the Slave River, Northwest Territories*. Ladysmith, BC: MacDonald Environmental Sciences Ltd.

MacDonald, D.D. 1994. *A discussion paper on the development of ecosystem maintenance indicators for the transboundary river systems within the Mackenzie River Basin: Slave, Liard, and Peel rivers*. Ladysmith, BC: MacDonald Environmental Sciences Ltd.

MacDonald, D.D., and S.L. Smith. 1990. *An approach to monitoring ambient environmental quality in the Slave River Basin, Northwest Territories: Toward a consensus*. Yellowknife, Northwest Territories: Indian and Northern Affairs Canada, NWT Region Renewable Resources & Environment

Results of a workshop on planning monitoring for environmental quality. Includes biotic monitoring.

Prowse, T.D., F.M. Conly, M. Church, and M.C. English. 2002. A review of hydroecological results of the Northern River Basins Study, Canada. Part 1. Peace and Slave rivers. *River Research and Applications* 18 (5): 429–46. DOI: 10.1002/rra.681

Stantec Consulting Ltd. 2016. *State of Aquatic Knowledge for the Hay River Basin*. Yellowknife, NT: Stantec Consulting Ltd. Available at: https://www.enr.gov.nt.ca/sites/enr/files/aquatic_knowledge_hay_river_basin.pdf

Two fish contaminant studies are summarized. Grey et al. 1995; Bujold 1995 as summarized in Hatfield 2009. None of these reports are available.

Wiklund, J.A., N. Bozinovski, R.I. Hall, and B.B. Wolfe. 2010. Epiphytic diatoms as flood indicators. *Journal of Paleolimnology* 44 (1): 25–42. DOI: 10.1007/s10933-009-9383-y

4.11 Research and Methods

Alberta Environment. 2008. *Handbook for State of the Watershed reporting: A guide for developing State of the Watershed reports in Alberta*. Edmonton, AB: Alberta Environment. Available at: http://www.landstewardship.org/media/uploads/Handbook_for_State_of_the_Watershed_Reporting_Nov2008.pdf

Purpose/scope: Provides guidance for development of state of the watershed reports. The purpose of these watershed reports is to help identify potential problems and concerns, thereby guiding future stewardship. The handbook "introduces a basic process that could be undertaken at any scale and/or on any landscape, for gathering and evaluating information to develop an understanding of past and current watershed conditions and the influencing factors."

Author Information: Government of Alberta (Alberta Environment); no individual authors named.

Location: Alberta (not specific to a region)

Findings: No research or monitoring findings. The handbook contains a checklist of what makes a good indicator and descriptions of types of indicators to consider (condition, pressure, and response indicators). A table lists examples of indicators, including biological indicators. For each indicator, the table includes a statement on the assessment role of the indicator and examples of metrics. Rating systems are presented, including for riparian health. Appendix A is sources of information.

Relevance: Includes methodology for development of watershed health indicators and a listing of data and information sources.

Features: The handbook is geared to a non-technical audience.

Alberta Environment and Sustainable Resource Development. 2012. *Guide to reporting on common indicators used in state of the watershed reports*. Water for Life. Alberta Government. Available at: https://d3n8a8pro7vhmx.cloudfront.net/lswc/pages/18/attachments/original/1485716188/SOW-Indicators.pdf?1485716188

Baird, D.J., and M. Hajibabaei. 2012. Biomonitoring 2.0: A new paradigm in ecosystem assessment made possible by next-generation DNA sequencing. *Molecular Ecology* 21: 2039–44. DOI: 10.1111/j.1365-294X.2012.05519.x

Barbour, M.T., J. Gerritsen, B. Snyder, and J.B. Stribling. 1999. *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish*. EPA 841-B-99-002. Second Edi. Washington, D.C.: United States Environmental Protection Agency Office of Water. Available at: https://nepis.epa.gov/Exe/ZyNET.exe/20004OQK.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1995+Thru+1999&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=

Beck, W.M. 1955. Suggested Method for Reporting Biotic Data. *Sewage and Industrial Wastes* 27 (10): 1193–97

Bernard, H.R. 2006. *Research Methods in Anthropology: Qualitative and Quantitative Approaches*. Fourth Edi. Toronto: Altamira Press

Coombs, M. 2008. *Indicators for assessing environmental performance of watersheds in southern Alberta*. Lethbridge, Alberta: Alberta Environment, Regional Environmental Management. Available at: http://www.assembly.ab.ca/lao/library/egovdocs/2008/alen/167026.pdf. ISBN: 9780778573449

Purpose/scope: Identifies generic indicators linked to provincial watershed management outcomes, one of which is "healthy ecosystems".

Author Information: Alberta government scientists

Location: Southern Alberta

Findings: Indicators for aquatic and riparian ecosystems are divided into species indicators and integrated multi-species measures.

Relevance: Outside of the area of interest and very generic. However, the report contains some good discussion on indicator development and on designing an integrated monitoring program.

Department of Environment and Natural Resources. 2016. *Northwest Territories Cumulative Impact Monitoring Program (NWT CIMP). Monitoring and Research Results 2010-2015: Fish*. Yellowknife, NT: Northwest Territories Cumulative Impact Monitoring Program, Department of Environment and Natural Resources, Government of the Northwest Territories. Available at: http://sdw.enr.gov.nt.ca/nwtdp_upload/CIMP_fish report_web_revised.pdf. ISBN: ISBN: 978-0-7708-0242-4

Purpose/scope: To combine geospatial modelling and isotope tracers with traditional and local knowledge to predict and evaluate important areas for spawning, rearing, and staging for fish linking cumulative effects to fish with local conditions of the Slave River

Author Information: University researchers

Location: Slave River, Slave River delta

Findings: A geospatial model for the Slave River and Delta is being developed. All of the mercury and arsenic levels found in the Slave River Delta sediment were below CCME levels.

Relevance: Refining predictive models to assess the health of the Slave River ecosystem.

Eaton, B., and T. Charette. 2016. *Drivers, stressors, and indicators of wetland change in Alberta's Oil Sands Region – potential for use in wetland monitoring*. Cold Lake, Athabasca, Peace River: Alberta Innovates - Technology Futures and CPP Environmental Corp. Available at: http://ftp.public.abmi.ca/home/publications/documents/455_Eaton_etal_2017_DriversStressorsIndicatorsofWetlandChangeinAlbertaOSR_ABMI.pdf

Purpose/scope: Summary of features needed to develop a wetland monitoring program for northeastern Alberta. Focus on measuring cumulative effects of natural and anthropogenic factors on wetlands (i.e., detect an impact); and detecting changes in

wetlands associated with specific anthropogenic activities (i.e., diagnose what caused an impact).

Author Information: Consultants, prepared for Alberta Innovates

Location: Cold Lake, Athabasca, and Peace River

Findings: Based on human footprint evaluation in the oil sands region and the identification of wetland indicators, the research considered the best diagnostic medium for change. The report recommends indicators, and multi-level sampling considerations.

Relevance: Summary of the influence of upstream and oil sands anthropogenic activities on wetlands.

Features: Extensive literature search, sampling, and research recommendations.

ECCC. 2017. "National Fish Contaminants Monitoring and Surveillance Program". http://www.ec.gc.ca/scitech/default.asp?lang=en&n=828EB4D2-1

Environment Canada. 2012. *Metal mining technical guidance for environmental effects monitoring*. ISBN: 9781100204963

Gray, C., D.J. Baird, S. Baumgartner, U. Jacob, G.B. Jenkins, E.J. O'Gorman, X. Lu, et al. 2014. Ecological networks: the missing links in biomonitoring science. Edited by Joseph Bennett. *Journal of Applied Ecology* 51 (5): 1444–49. DOI: 10.1111/1365-2664.12300

Hatfield Consultants. 2009. *Technical design and rationale*. Regional Aquatics Monitoring Program (RAMP)

Hatfield Consultants. 2011. *Addenda to the RAMP technical design and rationale*. Regional Aquatics Monitoring Program (RAMP

Table 10 has additional information on benthic monitoring stations. Tables 11 through 15 have additional information for fish monitoring stations.

Hill, B.H., A.T. Herlihy, P.R. Kaufmann, R.J. Stevenson, F.H. McCormick, and C.B. Johnson. 2000. Use of periphyton assemblage data as an index of biotic integrity. *Journal of the North American Benthological Society* 19 (1): 50–67. DOI: 10.2307/1468281

Hilsenhoff, W.L. 1977. *Use of arthropods to evaluate water quality of streams*. Technical Bulletin No. 100. Madison, WI: Department of Natural Resources. Available at: http://dnr.wi.gov/files/PDF/pubs/ss/SS0100.pdf

Hughes, R.M., P.R. Kaufmann, A.T. Herlihy, T.M. Kincaid, L. Reynolds, and D.P. Larsen. 1998. A process for developing and evaluating indices of fish assemblage integrity. *Canadian Journal of Fisheries and Aquatic Sciences* 55 (7): 1618–31. DOI: 10.1139/f98-060

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant, and I.J. Schlosser. 1986. *Assessing biological integrity in running waters: A method and its rationale*. Special Publication No. 5. Champaign, Illinois: Illinois Natural History Survey

Karr, J.R. 1981. Assessment of Biotic Integrity Using Fish Communities. *Fisheries* 6 (6). Taylor & Francis Group: 21–27. DOI: 10.1577/1548-8446(1981)006<0021:AOBIUF>2.0.CO;2

Karr, J.R., and E.W. Chu. 1999. *Restoring Life in Running Waters: Better Biological Monitoring*. Covelo, California: Island Press. ISBN: 1559636742

Lenat, D.R. 1988. Water Quality Assessment of Streams Using a Qualitative Collection Method for Benthic Macroinvertebrates. *Journal of the North American Benthological Society* 7 (3): 222–33. DOI: 10.2307/1467422

Morris, M., and R.C. de Loë. 2016. Cooperative and adaptive transboundary water governance in Canada's Mackenzie River Basin: status and prospects. *Ecology and Society* 21 (1): art26. DOI: 10.5751/ES-08301-210126

Palmer, C.M. 1969. A composite rating of algae tolerating organic pollution. *Journal of Phycology* 5 (1). Blackwell Publishing Ltd: 78–82. DOI: 10.1111/j.1529-8817.1969.tb02581.x

Prowse, T.D., and M. Conly. 1996. *Impacts of flow regulation on the aquatic ecosystem of the Peace and Slave rivers*. Synthesis Report No.1. Northern River Basin Study. Edmonton, Alberta: Northern River Basins Study. Available at: http://www.barbau.ca/sites/www.barbau.ca/files/0-662-24697-7-bw_0.pdf

SALMO Consulting Inc., URSUS Ecosystem Management Ltd., and GAIA Consultants Inc. 2001. *Review of predictive modeling tools for wildlife and fish key indicators in the Wood Buffalo region*. Fort McMurray, AB: Cumulative Environmental Management Association - Wood Buffalo Region Wildlife and Fish Working Group. Available at: http://library.cemaonline.ca/ckan/dataset/5a9271ef-d89a-40dc-959b-dca1de92637c/resource/d02fa441-74b8-415f-b482-7d1cba35a5ff/download/predmodtoolsfw.pdf

Sanders, R.E., R.J. Miltner, C.O. Yoder, and E.T. Rankin. 1999. The use of external deformities, erosion, lesions, and tumors (DELT anomalies) in fish assemblages for characterizing aquatic resources. In *Assessing the sustainability and biological integrity of water resources using fish communities*, edited by T.P. Simon, 203–24. Boca Raton: CRC Press

Smith, R., L. Bizikova, and K. MacDougall. 2016. *Aquatic ecosystem indicators for the Mackenzie River Basin. Final report*. Winnipeg, Manitoba: International Institute for Sustainable Development

"This report describes the outcome of a project undertaken by the International Institute for Sustainable Development (IISD) in response to a request from the Government of the Northwest Territories the for identification of indicators for the Mackenzie River Basin Board's (MRBB) 2017 State of the Aquatic Ecosystem Report (SOAER)." The report includes TK indicators.

Stevenson, R.J., and J.P. Smol. 2003. Use of algae in environmental assessements. In *Freshwater Algae of North America*, edited by John D. Wehr and Robert G. Sheath, 775–804. A Volume in Aquatic Ecology.

Thomsen, P.F., and E. Willerslev. 2015. Environmental DNA - An emerging tool in conservation for monitoring past and present biodiversity. *Biological Conservation* 183. Elsevier Ltd: 4–18. DOI: 10.1016/j.biocon.2014.11.019

Weitzel, R.L. 1979. Periphyton measurements and applications. In *Methods and Measurements of Periphyton Communities: A Review. ASTM STP 690*, edited by R.L. Weitzel, 3–33. Philadelphia, Pennsylvania: American Society for Testing and Materials. Available at: https://www.astm.org/DIGITAL_LIBRARY/STP/SOURCE_PAGES/STP690.htm

Wolfe, B.B., D. Armitage, S. Wesche, B.E. Brock, M.A. Sokal, K.P. Clogg-Wright, C.L. Mongeon, M.E. Adam, R.I. Hall, and T.W.D. Edwards. 2007. From isotopes to TK interviews: Towards interdisciplinary research in Fort Resolution and the Slave River Delta, Northwest Territories. *Arctic* 60 (1): 75–87. DOI: 10.2307/40513160

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