Regional Substance Load Allocation Study for the Athabasca River – Phase 2 & Updated Results Summary

Contents

Introduction

The original technical report and its update, released in 2014 and 2016 respectively, describe a Regional Substance Load Allocation Study for the Athabasca River (RSLA) that was undertaken by Canada's Oil Sands Innovation Alliance (COSIA). The study demonstrates how technical aspects of Alberta Environment and Sustainable Resource Development (now the Alberta Energy Regulator) policies for water quality protection could be implemented using a regional, collaborative, and equitable approach to determine acceptable substance levels and cumulative effects for hypothetical oil sands water releases to the Athabasca River. It builds on previous undertakings in this area by oil sands industry members, with a particular focus on a *regional* approach to watershed management that supports understanding the cumulative impacts of oil sands development.

Study Overview

The study considers a hypothetical future operational period between 2020 and 2040 in which seven companies representing 13 oil sands operations could seek authorization to release treated tailings water or other operational waters to the Athabasca River. Currently, water used for mining and extraction of bitumen at oil sands sites is recycled, resulting in a growing inventory of water and increasing salt concentrations up until mine closure (i.e., no water in the recycle loop is released to the natural environment during operations). The existing plan is to release this lower quality water at mine closure through pit lakes, but this study contemplates an alternative. Instead of releasing stored water when a mine is closed, it may be preferable to return it to the environment while the mine is still operational, as part of a sustainable water management framework. This would reduce the footprint of water inventories, manage the build-up of salts in recycle circuits, manage the quality of water that must ultimately be returned to the receiving environment, and potentially reduce the net water demand on the river.

The Substance Load Allocation (SLA), which is the amount of a stream's total permissible substance load that is allocated to one operation, was derived for each of the 13 oil sands operations simultaneously. SLAs were calculated such that site-specific instream thresholds associated with chronic effects to aquatic life would not be exceeded for "worst-case" conditions in the receiving environment. The worst-case modelling conditions included using the "7Q10" flow for the Athabasca River (i.e., the lowest stream flow for seven consecutive days that would be expected to occur once in ten years). The default non-attainment (i.e., exceedance) frequency corresponds to a one-in-three-year excursion from the instream threshold.

The outfall location and bitumen production capacity of each operation are key factors to consider. The outfalls from the 13 oil sands operations range from 20 to 116 km downstream of Fort McMurray. Bitumen production capacity ranges from 157,000 to 501,000 barrels per day. The location, timing, water quality, and toxicity of the hypothetical releases being considered are not fully defined. Therefore, 90 release configurations and many scenarios of release (between one and 13 simultaneous releases with different SLAs) were considered, resulting in thousands of modelling scenarios.

Water quality parameters of interest include constituents of potential concern (COPCs) and major ions. See the Appendix for a summary of these parameters and their water quality effects thresholds. However, SLAs were determined in this analysis for only a representative selection of parameters. Namely, chloride was considered because it is a limiting substance for water recycling; chronic toxicity was used as an overall indicator for potential impacts to aquatic life; and aluminum, iron, and chromium were considered because the natural background concentrations of these substances in the Athabasca River for the open-water season are above instream thresholds. These parameters will be discussed in more detail throughout this report.

For water quality parameters, instream thresholds should be achieved beyond a limited area (mixing zone) downstream of the outfall prior to further mixing in the Athabasca River. In the Athabasca River, lateral mixing of a release occurs slowly, particularly during low-flow periods. The derivation of SLAs must account for loadings from upstream release as well as local mixing characteristics for each release.

The Athabasca River Model (ARM) was used for predictive water quality modelling. ARM is uniquely suited to address the specific challenges of the study and has been used previously for similar studies as well as all oil sands mine Environmental Impact Assessments (EIAs). The model accounts for water withdrawals and point and non-point sources as well as local mixing characteristics for each release. It also includes loading from natural upstream sources and tributaries as well as existing releases that have been identified in EIAs. ARM is capable of efficiently implementing and analysing a large number of scenarios. ARM calculates SLAs automatically using an optimization routine to determine release loads that will achieve instream thresholds for a number of outfall locations simultaneously. More details on ARM will be presented below.

Rationale

Aside from muskeg drainage, overburden dewatering, and diverted drainage, oil sands operations do not currently have water releases to the Athabasca River. Instead, water used for mining and extraction of bitumen at oil sands sites is recycled, resulting in a growing inventory of water and increasing salt concentrations. At mine closure, this inventory will be released via pit lakes. This approach requires large storage locations for oil sands operations and results in the deterioration of water quality through multiple recycles. Furthermore, recycling water is expensive and energy-intensive, and will become more so as major ions accumulate. Elevated levels of major ions can cause problems with equipment and could result in receiving stream effects if released at elevated levels. Thus, there are many drivers which motivate the pursuit of an alternative to the current status quo.

As an alternative to releasing water only at closure, returning water during the operational phase of mines (as part of a sustainable water management framework) may have many benefits:

- reduction of footprint of water inventories
- managing the build-up of salts in recycle circuits
- managing the quality of water that must ultimately be returned to the receiving environment
- reducing the net water demand on the river

Regulatory Background

In principle, policies and Acts in Alberta enable the adoption of regional strategies for the release of operational waters. These include the *Alberta Environmental Protection and Enhancement Act* (AEP 2000), Industrial Release Limits Policy (AENV 2000), and Water Quality Based Effluent Limits Procedures Manual (AEP 1995).

The Industrial Release Limits Policy requires the adoption of end-of-pipe release limits that are the more stringent of either technology-based or water-quality based release limits on a parameter by parameter basis. Technology-based release limits are performance requirements for demonstrated and economically achievable treatment technology for an industrial sector. Water-quality based release limits are end-of-pipe quality or loading restrictions that are derived to maintain instream water quality at levels required for protection of aquatic life and water uses. The methods for developing water-quality based release limits are provided in the Water Quality Based Effluent Limits Procedures Manual.

The Industrial Release Limits Policy and Water Quality Based Effluent Limits Procedures Manual have been applied regionally for the Athabasca River in developing effluent limits for the pulp and paper mill industry (Mackenzie 1996; AENV 2005). At a federal level, similar procedures have been developed for municipal releases by the Canadian Council of Ministers of the Environment (CCME) in the Canada-wide Strategy for the Management of Municipal Wastewater Effluent (CCME 2008, 2009). Additional guidance on completing the RSLA study is obtained from a number of United States Environmental Protection Agency (USEPA) documents relating to Total Maximum Daily Loads (TMDLs).

This study is also informed by chronic effects benchmarks used in recent oil sands EIAs, and the Surface Water Quality Management Framework for the Lower Athabasca River (ESRD 2012a), which was developed as part of the Lower Athabasca Regional Plan (LARP) (GoA 2012). The framework includes monitoring instream concentrations, using an existing monitoring station (Old Fort, near Embarras), and evaluating concentrations relative to ambient water quality triggers and limits. Complete mixing of the oil sands-related releases would be achieved at Old Fort, 200 km downstream of Fort McMurray. In contrast to the triggers, the water quality release limits are considered conservatively-estimated effects thresholds. The management response would include evaluation of loading sources and, potentially, a required reduction of previously authorized releases.

Method

The approach for determining supportable loads for each loading source and allocating loads among sources is guided by the Industrial Release Limits Policy, the Water Quality Based Effluent Limits Procedures Manual, the previous pulp and paper mill industry and municipal wastewater release strategies, and the United States Environmental Protection Agency (USEPA). Critically, the regional strategy contemplated in this study must consider all current and future loads and allocate them in such a way that instream thresholds are met at the edge of the regulatory mixing zone for each release. This is expected to result in a more effective management strategy than considering applications on an individual basis.

Approach

Instream criteria

The methods for developing water-quality based release limits are provided in the Water Quality Based Effluent Limits Procedures Manual (AEP 1995). The steps to develop water quality based release limits are as follows:

- identify substances, characterize water uses, and determine appropriate instream thresholds
- calculate release water and river flow statistics
- characterize background (upstream) water quality
- complete mass balance dilution modelling
- evaluate results for mixing-zone boundaries to determine if there is a reasonable potential for instream thresholds to be exceeded and evaluate qualitative mixing-zone restrictions
- undertake SLA modelling, determine required loading apportionment among releases, and calculate water-quality based release limits for appropriate parameters

For COPCs, instream thresholds must be met beyond a mixing zone of limited spatial extent downstream of a release location (see Figure 1). Beyond the mixing zone, the duration and frequency of aquatic life exposure to substance concentrations above thresholds should be limited. For chronic instream thresholds, the mixing zone width is half the river width and its length is ten times the river width. For acute thresholds, the mixing zone is 30 m surrounding the outfall. Additionally, the following narrative mixing-zone restrictions must be achieved:

- protection from acute lethality is afforded to passing organisms
- the chronic or sub-lethal zone is limited to the extent that the water body as a whole is protected
- fish spawning grounds are avoided
- drinking water intakes are not impinged upon
- acute mixing zones do not overlap
- chronic mixing zones for the same substance do not overlap
- existing uses are not interfered with
- mixing zones are not used as an alternative to reasonable and practical treatment
- a mixing-zone allowance is not extended to bioaccumulative substances or hazardous substances for which provincial, national, or international instream guidelines do not exist unless it can be specifically demonstrated that they will not cause an adverse impact

Most of these conditions will usually be met by specified spatial mixing zone restrictions, but may require site-specific assessments.

Substances of interest and benchmarks for instream criteria were developed with reference to several existing provincial and federal government documents, and are consistent with the aforementioned pulp and paper mill industry and municipal wastewater regional approaches.

These benchmarks are best estimates of what ultimately would be site-specific water quality objectives derived by regulators.

To enable defensible predictions of potential instream substance concentrations the model must characterize existing loading sources, including natural upstream sources and tributaries, releases associated with developments that are approved, and potential future releases identified in EIAs. Contributions from existing operations and contributions from planned developments identified in EIAs are considered "existing" for the purposes of this study.

Determining SLAs

The SLA for a particular substance represents the loading (or concentration) in the release water that results in compliance with an instream threshold at a regulatory mixing-zone boundary under assumed conditions of flow, background contributions, existing contributions, and mixing characteristics of the river. SLAs should be based on the more restrictive of chronic and acute instream thresholds. The relationship between the instream threshold and the SLA is illustrated in Figure 1.

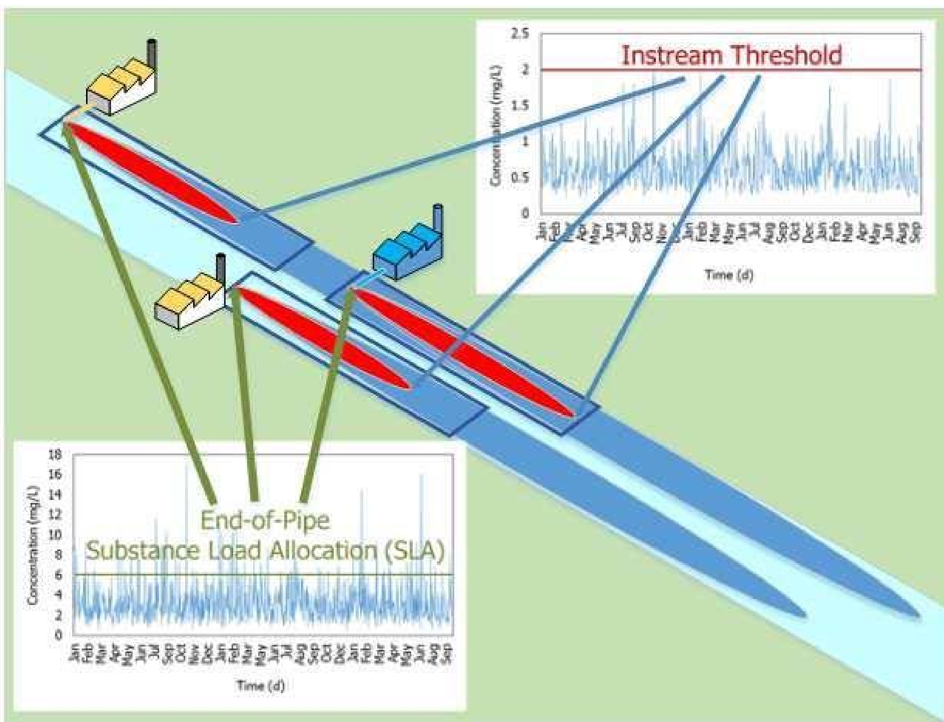

Figure 1: This figure depicts the relationship between the instream threshold and the substance load allocation (SLA). Note that the SLA is below the maximum daily limit that the release would be expected to achieve.

In this study, SLAs are derived, using a steady-state model, to account for variation in both the release water and the receiving environment. Analysis is completed such that both the end-of-pipe SLA and the instream threshold would only rarely be observed, and release water concentrations (or loading) would be well below the SLA and the instream concentration would be well below the instream threshold. The probability basis for the SLA has been selected, along with the worst-case steady-state modelling conditions (i.e. 7Q10), to achieve one-day-in-three-year excursion above the instream threshold at the regulatory mixing zone boundary corresponding to a 99.91th percentile compliance frequency. This conservative estimation for SLAs makes them protective for all flow conditions.

These procedures for determining SLAs were developed for industrial releases expected to have *constant* flows determined by process equipment. Therefore, constant release flows are typically assumed in the calculation of SLAs. However, the high on-site storage available to oil sands operations also enables the application of *variable* SLAs to the region. This flexibility was leveraged to derive a number of SLAs corresponding to potential flow management approaches. These SLAs are applied in the model:

- constant SLAs derived for ice-cover worst-case (7Q10) flow conditions and applied throughout the year
- seasonal SLAs derived for ice-cover and open-water worst-case (7Q10) flow conditions and applied in their respective season (note that ice-cover seasonal SLAs are the same as constant SLAs)
- flow-dependent SLAs derived as a function of historical daily flows in the Athabasca River. The flow levels used were low (i.e. 7Q10), mean, and high river flows

Constant and seasonal SLAs were derived using Chronic Effects Benchmarks (CEBs) developed for recent oil sands projects. The original purpose of the CEBs was for use in EIAs that used model predictions and literature-based effects benchmarks to assess potential impacts to aquatic health as a result of changes to water quality. The predicted changes to water quality as a result of a development are based on models with multiple conservative assumptions. Conservative modelling assumptions result in an overestimate of exposure, meaning that comparison of model predictions to the CEBs results in a conservative assessment. Application of the CEBs for the SLA study is also considered appropriate given that it is a scoping exercise and the modelling conducted as part of the study also applies similarly conservative assumptions.

Seasonal SLAs would be expected to achieve very similar compliance frequencies to constant SLAs, when derived using worst-case flow conditions. Seasonal SLAs are also useful to determine if open-water flow conditions are more limiting for some substances.

Approaches to achieve instream threshold compliance for flow-dependent SLAs have not been defined in general terms. Suitable flow-dependent SLAs were derived by considering a range of instream targets that were lower than or equal to the CEB, which was used to determine the constant and seasonal SLAs. It was anticipated that using the CEB to derive a flow-dependent SLA would not achieve an acceptable level of compliance with the instream threshold, so candidate instream targets were defined relative to the CEB, the background concentration, or the Lower Athabasca Regional Plan (LARP) trigger (which is the 95th percentile of historical modelling data at Old Fort). The instream targets were applied at the chronic mixing zone boundary to determine a corresponding flow-dependent SLA. An instream target of twice the LARP trigger was predicted to result in fewer guideline exceedances while allowing for higher overall loading to the Athabasca River.

The LARP triggers do not account for seasonality. In the updated study, seasonal triggers were calculated as the 95th percentile of predicted concentrations on a seasonal basis. Flow-dependent SLAs that were based on multiples of the LARP triggers were compared to constant SLAs (from the original and updated analyses, and updated seasonal SLAs) to show how a flow-dependent water management approach could minimize the change in substance concentrations from background, allowing for higher loading.

The Total of Individual SLAs (TSLA) for each operation plus loads from natural background and existing sources is the Total Maximum Daily Load (TMDL) (Figure 2). Because mixing efficiency in the Athabasca River is limited under low-flow conditions, the TMDL is well below what it would be if mixing was achieved instantaneously. Although complete mixing of a substance would not occur until much further downstream of the modelled region, the Complete-Mix Capacity (CMC) - the loading that would be supportable if the river was fully mixed - is a useful concept for benchmarking loads associated with the TMDL. Complete mixing of the oil sands-related releases would be achieved at Old Fort, 200 km downstream of Fort McMurray.

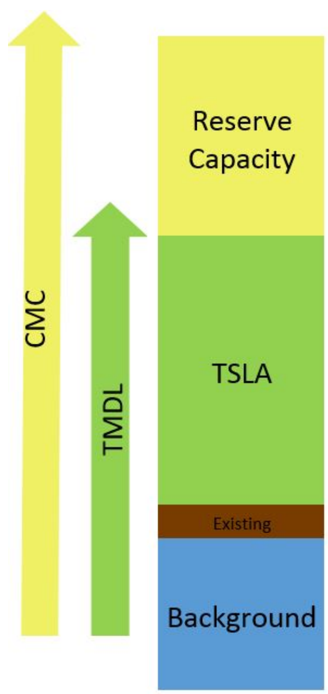

Figure 2: This figure depicts the components of the TMDL. The TSLA for each operation plus loads from natural background sources and from existing sources is the TMDL. The CMC is the loading that would be supportable if the river was fully mixed. The difference between the TMDL and the CMC is the reserve capacity, and corresponds to the total loading that could be added to achieve the instream threshold downstream of the study reach.

SLA schemes

The determination of SLAs is affected by the SLA scheme which is selected. When multiple releases are considered, loads must be allocated in such a way that the instream thresholds are met at the edge of all the regulatory mixing zones considered. This process necessarily involves a regional management strategy referred to as an “SLA scheme”. A scheme is a set of rules used to allocate total allowable load among loading sources; it should be technically and economically feasible, have a strong likelihood and ease of implementation, and be equitable for all involved. Schemes can be modeled using ARM for the simultaneous determination of SLAs for multiple releases.

The SLA scheme for this study assigned equal load per barrel bitumen production capacity, assuming wastewater production is proportional to bitumen production. The SLA is therefore the maximum load per barrel that does not cause the instream concentration to be above the instream threshold at the mixing-zone boundary of any of the hypothetical releases, even under worst-case conditions in the receiving environment.

The selected SLA scheme does not account for variation in operating conditions among operators determined by the local geology or other factors. It also does not account for circumstances where an operator may have an advantageous longitudinal or lateral location that could allow for greater relative loading without reducing other operators' SLAs. The use of equal load per barrel of bitumen production capacity provides an example of how an equitable allocation could be implemented.

Additional factors

In addition to the SLA scheme, the determination of SLAs depends on the longitudinal location along the river of a release relative to other releases, and the configuration of the outfall. The longitudinal and lateral proximity of a release relative to other release locations will govern the amount of mixing that can occur between releases. For this study, the lateral locations are defined as follows:

- "bank" - a bank outfall or single-port outfall near the river bank
- "off-bank" - lateral location is 25% of river width
- "centre release" - lateral location is the centre of the river

The configuration of the outfall, whether it is a bank outfall, single-port release, or a multi-port diffuser, also affects mixing efficiency. For the diffusers, it was assumed release water is vertically mixed within the water column and horizontally mixed along the length of the diffuser such that the details of the individual port configuration are not required. Diffuser configuration is based on the existing Alberta Pacific Forest Industries diffuser, located on the Athabasca River downstream of Athabasca. It is assumed that water is released at about 1 m^3/second. Outfalls can be single port (or bank), 20 m long multi-port, and 40 m long multi-port.

The SLAs were derived for various outfall configurations; however, the majority of the loading analysis focuses on a bank release which corresponds to the most limiting configuration. In reality, the implementation of a multi-port diffuser or off-bank release would increase the supportable loading.

Individual SLA estimates are constrained by the proximity of upstream loading sources and local hydraulic characteristics, including river depth and velocity. For the purposes of this study, outfall sites were selected to optimize the assimilative capacity and minimize the effects of local site selection on the overall supportable loads. As a result, the SLA estimates are primarily determined by regional considerations. A site-specific assessment would still be required for each application to confirm that local mixing and background concentrations are at least as favourable as what was assumed regionally for this study, and to evaluate qualitative mixing zone restrictions.

Determining additional characteristics

The statistical properties of the release water are described as a theoretical probability distribution that would correspond to the frequency distribution of the substance concentrations in release water samples. Characteristics of the probability distribution include the type of distribution (normal, log-normal or delta-log-normal), the mean, and the Coefficient of Variation (CV). The CV (the ratio of the standard deviation to the mean) is used rather than the standard deviation or variance, because there is a tendency for standard deviation of water quality data to be proportional to the mean. Water quality data also typically follows a log-normal probability distribution (USEPA 1991). If no data are available for the treated release water, then the CV can be estimated from the technical literature or from the untreated release water quality. If no information is available, a value of 0.6 is recommended (AEP 1995; USEPA 1991).

The percentile selected to calculate the z scores for each statistic is referred to as the probability basis. The probability basis has been selected to achieve the desired frequency of compliance for the release water quality assuming that basic assumptions of the steady-state model and selection of critical conditions are fulfilled (AEP 1995; USEPA 1991). This approach has also been upheld in legal challenges to the guidelines in the US (USEPA 1991).

The CV and averaging period of the instream threshold (typically four days for chronic instream thresholds) are used to estimate the Long-term Average (LTA) release water concentration from the SLA. The Average Monthly Limit (AML) and Maximum Daily Limit (MDL) are then derived from the LTA. The release statistics are shown relative to a time series plot of a hypothetical release water in Figure 3.

Typically, the LTA would not be applied as a regulatory limit, however it would be expected that the average of the release concentration or load over the long term would be close to the LTA. The LTA is more appropriate for direct comparison to concentrations or loads for the hypothetical release scenario because the water quality profiles were used to represent anticipated average concentrations.

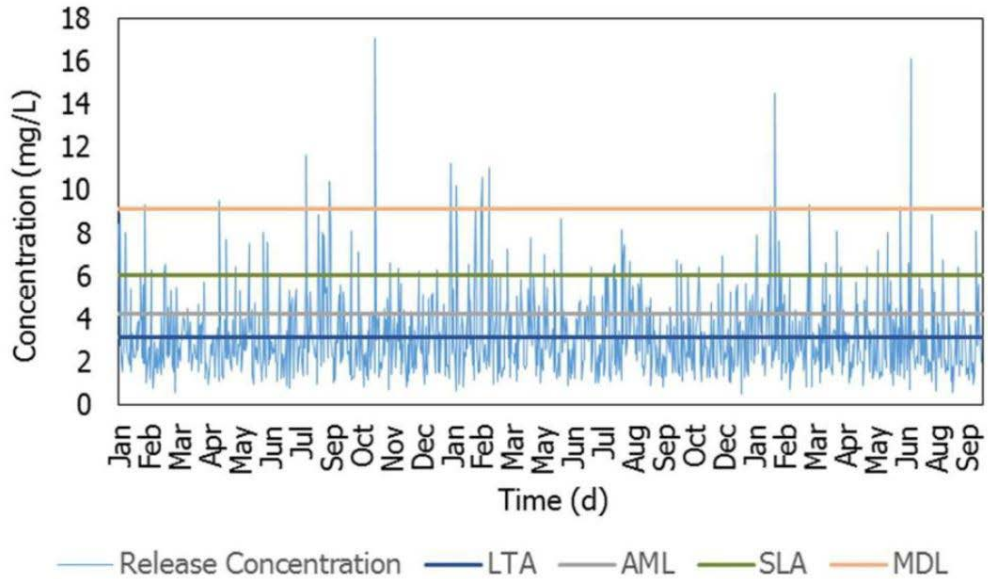

Figure 3: This figure depicts the concentration in a hypothetical release water over time. The LTA, AML, SLA, and MDL are shown. Note that although this hypothetical release does occasionally exceed the MDL, this would not be expected to occur under normal operating conditions.

Modelling

ARM is a water quality model developed in Excel and used to simulate substance concentrations in the Athabasca River from just downstream of Fort McMurray to the confluence with the Embarras River (Old Fort) at the upstream boundary of the Athabasca River Delta. The upstream boundary for ARM, however, includes flows (and their associated water quality) from the Athabasca and Clearwater rivers *upstream* of Fort McMurray. First developed in the 1990s and regularly updated since, it is a vertically-averaged, two-dimensional model that can predict how substance concentrations vary across the width and length of the Athabasca River within the study reach.

The underlying Excel model can be run in probabilistic or steady-state mode, and has been used extensively to model dispersion in rivers for EIAs, regulatory applications, regional water management initiatives, and the development of reach-specific water quality objectives. Probabilistic modeling allows for the simulation of average daily instream substance concentrations throughout the available flow record to capture the full potential range of water quality and flows. When used to derive SLAs, the model is run in steady-state mode. Model predictions are based on worst-case conditions with conservatively low estimates of river flow and conservatively high estimates of source concentrations.

ARM accounts for delayed mixing and differences in water quality between the Athabasca and Clearwater rivers. It also includes point sources, tributary inflows, natural groundwater inputs, seepage flows, and inputs from the Fort McMurray wastewater treatment plant, as well as water withdrawals using the most up-to-date information available (ongoing and planned withdrawals were updated as part of the 2016 study). As a conservative approach, it was assumed that all of the operations would continually use their annual allotted withdrawals. Thus, a total withdrawals rate of 18.5m^3/s was used, compared to recent projected water use in 2022 of less than 5.3m^3/s.

The model assumes rapid vertical mixing and constant flow and water quality for each day of simulation and therefore does not include longitudinal dispersion. The model makes the conservative assumption that once a substance enters the river, it remains in the water column. In other words, decay, settling, partitioning, and other removal mechanisms are not represented.

In addition to the aforementioned seasonal SLAs and water withdrawals updates, the following ARM updates were completed as part of the 2016 study:

- updates to upstream boundary conditions
- development of flow-dependent upstream inputs and calibration to downstream data for a subset of modelled total metals. Flow-dependent background concentrations were developed for open-water conditions and the following total metals: aluminum, arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, and vanadium. Flow-dependent background concentrations of total iron were also developed for ice-cover conditions
- addition of dissolved aluminum, dissolved iron, dissolved cadmium, and dissolved chromium
- updates to the water withdrawals according to the most recent Water Management Framework
- updates to seasonal flow estimates for seasonal SLAs (The 7Q10 ice-cover flow was updated to 101 m^3/s from 98 m^3/s, and the 7Q10 open-water flow was updated to 289 m^3/s from 208 m^3/s)
- updates to the location of natural high salinity groundwater seepage

Results & Discussion

In this section, the results of the analyses for constant, seasonal, and flow-dependant SLAs is presented. Of the substances included in the model, chloride and chronic toxicity were selected as a focus of the analyses. Chloride was selected because major ions are of particular concern and chloride has been identified as a limiting substance for recycling water and in previous SLA studies. Chronic toxicity was selected because it provides an overall indication of the potential of the release to affect aquatic life. In other words, the volumes of water that may be released to the environment will be regulated to ensure chloride and chronic toxicity volumes will not exceed instream thresholds, and the remaining constituents in the water will be lower than instream thresholds by virtue of the limit associated with chloride and chronic toxicity.

Although the focus of the analyses was on chloride and chronic toxicity, additional information on the derivation of SLAs for aluminum, iron, and chromium is also provided because natural background concentrations in the Athabasca River for the open-water season are above instream thresholds. While this analysis focused on the aforementioned substances, the model is capable of simulating load allocations for many other parameters, under numerous release scenarios. Thus, a nearly limitless number of scenarios can be modelled to ensure load allocations do not result in cumulative impacts in the Athabasca River.

Unless otherwise noted, ice-cover SLAs were found to be lower than open-water cases. Overall, SLAs derived in the 2016 update were typically higher for both ice-cover and open-water conditions than those predicted in the original work, due to the aforementioned updates to ARM. The updated flow-dependent SLAs were typically within 5% of the 2014 flow-dependent SLAs for open-water conditions, with the exception of chloride for ice-cover conditions. From the 2014 study to the 2016 study, the change to SLA for chloride and average ice-cover conditions was approximately 15% and was primarily the result of updating the location of natural high salinity groundwater seepage.

For most parameters (except chloride, mercury, uranium, zinc, copper, and dissolved aluminum), the acute SLA is higher than the chronic SLA, indicating that the chronic SLA is more restrictive. The key limiting substance for both chronic and acute SLAs is chloride and the degree of limitation is similar for both acute and chronic SLAs.

Predicted concentrations at the acute mixing zone are influenced more by the release immediately upstream than other upstream releases. Because of the relatively small mixing zone and relatively high instream thresholds, regional considerations (for example, the number of releases) have a minimal influence on the acute SLAs. Therefore, acute SLAs could be evaluated on a case-by-case basis and need not be considered in detail for the regional SLA analysis.

Figure 4 shows the SLA, the LTA, and the MDL for chloride for a single hypothetical release. For reference, an SLA calculated independently, not accounting for the other hypothetical releases, is also shown. The SLA is more than twice as high when calculated independently rather than on a regional basis. Note that if these individual SLAs derived on a case-by-case basis were approved, there would be a greater possibility that instream thresholds would be exceeded or that the target frequency of compliance would not be achieved. However, due to the conservative nature of the calculations, SLAs derived independently would not necessarily result in exceedance of instream thresholds. Only the regionally derived SLAs are considered in subsequent discussion.

Figure 5 is a representative time series of chloride concentrations in the Athabasca River as a result of 13 hypothetical releases. This plot illustrates the differences between constant and seasonal SLAs, as well as the interactions between background, existing, and released concentrations compared to the instream threshold.

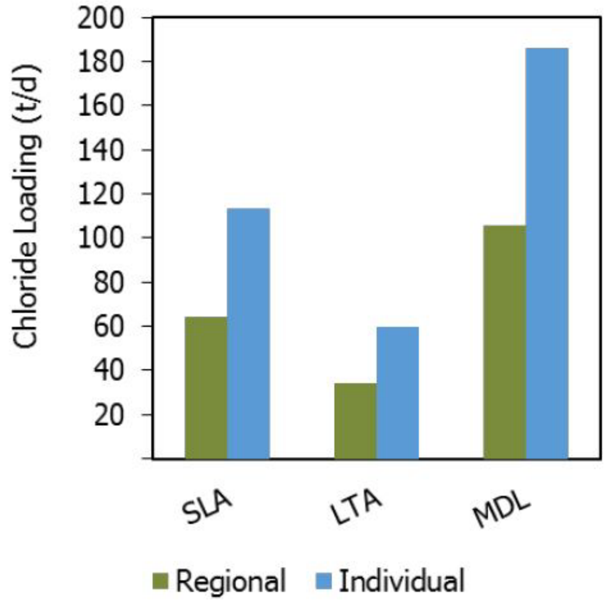

Figure 4: This figure depicts the SLA and the corresponding LTA and MDL for chloride on a regional basis. For reference, SLAs calculated independently, assuming that they would be assessed on a case-by-case basis, are also shown. SLAs were derived for ice-cover 7Q10 conditions.

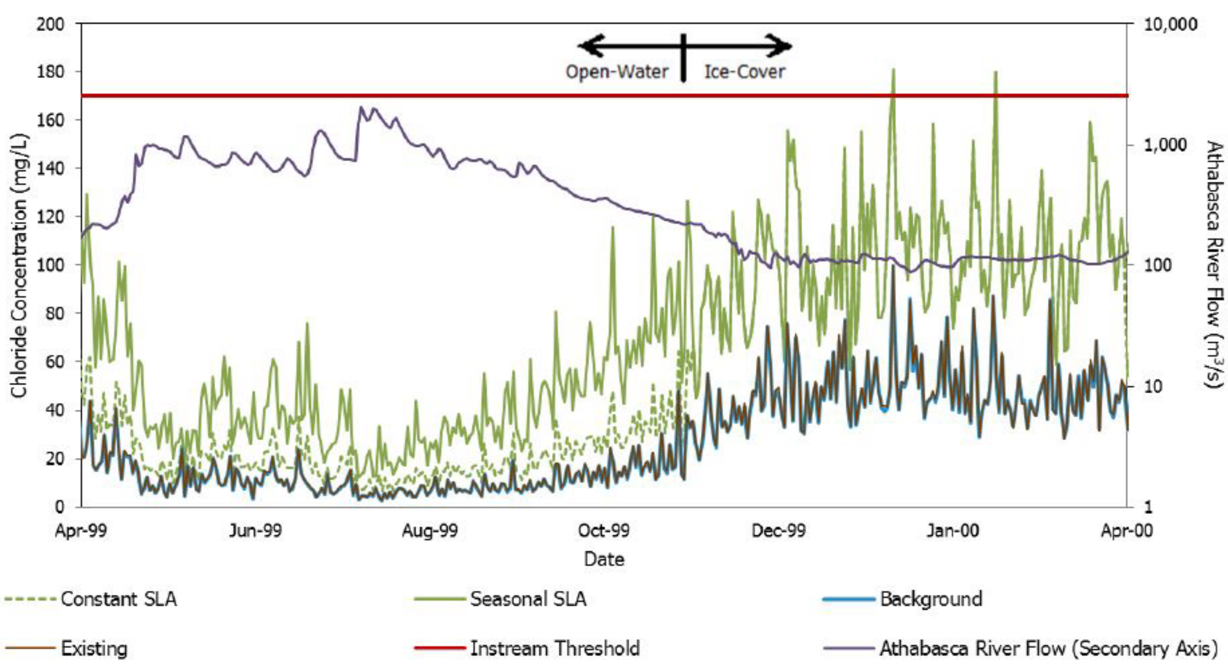

Figure 5: This figure depicts predicted instream concentrations at the edge of the regulatory mixing zone downstream of a given outfall for 13 hypothetical releases at SLA levels. The probabilistic ARM was used to predict background concentrations from sources within the study reach, existing concentrations (from approved and planned oil sands as represented in EIAs), and for hypothetical releases corresponding to either constant or seasonal SLAs. The constant SLA is based on ice-cover 7Q10 flow and the seasonal SLA is based on ice-cover 7Q10 flow and open-water 7Q10 flow for the respective seasons.

Overall, it was found that the conservative approach applied in this study produces a regional substance loading strategy that could be employed to manage process water accumulation without resulting in negative environmental outcomes. Concentrations were consistently predicted below instream thresholds over the modelled flow record; therefore, the model is conservative and additional loads could be warranted.

Below, the results for the constant and seasonal and flow-dependant SLA analyses are presented for:

- chloride
- chronic toxicity
- aluminium, cadmium, iron
- other substances

Although numerous scenarios were run in ARM, and the model itself is capable of an almost unlimited number of scenarios, only a handful of representative cases are presented in this analysis. In many cases, the LTA is compared to the SLA. As previously noted, the LTA may be a more representative indicator, but was not the focus of the study due to the conservative approach taken. Unless otherwise noted, the outfall type was a “bank” outfall and the model assumed 13 simultaneous releases.

Constant & Seasonal Substance Load Allocations

The constant SLAs derived for ice-cover 7Q10 flow conditions are equal to the seasonal SLAs for ice-cover 7Q10 conditions, but lower than the seasonal SLAs derived for open-water 7Q10 conditions. The SLAs are affected by overall assimilative capacity as well as local mixing characteristics. If additional loading capacity is required for an operation, SLAs can be increased by using multi-port diffusers or by siting the outfall in a location of greater-than-average depth.

Probabilistic modelling was carried out, in addition to the steady-state SLA analyses, to confirm the SLAs would achieve the required level of compliance with instream thresholds for the 7Q10 and mean-flow conditions. Figure 5 is a representative output of this probabilistic analysis, showing a time series for a given year.

Chloride

Five scenarios are presented for chloride loading. Even the worst-case flow conditions did not result in significant concentration impacts beyond around 20% of the mixing zone laterally.

Scenario	Conditions	Results
1	Ice-cover; 7Q10 flow; Constant SLAs & LTAs	SLA: Predicted concentrations exceed threshold for small area downstream of a few outfalls, but don’t impact concentrations substantially beyond around 20% of the mixing zone laterally. LTA: no exceedance of thresholds.

Scenario	Conditions	Results
2	Open-water; 7Q10 flow; Constant SLAs (derived for ice-cover) and Seasonal SLAs (derived for open-water); Constant & Seasonal LTAs	SLA: Constant SLAs resulted in instream concentrations well below threshold at Old Fort; Seasonal SLAs resulted in moderate exceedance during ice-covered conditions, but it is expected that operators would reduce/eliminate loading during these conditions. LTAs: no exceedance of thresholds.
3	Ice-cover; 7Q10 flow; Constant SLAs; off-bank multi-port diffusers	SLA: higher mixing from diffusers increases SLAs and concentration at Old Fort. Some exceedance of thresholds for small area downstream of a few outfalls.
4	Ice-cover; 7Q10 flow; Constant SLAs; 6 simultaneous releases	SLA: SLAs not recalculated for fewer releases to reduce management and regulatory complexity, and promote certainty; instream concentrations reduced, well below instream thresholds.
5	Ice-cover & Open-water; 7Q10, mean, and high flow; Constant SLAs (derived for ice-cover 7Q10), Seasonal SLAs (derived for open-water 7Q10); Constant & Seasonal LTAs	SLA: for ice-cover 7Q10 flow, small excursions above threshold predicted. For mean and high flow conditions, concentrations are well below thresholds. For open-water SLAs, no exceedance of threshold predicted. LTA: no exceedance of thresholds.

Chronic toxicity

The results for chronic toxicity are similar to those for chloride, above; for the four scenarios in this study, significant and prolonged exceedance of instream thresholds is not predicted, even for the worst-case flow conditions.

Scenario	Conditions	Results
1	Ice-cover; 7Q10 flow; Constant SLAs & LTAs	SLA: predicted concentrations modestly exceed threshold for small area downstream of a few outfalls. LTA: no exceedance of thresholds.
2	Open-water; 7Q10 flow; Constant SLAs (derived for Ice-cover), Constant LTAs	SLA: concentrations consistently below thresholds. LTAs: no exceedance of thresholds.
3	Open-water; 7Q10 flow; Seasonal SLAs (derived for open-water)	SLA: predicted concentrations are near the instream threshold for open-water 7Q10 flow. It is assumed operators would reduce or eliminate release flows during ice-cover conditions. LTAs: no exceedance of thresholds.

Scenario	Conditions	Results
4	Ice-cover & Open-water; 7Q10 mean, and high flow; Constant SLAs (derived for ice-cover 7Q10), Seasonal SLAs (derived for open-water 7Q10); Constant & Seasonal LTAs	SLA: for mean ice-cover and open-water flows, changes to predicted instream concentrations are small. LTA: no exceedance of thresholds.

Aluminum, cadmium, iron

Aluminum, cadmium, and iron are unique substances because background concentrations are above the instream threshold for open-water conditions and the SLA derived for the open-water period is lower than for the ice-cover period.

Because background concentrations of these substances are so high during open-water conditions, the addition of hypothetical releases corresponding to SLAs calculated for ice-cover conditions does not contribute substantially to the instream concentration for the open-water 7Q10 flow condition. Therefore, using the SLAs derived for ice-cover conditions is considered protective.

Other substances

The concentrations of other substances were compared as a proportion of the instream threshold at Old Fort for the ice-cover 7Q10 flow conditions. Relative to the instream threshold, the contribution from existing sources to instream concentrations is small for all substances with the exception of chronic toxicity. Background concentrations are highest relative to the instream threshold for total aluminum and total iron. Total aluminum has a reduced SLA for open-water conditions. Sulphide concentrations appear to be relatively high primarily because the detection limit for sulphide is near the threshold and background concentrations of sulphide were assumed to be half the detection limit. Exceedance of the instream threshold was not predicted for any of the other substances.

Flow-dependent Substance Load Allocations

The flow-dependant SLAs were derived using the CEB, the background concentration, and the LARP trigger, as per the aforementioned process, and applied at the chronic regulatory mixing zone boundary downstream of a given outfall.

As anticipated, flow-dependent SLAs based on the CEB results in additional instream threshold exceedances at the regulatory mixing zone boundary for both ice-cover and open-water conditions relative to the constant and seasonal SLAs. Therefore, flow-dependent SLAs based on instream targets below the CEB (e.g., five times the background concentration or twice the LARP trigger) would be more suitable for application to oil sands operators and would achieve the objectives of: meeting the desired level of compliance with the chronic instream threshold at the regulatory mixing zone boundary, maximizing supportable release loads, and minimizing changes in water quality over a range of flow conditions.

When comparing seasonal SLAs and flow-dependant SLAs, the flow-dependent SLAs typically result in lower chloride concentrations at the regulatory mixing zone boundary and fewer exceedances of the LARP trigger at Old Fort for the ice-cover period, but allow higher loading levels for the open-water season relative to the seasonal or constant SLAs. Active management of release flows through flow-dependent SLAs could be used to allow for higher overall load and to further minimize changes in substance concentrations in the Athabasca River relative to more conventional constant SLAs.

Third Party Review

A third party review of the study was conducted by Dr. Steven Chapra, F.ASCE, F.AEESP, of Tufts University. Dr. Chapra is a professor at Tufts University in the department of Civil and Environmental Engineering, and the Louis Berger Chair of Civil and Environmental Engineering. In his review, Dr. Chapra commended the thorough and conservative approach employed by the study authors. Because of these conservative assumptions, the model-determined SLAs have “a very high implicit safety margin”. With this margin in mind, Dr. Chapra echoes the conclusions of this study that the end-of-pipe SLA and instream threshold would rarely be observed, since typical concentration loading would be well below these limits.

Conclusions

The study demonstrates how technical aspects of Alberta Environment and Sustainable Resource Development (now the Alberta Energy Regulator) guidance for water quality protection could be implemented using a collaborative and equitable approach to determine acceptable substance levels for oil sands water releases to the Athabasca River.

In this analysis, the ARM was used to calculate SLAs for 13 oil sands operations, with a focus on chloride and chronic toxicity. Within this analysis alone, thousands of release scenarios were modelled for the substances of interest; however, the tool is capable of modelling an almost unlimited number of scenarios, by accounting for various release configurations and many substances of interest beyond those featured in this study. This powerful flexibility enables the study of load allocations to ensure there are no adverse effects from cumulative impacts within the Athabasca River.

Calculating SLAs simultaneously for all 13 operations results in approximately half of the overall loading allocation that would occur if the loading allocations are calculated on a case-by-case basis without accounting for other sources. The limited mixing in the Athabasca River results in an overall restriction in the derived SLAs that is protective of the river as a whole and results in reserve capacity at the downstream boundary of the reach.

Even for the worst-case modelling conditions used, substance concentrations are predicted to be elevated only in a small area downstream of the release outfalls. Additional modelling was completed to characterize potential changes in water quality for more representative conditions of river flow and release water quality. For representative conditions only a small change in substance concentrations in the Athabasca River was predicted, even directly downstream of the outfall. Continuous probabilistic modelling was undertaken to confirm that the required compliance frequencies for the instream thresholds would be achieved. Predicted concentrations are consistently below the instream threshold over the modelled flow record. These results demonstrate that the steady-state modelling approach used to derive the SLAs is conservative with respect to instream threshold compliance.

Use of existing on-site water storage capacity would allow oil sands operators to control release flows seasonally and therefore application of seasonally variable SLAs would be appropriate for the oil sands sector. Flow-dependent SLAs corresponding to an instream target of twice the LARP trigger and seasonal SLAs based on the CEB would both achieve the desired level of compliance with the chronic instream threshold at the regulatory mixing zone boundary and achieve the LARP trigger at Old Fort with a similar frequency to background concentrations.

The flow-dependent SLAs typically result in lower chloride concentrations at the regulatory mixing zone boundary and fewer exceedances of the LARP trigger at Old Fort for the ice-cover period. Additionally, the flow-dependent SLAs allow for higher overall loading to the Athabasca River. Active management of release flows through flow-dependent SLAs could be used to allow for higher overall load and to further minimize changes in substance concentrations in the Athabasca River relative to more conventional constant SLAs.

Numerous conservative assumptions have been used in the analysis and some of these assumptions could potentially be refined to allow for higher SLAs. SLA values released in the original study were preliminary and were revised in the 2016 release; however, further revisions could be made to refine the SLAs presented in this study, which are considered protective. This study demonstrates approaches for allocating release loading among hypothetical releases but does not include a complete assessment of potential effects associated with potential oil sands process water releases.

The release limits derived from SLAs may not, for every substance, dictate acceptable release rates. When an operation applies for an actual water release, a detailed and site-specific assessment will be completed. The assessment may reveal additional factors that modify acceptable release rates.

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Appendix

Substance	Unit	Water Quality Effects Thresholds			Sources		
		LARP Water Quality Limit	CEB	Acute Guidelines	LARP Water quality Limit	CEB	Acute Guidelines
Ammonia and Major Ions							
Total Ammonia (as N)	mg/L	3.18	0.857	8.11	USEPA (aquatic life)	ESRD 2014	USEPA 2015
Chloride	mg/L	100	170 - 354	640	CCME (agriculture)	CEB (SSD)	ESRD 2014
Nitrate (as N)	mg/L	3	3	124	CCME (aquatic life)	CCME (SSD)	ESRD 2014
Sodium	mg/L	200	680	-	HC (drinking water)	CEB	-
Sulphate	mg/L	500	309	-	HC (drinking water)	CEB (BC WQG)	-
Sulphide	mg/L	-	0.014	-	-	USEPA 2015	-
Metals							
Total aluminum	mg/L	-	0.1	0.75	-	ESRD (CCME)	USEPA 2015
Dissolved aluminum	mg/L	-	-	0.1	-	-	ESRD 2014
Antimony	mg/L	0.006	0.157	-	HC (drinking water)	CEB	-
Arsenic	mg/L	0.005	0.025	0.34	CCME (aquatic life)	CEB (SSD)	USEPA 2015
Barium	mg/L	1	5.8	-	HC (drinking water)	CEB	-
Beryllium	mg/L	0.1	0.0053	-	CCME (agriculture)	CEB	-
Boron	mg/L	0.5	1.5	29	CCME (agriculture)	CCME (SSD)	ESRD 2014
Total cadmium	mg/L	-	0.00021	0.0025	-	CEB	ESRD 2014
Dissolved cadmium	mg/L	-	-	0.0023	-	-	USEPA 2015
Chromium III	mg/L	0.05	0.0089	2.05	HC (drinking water)	ESRD (CCME)	USEPA 2015
Chromium IV	mg/L					CEB (SSD)	USEPA 2015
Dissolved chromium	mg/L	0.05	0.0083	-	HC (drinking water)	CEB (SSD)	USEPA 2015
Cobalt	mg/L	0.05	0.0025	-	CCME (agriculture)	CEB (SSD)	-
Copper	mg/L	-	0.011	0.019	-	CEB	ESRD 2014
Total iron	mg/L	-	1.5	-	-	CEB (SSD)	-
Dissolved iron	mg/L	-	-	-	-	-	-
Lead	mg/L	-	0.0039	0.099	-	AENV (CCME)	USEPA 2015
Manganese	mg/L	-	1.455	-	-	CEB (SSD)	-
Mercury	mg/L	-	0.00005	0.000013	-	CEB (SSD)	ESRD 2014
Molybdenum	mg/L	0.01	38.7	-	CCME (agriculture)	CEB (SSD)	-
Nickel	mg/L	0.059	0.059	0.535	USEPA (aquatic life)	ESRD (USEPA)	ESRD 2014
Selenium	mg/L	0.001	0.002	-	CCME (aquatic life)	CEB (BC WQG)	-
Silver	mg/L	0.0001	0.00022	0.00494	CCME (aquatic life)	CEB (SSD)	USEPA 2015
Strontium	mg/L	-	14.1	-	-	CEB (SSD)	-
Thallium	mg/L	0.0008	0.0008	-	CCME (aquatic life)	ESRD (CCME)	-
Uranium	mg/L	0.01	0.015	0.033	CCME (agriculture)	CCME (SSD)	ESRD 2014
Vanadium	mg/L	0.1	0.12	-	CCME (agriculture)	CEB (SSD)	-
Zinc	mg/L	-	0.138	0.137	-	CEB (SSD)	USEPA 2015

Substance	Unit	Water Quality Effects Thresholds			Sources		
		LARP Water Quality Limit	CEB	Acute Guidelines	LARP Water quality Limit	CEB	Acute Guidelines
PAHs							
PAH Group 1 Benzo(a)pyrene	µg/L	-	0.281	-	-	CEB (TLM)	-
PAH Group 2 7,12-Dimethylbenzanthracene	µg/L	-	0.278	-	-	CEB (TLM)	-
PAH Group 3 Chrysene	µg/L	-	0.99	-	-	CEB (TLM)	-
PAH Group 4 Acenaphthene	µg/L	-	41.5	-	-	CEB (TLM)	-
PAH Group 5 Anthracene	µg/L	-	5.6	-	-	CEB (SSD)	-
PAH Group 6 Biphenyl	µg/L	-	64	-	-	CEB (TLM)	-
PAH Group 7 Fluoranthene	µg/L	-	5.9	-	-	CEB (SSD)	-
PAH Group 8 Naphthalene	µg/L	-	32	-	-	CEB (SSD)	-
PAH Group 9 Pyrene	µg/L	-	2.3	-	CEB (SSD)	-	PAH Group 9 Pyrene
Phenolics							
Total phenolics	mg/L	-	0.01	-	-	CEB	-
Toxicity Units							
Chronic toxicity	TUc	-	1	-	-	ESRD	-
Acute toxicity	TUa	-	0.3	0.3	-	ESRD	ESRD 2014

Note: AENV = Alberta Environment; BC WQG = British Columbia Water Quality Guidelines; ESRD = Alberta Environment and Sustainable Resources Development; CCME = Canadian Council of Ministers of the Environment; CEB = Chronic Effects Benchmark; HC = Health Canada; LARP = Lower Athabasca Regional Plan; PAH =Polycyclic Aromatic Hydrocarbons; SSD = Species Sensitivity Distribution; TLM = Target Lipid Model; USEPA = United States Environmental Protection Agency