Petroleum Technology Alliance Canada (PTAC)

Final Report: Alternative Water Source Life-Cycle Management Framework

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Executive Summary

The draft Water Conservation Policy for Upstream Oil and Gas (October 2016) (WCP) articulates a preference for the use of alternative water sources over high-quality non-saline sources. Currently, the ability of multi-stage hydraulic fracturing (MSHF) operators to use many alternative sources (e.g. treated municipal effluent, produced and flowback water) is restricted by the existing regulatory system, where clear and functional definitions for alternative sources do not always exist, and there is not a clear regulatory and approvals process to enable their use.

To support broader utilization of alternative water sources in MSHF projects, regulators and industry are transitioning towards a risk-based regulatory approach, where appropriate. To support this transition, the Petroleum Technology Alliance of Canada (PTAC) engaged WaterSMART Solutions Ltd. and Catapult Water Midstream (the project team) to develop a high-level risk assessment framework for MSHF projects involving the use of treated municipal effluent and produced and flowback water. Throughout the project, the project team worked closely with representatives from PTAC and engaged representatives from the Alberta Energy Regulator (AER) and Alberta Environment and Parks (AEP).

The key output of the project is the Screening-Level Risk Matrix (SLRM), a functioning spreadsheet tool which provides users with a high-level assessment of the risks associated with the use of alternative water sources for MSHF projects. At this time, the SLRM is designed for projects involving treated municipal effluent and produced and flowback water, although it can be expanded to include additional alternative water sources in the future.

The SLRM assesses the risks to human and environmental health in terms of the consequence of acute exposure to an alternative water source and the likelihood of exposure occurring. The consequence of exposure is assessed quantitatively, by comparing the concentration of readily measurable key indicator contaminants in the alternative water source to established guidelines. Likelihood is assessed qualitatively, using a series of binary questions (i.e. Yes/No) about the location, materials, duration, and operations of the project. Operators can complete the SLRM at an early stage of project development, in the absence of detailed mitigations and project controls, to rapidly differentiate between low and higher risk projects. Ideally, projects identified as low risk by the SLRM can undergo a streamlined approval process, while higher risk projects will be subject to detailed review, including the application of suitable mitigations.

The SLRM is intended to fit within the evolving regulatory context and support the transition to risk-based regulation of MSHF projects; it is not meant to replace a detailed risk assessment or any other components of the application review process. For example, the SLRM can be used to support the Phase 1 Screening Level Risk Assessment required by the draft Alberta Water Reuse and Stormwater Use Guidebook (January 2019) and can help identify projects for which a Phase 2 Detailed Chemical Risk Assessment is necessary. The design of the SLRM, with strictly quantifiable components and binary question responses, also lends itself to potential integration with the AER's OneStop.

As part of the project, a meeting was convened with representatives from PTAC, the AER, and AEP to discuss opportunities for regulatory streamlining (i.e. "Red Tape Reduction") and how the SLRM might align with the future risk-based regulatory environment. At this meeting, all parties were aligned on the overarching goal of enabling MSHF operators to increase their use of alternative water sources in an efficient and environmentally responsible way.

The AER and AEP both appeared receptive to the concept of the SLRM, and some edits were suggested throughout the meeting. It was revealed the AER utilizes an internal risk assessment approach which is similar to the SLRM. However, it was noted some of the steps associated with potential utilization of the SLRM in the application approach, such as OneStop integration or regulatory changes, would be difficult to execute in the near term. Multiple teams within the AER (e.g. pipelines and storage) would need to be involved, and this effort would compete for resources and manpower with other AER priorities.

In this context, and keeping in mind the broader transition to risk-based regulations, the next step is for PTAC operators to use the SLRM to submit applications for MSHF projects using treated municipal effluent and produced and flowback water. As companies share experiences gained from each application (and iteration), the process will be improved until there is a clear system in place within the existing regulatory context to enable MSHF operators to make more use of alternative water sources. This effort could feed the development of codes of practice, or similar regulatory instruments, to streamline the application process and/or provide direction to operators regarding risk mitigations.

Contents

Definitions

AEP	Alberta Environment and Parks
AER	(the) Alberta Energy Regulator
Alternative water sources	Water that is not supplied from fresh surface or groundwater, such as treated municipal effluent, produced water from hydrocarbon extraction activities, and saline groundwater
BOD	Biological Oxygen Demand
Bq/L	Becquerel per Liter (SI derived unit of radioactivity)
CAPP	Canadian Association of Petroleum Producers
CCME	Canadian Council of Ministers of the Environment
cfu/100mL	Colony forming units per 100mL (related to bacteria)
Draft Guidebook	Alberta Water Reuse and Stormwater Use Guidebook (January 2019)
Draft WCP	Water Conservation Policy for Upstream Oil and Gas (October 2016)
E-Coli	Escherichia Coli
H_2S	Hydrogen Sulfide
LOAs	Letters Of Authorization
milliequivalents per liter (me/L)	One equivalent (Eq) is defined as the weight in grams of an element that combines with or replaces 1g of hydrogen ion (H^+). Milliequivalents per liter describes the ability of 1L of water to capture or release ions.
MSHF	Multi-Stage Hydraulic Fracturing
NORMs	Naturally Occurring Radioactive Materials
Oil and grease	A liquid compound that is insoluble with water, less dense than water, and which can form a microfilm on the surface of water.
OneStop	Online tool for submitting various types of applications to the Alberta Energy Regulator
PTAC	Petroleum Technology Alliance of Canada
SLRM	Screening-Level Risk Matrix
SWQ guidelines	2018 Environmental Quality Guidelines for Alberta Surface Waters
TDS	Total Dissolved Solids
USGS	United States Geological Survey
Water body	Includes wetlands, swamps, rivers, lakes, etc.

1.0 Introduction

1.1 Context

The draft Water Conservation Policy for Upstream Oil and Gas (October 2016) (WCP) articulates a preference for the use of alternative water sources over high-quality non-saline sources. Alternative water sources are defined as water that is not supplied from fresh surface or groundwater, such as treated municipal effluent, produced water from hydrocarbon extraction activities, and saline groundwater. Currently, the ability of multi-stage hydraulic fracturing (MSHF) operators to use many alternative sources is restricted by the existing regulatory system, where consistent and functional definitions for alternative sources do not always exist, and there is not a clear regulatory approval process to enable their use.

The regulatory restrictions encountered by MSHF operators are partly due to the definitions-based nature of the regulatory environment, rather than risk-based. An example of this is the definitions for produced and flowback waters. These definitions, developed many years ago when MSHF operations were fundamentally different, restrict the transportation, storage, and disposal of produced and flowback waters. These restrictions exist regardless of whether the water is treated, diluted, or blended to achieve a better overall quality. Thus, even if steps are taken to reduce the human and environmental health risks of an alternative water use project, the current regulatory framework may still treat the water sources as high risk, which is a barrier to achieving the goals of the draft WCP.

To address this, and other barriers to implementing the draft WCP, the Alberta Energy Regulator (AER) and Alberta Environment and Parks (AEP) are transitioning towards a risk-based regulatory environment, where appropriate, through the use of various policy and regulatory instruments. One example is the draft Alberta Water Reuse and Stormwater Use Guidebook (January 2019) (Guidebook), which outlines how a proponent would assess the watershed context of their projects, including impact to water availability (quantity) and industry activity level and stakeholder and indigenous communities impacts. The draft Guidebook also requires proponents to consider the water *quality* impacts of their projects by identifying and minimizing chemical hazards harmful to human and environmental health and operational hazards. According to the draft Guidebook, this can be accomplished using a two-stage risk assessment process for alternative water use projects for MSHF operations:

- Phase 1 – Screening Level Risk Assessment.
- Phase 2 – Detailed Chemical Risk Assessment (where necessary).

Because the WCP and Guidebook have not yet been released, their impact on the existing regulatory context can only be speculated. This project, and in turn this summary report, has been completed with these potential impacts in mind, and in the context of discussions with representatives from the AER, AEP, and the Petroleum Technology Alliance of Canada (PTAC). The outputs of the project work, summarized in this report, are intended to assist in the transition to risk-based regulations for the use of alternative water for MSHF projects.

1.2 Purpose

WaterSMART Solutions Ltd. (WaterSMART) and Catapult Water Midstream (Catapult) (the project team) were engaged by PTAC to develop a framework for classifying alternative water sources and assessing their life-cycle risks to human and environmental health. This framework was required to fit within the aforementioned regulatory context and support the transition to risk-based regulation of alternative water use for MSHF projects (discussed further in Section 4.0).

Part of preparing this framework involved developing quantitative definitions for relevant alternative water sources which could be linked to their associated risks to human and environmental health. These definitions are discussed in Section 2.0. The alternative water sources considered in this project are lagoon treated municipal effluent, produced water, and flowback water (although the framework can be expanded in the future to include additional sources).

The core element of this framework is a Screening-Level Risk Matrix (SLRM), which can be used by operators and regulators to assess the risks of alternative water use for MSHF projects, at a high level, where risk is defined in terms of likelihood and consequence of impacts to receptors. As discussed in Section 3.0, the SLRM fits within the current regulatory context and aligns with the Phase 1 Screening Level Risk Assessment outlined in the draft Guidebook. The SLRM is meant to enable the AER to streamline approvals for low-risk projects, while providing a pathway for operators and the AER to work together to mitigate risks associated with higher risk projects through more detailed analysis. It is not intended to replace or overrule any aspect of the draft WCP or draft Guidebook.

The SLRM is presented in this report in its current form. The risk scoring mechanics and numerical references, while defensible based on relevant literature, may be subject to refinement as the SLRM is reviewed by the AER, AEP, and PTAC in a subsequent phase of work. Additional work beyond the scope of this project, which will be discussed further in Section 5.0, could include identifying appropriate mitigations corresponding to risks identified in the SLRM and creating a more in-depth risk assessment for higher risk projects.

1.3 Project team

The project team consisted of WaterSMART and Catapult, who worked closely with representatives of PTAC with MSHF operations in Alberta. Participating PTAC organizations were:

- Repsol Oil & Gas Canada Inc.
- Shell Canada Ltd.
- Encana Corp.
- Husky Energy Inc.
- Tourmaline Oil Corp.
- Canadian Association of Petroleum Producers (CAPP)

2.0 Source Water Classification

As noted, an important objective of this project was to identify relevant water quality parameters for treated municipal effluent and produced and flowback waters. Although these water sources are commonly considered for use in MSHF projects, there is no clear consensus within the industry regarding their water quality parameter ranges. Once identified, these parameters served as the basis for classifying these source waters and identifying human and environmental risks associated with each. The typical water quality parameters are documented in this Section, while the risks associated with each source are discussed in Section 3.0.

2.1 Treated municipal effluent

Domestic wastewater can be treated by numerous methods that are selected based upon the population of the municipality, the cost of treatment, and the desired treated effluent quality. Typically, MSHF operators use municipal effluent that has been treated by lagoon processes. Lagoon treatment aims to achieve an effluent quality that is appropriate for surface discharge and will not pose a threat to human health or the environment when diluted by surface water bodies.

Lagoon-treated effluent quality data were sourced from eight lagoons throughout Canada:

- Madoc, Ontario.
- Village of Cumberland, British Columbia.
- Bracebridge, Ontario.
- Cannington, Ontario.
- Chesley Sewage Works, Ontario.
- Yellowknife (Fiddlers Lake), Northwest Territories.
- Janvier, Alberta.
- Rimbey, Alberta.
- Eckville, Alberta.

Table 2-1 shows the value ranges for the parameters reported at each lagoon. Not all parameters listed were reported for every lagoon. For example, some municipalities reported only fecal coliforms, others E-Coli count, and some only biological oxygen demand (BOD). The average values are derived using only those values which were reported.

Table 2-1 Summary of lagoon treated municipal effluent quality across Canada

	Biological Oxygen Demand (mg/L)	Total Suspended Solids (mg/L)	Total Phosphorus (mg/L)	Fecal Coliform (cfu/100mL)	Ammonia (mg/L)	E Coli (cfu/100mL)
Maximum	30	52.0	0.50	417	2.5	48
Minimum	1	1.0	0.03	185	0	0
Average	9	12.1	0.20	333	0.4	16

2.2 Produced and flowback waters

CAPP defines flowback water as "fracturing fluid that flows back to the wellbore after hydraulic fracturing," while produced water is defined as "water naturally present in the reservoir that is recovered along with hydrocarbon" (CAPP, 2019).

The AER does not currently have a standard definition for flowback water, but defines produced water as "water that is produced along with hydrocarbons (oil, gas and crude bitumen) from a well" (AER, 2014).

Produced and flowback water quality varies greatly within and between formations. Data were gathered from different formations to account for this variability. Initially, gathered data was categorised as produced or flowback water. However, analysis of the water quality parameters in the available data revealed significant overlap between the produced and flowback water samples. Indeed, it is impossible to meaningfully differentiate produced and flowback water on a chemical/quantitative basis (using available data). Hence, for the purposes of this project and the quantitative risk assessment discussed in Section 3.0, produced and flowback water are treated as a single source. For clarity, these waters will be referred to as produced/flowback water throughout the rest of this report.

The majority of produced/flowback water quality data was taken from the United States Geological Survey (USGS) produced water database (Blondes, et al., 2018). This was supplemented by select academic papers, which presented averages and ranges, rather than raw data (Zolfaghari, et al., 2015), (Engle, et al., 2016). Unfortunately, little data were available for produced/flowback water within Alberta; however, some data were sourced from academic papers (Blewett, et al., 2017), (He, et al., 2017). To ensure the applicability of the USGS data, a comparison was made with the available Alberta dataset. Despite being from different geological formations, the data ranges were similar for both the Alberta and USGS water quality data. Therefore, the USGS data were deemed of sufficient quality to determine average characteristics of Alberta produced/flowback waters.

The USGS data were analyzed to determine relevant ranges and trends. At first, the extreme range in some parameters (e.g. total dissolved solids, sodium, and chloride) challenged the value of data analysis. However, this was addressed by eliminating the 10^{th} and 90^{th} percentile for each parameter.

Following the narrowing of the data, further refinements were made:

- Taking an average, minimum and maximum for each parameter.
- Removing irrelevant parameters (e.g. Ra^{226} to Ra^{228} ratio).
- Removing parameters with no or minimal available data.

Following these updates, the ranges for certain parameters were still wide. Given the variation in water quality within and between formations and the wide parameter ranges, it was determined that assigning a single average for each parameter would not be useful. Instead, produced/flowback water quality parameters have been defined using a set of inequalities, as documented in Table 2-2. These ranges are considered representative for 90% of produced/flowback waters within Alberta, and all produced/flowback water discussed throughout this report. However, this table demonstrates the difficulty in defining "typical" produced/flowback water quality.

Table 2-2 Overview of typical concentrations of contaminants in produced and flowback waters

Contaminant	Typical Concentration	Health/Environmental Effect
Total Dissolved Solids (TDS) (mg/L)	>10,000	Env – Harmful to plant and aquatic life
Sodium (mg/L)	>10,000	Env – Harmful to plant and aquatic life
Chloride (mg/L)	>10,000	Env – Harmful to aquatic life
Strontium (mg/L)	~1500	Health & Env – harmful to bone structure
Total recoverable oil (mg/L)	Up to 210	Env – Harmful to aquatic life
Radium 226 (Bq/L)	~50	Health – Increased risk of cancer

3.0 Screening-Level Risk Matrix

To support the aforementioned transition to a risk-based assessment approach for projects involving the use of alternative water for MSHF projects, the SLRM was developed. The SLRM is a functioning spreadsheet tool which is intended to be easily completed by project proponents (i.e. detailed engineering work and expensive lab tests should not be required for completion). Per the scope of this project, the SLRM is currently geared towards assessing projects involving the use of treated municipal effluent and produced/flowback water. However, the SLRM can be expanded in the future to other alternative water sources.

A diagram outlining how the SLRM could be utilized within Alberta's regulatory context is provided in Figure 3-1. Operators can utilize the SLRM to complete the Phase 1 Screening Level Assessment described in the draft Guidebook. The SLRM is not intended to replace or overrule any elements of the draft Guidebook, nor is it meant to replace a detailed risk assessment, engineering analysis, and/or risk mitigation plan. Rather, the SLRM is intended to identify projects for which these steps are necessary and provide a pathway for project risk reduction to within acceptable levels for industry operation and Regulator approval.

In other words, the SLRM can be used to assess, at a high level and prior to the application of engineering project controls and mitigations, the risk of MSHF projects involving alternative water sources, where risk is defined in a water quality context with respect to specific human and environmental receptors (discussed below). This high-level assessment is intended to allow both proponents and the Regulator to distinguish between projects which are lower and higher risk, where lower risk projects can be approved rapidly (e.g. through an automatic approval in OneStop) and higher risk projects will receive further consideration.

This section outlines how the SLRM works, starting from a basic definition for risk, and includes discussion on receptors, exposure pathways, likelihood and consequence assessment, and overall risk scoring mechanics.

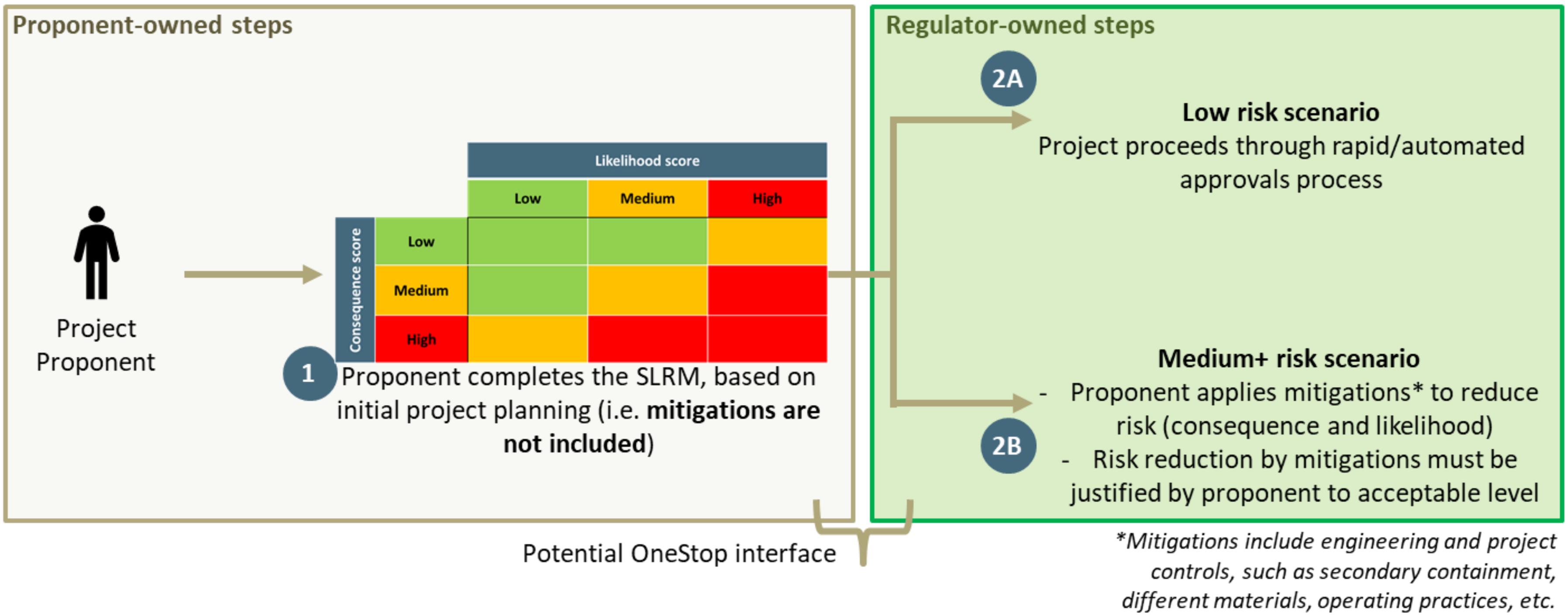

Figure 3-1 Illustrative diagram showing how the SLRM can be utilized by a proponent and interface with the regulatory/application process.

3.1 Definition of risk

According to the Intergovernmental Panel on Climate Change (IPCC), risk can be defined as:

"The potential for consequences where something of value [including humans] is at stake and where the outcome is uncertain… Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur." (Field, et al., 2014).

This definition for risk is the basis for the SLRM, where the *likelihood* (or "probability") and the *consequence* (or "impacts") of an exposure event to receptors are assessed individually before being combined to produce a risk score. This is illustrated in Figure 3-2.

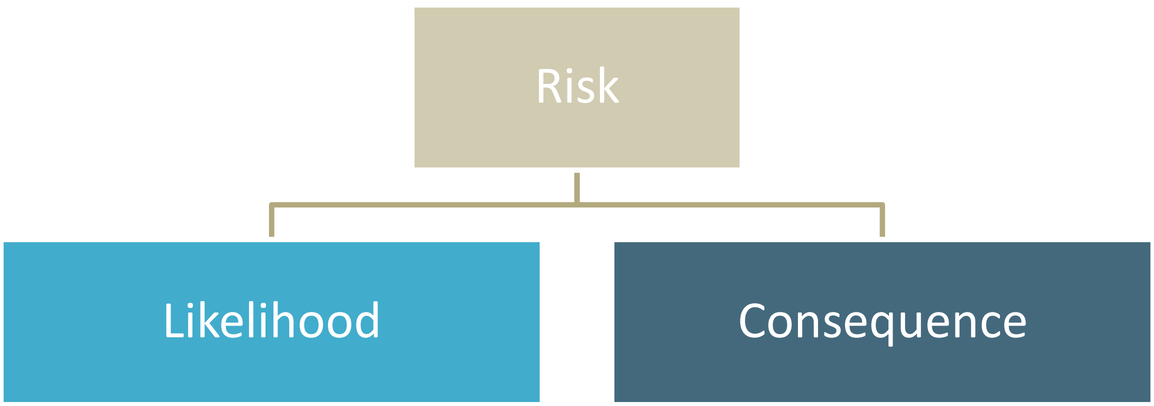

Figure 3-2 Visual representation for the definition of risk, which combines likelihood and consequence

3.2 Project Assumptions

The SLRM was designed to be simple to complete while still adequately describing the risks associated with conveyance and storage of alternative waters. To achieve this, some fundamental assumptions were made regarding the SLRM scope.

3.2.1 Physical boundaries

The SLRM is intended to assess storage and conveyance of water up to the well site boundary, but not activities occurring on the well site itself. Activities within scope include transport of water from an off-site location to an off-site storage area, followed by transport to a well site (although a project need not involve offsite storage for the SLRM to be applicable).

3.2.2 Alternative waters

In its current form, the SLRM is intended only to assess treated municipal effluent and produced/flowback waters. The key indicator contaminants used to assess water quality were selected only for these alternative waters. However, the SLRM can be adapted to assess other sources in the future through the inclusion of additional key indicator contaminants.

3.2.3 Trucking

Transportation of water via trucking is outside the scope of the SLRM. Trucking is already commonly used to transport alternative water sources.

3.2.4 Toxicity

The SLRM only considers the acute toxicity of contaminants for each receptor. It was assumed that a spill or leak would constitute a discrete event that would be detected and mitigated within a short time period, which would prevent the bioaccumulation of contaminants to any significant level.

3.2.5 Receptor selection

Receptors, detailed in Section 3.3, have been selected based on their sensitivity to the key indicator contaminants. It is assumed that the sensitivities of the selected receptors can accurately describe the risk profile of the alternative water sources.

3.3 Receptor identification

A generally accepted definition of an ecological receptor is an entity that may be adversely affected by contact with or exposure to a contaminant of concern (EUGRIS, 2019). For the SLRM, the contaminants of concern come from the alternative water sources (treated municipal effluent and produced/flowback water in this project) and exposure occurs through accidental release. To identify potential receptors, it was necessary to first determine the exposure pathways.

Exposure pathways are the mechanisms that would introduce contaminants of concern to a potential receptor. For example, exposure to plants could occur through root uptake or external contact, and for animals and humans, exposure can be through inhalation, ingestion or external contact. In the context of transport and storage of water for MSHF operations, four potential exposure pathways were identified:

- A spill during transport of the fluid from a catastrophic failure of the pipe or hose.
- A slow leak to the environment from the pipe or hose (e.g. a leaking connection).
- A spill during storage due to a catastrophic failure of containment.
- A slow leak to the environment from the storage equipment (e.g. pinhole leak).

The exposure pathways identified for the SLRM represent discrete events and thus lead to a short-term, acute exposure to the receptor, rather than a chronic exposure. The focus on acute exposure is a fundamental assumption of the SLRM and informs how both likelihood and consequence are scored. Note the SLRM is not intended to be applicable to disposal via surface pump-off, nor should it be compared to Alberta's pump-off guidelines. Pump-offs are a planned release, whereas the SLRM is concerned with assessing short-term, accidental releases.

In the context of the above exposure pathways, and considering the locations of real-world projects, receptors for the SLRM were identified in terms of broad categories. Because the SLRM is a high-level assessment, differentiation between species within these categories is not required. As Sections 3.4-3.6 will illustrate, the SLRM assesses the risk of alternative water use for MSHF projects with respect to each of these receptor categories. This provides useful information to project proponents regarding where to focus mitigations.

The receptor categories, and their predominant sensitivities, are:

- **Aquatic life** – including vertebrate and invertebrate animals and aquatic and wetland plant life.
    - Aquatic life is susceptible to changes in local water chemistry; aquatic animals are particularly sensitive to chloride contamination. In addition, hydrocarbon content can have a significant impact on aquatic plant life.
- **Terrestrial plants** – including commercial plants, such as grain, and non-commercial plants, such as shrubs and trees.
    - Terrestrial plants are most affected by changes to soil chemistry; contaminants that prevent the uptake of essential minerals through plant roots are particularly relevant in the context of alternative water sources.
- **Human health** – including operators and members of the public.
    - In the event of acute exposure, humans are most susceptible to biological contaminants; even a small number of bacteria can multiply within the human body, potentially leading to illness.

Animals, such as cattle and waterfowl, were also considered. However, it was found that for treated municipal effluent and produced/flowback water, the aquatic life, terrestrial plants, and human health receptors would be more sensitive to present contaminants than animals. Hence, the environmental and human health risks associated with reuse of the selected alternative waters for MSHF operations are adequately described by the selected receptors.

If the SLRM is expanded to include additional alternative water sources, it may be appropriate to consider animal receptors which are more sensitive to specific contaminants present in these other sources. For example, cattle are highly sensitive to the sulphate content of their drinking water. However, the sulphate content in the proposed alternative water sources is not at a concentration high enough to cause observable adverse effects during acute exposures (Government of Sakatchewan, 2019). Therefore, cattle are not included as a receptor in the SLRM at this time.

3.4 Likelihood assessment

Assessing the likelihood of receptors being exposed to contaminants during a MSHF project can be a complex exercise. Numerous project-specific factors can be considered (e.g. water body and soil type, topography, operator experience, materials, system design, etc.) and attempting to quantify the overall likelihood of exposure as a composite of all these interrelated factors would be a significant undertaking. With this complexity in mind, the SLRM was designed to enable a high-level likelihood assessment which is not onerous and can be completed at an early project stage. This is accomplished through a qualitative, rather than quantitative, approach.

The SLRM's qualitative approach to evaluating the relative likelihood of each receptor category being exposed to contaminants (via any of the identified exposure pathways) uses a series of Yes/No questions which the proponent answers. These questions are specific to MSHF projects and are meant to address the ways in which project variations could affect the exposure pathways. They were developed by the project team, in collaboration with representatives from PTAC, and reflect some high-level input from the AER.

Consistent with the exposure pathways, the likelihood assessment considers both transportation and storage of alternative water sources for MSHF operations. The likelihood questions are broken into four categories to ensure all relevant project factors are considered:

- The proximity of the project to receptors.
- The duration of the project (considering both equipment/material failure and operating error).
- The materials used for the operations.
- The operational parameters (e.g. flow rate, pressure etc.).

Each question category contains several questions which are relevant to specific receptor categories. The questions are framed such that a higher likelihood response is one which contravenes existing regulations, materials standards, and/or accepted operational practices. For example, using storage materials which are not consistent with *Directive 055: Storage Requirements for the Upstream Petroleum Industry* (or otherwise already approved via exemption) increases the likelihood of receptor exposure.

Select example questions are shown in Table 3-1 and a full list of questions, including justifications, is shown in *Appendix A1 Likelihood assessment details*.

Table 3-1 Sample questions from the likelihood assessment

#	Question category	Receptor category	Question	Response options	
				Lower likelihood	Higher likelihood
1.A.	Proximity	Aquatic Life	Is the project* within 100 m of a water body**?	No	Yes
1.B.	Proximity	Human Health	Does the project's transportation route include any water body crossings?	No	Yes

** Consider both transportation and storage of water.*

*** Water bodies include wetlands, swamps, rivers, lakes, etc.*

The likelihood score is determined by taking an average of the likelihood scores for each question category (i.e. proximity, duration, materials, operations). For each receptor category, only the relevant likelihood questions are included in its likelihood score (e.g. proximity to water affects the aquatic life receptor category but does not affect the terrestrial plants receptor category). Utilizing an average for the likelihood score balances the contributions of the many aforementioned inter-connected factors which impact likelihood.

As a refinement to the SLRM, the likelihood scoring weights the proximity questions at half the value of each other question category. This reflects input from PTAC representatives, as well as the fact that proximity alone is not sufficient to cause exposure to a receptor; a failure in materials or operations must also occur within sufficient proximity to result in exposure.

3.5 Consequence assessment

The consequence assessment portion of the SLRM evaluates the impact of the alternative water sources on each receptor group, while assuming exposure occurs (where actual probability of occurrence is considered in the likelihood assessment).

Alternative water sources may contain a wide variety of contaminants, many of which are harmful to the receptors identified in Section 3.3. It was considered impractical for a screening level risk assessment (and potentially expensive for operators) to assess all possible contaminants that could be present in alternative water sources. To streamline the assessment, contaminants to which the receptors categories are sensitive, or which are typically present in large quantities in treated municipal effluent and produced/flowback waters, were used as key indicator contaminants. Using a narrow list of key indicator contaminants allows the SLRM to be completed more easily by operators, who are not required to sample for every possible contaminant.

Narrowing down which contaminants should be considered key indicator contaminants was done by first considering the contaminants in the 2018 Environmental Quality Guidelines for Alberta Surface Waters (SWQ guidelines) (Government of Alberta, 2018). The SWQ guidelines set different limits based on three protection categories:

- Protection of aquatic life – Sets water quality limits to protect sensitive aquatic species.
- Wastewater for irrigation – Sets water quality limits to protect plant life when using surface water for irrigation.
- Recreational water – Sets water quality limits to protect human health in recreational waters.

These categories align with the receptor categories identified in Section 3.3, as shown in Table 3-2. The SWQ guideline categories and the limits identified within each category, together with the contaminant concentrations identified in Section 1.3, were used to identify the key indicator contaminants. *Appendix A2 Key indicator contaminant identification* includes a visual summary of how the key indicator contaminants were identified.

Table 3-2 Alignment between SWQ guidelines and receptors identified in Section 3.2

Receptor Type	Category identified in the surface water quality guidelines	Receptor group
Environmental	Protection of aquatic life	Aquatic life
	Wastewater for irrigation	Terrestrial plant life
Human Health	Recreational water	Humans

As noted, the key indicator contaminants, listed in Table 3-3, were selected because the receptors are highly sensitive to them and/or because they are present in high concentrations within the alternative water sources. The key indicator contaminants are not meant to be an exhaustive list of potentially harmful contaminants. Rather, they allow the SLRM to fully describe the risk to receptors from treated municipal effluent and produced/flowback water efficiently and without requiring excessive water quality testing by operators.

As Table 3-3 indicates, each key indicator contaminant maps to one or more receptor categories, based on the sensitivities of each receptor category. The primary receptor is the most sensitive receptor; however, there are instances where other receptors are also sensitive to the key indicator contaminant. For example, aquatic life is highly sensitive to chloride concentration (primary receptor), while terrestrial plants are also sensitive (secondary receptor).

The limit ranges for each key indicator contaminant, listed in Table 3-4 and Table 3-5, were derived from existing regulatory guidelines and academic papers detailing the effects of exposure to the selected receptor. The methodology behind the determination of the limit ranges is presented in *Appendix A3 Key indicator contaminant consequence levels*.

Table 3-3 Key indicator contaminants identified for consequence assessment and related receptors

Key indicator contaminant	Impacted receptors		Purpose
	Primary	Secondary	
Chloride ions	Aquatic life	Terrestrial plants	Quantifies risk to aquatic animals
Sodium Adsorption Ratio (SAR)	Terrestrial plants	N/A	Measures the potential of removal of essential minerals in soil
E-Coli	Human health	N/A	Quantifies risk to humans using surface waters

Key indicator contaminant	Impacted receptors		Purpose
	Primary	Secondary	
Hydrogen sulfide (H_2S)	Human health	N/A	Quantifies risk to MSHF operators
pH	Aquatic life	Terrestrial plants Human health	Quantifies risk to aquatic plants and animals
Oil and grease	Aquatic life	N/A	Quantifies risk to aquatic habitats

Table 3-4 Consequence assessment water quality limits for primary receptors

Consequence score (primary receptors)	Chloride (mg/L)	SAR (unitless)	E-Coli (cfu/100mL)	H_2S (mg/L)	pH	Oil & grease
Primary receptor	**Aquatic Life**	**Terrestrial plants**	**Humans**	**Humans**	**Aquatic Life**	**Aquatic life**
Low	<640	<10	<320	Not Detectable	6.5-9	Meets SWQ guidelines
Medium	640-2500	10-25	320-900	N/A	5.5-6.4	N/A
High	>2500	>25	>900	Detectable	<5.5 or >9	Does not Meet SWQ guidelines

Table 3-5 Consequence assessment water quality limits for secondary receptors

Consequence score (secondary receptors)	pH	Chloride (mg/L)
Secondary receptor	**Terrestrial Plants**	**Terrestrial Plants**
Low	5.0-8.0	<750
Medium	8.4-9.0	750-2800
High	<5.0 or >9.0	>2800

Both the primary and secondary receptors are considered when determining a consequence score. Consequence scores are determined for each receptor category based on the highest scoring key indicator contaminant which is relevant to that receptor, where each key indicator contaminant is equally weighted.

This scoring mechanism ensures the consequence of exposure for each receptor category is accurately reflected. For example, if aquatic life will be harmed by high chloride concentration in a water source, the impact will not be "balanced out" to a lower consequence score if the pH is within optimal levels for aquatic life; the impact of chloride concentration would dictate the consequence score for aquatic life in this case. This mechanism also allows operators to reduce their water testing requirements. If one key indicator contaminant gives the water source a high consequence score, additional testing to score the remaining key indicator contaminants is not required.

3.5.1 Other contaminants considered

Many other contaminants were considered, but not included, in the consequence assessment. These exclusions are consistent with the intent of the SLRM to give a high-level overview of areas where there may be risk associated with the proposed project and indicate where a more in-depth analysis may be necessary. This sub-section provides justification for excluding some contaminants which are typically considered pertinent to environmental and human health. As noted, contaminants with low concentrations (i.e. well below safe limits) in treated municipal effluent and produced/flowback waters were not included in the SLRM.

3.5.1.1 **Ammonia**

Ammonia (NH_3) is a chemical that can be found in trace quantities in nature but is a key constituent in many man-made products, including fertilizers (Mosaic , 2019). Ammonia's prevalence in the agriculture industry means it is commonly found in wastewater treatment plants and in surface runoff.

Ammonia is soluble in water, forming the weakly basic ammonium hydroxide solution (NH_4OH), which is highly toxic to aquatic organisms. The reaction between ammonia and water forms an equilibrium and at higher pH and temperature, the reaction favours the production of ammonium hydroxide. Hence, the toxicity of ammonia is highly dependent on pH and temperature (USEPA, 2013), with the impact of pH being particularly dramatic.

Specific ammonia limits were not included in the consequence assessment because the concentration of ammonia in municipal treated effluent and produced/flowback water is not typically high enough to cause concern. Instead, ammonia toxicity is accounted for using pH as a proxy, where high pH levels are a flag for potential ammonia toxicity consequences. Specifically, the 2018 Environmental Quality Guidelines for Alberta Surface Waters have ammonia limits detailed for temperatures between 0°C and 30°C and between pH 6 and 10 (Government of Alberta, 2018).

3.5.1.2 **Naturally Occurring Radioactive Materials (NORMs)**

Naturally Occurring Radioactive Materials (NORMs) are radioactive materials found within the earth's crust. These materials occur naturally and contribute to background radiation, posing no risk to human health while contained within the earth's crust. Processes, such as MSHF, can bring NORMs to the surface because many are soluble in water. The MSHF process and typical operating procedures have the potential to concentrate the NORMs, which could pose a risk to human health under the right circumstances, but they are not expected to impact terrestrial plants or aquatic life.

One of the most common radioactive materials in produced/flowback waters is radium, which has two common radioactive isotopes: Ra^{226} and Ra^{228} (Fisher, 1998). When brought to the surface by MSHF operations, radium is dilute and in its soluble form, thus posing no human health risk. However, produced/flowback waters often also contain sulphates, which react with the radium to form the insoluble solid compound radium sulphate ($RaSO_4$). Insoluble radium sulphate co-precipitates with barium sulphate, which can accumulate as a powder on pipe connections and within water storage areas (USGS, 1999). If disturbed, this powder can be inhaled into the lungs, with significant negative human health impacts. However, the powder is immobile and would likely not be transported beyond project boundaries (IAEA, 2014). The risk to the public is therefore very low. Operators performing equipment cleaning/maintenance are expected to follow the Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials, which mandates the use of protective equipment where required (Health Canada, 2014). Hence, the human health risk posed by NORMs is low.

In soil systems, radium is known to readily adsorb to clays and mineral oxides present in soils, meaning transportation of water-soluble NORMs in the event of a spill or leak would be limited (IEER, 2006). This, in turn, would limit contaminant uptake through plants and the subsequent potential bioaccumulation in humans and animals through ingestion of these plants.

In aquatic ecosystems, the NORMs-containing water, which already has only dilute concentrations of NORMs, would be further diluted. Hence, accumulation of NORMs to unsafe levels in aquatic ecosystems due to a spill of produced/flowback water is extremely unlikely.

Since exposure pathways for NORMs are limited and there are adequate operational health and safety guidelines in place to protect operators, there is no benefit to including NORMs in the SLRM.

3.5.1.3 **Conductivity**

The conductivity of water is defined as its ability to pass electrical flow, which is related to the concentration of ions within the water (Lenntech, 2019). Conductivity can be easily measured in the field and can be a useful indicator of water salinity. However, conductivity is not useful for assessing the consequence of exposure to specific receptor categories because it is not possible to differentiate between ions or assess ion balance using a conductivity measurement. The concentrations of specific ions drive receptor sensitivity, and the key indicator contaminants (Table 3-3) describe the consequences of exposure adequately. Therefore, conductivity was not included in the SLRM.

3.5.1.4 **Total dissolved solids (TDS)**

Total dissolved solids (TDS) is a measure of the combined content of all dissolved solids in the water (SDWF, n.d.). Typically, TDS is made up of inorganic dissolved solids with a small amount of organic dissolved solids. TDS is often used as an inexpensive indicator of salinity. However, like conductivity, TDS does not differentiate between specific contaminants and therefore cannot describe their associated consequences to receptors. TDS is not included in the consequence assessment, as ions and ion balances specific to the receptor categories better describe the exposure consequence of alternative water sources.

3.6 Scoring risk and mitigations

As noted in Section 3.4, the likelihood score is the average likelihood for each receptor category. As Section 3.5 indicates, the consequence score is determined for each receptor category by taking the highest individual contaminant score, based on the water quality of a given alternative water source. The low/medium/high scores for each of likelihood and consequence are combined to produce the overall risk score, which is also given on a low/medium/high basis, as shown in Table 3-6.

Table 3-6 Scoring risk matrix for assigning overall risk score

Scoring Risk Matrix Ranges		Likelihood		
		Low	**Medium**	**High**
Consequence	**Low**			
	Medium			
	High			

The SLRM is designed to be completed at the project planning stage when project details are still being determined by the operator. As such, the SLRM does not include mitigations, which are project elements a proponent may include to reduce their project's consequence score, likelihood score, or both. Hence, if a project receives a medium or high risk score in the SLRM, this does not necessarily mean it should be discounted as too risky to execute. Rather, the SLRM indicates where mitigations could be applied for maximum benefit, on a risk reduction basis, by providing risk scores for each receptor category.

Identifying specific mitigations was outside the scope of this project, although illustrative examples are provided in this report (e.g. Table 3-7). In the future, the SLRM could be augmented to include mitigations which are linked to particular contaminant levels (i.e. consequence scores), likelihood question responses, and/or receptor-specific risk scores. In practice, a proponent could reassess their project's risks once mitigations are accounted for, and work with the Regulator to validate resultant risk reductions. In other words, the SLRM provides a pathway for reducing project risks to within acceptable levels. This is illustrated in Table 3-7, using arbitrary example mitigations for an arbitrary alternative water reuse project.

Table 3-7 Example SLRM output, showing the likelihood, consequence, and risk scores for each receptor category prior to the application of mitigations. Example mitigations and an example updated risk score, accounting for mitigations, is shown for each receptor category

Receptor category	**Consequence score**	**Likelihood score**	**Unmitigated Risk score**	**Example mitigations** (for consequence & likelihood)	**Risk with mitigations in place** (future work area)
Aquatic Life	High	Low	**Medium**	• Treat water to reduce consequence • Bolted hose connections • Pressure testing prior to use • Low pressure shutdown for leak detection • Centrifugal pumps to minimize over-pressure risk • 24 hr manned operations • Culverts for driveway crossings • Etc.…	**Low**
Terrestrial Plants	High	Medium	**High**		**Low**
Human Health	Low	Medium	**Low**		**Low**

3.7 Scenario analysis

The likelihood and consequence assessments of the SLRM were initially developed by the project team based on research and operating experience. Through discussions with PTAC operators, both assessments were iteratively improved to produce the previously described approaches. As the SLRM was improved, the project team tested it using a realistic operating scenario (developed in concert with PTAC operators). This scenario analysis allowed validation of the key indicator contaminant consequence limits and likelihood assessment structure.

The scenario, per discussions with PTAC operators, can be summarized as follows:

- The project uses "typical" produced/flowback water, with water quality defined in Table 3-8.
- Produced/flowback water is transported and stored nearby to domestic residences and crops, but far from water bodies and recreational swimming areas (and includes no water body crossings).
- The project is operational for less than one year.

- The water source and end point are within visual range of one another.
- The project operates in the summer when temperatures are above 0°C.
- The system is operated well below the design burst pressure of its components.
- The length of pipe between automatic shut offs is short and the volume contained within these lengths is small (i.e. spill volumes would be low).
- Materials used for transport and storage are not in exception to AER or AEP regulations.

Table 3-8 Produced/flowback water quality for scenario analysis

Chloride (mg/L)	SAR (unitless)	E-Coli (cfu/100mL)	H_2S (mg/L)	pH	Oil & grease
45,000	75.6	20	ND	7.4	Does not meet SWQ guidelines

Table 3-9 shows how the example scenario would score in the SLRM, for both consequence and likelihood in each receptor category. The SLRM shows the scenario presents little risk to human health, but a more detailed assessment of the risks to aquatic life and terrestrial plants would be required. As discussed in Section 3.6, the identification of appropriate mitigations would be part of this detailed assessment.

It was determined that the participating PTAC operators were comfortable with the risk scores assigned to this scenario by the SLRM; there is an inherent risk in transporting produced/flowback waters, but there are opportunities to manage this risk in initial project design (e.g. through project siting, since the human health risk is low in the absence of humans), as well as through mitigations (not shown in Table 3-9). A sensitivity analysis was conducted on this scenario by altering likelihood question responses (e.g. changing project materials). The resultant risk scores were found to be reasonable by the project team and PTAC operators.

Table 3-9 SLRM output for hypothetical MSHF scenario

Receptor Type	Consequence Level	Likelihood Level	Overall Receptor Risk Level
Human health	Low	Low	**Low**
Aquatic life	High	Low	**Medium**
Terrestrial plants	High	Low	**Medium**

4.0 Regulatory Opportunities

As noted in Section 1.1, the current regulatory environment does not facilitate the use of alternative waters for MSHF operations. Existing regulations are rooted in a definitions-based system that does not adequately reflect environmental and human health risks posed by alternative waters. Regulators and industry are now moving towards a risk-based approach to determine the suitability of alternative waters for reuse.

4.1 Recommendations from industry

As the transition to a risk-based regulatory approach continues, there have been opportunities for industry to provide feedback to the AER and AEP on existing regulatory barriers and recommend pathways to overcome those barriers in a manner that allows operations to be carried out efficiently while maintaining environmental protections.

4.1.1 Area Based Regulations report

A pilot project for area-based regulation was conducted by the AER and AEP in 2017 in an effort to address the shift in focus of energy development from conventional to unconventional sources, while improving cumulative effects management. The project highlighted several areas for regulatory enhancements, including the use of alternative waters. The following pertinent industry recommendations come from the recommendations report distributed to the AER and AEP upon conclusion of the project (ABR Pilot Panel, 2017).

- *"The AER should develop a risk-based, full lifecycle fluid management framework that improves industry performance in the use of alternatives by:*
    - *Applying regulatory controls for transportation, storage and use that are based on the risk profile for alternatives to [high-quality non-saline sources] water.*
    - *Accommodating changes in fluid composition that may occur as a result of treatment of co-mingling.*
    - *…Requiring industry reporting on character of the fluids, their associated risk, and range of potential contamination over the full activity lifecycle described…*
- *The AER should expand which fluids it allows to be transported using temporary surface hose and pipeline, using evidence of environmental performance and protection, including heightened operational oversight by industry. This expansion should include demonstrated reduction of fragmentation (linear disturbance footprint) risk and any needed monitoring and public reporting for performance assurance.*
- *For basins not currently under water restrictions, enable low-risk transfers (as defined under the Water Act) across major basin boundaries when intended for consumptive use by operators who can demonstrate an overall decrease in net environmental effects resulting from a transfer.*
- *To enable the access and use of alternatives…:*
    - *AER adjust* Directive 056: Energy Development Applications and Schedules *(s.7.11.11) to require notification only from operators targeting deep [low-quality non-saline] and deep saline water, instead of the current requirement for obtaining consent from the mineral rights lessee for the water sourcing activity.*

- *Department of Energy set clear criteria including minimum hydrocarbon content to trigger trespass investigations for wells under the* Mines and Minerals Act *(s.54(1)) to allow for access to deep [low-quality non-saline] and saline water sources."*

4.1.2 CAPP letter to the AER

In October 2019, CAPP sent a letter to the AER highlighting key opportunities to streamline the regulatory process and enable the use of alternative waters for MSHF. The following recommendations were made within the letter:

- Approval of the draft Water Conservation Policy for Upstream Oil and Gas (October 2016).
- Harmonization of alternative water classifications – alignment of the definitions of alternative waters with definitions in *Directive 081: Water Disposal Limits and Reporting Requirements for Thermal In Situ Oil Sands Schemes* would result in standardization and remove ambiguity from MSHF applications.
- Storage and logistics of produced/flowback waters for reuse – the use of a risk-based approach for the storage and conveyance of alternative waters would allow the use of poor quality alternative waters, such as produced/flowback water, when appropriate controls and mitigations are in place to mitigate risk.
- Provisions for amending water licenses to enable reuse – operators could increase their water reuse if provisions were in place to share or reuse waters between operators in the same basin. New guidance could be set out parameters to share water issued under temporary diversion licenses.
- Authorization for reuse of municipal and industrial wastewater – a standardized application process for Letters of Authorization (LOAs) would be beneficial for both the operator and the Regulator. Ideally, this approach would also be standardized between the AER and AEP so that one application package can be issued. As part of this project, the project team reviewed existing LOAs to identify constraints of, and opportunities for streamlining, the application process. A summary of this review is included in *Appendix A4 Review of Letters of Authorization*.

4.2 Regulators meeting & potential next steps

As part of the project, a meeting was convened with representatives from PTAC, the AER, and AEP to discuss opportunities for regulatory streamlining (i.e. "Red Tape Reduction") and how the project's outputs, particularly the SLRM (as described in Section 3.0), might align with the future risk-based regulatory environment. At this meeting, all parties were aligned on the overarching goal of enabling MSHF operators to increase their use of alternative water sources in an efficient and environmentally responsible way. From a practical perspective, all attendees agreed the industry is currently unlikely to treat poor quality water to higher quality to enable its use[1]. Instead, opportunities to enable alternative water use are primarily in the area of mitigations to reduce the likelihood of a spill (e.g. engineered materials, project controls, alternate

[1] Because operators can currently utilize low quality water in their MSHF operations, there is little economic incentive to treat this water for transportation and storage, which would be expensive using currently available technologies.

routing, etc.).

The AER and AEP representatives indicated that both organizations were busy investigating regulatory improvement opportunities. The AER was investigating regulatory instruments and process improvements which fit within the existing policy framework laid out by AEP, which in turn was progressing policy improvements (e.g. approving the draft WCP) and streamlining activities involving codes of practice. AEP also signaled that water reuse and low risk inter-basin transfers were being investigated. It was noted that some opportunities can be capitalized on rapidly, while others (e.g. those requiring legislative changes) will take longer to execute. Industry feedback was identified as an important part of the regulatory improvement process; operators and industry associations can highlight the biggest opportunities and provide valuable context regarding their scope and scale.

The AER and AEP both appeared generally receptive to the concept of the SLRM, and some edits were suggested throughout the meeting. It was revealed the AER utilizes an internal risk assessment approach which is similar to the SLRM. Hence, there may be some opportunities to align future risk-based applications by industry with the embedded approaches and systems of the AER. However, it was noted some of the steps associated with potential utilization of the SLRM in the application approach, such as OneStop integration or regulatory changes, would be difficult to execute in the near term. Multiple teams within the AER (e.g. pipelines and storage) would need to be involved, and this effort would compete for resources and manpower with other AER priorities.

Given the regulatory and policy context of MSHF operations; shift towards risk-based assessments; ongoing efforts to streamline the regulatory environment; current changes within the AER and AEP; and complexity of updating the regulatory process, given practical and policy constraints, the following next steps were discussed at the meeting:

- Representatives of the AER are encouraged to discuss the SLRM within their groups and consider how this project's outputs may be leveraged to improve the regulatory process for alternative water use in MSHF projects.
- PTAC operators can utilize the SLRM and associated approach to submit consistent applications to the AER and work through the details of authorization. With each application (and iteration), the process will be improved until there is a clear system in place within the existing regulatory context.
- All participants can consider the value of developing codes of practice, or similar instruments, for alternative water use in MSHF. Codes of practice may be appropriate for streamlining the application process (e.g. for reuse of treated municipal effluent) or for giving direction to operators regarding risk mitigations. This could be similar to the work AEP is doing around wetlands and power line pole placement with codes of practice.

5.0 Conclusions & Recommendations

This project resulted in the collaborative development of a spreadsheet tool, the SLRM, for performing high-level risk assessments of MSHF projects utilizing treated municipal effluent and produced/flowback water. In the future, the SLRM can be expanded to assess the risks of using additional alternative water sources.

As noted in Section 4.2, the SLRM, as the basis for an industry led approach to licence applications, was generally well received by the AER and AEP. Although the precise scoring limits and mechanics of the SLRM could be modified through future work with the AER, the risk assessment framework is consistent with many of the AER's internal processes.

It is recommended that representatives from PTAC utilize the SLRM and learnings from this project to submit applications for MSHF projects utilizing alternative water sources. In doing so, representatives can take advantage of the opportunity to improve the approvals process for these projects by submitting multiple applications using a consistent approach and working through questions and follow ups with the AER. Applications covering a range of regulatory requirements could be applied for, such that the approvals process for alternative water use for MSHF can be improved for both storage and transportation of alternative water sources. Multiple applications of the same type could be submitted to ensure an efficient approvals process is developed. For example, the following applications could be submitted:

- Short distance (no connections) overland transfer of produced water within a known right of way between two owned mineral surface leases, owned by a single owner.
- Short distance overland transfer of produced water within a known right of way between two different operators.
- "Simple" design of produced water pond (i.e. take a design approved in British Columbia and bring to Alberta).
- Longer distance (multiple connections) overland transfer of produced water within a known right of way.
- Water storage of "treated to discharge specifications" produced water in aboveground synthetically-lined wall storage systems.
- Simple receipt (by truck) of another operator's produced/flowback (wastewater) on an operator's site for use in hydraulic fracturing.

This approach will produce the greatest benefits to industry as a whole if each application uses the SLRM tool and this project's learnings in a consistent way, and if information from each application approval process is shared broadly. This strategy will ensure consistent, mutually beneficial changes are made to streamline the approvals process, as has been documented for other novel applications. This success can be repeated using the SLRM as part of a coordinated application approach.

Building on the learnings from this approach, including identified gaps, future effort should be dedicated to fleshing out the mitigations required to reduce the risk of MSHF projects with alternative water sources. Both PTAC representatives and the AER could collaborate to identify economical mitigations to reduce the environmental and human health risks of projects to within acceptable levels for all parties. Once appropriate mitigations have been identified, these can be formalized to streamline their future use and the associated approvals process. This could include the development of codes of practice for the use of specific materials or operating procedures.

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