Risk Assessment of Solvent Injection Processes

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Alberta Energy Regulator
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Preface

This report describes an option in providing regulatory assurance at the Alberta Energy Regulator (AER) in the face of rapid technological advances being adopted in Alberta's petroleum industry. It addresses a new innovative practice for regulatory review and should be regarded as a prototype for a more rapid, evidence-based and science-informed regulatory response to new technology when that is proposed for development of Alberta's energy resources.

This preface is meant to provide context to this option, whereas the contents of the report stand on their own merit. I recommend their conclusions be accepted by the AER for information and guidance without prejudice to any regulatory application under current or future review.

This particular work concerns new technology for underground, or in situ, development of oil sands. The goal of the Province of Alberta has always been to develop its immense in situ oil sands resources in a way that provides economic benefits to all Albertans. The role of the AER is to assure Albertans that this development is done in a way that is safe, efficient, orderly, and environmentally responsible.

The history of oil sands development in Alberta has been one of responsible resource stewardship, intense regulatory oversight, and made-in Alberta commercial innovation. A historical review is partly captured in the peer-reviewed paper by AER Chief Geologists (past) Dr. F.J. Hein and (present) Dr. K.P. Parks, published in 2016 by the Canadian Society of Petroleum Geologists[1]. In the past decade, Albertans' concerns have included growing calls for more environmental protection, stakeholder engagement, respect for indigenous and traditional rights, and response to climate change in the in situ oil sands sector. In response, government leaders and policy-makers are focusing their attention on these issues, and regulators need to respond accordingly. A real challenge for regulators like the AER is to adapt to these tectonic shifts in social concerns and government direction using regulatory instruments already in force, while going through the process to create new ones.

Regulatory development is a detailed process involving stakeholder consultation, risk assessment, policy alignment, legal review, and possibly legislative changes. As such, it can move relatively slowly. In contrast, technological innovation driven by economic forces, moves relatively quickly. These dynamics put the regulatory system under tension to allow industry to capture immediate value through innovation while respecting the process needed for quality regulatory changes that balance society's goals and values.

[1] Hein, F.J., and K.P. Parks, 2016. Public geoscience in regulating Alberta's oil sands development: A Historical Retrospective 1960–2010. Bulletin of Canadian Petroleum Geology, 64(2), pp.362-383.

This document represents an innovative approach inside the AER to better respond to that tension. The specific challenge is around the use of solvent-assisted Steam-Assisted Gravity Drainage (SAGD) technology to recover oil sands in northeast Alberta, but it could be applied equally to a number of other areas of energy development in Alberta.

Over the past decade, the in situ oil sands industry in Alberta has invested in innovation to reduce water use in SAGD in situ oil sands-recovery processes in order to reduce costs and decrease environmental impacts. As well, conservation of water and minimization of waste is a prime mandate for the AER and thus AER has been requiring industry to reduce its use of water in SAGD. One opportunity to reduce the water footprint of SAGD is to deploy new technologies that actually replace the use of water in the development of in situ oil sands, but does not introduce unacceptable or unmanageable new risk to public safety or the environment. Solvent-assisted SAGD is one of these technologies.

Solvent-assisted SAGD, while not new in concept or pilot stage application, is relatively new in commercial-scale application in Alberta. As the practice evolves and matures, the AER will need to apply its existing regulatory instruments to evaluate and control risks, recognizing that the regulatory instruments that were developed in other oilfield contexts have general applicability to solvent-assisted SAGD projects. The economic interests of Albertans will be hurt if industry is not allowed to proceed with its safe use in the field at pilot and commercial scales.

This document summarizes the work of staff at the AER, which provides information to the AER leadership. The intent of this work was to provide an assessment of the AER's regulatory requirements and their effectiveness in regards to the application of solvent technology for in situ development of oil sands. This document concludes that the existing regulatory instruments will be sufficient to meet the goals of public safety and environmental protection demanded by Albertans, while allowing commercial development to proceed in an orderly, efficient, and environmentally responsible manner, during which time fit-for-purpose regulations can be developed to suit both the specific nature of this technology and the site-specific contexts of oil sands areas where it will be deployed.

This work benefited from the contributions of AER subject-matter experts in many fields, including the AER Risk Assessment Team. Thanks go to H. Deng, M. Dumanski, K. Hale, J. Du, F. Chiang, S. Harbidge, L. Kopf, C. Dickinson, H. Huang, E. Giry, G. Boyer, T. Hussain, A. Panwar, C. Filewich, B. Hathway, T. Hauck, K. Haug, T. Arciszewski, and C. Evans.

Dr. Kevin Parks, P. Geo.
AER Chief Geologist
July 2018, Calgary

Executive Summary

Solvent injection processes, assessed in this report, are bitumen recovery technologies that involve **injecting solvents** (such as propane, diluent or other hydrocarbons) or **co-injecting solvents with steam** into a reservoir to produce bitumen reserves.

A risk assessment was conducted by AER staff to assess the effectiveness of existing regulatory controls in this context. The objective of this risk assessment is to understand the effectiveness of existing AER controls that could reduce the chance and magnitude of potential risks occurring given a generic understanding of a solvent-assisted SAGD project. This includes consideration of risk factors that could be associated with this technology including:

- general types of Contaminate(s) of Potential Concern (CoPC) potentially used in typical activities at solvent injection facilities;
- potential failure/release scenarios and transport pathways by which substances could enter the environment (e.g., groundwater, surface water, air, and soil);
- potential exposure routes (e.g., breathing, eating, or drinking) by which people could come into contact with CoPCs released into the environment.

This assessment is not intended to complete, amend, substitute for, or agree or disagree with any particular site-specific application of this technology under consideration, application, review, or other regulatory process. Rather this is an inward directed assessment of the regulatory instruments that will be applied to reviews of this technology at AER. The intent of this assessment is to provide the AER assurance that its own instruments are complete and sufficient with regard to controlling risk and to identify areas where improvements may be needed.

The risk assessment identified four key findings that can be used in risk-informed decision making and discussions for solvent injection processes:

1. A total of 20 potential failure/release scenarios that could result in the release of CoPCs from solvent injection processes were identified. This list can inform future application reviews for completeness.
2. 16 out of the total 20 potential failure/release scenarios with associated potential transport pathways and exposure routes were identified as lower band risk scenarios, for which the probability of exposure is very low or the potential magnitude of exposure is negligible given our knowledge of the technology and subsurface conditions in Alberta where this technology is likely to be applied. These risk scenarios are broadly tolerable; and they can be managed by existing risk reduction measures and no additional risk reduction measures are needed. To prevent these failure events and ensure their impacts are negligible, it is critical for operators to fully comply with AER's regulatory requirements.

3. 4 out of the total 20 potential failure/release scenarios have potential transport pathways and exposure routes ranked as middle band risk scenarios with the consideration of AER's existing regulatory controls. These risk scenarios warrant a thorough consideration of individual applications or operations to determine the necessity of employing practicable risk reduction measures (e.g., carry out additional review and surveillance - such as monitoring, inspections and audit; enhanced ongoing stakeholder engagement). These middle band risk scenarios include:

    - Caprock fracture (e.g., slow release of fluid to the surface) and caprock and overlying formation fracture (e.g., Total Joslyn incident) – if these failure event occurred, the magnitude of exposure would not be negligible. Existing regulatory instruments that could prevent or mitigate these failure events include AER *Directive 086 Reservoir Containment Application Requirements for Steam-Assisted Gravity Drainage Projects in the Shallow Oil Sands Area*.

    - Loss of containment from pipeline transportation – among the 20 potential failure/release events, pipeline spills/leaks are the most likely ones to occur off lease. Existing regulatory instruments that could prevent or mitigate these failure events include *Pipeline Act*; *Directive 077 Pipelines – Requirements and Reference Tools*; *Water Act*; *Manual 001 Facility and Well Site Inspections*; *Manual 005 Pipeline Inspections*; and requirements under Alberta Boilers Safety Association (ABSA).

4. Potential CoPCs at solvent injection facilities are not limited only to hydrocarbons. Collecting data on CoPCs associated with solvent injection process and assessing risks to people and environment could provide a technical rationale for developing monitoring programs for selected CoPCs, and deploy adaptive management strategies to mitigate these risks when they are identified. Having a comprehensive and responsive monitoring program based on trigger-warning systems allows identification of a chronic problem before it reaches critical levels or exceeds an exposure limit.

The risk assessment conducted here is limited by a number of factors. Interpretation of the key findings and future discussions should reflect these limitations and assumptions.

1 Introduction

1.1 Background

Solvent injection processes, assessed in this report, are bitumen recovery technologies that involve:

1. **injecting solvents** into a reservoir (see **Figure 1** below)

   Similar to steam-assisted gravity drainage (SAGD), this technology uses horizontal well pairs to access bitumen reservoirs that are uneconomic to mine. However, instead of injecting steam, a clean condensable solvent (such as propane) is injected into the reservoir.

2. **co-injecting solvents with steam** into a reservoir (see **Figure 2** below)

   This technology is a modification of SAGD or cyclic steam stimulation (CSS), which involves injecting a mixture of solvent and steam into the reservoir.

The injected steam and/or solvent (such as propane, diluent or other hydrocarbons) decrease the bitumen viscosity allowing it to flow more freely to the surface (producing well). While these technologies vary in name, solvent formulation, and operating conditions, all are intended to increase bitumen production rate, reduce water use and greenhouse gas emissions, and ensure economic viability while producing bitumen reserve. Comparison of processes injecting clean condensable solvents with the ones co-injecting solvents with steam were summarized in **Table 1**.

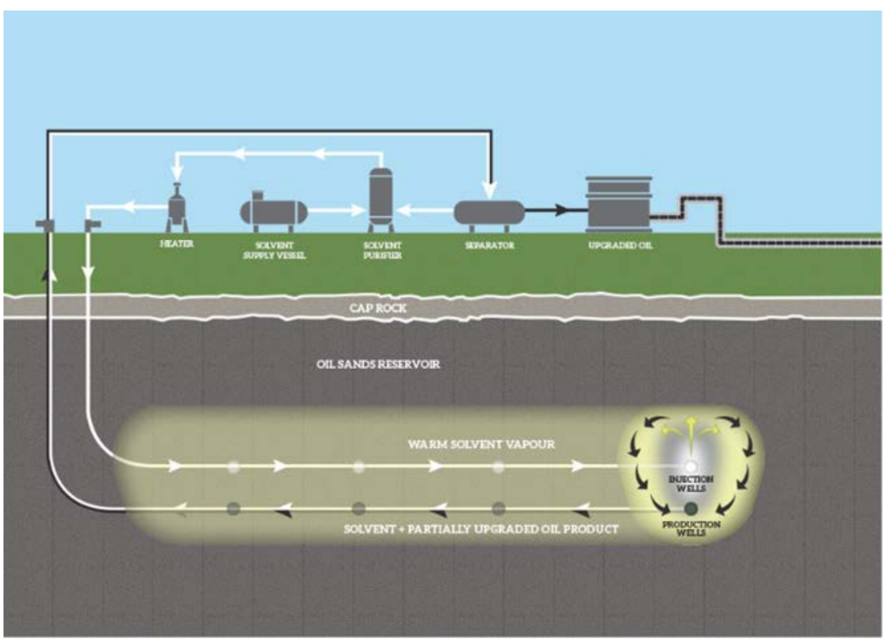

Figure 1: Illustration of in situ bitumen recovery technologies involving injecting solvent[2]

[2] Source: www.nsolv.ca

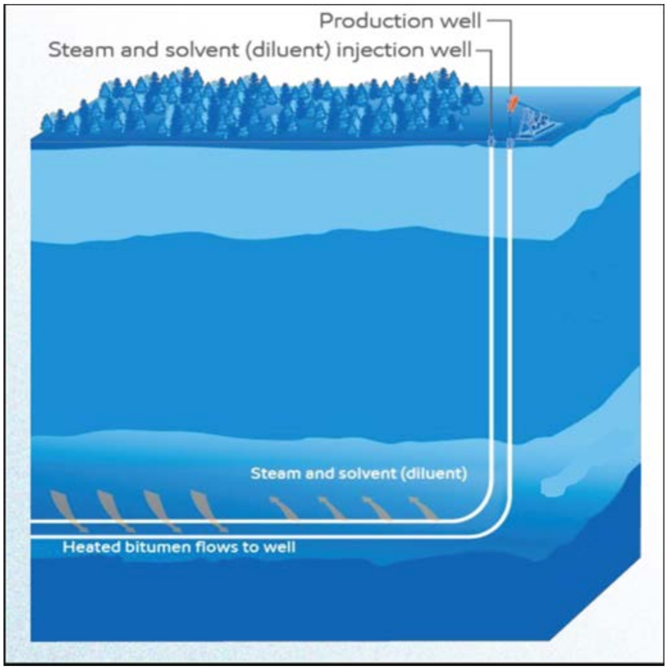

Figure 2: Illustration of in situ bitumen recovery technologies involving co-injecting solvent with steam[3]

Table 1: Comparing processes of injecting clean condensable solvents with the ones co-injecting solvents with steam

	Injecting solvents	Co-injecting solvents with steam
Similarities	• Improve bitumen recovery • Reduce water use and greenhouse gas emissions • Substances used in both processes include: - Hydrocarbon chemicals used to enhance recovery - Non-hydrocarbon chemicals used to enhance recovery - Common additives for well maintenance	
Differences	• Use only solvent, not steam • Use less energy and emit less greenhouse gas comparing with co-injecting solvent with steam	• Use a mixture of solvent (< 20% by volume) and steam • First commercial scale

1.2 Scope

This assessment was conducted on risks related to both surface and subsurface activities at solvent injection facilities. **Table 2** below summarizes activities and associated substances considered in this risk assessment.

[3] Source: Oil Sands Magazine

Table 2: Potential Interaction of solvent injection processes with the Environment

Activities	Associated Substances
Subsurface activities	
Solvent injection process - subsurface activities	Solvent, additives, steam, bitumen, produced water, and salts
Disposal	Solvent, residual hydrocarbons, produced water, and salts
Surface activities	
Chemical storage	Solvent, chemical additives
Flaring	Solvent, flowback fluid (solvent, formation product)
Ground transportation	Solvent, chemical additives, disposal fluid/solids
Pipeline transportation	Steam, solvent, dilbit, disposal fluid
Processing facility	Produced water, solvent, bitumen, dilbit, water treatment chemicals
Flue stacks	PM2.5, NOx, VOCs, SOx
Other venting	Produced gas (hydrocarbon, VOCs, RSCs, blanket gas) and water vapour

1.3 Objectives

The objective of this risk assessment is to understand:

- General types of Contaminants of Potential Concern (CoPCs) that could be used in typical activities at solvent injection facilities, including
  - solvent injection process
  - well and plant process, and
  - emission sources.
- Potential failure/release scenarios and transport pathways by which substances can enter the environment at solvent injection facilities, including
  - unplanned releases that occur over a short or intermittent duration, e.g., accident, emergency or upset release; and
  - controlled continuous releases, e.g., emission sources.
- Potential exposure routes (e.g., breathing, eating, or drinking) by which people could come into contact with CoPCs released into the environment.
- Effectiveness of existing AER’s regulatory controls which could reduce the chance and/or magnitude of potential risks occurring.

1.4 Context and Stakeholders

1.4.1 Internal Context

This study is conducted to ensure the following AER strategic outcomes are achieved:

- The environment is protected,
- The public is safe from harm, and,
- Citizens are confident about how energy is developed within the province.

1.4.2 External Stakeholders

The main external stakeholder or indigenous community for this study is Fort MacKay First Nation. Their concerns are related to commercial scale solvent injection processes in Fort Mackay's traditional territory and are detailed in the two letters to the AER dated October 13, 2016 and March 9, 2017. Results of this work may be used to engage the external stakeholder or indigenous community at a future potential Solvent Forum.

2 Limitations and Assumptions

The risk assessment conducted here is limited by a number of factors. Interpretation of the results and future discussions should reflect these limitations and assumptions.

1. Risk analysis was based on AER staff's knowledge and experiences, and generic information gathered from publically available applications, approvals, and correspondence.

2. The effectiveness assessment of AER's regulatory controls was based on the assumption that operators fully comply with these requirements. The AER follows its Integrated Compliance Assurance Framework to ensure operators comply with these requirements.

3. Risks to environmental receptors require site-specific information, therefore it was not conducted. However, ecological health assessment could be done in the future if it is determined as needed.

4. Exposure assessment to human receptors requires site-specific data (e.g., quantity and composition of used substances, location of human receptor), therefore it was not conducted. However, it could be done in the future if it is determined as needed.

3 Risk Assessment

The following risk assessment was conducted by members of AER's Environmental Science Group, Industry Operations - In Situ group, and Enterprise Risk Management team.

This risk assessment is to identify the risk associated with solvent injection process and to assess the effectiveness of regulatory controls, to ensure AER strategic outcomes are achieved. It started with identifying scenarios that have potential to release CoPCs to the environment, and various exposure pathways through which people could be in contact with contaminated soil, water and air. It also evaluated the likelihood of potential failure scenarios and exposure pathways based on the effectiveness of existing regulatory controls that could reduce the chance and/or consequence of potential failures occurring.

3.1 Risk Identification

The purpose of risk identification is to identify contaminant sources, subsurface failure/release scenarios, surface failure/release scenarios, transport pathways, and exposure routes.

3.1.1 Contaminant of Potential Concern (CoPC)

CoPCs potentially used at solvent injection facilities generally fall into four categories and the usage rates vary depending on the operational scheme:

1. Hydrocarbons to enhance recovery
2. Non-hydrocarbon chemicals to enhance recovery
3. Additives for well and plant processes
4. Chemicals in disposal wells

While currently companies are not required to disclose the detailed compositions of substances used in solvent injection process, some examples of potentially used substances were obtained from In Situ Performance Presentations submitted to the AER. See **Appendix 2** for details.

3.1.2 Potential Subsurface Failure/Release Scenarios

Potential subsurface failure/release scenarios for solvent injection process can be categorized by geological leakage or engineering failures. Nine potential scenarios were identified (see Figure 3) with associated activities that may lead to the release of the substance(s). **Table 3** below provides detailed descriptions of these scenarios.

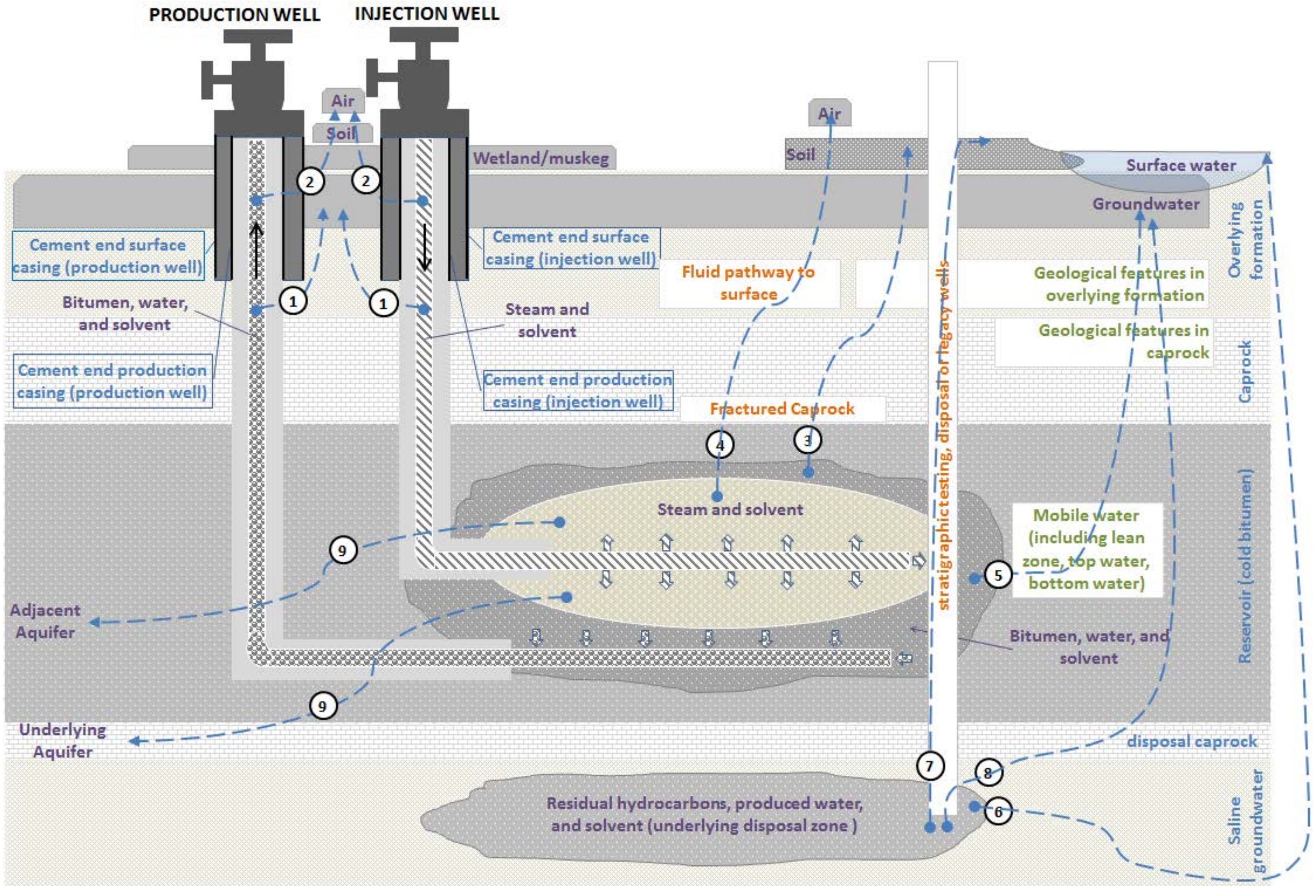

Figure 3: Illustration of potential subsurface failure/release scenarios

Table 3: Detailed description of potential subsurface failure/release scenarios identified in Figure 3

No.	Potential Source		Potential subsurface failure/release scenarios		Existing regulatory instruments that could prevent or mitigate the failure scenario
	Activity	Potential substances	Description	Expected release duration[4]	
1	Solvent injection process - subsurface activities	Solvent, additives, steam, bitumen, produced water, salts	Production/injection casing failures with surface casing failure	Short	AER directives related to drilling, completions, recompletions, repair, and abandonment (Dir 08, 09, 10, 13, 20, and 51); ID2003-01, Industry Recommended Practices (IRPs) 03, 25, and 26 (future);

[4] Potential failure/release types were characterized as **short** (i.e., an unplanned release or emergency that occurs over a short duration, such as immediate, hours, or days), **intermittent** (frequently intermittent event, such as weeks), or **continuous** (i.e., a continuous for months or continuous year-around)

No.	Potential Source		Potential subsurface failure/release scenarios		Existing regulatory instruments that could prevent or mitigate the failure scenario
	Activity	Potential substances	Description	Expected release duration[4]	
2	Solvent injection process - subsurface activities	Solvent, additives, steam, bitumen, produced water, salts	Cement, casing, or wellhead failure	Short or intermittent	AER directives related to drilling, completions, recompletions, repair, and abandonment (Dir 08, 09, 10, 13, 20, and 51); ID2003-01, Industry Recommended Practices (IRPs) 03, 25, and 26 (future)
3	Solvent injection process - subsurface activities	Solvent, bitumen, produced water, salts	Caprock fracture (e.g., slow release of fluid to the surface)	Short or intermittent	AER Directive 086 for shallow Athabasca Oil Sands Area
4	Solvent injection process - subsurface activities	Solvent, bitumen, produced water, salts	Caprock and overlying formation fracture (e.g., Total Joslyn incident)	Short	AER Directive 086 for shallow Athabasca Oil Sands Area AER Directive 023 for non-shallow area (e.g., application review process, SIRs, approval conditions, and caprock monitoring)
5	Solvent injection process - subsurface activities	Solvent, bitumen, produced water. salts	Lateral loss of solvent to highly mobile water in the reservoir	Short or intermittent	AER Directive 023 application information related to geology and reservoir quality
6	Disposal / Strat. testing / legacy wells	Solvent, bitumen, produced water, salts	Loss of disposal zone containment[5]	Short or intermittent	AER Directive 023 Applications and Scheme Approval Conditions, Directive 065, and Directive 054 monitoring related to Devonian disposal operations
7	Disposal / Strat. testing / legacy wells	Solvent, bitumen, produced water, salts	Enters stratigraphic testing, disposal, or legacy wells with poor cement and/or casing	Short or Intermittent	AER directives related to drilling, completions, recompletions, repair, and abandonment (Dir 08, 09, 10, 13, 20, and 5); ID2003-01, Industry Recommended Practices (IRPs) 03, 25, and 26 (future)
8	Disposal / Strat. testing / legacy wells	Solvent, bitumen, produced water, salts	Enters stratigraphic testing, disposal, or legacy wells with open flow wellbore	Short or intermittent	AER directives related to drilling, completions, recompletions, repair, and abandonment (Dir 08, 09, 10, 13, 20, and 51); ID2003-01, Industry Recommended Practices (IRPs) 03, 25, and 26 (future)
9	Solvent injection process - subsurface activities	Solvent, bitumen, produced water, salts	Lateral loss of solvent to adjacent or underlying zones	Short, intermittent or continuous	AER Directive 023 (e.g., application review process, SIRs, approval condition, and caprock monitoring)

[5] Fort McKay First Nation raised their concern on this failure scenario in their letter to the AER on March 9, 2017.

3.1.3 Potential Surface Failure/Release Scenarios

Potential surface failure/release scenarios were identified for typical infrastructures used in solvent injection process, including on site storage, ground and pipeline transportation, processing facility, and emission sources. **Table 4** summarizes the potential surface failure/release scenarios.

Table 4: Potential Surface Failure/Release Scenarios

No.	Potential Source		Potential surface failure/release scenarios		Existing regulatory instruments that could prevent or mitigate the failure scenario
	Activity	Potential substances	Description	Expected release duration	
10	Chemical storage	Solvent, additives	Loss of containment (reportable spill or leak)	Short	*AER Directive 055 Storage Requirements for Upstream Petroleum Industry*
11	Chemical storage	Solvent, additives	Loss of containment (non-reportable spill or leak)	Short or intermittent	*AER Directive 055 Storage Requirements for Upstream Petroleum Industry*
12	Ground transportation	Solvent, additives, disposal fluid/solids	Loss of containment on lease (reportable spill or leak)	Short	A spill or leak on lease would be regulated by AER through *EPEA*. If it is off lease it is out of the AER's jurisdiction.
13	Ground transportation	Solvent, additives, disposal fluid/solids	Loss of containment on lease (non-reportable spill or leak)	Short or intermittent	A spill or leak on lease would be regulated by AER through *EPEA*. If it is off lease it is out of the AER's jurisdiction.
14	Pipeline transportation	Steam, solvent, dilbit, disposal fluid	Loss of containment (reportable spill or leak)	Short	*Pipeline Act, Directive 077, Water Act, Manuals 1 and 5; ABSA*
15	Pipeline transportation	Steam, solvent, dilbit, disposal fluid	Loss of containment (non-reportable spill or leak)	Short or intermittent	*Pipeline Act, Directive 077, Water Act, Manuals 1 and 5; ABSA*
16	Processing facility	Produced water, solvent, bitumen, dilbit, water treatment chemical	Loss of containment (reportable incident)	Short	Facility Application Review (*D023* & *D078*), *EPEA, D055*
17	Processing facility	Produced water, solvent, bitumen, dilbit, water treatment chemical	Loss of containment (non-reportable spill or leak)	Short or intermittent	Facility Application Review (*D023* & *D078*), *EPEA, D055*

No.	Potential Source		Potential surface failure/release scenarios		Existing regulatory instruments that could prevent or mitigate the failure scenario
	Activity	Potential substances	Description	Expected release duration	
18	Flaring	Solvent, flowback fluid (solvent, formation product)	Upset condition	Short	*AER Directive 060 Upstream Petroleum Industry Flaring, Incinerating, and Venting*; *EPEA*
19	Flue stacks	PM2.5, NOx, VOCs, SOx	Emission source	Continuous	*EPEA, ID 2001-03*
20	Venting	Produced gas (hydrocarbon, VOCs, RSCs, blanket gas)	Upset condition	Short	*AER Directive 060 Upstream Petroleum Industry Flaring, Incinerating, and Venting; EPEA; ID 2001-03*

3.1.4 Potential Transport Pathways

Transport pathways are how substances move into environmental media (air, surface water, sediment, groundwater, and soil) and diet items (wildlife, fish, and plants). Sections **3.1.2 and 3.1.3** illustrates the potential failure/release scenarios at solvent injection facilities. These scenarios with associated potential transport pathways are described in **Table 5** below.

Table 5: Potential Failure/Release Scenarios and Potential Transport Pathways

NO.	Potential Source		Potential failure/release scenarios		Potential transport pathway
	Activity	Potential substances	Description	Expected release duration	
1	Solvent Injection Process – subsurface activities	Solvent, additives, salts	Production / injection casing failures with surface casing failure	Short	Release to groundwater
					Release to surface water via groundwater interaction
2	Solvent Injection Process – subsurface activities	Solvent, additives, salts	Cement, casing or wellhead failure	Short or intermittent	Release to surface water
					Release to soil
3	Solvent Injection Process – subsurface activities	Solvent, bitumen, produced water, salts	Caprock fracture (e.g., slow release of fluid to the surface)	Short or intermittent	Release to groundwater
					Release to surface water via groundwater interaction
4	Solvent Injection	Solvent, bitumen, produced water,	Caprock and Overlying	Short	Release to groundwater

NO.	Potential Source		Potential failure/release scenarios		Potential transport pathway
	Activity	**Potential substances**	**Description**	**Expected release duration**	
	Process – subsurface activities	salts	Formation Fracture (e.g., Total Joslyn incident)		Release to surface water via groundwater interaction
					Direct release to surface water
					Direct release to air
5	Solvent Injection Process – subsurface activities	Solvent, additives, bitumen, produced Water, salts	Lateral loss of solvent to highly mobile water in the reservoir	Short, intermittent or continuous	Release to groundwater
					Release to surface water via groundwater interaction
6	Disposal	Diluent, residual hydrocarbons, produced water, salts	Loss of disposal zone containment	Short or intermittent	Indirect release to surface water (long migration pathway)
7	Disposal	Diluent, residual hydrocarbons, produced water, salts	enters stratigraphic testing, disposal, or legacy wells with poor cement or casing	Short or intermittent	Release to groundwater
					Release to surface water via groundwater interaction
8	Disposal	Diluent, residual hydrocarbons, produced water, salts	enters stratigraphic testing, disposal, or legacy wells with open flow wellbore	Short or intermittent	Release to surface water
					Direct release to soil
9	Solvent Injection Process – subsurface activities	Solvent, additives, bitumen, produced Water, salts	Lateral loss of solvent to adjacent or underlying zones	Short, intermittent or continuous	Release to groundwater
					Release to surface water via groundwater interaction
10	Chemical storage	Additives, solvent	Loss of containment (reportable spill or leak)	Short	Release to surface water (direct or in-direct)
					Direct release to soil
					Direct release to air
					Release to groundwater

NO.	Potential Source		Potential failure/release scenarios		Potential transport pathway
	Activity	**Potential substances**	**Description**	**Expected release duration**	
11	Chemical storage	Additives, solvent	Loss of containment (non-reportable spill or leak)	Short or intermittent	Release to surface water (direct or in-direct)
					Direct release to soil
					Direct release to air
					Release to groundwater
12	Ground transportation	Additives, diluent, disposal fluid/solid	Loss of containment on lease (reportable spill or leak)	Short	Release to surface water (direct or in-direct)
					Direct release to soil
					Direct release to air
					Release to groundwater
13	Ground transportation	Additives, diluent, disposal fluid/solid	Loss of containment on lease (non-reportable spill or leak)	Short or intermittent	Release to surface water (direct or in-direct)
					Direct release to soil
					Direct release to air
					Release to groundwater
14	Pipeline transportation	Steam, diluent, dilbit, disposal fluid	Loss of containment (reportable spills or leaks)	Short	Release to surface water (direct or in-direct)
					Direct release to soil
					Direct release to Air
					Release to groundwater
15	Pipeline transportation	Steam, diluent, dilbit, disposal fluid	Loss of containment (non-reportable spills and leaks)	Short or intermittent	Release to surface water (direct or in-direct)
					Direct release to soil
					Direct release to air
					Release to groundwater

NO.	Potential Source		Potential failure/release scenarios		Potential transport pathway
	Activity	Potential substances	Description	Expected release duration	
16	Processing facility	Produced water, diluent, bitumen, dilbit, water treatment chemical	Loss of containment (reportable incident)	Short	Release to surface water (direct or in-direct)
					Direct release to soil
					Direct release to air
					Release to groundwater
17	Processing facility	Produced water, diluent, bitumen, dilbit, water treatment chemical	Loss of containment (non-reportable spill)	Short or intermittent	Release to surface water (direct or in-direct)
					Direct release to soil
					Direct release to air
					Release to groundwater
18	Flaring	Solvent, flowback (diluent, formation products, additives)	Upset condition	Short	Direct release to air
19	Flue stacks	PM2.5, NOx, VOC, SOx	Emission source	Continuous	Direct release to air
20	Venting	Produced gas - hydrocarbon, VOCs, RSCs; blanket gas	Upset condition	Short	Direct release to air

3.1.5 Potential Exposure Routes

Exposure routes are the ways people could come into contact with a CoPC. The potential exposure routes considered for this risk assessment were:

- Humans
  - Ingestion of groundwater
  - Ingestion of surface water
  - Dermal contact with surface water
  - Inhalation

3.2 Risk Analysis and Evaluation

Risk analysis involves developing an understanding of the risk. It provides an input to risk evaluation and to decisions on whether additional risk reduction measures are needed (e.g., new AER regulatory controls).

In general, risk can be expressed as:

RISK = LIKELIHOOD × CONSEQUENCE

In this risk assessment, risk was expressed as:

RISK = EXPOSURE × HAZARD

Where, “exposure” is equivalent to likelihood of exposure and considers potential CoPCs associated with activity (*factor 1*), potential failure pathway for CoPCs release to the environment (*factor 2*), potential transport mechanism for CoPCs movement in environmental media (*factor 3*), and potential receptor exposure route (*factor 4*); while “hazard” considers the potential magnitude of exposure (*factor 5*).

A semi-quantitative risk analysis was conducted through assigning binary values to the above five factors (i.e., *0* and *1* for factors 1 to 4; *1 or 2* for factor 5):

RISK = {EXPOSURE (*factor 1* + *factor 2* + *factor 3* + *factor 4*) × HAZARD (*factor 5*)}

The risk assessment team ranked the 20 potential failure/release scenarios with associated transport pathways and exposure route (see **Section 3.1**) using the criteria described in **Table 6**. The effectiveness of existing AER regulatory control was considered when determining the level of risk. The risk scores for all scenarios are listed in **Appendix 2**.

Based on the risk score, each potential failure/release scenario was classified as one of the following categories:

- Lower band (*risk score = 0, 1, or 2*) – for which the probability of exposure is low or the potential magnitude of exposure is negligible, indicate the level of risk is broadly tolerable; and they can be managed by existing risk reduction measures and no additional risk reduction measures are needed.

- Middle band (*risk score = 3, or 4*) – indicate the level of risk is tolerable only if all reasonably practicable risk reduction measures have been implemented; further detailed risk assessment and cost-benefit analysis may need to determine whether all reasonably practicable risk reduction measures have been implemented or not.

- Upper band (*risk score = 6, or 8*) – indicates the level of risk is regarded as intolerable whatever benefits the activity may bring, and risk reduction measure is essential at any cost if activity is to continue.

Table 6: Semi-Quantitative Risk Analysis Criteria Used in this Risk Assessment

Factors	Likelihood of Exposure				Hazard
	Factor 1: Potential CoPCs associated with activity	**Factor 2: Potential failure pathway for COPCs release to the environment**	**Factor 3: Potential transport mechanism for COPCs movement in environmental media**	**Factor 4: Potential receptor exposure route**	**Factor 5: Potential magnitude of exposure**
Parameter	- Do the substances used in the activity have the potential to contain CoPCs? - Is there any effective control to prevent using CoPCs?	- Is the release mechanism a normal operation, upset condition, or failure event? - Is there any effective control to prevent the failure event?	- Is there any effective control of monitoring CoPCs in the environmental media?	- Is receptor present? - Is the release on-site or off-site? - Is there any effective measure can prevent the presence of receptor?	- What is the concentration of CoPCs in environmental media? - What is the release rate and duration from source emissions? - Is the release acute or chronic?
Value	0 - very low 1 – uncertain*	0 - very low 1 – uncertain*	0 - very low 1 – uncertain*	0 - very low 1 – uncertain*	1 - negligible 2 – uncertain*
Risk score calculation	$\boldsymbol{Risk} = \{\, \boldsymbol{Exposure}\,(factor\ 1 + factor\ 2 + factor\ 3 + factor\ 4) \times \boldsymbol{Hazard}\,(factor\ 5)\,\}$				
Criteria	***Risk = 0, 1 or 2*: lower band risk**				
	***Risk = 3 or 4*: middle band risk**				
	***Risk = 6 or 8*: upper band risk**				

* "uncertain" means: depends on specific solvent injection operation (e.g., specific nature of the technology, site-specific subsurface condition), the likelihood or magnitude of exposure could be very low or higher.

4 Key Findings

The risk assessment identified four key findings that can be used in risk-informed decision making and discussions at solvent injection facilities.

1. We identified a total of 20 potential failure/release scenarios (see **Table 5**) that could result in release of CoPCs from solvent injection facilities.

2. 16 out of the total 20 potential failure/release scenarios with associated potential transport pathways and exposure routes were identified as lower band risk scenarios, for which the probability of exposure is low or the potential magnitude of exposure is negligible given our knowledge of the technology and subsurface conditions in Alberta where this technology is likely to be applied. These risk scenarios are broadly tolerable; and they can be managed by existing risk reduction measures and no additional risk reduction measures are needed. To prevent these failure events and ensure their impacts are negligible, it is critical for operators to comply with AER's requirements listed in **Table 3** and **Table 4**.

3. 4 out of the total 20 potential failure/release scenarios have potential transport pathways and exposure routes ranked as middle band risk scenarios with the consideration of AER's existing regulatory controls. These risk scenarios warrant a thorough consideration of individual applications or operations to determine the necessity of employing practicable risk reduction measures (e.g., carry out additional review and surveillance - such as monitoring, inspections and audit; enhanced ongoing stakeholder engagement). These middle band risk scenarios include:

   - Caprock fracture (e.g., slow release of fluid to the surface) and caprock and overlying formation fracture (e.g., Total Joslyn incident) – if these failure event occurred, the magnitude of exposure would not be negligible. Existing regulatory instruments that could prevent or mitigate these failure events include AER *Directive 086 Reservoir Containment Application Requirements for Steam-Assisted Gravity Drainage Projects in the Shallow Oil Sands Area*.

   - Loss of containment from pipeline transportation – among the 20 potential failure/release scenarios, pipeline spills/leaks are the most likely ones to occur off lease. Existing regulatory instruments that could prevent or mitigate these failure events include *Pipeline Act*; *Directive 077 Pipelines – Requirements and Reference Tools*; *Water Act*; *Manual 001 Facility and Well Site Inspections*; *Manual 005 Pipeline Inspections*; and requirements under Alberta Boilers Safety Association (ABSA).

4. Potential CoPCs at solvent injection facilities are not limited only to hydrocarbons. Collecting data on CoPCs associated with the substances identified in **Table 5** and assessing risks to people and environment could provide a technical rationale for developing monitoring program for selected CoPCs and adaptive management strategies to mitigate these risks when they are identified.

Having a comprehensive and responsive monitoring programs based on trigger-warning systems allows identification of a chronic problem before it reaches critical levels or exceeds an exposure limit.

Appendix 1 Glossary and Abbreviations

Glossary

adverse effect	impairment of or damage to the environment, human health or safety or property (source: Environmental Protection and Enhancement Act).
contaminant of potential concern (CoPC)	any substance that is identified as potentially present on, in or under the site and surrounding area that, if released, has the potential for adverse effect (source: Alberta Environmental Site Assessment Act).
CO_2	carbon dioxide
exposure route	the ways people could come into contact with a CoPC
H_2S	hydrogen sulfide
NO_x	a generic term for the mono-nitrogen oxides
$PM_{2.5}$	atmospheric particulate matter that have a diameter of less than 2.5 micrometers
RSC_s	reduced sulphur compounds
transport pathways	how substances move into environmental media (air, surface water, sediment, groundwater, and soil) and diet items (wildlife, fish, and plants).
SO_x	sulfur oxide
VOC_s	volatile organic compound

Abbreviations

AER	Alberta Energy Regulator
ABSA	Alberta Boilers Safety Association
CSS	Cyclic Steam Stimulation
SAGD	Steam-Assisted Gravity Drainage

Appendix 2 Examples of Substances Potentially Used in Activities at Solvent Injection Facilities

Table A1:Example: hydrocarbons used to enhance recovery (based on typical composition of diluent)

Component	Carbon Number
i-Butane	i-C4
n-Butane	n-C4
i-Pentane	i-C5
n-Pentane	n-C5
Hexanes	C6
Heptanes	C7
Octanes	C8
Nonanes	C9
Decanes	C10
Undecanes	C11
Dodecanes	C12
Tridecanes	C13
Benzene	C6H6
Toluene	C7H8
Ethylbenzene, P + m-Xylene	C8H10
o-Xylene	C8H10
1, 2, 4 Trimethylbenzene	C9H12
Cyclopentane	C5H10
Methylcyclopentane	C6H12
Cyclohexane	C6H12
Methylcyclohexane	C7H12

Table A2: Example: non-hydrocarbon chemicals used to enhance recovery

Non-hydrocarbon chemicals used to enhance recovery
Urea
Brine Solution
Ammonia
Surfactant (soap)
Alkali
CO_2

Table A3: Example: chemicals used in well and plant process

Additives
Hydrochloric acid
Nitrogen
Phosphoric hydrofluoric acid
Bleach (sodium hypochlorite)
Other Biocide
Clay Stabilizer (3% potassium chloride water, nutra clay)
Aromatic solvent (Xylene)
Scale inhibitor
Oxygen scavenger
H_2S scavenger
CO_2 scavenger
Antifoam agent
Sulphur scrubbers
Flocculants
Corrosion inhibitors (amines)
Surfactants
Ashphaltene dispersants
Fuels
Degreasers and cleaners

Appendix 3 Risk Assessment Results

Table B1: Risk Assessment Results – Risk Score without Considering AER's Existing Regulatory Controls

NO.	Potential Source		Potential Failure/Release Scenarios		Potential Transport Pathway	Potential Exposure route	Receptor	Likelihood of Exposure				Hazard	Risk Score without considering AER's existing regulatory controls
	Activity	Potential Substances	Description	Expected Release Duration			Human	Factor #1: Potential COPCs associated with activity 0 - very low 1 - uncertain	Factor #2: Potential failure pathway for COPCs release to the environment 0 - very low 1 - uncertain	Factor #3: Potential transport mechanism for COPCs movement in environmental media 0 - very low 1 - uncertain	Factor #4: Potential receptor exposure route 0 - very low 1 - uncertain	Factor #5: Potential magnitude of exposure 1 - negligible 2 - uncertain	
1	Solvent injection process - subsurface activities	Solvent, additives, steam, bitumen, produced water, salts	Production/injection casing failure with surface casing failure	Short	Release to groundwater	Ingestion	X	1	1	1	1	2	8
					Release to surface water via groundwater interaction	Ingestion	X	1	0	1	1	2	6
						direct contact	X	1	0	1	1	2	6
						Inhalation	X	1	0	1	1	2	6
2	Solvent injection process - subsurface activities	Solvent, additives, steam, bitumen, produced water, salts	Cement, casing, or wellhead failure	Short or intermittent	Release to surface water	Ingestion	X	1	0	1	1	2	6
						direct contact	X	1	0	1	1	2	6
					Direct release to soil	Ingestion	X	1	1	1	1	1	4
						direct contact	X	1	1	1	1	1	4
						Inhalation	X	1	1	1	1	1	4
					Direct release to air	Inhalation	X	1	1	1	1	1	4
3	Solvent injection process - subsurface activities	Solvent, additives, steam, bitumen, produced water, salts	Caprock fracture (e.g., slow release of fluid to the surface)	Short or intermittent	Release to groundwater	Ingestion	X	1	1	1	1	2	8
					Release to surface water via groundwater interaction	Ingestion	X	1	1	1	1	2	8
						direct contact	X	1	1	1	1	2	8
						Inhalation	X	1	1	1	1	2	8
4	Solvent injection process - subsurface activities	Solvent, additives, steam, bitumen, produced water, salts	Caprock and Overlying Formation Fracture (e.g., Total Joslyn incident)	Short	Release to groundwater	Ingestion	X	1	1	1	1	1	4
					Release to surface water via groundwater interaction	Ingestion	X	1	1	1	1	1	4
						direct contact	X	1	1	1	1	1	4
						Inhalation	X	1	1	1	1	1	4
					Direct release to surface water	Ingestion	X	1	1	1	1	1	4
						direct contact	X	1	1	1	1	1	4
						Inhalation	X	1	1	1	1	1	4
					Direct release to air	Inhalation	X	1	0	1	1	2	6
						Deposition to soil	X	1	0	1	1	2	6
5	Solvent injection process - subsurface activities	Solvent, additives, steam, bitumen, produced water, salts	Lateral loss of solvent to highly mobile water in the reservoir	Short, intermittent, or continuous	Release to Groundwater	Ingestion	X	1	1	1	1	1	4
					Release to Surface water via Groundwater interaction	Ingestion	X	1	1	1	1	1	4
						direct contact	X	1	1	1	1	1	4
						Inhalation	X	1	1	1	1	1	4
6	Disposal / Strat. Testing /	Solvent, residual hydrocarbons,	Loss of disposal zone	Short or intermittent	Indirect release to surface water (long migration	Ingestion	X	1	1	1	1	2	8

NO.	Potential Source		Potential Failure/Release Scenarios		Potential Transport Pathway	Potential Exposure route	Receptor	Likelihood of Exposure				Hazard	Risk Score without considering AER's existing regulatory controls
	Activity	Potential Substances	Description	Expected Release Duration			Human	Factor #1: Potential COPCs associated with activity 0 - very low 1 - uncertain	Factor #2: Potential failure pathway for COPCs release to the environment 0 - very low 1 - uncertain	Factor #3: Potential transport mechanism for COPCs movement in environmental media 0 - very low 1 - uncertain	Factor #4: Potential receptor exposure route 0 - very low 1 - uncertain	Factor #5: Potential magnitude of exposure 1 - negligible 2 - uncertain	
	legacy wells	produced Water, salts	containment		pathway)	direct contact	X	1	1	1	1	2	8
7	Disposal / Strat. Testing / legacy wells	Solvent, residual hydrocarbons, produced Water, salts	enters stratigraphic testing, disposal, or legacy wells with poor cement and/or casing	Short or intermittent	Release to groundwater	Ingestion	X	1	1	1	1	1	4
					Release to surface water via groundwater interaction	Ingestion	X	1	1	1	1	1	4
						direct contact	X	1	1	1	1	1	4
						Inhalation	X	1	1	1	1	1	4
8	Disposal / Strat. Testing / legacy wells	Solvent, residual hydrocarbons, produced Water, salts	enters stratigraphic testing, disposal, or legacy wells with open flow wellbore	Short or intermittent	Release to surface water	Ingestion	X	1	1	1	1	1	4
						direct contact	X	1	1	1	1	1	4
					Direct release to soil	Ingestion	X	1	1	1	1	1	4
						direct contact	X	1	1	1	1	1	4
						Inhalation	X	1	1	1	1	1	4
9	Solvent injection process - subsurface activities	Solvent, additives, steam, bitumen, produced water, salts	Lateral loss of solvent to adjacent or underlying zones	Short, intermittent, or continuous	Release to Groundwater	Ingestion	X	1	1	1	1	1	4
					Release to Surface water via Groundwater interaction	Ingestion	X	1	1	1	1	1	4
						direct contact	X	1	1	1	1	1	4
						Inhalation	X	1	1	1	1	1	4
10	Chemical storage	Additives, solvent	Loss of containment (reportable spill or leak)	Short	Release to Surface water (direct or in-direct)	Ingestion	X	1	1	1	1	2	8
						direct contact	X	1	1	1	1	2	8
					Direct Release to soil	Ingestion	X	1	1	1	1	2	8
						direct contact	X	1	1	1	1	2	8
						Inhalation	X	1	1	1	1	2	8
					Direct Release to Air	Inhalation	X	1	1	1	1	2	8
					Release to Groundwater	Ingestion	X	1	1	1	1	2	8
11	Chemical storage	Additives, solvent	Loss of containment (non-reportable spill or leak)	Short or intermittent	Release to Surface water (direct or in-direct)	Ingestion	X	1	1	1	1	2	8
						direct contact	X	1	1	1	1	2	8
					Direct release to soil	Ingestion	X	1	1	1	1	2	8
						direct contact	X	1	1	1	1	2	8
						Inhalation	X	1	1	1	1	2	8
					Direct release to air	Inhalation	X	1	1	1	1	2	8
					Release to groundwater	Ingestion	X	1	1	1	1	2	8
12	Ground transportation	Additives, diluent, disposal fluid/solid	Loss of containment on lease (reportable spill or leak)	Short	Release to surface water (direct or in-direct)	Ingestion	X	1	1	1	1	2	8
						direct contact	X	1	1	1	1	2	8
					Direct release to soil	Ingestion	X	1	1	1	1	2	8
						direct contact	X	1	1	1	1	2	8
						Inhalation	X	1	1	1	1	2	8

NO.	Potential Source		Potential Failure/Release Scenarios		Potential Transport Pathway	Potential Exposure route	Receptor	Likelihood of Exposure				Hazard	Risk Score without considering AER's existing regulatory controls
	Activity	Potential Substances	Description	Expected Release Duration			Human	Factor #1: Potential COPCs associated with activity 0 - very low 1 - uncertain	Factor #2: Potential failure pathway for COPCs release to the environment 0 - very low 1 - uncertain	Factor #3: Potential transport mechanism for COPCs movement in environmental media 0 - very low 1 - uncertain	Factor #4: Potential receptor exposure route 0 - very low 1 - uncertain	Factor #5: Potential magnitude of exposure 1 - negligible 2 - uncertain	
					Direct release to air	Inhalation	X	1	1	1	1	2	8
					Release to groundwater	Ingestion	X	1	1	1	1	2	8
13	Ground transportation	Additives, diluent, disposal fluid/solid	Loss of containment on lease (non-reportable spill or leak)	Short or intermittent	Release to surface water (direct or in-direct)	Ingestion	X	1	1	1	1	1	4
						direct contact	X	1	1	1	1	1	4
					Direct release to soil	Ingestion	X	1	1	1	1	1	4
						direct contact	X	1	1	1	1	1	4
						Inhalation	X	1	1	1	1	1	4
					Direct release to air	Inhalation	X	1	1	1	1	1	4
					Release to groundwater	Ingestion	X	1	1	1	1	1	4
14	Pipeline transportation	Steam, diluent, dilbit, disposal fluid	Loss of containment (reportable spills or leaks)	Short	Release to surface water (direct or in-direct)	Ingestion	X	1	1	1	1	2	8
						direct contact	X	1	1	1	1	2	8
					Direct release to soil	Ingestion	X	1	1	1	1	2	8
						direct contact	X	1	1	1	1	2	8
						Inhalation	X	1	1	1	1	2	8
					Direct release to air	Inhalation	X	1	1	1	1	2	8
					Release to groundwater	Ingestion	X	1	1	1	1	2	8
15	Pipeline transportation	Steam, diluent, dilbit, disposal fluid	Loss of containment (non-reportable spills and leaks)	Short or intermittent	Release to surface water (direct or in-direct)	Ingestion	X	1	1	1	1	2	8
						direct contact	X	1	1	1	1	2	8
					Direct release to soil	Ingestion	X	1	1	1	1	2	8
						direct contact	X	1	1	1	1	2	8
						Inhalation	X	1	1	1	1	2	8
					Direct release to air	Inhalation	X	1	1	1	1	2	8
					Release to groundwater	Ingestion	X	1	1	1	1	2	8
16	Processing facility	Produced water, diluent, bitumen, dilbit, water treatment chemical	Loss of containment (reportable incident)	Short	Release to Surface water (direct or in-direct)	Ingestion	X	1	1	1	1	2	8
						direct contact	X	1	1	1	1	2	8
					Direct release to soil	Ingestion	X	1	1	1	1	2	8
						direct contact	X	1	1	1	1	2	8
						Inhalation	X	1	1	1	1	2	8
					Direct release to air	Inhalation	X	1	1	1	1	2	8
					Release to groundwater	Ingestion	X	1	1	1	1	2	8
17	Processing facility	Produced water, diluent, bitumen, dilbit, water treatment chemical	Loss of containment (non-reportable spill)	Short or intermittent	Release to surface water (direct or in-direct)	Ingestion	X	1	1	1	1	2	8
						direct contact	X	1	1	1	1	2	8
					Direct release to soil	Ingestion	X	1	1	1	1	2	8
						direct contact	X	1	1	1	1	2	8
						Inhalation	X	1	1	1	1	2	8
					Direct release to air	Inhalation	X	1	1	1	1	2	8

NO.	Potential Source		Potential Failure/Release Scenarios		Potential Transport Pathway	Potential Exposure route	Receptor	Likelihood of Exposure				Hazard	Risk Score without considering AER's existing regulatory controls
	Activity	Potential Substances	Description	Expected Release Duration			Human	Factor #1: Potential COPCs associated with activity 0 - very low 1 - uncertain	Factor #2: Potential failure pathway for COPCs release to the environment 0 - very low 1 - uncertain	Factor #3: Potential transport mechanism for COPCs movement in environmental media 0 - very low 1 - uncertain	Factor #4: Potential receptor exposure route 0 - very low 1 - uncertain	Factor #5: Potential magnitude of exposure 1 - negligible 2 - uncertain	
					Release to Groundwater	Ingestion	X	1	1	1	1	2	8
18	Flaring	Solvent, flowback (diluent, formation products, additives)	Upset condition	Short	Direct release to air	Inhalation	X	1	1	1	1	2	8
19	Flue stacks	PM2.5, NOx, VOC, SOx	Emission source	Continuous	Direct release to air	Inhalation	X	1	1	1	1	2	8
20	Venting	Produced gas - hydrocarbon, VOCs, RSCs; blanket gas	Upset condition	Short	Direct release to air	Inhalation	X	1	1	1	1	2	8

Table B2: Risk Assessment Results – Risk Score Considering AER's Existing Regulatory Controls

NO.	Potential Source		Potential Failure/Release Scenarios		Potential Transport Pathway	Potential Exposure route	Receptor	Likelihood of Exposure				Hazard	Risk Score considering AER's existing regulatory controls	Explanation on the effectiveness of AER regulatory instrument
	Activity	Potential Substances	Description	Expected Release Duration			Human	Factor #1: Potential COPCs associated with activity 0 - very low 1 - uncertain	Factor #2: Potential failure pathway for COPCs release to the environment 0 - very low 1 - uncertain	Factor #3: Potential transport mechanism for COPCs movement in environmental media 0 - very low 1 - uncertain	Factor #4: Potential receptor exposure route 0 - very low 1 - uncertain	Factor #5: Potential magnitude of Exposure 1 - negligible 2 - uncertain		
1	Solvent injection process - subsurface activities	Solvent, additives, steam, bitumen, produced water, salts	Production /injection casing failure with surface casing failure	Short	Release to groundwater	Ingestion	X	1	1	0	0	1	2	No groundwater well used by public; therefore, magnitude of exposure considered as negligible.
					Release to surface water via groundwater interaction	Ingestion	X	1	0	0	0	2	2	There are setback distances between wells and surface water; therefore, the likelihood of release to surface water via groundwater interaction is considered as very low.
						direct contact	X	1	0	0	0	2	2	
						Inhalation	X	1	0	0	0	2	2	
2	Solvent injection process - subsurface activities	Solvent, additives, steam, bitumen, produced water, salts	Cement, casing, or wellhead failure	Short or intermittent	Release to surface water	Ingestion	X	1	0	0	0	2	2	There are setback distances between wells and surface water. Liquid phase solvent are not as likely as methane to migrate to surface water. Therefore, the likelihood of release to surface water is very low.
						direct contact	X	1	0	0	0	2	2	
					Direct release to soil	Ingestion	X	1	1	0	0	1	2	The release would be on lease and operators own the lease. Liquid phase solvent are not as likely as methane to migrate to surface water. Therefore, the magnitude of exposure at off-lease is considered as very low.
						direct contact	X	1	1	0	0	1	2	
						Inhalation	X	1	1	0	0	1	2	
					Direct release to air	Inhalation	X	1	1	0	0	1	2	The release could go off-lease. However, liquid phase solvent are not as likely as methane to migrate to air. Therefore, the magnitude of exposure at off-lease is considered as very low.
3	Solvent injection process - subsurface activities	Solvent, additives, steam, bitumen, produced water, salts	Caprock fracture (e.g., slow release of fluid to the surface)	Short or intermittent	Release to groundwater	Ingestion	X	1	0	1	0	2	4	When operators comply with AER's existing requirements (e.g., *Directive 86*), the likelihood of caprock fracture is very low. The AER is confident about this control. The likelihood of release to groundwater depends on site-specific features. If the failure occurred, slow releases of fluid to surface would be on-lease. Also, depends on the type of fluid, some may not migrate far in the groundwater.
					Release to surface water via groundwater interaction	Ingestion	X	1	0	1	0	2	4	
						direct contact	X	1	0	1	0	2	4	
						Inhalation	X	1	0	0	0	1	1	

NO.	Potential Source		Potential Failure/Release Scenarios		Potential Transport Pathway	Potential Exposure route	Receptor	Likelihood of Exposure				Hazard	Risk Score considering AER's existing regulatory controls	Explanation on the effectiveness of AER regulatory instrument
	Activity	Potential Substances	Description	Expected Release Duration			Human	Factor #1: Potential COPCs associated with activity 0 - very low 1 - uncertain	Factor #2: Potential failure pathway for COPCs release to the environment 0 - very low 1 - uncertain	Factor #3: Potential transport mechanism for COPCs movement in environmental media 0 - very low 1 - uncertain	Factor #4: Potential receptor exposure route 0 - very low 1 - uncertain	Factor #5: Potential magnitude of Exposure 1 - negligible 2 - uncertain		
4	Solvent injection process - subsurface activities	Solvent, additives, steam, bitumen, produced water, salts	Caprock and Overlying Formation Fracture (e.g., Total Joslyn incident)	Short	Release to groundwater	Ingestion	X	1	0	0	0	1	1	If blow-out occurred, sediment would be removed. Most of solvent and steam would be released to air instead of groundwater or surface water. Therefore, the magnitude of exposure is considered as very low.
					Release to surface water via groundwater interaction	Ingestion	X	1	0	1	0	1	2	
						direct contact	X	1	0	1	0	1	2	
						Inhalation	X	1	0	1	0	1	2	
					Direct release to surface water	Ingestion	X	1	0	1	0	1	2	
						direct contact	X	1	0	1	0	1	2	
						Inhalation	X	1	0	1	0	1	2	
					Direct release to air	Inhalation	X	1	0	1	0	2	4	If a blow-out occurred, sediment would be removed. Most of solvent and steam would be released to air. However, the likelihood of a blow-out is considered as very low if operators fully comply with AER's requirements (Directive 086 for shallow area and Directive 023 for non-shallow area). The AER is confident about these controls.
						Deposition to soil	X	1	0	1	0	2	4	
5	Solvent injection process - subsurface activities	Solvent, additives, steam, bitumen, produced water, salts	Lateral loss of solvent to highly mobile water in the reservoir	Short Intermittent continuous	Release to Groundwater	Ingestion	X	1	0	0	0	1	1	Fluid could escape into non-saline groundwater if reservoir is directly connected to a non-saline aquifer. However, the likelihood of reservoir is directly connected to a non-saline aquifer is considered as very low if operators fully comply with AER's requirements (*Directive 023*). The magnitude of exposure is also considered as very low.
					Release to Surface water via Groundwater interaction	Ingestion	X	1	0	0	0	1	1	
						direct contact	X	1	0	0	0	1	1	
						Inhalation	X	1	0	0	0	1	1	
6	Disposal / Strat. Testing / legacy wells	Solvent, residual hydrocarbons, Produced Water, salts	Loss of disposal zone containment	Short or intermittent	Indirect release to surface water (long migration pathway)	Ingestion	X	1	0	0	0	1	1	First, AER will only allow certain type of substances be disposed. Second, operators are required to monitor the pathway to ensure there is no loss of disposal zone containment. Therefore, the likelihood and magnitude of exposure at off-lease are very low.
						direct contact	X	1	0	0	0	1	1	

NO.	Potential Source		Potential Failure/Release Scenarios		Potential Transport Pathway	Potential Exposure route	Receptor	Likelihood of Exposure				Hazard	Risk Score considering AER's existing regulatory controls	Explanation on the effectiveness of AER regulatory instrument
	Activity	**Potential Substances**	**Description**	**Expected Release Duration**			**Human**	**Factor #1: Potential COPCs associated with activity** 0 - very low 1 - uncertain	**Factor #2: Potential failure pathway for COPCs release to the environment** 0 - very low 1 - uncertain	**Factor #3: Potential transport mechanism for COPCs movement in environmental media** 0 - very low 1 - uncertain	**Factor #4: Potential receptor exposure route** 0 - very low 1 - uncertain	**Factor #5: Potential magnitude of Exposure** 1 - negligible 2 - uncertain		
7	Disposal / strat. testing / legacy wells	Solvent, residual hydrocarbons, produced water, salts	enters stratigraphic testing, disposal, or legacy wells with poor cement and/or casing	Short or intermittent	Release to groundwater	Ingestion	X	1	0	0	0	1	1	First, operators are required to check other wells in the area. Second, the AER requires setback from legacy well. Third, pressure drops significantly in other wells. Therefore, the likelihood and magnitude of exposure is very low.
					Release to surface water via groundwater interaction	Ingestion	X	1	0	0	0	1	1	
						direct contact	X	1	0	0	0	1	1	
						Inhalation	X	1	0	0	0	1	1	
8	Disposal / strat. testing / legacy wells	Solvent, residual hydrocarbons, produced water, salts	enters stratigraphic testing, disposal, or legacy wells with open flow wellbore	Short or intermittent	Release to surface water	Ingestion	X	1	0	1	0	1	2	First, operators are required to check other wells in the area. Second, the AER requires setback from legacy well. Third, pressure drops significantly in other wells. Therefore, the likelihood and magnitude of exposure is very low.
						direct contact	X	1	0	1	0	1	2	
					Direct release to soil	Ingestion	X	1	0	0	0	1	1	
						direct contact	X	1	0	0	0	1	1	
						Inhalation	X	1	0	0	0	1	1	
9	Solvent injection process - subsurface activities	Solvent, additives, steam, bitumen, produced water, salts	Lateral loss of solvent to adjacent or underlying zones	Short, intermittent, or continuous	Release to Groundwater	Ingestion	X	1	0	0	0	1	1	Fluid could escape into non-saline groundwater if reservoir is directly connected to a non-saline aquifer. However, the likelihood the likelihood of reservoir is directly connected to a non-saline aquifer is considered very low if operators fully comply with AER's requirements (*Directive 023*). The magnitude of exposure is also considered as very low.
					Release to Surface water via Groundwater interaction	Ingestion	X	1	0	0	0	1	1	
						direct contact	X	1	0	0	0	1	1	
						Inhalation	X	1	0	0	0	1	1	
10	Chemical storage	Additives, solvent	Loss of containment (reportable spill or leak)	Short	Release to Surface water (direct or in-direct)	Ingestion	X	1	1	0	0	1	2	Spill/leak would be on lease. Sites are required to have 100 meters setback from surface water. For reportable spills/releases, EPEA requires operators to report, monitor, and clean them up. Therefore, the magnitude of exposure at off-lease is considered as negligible.
						direct contact	X	1	1	0	0	1	2	
					Direct Release to soil	Ingestion	X	1	1	0	0	1	2	
						direct contact	X	1	1	0	0	1	2	
						Inhalation	X	1	1	0	0	1	2	
					Direct Release to Air	Inhalation	X	1	1	0	0	1	2	
					Release to Groundwater	Ingestion	X	1	1	0	0	1	2	
11	Chemical storage	Additives, solvent	Loss of containment (non-reportable spill or leak)	Short or intermittent	Release to Surface water (direct or in-direct)	Ingestion	X	1	1	0	0	1	2	Spill/leak would be on lease; and very small volume and substance. Sites are required to have 100 meters setback from surface water.
						direct contact	X	1	1	0	0	1	2	

NO.	Potential Source		Potential Failure/Release Scenarios		Potential Transport Pathway	Potential Exposure route	Receptor	Likelihood of Exposure				Hazard	Risk Score considering AER's existing regulatory controls	Explanation on the effectiveness of AER regulatory instrument
	Activity	Potential Substances	Description	Expected Release Duration			Human	Factor #1: Potential COPCs associated with activity 0 - very low 1 - uncertain	Factor #2: Potential failure pathway for COPCs release to the environment 0 - very low 1 - uncertain	Factor #3: Potential transport mechanism for COPCs movement in environmental media 0 - very low 1 - uncertain	Factor #4: Potential receptor exposure route 0 - very low 1 - uncertain	Factor #5: Potential magnitude of Exposure 1 - negligible 2 - uncertain		
					Direct release to soil	Ingestion	X	1	1	0	0	1	2	EPEA requires them to monitor any release on site to ensure it is not going off-lease. Therefore, the magnitude of exposure at off-lease is considered as negligible.
						direct contact	X	1	1	0	0	1	2	
						Inhalation	X	1	1	0	0	1	2	
					Direct release to air	Inhalation	X	1	1	0	0	1	2	It is most likely dispersed to insignificant concentration. Therefore. The magnitude of exposure at off-lease is considered as negligible.
					Release to groundwater	Ingestion	X	1	1	0	0	1	2	No groundwater well used by public; therefore, magnitude of exposure considered as negligible.
12	Ground transportation	Additives, diluent, disposal fluid/solid	Loss of containment on lease (reportable spill or leak)	Short	Release to surface water (direct or in-direct)	Ingestion	X	1	1	0	0	1	2	A spill or leak on lease would be regulated by AER through EPEA. If it is off lease it is dealt with provincially. Transportation containment itself is dealt with federally and/or provincially. Spill/leak would be on lease; and very small volume and substance. Sites are required to have 100 meters setback from surface water. EPEA requires them to monitor any release on site to ensure it is not going off-lease. Therefore, the magnitude of exposure at off-lease is considered as negligible.
						direct contact	X	1	1	0	0	1	2	
					Direct release to soil	Ingestion	X	1	1	0	0	1	2	
						direct contact	X	1	1	0	0	1	2	
						Inhalation	X	1	1	0	0	1	2	
					Direct release to air	Inhalation	X	1	1	0	0	1	2	
					Release to groundwater	Ingestion	X	1	1	0	0	1	2	
13	Ground transportation	Additives, diluent, disposal fluid/solid	Loss of containment on lease (non-reportable spill or leak)	Short or Intermittent	Release to surface water (direct or in-direct)	Ingestion	X	1	1	0	0	1	2	A spill or leak on lease would be regulated by AER through EPEA. If it is off lease it is dealt with provincially. Transportation containment itself is dealt with federally and/or provincially. Spill/leak would be on lease; and very small volume and substance. Sites are required to have 100 meters setback from surface water. EPEA requires them to
						direct contact	X	1	1	0	0	1	2	
					Direct release to soil	Ingestion	X	1	1	0	0	1	2	
						direct contact	X	1	1	0	0	1	2	

NO.	Potential Source: Activity	Potential Source: Potential Substances	Potential Failure/Release Scenarios: Description	Potential Failure/Release Scenarios: Expected Release Duration	Potential Transport Pathway	Potential Exposure route	Receptor: Human	Likelihood of Exposure: Factor #1: Potential COPCs associated with activity 0 - very low 1 - uncertain	Likelihood of Exposure: Factor #2: Potential failure pathway for COPCs release to the environment 0 - very low 1 - uncertain	Likelihood of Exposure: Factor #3: Potential transport mechanism for COPCs movement in environmental media 0 - very low 1 - uncertain	Likelihood of Exposure: Factor #4: Potential receptor exposure route 0 - very low 1 - uncertain	Hazard: Factor #5: Potential magnitude of Exposure 1 - negligible 2 - uncertain	Risk Score considering AER's existing regulatory controls	Explanation on the effectiveness of AER regulatory instrument
						Inhalation	X	1	1	0	0	1	2	monitor any release on site to ensure it is not going off-lease. Therefore, the magnitude of exposure at off-lease is considered as negligible.
					Direct release to air	Inhalation	X	1	1	0	0	1	2	It is most likely dispersed to insignificant concentration. Therefore. The magnitude of exposure at off-lease is considered as negligible.
					Release to groundwater	Ingestion	X	1	1	0	0	1	2	No groundwater well used by public; therefore, magnitude of exposure considered as negligible.
14	Pipeline transportation	Steam, diluent, dilbit, disposal fluid	Loss of containment (reportable spills or leaks)	Short	Release to surface water (direct or in-direct)	Ingestion	X	1	0	0	1	2	4	Pipeline transportation is regulated under *Directive 077*, *Pipeline Act*, *Water* Act, and other provincial regulations such as ABSA. Although the frequency of reportable pipeline spill/leak is very low, it could release large volume of substances if the failure is not detected and stopped quickly enough. Comparing with other failure events, pipeline spills are more likely to occur off site. Therefore, the magnitude of exposure is not considered as negligible.
						direct contact	X	1	0	0	1	2	4	
					Direct release to soil	Ingestion	X	1	0	0	1	2	4	
						direct contact	X	1	0	0	1	2	4	
						Inhalation	X	1	0	0	1	2	4	
					Direct release to air	Inhalation	X	1	0	0	1	2	4	
					Release to groundwater	Ingestion	X	1	0	0	1	2	4	
15	Pipeline transportation	Steam, diluent, dilbit, disposal fluid	Loss of containment (non-reportable spills and leaks)	Short or intermittent	Release to surface water (direct or in-direct)	Ingestion	X	1	1	0	1	1	3	Pipeline transportation is regulated under Directive 077, Pipeline Act, Water Act, and other provincial regulations such as ABSA. Although the frequency of non-reportable pipeline spill/leak is higher than reportable spill/leak, the release volume is most likely very small. Therefore, the magnitude of exposure is not considered as negligible.
						direct contact	X	1	1	0	1	1	3	
					Direct release to soil	Ingestion	X	1	1	0	1	1	3	
						direct contact	X	1	1	0	1	1	3	
						Inhalation	X	1	1	0	1	1	3	

NO.	Potential Source		Potential Failure/Release Scenarios		Potential Transport Pathway	Potential Exposure route	Receptor	Likelihood of Exposure				Hazard	Risk Score considering AER's existing regulatory controls	Explanation on the effectiveness of AER regulatory instrument
	Activity	Potential Substances	Description	Expected Release Duration			Human	Factor #1: Potential COPCs associated with activity 0 - very low 1 - uncertain	Factor #2: Potential failure pathway for COPCs release to the environment 0 - very low 1 - uncertain	Factor #3: Potential transport mechanism for COPCs movement in environmental media 0 - very low 1 - uncertain	Factor #4: Potential receptor exposure route 0 - very low 1 - uncertain	Factor #5: Potential magnitude of Exposure 1 - negligible 2 - uncertain		
					Direct release to air	Inhalation	X	1	1	0	1	1	3	
					Release to groundwater	Ingestion	X	1	1	0	1	1	3	
16	Processing facility	Produced water, diluent, bitumen, dilbit, water treatment chemical	Loss of containment (reportable incident)	Short	Release to Surface water (direct or in-direct)	Ingestion	X	1	1	0	0	1	2	Spill/leak would be on lease; and very small volume and substance. Sites are required to have 100 meters setback from surface water. EPEA requires them to monitor any release on site to ensure it is not going off-lease. Therefore, the magnitude of exposure at off-lease is considered as negligible.
						direct contact	X	1	1	0	0	1	2	
					Direct release to soil	Ingestion	X	1	1	0	0	1	2	
						direct contact	X	1	1	0	0	1	2	
						Inhalation	X	1	1	0	0	1	2	
					Direct release to air	Inhalation	X	1	1	0	0	1	2	
					Release to groundwater	Ingestion	X	1	1	0	0	1	2	
17	Processing facility	Produced water, diluent, bitumen, dilbit, water treatment chemical	Loss of containment (non-reportable spill)	Short or intermittent	Release to surface water (direct or in-direct)	Ingestion	X	1	1	0	0	1	2	Spill/leak would be on lease; and very small volume and substance. Sites are required to have 100 meters setback from surface water. EPEA requires them to monitor any release on site to ensure it is not going off-lease. Therefore, the magnitude of exposure at off-lease is considered as negligible.
						direct contact	X	1	1	0	0	1	2	
					Direct release to soil	Ingestion	X	1	1	0	0	1	2	
						direct contact	X	1	1	0	0	1	2	
						Inhalation	X	1	1	0	0	1	2	
					Direct release to air	Inhalation	X	1	1	0	0	1	2	It is most likely dispersed to insignificant concentration. Therefore. The magnitude of exposure is considered as negligible.

NO.	Potential Source		Potential Failure/Release Scenarios		Potential Transport Pathway	Potential Exposure route	Receptor	Likelihood of Exposure				Hazard	Risk Score considering AER's existing regulatory controls	Explanation on the effectiveness of AER regulatory instrument
	Activity	Potential Substances	Description	Expected Release Duration			Human	Factor #1: Potential COPCs associated with activity 0 - very low 1 - uncertain	Factor #2: Potential failure pathway for COPCs release to the environment 0 - very low 1 - uncertain	Factor #3: Potential transport mechanism for COPCs movement in environmental media 0 - very low 1 - uncertain	Factor #4: Potential receptor exposure route 0 - very low 1 - uncertain	Factor #5: Potential magnitude of Exposure 1 - negligible 2 - uncertain		
					Release to Groundwater	Ingestion	X	1	1	0	0	1	2	No groundwater well used by public; therefore, magnitude of exposure considered as negligible.
18	Flaring	Solvent, flowback (diluent, formation products, additives)	Upset condition	Short	Direct release to air	Inhalation	X	1	1	0	0	1	2	The purpose of flaring is to reduce emissions during upset condition. These flaring stacks are designed and engineered for very high combustion efficiency. Operators also conduct dispersion modeling, which considering all emission sources in the area to ensure the emission will not exceed Alberta Ambient Air Quality Objectives, Under *Directive 060*, operators are required to report flaring over certain time and conditions. Therefore, the magnitude of exposure at off-lease is considered as negligible.
19	Flue stacks	PM2.5, NOx, VOC, SOx	Emission source	Continuous	Direct release to air	Inhalation	X	1	1	0	0	1	2	These flue stacks are designed and engineered for very high combustion efficiency. Operators also conduct dispersion modeling, which considering all emission sources in the area to ensure the emission will not exceed Alberta Ambient Air Quality Objectives. EPEA has requirement on the concentration and regular monitoring. Therefore, the magnitude of exposure at off-lease is considered as negligible.

NO.	Potential Source		Potential Failure/Release Scenarios		Potential Transport Pathway	Potential Exposure route	Receptor	Likelihood of Exposure				Hazard	Risk Score considering AER's existing regulatory controls	Explanation on the effectiveness of AER regulatory instrument
	Activity	**Potential Substances**	**Description**	**Expected Release Duration**			**Human**	**Factor #1: Potential COPCs associated with activity** 0 - very low 1 - uncertain	**Factor #2: Potential failure pathway for COPCs release to the environment** 0 - very low 1 - uncertain	**Factor #3: Potential transport mechanism for COPCs movement in environmental media** 0 - very low 1 - uncertain	**Factor #4: Potential receptor exposure route** 0 - very low 1 - uncertain	**Factor #5: Potential magnitude of Exposure** 1 - negligible 2 - uncertain		
20	Venting	Produced gas - hydrocarbon, VOCs, RSCs; blanket gas	Upset condition	Short	Direct release to air	Inhalation	X	1	1	0	0	1	2	For high pressure line, operators are required to flare the produced gas as per EPEA. For low pressure line, produced gas may be vented. However, mass majority of all produced gas will be captured and used on-site. Under *Directive 060*, operators are required to report venting over certain time and conditions. Therefore, the magnitude of exposure at off-site is considered as negligible.