Appendix 1 – Methodology and Sample Calculations

Jeremy Moorhouse E.I.T.

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the PEMBINA institute
Sustainable Energy Solutions

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The Pembina Institute creates sustainable energy solutions through research, education, consulting and advocacy. It promotes environmental, social and economic sustainability in the public interest by developing practical solutions for communities, individuals, governments and businesses. The Pembina Institute provides policy research leadership and education on climate change, energy issues, green economics, energy efficiency and conservation, renewable energy and environmental governance. More information about the Pembina Institute is available at http://www.pembina.org or by contacting info@pembina.org.

Appendix 1 – Methodology and Sample Calculations

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1. Data and Detailed Methodology

1.1 Introduction

Environmental Defence contracted Pembina Corporate Consulting (Pembina) to quantify seepage from current and proposed oil sands mining operations. For the purposes of this report seepage is defined as process-affected water that seeps from current and proposed tailings ponds that by-passes proposed mitigation measures. Process-affected water is defined in this report as any water that is contained within external or in pit tailings areas.

Pembina developed five seepage scenarios to understand the range of seepage rates possible using a range of assumptions. The results of one of the more conservative scenarios, scenario 3, are presented in the final report. The methodology, assumptions and data used to develop scenario 3 is discussed in detail in this appendix. A summary of the remaining four scenarios, including key assumptions and a comparison of the results with scenario three is also presented in this document.

For all scenarios Pembina used data from environmental impact assessments whenever possible. However, actual seepage rates that are expected to by pass mitigation measures are not always clear and in some instances do not exist. Table 1 lists the projects included in this assessment, data availability and the estimation technique used.

Table 1: Summary of projects included in assessment and data availability

Project	Data Availability	Estimation Technique
Albian – Muskeg current and expansion	Detailed seepage estimates available in project application	Application values used
Canadian Natural – Horizon Phase 1 and 2	Detailed seepage estimates available in project application.	Application values used
Canadian Natural – Horizon Phase 3 and 4	No publicly available values	Average value used
Imperial – Kearl	Detailed seepage estimates available in project application.	Application values used
Petro-Canada Oil Sands – Fort Hills	Detailed seepage estimates available in project application.	Application values used

Shell Canada Inc. – Jackpine Expansion	Detailed seepage estimates available in project application.	Application values used
Shell Canada Inc. – Jackpine phase 1	Detailed seepage estimates available in project application.	Application values used
Shell Canada Inc. – Pierre River	Detailed seepage estimates available in project application.	Application values used
Suncor - Current	Publicly available records available but not accessible[1]	Average value used
Suncor - Expansions (Voyageur South)	Detailed seepage estimates available but in incompatible format.	Average value used
Syncrude – Announced	No publicly available values	Average value used
Syncrude - Current	Publicly available records available but not accessible	Average value used
Synenco – Northern Lights	Estimates available but not in detail required	Average value used
Total – Deer Creek Announced	No publicly available values	Average value used
Total - Deer Creek Application	Seepage discussed in application but values no provided.	Average value used
UTS/Tek Cominco – Announced	No publicly available values	Average value used

The appendix is divided in to four primary sections. The first section, “Seepage Data from Environmental Impact Assessments” lists reported seepage rates and sources and discusses key assumptions and uncertainties. This section is followed by the “Factor Calculation” sections which illustrates the methodology and calculations used to estimate seepage for projects without publicly-disclosed seepage factors. The third section presents the key assumptions for the other four scenario and compares the results with the third scenario. The final section discusses the limitations associated with the seepage calculations.

[1] Current operations are required to report seepage rates and water quality.

Pembina invite feedback on the data and methodology used. Feedback on the data should be directed towards Jeremy Moorhouse (jeremym@pembina.org, 403-269-3344 ext. 123). The primary goal of this research and report is to determine a realistic and publicly available cumulative value for current and proposed oil sands projects.

1.2 Seepage Data from Environmental Impact Assessments

The following data are used for all scenarios.

1.2.1 Canadian Natural - Horizon

The data used to estimate seepage that escapes mitigation measures associated with the operation of the Canadian Natural – Horizon project are provided in Table 2. The primary assumptions with this data are provided below the table.

Table 2: Seepage lost to deep aquifers

Seepage to Deep Aquifers - Lost		
Year	Value	Unit
2007	0	m3/hr
2008	0	m3/hr
2009	0	m3/hr
2010	0	m3/hr
2011	0	m3/hr
2012	0	m3/hr
2013	0	m3/hr
2014	0	m3/hr
2015	0	m3/hr
2016	0	m3/hr
2017	0	m3/hr
2018	0	m3/hr
2019	0	m3/hr
2020	0	m3/hr
2021	175	m3/hr
2022	346	m3/hr
2023	346	m3/hr
2024	346	m3/hr
2025	346	m3/hr
2026	315	m3/hr
2027	285	m3/hr
2028	284	m3/hr
2029	232	m3/hr
2030	180	m3/hr
2031	180	m3/hr
2032	180	m3/hr
2033	180	m3/hr
2034	500	m3/hr
2035	500	m3/hr

2036	500	m3/hr
2037	500	m3/hr
2038	500	m3/hr
2039	462	m3/hr
2040	347	m3/hr
2041	347	m3/hr
2042	347	m3/hr
2043	347	m3/hr
2044	347	m3/hr
2045	466	m3/hr
2046	466	m3/hr
2047	466	m3/hr
2048	466	m3/hr

Source

Canadian Natural. "Horizon Oil Sands Project: Application for Approval" 2003.

Assumptions:

- Seepage to deep aquifers is assumed to be lost from the mine site and not recoverable by mitigation methods.

1.2.2 Imperial Oil Ventures Ltd. - Kearl

The data used to estimate seepage that escapes mitigation measures associated with the operation of the Imperial Oil Ventures Ltd. – Kearl project are provided in Table 3. The primary assumptions with this data are provided below the table.

Table 3: Seepage lost from site

Seepage Lost to Overburden		
Year	Value	Unit
2007	0	m3/hr
2008	0	m3/hr
2009	0	m3/hr
2010	296.8	m3/hr
2011	1221.5	m3/hr
2012	1929.2	m3/hr
2013	639.3	m3/hr
2014	388.1	m3/hr
2015	285.4	m3/hr
2016	239.7	m3/hr
2017	205.5	m3/hr
2018	205.5	m3/hr
2019	182.6	m3/hr
2020	137.0	m3/hr
2021	91.3	m3/hr
2022	79.9	m3/hr
2023	45.7	m3/hr
2024	45.7	m3/hr
2025	45.7	m3/hr
2026	45.7	m3/hr
2027	45.7	m3/hr
2028	45.7	m3/hr
2029	45.7	m3/hr
2030	34.2	m3/hr
2031	22.8	m3/hr
2032	22.8	m3/hr
2033	11.4	m3/hr
2034	11.4	m3/hr
2035	0	m3/hr
2036	0	m3/hr
2037	0	m3/hr
2038	0	m3/hr

Source

Imperial Oil Resource Ventures Ltd. "Kearl Oil Sands Project - Mine Development: Regulatory Application." 2005. Volume 2, Section 9, Table 5-4

Assumptions:

- Imperial labels seepage as “Seepage to Overburden Sands at ETA”. It is unclear how this seepage escapes the mine site. However, it is assumed to escape as it is included in the outflows of the mine site water balance.
- Imperial assumes no seepage to deep aquifers.

1.2.3 Petro-Canada Oil Sands Inc. – Fort Hills

The data used to estimate seepage lost to the environment associated with the operation of the Canadian Natural – Horizon project are provided in Table 4. The primary assumptions with this data are provided below the table.

Table 4: Seepage lost to deep aquifers

Expected to Pass Interception Wells		
Year	Value	Unit
2007	0	m3/hr
2008	0	m3/hr
2009	0	m3/hr
2010	0	m3/hr
2011	0	m3/hr
2012	0	m3/hr
2013	0	m3/hr
2014	0	m3/hr
2015	0	m3/hr
2016	0	m3/hr
2017	0	m3/hr
2018	0	m3/hr
2019	0	m3/hr
2020	0	m3/hr
2021	574.85	m3/hr
2022	574.85	m3/hr
2023	574.85	m3/hr
2024	574.85	m3/hr
2025	574.85	m3/hr
2026	574.85	m3/hr
2027	574.85	m3/hr
2028	574.85	m3/hr
2029	574.85	m3/hr
2030	574.85	m3/hr
2031	574.85	m3/hr
2032	574.85	m3/hr
2033	574.85	m3/hr
2034	574.85	m3/hr
2035	574.85	m3/hr
2036	574.85	m3/hr
2037	574.85	m3/hr
2038	574.85	m3/hr
2039	574.85	m3/hr
2040	574.85	m3/hr
2041	574.85	m3/hr
2042	574.85	m3/hr
2043	574.85	m3/hr
2044	574.85	m3/hr
2045	574.85	m3/hr
2046	574.85	m3/hr

2047	574.85	m3/hr
2048	574.85	m3/hr
2049	574.85	m3/hr
2050	574.85	m3/hr
2051	574.85	m3/hr
2052	574.85	m3/hr
2053	574.85	m3/hr
2054	574.85	m3/hr
2055	574.85	m3/hr
2056	574.85	m3/hr
2057	574.85	m3/hr
2058	574.85	m3/hr
2059	574.85	m3/hr
2060	574.85	m3/hr
2061	574.85	m3/hr
2062	574.85	m3/hr
2063	574.85	m3/hr
2064	574.85	m3/hr
2065	574.85	m3/hr
2066	574.85	m3/hr
2067	574.85	m3/hr
2068	574.85	m3/hr
2069	574.85	m3/hr
2070	574.85	m3/hr
2071	574.85	m3/hr
2072	574.85	m3/hr
2073	574.85	m3/hr
2074	574.85	m3/hr
2075	574.85	m3/hr
2076	574.85	m3/hr
2077	574.85	m3/hr
2078	574.85	m3/hr
2079	574.85	m3/hr
2080	574.85	m3/hr
2081	574.85	m3/hr

Source

Fort Hills Energy Corporation. "Fort Hills Oil Sands Amendment Application." 2 (2006). Volume 2, Table 8-5 and 8-6 and text.

Assumptions:

- Petro-Canada provided total seepage rates from all ponds that are expected to by pass interception wells.
- This assessment assumes that all seepage that by-passes the interception wells will not be intercepted by other means.

1.2.4 Albian – Muskeg River Mine and Expansion

The data used to estimate seepage that escapes mitigation measures associated with the operation of the Albian – Muskeg River Mine and Expansion project are provided in Table 5. The primary assumptions with this data are provided below the table.

Table 5: Seepage lost to deep aquifers

ETDA Seepage - Basal Aquifer		
Year	Value	Unit
2007	0	m3/hr
2008	0	m3/hr
2009	0	m3/hr
2010	29.17	m3/hr
2011	29.17	m3/hr
2012	29.17	m3/hr
2013	29.17	m3/hr
2014	29.17	m3/hr
2015	29.17	m3/hr
2016	29.17	m3/hr
2017	29.17	m3/hr
2018	29.17	m3/hr
2019	29.17	m3/hr
2020	29.17	m3/hr
2021	29.17	m3/hr
2022	29.17	m3/hr
2023	29.17	m3/hr
2024	29.17	m3/hr
2025	29.17	m3/hr
2026	29.17	m3/hr
2027	29.17	m3/hr
2028	29.17	m3/hr
2029	29.17	m3/hr
2030	29.17	m3/hr
2031	29.17	m3/hr
2032	29.17	m3/hr
2033	29.17	m3/hr
2034	29.17	m3/hr
2035	10.00	m3/hr
2036	10.00	m3/hr
2037	10.00	m3/hr
2038	10.00	m3/hr
2039	10.00	m3/hr
2040	10.00	m3/hr
2041	10.00	m3/hr
2042	10.00	m3/hr
2043	10.00	m3/hr
2044	10.00	m3/hr

2045	10.00	m3/hr
2046	10.00	m3/hr
2047	10.00	m3/hr
2048	10.00	m3/hr
2049	10.00	m3/hr
2050	10.00	m3/hr
2051	10.00	m3/hr
2052	10.00	m3/hr
2053	10.00	m3/hr
2054	10.00	m3/hr
2055	10.00	m3/hr
2056	10.00	m3/hr
2057	10.00	m3/hr
2058	10.00	m3/hr
2059	10.00	m3/hr
2060	10.00	m3/hr
2061	10.00	m3/hr
2062	10.00	m3/hr
2063	10.00	m3/hr
2064	10.00	m3/hr
2065	10.00	m3/hr
2066	10.00	m3/hr
2067	10.00	m3/hr
2068	10.00	m3/hr
2069	10.00	m3/hr
2070	10.00	m3/hr
2071	10.00	m3/hr
2072	10.00	m3/hr
2073	10.00	m3/hr
2074	10.00	m3/hr
2075	10.00	m3/hr
2076	10.00	m3/hr
2077	10.00	m3/hr
2078	10.00	m3/hr
2079	10.00	m3/hr
2080	10.00	m3/hr
2081	10.00	m3/hr

Source

Shell Canada Ltd. "Application for the Approval of the Muskeg River Mine Expansion Project." 2005.

Assumptions:

- External Tailings Disposal Area (ETDA) pit seepage is not intercepted by any method. All other seepage is assumed to be captured by mitigation measures.

- Backfilled pits do not seep.
- The 10 m^3/hr seepage rate continues into the far future

1.2.5 Shell Canada Inc. – Jackpine Mine

The data used to estimate seepage that escapes mitigation measures associated with the operation of the Canadian Natural – Horizon project are provided in Table 6. The primary assumptions with this data are provided below the table.

Table 6: Seepage lost to basal aquifer

ETDA Seepage - Basal Aquifer		
Year	Value	Unit
2007	0	m3/hr
2008	0	m3/hr
2009	282.500	m3/hr
2010	282.500	m3/hr
2011	282.500	m3/hr
2012	282.500	m3/hr
2013	282.500	m3/hr
2014	282.500	m3/hr
2015	282.500	m3/hr
2016	282.500	m3/hr
2017	282.500	m3/hr
2018	282.500	m3/hr
2019	282.500	m3/hr
2020	282.500	m3/hr
2021	282.500	m3/hr
2022	282.500	m3/hr
2023	282.500	m3/hr
2024	282.500	m3/hr
2025	282.500	m3/hr
2026	282.500	m3/hr
2027	282.500	m3/hr
2028	282.500	m3/hr
2029	282.500	m3/hr
2030	282.500	m3/hr
2031	282.500	m3/hr
2032	4.25	m3/hr
2033	4.25	m3/hr
2034	4.25	m3/hr
2035	4.25	m3/hr
2036	4.25	m3/hr
2037	4.25	m3/hr
2038	4.25	m3/hr
2039	4.25	m3/hr
2040	4.25	m3/hr
2041	4.25	m3/hr
2042	4.25	m3/hr
2043	4.25	m3/hr
2044	4.25	m3/hr

2045	4.25	m3/hr
2046	4.25	m3/hr
2047	4.25	m3/hr
2048	4.25	m3/hr
2049	4.25	m3/hr
2050	4.25	m3/hr
2051	4.25	m3/hr
2052	4.25	m3/hr
2053	4.25	m3/hr
2054	4.25	m3/hr
2055	4.25	m3/hr
2056	4.25	m3/hr
2057	4.25	m3/hr
2058	4.25	m3/hr
2059	4.25	m3/hr
2060	4.25	m3/hr
2061	4.25	m3/hr
2062	4.25	m3/hr
2063	4.25	m3/hr
2064	4.25	m3/hr
2065	4.25	m3/hr
2066	4.25	m3/hr
2067	4.25	m3/hr
2068	4.25	m3/hr
2069	4.25	m3/hr
2070	4.25	m3/hr
2071	4.25	m3/hr
2072	4.25	m3/hr
2073	4.25	m3/hr
2074	4.25	m3/hr
2075	4.25	m3/hr
2076	4.25	m3/hr
2077	4.25	m3/hr
2078	4.25	m3/hr
2079	4.25	m3/hr
2080	4.25	m3/hr
2081	4.25	m3/hr

Source:

Shell Canada Ltd. "Application for Approval of the Jackpine Mine - Phase 1." 2002. Volume 3, page 4-49, and Table 4.4-8

Assumptions:

- The seepage rates presented above are assumed to by pass mitigation measures.
- The values above are based on snap shots provided in the EIA

- The seepage rate of 4.25 m^3/hr is assumed to continue into the far future

1.2.6 Shell Canada Inc. – Jackpine Expansion

The data used to estimate seepage that escapes mitigation measures associated with the operation of the Canadian Natural – Horizon project are provided in Table 7. The primary assumptions with this data are provided below the table.

Table 7: Seepage lost to deep aquifers

ETDA Seepage - Seepage to Aquifer from ETDA		
Year	Value	Unit
2007	0	m^3/hr
2008	0	m3/hr
2009	0	m3/hr
2010	0	m3/hr
2011	0	m3/hr
2012	0	m3/hr
2013	0	m3/hr
2014	0	m3/hr
2015	78.767	m3/hr
2016	157.534	m3/hr
2017	264.840	m3/hr
2018	374.429	m3/hr
2019	476.027	m3/hr
2020	583.333	m3/hr
2021	692.922	m3/hr
2022	801.370	m3/hr
2023	864.155	m3/hr
2024	864.155	m3/hr
2025	864.155	m3/hr
2026	0.000	m3/hr
2027	0.000	m3/hr
2028	0.000	m3/hr
2029	0.000	m3/hr
2030	0.000	m3/hr
2031	0.000	m3/hr
2032	0.000	m3/hr
2033	0.000	m3/hr
2034	0.000	m3/hr
2035	0.000	m3/hr
2036	0.000	m3/hr
2037	0.000	m3/hr
2038	0.000	m3/hr
2039	0.000	m3/hr
2040	0.000	m3/hr
2041	0.000	m3/hr
2042	0.000	m3/hr

2043	0.000	m3/hr
2044	0.000	m3/hr
2045	0.000	m3/hr
2046	0.000	m3/hr
2047	0.000	m3/hr
2048	0.000	m3/hr
2049	0.000	m3/hr
2050	0.000	m3/hr
2051	0.000	m3/hr
2052	0.000	m3/hr
2053	0.000	m3/hr
2054	0.000	m3/hr
2055	0.000	m3/hr
2056	0.000	m3/hr
2057	0.000	m3/hr
2058	0.000	m3/hr
2059	0.000	m3/hr
2060	0.000	m3/hr
2061	0.000	m3/hr
2062	0.000	m3/hr
2063	0.000	m3/hr
2064	0.000	m3/hr
2065	0.000	m3/hr
2066	0.000	m3/hr
2067	0.000	m3/hr
2068	0.000	m3/hr
2069	0.000	m3/hr
2070	0.000	m3/hr
2071	0.000	m3/hr
2072	0.000	m3/hr
2073	0.000	m3/hr
2074	0.000	m3/hr
2075	0.000	m3/hr
2076	0.000	m3/hr
2077	0.000	m3/hr
2078	0.000	m3/hr
2079	0.000	m3/hr
2080	0.000	m3/hr
2081	0.000	m3/hr

Source

Shell Canada Limited. "Application for Approval of the Jackpine Mine Expansion & Pierrer River Mine Project - Environmental Impact Assessment." Calgary, 2007. Volume 1 Table 10-2, pg. 10-14

Assumptions:

- Seepage to Aquifer from the external tailings disposal area is the only source of seepage on site.
- Far future seepage is not included in this assessment.

1.2.7 Suncor – Tar Island Dyke

The data used to estimate seepage that escapes mitigation measures associated with the operation of the Suncor – Tar Island Dyke project are provided in Table 8. The primary assumptions with this data are provided below the table.

Table 8: Seepage lost to deep aquifers

Seepage to Deep Aquifers - Lost			Construction Water Seepage		
Year	Value	Unit	Year	Value	Unit
2007	7.2	m3/hr	2007	234	m3/hr
2008	7.2	m3/hr	2008	234	m3/hr
2009	7.2	m3/hr	2009	234	m3/hr
2010	7.2	m3/hr	2010	234	m3/hr
2011	7.2	m3/hr	2011	234	m3/hr
2012	7.2	m3/hr	2012	0	m3/hr
2013	7.2	m3/hr	2013	0	m3/hr
2014	7.2	m3/hr	2014	0	m3/hr
2015	7.2	m3/hr	2015	0	m3/hr
2016	7.2	m3/hr	2016	0	m3/hr
2017	7.2	m3/hr	2017	0	m3/hr
2018	7.2	m3/hr	2018	0	m3/hr
2019	7.2	m3/hr	2019	0	m3/hr
2020	7.2	m3/hr	2020	0	m3/hr
2021	7.2	m3/hr	2021	0	m3/hr
2022	7.2	m3/hr	2022	0	m3/hr
2023	7.2	m3/hr	2023	0	m3/hr
2024	7.2	m3/hr	2024	0	m3/hr
2025	7.2	m3/hr	2025	0	m3/hr
2026	7.2	m3/hr	2026	0	m3/hr
2027	7.2	m3/hr	2027	0	m3/hr
2028	7.2	m3/hr	2028	0	m3/hr
2029	7.2	m3/hr	2029	0	m3/hr
2030	7.2	m3/hr	2030	0	m3/hr
2031	7.2	m3/hr	2031	0	m3/hr
2032	7.2	m3/hr	2032	0	m3/hr
2033	7.2	m3/hr	2033	0	m3/hr
2034	7.2	m3/hr	2034	0	m3/hr
2035	7.2	m3/hr	2035	0	m3/hr
2036	7.2	m3/hr	2036	0	m3/hr
2037	7.2	m3/hr	2037	0	m3/hr
2038	7.2	m3/hr	2038	0	m3/hr
2039	7.2	m3/hr	2039	0	m3/hr
2040	7.2	m3/hr	2040	0	m3/hr
2041	7.2	m3/hr	2041	0	m3/hr
2042	7.2	m3/hr	2042	0	m3/hr
2043	7.2	m3/hr	2043	0	m3/hr

2044	7.2	m3/hr	2044	0	m3/hr
2045	7.2	m3/hr	2045	0	m3/hr
2046	7.2	m3/hr	2046	0	m3/hr
2047	7.2	m3/hr	2047	0	m3/hr
2048	7.2	m3/hr	2048	0	m3/hr

Source

Grace P. Hunter. "Investigation of Groundwater Flow within an Oil Sand Tailings Impoundment and Environmental Implications." University of Waterloo, 2001.

Jim Barker, Dave Rudolph, Trevor Tompkins, Alex Oiffer, Francoise Gervais, . "Attenuation of Contaminants in Groundwater Impacted by Surface Mining of Oil Sands, Alberta, Canada." Paper presented at the IPEC 2007.

Assumptions:

- Seepage of construction water will reduce to zero m^3/hr over the next five years.
- Seepage through the base of the pond will continue into the far future 2080

1.3 Factor Calculation

1.3.1 Introduction

Several oil sands mines do not have seepage data for a variety of reasons. Proponents of projects in early stages of development have not completed detailed water balances. In other instances projects with impact assessments did not provide detailed information on seepage rates expected to by-pass mitigation measures. Current projects do report seepage rates and seepage water quality to the Government of Alberta. In spite of numerous requests for this information Alberta Environment did not make this information available for this assessment.

The methodology and key assumptions discussed below are for scenario three. The remaining four scenarios used a similar methodology; however, some key assumptions are different. The differences between scenario three and the other four scenarios is discussed in the Other Scenarios section.

1.3.2 Methodology

This assessment estimated seepage for these projects using the following methodology.

The following describes Pembina's methodology to develop seepage rates for current and proposed oil sands mines:

1. Pembina first converted the available seepage rates into production intensity basis (m^3 seepage / m^3 production).
2. Pembina then developed two average seepage factors: one for the beginning of a project (the beginning seepage rate) and the other for the end of project (the end seepage rate). This technique is used to simulate the sealing of ponds overtime.
    a. The beginning seepage rate is based on the average seepage intensity *over the life of the project*. Pembina used the average seepage intensity over the life of the project to make the calculations more conservative. Some of the EIA data project that tailings ponds will seep more at the beginning of operations than at the end. The average seepage rate over the life of a tailings pond is, therefore, lower than the seepage at the beginning of operations. Table 9 contains the calculated average seepage rate based on the data provided for each mine in the section above.

Table 9: Average seepage rates for six proposed oil sands mines

Project	Average Seepage Rate (m^3 Seep / m^3 bitumen produced)
Canadian Natural – Horizon	0.20
Imperial Oil Resources Ventures Limited (Imperial Oil) - Kearl	0.12
Petro-Canada Oil Sands Inc. – Fort Hills	0.46

Albian Sands – Muskeg River Mine (Current and Expansion)[2]	0.04
Shell Canada Ltd. – Jackpine	0.39
Shell Canada Ltd. – Jackpine Expansion and Pierre River	0.37
Average	**0.26**

b. The end seepage rate is based on a seepage reduction factor. Pembina used this method to address sealing in current tailings ponds. For example, a University of Waterloo study found that at Suncor's Pond 1 (Tar Island), "The thick sequence of fine tailings and residual bitumen below the pond, and the unsaturated zone that has developed in the underlying sand tailings, form an effective hydraulic barrier to flow. As a result, drainage flows form the oil sand tailings impoundment are lower and will approach steady state sooner than if pond water were freely flowing into the sand tailings."[3] Projected seepage rates for the Muskeg River Mine Expansion, Jackpine and Jackpine expansion[4] demonstrate this reduced seepage rate. The average seepage reduction rate based on these three projects is 84%. Using the average seepage rate calculated above the end of project seepage rate is 0.04 m^3/m^3 production.

3. Pembina then estimated seepage rates based on bitumen production for current and proposed oil sands mines without seepage data using the two seepage factors (0.26 m^3/m^3 and 0.04 m^3/m^3). The beginning seepage rate is applied during the first 18 years of operations.[5] The end seepage rate is used during the remaining years of operation.
4. Pembina then aggregated the seepage rates to generate total seepage rates per year.

[2] The seepage reported by Albian Sands is significantly lower than other projects. Pembina is unclear as to why this value is lower.

[3] Grace P. Hunter (2001). Investigation of Groundwater Flow Within an Oil Sand Tailings Impoundment and Environmental Implications. Earth Sciences, University of Waterloo. **Master of Science:** 363.

[4] The data presented in the data tables for Jackpine Expansion does not demonstrate this reduced seepage rate. However, specific pond seepage rates are discussed in more detail in the project application, see Shell Canada Limited. "Application for Approval of the Jackpine Mine Expansion & Pierrer River Mine Project - Environmental Impact Assessment." Calgary, 2007. ETDA seepage, pg. 6-211 table 6.3-18

[5] Three project clearly projected reduced seepage over time (Muskeg River Mine Expansion, Jackpine and Jackpine expansion). For these three projects the average time period until a reduced seepage rate is projected in a given tailings pond is 18 years.

1.3.3 Example Calculations

The following demonstrates the calculation methodology used for developing estimated seepage values for one proposed mine, Suncor Voyageur South. The expected start up time for Suncor Voyageur South is 2011 with production of 18,216 m^3 bitumen/day.[6]

Where,

BP = Bitumen Production (m^3/d)

SF_b = Beginning seepage factor (m^3 seepage / m^3 production)

SF_e = End seepage factor (m^3 seepage / m^3 production)

S_e = Estimated Seepage (m^3/d)

Then,

$$S_e = SF_b \times BP$$

Given,

BP = 18,216(m^3/day)

SF_b = 0.26 (m^3/m^3)

SF_e = 0.04 (m^3/m^3)

Then seepage for the first 18 years will be calculated using the beginning seepage factor as below,

$$S_e = 18{,}216(m^3 / day) \times 0.26(m^3 / m^3)$$

$$S_e = 4736(m^3 / day)$$

The seepage for the remainder of the project will be calculated using the end seepage factor as below,

$$S_e = 18{,}216(m^3 / day) \times 0.04(m^3 / m^3)$$

$$S_e = 728(m^3 / day)$$

The analysis made similar calculations for all proposed projects.

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[6] Dunbar, B. (2008). "Existing and Proposed Canadian Commercial Oil Sands Projects." Retrieved November 20, 2008, from http://www.strategywest.com/downloads/StratWest_OSProjects.pdf.

Table 10: Summary of estimated seepage rates per project

Project	Production (m^3/day)	Beginning Seepage Rate (m^3/day)	End Seepage Rate (m^3/day)
Canadian Natural – Horizon Phase 3 and 4	48,800	12,816	2,054
Suncor – Current[7]	46,728[8]	1,968	1,968
Suncor – Expansions (Voyageur South)	19,000	5,016	804
Syncrude Current[9]	64,713	2,724	2,724
Syncrude – Announced	29,568	7,776	1,246
Synenco – Northern Lights	18,206	4,788	765.6
Total – Deer Creek Announced	15,900	4,180	669.6
Total - Deer Creek Application	15,900	4,180	669.6
UTS/Tek Cominco – Announced	33,391	8,784	1,404

1.4 Other Scenarios

Pembina developed 4 other scenarios in order to assess the range of seepage values possible by varying key assumptions in the model. As all scenarios use the same base EIA information (see the Seepage Data from Environmental Impact Assessments section) the differences between the scenarios result from how Pembina used the EIA data to develop generic seepage factors. The seepage factor is the most influential variable on the results of each scenario in Pembina's

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[7] Excludes Tar Island. Also, all of Sunco'r current ponds are considered as sealed because they have been in operation for a longer period of time.

[8] Assumed maximum current production. Actual production may be lower.

[9] Production is based on maximum potential production as per Dunbar, B. (2008). "Existing and Proposed Canadian Commercial Oil Sands Projects." Retrieved November 20, 2008, from http://www.strategywest.com/downloads/StratWest_OSProjects.pdf. Actual production may be lower. All Syncrude ponds are assumed to be sealed.

seepage model. These differences are discussed in detail below. This discussion is followed by a comparison of the results for each of the scenarios.

Scenario 3 is the scenario used in the report and is summarized first below, followed by the other scenarios.

1.4.1 Scenario 3 – Report Scenario

There are three main assumptions associated with scenario 3 that are varied for the other assumptions.

1. **Beginning and End Seepage Factor:** Scenario 3 uses two seepage factors. One used to estimate the seepage at the beginning of a project and the other to estimate the seepage near the end of the project. The intent of the two seepage factors is to incorporate the concept of tailings ponds sealing over time.
2. **Seepage Factor Basis:** The beginning seepage factor is based on an average of projected seepage rates available in EIAs (0.26m^3 seepage/m^3 production). The end seepage factor is based on an 85% reduction in this seepage rate (0.04 m^3 seepage / m^3 production). The 85% reduction value is calculated from the projected decrease in seepage from three proposed tailings ponds (see the factor calculation section above for more details).
3. **Sealing:** Scenario 3 assumes all current ponds are sealed and that future ponds will seal after 18 years[10]. Sealed ponds are still assumed to seep but at a much reduced rate (85% lower).

1.4.2 Scenario 1 – Average

Scenario 1 differs in two important ways in comparison with Scenario 3:

1. **Beginning and End Seepage Factor:** Scenario 1 does not disaggregate seepage rates into beginning and end. Only one seepage rate is used over the life of proposed and current projects without seepage data.
2. **Seepage Factor Basis:** As in Scenario 3, Scenario 1 uses a seepage factor based on the average seepage of all projects with EIAs. This seepage factor is 0.26 m^3/m^3 production. However, unlike scenario 3, scenario 1 does not assume ponds seal over time. The average seepage factor is applied over the entire project life.

[10] Three project clearly projected reduced seepage over time (Muskeg River Mine Expansion, Jackpine and Jackpine expansion). For these three projects the average time period until a reduced seepage rate is projected in a given tailings pond is 18 years.

3. **Sealing:** Scenario 1 assumes current tailings ponds have not sealed and applies the average seepage factor to current operations as well.

1.4.3 Scenario 2 – Current Ponds Sealed

Scenario 2 is very similar to scenario 3 but does not apply an end seepage factor. Specific differences and similarities are discussed below.

1. **Beginning and End Seepage Factor:** Scenario 2 uses two seepage factors. One used to estimate the seepage at the beginning of a project and the other to estimate the seepage of current projects. The intent of the two seepage factors is to address the fact that current tailings ponds at Suncor and Syncrude's facilities have likely sealed over time and so seep less then a new tailings pond would.
2. **Seepage Factor Basis:** The beginning seepage factor is based on an average of projected seepage rates available in EIAs (0.26m^3 seepage/m^3 production). This factor is applied to all future projects without seepage data. A different seepage factor is applied to current operation and is calculated in the same way as the end seepage factor is calculated for scenario 3. That is it is 85% lower than the average seepage rate (0.04 m^3 seepage / m^3 production).
3. **Sealing:** Scenario 2 assumes all current ponds are sealed but future ponds will seep at the average rate over their lifetime.

1.4.4 Scenario 4 – Most conservative

Scenario 4 is also very similar to scenario 3; however, it uses the lowest reported seepage rate in place of the average seepage rate used in scenario 3.

4. **Beginning and End Seepage Factor:** Scenario 4 uses the beginning and end seepage factors in the same manner as scenario 3. However, the factors themselves are different.
5. **Seepage Factor Basis:** The beginning seepage factor is based on the lowest reported seepage rate (Albian Sands – Muskeg River Mine Expansion – 0.04 m^3 seepage / m^3 production). The beginning seepage factor is applied during the first 18 years of the projects life. The end seepage factor is 85% lower then this value (0.006 m^3 seepage / m^3 production). The end seepage factor is applied for the remaining years of the project.
6. **Sealing:** Scenario 4 assumes all current ponds are sealed and future ponds will seal after 18 years of operation. Sealed ponds will seep 0.006 m^3 per m^3 of production.

1.4.5 Scenario 5 – Match Profile

Scenario 5 is also very similar to scenario 3; however, it attempts to match the seepage profile of reported seepage rates.

7. **Beginning and End Seepage Factor:** Scenario 5 also uses beginning and end seepage factors; however they are calculated differently than in scenario 1.
8. **Seepage Factor Basis:** The beginning seepage factor is based on the average reported seepage rate of projects with EIAs during their startup period. The seepage value calculated using this methodology is 0.73 m^3 seepage / m^3 production. Similarly an end seepage rate is calculated from reported seepage rates. The seepage value is 0.161 m^3 seepage per m^3 production. The beginning seepage factor is applied during the first 18 years of the projects life (for projects without seepage rates reported in EIAs). The end seepage factor is applied for the remaining years of the project.
9. **Sealing:** Scenario 5 assumes all current ponds are sealed and future ponds will seal after 18 years of operation. Sealed ponds will seep 0.161 m^3 per m^3 of production.

1.4.6 Comparison

Table 11 presents a summary of key assumptions and seepage results for each scenario.

Table 11: Summary of key assumptions and results for each scenario

Scenario	Beginning Seepage Factor (m^3 seepage / m^3 production)	End Seepage Factor (m^3 seepage / m^3 production)	Total Seepage (Mm^3 present – 2080)	Peak Seepage (Mm^3 /yr)	Year of Peak Seepage
1 – Average	0.26	0.26	2293	36	2012
2 – Current Ponds Sealed	0.26	0.04[11]	1587	26	2012
3 – Report	0.26	0.04	945	26	2012
4 – Conservative	0.04	0.006	405	21	2012
5 – Mirror	0.73	0.161	1967	57	2024

Total seepage (the sum of seepage from all projects between now and 2080) is estimated to be between 405 Mm^3 and 2293 Mm^3. Scenario 3, the scenario used in the report, estimates total seepage at 945 Mm^3 which is relatively conservative given the range of seepage values.

Figures 1 to 5 below profile the annual seepage rates per scenario for current projects, projects with applications and proposed projects. Current projects include Suncor, Syncrude and Albian.

[11] Only applied to current ponds

Projects with applications include all approved projects and those with approvals pending but with project applications. Proposed projects include all other projects. A total list of projects included in this assessment is available in Table 1.

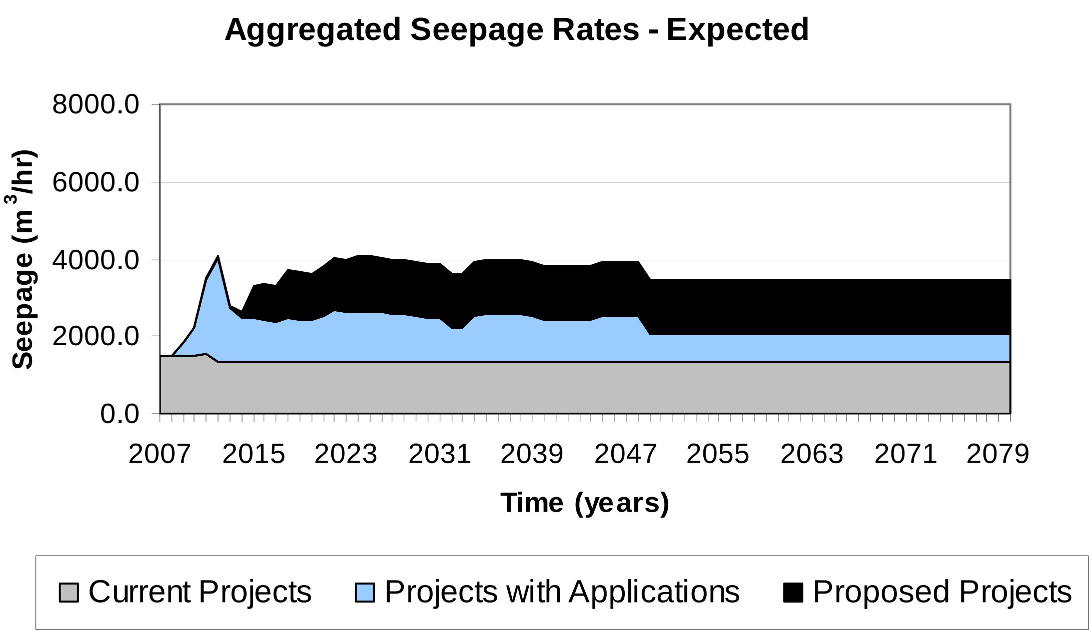

Figure 1: Scenario 1 – Projected seepage rates for current and proposed projects

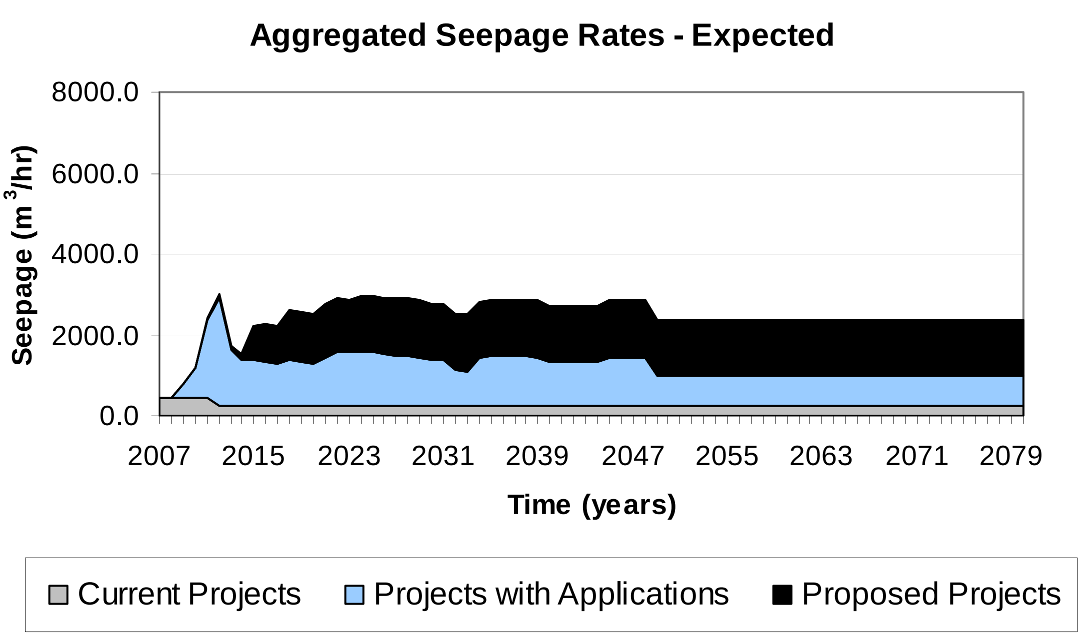

Figure 2: Scenario 2 – Projected seepage rates for current and proposed projects

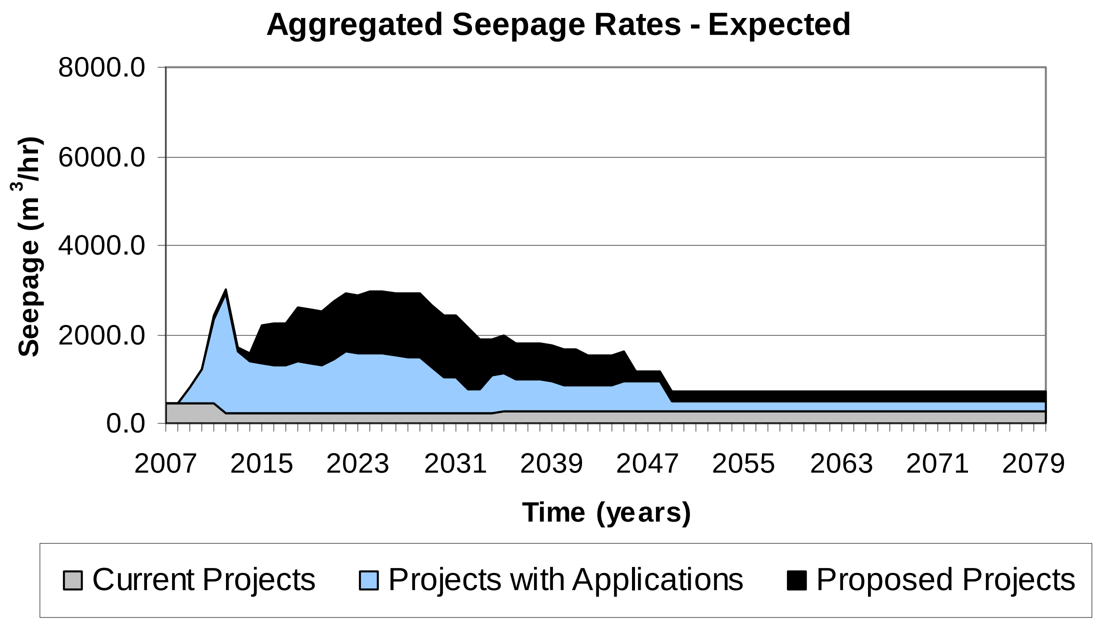

Figure 3: Scenario 3 - Projected seepage rates for current and proposed projects

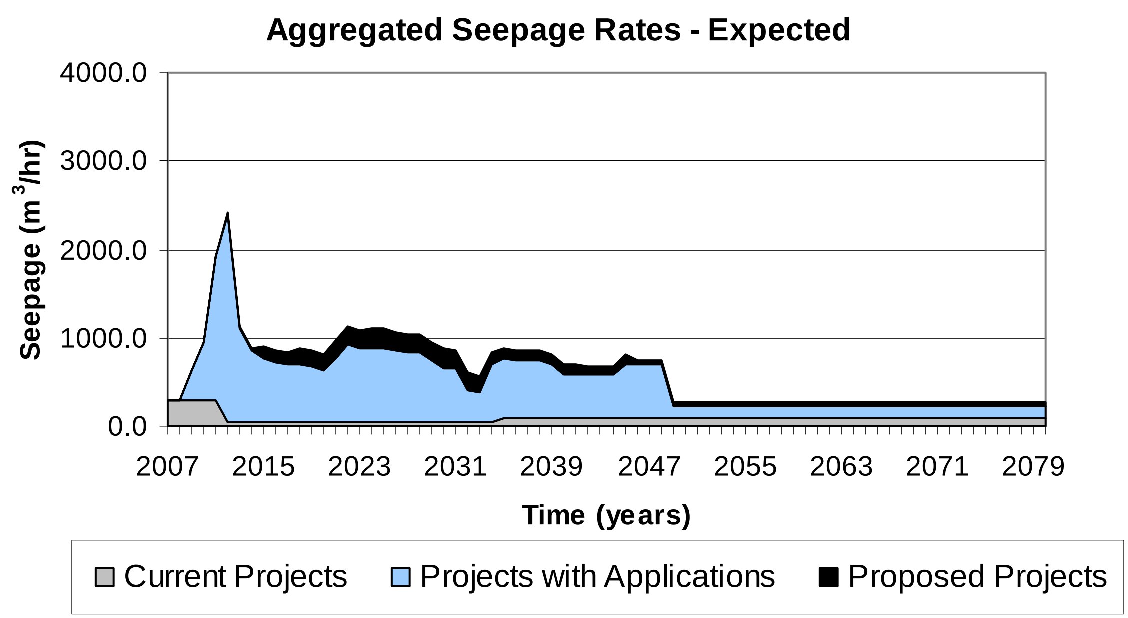

Figure 4: Scenario 4 – Projected seepage rates for current and proposed projects

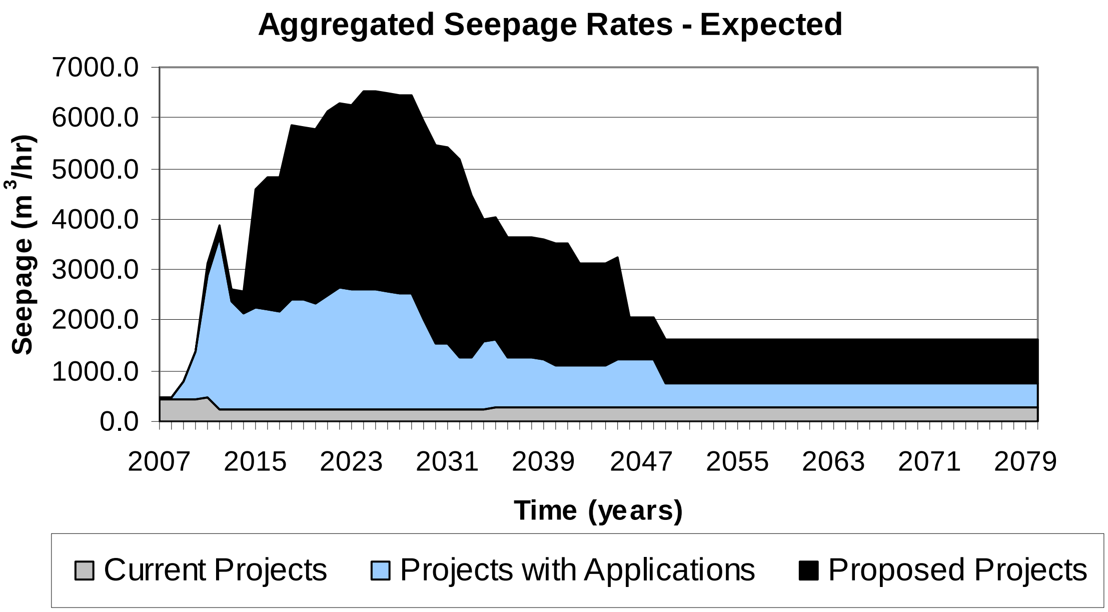

Figure 5: Scenario 5 – Projected seepage rates for current and proposed projects

For information on Pembina's methodology and data used please contact Jeremy Moorhouse at jeremym@pembina.org or at 403-269-3344 ext. 123.

1.5 Limitations

Although the methodology and calculations described and presented above are intended to be conservative estimates of current and proposed seepage rates, there are several limitations in their calculation. These are:

- Slowdown: Changes in project timelines as a result of the current financial uncertainty are not incorporated into this analysis.
- Use of Averages: The analysis used herein to estimate seepage rates for projects without seepage data does not account for the geological characteristics of each individual site. Where information is unavailable at the time of writing, averages are based on information published by the project proponents.
- Fate of the Seepage: This analysis does not attempt to determine the final (receiving water bodies), or even the immediate fate of the seepage (specific receptors such as the basal aquifer). The intent of this analysis is to estimate the rate of process affected seepage that is projected to by-pass mitigation measures.
- The Very Long-Term: Decommissioning a mine includes constructing end pit lakes and incorporating tailings into the landscape. Both end pit lakes and tailings will seep process-affected water into groundwater. This analysis does not attempt to quantify seepage rates for these sources over the very long term (i.e. more than several decades into the future).
- Current Tailings Ponds: Seepage rates for current ponds should be based on reported seepage rates that are publicly available information. Pembina requested these public documents on seepage rates from current tailings facilities from Alberta Environment. However, Alberta Environment did not provide these documents. In the absence of this data Pembina generated estimates as described in the methodology above.