Beach Fines Capture Study

June 2013
CG25409

Submitted to:
COSIA
Calgary, Alberta

Submitted by:
AMEC
Environment & Infrastructure
Calgary, Alberta
BEACH FINES CAPTURE STUDY

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EXECUTIVE SUMMARY

Conventional oil sands tailings operations consist of depositing segregating tailings streams into tailings facilities, resulting in large beaches and a pond of mature fine tailings (MFT). Operational approaches that would increase fines capture would reduce the amount of fines forming MFT in the first place. In turn, this would result in smaller quantities of MFT requiring secondary treatment with alternate technologies and associated costs. Operational approaches to enhance primary fines capture for conventional segregating tailings include:

1. Operate large deep ponds with full perimeter discharge; this may no longer be practical.
2. Develop layouts that maximize fines capture as per Syncrude’s 1989/90 trial (fines capture of 66%), which includes operating a contained beach with a mini-pond.
3. Increase slurry density and maintain constant flow conditions, as much as practical.
4. Consider co-disposal as per the northeast beaches at Shell’s Muskeg River Mine external tailings facility (ETF).
5. Consider using contained beaching or co-disposal rather than spiking a coarse tailings line with fine tailings, as these approaches may be more effective at fines capture.
6. Avoid long open-ended beaches with a small pond, as this maximizes secondary fines treatment requirements.

In most instances, the outer shell of an ETF is constructed using an overburden starter dyke followed by annual raises of tailings sand. In these cases, sand required for shell construction must have relatively low fines contents in order to deliver the necessary geotechnical stability. Conventional operational processes typically meet this requirement; operational processes that increase fines capture in the upper part of the beach may require additional "on-off" controls to limit the fines content in the shell portion of an ETF.

Based on information provided by COSIA or available in the public domain, this study considered deposits formed by segregating tailings in some existing commercial scale ETFs, flume tests, and field trials. The case records were reviewed in varying levels of detail, depending on the amount of information available. The project scope did not include reviewing case records for tailings slurries that are intended to be non-segregating. Table ES-1 provides a summary of fines capture for the case records considered in this study, as either reported by the given operator or inferred based on the information available for this study. The project scope did not include auditing an operator's mass balance for a given facility.

All of the commercial scale ETFs considered in this study included large deep ponds, resulting in large beaches below water (BBW), and fines captures ranging from about 60% to almost 80%. Canadian Natural's Horizon Mine ETF is the youngest facility, with the shallowest pond; therefore, it is not surprising that it currently has the lowest reported fines capture of the commercial scale ETFs considered in this study. In the northeast corner of Shell's Muskeg River Mine (MRM) ETF, fine tailings streams and coarse tailings streams were co-disposed and intermingled on the resulting beaches. During the initial years of operation, this area was contained by an internal dyke and, although it was not raised along with the rest of the facility, it affected the beaches that developed in this area. From 2008 to 2011, the reported fines capture for this northeast beach area was about 65%. 
### Table ES-1. Fines Captures for Case Records Considered in this Study

<table>
<thead>
<tr>
<th>Operator</th>
<th>Tailings Facility</th>
<th>Time Period</th>
<th>44 Micron Fines Capture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syncrude</td>
<td>Aurora Settling Basin (ASB)</td>
<td>2000 to 2009</td>
<td>77%</td>
</tr>
<tr>
<td>Shell</td>
<td>Muskeg River Mine (MRM) ETF</td>
<td>2003 to 2011</td>
<td>70%</td>
</tr>
<tr>
<td>Suncor</td>
<td>Tar Island Pond (Pond 1)</td>
<td>Up to early 1990's</td>
<td>63%</td>
</tr>
<tr>
<td>Syncrude</td>
<td>Mildred Lake Settling Basin (MLSB)</td>
<td>1989/90, 1,000 Mt Ore</td>
<td>62%</td>
</tr>
<tr>
<td>CNRL</td>
<td>Horizon Mine ETF</td>
<td>2008 to 2012</td>
<td>62%</td>
</tr>
</tbody>
</table>

#### Commercial Scale ETFs

#### Commercial Scale Co-Disposition

<table>
<thead>
<tr>
<th>Operator</th>
<th>Tailings Facility</th>
<th>Time Period</th>
<th>44 Micron Fines Capture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell</td>
<td>MRM ETF – NE Beach Only¹</td>
<td>2008 to 2011</td>
<td>65%</td>
</tr>
</tbody>
</table>

#### Field Monitoring, Flume Tests and Field Trials²³

<table>
<thead>
<tr>
<th>Operator</th>
<th>Tailings Facility</th>
<th>Time Period</th>
<th>44 Micron Fines Capture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syncrude</td>
<td>Contained 1200 m Long Beaching Trial</td>
<td>1989/90</td>
<td>66%</td>
</tr>
<tr>
<td>Syncrude</td>
<td>Southwest Sands Storage (SWSS) Field Monitoring of Uncontained Beaches Above Water (BAW)</td>
<td>2004</td>
<td>37%</td>
</tr>
<tr>
<td>OSLO</td>
<td>Contained 100 m Long Beaching Trials</td>
<td>1991</td>
<td>30 to 40%</td>
</tr>
<tr>
<td>Syncrude</td>
<td>Contained 300 m Long Spiking Trials</td>
<td>1993</td>
<td>20 to 30%</td>
</tr>
<tr>
<td>Total</td>
<td>Contained 8 m Long Flume Tests</td>
<td>2011</td>
<td>25%</td>
</tr>
<tr>
<td>Syncrude</td>
<td>Uncontained Beaching Trials</td>
<td>1988</td>
<td>≤ 21%</td>
</tr>
</tbody>
</table>

Notes:

1. The combined overall average fines content of the three tailings streams reporting to the northeast beach portion of the MRM ETF was significantly higher than that for the MRM ETF as a whole and the other commercial scale ETFs.
2. For each set of flume tests and field trials, a range of slurry properties was tested; the fines capture reported here is for the test or trial that had the slurry fines content closest to the overall averages for the commercial operations, for direct comparison.
3. "Contained" tests and trials included some degree of containment at the far end, causing some amount of ponding to develop. "Uncontained" trials were open-ended, and any solids that did not deposit on the beaches could flow directly to the pond.

Syncrude’s Southwest Sands Storage (SWSS) facility was operated with a smaller pond than the other commercial scale ETFs, resulting in longer beaches above water (BAW). A global fines capture for SWSS, based on a mass balance for the facility as a whole, was not available for this study. However, a field monitoring program that was completed over a discrete time period in 2004 indicated that the BAW placed during this time period had a fines capture of about 37%; i.e. much lower than the overall fines captures at the other commercial scale ETFs.

For the flume tests and field trials, higher overall fines captures were achieved when some degree of containment was provided at the far end, generating a BBW component, all else being equal. However, fines captures were typically much lower than in the commercial scale ETFs. The exception was a large scale contained beaching trial at Syncrude in Winter 1989/90, which achieved an overall fines capture of about 66%.

Shell’s MRM ETF, Canadian Natural’s Horizon Mine ETF and Syncrude’s Aurora Settling Basin (ASB) were reviewed in further detail, relative to depositional environment. The findings confirmed that subaqueously deposited BBW zones are more effective in capturing fines than subaerially deposited BAW zones, and indicated that the fines capture effectiveness of BBW increases as one moves further out into beach deposits located below a progressively deeper pond. In general terms, the energy of the depositional environment directly affects fines capture, with lower energy environments being more effective at capturing fines. For BBW, submarine slope instabilities and turbidity currents result in some of the existing MFT becoming entrapped and entrained in the BBW, thereby increasing the overall fines capture for a facility.
There are no existing models that can predict fines capture over the wide range of depositional environments that occur simultaneously in a typical tailings facility. Moreover, the typical operational variability of an oil sands extraction plant means that some of the key parameters that affect the tailings behaviour upon deposition, and therefore fines capture, are constantly varying and not predictable. These include slurry density, flow rate and fines content. Directionally, increasing slurry density and decreasing flow rate would increase fines capture. Upset conditions will play some role, and episodic periods of water flushing through tailings lines are a typical part of operations at an oil sands extraction plant. Pond chemistry is expected to also play a role, but was not part of the scope of this study. Both the ASB and the MRM ETF may have pond chemistries favourable to fines capture.

In conclusion, segregating tailings streams that are directed to conventional tailings facilities with large deep ponds, resulting in large BBW deposits, can deliver global fines captures as high as 70% to almost 80%. At the other end of the range, small pond operations, with large uncontained BAW deposits, lead to lower fines captures, in the order of 30 to 40% for typical whole tailings. Contained beaching creates a lower energy environment with some ponding, and results in a higher overall fines capture than in a typical uncontained BAW deposit, but the fines capture is still less than in the best commercial scale ETFs. Co-disposal of fine tailings and coarse tailings streams may be more effective at fines capture than spiking fines into a coarse tailings stream, all else being equal. Internal cross dykes and perimeter discharge around a more circular facility may assist fines capture by providing more of a "bathtub" effect.
1.0 INTRODUCTION

1.1 Background

Conventional oil sands tailings operations consist of depositing segregating tailings streams into tailings facilities, resulting in large beaches containing a pond of fluid fine tailings. The outer containment shell portion of external tailings facilities (ETFs) is typically constructed using an overburden starter dyke followed by annual dyke raises of tailings sand using cell construction techniques. Some fines are captured by the shell and beaches, with the remainder of the fines reporting to the pond. Obtaining an enhanced understanding of the processes controlling fines capture in beaches could lead to implementation of operational changes that would increase beach fines capture and reduce the amount of fines forming fluid tailings in the first place. In turn, this would result in smaller quantities of mature fine tailings (MFT) requiring treatment using alternate technologies, with associated costs.

1.2 Objectives of Current Study

The main objectives of this study are, for conventional segregating tailings, to:

- Review a number of case records to understand fines capture rates in existing facilities.
- Develop an enhanced understanding of the processes controlling beach fines capture and the operational changes that may increase fines capture.
- Complete a high level review of available modeling tools to assess if operational factors are appropriately addressed within the models.
- Discuss potential operational enhancements that could increase fines capture in conventional beaches.

Specifically, the project scope does not address segregation of notionally non-segregating tailings slurries such as composite tailings (CT), non-segregating tailings (NST), thickened tailings (TT), fluid fine tailings (FFT; also known as MFT) and so on.

1.3 Project Scope

As agreed to at the project meeting held on 06 March 2013, the final project scope includes:

- Completing a detailed review\(^1\) of:
  - Three commercial scale case records, namely: Shell's Muskeg River Mine (MRM) External Tailings Facility (ETF), Canadian Natural's Horizon Mine ETF and Syncrude's Aurora Settling Basin (ASB).
  - Laboratory testing (cylinder and flume tests) completed by Total in 2011.
- Completing a high level review of the following two models for predicting fines capture:
  - The Marsh pore capture model
  - The BARR/Deltares model
- Compiling an inventory of other relevant case records, both field and laboratory scale. If possible, provide some discussion of each, but, at minimum, simply provide a listing of other case records that may be worth further consideration in a subsequent study.
- Providing a discussion of various mechanisms affecting fines capture.
- Providing high level input to discussions regarding potential 2013 field trials.
- Participating in weekly telephone call meetings and regular working group meetings.

\(^1\) The reviews are to focus on 44 micron fines contents; however, where possible, some commentary should also be made on 2 micron clay contents and the clay to fines ratios.
The following items are excluded from the project scope:

- Auditing an operator's mass balance for a given facility.
- Evaluating the impacts, if any, of the different measurement methods used by various operators (e.g. to determine 44 micron fines content, to locate pond bottom, etc.) on the calculated fines capture for a given facility.
- Addressing the depositional behaviour of composite tailings (CT) or non-segregating tailings (NST) mixes, including segregation potential.
- Reviewing other relevant case records in detail.
- Planning/designing any potential 2013 field trials in detail.
- Providing input to any other testing/trials being planned by individual operators.

1.4 Report Organization

The remainder of this report is organized as follows:

- **Section 2.0** – presents the terms and definitions used in this report.
- **Section 3.0** – presents a number of case records that were reviewed from a global fines capture perspective, including laboratory scale flume tests, field scale trials and commercial scale operations.
- **Section 4.0** – presents the three commercial case records that were reviewed in detail from a depositional environment perspective, namely Shell's Muskeg River Mine ETF, Canadian Natural's Horizon Mine ETF and Syncrude's Aurora Settling Basin.
- **Section 5.0** – discusses two models available for predicting fines capture, and their associated limitations. Also discusses some potential factors affecting fines capture.
- **Section 6.0** – presents lessons learned from the study and describes potential methods for fines capture enhancement.
- **Section 7.0** – provides a list of references used in this study.
- **Section 8.0** – closure & limitations.

In addition, this report includes four major appendices, each providing a summary of the information provided by the applicable operator for one of the four case records forming the primary scope of the current study, as follows:

- **Appendix A** – Total's 2011 cylinder and flume testing
- **Appendix B** – Shell's Muskeg River Mine ETF case record
- **Appendix C** – Canadian Natural's Horizon Mine ETF case record
- **Appendix D** – Syncrude's Aurora Settling Basin case record

A fifth appendix, Appendix E, presents a series of figures for the MRM ETF, Horizon ETF and ASB case records, with the results of the beach classification by depositional environment.
2.0 TERMS & DEFINITIONS

2.1 Fines Capture Definitions Used in This Study

Figure 1 presents a schematic illustrating the fate of fines at an oil sands mine, from the mined ore through to the tailings deposits. In this study, as shown in Figure 1, fines capture is defined as follows:

\[
Fines\ capture = \frac{M_{FD}}{M_{FS}}
\]  

[1]

where:

- \( M_{FD} \) = mass of fines in all tailings deposits, excluding fluid tailings
- \( M_{FS} \) = mass of fines in tailings slurry
- Fines = mineral solids less than or equal to 44 microns

In this definition, the term "tailings deposits" encompasses all tailings sand deposits in a given facility, including beaches above and below the pond level as well as the containment shell constructed using cell construction techniques, but excluding fluid tailings. The term "tailings slurry" refers to the total tailings discharged into the facility through all tailings lines directed from the extraction plant to the given facility; i.e., net of any oversize rejects generated at the mine.

As shown in Figure 1, the mass of fines in the tailings deposits (and, hence, the fines capture) can be determined in two ways, as follows:

1. Directly, through sufficient sampling and testing of the tailings deposits to assess the total mass of fines contained in the tailings deposits.
2. Indirectly, by subtraction, by subtracting the mass of fines in the MFT from the mass of fines in the tailings slurry; this requires sufficient sampling and testing of the MFT.

The conventional and accepted discriminator between fluid fine tailings (FFT) or mature fine tailings (MFT) and tailings beach deposits is the weight probe used to define the "pond bottom".

Both of the above methods require sufficient sampling and testing of the tailings slurry. Given the significant variability present within tailings beaches, but the relatively consistent profile with depth that develops within a given MFT deposit, Method 2 is more straightforward and more economical than Method 1. When the two methods yield similar results, the degree of "closure" for the overall mass balance for the facility is high, lending more confidence to the results (and, hence, the calculated fines capture for the facility).

Equation 1 considers all tailings deposits as a whole. However, as shown in Figure 2, the tailings deposits can be subdivided into a number of regions, based on depositional environment. Therefore, Equation 1 can be re-written as follows:

\[
Fines\ capture = \frac{M_{FDi}}{M_{FS}}
\]  

[2]

where:

- \( M_{FDi} \) = mass of fines in a given region, \( i \), of the tailings deposit
- \( M_{FS} \) = mass of fines in tailings slurry
- \( i = 1 \) to \( n \)
- \( n \) = number of regions
A sufficient amount of sampling and testing is required to determine representative overall weighted average fines contents and dry densities (or solids contents) for the tailings slurry over a given time period, and for a given tailings deposit region. Provided that this has been completed, the mass of fines in the tailings slurry, $M_{FS}$, is defined as:

$$M_{FS} = \%F_S \cdot C_w \cdot \gamma_{bs} \cdot Q \cdot t$$

where:
- $\%F_S$ = fines content of slurry
- $C_w$ = concentration of mineral solids in the slurry, on a weight basis
- $\gamma_{bs}$ = bulk density of slurry
- $Q$ = flow rate of slurry
- $t$ = time period over which slurry was discharged

Similarly, the mass of fines in a given tailings deposit region, $M_{FDi}$, is defined as:

$$M_{FDi} = \%F_i \cdot V_i \cdot \gamma_{di}$$

where:
- $\%F_i$ = overall weighted average fines content of the given region
- $V_i$ = volume of the given region
- $\gamma_{di}$ = overall weighted average mineral dry density of the given region

When determining the appropriate bulk density for the slurry and mineral dry density for the tailings deposits, the presence of bitumen needs to be taken into account.

The fines contents of the tailings slurry ($\%F_S$) and each individual tailings deposit region ($\%F_i$) are defined as follows:

$$\%F_S = \frac{M_{FS}}{M_{FS} + M_{SS}}$$

where:
- $M_{FS}$ = mass of fines in tailings slurry
- $M_{SS}$ = mass of sand in tailings slurry
- Sand = mineral solids greater than 44 microns

$$\%F_i = \frac{M_{FDi}}{M_{FDi} + M_{SDi}}$$

where:
- $M_{FDi}$ = mass of fines in tailings deposit region i
- $M_{SDi}$ = mass of sand in tailings deposit region i

The overall fines capture by a given point in time for a given facility is estimated by the operator through the completion of detailed annual site investigations, surveys and mass balances for the facility. However, directly comparing the properties of the incoming tailings slurry to the resulting beaches in the facility provides a relative index of fines capture. As defined in the subsequent subsections of this report, two indices have been adopted in this study; the first
based on sand to fines ratio (SFR) and the second based on fines content (%F). In this report, the first is used in the global assessment of several case records, while the second is used in the depositional environment assessment of three specific commercial case records.

2.1.1 Sand to Fines Ratio (SFR) Index

Re-arranging Equations 5 and 6 results in the following:

\[ M_{FS} = M_{SS} \cdot \frac{\%F_s}{1 - \%F_s} \]  
\[ M_{FDi} = M_{SDi} \cdot \frac{\%F_i}{1 - \%F_i} \]  

Substituting Equations 7 and 8 into Equation 2 results in the following:

\[ \text{Fines capture} = \frac{M_{SD1} \cdot \frac{\%F_i}{1 - \%F_i} + M_{SDi} \cdot \frac{\%F_i}{1 - \%F_i} + ... + M_{SDn} \cdot \frac{\%F_i}{1 - \%F_i}}{M_{SS} \cdot \frac{\%F_s}{1 - \%F_s}} \]  

This simplifies to:

\[ \text{Fines capture} = \frac{SFR_S \cdot M_{SD1} \cdot M_{SS} + SFR_S \cdot M_{SD2} \cdot M_{SS} + ... + SFR_S \cdot M_{SDn} \cdot M_{SS}}{SFR_D \cdot M_{SS}} \]  

where:

\( SFR = \text{sand to fines ratio} = (1 - \%F)/\%F \)

\( M_{SD}/M_{SS} = \text{sand capture rate in a given tailings deposit region} \)

Equation 10 considers the tailings deposits by region. However, when considering the overall global fines capture for a given facility as a whole, the tailings deposits can be considered together as a whole, resulting in the following simplified equation:

\[ \text{Fines capture} = \frac{SFR_S \cdot M_{SD}}{SFR_D \cdot M_{SS}} \]  

because:

\[ \frac{M_{SD}}{SFR_D} = \frac{M_{SD1}}{SFR_1} + \frac{M_{SD2}}{SFR_2} + ... + \frac{M_{SDn}}{SFR_n} \]
If the sand capture by all tailings deposits combined (i.e. $M_{SD}/M_{SS}$) is 100%, then all of the sand in the tailings slurry reports to the tailings deposits (i.e. none reports to MFT), and the fines capture equation simplifies further to:

$$\text{Fines capture} = \frac{SFR_S}{SFR_D}$$  \[12\]

If, in reality, some sand reports to MFT, then the sand capture in the tailings deposits will be less than 100%, and the fines capture will be some amount less than that calculated using Equation 12. However, assuming that, in most cases, the majority of the sand reports to the tailings deposits, the ratio of SFR values, as given by Equation 12, provides a simple index parameter for assessing and comparing the global fines captures for various case records; therefore, this approach is used later in Section 3.0.

### 2.1.2 Fines Capture Effectiveness Ratio (FCER)

Küpper (1991) proposed the use of an index parameter comparing the fines content of a tailings deposit to the fines content of the tailings slurry as a measure of the efficiency of the fines capture process in a given depositional environment. In this report, this index parameter is referred to as Fines Capture Effectiveness Ratio (FCER), and is defined as follows:

$$\text{FCER} = \frac{\%F_D}{\%F_S}$$  \[13\]

where:

- $\%F_D$ = fines content of tailings deposit
- $\%F_S$ = fines content of tailings slurry

Substituting Equations 3 and 4 into Equation 2 results in the following:

$$\text{Fines capture} = \frac{\%F_1 \cdot V_1 \cdot \gamma_{d1} + \%F_2 \cdot V_2 \cdot \gamma_{d2} + \ldots + \%F_n \cdot V_n \cdot \gamma_{dn}}{\%F_S \cdot C_w \cdot Y_{bs} \cdot Q \cdot t}$$  \[14\]

or

$$\text{Fines capture} = \frac{1}{C_w \cdot Y_{bs} \cdot Q \cdot t} \left( \frac{\%F_1}{\%F_S} \cdot V_1 \cdot \gamma_{d1} + \frac{\%F_2}{\%F_S} \cdot V_2 \cdot \gamma_{d2} + \ldots + \frac{\%F_n}{\%F_S} \cdot V_n \cdot \gamma_{dn} \right)$$  \[15\]

where:

- $V_1 \cdot \gamma_{d1} =$ mass of mineral solids in tailings deposit region $i = M_{MDi}$
- $C_w \cdot Y_{bs} \cdot Q \cdot t =$ mass of mineral solids in tailings slurry = $M_{MS}$

Therefore, Equation 15 can be simplified to:

$$\text{Fines capture} = \frac{\%F_1}{\%F_S} \cdot \frac{M_{MD1}}{M_{MS}} + \frac{\%F_2}{\%F_S} \cdot \frac{M_{MD2}}{M_{MS}} + \ldots + \frac{\%F_n}{\%F_S} \cdot \frac{M_{MDn}}{M_{MS}}$$  \[16\]
Note that Equation 16 and Equation 10 are identical to each other and are completely interchangeable. The only difference is that Equation 16 is expressed in terms of fines content and mass of total mineral solids (%F and M_Ms), while Equation 10 is expressed in terms of sand to fines ratio and mass of sand (SFR and M_Ms).

Combining Equations 13 and 16 results in the following:

\[
\text{Fines capture} = F\text{CER}_1 \cdot \frac{M_{MD1}}{M_{MS}} + F\text{CER}_2 \cdot \frac{M_{MD2}}{M_{MS}} + \ldots + F\text{CER}_n \cdot \frac{M_{MDn}}{M_{MS}}
\]  

where:
\[M_{MDi}/M_{MS} = \text{the percentage of total mineral solids in the tailings slurry that are captured by a given tailings deposit region.}\]

In other words, the overall fines capture for a given tailings facility is a function of both the FCERs and the total mineral capture rates for each of the individual tailings deposit regions. In general, for a given region, a higher FCER will result in a higher contribution towards overall fines capture. When considering tailings deposits by region, FCER provides a simple index parameter for assessing the effectiveness of different depositional environments within a given case record; therefore, this approach is used later in Section 4.0.

As illustrated in Equation 14, the global fines capture could be calculated by summing the mass of fines in each zone of tailings. This, however, requires the dry density of each zone. For each zone, accurate determination of the total mineral solids dry density, or fines dry density, can be estimated based on sampling and testing. However, accurate determination of the total mineral solids dry density by calculation from typical solids content samples is, at best, approximate. For saturated deposits, sampling of sand structure dominated tailings is subject to void ratio changes from sampling disturbance and water loss from the typically adopted sonic samples during handling. That is to say, water is squeezed out of an in situ deposit by vibration, and further water is drained as the sample is extruded (often with vibration) from the core tube. Thus, solids contents, and hence dry densities, are typically over-reported for sandy tailings.

2.2 Discussion of Effects of Bitumen Content on Fines Capture

Usually, bitumen is reported on a total weight of slurry basis; that is, weight of bitumen divided by weight of bitumen, water, and solids, or OWS, as determined in a Dean Stark test. However, depending on the total solids content, the ratio of the volume of bitumen to the volume of mineral solids changes. Take, for example, raw MFT at an OWS mineral solids content of 28% and, say, an OWS bitumen content of 2%. A bitumen content of 2% may not sound too important; however, the ratio of bitumen to minerals is about 0.071 on a weight basis and about 0.19 on a volume basis. For MFT at a mineral solids content of 55% and, say, an OWS bitumen content of 2.5%, the ratio of bitumen to minerals is 0.046 on a weight basis and 0.12 on a volume basis. Thus, depending on how the information is presented, the relative impression of the potential impact of bitumen content can change.
2.2.1 Effect of Bitumen on Calculations

The presence of bitumen in MFT must be accounted for in any of the fines capture or FCER calculations made. Methods using a “subtraction approach” for which MFT volumes are used require correction for bitumen contribution to total volume. For the case records presented herein, this is believed to be the case. If the volume of bitumen were not factored out, the fines capture calculated by subtraction would be too low.

2.2.2 Effect of Bitumen on Fines Capture

While it is easy to visualize that bitumen could impact fines capture by allowing fines to adhere to sand particles, or be trapped on beaches, there is no rigorous treatment of this mechanism of which AMEC is aware.

2.3 Glossary

The following abbreviations and terms are used in this report (listed in alphabetical order):

- ASB = Aurora Settling Basin, the ETF for Syncrude’s Aurora North Mine
- Beach above water (BAW) = subaerial beach deposits, placed above the waterline at the time of deposition.
- Beach below water (BBW) = subaqueous beach deposits, placed below the waterline at the time of deposition. BBW is further subdivided into the following components, based on depositional environment, each of which is described in more detail in Section 4.0:
  - Proximal BBW
    - Upper (U) BBW
    - Lower (L) BBW
  - Distal BBW or Pond Centre (PC)
- Bitumen content (mining definition) = \( \frac{\text{mass of bitumen}}{\text{total mass of bitumen, water and mineral solids}} \)
- Bulk (or wet) density (\( \gamma_b \)) = \( \frac{\text{total mass of mineral solids, bitumen and water}}{\text{total volume}} \)
- Cell = tailings deposits placed using compacted cell (CC) construction techniques (i.e. using dry dykes to provide containment, a spillbox at the far corner, and dozer compaction during placement)
- Clay = mineral solids less than or equal to 2 microns; different operators use different methods to determine the particle size distribution of the mineral solids. Not all clay minerals are less than 2 microns in size.
- Clay content (%C) = \( \frac{\text{mass of clay}}{\text{total mass of mineral solids}} \)
- Coarse tailings = conventional coarse tailings or "straight coarse tailings" (SCT), as used by Syncrude to describe its typical whole tailings.
Controlled or contained beaching (CB) = a variation of cell construction, in which tailings are hydraulically placed in long beaches between pre-built containment dykes. The downstream end of a controlled beach is usually open-ended, while a contained beach is closed-ended with a small dyke and an overflow system.

CST = coarse tailings at Shell's MRM; depending on how the MRM extraction plant is operating, this tailings stream is either cyclone underflow tailings or whole tailings.

Dry density \( (\gamma_d) \) = \( \frac{\text{mass of mineral solids}}{\text{total volume}} \)

ETF = external tailings facility

Extraction Tailings = whole tailings at Canadian Natural's Horizon mine, excluding froth treatment tailings, which are a separate stream.

FFT = fluid fine tailings (often referred to as MFT)

Fines = mineral solids less than or equal to 44 microns; different operators use different methods to determine the particle size distribution of the mineral solids.

Fines capture = \( \frac{\text{mass of fines accounted for in cell and beaches}}{\text{total mass of fines reporting to the tailings facility}} \)

Fines capture effectiveness ratio (FCER) = \( \frac{\text{fines content of beach}}{\text{fines content of tailings slurry}} \). An index of fines capture effectiveness.

Fines content (%F) = \( \frac{\text{mass of fines}}{\text{total mass of mineral solids}} \)

Fines dry density = \( \frac{\text{mass of fines}}{\text{total volume of tailings deposit}} \)

Fines over fines plus water (FOFW) = \( \frac{\text{mass of fines}}{\text{mass of fines} + \text{mass of water}} \)

Fines storage (or fines dry density of tailings deposits) = mass of fines stored per unit volume of tailings deposit

Flotation tailings = flotation unit tailings at Syncrude's Aurora North Mine

FTT = froth treatment tailings at Canadian Natural's Horizon Mine

HR = high rate of beach deposition (> 5 m/year)

LR = low rate of beach deposition (< 5 m/year)

L1/L2 = used on various beach classification figures in this report to refer to data from the main pond portion of Shell's MRM ETF facility, as the tailings lines used in this area are CST Line 1 (L1) and Line 2 (L2)

Mature fine tailings (MFT) = all fluid fine tailings above the pond bottom

MBI = methylene blue index
- MLSB = Mildred Lake Settling Basin, an ETF at Syncrude's Mildred Lake operations
- MRM = Shell's Muskeg River Mine
- Mudline = interface between water cap and MFT in a tailings facility
- OWS = weight of oil, water and mineral solids, as measured in a Dean Stark test
- PC = pond centre (i.e. distal BBW)
- Pond bottom (interface between MFT and beach) = elevation at which the AK97 or CT09 tool stops during a pond sounding
- Recycle water (RCW) = water cap overlying MFT
- Sand = mass of mineral solids greater than 44 microns
- Sand to fines ratio (SFR) = (mass of sand)/(mass of fines)
- SEA = South Expansion Area, a tailings deposit at the south end of the MRM ETF
- SFR index = (SFR of slurry)/(SFR of beach). An index of fines capture.
- Solids content (mining definition) = (mass of mineral solids)/(total mass of bitumen, water and mineral solids)
- SWSS = Southwest Sands Storage, an ETF at Syncrude's Mildred Lake operations
- TSRU tailings = tailings solvent recovery unit tailings at Shell's MRM
- TT = thickened tailings at Shell's MRM
- TTTS = used on various beach classification figures in this report to refer to data from the NE beach portion of Shell's MRM ETF facility, as the tailings lines used in this area are the TT and TSRU lines, as well as CST lines
- Waterline = water surface in a tailings facility
- Water content (mining and geotechnical definitions)
  - Mining = (mass of water)/(total mass of bitumen, water and mineral solids)
  - Geotechnical = (mass of water)/(mass of mineral solids)
3.0 GLOBAL FINES CAPTURE CASE RECORDS

3.1 Review Methodology

This section of the report considers several case records from a global fines capture perspective. The case records include:

- Laboratory scale tests (flume tests)
- Field scale trials
- Commercial scale tailings facilities

The case records were evaluated based on either information specifically provided by the various operators for this study or information that was available in the public domain. The global fines capture represents the overall fines capture for the given test, trial or facility, as a whole, without considering how the fines are distributed within the cell and/or beach deposits.

The subsequent sections present a synthesis of each case record, including the calculated global fines capture based on the information available as well as the SFR index, as per Equation 12. For each case record, the SFR index was determined based on assigning a single overall SFR to the tailings slurry and a single overall SFR to the tailings deposits. The various case records are compared on a series of charts, by plotting the SFR of the tailings deposits versus the SFR of the tailings slurry.

3.2 Case Records

3.2.1 Laboratory Scale Tests

3.2.1.1 Total's 2011 Test Program

Appendix A provides a memorandum summarizing the information provided for Total's 2011 laboratory testing program, which consisted of a series of 2L cylinder tests as well as a series of flume tests. The tests were completed using tailings slurries having a range of solids contents and fines contents. Appendix A documents only those tests that were completed without any chemical additives – 14 cylinder tests and 9 flume tests.

As stated in Appendix A, all of the flume tests were operated with containment during the initial part of the test. While the slurry was being discharged at the inlet end of the flume, the outlet end of the flume was blocked, preventing immediate runoff at the far end of the flume. The mixture was allowed to settle for 1 hour before runoff was drained from the far end of the flume by slowly opening rubber plugs on the weir at the end of the flume.

As described in Appendix A, the mass balances that were completed for the flume tests did not have 100% closure for all tests. This likely reflects the difficulty in characterizing the mass of fines and sand in the beach, given the limited number of samples (6 to 8 samples per 8 m long flume) and the variability of the beach deposits. Therefore, for the purposes of this study, the method of subtraction was considered more reliable for assessing the mass of fines and mass of sand captured in the beach and, hence, the fines capture.

In terms of global fines capture and SFR index, the 9 tests can be summarized as follows:

- Average slurry SFR ranged from 3.8 to 16.4
- Average beach SFR ranged from 7.8 to 18.6
  - In all tests, the SFR decreased with distance down the beach.
- SFR index ($SFR_s/SFR_D$) ranged from 0.44 to 0.88
• With the exception of one test that had a sand capture of 50%, the sand capture ranged from 97% to 100%; therefore, in most tests, the vast majority of the sand reported to the beach deposit.

• Fines capture ($M_{FD}/M_{FS}$) for the one test with a sand capture of 50% was only 24%. For the remaining tests, the fines capture ranged from 43% to 88%, consistent with the range in SFR index. If the one test with the highest fines capture (88%) is also excluded, the rest of the tests had a tighter range in fines capture, from 43% to 64%.

• All tests had relatively similar slurry solids contents, ranging from 49% to 55%.

• In general, fines capture increased with increasing slurry SFR. The test with the highest fines capture (88%) had, by far, the highest slurry SFR (16.4). The test with the lowest fines capture (24%) had the lowest slurry SFR (3.8). The remaining tests had slurry SFR values ranging from 5.9 to 9.3.

• Conversely, in general, the overall average beach fines content decreased with increasing slurry SFR. The test with the lowest beach fines content (5.1%) had, by far the highest slurry SFR (16.4). The test with the highest beach fines content (11.4%) had the lowest slurry SFR (3.8). The remaining tests had beach fines contents ranging from 6.4 to 9.2% and slurry SFR values ranging from 5.9 to 9.3.

The 2L cylinder tests were much smaller scale tests, but as described in Appendix A, gave results that were generally consistent to the flume tests.

### 3.2.1.2 Canadian Natural's 2011 Test Program

Ten flume tests were completed for Canadian Natural in 2011 (BARR/Deltares, 2012). The objectives of the testing were mostly focussed on understanding the depositional behaviour of chemically treated NST mixtures and evaluating different discharge methods (tremie-diffuser, buried pipe and open end pipe). However, some flume tests were completed using "Weak NST" near the static segregation boundary (see Section 5.2 for a description of NST mixtures and the segregation boundaries determined by BARR/Deltares). Weak NST was CO$_2$-treated to a pH of 6.9, with a nominal SFR of about 4 and a FOFW in the order of 20%.

A large flume was used for all of the tests (25 m long by 1 m by 1.2 m), with its base sloped at 0.7%. The tailings slurry was discharged into the flume at a rate of 250 L/minute. For most of the flume tests, tailings were not removed from the far end of the flume during the test (these tests were referred to as ones completed with "backpressure"). However, for two flume tests (Tests FL09 and FL10), both using an open end pipe discharge, slurry was removed at the far end of the flume at the same rate as it was introduced at the discharge end (these tests were referred to as having "no backpressure"). Test FL09 had a slurry SFR of 3.8 (i.e. Weak NST), while Test FL10 had a slurry SFR of 5.9 (i.e. Strong NST). In this context, BARR/Deltares's "backpressure" appears to be the presence of discharge into a pond, and is similar to the operational conditions imposed during, for example, the Total flume tests or the Syncrude Winter 1989/90 trial.

The BARR/Deltares (2012) report does not appear to provide sufficient details regarding the flume test results to directly consider the Weak NST flume tests as potential case records herein. However, the following comments can be made with the information available.
Two of the tests are considered the most relevant to this study, as they both involved open
ended pipe discharge of Weak NST (SFR about 4.0) with no additional chemical augmentation
beyond CO₂, as follows:

- Test FL03 – with backpressure, slurry SFR of 4.0, slurry solids content of 56%, slurry
  FOFW of 20.5%, pH 7.0, prepared using Syncrude flotation tailings and pit sand
- Test FL09 – no backpressure, slurry SFR of 3.8, slurry solids content of 50%, slurry
  FOFW of 17.3%, pH 7.0, prepared using CNRL flotation tailings and pit sand

The tailings mixture in Test FL03 was just dry of the static segregation boundary. Figure 5-9 of
the BARR/Deltares report indicates that, in general, the SFR of the resulting deposit remained
about 4.0. The primary exception was at the base of the deposit near the discharge end, where
some segregation occurred and an SFR of about 6 was measured. Overall, the fines capture in
the tailings deposit as a whole would be close to 100%, since the vast majority of the beach
maintained an SFR similar to that of the tailings slurry.

For Test FL09, the BARR/Deltares report stated that the tailings mixture was actually wetter
than the static segregation boundary, and that the test conclusively formed a segregated sand
bed at the maximum sand porosity achievable for flowing sand. Figure 5-16 of the
BARR/Deltares report indicates that the sand bed that formed in Test FL09 had SFR values
ranging from 9 to 20. Based on this figure, a rough overall average SFR for the beach in
Test TL09 as a whole is likely in the order of 16. Assuming 100% sand capture, this would
 correspond to a fines capture in the order of 25%.

3.2.2 Field Scale Trials

3.2.2.1 Syncrude’s Winter 1989/1990 Contained Beaching Trial

As reported by Plewes et al. (1995), an intensive 2 week trial of tailings deposited in a 200 m
wide by 1200 m long test cell was undertaken as part of the west berm of the MLSB facility.
The objective of the trial was to evaluate the technique of "contained beaching". This term
signifies that the cell is closed ended with a sluice box used to maintain a settling pond at the
end of the subaerial beach to promote sand capture, and which has the effect of increasing
fines captures in the beaches below the "mini-pond" that is formed.

This deposit was constructed as a contained beach, and a relatively large pool was maintained
upstream of the spillbox. A summary of the operational details is as follows:

- Full scale trial cell 200 m x 1200 m long
- 24" pipeline discharging to four 24" offtake pipes, used one at a time.
- Some pre-trial beaching was completed prior to the start of the trial, forming positive
  drainage towards the spillbox.
- Offtake pipes located about 1 m above beach, and formed plunge pool. Once tailings
  had built up at one discharge point, flow was directed to another discharge line.
- Pipelines extended down the beach in 24.4 m increments for about 175 m (suggests a
  total of 7 extensions per offtake pipe).
- Spillbox pond was maintained at about 100 m to 250 m upstream of the spillbox.
- Plunge pool was 2 m deep, then next 200 m to 300 m consisted of channelized flow,
  then tailings flow progressed to shallow wide sheet flow.
- It is assumed that the pond upstream of the spillbox was drained prior to the site
  investigation sampling and testing, and was considered part of the runoff in the overall
  mass balance that was completed for the trial.
The slurry had the following characteristics:

- Flow rate of 0.9 to 1.2 m$^3$/s.
- Solids content of 51%.
- Average tailings inflow fines content of 19% ($SFR_S = 4.3$).

The beach had the following characteristics:

- Beach dry density of 1.584 t/m$^3$ and overall water content of 25.5%.
- Beach slope of 1% near discharge decreasing to 0.3% 800 to 1000 m from discharge.
- Average beach fines content of 13% ($SFR_D = 6.7$).
- Plewes et al. (1995) stated that there was a noticeable increase in fines content in the last 250 m of beach, and that the 250 m long zone of increased fines concentration was consistent with the size of the spillbox pond during the trial.

Key findings are as follows:

- The ratio $SFR_S/SFR_D = 64\%$.
- Therefore, assuming 100% sand capture, a fines capture of 64% would be calculated. This compares well with the fines capture of 66% reported by Plewes et al. (1995), based on a detailed mass balance.
- According to Plewes et al. (1995), the achieved beach angle was no more than half of what was being obtained in the adjacent MLSB beaches. The flatter beach in the trial indicates a lower energy environment, arguably conducive to higher void ratios and higher capture.
- The beaches were not trafficked by cell cats except for extending the offtake pipes. This would mean that loose void ratios were maintained with commensurate fines capture, as well as potentially less fines erosion during track-packing which leads to densification (manifested by ejection of dirty water). That is to say, fines capture is lessened for a beach that is trafficked after placement, due to some loss of fines. The pore capture model would predict this via a reduction in sand void ratio by compaction, but there may also be an additional component due to erosion of fines by the expelled fluid (consisting of fines and water).

### 3.2.2.2 Küpper Field Trials

Küpper (1991) documents eight large scale BAW field tests that were performed at MLSB in the 1980’s to study the deposition process and the effect of placement method on the resulting beach characteristics (geometry, density, grain size distribution, fabric and fines capture). The tests included a pilot test (Test 0) completed during Winter 1986 and seven subsequent tests (Tests 1 to 7) completed during 1988. As described by Küpper (1991), the field tests used spigots to discharge tailings on the MLSB beach, as follows:

- Most of the tests used 5 spigots having a diameter of either 3 inches (Tests 5 to 7) or 6 inches (Tests 0 to 4) installed on a 24 inch pipeline. The spigots were used to obtain varying solids contents depending on the relative location of the spigot on the circumference of the 24 inch pipe.
- The 3 inch spigots were 4.6 m long and the 6 inch spigots were 3 m long.
Four of the five spigots were grouped together (equally spaced every 24.4 m) to create a 2-D depositional pattern, in which tailings being discharged from different spigots could interact with each other.

The fifth spigot was placed at a distance (73.2 m) from the group to simulate a 3-D depositional pattern in which the tailings being discharged from the spigot could form a fan. This last spigot was not used for tests using the 3 inch spigots.

The end of the pipeline was open, discharging the remaining slurry to the beach.

This study considered only the results of Tests 1, 2 and 4, all of which used 6 inch spigots, as these tests had the most data collected for both the tailings slurry and the resulting beaches. Fines contents reported by Küpper (1991) were based on 75 microns, but were converted to estimated 44 micron values using a conversion factor of 0.6325 based on other Syncrude experience (personal communication from Mr. Bill Shaw). Measurements made for Test 1 indicated an average flow rate per spigot of about 60 litres/second. Operating hours, slurry solids contents concentrations and SFR values were as follows:

- Test 1 – 32.5 operating hours over 2 days, overall average slurry concentration of about 64%, and average slurry SFR of about 13
- Test 2 – 254 operating hours over 15 days, overall average slurry concentration of about 56%, and average slurry SFR of about 4
- Test 4 – operated for almost 8 days, 24 hours a day (i.e. almost 192 operating hours), overall average slurry concentration of about 37%, and average slurry SFR of about 2.5

Küpper (1991) noted that the reason Test 2 was operated for so long was "because the deposition was very unstable, depositing and eroding in a cyclic pattern". Küpper (1991) also commented that "this phenomenon seemed to have cycles of approximately 2 hours and it did not seem to happen necessarily in all channels at the same time" and "for most of the 15 days of this test there was no permanent variation in beach elevation, with all the material discharged being transported to the pond".

Table 1 summarizes the fines capture observations for Tests 1, 2 and 4. Assuming 100% sand capture, the SFR index values suggest overall fines captures in the BAW deposits as follows:

- Test 1 – in the order of 40%
- Test 2 – in the order of 20%
- Test 4 – in the order of 20%

Since the tests were uncontained, it is likely that some amount of sand reported to the pond; therefore, the actual fines captures would have been some amount lower. This appears to be particularly true for Test 2, given the comments cited above.

3.2.2.3 OSLO Field Trials

A package of information on the OSLO field trials was provided for this study (personal communication, Mr. Bill Shaw). This included the following:

- Copy of paper by Shaw et al. (1993) describing the trials.
  - Note that this paper uses a 22 micron definition of fines content.
- Copy of letter report by Hardy BBT Limited (1991)
Excel file prepared by Mr. Bill Shaw, summarizing the tailings slurry and beach data collected for each trial.
  o Included 44 micron test data for the tailings slurry and tailings beaches. The summary of the trials presented herein uses this 44 micron data.

As described in Shaw et al. (1993), nine large scale field deposition trials were completed by OSLO on test cells at MLSB, between Cells 3 and 4. One of the objectives of the study was to assess the potential of increasing fines content within the beaches by controlling the density and fines content of the tailings stream. Tailings feed was cycloned and the underflow was mixed with MFT dredged from the pond, using different proportions and concentrations. The resulting mixture was then discharged into test cells (Tests 1 to 9) that were approximately 10 m wide by 100 m long by 3 m deep. The cells were formed by dry dyking the tailings sand on the existing beaches, and a modified spillbox was installed at the end of each cell to control and monitor runoff. With the exception of Test 1, the tailings were discharged using an 8 inch line into the different cells using two 4 inch spigot pipes. Test 1 consisted of straight discharge of Syncrude extraction tailings into the test cell, to represent conventional disposal practices at Syncrude.

Slurry characterization included measurements of solids content, particle size distribution, flow rates and slurry concentration (density). Beaches were characterized in terms of particle size distribution, density, slope angle, strength and permeability.

One of the tests (Test 6) also included descriptions of the resulting flow characteristics and bedforms, in support of selecting locations for sampling and testing (Hardy BBT, 1991). The report commented that, overall, the flow in Test 6 appeared to be comparable to the typical segregating slurry flow on MLSB beaches.

Table 2 summarizes the fines capture observations for the nine OSLO trial cells, based on the Excel file provided. Assuming 100% sand capture, the SFR index values suggest overall fines captures in the deposits ranging as follows:

- Test 1 (slurry SFR$_S$ of about 12; no spigots) – 70%
- Tests 7, 8 and 9 (slurry SFR$_S$ of about 9 to 10.5) – 60 to 80%
- Tests 2 and 4 (slurry SFR$_S$ of about 4 to 5) – about 40%
- Tests 3, 5 and 6 (slurry SFR$_S$ of about 2.5 to 3) – about 30%

Given that all of the tests were operated as cells with a modified spillbox, 100% sand capture is considered a reasonable assumption.

### 3.2.2.4 Syncrude's 1990, 1993 & 1994 MFT Spiking Trials

In 1990, 1993 and 1994, Syncrude completed various trials to investigate the depositional behaviour and characteristics of beaches that formed when tailings slurry was spiked with MFT. The 1990 trials at MLSB (Cuddy et al., 1991) have not been considered herein.

The 1993 trials are described by Cuddy et al. (1993). An Excel file with tailings slurry and beach characterization data for the trials was provided for this study (personal communication, Mr. Bill Shaw). A summary is as follows:

- Two test cells, each 40 m wide by 300 m long, were poured at MLSB. One of the cells (in Cell 10) was filled with coarse tailings and served as the Base Case (no spiking), while the other cell (in Cell 9) was filled with coarse tailings spiked with MFT.
• Slurry properties  
  o Cell 10 (no spiking) – average fines content of 11.5% (SFR\textsubscript{S} of 7.7), average solids content of 51.5%  
  o Cell 9 (with spiking) – average fines content of 27.3% (SFR\textsubscript{S} of 2.7), average solids content of 46.5%  

• Beach properties (based on samples collected from trenches through the deposits)  
  o Cell 10 (no spiking) – average fines content of 6.8% (SFR\textsubscript{D} of 13.7)  
    ▪ Note: samples collected from drilling boreholes gave a similar average fines content of 7.2% (SFR\textsubscript{D} of 12.8)  
  o Cell 9 (with spiking) – average fines content of 7.1% (SFR\textsubscript{D} of 13.2)  
    ▪ Note: samples collected from drilling boreholes gave slightly different results, with an average fines content of 9.6% (SFR\textsubscript{D} of 9.4)  

• Assuming 100% sand capture, the following fines captures are inferred:  
  o Cell 10 (no spiking) – 7.7/13.7 = 56%  
  o Cell 9 (with spiking) – 2.7/13.2 = 20% (or 29% if borehole beach data were used)  

The 1994 trials, which were completed at SWSS, are described by McKenna et al. (1999). A few key points are as follows:  
• 1,000 to 3,000 USgpm of MFT were spiked into a coarse tailings line at 16,000 USgpm  
• The beach slope angles were found to be 0.3 to 0.4% and unaffected by spiking.  
• Spiking reduced trafficability, but could be managed.  
• The trials were conducted near original ground, with no downwards drainage (as compared to earlier MLSB trials)  
• Very little useful data relative to fines capture appear to have been collected.

We note that Table 6-2 of Volume 2 of the final report for the Tailings Roadmap Project (CMTC, 2012) describes the status of pilots and prototypes completed for MFT spiking as a potential oil sands tailings technology as follows:  
• "Pilot/prototype company; date; scale of test – Syncrude; 1993, 1995, 1996, 1997; 20,000 USgpm  
• Result of pilot – successful pilot, applied as dyke construction technology; found not [to] work for beaching – no increase in fines capture  
• Claim for tailings – increased fines capture in tailings pores without too much loss in geotechnical performance  
• Fate of technology – shelved due to poor fines capture and significant changes to permeability of deposit  
• What would it take to make the technology interesting again? – would require someone to run it commercially and prove it works”  

In addition, Volume 5 of the same report describes the technology of MFT spiking as follows: "Creating spiked tailings (ST) involves adding mature fine tailings (MFT) either to a coarse tailings stream or a 'densified' cyclone underflow tailings (sand) stream to create fines enriched segregating slurry. The spiked tailings slurry is deposited sub-aerially to form a relatively rapid consolidating, soft deposit capable of meeting various land uses." The report lists several benefits and risks associated with the technology. Included in the benefits are that MFT spiking could "potentially increase the fines capture in the beach deposits by increasing the density and fines concentration in tailings slurry" and "under ideal conditions, this technique would create no soft tailings". Included in the risks are that MFT spiking could lead to "potentially less favourable geotechnical performance, if the fines content of the beaches significantly
increased”, "a portion of the deposit may be 'soft tailings' and will require a longer time to consolidate”, and that it is a "new technology" for which "the principles of the process are not well understood".

For conventional tailings, the application of MFT Spiked Whole Tailings was identified in the CMTC (2012) report as being one of four potential gap filler technologies under the identified opportunity for improvement associated with segregation during beaching. The report also commented that, "by varying the degree of fines-spiking, the whole tailings product can be tailor-made for cell construction or tailings beaching".

### 3.2.2.5 Muskeg River Mine Pilot Program

In 1999, Shell Canada Limited completed a pilot plant tailings testing program at the Muskeg River Mine pilot plant. AMEC's scope was limited to data collection under the direction of Shell and Muskeg River Contractors staff, and preparation of a data report, with no interpretation of the data collected (AGRA E&E², 2000).

Two large scale beaching tests of non-caustic cyclone underflow (coarse tailings) with solids content and particle size distribution considered representative of the planned commercial operation were completed. The first test evaluated above water or sub-aerial tailings deposition (the AWBT Test) and the second test evaluated below water or sub-aqueous tailings deposition (the BWBT Test). The second test included both above water and below water deposition.

Based on data in AGRA E&E (2000), the following comments can be made:

- **BWBT Test**
  - Based on Figure 6 in AGRA E&E (2000), most of the test was actually BAW; only the far portion of the test was BBW
  - Over 6 days of infilling the test area, the slurry fines content ranged from 2% to 32%, with an average value of 11% (SFR₆ of 8.1)
  - Based on all test pit samples of beach collected, the beach fines content ranged from 2 to 9%, with an average of 5.1% (SFR₀ of 18.6)
  - There was no clear trend with fines content down the beach
  - Only one of the test pits was in the BBW portion of the deposit, and it had results that were similar to the BAW test pits

- **AWBT Test**
  - Over 6 days of infilling the test area, the slurry fines content likely ranged from about 5 to 18%, with an average of 13% (SFR₆ of 6.7)
    - Note: unlike the BWBT test, the slurry characterization for the AWBT test only included 75 micron data, and not 44 micron data. Therefore, the fines contents cited here as likely 44 micron values are based on the measured 75 micron data and an assumed conversion factor of 0.59 (the average ratio for the slurry data in the BWBT test)
  - Based on all of the test pit samples of beach collected, the beach fines content ranged from 5 to 50%, with an average of 20% (SFR₀ of 4)
    - Note: this is a higher average fines content than the average slurry fines content, which seems unusual for a BAW deposit.

² Now AMEC.
During both tests, the flow rates varied significantly, and it is difficult to assess if the overall flow rate was typically higher in one test than the other. The slurry solids contents also varied significantly in both tests; however, in general, it appears that the BWBT slurry had a higher solids content than the AWBT slurry. The slurry fines contents also varied significantly in both tests, with the range in values being larger in the BWBT test; therefore, characterizing each slurry with a single average fines content may not be representative. During both tests, the pipe was moved from side to side; however, in the BWBT test, it was also extended much further down the beach than in the AWBT test.

There is insufficient information available in the AGRA E&E (2000) data report to make any conclusive comments as to what operational differences might have existed and could explain why the AWBT test apparently resulted in a significantly higher beach fines content than the BWBT test, when the tailings slurry in the AWBT test likely had only a slightly higher fines content than the BWBT test. Therefore, these tests are not included in subsequent case record comparison plots for the current study.

3.2.3 Commercial Scale Tailings Facilities
3.2.3.1 Suncor Tar Island Pond
Sheeran analyzed data sets from Suncor in the early 1990's, the results of which were reported more recently by Mikula et al. (2008). Figure 3 provides his analysis of data sets, primarily based on Tar Island Pond experience (taken from Mikula et al., 2008). Importantly, Sheeran made a clear distinction between entrained sludge and entrapped sludge. Entrained fines are considered to be equivalent to the pore capture model, discussed later in this report. However, Sheeran (personal communication to Dr. Ed McRoberts) also considered that MFT was entrapped by BBW sand beaching as well, and there certainly is evidence of this in samples taken below the pond bottom, where consolidated MFT can be found in layers. Therefore, when one is measuring a pond bottom, it can be expected that below this bottom, fines captures can be greater than what is expected from a pore capture model.

For the early Suncor experience, based on Figure 3, of the mined fines:

- 13.5% reported to rejects, with the remaining 86.5% reporting to tailings
- 32% were contained within the MFT (i.e. above the pond bottom)

Therefore, by subtraction, the fines capture is (86.5 – 32.0)/86.5 or 63%.

Based on MacKinnon and Sethi (1993), the average fines content of the ore was 13.5%, and the average fines content of the tailings slurry was 11.9%, or an SFR$_S$ of 7.4.

A slurry SFR$_S$ of 7.4 and a fines capture of 63% implies, assuming 100% sand capture, a tailings deposit SFR$_D$ of 11.7, or a fines content of 8% (BAW and BBW, combined).

3.2.3.2 Syncrude 1$^{st}$ 1,000 MT Ore
In the early days of Syncrude operations, all fines except for those in rejects reported to the Mildred Lake Settling Basin (MLSB); there was no other source of fines reporting to MLSB as there is now with froth from the Aurora North Mine. As pointed out by Fair (2008), Syncrude historical data indicated that 1 m$^3$ of ore produced 0.34 m$^3$ of MFT. Based on an assumed in situ ore density of 2.085 tonnes/m$^3$, MFT production is therefore about 0.163 m$^3$/tonne ore.
The following assumptions are made:

- 1 m³ of ore produces 0.34 m³ MFT
- Ore body fines content of 22%
- Rejects are equal to 5% of ore, and have a fines content of 50% fines
- Total solids content circa 1990 in all MFT of 36.5%
- Fines content in all MFT to pond bottom of 80%

The resulting estimate of fines capture is about 62%.

It should be noted that List and Lord (1997) quoted the perspective that:

"It is estimated that approximately 50% of the fines are captured in the voids of the coarse tailings fraction upon deposition".

It is also generally understood that this level of fines capture was supported by the predictions made by the "pore capture model", as discussed later in this report, and did not account for additional capture from BBW sand interactions with the pond bottom.

Based on the ore and rejects assumptions given above, the slurry is assumed to have an average SFR of 3.88 (fines content of 20.5%). A slurry SFR of 3.88 and a fines capture of 62% implies, assuming 95% sand capture (to account for some loss of sand to MFT), a tailings deposit SFR of 6.6, or a tailings deposit fines content of 13% (BAW and BBW, combined). Unfortunately, there are no 44 micron fines content data below pond bottom publically reported for BBW deposits, of which the authors are currently aware, for comparison.

Syncrude (1989) describes the results of a September 1987 investigation into beaches at MLSB using a barge mounted drill rig. Two cross-sections on the east side of MLSB were selected for investigation – one in Cell 22 and one in Cell 25. Using annual aerial photographs as well as some bathymetric and sonar survey data, beach profiles were developed for each cross-section, in an attempt to show the depositional environment. Fines were determined using Microtrac equipment by the "dry sieving" method, rather than the "wet sieving" method, and the report commented that "it is well known that wet sieving gives fines contents about 50% higher than [those] obtained by dry sieving". Therefore, while the report cautioned that the results would not be directly comparable to other data on a quantitative basis, the results were still considered to be directly relevant for relative comparisons of beaches deposited underwater and under MFT. The report concluded that the average fines content (22 micron) of beaches under MFT was about double that of underwater beaches. However, when the measured 22 micron values are converted to approximate 44 micron values using a conversion factor of 1.51 (personal communication, Mr. Bill Shaw), the absolute values measured are low (3.6% in BBW and 7.0% in beach below MFT). It is unclear what higher values would have been obtained using more conventional techniques than the "dry sieving" Microtrac method that was used.

### 3.2.3.3 Syncrude’s SWSS

Syncrude’s Southwest Sands Storage (SWSS) facility was commissioned in 1991 (List et al., 1997), and was originally intended to be constructed using coarse tailings with a long sand beach and small pond operation. Any thin fine tailings (TFT) reporting to the facility were to be transferred out of the facility to other storage areas. However, due to a number of operating decisions and realities, the original plan was modified and a large pond developed. Nevertheless, the beaches around the north end of the facility remained relatively long.
During a discrete time period in 2004, Syncrude completed some large scale field monitoring of the tailings slurry deposited at SWSS and the resulting BAW deposits that formed during this time period (Syncrude, 2011). This included an assessment of the incremental volumes of BAW and BBW that were placed. During the monitoring time period, the average slurry density was about 1.43 t/m$^3$ and the average slurry fines content was about 30% (Syncrude, 2011). The average fines content in the BAW was about 15% (personal communication, Mr. Nan Wang), and the mass balance that was completed indicated a BAW fines capture of about 50% (Syncrude, 2011). In terms of SFR, the tailings slurry and BAW fines contents of 30% and 15% correspond to SFR values of 2.3 and 5.7, respectively, resulting in an SFR index ($\frac{SFR_D}{SFR_0}$) of 41%. Comparing this SFR index to the reported fines capture of 37% implies a BAW sand capture of 90%, which seems reasonable, given that some sand reported to BBW.

In 2007, a site investigation of the SWSS beaches was completed in support of the design for raising the SWSS by stepping out over the existing beaches (AMEC E&E, 2008). At the time of the 2007 site investigation, the longest above water beaches were in the northeast corner of the SWSS facility, and were up to about 1400 m long; however, the objectives of the 2007 site investigation program did not include characterizing these long beaches. Therefore, if Syncrude has any fines content data in this area, the information could be useful in better understanding fines capture on long BAW beaches. The following comments can be made based on the results of the 2007 site investigation:

- Tested 70 beach samples mostly collected from boreholes drilled in Cells 34 and 35, but a few samples were also collected in Cells 31, 45 and 47.
- The boreholes in Cell 34 were along a cross-section, with borehole locations ranging from the compacted sand shell to about 500 m down the beach.
- The boreholes in Cell 35 were part of the baseline investigations for a trial embankment, constructed about 200 to 400 m down the beach.
- Samples were collected at depths ranging from about 3 to 26 m.
- Based on an assessment of the depositional history, some samples were in BAW and some were in likely BBW.
- Considering all samples collected (i.e. not separating based on BAW or likely BBW), the fines contents ranged from about 2 to 22%, with an average of 7.7% ($SFR_0$ of 12).
- Excluding the 35 samples from the trial embankment area (which included several samples within two likely BBW layers), the fines content for the remaining 35 samples ranged from about 2 to 14%, with an average of 6.7% ($SFR_0$ of 14).
- It is difficult to draw any clear conclusions on potential trends in fines content down the beach.

As part of an earlier study on cyclic liquefaction of beaches under equipment loading, Wood (2003) reported 44 micron fines contents of 0.2 to 2.2% (i.e. SFR > 44) for BAW samples collected at depths between 0.1 and 2 m, about 250 m down beach in Cell 31.

Assuming an overall average tailings slurry fines content of about 20% (i.e. $SFR_0 = 4.0$) as per List et al. (1997), and assuming 100% sand capture, the 2007 site investigation data suggests, based on all samples collected ($SFR_0$ of 12), an average fines capture in the vicinity of 33%. This is relatively consistent with the BAW fines capture of 37% that was estimated based on the results of the field monitoring and testing completed in 2004, as described above.
3.2.3.4 Shell’s Muskeg River Mine ETF

Appendix B provides a memorandum summarizing the information provided for Shell’s MRM ETF case record. As summarized in Appendix B, the following key points can be made, when considering the facility as a whole:

- MRM produces three tailings streams – cyclone underflow coarse tailings, thickened tailings and tailings solvent recovery unit (TSRU) tailings. At times, during various bypass conditions in the extraction plant, whole tailings are produced instead of separate coarse and thickened tailings.
- The ETF started out as a segmented facility, with a cross dyke separating the northeast corner (NE Pool) from the rest of the facility (Main Pond). TT and TSRU tailings, along with some coarse/whole tailings were discharged in the NE Pool. With the exception of some TSRU disposal in 2004, only coarse/whole tailings were discharged into the Main Pond. The cross dyke was not raised along with the perimeter dykes for the facility as originally planned, but TT and TSRU disposal, along with some coarse/whole tailings, continued to be discharged in the NE corner only, and a long beach developed. The Main Pond continued to receive only coarse/whole tailings.
- Using information provided at the time of the original design (AMEC, 2001), it is estimated that the fines content of all three of the tailings streams combined (i.e. mined ore net of rejects) is 18.1% (SFR of 4.54).
- Based on Shell's 2011 tailings plan submission to the ERCB (Shell, 2011), based on laser diffraction particle size distribution data, the following dry fines could be accounted for in tailings facilities at the MRM site as a whole:
  - 101.8 Mt total
  - 30.1 Mt in fluid tailings
  - 71.7 Mt in dykes and beaches (i.e. 70.4% of all fines that could be accounted for in MRM tailings facilities were captured)
- The above numbers reflect the combined total of fines in the ETF, the South Expansion Area (SEA) and In-Pit Cell 1 (IPC1). However, the vast majority are in the ETF, as tailings disposal into the SEA started in late 2009 and disposal into IPC1 started in 2010. Prior to this, all tailings from start-up in 2003 were discharged into the ETF only. It is difficult to assess the fines capture for the ETF alone, as MFT has been transferred out of and into the ETF, and, while the volumes of transferred MFT were tracked, the specific tonnages of dry fines transferred between facilities have not been tracked.
- Considering the NE Beach on its own, Esposito and Nik (2012) report the following:
  - For 2008 to 2011, inclusive, the beach was formed by continuous deposition of TT and TSRU, along with intermittent deposition of CST/WT. Considering the three streams together, over this 4 year time period, the overall average slurry fines content was 33.5% (i.e. SFR of 2.0). The tonnage of CST/WT total mineral solids comprised about 58% of the total mineral solids disposed in the NE.
  - The beach has an average fines content of about 25% (i.e. SFR of 3.0).
  - The NE beach captured about 65% of all fines deposited in the NE corner.
- A slurry SFR of 4.54 and a fines capture of 70.4%, assuming 100% sand capture, infers an overall tailings deposit SFR for the whole ETF of 6.48 (or a fines content of 13.3%).
- For the NE beach on its own the ratio SFR/SFR is equal to 66%, essentially the same as the 65% fines capture reported by Shell (2012).
- As shown in Appendix B, the fines contents of the tailings deposits vary significantly, depending on location – NE Beach vs Main Pond and, within the Main Pond, beaches above and below water.
3.2.3.5 Canadian Natural's Horizon Mine ETF

Appendix C provides a memorandum summarizing the information provided for Canadian Natural's Horizon Mine ETF case record. As summarized in Appendix C, the following key points can be made, when considering the facility as a whole:

- The Horizon Mine produces two tailings streams – extraction tailings and froth treatment tailings (FTT). Extraction tailings comprise the vast majority of the tailings produced.
- The Horizon Mine produces essentially no rejects, and those that are produced are considered to be free of fines, as any rejects produced are recycled until they are washed out. Therefore, unlike other oil sand mines, essentially all of the fines mined report to tailings.
- The containment dyke (Dyke 10) for the Horizon ETF is being constructed entirely of overburden and interburden; unlike other ETFs in the oil sand industry, conventional cell construction is not being used. All tailings produced are beached from Dyke 10.
- Tailings disposal and dyke raising activities alternate between the north and south halves of the facility: when the dyke is being raised in the north, tailings are discharged in the south over a significant period of time; when the dyke is being raised in the south, tailings are discharged in the north for a significant period of time. This results in alternating large BBW and BAW zones.
- Based on information provided in the 2011 annual ETF status submission to the ERCB (AMEC, 2012):
  - The overall average SFR of the ore mined to date is 3.53 (i.e. SFR$_S$ of 22.1%, since no fines to rejects).
  - By subtraction, the overall fines capture in the ETF beaches was 57.1%.
- A slurry SFR$_S$ of 3.53 and a fines capture of 57.1%, assuming 100% sand capture, infers an overall beach deposit SFR$_D$ for the whole ETF of 6.19 (or a fines content of 13.9%). The actual sand capture is slightly less than 100% as AMEC (2012) indicated that the MFT had a fines content of 97% and, therefore, contained a small amount of sand.

3.2.3.6 Syncrude's Aurora Settling Basin

Appendix D provides a memorandum summarizing the information provided for Syncrude's ASB case record. As summarized in Appendix D, the following key points can be made, when considering the facility as a whole:

- The Aurora North Mine produces two tailings streams – coarse tailings and flotation tailings. Froth produced by the Extraction Plant is directed to Syncrude’s Mildred Lake operations and the tailings produced are disposed in MLSB.
- Based on information provided in BGC (2011), based on the fines and sand that can be accounted for within ASB:
  - The overall average slurry fines content of all tailings lines combined would have been about 19.4% (i.e. SFR$_S$ of 4.15).
  - The fines are distributed as follows:
    - 104.2 Mt total
    - 23.8 Mt in MFT
    - 80.4 Mt in shell and beaches (i.e. 77% of all fines that could be accounted for in ASB were captured)
  - The overall average fines content for the tailings deposits (cell, BAW, BBW, and BB-MFT combined) was 15.8% (SFR$_D$ = 5.34)
  - Sand capture was 99%.
• A slurry SFR\textsubscript{S} of 4.15, a beach deposit SFR\textsubscript{D} of 5.33 and 99% sand capture results in a fines capture of 77%, as stated above.
• However, if Aurora froth went to ASB, the total capture rate would be lower, somewhere between 70 and 77%, assuming partial capture of froth fines.
• As shown in Appendix D, the fines contents of the tailings deposits vary significantly, depending on the deposit – cell, BAW, BBW, BB-MFT (as per BGC nomenclature).

3.3 Discussion

3.3.1 SFR Comparison

Figure 4 to Figure 6 plot the case records discussed above on graphs of tailings deposit SFR\textsubscript{D} versus tailings slurry SFR\textsubscript{S}, as follows:

• Figure 4  – flume tests and field trials
• Figure 5  – commercial scale case records, including the Winter 1989/90 MSLB trial
• Figure 6  – all case records

Superimposed on each plot are lines corresponding to 25%, 50%, 67% and 100% fines capture, assuming 100% sand capture.

While each datapoint needs to be considered on its own merits, as it is difficult to generalize observations on fines capture without doing so, the following comments can be made:

• Flume tests and field trials
  o Interpretation of overall fines capture is complicated by whether or not there is lower energy and/or a "ponded" segment in a closed cell or a cell run with a spillbox. Deposition in these circumstances increases fines capture, depending on the relative proportions of BAW and BBW deposition.
  o For a given slurry SFR, the closed ended trials (Total flume tests, OSLO spiking trials and 1993 spiking trials) resulted in higher fines capture than the open ended trials (Kupper, 1991).
  o Within a given group of trials, a test with a higher slurry SFR achieved a higher fines capture on a percentage basis. However, at higher slurry SFR\textsubscript{S} values, there are fewer fines in the slurry to capture in the first place, and the resulting beach SFR\textsubscript{D} values are also higher. Therefore, if the objective is to increase the fines content of the beach deposit (i.e. increase fines storage per unit volume of beach), lower SFR slurries should be used, even though on a percentage basis the fines capture will be lower.

• Commercial scale trials
  o The SWSS case record, despite the limitations of the dataset available, appears to indicate that a BAW dominated case record results in less fines capture than a case record with BBW.
  o The Winter 1989/90 trial at MSLB, which included containment and a relatively long pond upslope of the spillbox during operations, resulted in similar overall fines captures at the other commercial scale case records considered.
  o All of the commercial case records that involved large deep ponds with significant amounts of BBW have fines captures in the order of 60 to 70%, significantly higher than the perceived value of about 40%.
Achieved SFR / fines content of beach
  o Most of the case records with BBW zones and high fines capture had similar overall average fines contents (or SFR\(_D\) values) for the tailings deposit as a whole (i.e. cell, BAW and BBW combined), as follows:
    ▪ Winter 1989/90 trial – 13% (SFR\(_D\) = 6.7)
    ▪ Suncor Tar Island Pond – 8% (SFR\(_D\) = 11.7)
    ▪ Syncrude 1\(^{st}\) 1,000 MT Ore – 13% (SFR\(_D\) = 6.6)
    ▪ MRM ETF – 13.3% (SFR\(_D\) = 6.5)
    ▪ Horizon ETF – 13.9% (SFR\(_D\) = 6.2)
    ▪ ASB – 15.8% (SFR\(_D\) = 5.3)
  o The lower overall average tailings deposit fines content of 8% for the Suncor case record, compared to the other case record values of 13 to 16%, reflects the lower slurry fines content for this case record (i.e. 11.9% versus 18 to 22% for the other case records).\(^3\)
  o In order to achieve beach SFR values in the vicinity of 6 or less (considered necessary to provide sufficient fines storage on a total mass per unit volume of beach basis), the case records indicate that BBW deposition is required.

3.3.2 Application of Fines Capture Data

Generalizing fines capture data can be considered on two separate levels, if one considers the relationship between fines capture and slurry SFR, as presented in Figure 7, and the relationship between beach fines content and slurry SFR, as presented in Figure 8. In both of these figures, labels have been included next to data points for flume tests and field trials, to indicate the average tailings slurry solids content for each test or trial.

**Fines capture for a given beach type.** The Total, OSLO, and Küpper trials reveal trends between fines capture and slurry SFR. As can be seen in Figure 7, the fines capture increases as the slurry SFR increases. However, in broad terms, there is no consistent correlation with fines capture and solids content of the slurry, as might be expected from both the pore capture model and BARR/Deltares testing of segregation. However, for the Total flume tests, for example, this is further complicated by the combination of BAW and BBW deposition as lumped into an overall capture for a given test.

**Fines capture for commercial scale operations.** The commercial scale operations tend to cluster around a slurry SFR of 4 reflecting as-reported fines content averages from different leases. The variation in global fines captures at about the same SFR reflect different operational controls, and other factors discussed elsewhere in this report.

The use of fines capture, especially when considering operational scenarios such as spiking, also needs to consider the net achieved fines storage. The tests indicate that for a given depositional technique that fines capture can drop for lower slurry SFR. However, the total fines storage may go up, but requires a separate calculation for tailings planning purposes. This can be seen in Figure 6 for the Küpper trials where the beach SFR is plotted against the slurry SFR. It can be seen that, as the slurry SFR is lowered, the beach SFR is also lowered, although the percent fines captures have decreased. This is also shown in Figure 8, but in terms of beach fines content; as the slurry SFR decreases, the fines content of the resulting beach increases.

\(^3\) This difference may reflect different measurement methods for fines and/or differences in ore bodies. It is understood that this is under consideration by COSIA.
The higher fines capture, for commercial scale operations, all at about the same SFR, indicate the importance of the relative scale of pond capture of fines in BBW units as compared to BAW only deposits. Fines captures are the lowest in open ended beaches reported as Kupper trials and highest for the very effective fines capture of the ASB. Fines captures in contained beaches at a commercial scale, the Winter 89/90 trial are higher than the closed ended Total or OSLO trials with smaller "ponds".

**Fines capture for NE quadrant of MRM ETF.** Co-disposal (BAW + BBW) in the NE quadrant of Shell's MRM ETF (separate TT and TSRU discharge as well as intermittent CST line discharge having about 60% solids) achieved 65% fines capture, based on one of Shell's 2012 IOSTC papers. This MRM type co-disposal appears to be more effective at fines capture than could be inferred from co-mixing (i.e. spiking) trials at the same equivalent slurry SFR (see Figure 7 and Figure 8).

### 3.3.3 Three Main Commercial Case Records for this Study

Table 3 presents a comparison of various operational factors for the three main case records forming the scope of the current study, namely the MRM ETF, the Horizon Mine ETF and ASB. Accounting for Aurora froth being directed elsewhere, the ASB and the MRM ETF have similar overall fines captures in the order of 70%. The Horizon Mine ETF, which is a much younger facility has a lower overall fines capture of about 60%.

As shown in Table 3, each case record has a combination of operational factors and features that, together, contribute to the high fines captures observed. There are also both similarities and differences between three case records, but the net effect appears to result in relatively similar fines captures at the MRM ETF and ASB, and somewhat lower fines captures in the less mature Horizon ETF. For example, slurry flow rates at MRM are lower than at either Horizon or Aurora, but slurry densities at Horizon are lower than at either MRM or Aurora. Discharge into the MRM ETF and ASB is from all sides, whereas discharge at the Horizon ETF is from one side only (towards the natural hillside).

As described in Appendices B, C and D, a key observation that can be made from the flow rate and density data provided for this study is that the amount of time that the tailings lines are on flush is significant. At all three mines, typically about 10 to 20% of the data indicates that flow rates less than 1100 kg/m$^3$ for the coarse or whole tailings lines have, and are pumping essentially just water.
4.0 DEPOSITIONAL ENVIRONMENT CASE RECORDS

4.1 Introduction

In this section, the fines captures are assessed based on the depositional environment that created each deposit. The previous section analysed fines capture on a global basis by considering the total amount of fines discharged onto a certain facility minus the fines that formed MFT and/or reported out of the facility. The global method is a more accurate method of determining total fines capture and it is relatively simple to implement. It is an approach that provides a measure of the global amount of fines in a facility but it does not specify where the fines are located or how they got there. However, being a factual description of the overall fines capture, it does not provide guidance for the possible changes that could be made to improve fines capture except by inference.

The approach taken in this section is to look into the fines located in the various areas of the facility and the physical mechanisms that could explain how these fines reported to each location. The implementation of this method requires representative sampling and testing of the material deposited in each area of the facility and, therefore, is more onerous since the tailings deposits have more variability than the MFT column. Another difficulty of this approach is that the current understanding of the physical mechanisms is limited – for some depositional environments more than others. This approach was pursued to help shed some light on the physical mechanisms that contribute the most to fines capture and the aspects of the construction and operation of the facilities that could be changed if one intends to maximize fines capture.

4.2 Fines Capture Mechanisms

4.2.1 Introduction

Fines capture in a tailings deposit is a function of the physical mechanisms associated with depositional environment that led to the formation of the tailings deposit. This section will explore the impact of the depositional environment on fines capture for the three main case histories discussed in the previous section in terms of global fines capture.

For the purpose of discussing fines capture in tailings deposits, the discharge and deposition of tailings into an oil sands tailings facility will be divided into the following general regions:

1. Pipeline discharge
2. Subaerial deposits
   a. Beach above water (BAW)
   b. Controlled beach (CB)
   c. Compacted cell (CC)
3. Subaqueous deposits
   a. Proximal – Beach below water (BBW)
   b. Distal – Pond centre (PC)

The physical mechanisms are different in each of these areas, so for simplicity, each area will be discussed separately. However, it is noted that the variables affecting these areas are, in reality, interconnected as these areas are contiguous along the flow path and, thus, the outflow of one area is often the inflow to the next one. Each of the subsections below discusses the mechanisms potentially associated with tailings discharge and deposition in each of these areas and the issues related to fines capture.
4.2.2 Pipeline Discharge

The characteristics of the slurry, the flow parameters and the discharge method are important to determining the depositional environment, which in turn affects the final characteristics (and properties) of the resulting tailings deposit.

The flow parameters, which include flow rate, flow velocity, density of the slurry, solids concentration and particle size of the solid fraction, determine the energy of the flow that feeds the tailings deposit, a significant factor in defining the depositional environment and the properties of the tailings deposit such as beach angle, beach density and fines capture. The energy of the flow can be represented by the Froude number, which is the ratio between inertial and gravitational forces. The tailings deposit is formed as this energy is dissipated along the length of the flow path.

The discharge method can be (i) single point discharge, which is the method used in the three main commercial case histories analyzed in this section of the report, or (ii) spigots, where the flow is divided into several smaller discharge points, thus changing the energy of each flow stream that forms the tailings deposit. Single point discharge may or may not include an energy-reducer device (like a "spoon"). If the discharge point is located high relative to the beach, the jet will form a plunge pool, which acts as an energy dissipation device.

An important aspect to be mentioned is whether the slurry properties and the flow parameters will discharge a segregating or a non-segregating slurry. The triangular diagram proposed by Scott and Cymerman (1984) helps establish a boundary between notionally segregating and non-segregating behaviours; however, the higher the energy of the flow (thus the "shear"), the greater its ability to promote segregation, thus moving the segregating/non-segregating boundary. The triangular diagram does not account for flow parameters.

4.2.3 Subaerial Deposits

4.2.3.1 Beach Above Water (BAW)

The tailings slurry discharged from the pipelines will typically form subaerial deposits before forming subaqueous deposits. The subaerial deposits formed by free discharge of tailings slurry along the perimeter of a tailings facility are commonly called beach above water (BAW) in the oil sands industry. The formation of BAW and the flow on the beach have similar patterns and mechanisms as alluvial fans in nature. The deposit tends to form a cone with the apex at the discharge point. Flows tend to meander across the deposit surface typically in more than one shallow channel as well as some areas of surface flow. The flow interacts with the erodible bed by one affecting the other. The flow affects the bed by eroding or depositing material. The particles move and get organized into morphological elements called bedforms. The bed affects the flow conditions by deforming the flow lines and by imposing resistance to the flow. The complex interaction between the flow and the erodible bed affects both the characteristics of the tailings deposit (BAW) that is formed, and the properties of the flow that feeds the next part of the flow path (the subaqueous deposit).

Several types of bedforms can be formed, depending on the flow conditions. Bedforms include ripples, dunes, upper stage plane beds, anti-dunes and chute-and-pools. Each of these bedforms will have different characteristics and geotechnical behaviour (Küpper, 1991). Bedform phase diagrams are typically used to describe the typical bedforms for the various hydraulic regimes. Some bedforms might entrap more fines than others but fines capture tends to be relatively low in typical BAW deposits, as confirmed by the analyses of the case histories described below. Long beaches might have a somewhat higher fines entrapment due to the
lower energy levels. Bedforms that are likely to entrap more fines are also bedforms likely to have poorer geotechnical behaviour. Since the design of most tailings containment facilities in the oil sands counts on relatively good geotechnical performance of BAW, significant fines capture in BAW would be detrimental to the overall performance of the containment structure.

Bedforms can change along the flow path down the beach, as the energy dissipates. Consequently beach characteristics including beach slope, density, gradation and fines capture can vary with distance from the discharge point. The analyses of the case histories did indicate changing characteristics along the flow path, with lower part of the BAW (lower energy level) entrapping more fines than upper part of the beach, as expected.

The flow at the downstream end of a BAW deposit is the flow that creates the subaqueous (BBW) deposit and thus affects the properties of this deposit. Therefore, even if the BAW itself may not be of significance for fines capture, its flow conditions are relevant to the nature of the BBW deposit.

As described in Küpper (1991), in some cases, variations in slurry parameters due to changes at the plant site (increase in flow rate, reduction in solids content, increase in fines content) can cause the flow on the beach to channelize. In the channels, the fines capture is likely even lower. Most importantly, more of the solids are carried directly to the upper part of the BBW, affecting the depositional mechanisms in this deposit.

### 4.2.3.2 Controlled Beach / Contained Beach (CB)

Controlled beaches are similar to BAW; however, small dykes or windrows constrain the flow in a certain direction and within a certain width, thus changing the hydraulic regime. The downstream end of a controlled beach is usually open-ended, while a contained beach is closed-ended with a small dyke and an overflow system. Controlled/contained beaches tend to be longer and, if so, they might have a higher fines entrapment. Moreover, the overflow system may be used to enhance fines capture to some degree.

### 4.2.3.3 Compacted Cell (CC)

Compacted cells have a similar configuration to controlled beaches but the material placement is aided by mechanical spreading and compaction by dozers on tracks. In this case, natural bedforms are not allowed to develop due to dozer traffic and constant re-working of the materials so the structure of the deposit will differ from BAW and CB. The density of the deposit is higher due to mechanical compaction and fines capture is affected by the overflow system (“spillboxes”) and by the dozer work.

### 4.2.4 Subaqueous Deposits

#### 4.2.4.1 Proximal – Beach Below Water (BBW)

Once the flow over BAW enters the pond, there is a sudden loss of energy due to the rapid reduction in velocity. The loss of energy leads to deposition of the larger particles and the formation of a relatively steep slope that is termed Beach Below Water (BBW) in the oil sands industry. Several mechanisms are at play in the BBW depositional environment including:

- Sedimentation as the particles settle out of suspension as the flow enters the pond and suffers a sudden loss of energy.
• Small and large scale slope instabilities, which occur more readily when there is fast aggradation of the upper part of the slope, waves and/or a quick reduction in pond level.
• Turbidity currents which are formed due to the difference in density between the sediment laden flow and the pond water. This is discussed in more detail below.

Slope instability can include small, relatively surficial mechanisms, when a top set aggrading deposit slides down the steep BBW slope. This mechanism can lead to the failed material being spread along the slope as the movement of the failed mass loses energy due to the drag of the pond fluid or it can lead to the formation of a turbidity current.

Deep-seated instability of the BBW slope can also occur. In this case, the failed mass tends to form a bulge at the toe of the slope. This type of movement is expected to entrap MFT as the failed mass moves towards the bottom of the slope. Some examples of this mechanism were analyzed below with the case history data.

Turbidity currents are generated by the difference in density between the pond fluid and the moving current, which typically has a higher density than the pond fluid due to the suspended particles. Depending on the balance between potential energy and turbulent energy, turbidity currents may be depositing currents that form a deposit, or eroding currents that remove material from the bed, or "auto-suspension" currents that neither deposit nor remove material from the bed. Therefore, turbidity currents can affect the BBW deposit as they flow down the slope.

In a typical oil sands pond, the physics of turbidity currents is complicated by the fact that the pond fluid density is high and increases with depth. In this case, a turbidity current may flow along the bed for a while but it may insert itself into the MFT column at a particular elevation given the available energy and the density difference between the turbidity current and the MFT.

4.2.4.2 Distal – Pond Centre (PC)

The distal subaqueous deposit is considered to be the relatively flat zone beyond the toe of the BBW slope in the centre of the pond. It is termed Pond Centre (PC) for the purposes of this report. The Pond Centre (PC) deposit is formed by flow that continues beyond the toe of the steep BBW slope (where most of the energy dissipation and main coarser particle sedimentation occur), by material carried beyond the toe of the BBW slope by failure of this slope and by turbidity currents. Turbidity currents can be formed by the continuous flow coming from the BAW or by plug flows generated by BBW slope failures. As discussed above, turbidity currents could run along the pond bottom or insert themselves at a certain elevation within the MFT column depending on its potential/turbulent energy and relative density between the turbidity current and the MFT. Either way, these mechanisms are expected to entrain or entrap some MFT.

The turbulent kinetic energy of a turbidity current is partly dissipated by entraining ambient fluid through the interface between the turbidity current and the pond fluid. The entrainment of ambient fluid increases for steeper slopes. This mechanism would enhance fines capture.

When a turbidity current inserts itself in the MFT column, it loses its remaining energy and stops. Some coarser particles may settle down through the MFT to the pond bottom with time. Given the density and the viscosity of MFT, other particles may just sit there or settle some distance but never make it to the pond bottom. The available data on MFT do indicate an increased "sand" (>44 microns fraction) content near the bottom of the MFT column. The presence of >44 microns material at this location could also be due to wind blown particles that
"rain down" through the pond and eventually stop near the bottom of the MFT column; however, this phenomenon alone probably could not explain the amount of coarser particles encountered at the bottom of the MFT column. If a turbidity current takes a significant amount of >44 micron material to a particular location within the MFT column, this material may move to the bottom of the pond as a mass (not individual particles) in a manner that entraps MFT.

Turbidity currents created by a plug flow, such as a slope failure, form a "head" or "nose", which is the leading part of the flow. The head is typically thicker than the shallower flow behind, has a lower velocity and the foremost point of the flow typically occurs at some height above the bottom surface where the turbidity current runs. In this case, the advance of the turbidity current is controlled by the densimetric Froud number at the head. This type of flow and the formation of a head are important to fines capture because the head tends to be where most of the entrainment of ambient fluid (MFT in this case) occurs. This entrainment increases for steeper slopes.

Given the mechanisms discussed above, PC deposits are expected to have larger fines captures that the other depositional environments.

4.3 Case Records

4.3.1 Assessment Methodology

The general methodology used to define the depositional environments for the various sampling locations is described here. Survey and bathymetry data were used to produce surfaces of the tailings facility at various dates depending of the data available. Cross sections of the tailings facility were then obtained through the sampling locations showing the configuration of the deposit at each bathymetry date. Borehole locations and sampling depths for the various investigation programs were superimposed on these cross sections. When possible, each sample was then classified according to its location on these cross sections, relative to the depositional environments at the time of formation of the deposit at that specific location.

The depositional environments typically considered were BAW, BBW and Pond Centre (PC), as per the descriptions in Section 4.2. Recognizing the differences that can exist along the flow path in BAW and in BBW, where applicable, a further distinction was made between the upper part (U) and the lower part (L) of each deposit. This created the following classifications: upper BAW, lower BAW, upper BBW and lower BBW. In some cases, when failure of the BBW slope was evident from the slope configuration indicated by the bathymetry, the deposit at the toe of the BBW slope was classified as "failed BBW". Furthermore, to evaluate the potential effect of the rate of deposition on fines capture, deposits were also classified as either "high rate" (HR) of deposition, when the difference in elevation at a particular location changed by more than approximately 5 m in a year, or "low rate" (LR) of deposition.

Each depositional environment was analyzed both in terms of the fines content measured for each sample and in terms of the Fines Capture Effectiveness Ratio (FCER), the fines content of the sample divided by the fines content in the slurry, as discussed in Section 2.1.2.

In all cases, the data (fines content or FCER) were plotted against estimated depth at the time of deposition as a manner of indicating both the distance from the discharge point and the hydraulic condition of the deposition (impact of pond depth and hydraulic drag). Since the exact date of deposition of the material collected by a given sample is not known, the depth at the time of deposition of a sample is estimated using the pond level at the date of the next bathymetric survey. Consequently, there is an error that could be as much as 5 to 10 m on the
estimated depth at the time of deposition. This error is not relevant given the variabilities inherent in the system being analyzed and the importance of this particular variable.

Fines capture was studied by considering only the fraction finer than 44 microns. Plotting the percentage of fines less than 2 microns (or MBI in the case of the Horizon ETF) against the percentage of fines less than 44 microns for the available beach samples indicates a relatively linear relationship with a relatively small scatter (see Figures B.43, C.57 and D.32 in Appendices B, C and D, respectively). Therefore, there is no variability in fines capture across the range of particle sizes contained in the beach deposits, and an assessment of the mechanisms that capture the <44 micron fraction is also valid for the smaller fractions.

4.3.2 Shell’s Muskeg River Mine ETF

Shell’s Muskeg River Mine (MRM) External Tailings Facility (ETF), its operation and its associated data set have been described in Section 3.2.3.4 and Appendix B. The sections developed for this work and the plan view showing the locations of these sections are presented in Appendix B.

Line 1 discharged tailings on the east and south sides of the MRM ETF, whereas Line 2 discharged along the north and west sides. An internal cross dyke was built that initially separated the NE corner of the facility from the rest of the facility. The TT and the TSRU lines were preferentially discharged at the NE corner, which has also received coarse tailings from Line 1. Coarse tailings included Coarse Sand Tailings (CST) and Whole Tailings (WT), which were produced approximately 30% of the time whenever a component of the extraction plant was on bypass. When WT were being produced, neither CST nor TT were being produced by the plant. Analyzing the plots of solids content and grain size versus time, it can be concluded that, given the variability of the system, there is no clear distinction between properties of the slurry when CST was being produced versus when WT was being produced. Consequently, Lines 1 and 2 can be considered to produce a single type of slurry with a certain range of properties and associated variability:

- Flow rate \( Q = 3000 \) to \( 7000 \) m\(^3\)/h
- Slurry solids content by weight \( C_w = 40 \) to \( 60\% \)
- %F<44microns = 6 to 18%

The TT and the TSRU lines appear to have similar hydraulic parameters and similar slurry properties; therefore, for this study, they were considered to be the same system with the following parameters:

- Flow rate \( Q = 1000 \) to \( 1500 \) m\(^3\)/h
- Slurry solids content by weight \( C_w = 15 \) to \( 18\% \)
- %F<44microns = 40 to 80%
Given the general location of the tailings lines and the significant difference in parameters between Line 1 / Line 2 and the TT/TSRU lines, an additional classification was used for the MRM ETF, as follows:

- Beach sampling locations on the west, south and southeast portions of the main facility were classified as being deposited by Line 1 / Line 2 (referred to as L1/L2 on subsequent figures). The contours produced with data from each bathymetry were analyzed in detail to exclude sampling locations that were considered to be affected by TT/TSRU tailings from the NE corner overflowing the internal dyke when this started to occur.

- Beach sampling locations in the NE quadrant had their depositional environments classified considering the presence of the internal dyke (referred to as TTTS on subsequent figures). The NE beach that developed over time resulted from co-disposal of TT, TSRU and CST/WT. In the initial years, BAW, BBW and PC environments were used. As the toe of the BBW started getting closer to the internal dyke, an additional classification was added – “near dyke” – to take into consideration the situation of deposits formed by materials that were pushed against the internal dyke.

A series of figures illustrating the results of the beach classification by depositional environment for the MRM ETF case record is provided in Appendix E (Figures E.1 to E.14).

Figure E.7 shows the fines content in the BBW beaches in the NE quadrant of the pond, which received TT, TSRU and some CST/WT. Figure E.6 shows the fines content in the BBW beaches in the rest of the facility (deposited by Lines L1 and L2). Comparing the two figures, it can be seen that, at similar depths at time of deposition, much higher fines contents are present in the NE quadrant BBW than in the beaches formed by Lines 1 and 2. The pattern shown in Figure E.6 (i.e. higher fines contents with depth) is what one would expect, given the theory explained above, as the fines content increases with depth of deposition. This pattern is not evident in Figure E.7, and is possibly due to the co-disposal of materials being discharged into the NE quadrant with significantly different operational parameters (e.g. slurry solids content, slurry fines content, slurry flow rate).

Figure E.13 and Figure E.14 show the FCER for the BBW beaches in the NE quadrant of the pond and the beaches formed by CST Lines 1 and 2, respectively. The FCER values have been calculated based on the following representative average slurry fines contents:

- Beaches formed by CST Lines 1 and 2 – varied over time, and ranged from 6% to 15%.
- NE Beach (TT, TSRU and some CST) – 33.5%

The fines content of 33.5% assumed for the tailings slurry discharged into the NE Beach area is based on the overall average combined slurry fines content for the TT, TSRU and CST that was discharged into the NE Beach area from 2008 to 2011 (Esposito and Nik, 2012).

The FCER for BBW in the NE quadrant and the Upper BBW from Lines 1 and 2 are relatively similar; however the FCER values are higher in the Lower BBW from Lines 1 and 2. This indicates that Lower BBW formed from Lines 1 and 2 has a higher fines capture effectiveness, and the value of discharging into a deep pond. This argument is supported by Figure E.10, which shows that pond centre beaches resulting from Lines 1 and 2 have the highest FCER values, and are much higher than the FCER for pond centre beaches in the NE quadrant, although the amount of data is limited.
Similar patterns are observed in BAW, even though the amount of data is not sufficient to be statistically representative.

The figures do not appear to demonstrate any meaningful trends when data points are considered in terms of high rate of deposition versus low rate of deposition.

### 4.3.3 Canadian Natural's Horizon ETF

Canadian Natural's Horizon External Tailings Facility (ETF), its operation and its associated data sets have been described in Section 3.2.3.5 and Appendix C. The sections developed for this work and the plan view showing the locations of these sections are presented in Appendix C. This facility differs from the others for two reasons:

- It is a relatively young pond.
- It is a "side hill" facility with a three-sided dyke impounding fluid against the natural ground that rises away from the containment dyke. This configuration minimizes the Pond Centre (PC) depositional environment.

Another difference is the long BAW deposits that were created in this facility. The containment dyke (Dyke 10) is being constructed entirely of overburden and interburden, with the tailings being discharged inside the dyke creating very long subaerial beaches. Given this, the BAW sample results were also plotted against distance from the dyke as a more accurate manner of depicting distance along the flow path.

A series of figures illustrating the results of the beach classification by depositional environment for the Horizon ETF case record is provided in Appendix E (Figures E.15 to E.28).

Figures E.15 to E.17 plot fines content data in terms of the distance from Dyke 10. They appear to indicate a small increase in fines content with distance from the discharge point as expected.

Figures E.18 to E.21 plot fines content data in terms of depth at time of deposition. The Horizon ETF is less than 15 m deep, has only been operated for a few years, does not have complete perimeter discharge, and is discharging against a natural hillside. All of these factors affect the nature of the data.

Figures E.22 to E.28 plot the same data in terms of FCER. These values have been calculated assuming an average fines content for the slurry of 21% for the entire period from 2009 to 2012.

The FCER for the Canadian Natural's Horizon ETF for all samples averages in the order of 0.6. The results indicate that, on average, moving from BAW to BBW to PC, the depositional environments are increasingly more efficient at capturing fines. As expected, the lower part of the BAW has a lower energy regime; thus, it is more efficient at capturing fines. A similar fact is observed for BBW, although in this case the difference is not as marked: Upper BBW has a slightly lower average FCER than Lower BBW.
4.3.4 Syncrude's Aurora Settling Basin

Actual bathymetry data for Syncrude’s Aurora Settling Basin (ASB) was not provided, so the analyses were limited to three specific cross-sections prepared and plotted by others, as described in Appendix D. A detailed analysis of the bathymetry results to define the various depositional environments was also not possible. Syncrude’s ASB, its operation and its associated data sets have been described in Section 3.2.3.6 and Appendix D. The sections used for this work and the plan view showing the locations of these sections are presented in Appendix D.

A series of figures illustrating the results of the beach classification by depositional environment for the MRM ETF case record is provided in Appendix E (Figures E.29 to E.39). FCER values have been calculated assuming an average fines content for the slurry of 23% for Cell 53 and 13% for Cells 58 and 60, both applied to the entire time period from start-up to 2009.

Fines content increases with depth of the material at the time of deposition (Figure E.29) and tends to be higher for BBW than for BAW and the highest for PC (Figure E.30). Failed BBW has fines contents on the high end of the BBW range and almost as high as PC, indicating that, as expected, this mechanism leads to entrapment of MFT as the failed mass moves towards the bottom of the slope.

A more detailed analysis of the BAW depositional environment is shown in Figure E.32. As expected, upper BAW tends to have lower fines content than lower BAW. This trend reflects not only the natural sorting (larger particles deposited sooner than smaller particles) but also the dissipation of energy that has already happened by the time the flow is in the lower BAW area. This figure also indicates that in BAW a lower rate of deposition may promote higher fines capture.

Figure E.33 shows the analysis of the BBW area. Upper BBW tends to have a lower fines content than lower BBW, as expected. The trend for high and low rate of deposition is less clear in this case.

4.4 Case Records Combined

Data for the three major commercial case records have been combined in a series of summary plots (Figure 9 to Figure 18). Table 4 provides a summary of the fines content and FCER by depositional environment for each case record.

Referring to Figure 10 and Table 4, it can be seen that, in general terms, the fines content of Horizon beaches are somewhat lower than those observed at MRM or ASB, reflecting the fact that it is a less mature pond. It is noted that both MRM and ASB have ponds that are in the order of 45 m deep whereas Horizon is only 15 m deep. These results indicate that mature, deeper ponds maximize fines capture. The data in Figure 10 have minimum fines contents of 10% and increasing with depth (up to 30%) for deposition depths of 30 m and greater; fines contents less than 10% are only present at shallower deposition depths.

A breakdown of fines content for BAW, BBW and PC are provided in Figure 11. While fines contents for BBW can be similar to those for BAW, the range in fines contents for BBW is significantly higher. Fines contents in the upper BBW are relatively similar to those in the BAW, indicating similar depositional environments. Fines contents above about 10% and up to about 70% in the BBW and PC reflect different depositional environments. Although there is limited data, fines contents in PC range from about 30% to 60%, reflecting the highest effectiveness of
fines capture in these facilities. Figure 12 and Figure 13 provide a breakdown of BAW versus BBW, supporting the conclusions from Figure 11. Discrimination between high and low rates of deposition doesn't appear to result in any meaningful trends. Excluding some high fines content datapoints at lower depths of deposition, which are from the NE quadrant of the MRM ETF case record, Upper BBW has lower fines contents than Lower BBW.

Figure 14 to Figure 18 present the same data in terms of FCER. Similar trends are indicated. BBW is more effective that BAW, and PC is typically more effective than BBW. It is expected that the best opportunities for fines capture enhancement in conventional tailings facilities are in the subaqueous deposits. Obtaining a better understanding of the subaqueous mechanisms, and the potential degree of control of these mechanisms, would be of value.

Enhancing fines capture in typical BAW should not be considered for several reasons:

- The subaerial depositional environment creates bedforms that are not efficient in capturing fines. Fines content can vary depending on the bedform created but they are all typically low.
- Bedforms that could increase fines capture are also detrimental to the geotechnical properties of the deposit.
- The design of tailings facilities often count on adequate geotechnical properties of the BAW for stability of the containment structures.
- In mature tailings facilities, the overall volume of BAW tends to be insignificant relative to the volume of subaqueous deposits; therefore, an effort to increase the fines content of BAW would not have a significant impact of the overall fines capture for a facility.

As shown in Table 4, the beaches deposited by coarse tailings Lines 1 and 2 at the MRM ETF were by far the most effective at fines capture. Figure 19 provides a schematic cross-section through the north end of the MRM ETF (not to scale) illustrating some of the lower energy depositional environments that were present in this facility and contributed to the high fines captures observed, including:

- During initial deposition in the NE quadrant:
  - Pond centre deposits
  - "Bathtub" effects due to the presence of the Cross Dyke
- Once the Cross Dyke was no longer raised, and tailings deposited in the NE quadrant could flow into the Main Pond:
  - Flow down a long BAW deposit plus weir effects
  - Depositing against a deep pond
  - Run-out further limited by inter-fingering with flow in the opposite direction

Use of longer controlled/contained beaches in toe berms or buttress areas may provide an opportunity for fines entrapment without compromising the stability of the containment structures or fines capture mechanisms that occur in the subaqueous deposits of deeper mature ponds.
5.0 AVAILABLE MODELS FOR PREDICTING FINES CAPTURE

5.1 Marsh Pore Capture Model

A model for fines pore capture was originally developed by Mr. C. Marsh working at Syncrude. The model is based on the following premises:

1. All sand (mineral solids > 44 microns) in a tailings pipeline settles out as a sand skeleton or, in other words, exhibits a sand void ratio. No sand reports to MFT (i.e. in the context of Equation 11 presented earlier, sand capture is 100%).
2. Fines (mineral solids ≤ 44 microns) and water form a slurry, and the voids in the sand skeleton trap a proportion of this slurry as determined by the sand skeleton porosity.
3. The remainder of the non-trapped fines slurry reports to the top of the MFT as thin fine tailings (TFT) which thickens to MFT.

This simple model can be explored as follows.

1. Conventional void ratio, $e_{geo}$, is defined as the volume of voids (or water in a completely saturated soil) to the total volume of mineral solids (sand plus fines).
2. Following a similar logic, sand void ratio, $e_{sand}$, can be defined as the volume of voids (water plus fines) to the volume of sand; i.e. $e_{sand}$ is the void ratio of the sand skeleton.
3. Therefore, assuming the same specific gravity for both the sand and fine fractions, it can be established that:

$$e_{sand} = e_{geo} + \frac{(e_{geo} + 1)}{SFR}$$  \[18\]

where:
SFR is the sand to fines ratio of the beach deposit.

In order to establish the range of possible sand void ratios, reasonable dry density and fines content values for cell sand, BAW, and BBW are provided in Table 5. The calculations for the estimates of $e_{sand}$ included in Table 5 assume that both the sand and fines fraction have a specific gravity of 2.65.

The main variables in a pore capture model are:

- Fines content of slurry in pipeline, taken here as ranging from 15% to 22%.
- Slurry density, usually denoted as "Spec.Grav." in extraction terminology, with the same number being a bulk density in geotechnical terminology. A range of 1.35 to 1.55 t/m$^3$ has been used here.
- The sand void ratio, for which sensitivity studies suggests a reasonable range to consider is 0.7, 1.0 and 1.13, as discussed above.

Figure 20 plots the predicted fines captures versus slurry density and presents the results for the three sand void ratios selected. For each sand void ratio grouping, the slurry fines contents are indicated as the nested lines.
Several points emerge:

1. Fines capture does not exceed about 45% unless slurry densities are higher than usual.
2. Fines capture in cells or relatively dense beaches with low sand void ratios will be lower.
3. Loose beaches will capture more slurry, and therefore have a higher fines capture.
4. The predicted deposit dry densities are indicated in Figure 20, which are similar to premises given in Table 5 for the cell case \((e_{\text{sand}} = 0.7)\), close for the designated BAW case \((e_{\text{sand}} = 1.0)\), but low for the BBW case \((e_{\text{sand}} = 1.13)\) premises in Table 5.
5. However the presumed fines contents that are predicted within the model are lower than the premises in Table 5.

The fit between assumptions and predictions is not great; nevertheless, the analysis indicates an inability for the pore capture model to predict fines contents of some tailings types, and therefore fines capture. This certainly suggests that there are other mechanisms at work.

### 5.2 BARR/Deltares Model

BARR and Deltares, under direct contract to Canadian Natural, have developed a model for predicting the depositional behaviour of non-segregating tailings (NST) to be produced at Canadian Natural's Horizon Mine. Therefore, the following report was provided by Canadian Natural for the current beach fines capture study: "Non-Segregating Tailings (NST) Deposition Study, Part 2"; report dated May 2012, and prepared by BARR and Deltares. No details of the inner workings of the model were provided.

The BARR/Deltares (2012) report documents the results of a number of shear cell tests and flume tests completed on various tailings mixtures. The focus of the testing, and the subsequent model development, was to understand the behaviour of NST that will be produced at the Horizon Mine (using CO\(_2\) as a flocculant). Therefore, the BARR/Deltares model is not directly relevant to the current beach fines capture study of segregating tailings streams. However, the testing that was completed in support of the model development is of some relevance as the testing was used to determine static and dynamic segregation boundaries.

The tailings mixtures used for the BARR/Deltares tests consisted of varying mixtures of sand and thickened tailings (TT). The sand was Pleistocene fluvial sand (Pfs) rather than tailings beach sand from the Horizon ETF, but was considered to be relatively similar in composition. The TT was produced at SGS's test facility using flotation tailings. For eight of the flume tests, flotation tailings from Syncrude's Aurora mine were used, and for two of the flume tests, flotation tailings from the Horizon mine were used.

Based on the shear cell test results, the report presented a plot of sand to fines ratio (SFR) versus fines over fines plus water (FOFW) as shown in Figure 21. Static segregation boundaries for tailings with and without the addition of CO\(_2\) are indicated. In addition, the plot indicates that the dynamic segregation boundary is located to the right of the static boundary, with the location of the dynamic boundary being dependent on the shear rate imposed by the dynamic conditions. The higher the shear rate, the further the dynamic segregation boundary moves to the right. Channelized or turbulent flow conditions that develop as the tailings are being discharged into a commercial scale tailings facility can lead to high shear conditions. Segregating tailings streams would be expected to fall to the left of the Static no CO\(_2\) boundary.
The BARR/Deltares report also introduced the terms "settled sand bed" and "gelled bed", and distinguished them as follows:

- **Settled sand bed** – sand that settles out of the tailings mixture and forms a sand skeleton, with the sand particles in contact with each other. When this happens, the BARR/Deltares report stated "it appears that the porosity of the sand in the bed is at its maximum" and that, for the specific shear cell sand bed samples that were tested, "all samples with varying FOFW and SFR are consistent with the maximum porosity of the [Pleistocene fluvial] sand at 44.2%". The report also stated that "shear tests that allowed sand segregation produce a settled sand bed that consistently produced SFRs that matched the maximum sand porosity for the flowing sand".

- **Gelled bed** – forms when sand that is settling in a shearing slurry flow results in a sand concentration near the bed that increases to the point that the slurry strengthens and slows down, causing the sand settling velocity to slow down. If the velocity becomes sufficiently low before the maximum porosity of a sand skeleton that has particles in contact with each other is reached, a gelled bed forms. The gelled bed has a significantly higher porosity than that of a settled sand bed because the sand particles are not in contact with each other in the gelled bed, and its behaviour is dominated by the characteristics of the strengthened carrier fluid, rather than grain to grain contact between sand particles, as is the case for a settled sand bed.

The BARR/Deltares report concluded that "for Weak NST that forms a settled sand bed, the SFR of that bed can be forecast knowing the SFR and FOFW of the slurry from which it formed, using the maximum sand porosity of 44.2%". This is essentially identical to the pore capture model, with the sand skeleton void ratio being determined from the assumed maximum porosity for the particular type of sand. On the other hand the report also concluded that "Strong NST produces a gel bed layer with very different properties than Weak NST".

The terms Weak NST and Strong NST were defined by BARR/Deltares as follows:

- Weak NST – material very close to the static segregation boundary
- Strong NST – material for which sand settles only when adequate shear is applied

The gelled bed concept, which "suspends" sand without grain to grain contact, may be the physical explanation of some or all of the fines capture mechanism in BBW sands at the pond bottom where higher solids content more viscous MFT is present. The much higher void ratio that must be inferred in attempting to apply the pore capture model to BBW is a mathematical consequence, but not the appropriate mechanism.

In terms of fines capture, the Barr/Deltares report concluded that, based on the shear test results, the following factors caused sand to settle more slowly and increased fines capture:

- Increasing FOFW (the report commented that "a FOFW greater than about 31% will always have slow settling or no settling")
- Increasing SFR
- Decreased shear rate
- Decreased shearing time
5.3 Sand Entrapment of MFT

It is clear that tailings sands report to the bottom of the pond where sand entrains and entraps MFT. The solids content of the MFT is typically not constant and the idea held by many that MFT is 100% fines and at a solids content of 30% is entirely misleading. The variation in total solids above 30 to 35% (44 micron solids) is usually due to sand (> 44 micron sizes), but can also be due to consolidation depending on the silt content. If the fines are dominated by clay (measured by MBI or 2 to 5 micron sizes), then typically the fines solids content (44 micron and also called FOFW) tends to be 35% solids or so with little or no true consolidation beyond that level for clay gel dominated mixes.

5.3.1 Sand "Raining"

One theory of sand distribution in the pond has held that wind blown sands are moved out over a pond surface and settle through the MFT. Analyses by Scott (1992) indicate that typical MFT is too viscous to support this argument.

5.3.2 Turbidity Currents

Turbidity currents are discussed earlier in Section 4.2.4.

5.3.3 Sand Erosion

As demonstrated in this report, see Section 3.3.3, the data suggest that there are periods of time which may amount to as much as 10 to 20% of the tailings discharge when the tailings lines are on water flush, discharging little or no tailings, but at pumping rates which approach full capacity. The duration of these events has not been quantified in this study, but it is reasonable to believe that erosion of previously placed beaches may occur during these time periods.

This erosion may result in a "slug" of sand reporting to the pond, and contributing to turbidity currents in one form or another. Occasionally, changes in the slurry properties due to changes in the extraction plant can result in an erosion gully forming, which subsequently routes sand directly to the pond until such time as the gully is infilled.

5.4 Fines Suffusion & Cake

Fines suffusion is a process in which fines are drawn into sand voids by high seepage gradients. For sand shell dykes such as Tar Island Pond, Shell MRM ETF, ASB, and Syncrude MLSB, it is usually found that the pond is perched above a lower phreatic surface in the shell. This lower phreatic surface results because the rate of seepage out of the sand shell is greater than the leakage out of the pond. This leakage or downwards flux results from fines being drawn into the beaches (suffusion) by the high gradients that develop at the pond bottom. In addition, these seepage forces consolidate the MFT creating a cake. As the shell continues to rise, and as the pond grows, the process continues.

This effect will contribute to the overall fines captures obtained for a conventional tailings pond, but will be less important for impermeable overburden structures, or shorter term trials.
5.5 Slurry Parameters

Theoretical considerations indicate that controls on the following slurry parameters can increase fines capture for BAW:

- Discharge flow rate, Q
- Specific flow rate (Q/W, where W = width of discharge area)
- Solids content / density
- Grain size distribution
- SFR / fines content, possibly clay content or FOFW
- Frequency of moving discharge point
- Energy dissipation

Table 6 and Table 7 summarize a range of tailings slurry and tailings deposit characteristics for the case records considered in this study. In general, these tables indicate the following:

- Flume tests and field trials (Table 6) – as the tailings slurry fines content increases, the fines capture decreases, but the fines content of the beaches increases
- Commercial scale ETFs (Table 7) – older, deeper ETFs with the largest BBW deposits have the highest fines captures, while BAW deposits have much lower fines captures.

Figure 22 attempts a correlation between fines capture and specific flow rate for the flume tests and field trials, for which the flow rate and width were available, and indicates the solids content of the slurry. No discernable pattern is noted.

It might be speculated that random variations in these parameters, rather than their absolute values, play a significant role in the nature and distribution of fines captured within the tailings deposits. If this is the case, and given the variations that must be expected as a result of extraction operations in a typical oil sands mine, attempting to predict essential elements such as fines capture or FCER based on theoretical models will never prove to be satisfactory.
6.0 LESSONS LEARNED AND POTENTIAL FINES CAPTURE ENHANCEMENT

6.1 Solids Content & Effects of Shear

An increase in solids content in the pipeline leads to an increase in fines capture, as predicted by both the pore capture and BARR/Deltares models. This is certainly the case within the non-segregating domain where fines capture approaches a fully efficient system. Previous discussion of Figure 7 (see Section 3.3.2) does, however, note that there is no consistent correlation with solids content apparent, as expected, for some trials and flume testing.

Oil sands tailings planning takes the view that there are either segregating or non-segregating tailings slurries. While this concept is broadly useful, it is simplistic, and the issue of shearing is at the heart of an improved understanding. In the early days of CT development, tests to establish a segregating versus non-segregating boundary used column tests, with no shear – referred to today as static tests. At the same time, tests on pumping CT established that flow had to be kept well into the turbulent range, or sand settled out in the flowing pipelines. That is to say, shearing at lower pumping rates caused segregation for slurries that were thought to be dry of the segregation / non-segregation boundary.

The results of the Syncrude CT commercial prototype development, see Pollock et al. (2000), showed that zonation of the CT occurred downstream of the single point discharge in the first year of operations. This was, to some extent, corrected in the second year of deposition with multi-point perimeter discharge. Observations of thickened tailings (TT) discharge at Syncrude trials indicated channelization of flow, and it is inferred that there was sufficient shear to result in some particle size segregation along the field scale flume.

The recent study by BARR/Deltares (2012) provides a test procedure with column settling tests wherein a concentric rotating bob provides a sheared annulus through which segregation effects can be investigated quantitatively. This work indicated that to obtain a truly non-segregating NST mix, the total solids content needed to approach or exceed the pumping limit.

The relevance of this work to conventional segregating slurries is as follows:

1. The higher the solids content, the less the segregation upon deposition.
2. Controlling shearing on deposition should reduce segregation.
3. Spiking a conventional tailings line with additional fines increases fines storage, on a total mass per unit volume of tailings deposit basis, but segregation will likely still occur, assuming the mix is pumpable and flowable like a fluid. (Eventually, at very high solids contents, mixes that are not pumpable would exhibit a soil like condition and segregation would be eliminated).

6.2 Potential Methods for Fines Capture Enhancement

Table 8 outlines a number of potential methods for enhancing fines capture.

6.3 Summary

Based on Figure 6, it can be seen that conventional tailings dams with subaqueous environments (BBW and PC) can deliver global fines captures of 70 to 77% as measured for Shell’s MRM ETF and Syncrude’s ASB, respectively. Historically, fines captures of 63% were reported for Suncor’s Tar Island Pond, and approximations for the first 1,000 Million tonnes of ore for Syncrude’s MLSB suggest a fines capture of 62%. Deeper ponds may increase fines
capture/fines capture efficiency. Cross dykes, such as the original in-pond dykes in the MRM ETF, may also assist.

For the same volume of tailings, one larger/deeper pond appears to be more favourable to fines capture than a number of smaller ponds since BBW and PC deposits have high fines capture (especially so when formed against higher solids content MFT columns).

At the other end of the fines capture range, subaerial environments (BAW) with long uncontained beaches lead to lower fines capture. For whole tailings with slurry SFR values typical of ore, fines captures of about 35-40% are achieved on long BAW. Trials and flume tests indicate that if a BAW segment is operated in a contained beach scenario, then the total fines capture – including the ponded component – increases, but does not approach the best commercial scale ponds.

Theoretical considerations indicate that controls on discharge flow rate, solids content, grain size distribution, and energy dissipation can increase fines capture for BAW. It might be speculated that random variations in these parameters play a significant role. However, BAW is typically required for dyke stability in most designs; thus, the BAW properties (e.g. strength, liquefaction potential, permeability) cannot be compromised by excessive fines capture.

A winter contained beach trial conducted by Syncrude is instructive as to the ability to enhance fines capture in a long cell up to 64%. This resulted from a combination of a rather steady discharge rate, no compaction, and BBW deposition in a mini-pond and sluice box at the far end of the scale. This range of fines capture has also been reported in contained beach equivalents for the Total flumes and Oslo trials.

For spiking considerations (see Figure 7 and Figure 8), it is important to note that directionally decreasing the slurry SFR lowers fines capture, but does increase the beach fines content for the same mode of deposition. Discharge of slurries with higher fines contents results in improved fines storage (that is increased fines content of beaches) but the fines capture on a percentage basis drops.

Co-disposal (BAW + BBW) in the NE quadrant of Shell's MRM ETF (separate TT and TSRU discharge as well as intermittent CST line discharge having about 60% solids) achieved 65% fines capture, based on one of Shell's 2012 IOSTC papers. This MRM type co-disposal appears to be more effective at fines capture than co-mixing (spiking).

While not studied, it can be speculated that pond chemistry, which in some cases may cause partial flocculation of clayey fines, may increase fines capture by affecting equivalent particle size.
7.0 REFERENCES


8.0 CLOSURE & LIMITATIONS

This report has been prepared for the exclusive use of COSIA for the specific application described within. Any use which a third party makes of this report, or any reliance on or decisions to be made based on it are the responsibility of such third parties. AMEC cannot accept responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report. This report has been prepared in accordance with accepted practices in the oil sands industry. No other warranty, expressed or implied, is made.

Respectfully submitted,

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Vice President

APEGA Permit to Practice No.: P-04546

Reviewed by:
Principal Geotechnical Engineer  
Senior Vice President
### Table 1. Fines Capture Observations for Küpper (1991) Tests 1, 2 and 4

<table>
<thead>
<tr>
<th>Test</th>
<th>Spigot</th>
<th>Solids Content</th>
<th>Fines Content</th>
<th>SFR&lt;sub&gt;S&lt;/sub&gt;</th>
<th>Fines Content</th>
<th>SFR&lt;sub&gt;D&lt;/sub&gt;</th>
<th>SFR Index (SFR&lt;sub&gt;S&lt;/sub&gt;/SFR&lt;sub&gt;D&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Spigot</td>
<td>Test</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test 1</td>
<td>Spigot 1</td>
<td>68.4%</td>
<td>6.2%</td>
<td>15.13</td>
<td>3.0%</td>
<td>32.11</td>
<td>47%</td>
</tr>
<tr>
<td></td>
<td>Spigot 2</td>
<td>65.8%</td>
<td>7.0%</td>
<td>13.29</td>
<td>2.5%</td>
<td>39.54</td>
<td>34%</td>
</tr>
<tr>
<td></td>
<td>Spigot 3</td>
<td>67.0%</td>
<td>6.4%</td>
<td>14.63</td>
<td>3.3%</td>
<td>29.11</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>Spigot 4</td>
<td>60.8%</td>
<td>7.4%</td>
<td>12.51</td>
<td>2.2%</td>
<td>43.85</td>
<td>29%</td>
</tr>
<tr>
<td></td>
<td>Spigots 1 to 4 combined</td>
<td>65.5%</td>
<td>6.7%</td>
<td>13.93</td>
<td>3.1%</td>
<td>31.13</td>
<td>45%</td>
</tr>
<tr>
<td></td>
<td>Spigot 5</td>
<td>59.0%</td>
<td>8.7%</td>
<td>10.49</td>
<td>3.6%</td>
<td>26.74</td>
<td>39%</td>
</tr>
<tr>
<td>Test 2</td>
<td>Spigot 1 &amp; 2</td>
<td>54.5%</td>
<td>20.6%</td>
<td>3.85</td>
<td>5.1%</td>
<td>18.46</td>
<td>21%</td>
</tr>
<tr>
<td></td>
<td>Spigot 3</td>
<td>55.1%</td>
<td>20.2%</td>
<td>3.95</td>
<td>5.9%</td>
<td>15.82</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>Spigot 5</td>
<td>59.2%</td>
<td>20.1%</td>
<td>3.98</td>
<td>4.3%</td>
<td>22.00</td>
<td>18%</td>
</tr>
<tr>
<td>Test 4</td>
<td>Spigot 1</td>
<td>34.8%</td>
<td>32.9%</td>
<td>2.04</td>
<td>7.0%</td>
<td>13.22</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>Spigot 2</td>
<td>37.3%</td>
<td>28.4%</td>
<td>2.52</td>
<td>8.8%</td>
<td>10.37</td>
<td>24%</td>
</tr>
<tr>
<td></td>
<td>Spigot 3</td>
<td>38.6%</td>
<td>27.6%</td>
<td>2.62</td>
<td>7.6%</td>
<td>12.15</td>
<td>22%</td>
</tr>
</tbody>
</table>

**Notes:**
1. Estimated 44 micron fines content, based on measured 75 micron fines content and an assumed conversion factor of 0.6325.
2. SFR values are based on the estimated 44 micron fines contents.
### Table 2. Fines Capture Observations for OLSO Field Trials

<table>
<thead>
<tr>
<th>Test&lt;sup&gt;1,2&lt;/sup&gt;</th>
<th>Average Properties for Tailings Slurry</th>
<th>Average Properties for Tailings Beach</th>
<th>SFR Index (SFR&lt;sub&gt;S&lt;/sub&gt;/SFR&lt;sub&gt;D&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Solids Content</td>
<td>Fines Content</td>
<td>SFR&lt;sub&gt;S&lt;/sub&gt;</td>
</tr>
<tr>
<td>1</td>
<td>58.3%</td>
<td>7.7%</td>
<td>12.0</td>
</tr>
<tr>
<td>2</td>
<td>59.7%</td>
<td>17.4%</td>
<td>4.75</td>
</tr>
<tr>
<td>3</td>
<td>52.7%</td>
<td>27.2%</td>
<td>2.68</td>
</tr>
<tr>
<td>4</td>
<td>62.2%</td>
<td>20.2%</td>
<td>3.95</td>
</tr>
<tr>
<td>5</td>
<td>57.3%</td>
<td>28.2%</td>
<td>2.55</td>
</tr>
<tr>
<td>6</td>
<td>56.4%</td>
<td>24.8%</td>
<td>3.03</td>
</tr>
<tr>
<td>7</td>
<td>56.7%</td>
<td>10.3%</td>
<td>8.71</td>
</tr>
<tr>
<td>8</td>
<td>62.8%</td>
<td>10.2%</td>
<td>8.80</td>
</tr>
<tr>
<td>9</td>
<td>65.3%</td>
<td>8.7%</td>
<td>10.49</td>
</tr>
</tbody>
</table>

Notes:
1. Tests 2 to 9 consisted of various mixtures of cyclone underflow and fine tailings. Test 1 consisted of Syncrude extraction tailings (no cyclone).
2. Tests 2 to 9 had tailings deposited using spigots; Test 1 did not.
Table 3. Comparison of Three Main Case Records for this Study

<table>
<thead>
<tr>
<th>Factor</th>
<th>MRM ETF</th>
<th>Horizon ETF</th>
<th>ASB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Years of operation</td>
<td>2003 to present</td>
<td>Q3 2008 to present</td>
<td>Current study based on 2000 to 2009 only</td>
</tr>
<tr>
<td>Shape of facility</td>
<td>Dyke around entire perimeter; up until 2004, divided into two (NE Pool and Main Pond) by a Cross Dyke; currently NE Beach occupies the NE quadrant.</td>
<td>Horseshoe-shaped dyke; natural hillside to west; facility much longer north to south than east to west.</td>
<td>Dyke around entire perimeter; facility relatively circular in plan view.</td>
</tr>
<tr>
<td>Total footprint area</td>
<td>Approx. 3 km x 4 km</td>
<td>Approx. 3 km x 7 km</td>
<td>Approx. 4 km x 4 km</td>
</tr>
<tr>
<td>Thickness of beach deposits adjacent to dyke</td>
<td>As of 2012, up to 50 m</td>
<td>As of 2012, up to 20 m</td>
<td>As of 2009, up to 50 m</td>
</tr>
<tr>
<td>Thickness of water cap</td>
<td>Typically 3 m</td>
<td>Typically 3 m</td>
<td>Typically 10 m</td>
</tr>
<tr>
<td>Type of dyke construction</td>
<td>Overburden starter dykes; Main Pond upstream cell and beach construction; NE Corner centreline cell construction.</td>
<td>Downstream method of construction using all overburden and interburden; alternating raising north and south halves of dyke, with tailings discharged in other half</td>
<td>Overburden starter dykes; upstream cell and beach construction.</td>
</tr>
<tr>
<td>Types of tailings produced</td>
<td>CST and TT OR Whole Tailings (CST = cyclone underflow coarse tailings, TT = thickened tailings) Tailings Solvent Recovery Unit (TSRU) Tailings</td>
<td>Extraction Tailings (ET) Froth Treatment Tailings (FTT)</td>
<td>Coarse Tailings (SCT) Flotation Tailings (FT)</td>
</tr>
<tr>
<td>Note: Aurora froth is pipelined to the Mildred Lake operation, and the solids are deposited in MLSB, not ASB.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of Tailings Used for Cell Construction &amp; Primary Beaching</td>
<td>Main Pond – CST NE Beach – CST, TT &amp; TSRU</td>
<td>ET</td>
<td>SCT</td>
</tr>
<tr>
<td><strong>“Average” Slurry Properties</strong></td>
<td>CST – 3 (typically 2 operational) TT – 1 TSRU – 1</td>
<td>ET – 3 (typically 2 operational) FTT – 1</td>
<td>SCT – 3 FT – 2</td>
</tr>
<tr>
<td><strong>Flow Rate</strong></td>
<td>CST – 5000 m³/hr TT – 2500 m³/hr TSRU – 1350 m³/hr</td>
<td>ET – 7000 m³/hr FTT – 3000 m³/hr</td>
<td>SCT – 7000 m³/hr FT – 1500 m³/hr</td>
</tr>
<tr>
<td><strong>Density</strong></td>
<td>CST – 1500 kg/m³ TT – 1150 kg/m³ TSRU – 1075 kg/m³</td>
<td>ET – 1.35 t/m³ FTT – 1.15 t/m³</td>
<td>SCT – 1.5 t/m³ FT – 1.15 t/m³</td>
</tr>
<tr>
<td><strong>Fines Content (SFR)</strong></td>
<td>CST – 5 to 10% (19 to 9) TT – 60% (0.7) TSRU – 60% (0.7)</td>
<td>ET – 20% (4) FTT – 60% (0.7)</td>
<td>SCT – 10 to 13% (9 to 7) FT – 23 to 39% (3.3 to 1.6)</td>
</tr>
<tr>
<td>Length of BAW</td>
<td>Main Pond – short NE Beach – long</td>
<td>Alternates between none and long, as beaching switches back and forth between north and south halves of ETF, opposite to dyke construction</td>
<td>Short</td>
</tr>
<tr>
<td>Drop from discharge point to existing beaches</td>
<td>Up to 4 m</td>
<td>Up to 12 m</td>
<td>Up to 3 to 4 m?</td>
</tr>
<tr>
<td>Other factors that may be helping to increase overall fines capture at the given ETF</td>
<td>Dedicated disposal of higher fines content streams (TT and TSRU) in NE Beach Area</td>
<td>CO₂ injection to tailings streams</td>
<td>Calcium levels in pond water</td>
</tr>
<tr>
<td>Some mined fines lost to rejects</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Fines Sent Elsewhere</td>
<td>As of 2009, some to SEA As of 2010, some to IPC1</td>
<td>None</td>
<td>Froth to MLSB</td>
</tr>
<tr>
<td>Fines Capture Relative to Fines Sent to ETF</td>
<td>70% site-wide (including ETF, SEA and IPC1, of which the majority of the tailings are in the ETF)</td>
<td>62%</td>
<td>77% of fines routed to ASB However, 85.4% of fines mined are sent to ASB, with 6.5% lost to rejects and 8.1% lost to froth. If Aurora froth went to ASB, the total capture rate would be between 70 and 77%, assuming partial capture of froth fines.</td>
</tr>
</tbody>
</table>
Table 4. Fines Content and FCER by Depositional Environment

<table>
<thead>
<tr>
<th></th>
<th>MRM ETF</th>
<th></th>
<th>Horizon ETF</th>
<th></th>
<th>ASB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L1/L2¹</td>
<td>NE Beach²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No.</td>
<td>Average</td>
<td>No.</td>
<td>Average</td>
<td>No.</td>
</tr>
<tr>
<td>Representative Slurry 44 Micron Fines Content</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slurry</td>
<td>N/A</td>
<td>6 to 15%</td>
<td>N/A</td>
<td>33.5% (TT, TSRU &amp; CST/WT combined)</td>
<td>N/A</td>
</tr>
<tr>
<td>Beach 44 Micron Fines Content</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BAW</td>
<td>6</td>
<td>5%</td>
<td>36</td>
<td>22%</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>U²</td>
<td>-</td>
<td>3</td>
<td>24%</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>L³</td>
<td>6</td>
<td>24</td>
<td>18%</td>
<td>-</td>
</tr>
<tr>
<td>BBW</td>
<td>173</td>
<td>24%</td>
<td>127</td>
<td>33%</td>
<td>256</td>
</tr>
<tr>
<td></td>
<td>U</td>
<td>81</td>
<td>46</td>
<td>27%</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>92</td>
<td>23</td>
<td>19%</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>F-BBW⁴</td>
<td>37</td>
<td>-</td>
<td>32%</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>BT⁵</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>PC</td>
<td>12</td>
<td>5</td>
<td>33%</td>
<td>-</td>
</tr>
<tr>
<td>Beach FCER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BAW</td>
<td>6</td>
<td>0.67</td>
<td>36</td>
<td>0.65</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>U</td>
<td>-</td>
<td>3</td>
<td>0.73</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>6</td>
<td>0.67</td>
<td>24</td>
<td>0.55</td>
</tr>
<tr>
<td>BBW</td>
<td>173</td>
<td>3.09</td>
<td>127</td>
<td>0.99</td>
<td>256</td>
</tr>
<tr>
<td></td>
<td>U</td>
<td>81</td>
<td>46</td>
<td>0.81</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>92</td>
<td>23</td>
<td>0.57</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>F-BBW</td>
<td>37</td>
<td>3.82</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>BT</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>PC</td>
<td>12</td>
<td>5.36</td>
<td>0.99</td>
<td>-</td>
</tr>
</tbody>
</table>

Notes:
1. For the MRM ETF, L1/L2 refers to the Main Pond beaches resulting from CST Lines 1 and 2 (coarse or whole tailings).
2. The NE Beach area of the MRM ETF resulted from the TT, TSRU and CST lines.
3. U = upper beach; L = lower beach.
4. F-BBW = failed BBW.
5. BT = BBW affected by a "bathtub" effect.
Table 5. Premises to Establish Sand Void Ratio

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Dry density (t/m$^3$)</th>
<th>$e_{geo}$</th>
<th>Fines Content (%)</th>
<th>$e_{sand}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CELL</td>
<td>1.65</td>
<td>0.61</td>
<td>6</td>
<td>0.71</td>
</tr>
<tr>
<td>BAW</td>
<td>1.50</td>
<td>0.77</td>
<td>11</td>
<td>0.99</td>
</tr>
<tr>
<td>BBW</td>
<td>1.50</td>
<td>0.77</td>
<td>17</td>
<td>1.13</td>
</tr>
<tr>
<td>Case Record</td>
<td>Test</td>
<td>Sc</td>
<td>%F_s</td>
<td>SFR_s</td>
</tr>
<tr>
<td>-------------</td>
<td>------</td>
<td>-----</td>
<td>------</td>
<td>-------</td>
</tr>
<tr>
<td>Total Flume Tests</td>
<td>C1</td>
<td>55%</td>
<td>6%</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>C2A, C3 &amp; D3</td>
<td>49 to 54%</td>
<td>10 to 12%</td>
<td>7 to 9</td>
</tr>
<tr>
<td></td>
<td>D1, D7, D2 &amp; D4</td>
<td>51 to 55%</td>
<td>13 to 15%</td>
<td>6 to 7</td>
</tr>
<tr>
<td></td>
<td>D6</td>
<td>49%</td>
<td>21%</td>
<td>4</td>
</tr>
<tr>
<td>Kupper Field Trials</td>
<td>1</td>
<td>64%</td>
<td>7%</td>
<td>13.3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>56%</td>
<td>20%</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>37%</td>
<td>30%</td>
<td>2.3</td>
</tr>
<tr>
<td>OSLO Field Trials</td>
<td>1</td>
<td>58%</td>
<td>8%</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>65%</td>
<td>9%</td>
<td>10.5</td>
</tr>
<tr>
<td></td>
<td>7, 8</td>
<td>57 to 63%</td>
<td>10%</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>2, 4</td>
<td>60 to 62%</td>
<td>17 to 20%</td>
<td>4 to 5</td>
</tr>
<tr>
<td></td>
<td>3, 5, 6</td>
<td>53 to 57%</td>
<td>26 to 28%</td>
<td>2.5 to 3</td>
</tr>
<tr>
<td>Winter 89/90 Trial</td>
<td>51%</td>
<td>19%</td>
<td>4.3</td>
<td>900 to 1200 L/s</td>
</tr>
<tr>
<td>1993 Spiking Trials</td>
<td>Cell 10</td>
<td>51.5%</td>
<td>11.5%</td>
<td>7.7</td>
</tr>
<tr>
<td></td>
<td>Cell 9</td>
<td>46.5%</td>
<td>27.3%</td>
<td>2.7</td>
</tr>
</tbody>
</table>
### Table 7. Commercial Case Records – Summary of Characteristics

<table>
<thead>
<tr>
<th>Operator</th>
<th>Case Record</th>
<th>Type of Tailings Line</th>
<th>Density (kg/m³)</th>
<th>Per Line</th>
<th>All Lines Combined</th>
<th>SFRs (all lines combined)</th>
<th>Flow Rate, Q (m³/hr)</th>
<th>%F₀</th>
<th>SFR₀</th>
<th>M₀/M₀</th>
<th>SFR₀/SFR₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suncor</td>
<td>Tar Island Pond</td>
<td></td>
<td></td>
<td>11.9%</td>
<td>7.4</td>
<td>8% *</td>
<td>11.7 *</td>
<td>63%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syncrude</td>
<td>1st 1,000 MT Ore (MLSB)</td>
<td></td>
<td></td>
<td>20.5%</td>
<td>3.9</td>
<td>13% **</td>
<td>6.6 **</td>
<td>62%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syncrude</td>
<td>SWSS BAW</td>
<td></td>
<td></td>
<td>20%</td>
<td>4.0</td>
<td>7.7%</td>
<td>12</td>
<td>33%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASB</td>
<td>Coarse</td>
<td></td>
<td>1500</td>
<td>10 to 15%</td>
<td>20%</td>
<td>19.4%</td>
<td>4.15</td>
<td>7000</td>
<td>15.8%</td>
<td>5.34</td>
<td>77%</td>
</tr>
<tr>
<td>ASB</td>
<td>Flotation</td>
<td></td>
<td>1150</td>
<td>23 to 35%</td>
<td>1500</td>
<td>11.4%</td>
<td>4.15</td>
<td>1500</td>
<td>15.8%</td>
<td>5.34</td>
<td>77%</td>
</tr>
<tr>
<td>Shell</td>
<td>MRM ETF Overall</td>
<td>CST/WT</td>
<td>1500</td>
<td>5 to 10%</td>
<td>18.1%</td>
<td>4.54</td>
<td>5000</td>
<td>13.3%</td>
<td>6.5 *</td>
<td>70%</td>
<td>65%</td>
</tr>
<tr>
<td>Shell</td>
<td>TTT</td>
<td></td>
<td>1150</td>
<td>60%</td>
<td>1350</td>
<td>13.3%</td>
<td>6.5 *</td>
<td>70%</td>
<td>65%</td>
<td>66%</td>
<td>66%</td>
</tr>
<tr>
<td>Shell</td>
<td>TSRU</td>
<td></td>
<td>1075</td>
<td>60%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shell</td>
<td>MRM NE Beach Only</td>
<td>CST/WT, TT &amp; TSRU</td>
<td>1500</td>
<td>60%</td>
<td>1350</td>
<td>33.5% ***</td>
<td>2.0 ***</td>
<td>25%</td>
<td>3.0</td>
<td>65%</td>
<td>66%</td>
</tr>
<tr>
<td>CNRL</td>
<td>Horizon ETF</td>
<td></td>
<td></td>
<td>1350</td>
<td>20%</td>
<td>22.1%</td>
<td>3.53</td>
<td>7000</td>
<td>13.9%</td>
<td>6.2 *</td>
<td>57%</td>
</tr>
<tr>
<td>CNRL</td>
<td>FTT</td>
<td></td>
<td>1150</td>
<td>60%</td>
<td>3000</td>
<td>13.9%</td>
<td>6.2 *</td>
<td>57%</td>
<td>65%</td>
<td>66%</td>
<td>66%</td>
</tr>
</tbody>
</table>

*Inferred from SFR₀ and fines capture, assuming 100% sand capture. ** Inferred from SFR₀ and fines capture, assuming 95% sand capture. *** 2008 to 2011.
Table 8. Potential Methods for Enhancing Fines Capture

<table>
<thead>
<tr>
<th>Pipeline</th>
<th>BAW</th>
<th>BBW</th>
<th>Other Operational Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Controls on off-spec line density</strong>&lt;br&gt;- Reducing erosion events and upset conditions may improve fines capture in BAW; however, most dyke designs have geotechnical limits on BAW fines content.&lt;br&gt;- Fines capture in BBW may be improved by episodic releases of sand into the pond; therefore, periods of off-spec line densities may actually be useful.</td>
<td>Change flow regime to achieve bedform that captures more fines&lt;br&gt;- it could be difficult to do, but moreover, the relative increases in fines capture will likely be small</td>
<td>Promoting failures of the BBW slope, or turbidity currents&lt;br&gt;- extended tailings beach buildup at an appropriate location</td>
<td>Construction of cross dykes&lt;br&gt;- Change in pond flow dynamics&lt;br&gt;- Encroaching of BBW slope</td>
</tr>
<tr>
<td><strong>Spiking</strong>&lt;br&gt;- an increase in fines content in the line increases the fines content in the deposit, although the percentage fines capture will decrease</td>
<td>Use of longer beaches&lt;br&gt;- Longer beaches lead to higher fines capture due to re-working of material and lower energy regime.</td>
<td>Perimeter discharge&lt;br&gt;- promoting a PC deposit under a deeper pond</td>
<td>Contained Beaching&lt;br&gt;- Using long contained beaches as per the 1989/90 trial. Difficult to retrofit onto existing beaches.</td>
</tr>
<tr>
<td><strong>Flow rate / flow velocity</strong>&lt;br&gt;- lower flow rate and lower flow velocity would both increase fines capture for BAW.</td>
<td>Use of controlled beaching / polders&lt;br&gt;- Controlled beching can be used to reduce the flow energy, promote sedimentation and percolation, enhancing fines capture</td>
<td>Keep pond level relatively high&lt;br&gt;- maximize BBW, minimize BAW</td>
<td>Co-disposal&lt;br&gt;- Investigating the effects of co-disposal further would be worthwhile; e.g. similar to the NE quadrant at Shell's MRM ETF</td>
</tr>
<tr>
<td><strong>Reduce energy of discharge</strong>&lt;br&gt;- e.g. use of “spoons”&lt;br&gt;- e.g. use of spigots</td>
<td>Enhancing BAW underdrainage&lt;br&gt;- Probably better to use sand cell construction for large ETF, not overburden</td>
<td>Pond chemistry&lt;br&gt;- consider upsides of ionic loading in pond; i.e. calcium (e.g. higher calcium levels in ASB pond)&lt;br&gt;- Shell used citrate as a process aid</td>
<td></td>
</tr>
</tbody>
</table>
MINE (ORE SENT TO PLANT) → EXTRATION PLANT → TAILINGS LINE SLURRY → TAILINGS DEPOSITS (CELL & BEACHES)

Notes:

- $M_{FO}$ = mass of fines in mined ore
- $M_{FR}$ = mass of fines in rejects
- $M_{FS}$ = mass of fines in tailings slurry directed to tailings facility = $M_{FO} - M_{FR}$
- $M_{FD}$ = mass of fines in tailings cell and beach deposits
- $M_{FF}$ = mass of fines in fluid tailings

Fines capture used in this study:

- $M_{FD}/M_{FS}$ (direct method)
- $(M_{FS} - M_{FF})/M_{FS}$ (indirect method, by subtraction)
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Slurry</th>
<th>Region 1</th>
<th>Region 2</th>
<th>Region 3</th>
<th>Region 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of fines</td>
<td>$M_{FS}$</td>
<td>$M_{F1}$</td>
<td>$M_{F2}$</td>
<td>$M_{F3}$</td>
<td>$M_{F4}$</td>
</tr>
<tr>
<td>Mass of sand</td>
<td>$M_{SS}$</td>
<td>$M_{S1}$</td>
<td>$M_{S2}$</td>
<td>$M_{S3}$</td>
<td>$M_{S4}$</td>
</tr>
<tr>
<td>Fines content</td>
<td>$%F_S$</td>
<td>$%F_1$</td>
<td>$%F_2$</td>
<td>$%F_3$</td>
<td>$%F_4$</td>
</tr>
<tr>
<td>Flow rate</td>
<td>$Q$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concentration by weight</td>
<td>$C_w$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>$Q \times$ time</td>
<td>$V_1$</td>
<td>$V_2$</td>
<td>$V_3$</td>
<td>$V_4$</td>
</tr>
<tr>
<td>Bulk density</td>
<td>$\gamma_{bs}$</td>
<td>$\gamma_{d1}$</td>
<td>$\gamma_{d2}$</td>
<td>$\gamma_{d3}$</td>
<td>$\gamma_{d4}$</td>
</tr>
<tr>
<td>Dry density</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**BEACH FINES CAPTURE STUDY**

Fines Captured by Tailings Deposit Regions

Canada's Oil Sands Innovation Alliance

AMEC Environment & Infrastructure
ONLY 32% OF TOTAL FINES CONTRIBUTE TO SLUDGE RESERVES

Schematic of Fines Capture at Suncor by Dr. D. Sheeran (taken from Mikula et al., 2008).
Notes:
1. Field trials reported by Kupper (1991) were open-ended BAW trials.
2. OSLO and 1993 spiking trials were closed-ended cells with spill boxes.
3. Total data points are flume tests which were kept closed-ended during the first hour after infilling with slurry.
Fines capture = \frac{\text{Mass of sand in beach}}{\text{Mass of sand in feed}} \times \frac{\text{FCfeed} (1 - \text{FCfeed})}{\text{FCbeach} (1 - \text{FCbeach})} \\
where \( X = \text{Sand capture} = \frac{\text{Mass of sand in beach}}{\text{Mass of sand in feed}} \)

- Suncor (GCOS) - Sheenan, circa 1991
- Syncrude 1st 1,000 Mt Ore - Fair (2008)
- MRM ETF - Overall as a Whole
- Horizon ETF - Overall as a Whole
- ASB - Overall as a Whole
- MLSB Winter Trial 1989-90
- SWSS - BAW
- Fines Capture if \( X = 100\% \)

Notes:
1. All case records presented on this plot include some amount of BBW in addition to BAW, with the exception of the SWSS data point which is for BAW only.
SFrD vs SFrS
All Case Records

Notes:
1. For MRM Main Pond (coarse or whole tailings only) and
   ASB, different portions of beach are identified by labels.
2. All commercial cases involve BBW and BAW. Exception is
   data point for SWSS which is for BAW only.
3. Total flume tests were a combination of BAW & BBW.
4. MLSB Winter Trial 1989-90 influenced by some BBW.
5. All other data are for BAW.
6. Kupper (1993) field trials were open-ended; other field
   trials and flume tests were closed-ended.
Notes:
1. Fines captures for Kupper (1991) field trials, OSLO spiking trials, 1993 spiking trials and SWSS BAW are based on SFR\textsubscript{d}/SFR\textsubscript{d}, assuming 100% sand capture. Sand capture for the open-ended Kupper (1991) trials was likely less than 100%, and the actual fines captures are likely lower than shown here.
2. Fines captures for all other case records are based on M\textsubscript{d}/M\textsubscript{ss}.
3. For flume tests and field trials, datapoint labels indicate average slurry solids contents.

- ▲ Suncor (GCOS) - Sheeran, circa 1991
- △ Syncrude 1st 1,000 Mt Ore - Fair (2008)
- ● MRM ETF - Overall as a Whole
- ○ MRM ETF - NE Beach Only
- ■ Horizon ETF - Overall as a Whole
- ○ ASB - Overall as a Whole
- ▲ MLS8 Winter Trial 1989-90
- ● Total Flume Tests
- ◆ Kupper (1991) Field Trials
- ▲ OSLO Spiking Trials
- □ SWSS - BAW
- △ 1993 Spiking Trials
FIGURE 8 AS SHOWN

Canada’s Oil Sands Innovation Alliance

AMEC Environment & Infrastructure

Tailings Deposit Fines Content vs SFRS
All Case Records

Notes:
1. For flume tests and field trials, data point labels indicate average slurry solids contents.
"Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-7m less for all points.

- %F FOR ALL DATA
- %F FOR MRM ETF NE BEACH

---

Canada's Oil Sands Innovation Alliance

BEACH FINES CAPTURE STUDY

SUMMARY OF ALL THREE CASE RECORDS
FINES CONTENT - ALL DATA

AMEC Environment & Infrastructure
"Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-7m less for all points.

- %F FOR ALL DATA
- MRM ETF
- HORIZON ETF
- ASB

**Approximate Depth at Time of Deposition *(m)**

**Fines Content (% < 44μm)**

%F FOR ALL DATA
MRM ETF
HORIZON ETF
ASB

* "Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-7m less for all points.
* "Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-7m less for all points.

Fines Content (% < 44μm)

Approximate Depth at Time of Deposition *(m)
*"Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-7m less for all points.
* "Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-7m less for all points.

HR - High Rate of Deposition
LR - Low Rate of Deposition
U - Upper BBW
L - Lower BBW

%F FOR BBW ONLY
- HR BBW
- LR BBW
- U BBW
- L BBW

Approximate Depth at Time of Deposition *(m)

Fines Content (% < 44μm)
*FCER based on tailings slurry fines contents specific to each case record.

* "Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-7m less for all points.

FCER FOR ALL DATA
FCER FOR MRM ETF NE BEACH

Approximate Depth at Time of Deposition *(m)
FCER based on tailings slurry fines contents specific to each case record.

* "Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-7m less for all points.

**Approximate Depth at Time of Deposition *(m)**

FCER for All Data
MRM ETF
HORIZON ETF
ASB

Summary of all three case records

FCER - by case record

---

**FCER based on tailings slurry fines contents specific to each case record.**

* "Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-7m less for all points.
FCER based on tailings slurry fines contents specific to each case record.

* "Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-7m less for all points.

Approximate Depth at Time of Deposition *(m)
FCER based on tailings slurry fines contents specific to each case record.

* "Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-7m less for all points.

FCER FOR BAW ONLY
- HR BAW
- LR BAW
- U BAW
- L BAW

HR - High Rate of Deposition
LR - Low Rate of Deposition
U - Upper BAW
L - Lower BAW

Approximate Depth at Time of Deposition *(m)
*FCER based on tailings slurry fines contents specific to each case record.

* "Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-7m less for all points.

FCER FOR BBW ONLY
- HR BBW
- LR BBW
- U BBW
- L BBW

HR - High Rate of Deposition
LR - Low Rate of Deposition
U - Upper BBW
L - Lower BBW

BEACH FINES CAPTURE STUDY
SUMMARY OF ALL THREE CASE RECORDS
FCER - BBW
• Low energy depositional environment – end of a long BAW + weir effect
• Depositing against a deep pond
• Run-out further limited by interfingering with flow in the opposite direction
Reasonable sand void ratios assumed for:

**Sand void ratio = 1.13**  **BBW**
(Predicted beach dry densities range from 1.30 to 1.38 t/m³ and predicted beach fines contents range from 4.2 to 10.1%

**Sand void ratio = 1.0**  **BAW**
(Predicted beach dry densities range from 1.38 to 1.46 t/m³ and predicted fines contents range from 3.7 to 9.0%

**Sand void ratio = 0.7**  **CELL**
(Predicted beach dry densities range from 1.60 to 1.67 t/m³ and predicted beach fines contents range from 2.6 to 6.5%

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**Fines Capture Predicted by Pore Capture Model**

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**Figure 20:**
Increasing slurry fines content from 15% to 22%
Canada's Oil Sands Innovation Alliance

AMEC Environment & Infrastructure

BEACH FINES CAPTURE STUDY

Static and Dynamic Segregation Boundaries for Canadian Natural Tailings Mixtures (taken from Barr/Deltares report, May 2012).

FIGURE 21

Static CNRL CO2
Static CNRL no CO2
Dynamic 0.01 1/s CNR w/CO2
Dynamic 0.1 1/s CNRL w/CO2
Dynamic 1 1/s CNRL w/CO2
Dynamic 10 1/s CNRL w/CO2
Dynamic 100 1/s CNRL w/CO2

Winter Low (10% of total)
Summer High (10% of total)
Fall Average (80% of total)

Rapidly Settling Sand under static conditions
Slower Settling Sand under various conditions
Fines Capture vs Specific Flow Rate or Flume Tests and Field Trials

Notes:
1. Fines captures for Kupper (1991) field trials, OSLO spiking trials, 1993 spiking trials and SWSS BAW are based on SFR/SFR₀ assuming 100% sand capture. Sand capture for the open-ended Kupper (1991) trials was likely less than 100%, and the actual fines captures are likely lower than shown here.
2. Fines captures for all other case records are based on $M_{sd}/M_{sp}$.
3. For flume tests and field trials, datapoint labels indicate average slurry solids contents.
Appendix A

Total's 2011 Cylinder and Flume Testing
Memo

To: File
File No: CG25409
Date: June 2013
From: Catherine Fear
Reviewed by: Ed McRoberts
Subject: Total's 2011 Laboratory Testing – Cylinders & Flume Tests

1.0 INTRODUCTION

Under contract to Total E&P Canada (Total), the Saskatchewan Research Council (SRC) completed a series of cylinder and flume tests in 2011 to evaluate the potential for spiking coarse tailings with MFT, and the resulting effects on beach fines capture.

2.0 INFORMATION PROVIDED BY TOTAL FOR CURRENT STUDY

Table 1 presents a summary of the information provided by Total for this study. The summary of the 2011 laboratory testing presented herein is based on this information as well as some email and telephone discussions with Total.

3.0 CYLINDER TESTS

3.1 Test Procedure

18 cylinder tests were completed, as follows:

- 7 on samples prepared using High Grade (HG) sand, with varying amounts of fines; one of the tests included the addition of gypsum (test A17)
- 9 on samples prepared using Medium Grade (MG) sand, with varying amounts of fines; 3 of the tests included the addition of flocculants (tests A12, A16 and A18)
- 2 on samples prepared using Low Grade (LG) sand, with varying amounts of fines; neither test included any flocculant

The HG, MG and LG classifications refer to the bitumen content of the original ore, with each category having a different typical SFR / fines content, as follows:

- HG – SFR of 17.7 (fines content of 5.4%)
- MG – SFR of 9.2 (fines content of 9.8%)
- LG – SFR of 6.4 (fines content of 13.4%)
SRC’s report indicates that the procedure for the cylinder tests was as follows:

- A known amount of MFT or TT was mixed with known amounts of coarse sand and process water to form a 2.1 L mixture.
- The mixture was thoroughly mixed and 0.1 L was withdrawn for analysis, to characterize the cylinder feed properties for each test. However, it is understood that this did not include particle size distribution testing of the cylinder feed.
- The remaining 2 L sample was transferred into a 2 L volumetric cylinder and allowed to settle for either 24 or 48 hours.
- The sample settled into three parts, as follows:
  - S1 – top part: light liquid, mainly water with little fines
  - S2 – middle part: heavy liquid, water and fines
  - S3 – bottom part: heavy mixture, mainly sand with fines and water; S3 was the main focus of the testing as it was considered to represent the beach that would form during the actual beach discharge process.
- The volumes of S1, S2 and S3 were recorded over time, up to 48 hours.
  - It is understood from discussion with Total that the interfaces between S1/S2 and S2/S3 were often difficult to identify, and some judgement was involved.
- At the end of the test, each layer was removed from the 2 L cylinder and analyzed for solids content and sand to fines ratio (SFR).
- Based on the results of the analysis the fines capture in S3 was calculated. Two methods were used – referred to by SRC as the “volume” and “weight” methods. While the details are not completely clear, and are not explained in the SRC (2011 report), it is understood from discussion with Total that the "volume" method was based on careful sampling and measurements made at the end of each test, while the "weight" method made some adjustments to these measurements to account for potential losses during sampling. In Total’s opinion, the "volume" method likely yields more appropriate results.

3.2 Cylinder Feed

Excluding those cylinder tests that had gypsum or flocculant added to the feed, Figure 1 shows all of the cylinder tests on a plot of SFR of the feed versus FOFW of the feed. Superimposed on Figure 1 is the Static no CO₂ boundary for Horizon Mine tailings from BARR/Deltares (2012). While this static boundary may not be directly applicable to the specific Total test mixtures, it may still be useful to make the comparison. The following observations are made:

- With the exception of two tests, all tests fall on the "wet" side of the static segregation boundary, with most tests falling significantly to the left of the boundary. All of these cylinder tests segregated, as would be predicted by the plot.
  - Test A13, which plots closest to the boundary, only partially segregated based on the details provided in the Excel summary file, with no distinguishable interface between S1 and S2, even at 48 hours. Furthermore, the interface between S2 and S3 was not distinguishable at 24 hours in Test A13 as it was in all other tests that segregated, but was visible at 48 hours. This test also had the smallest reported volume for S3, and the lowest reported fines capture in S3 (11%).

---

- Two tests fall on the "dry" side of the static segregation boundary, as follows:
  - Test A14 – S3 was reported as "non-distinguishable" in Table 4.1 of SRC's report, and the details provided in the Excel summary file indicated that both the boundaries between S1/S2 and S2/S3 were non-distinguishable. This has been interpreted herein to mean that this cylinder test was non-segregating, as would be predicted by the plot.
  - Test A15 – results were reported for S1, S2 and S3, indicating that the cylinder test was segregating despite that fact that it falls somewhat to the right of the Horizon Mine static no CO$_2$ segregation boundary.

3.3 Mass Balance & Fines Capture

Taking the information presented in Table 4.1 of SRC (2011) at face value, and using this information to determine the mass distribution in both the feed and S3 for each cylinder test, several observations can be made:

- Excluding the 4 tests that involved the addition of gypsum or flocculant, and excluding the one test that, although it didn't have gypsum or flocculant added, was non-segregating (Test A14):
  - The average mineral solids content of S3 was about 80% and, with the exception of Test A13 with a solids content of 91%, typically ranged from 78% to 81%.
  - With the exception of Test A13, S3 typically captured in the order of 80% of the sand in the feed, not 100%, and some sand did report to S2. The actual percentage of sand captured in S3 varied from test to test.
  - The porosity of the sand within S3 ranged from 0.38 to 0.48, with an average of 0.45. This is similar to the maximum porosity of 0.44 that BARR/Deltares (2012) indicated for the Pleistocene fluvial sand (Pfs) that was used for the segregation boundary testing that they completed for the Horizon Mine.
  - On average, the FOFW of S3 was about 1.9 times the FOFW of the feed. This is significantly higher than what the Marsh pore capture theory for whole tailings would predict, as it assumes that the FOFW of the fines slurry trapped within the voids of a sand beach is the same as the FOFW of the tailings discharge.
  - In order to maintain the same FOFW that was achieved in the voids of the sand in S3, the original solids content of the feed to the cylinder would have had to be about 71%, on average. This is much higher than the actual average solids content of the cylinder feed, of about 54%. As a hypothesis, if the cylinder feed solids contents were low enough that a certain amount of clear water was released into S1 very rapidly after filling the cylinders, then the sand would have settled through a fines slurry that had a higher FOFW than that of the original feed. For a 2 L cylinder tests, the difference between 54% solids and 71% solids is a volume of water of about 660 mL. For comparison, on average, the measured volume of S1 at the end of the test was about 600 mL. Therefore, while this hypothesis cannot completely explain the higher than expected achieved FOFW in S3, it may have been a contributing factor.
- The one test that was non-segregating ("non-distinguishable" boundaries for S1/S2/S3), but didn't have gypsum or flocculant added (Test A14) had a SFR of 4.6 and a FOFW of 25.6, the highest FOFW of all cylinder feeds. This test was reported as having an S3 fines capture of 0%; however, if it was truly non-segregating, this should be 100%.
- As noted above, Test A15 was reported as being segregating, but it also had a high feed FOFW value (SFR of 6.2 and FOFW of 21.1).

In comparing the fines captures reported for the cylinder tests in Table 4.1 of SRC (2011) to the raw data in the tab called "Original from SRC Feb 18" in the Excel file called "Data processing Feb 22 2011.xls", for some of the tests, it is unclear how the results reported in Table 4.1 were selected. For example, for Test A1, Table 4.1 reports a value of 47.5%, but the Excel file reports three values, as follows:

- 47.5% – redo – 24 hours
- 83.0% – 48 hours original
- 62.4% – 48 hours

On the other hand, for Test A2, Table 4.1 reports a value of 69.7%, but the Excel file reports two values, as follows:

- 45.7% – 24 hours
- 69.7% – 48 hours

It is understood from discussion with Total that re-do tests involved more careful post-test sampling procedures than original tests, and likely give more reliable results.

4.0 FLUME TESTS

4.1 Test Procedure

11 flume tests were completed, as follows:

- 4 on samples prepared using High Grade (HG) sand, with varying amounts of fines; one of the tests included the addition of flocculant
- 5 on samples prepared using Medium Grade (MG) sand, with varying amounts of fines; one of the tests included the addition of flocculant
- 2 on samples prepared using Low Grade (LG) sand, with varying amounts of fines; neither test included any flocculant

SRC's report indicates that the procedure for the flume tests was as follows:

- The flume dimensions were 0.25 m wide by 0.5 m deep by 8.0 m long.
- For all tests, the flume was inclined such that the base sloped at 1%.
- A known amount of MFT or TT was mixed with known amounts of coarse sand and process water to form about 600 to 800 L of slurry in a mixing tank. The slurry in the feed tank was fully homogenized by using at least one mixer impeller in the slurry while loading the flume.
• For each test, 400 L of slurry was discharged into the flume at a rate of 100 L/minute, using a discharge angle of 45 degrees. Therefore, it took about 4 minutes to discharge all of the slurry into the flume, and four 8-oz cut-a-stream samples were taken at the start of each minute. These samples were tested to characterize the feed to the flume.
• While the slurry was being discharged at the inlet end of the flume, the outlet end of the flume was blocked, preventing immediate runoff at the far end of the flume.
• The mixture was allowed to settle for 1 hour before runoff was drained from the far end of the flume by slowly opening rubber plugs on the weir at the end of the flume. The runoff was collected in separate drum(s) for weight and composition analysis.
• For each test, the following measurements were made at 4 points along the length of the flume (at 1 m, 2.6 m, 4.4 m and 6.4 m from the inlet end):
  o Slurry surface after loading
  o Beach surface after runoff drained off (after 1 hour)
  o Beach surface after 24 hours
• At each of these same 4 points, samples were collected and tested (Dean Stark testing and grain size analysis). At each of the 4 points, samples were collected from two depths, a "top beach" sample and a "bottom beach" sample.
  o The exception was Test C1, for which only 6 samples were collected; no samples were collected at the fourth location, 6.4 m from the inlet end.

4.2 Flume Feed

Excluding those flume tests that had flocculant added to the feed, Figure 2 shows all flume tests on a plot of SFR of the feed versus FOFW of the feed. Superimposed on Figure 2 is the Static no CO2 boundary for Horizon Mine tailings from BARR/Deltares (2012). While this static boundary may not be directly applicable to the specific Total test mixtures, it may still be useful to make the comparison. All tests fall on the "wet" side of the static segregation boundary, with most tests falling significantly to the left of the boundary. All of these flume tests segregated, as would be predicted by the plot. Particle size distribution testing was completed on the feed for each flume test, with two tests completed per flume test.

4.3 Beach Geometry and Characterization

For each of the 11 tests, Figure 3 illustrates the relative position of the slurry surface after infilling the flume to the beach surface that formed. Only tests that did not include the addition of flocculant are shown. The plots are shown on one page at approximately the same scale, to also show a side by side comparison of all 11 tests. As stated earlier, any excess slurry was not allowed to run off until an hour after infilling. Therefore, as shown in Figure 3, the initial slurry surface covered some to all of the beach that formed in the flume, depending on the test. In all tests, the third and fourth beach sampling locations (4.4 m and 6.4 m from the discharge) were in beach that had been covered by slurry for the first hour of the test.

As described earlier, the typical sampling and testing procedure consisted of two samples (top beach and bottom beach) at each of the four sampling points (1 m, 2.6 m, 4.4 m and 6.4 m from the discharge point). Figure 4 to Figure 7 present a series of plots illustrating the variation in mineral solids content (from Dean Stark testing), SFR, fines content, and FOFW, respectively, down the beach. Only tests that did not include the addition of flocculant are shown. The values plotted at each of the four locations in Figure 4 to Figure 7 represent the average of the
top and bottom beach sample test results. In Figure 5, data labels are included to indicate the SFR and FOFW of the feed for each flume test.

With increasing distance from the discharge, the following observations can be made:

- Solids content typically decreases
- SFR typically decreases
- Fines content typically increases
- FOFW typically increases
- In most cases, the test result for the last sampling location, the farthest down the beach (6.4 m from the discharge) stands out as being significantly different (higher or lower, depending on the parameter) than those for the first three locations.

4.4 Mass Balance & Fines Capture

Taking the mass balance information presented in SRC's appendices at face value to compare the feed and beach for each flume test, and excluding the 2 tests that involved the addition of flocculant, several observations can be made. However, some of the values cited would be affected by the lack of closure in the fines mass balance, as discussed below.

- The average mineral solids content of the beach was about 76% and ranged from 73% to 78%, slightly lower than that of S3 in the cylinder tests.
- With the exception of Test D6, which had a low sand capture, the beach typically captured most of the sand in the feed, but some sand did report to the runoff.
- The porosity of the sand within the beach ranged from 0.44 to 0.57, with an average of 0.50. This is higher than the maximum porosity of 0.44 that the Barr/Deltares report indicated for Pleistocene fluvial sand (Pfs) used for the segregation boundary testing that they completed for CNRL.
- On average, the FOFW of the beach deposit in the flume was about 1.5 times the FOFW of the feed. This is higher than what the Marsh pore capture theory for whole tailings would predict, as it assumes that the FOFW of the fines slurry trapped within the voids of a sand beach is the same as the FOFW of the tailings discharge.

Various appendices of SRC's report present mass balance tables for the flume tests that were completed. In reviewing these appendices, it appears that 100% closure was not obtained for the fines mass balance for each test, despite the controlled test environment. Table 2 presents a summary. As a result, as indicated in Table 2, different fines captures can be calculated for some of the tests, depending on whether a direct or indirect method is used to determine the mass of fines in the resulting beach deposit. As in a commercial scale tailings facility, one can imagine that the indirect method of calculating fines capture is likely more accurate, given the difficulties associated with assessing the total mass of fines trapped in the beach based on a limited number of samples (in this case, 6 to 8 samples per 8 m long flume) and the variability of the beach deposits.

The test with the fines mass balance closurefarthest from 100% was test C1 (closure of 58%). This may not be surprising because this test only had 6 samples collected, two from each of the first three sample points (1 m, 2.6 m and 4.4 m from the inlet). No samples were collected from the fourth sample point located at 6.4 m from the inlet, where the beach fines content would be expected to be highest based on the results of the other tests.
Table 3 presents a summary of the slurry and beach properties for the 9 flume tests that did not involve a chemical additive. In Table 3, the beach properties are based on calculating both the mass of sand and the mass of fines in the beach by subtraction, given the fact that 100% mass balance closure was not obtained for each test. In terms of global fines capture and SFR index, the 9 tests can be summarized as follows:

- Average slurry SFR ranged from 3.8 to 16.4
- Average beach SFR ranged from 7.8 to 18.6
  - In all tests, the SFR decreased with distance down the beach (see Figure 5).
- SFR index \( \frac{\text{SFR}_s}{\text{SFR}_b} \) ranged from 0.44 to 0.88
- With the exception of one test (Test D6) that had a sand capture (mass of sand in beach divided by mass of sand in slurry) of 50%, the sand capture ranged from 97% to 100%; therefore, in most tests, the vast majority of the sand reported to the beach deposit.
- Fines capture (mass of fines in beach divided by mass of fines in slurry) for the one test with a sand capture of 50% was only 24%. For the remaining tests, the fines capture ranged from 43% to 88%, consistent with the range in SFR index. If the one test with the highest fines capture (88%) is also excluded, the rest of the tests had a tighter range in fines capture, from 43% to 64%.
- All tests had relatively similar slurry solids contents, ranging from 49% to 55%.
- In general, fines capture increased with increasing slurry SFR. The test with the highest fines capture (88%) had, by far, the highest slurry SFR (16.4). The test with the lowest fines capture (24%) had the lowest slurry SFR (3.8). The remaining tests had slurry SFR values ranging from 5.9 to 9.3.
- Conversely, in general, the overall average beach fines content decreased with increasing slurry SFR. The test with the lowest overall average beach fines content (5.1%) had, by far the highest slurry SFR (16.4). The test with the highest overall average beach fines content (11.4%) had the lowest slurry SFR (3.8). The remaining tests had overall average beach fines contents ranging from 6.4 to 9.2% and slurry SFR values ranging from 5.9 to 9.3.

5.0 COMPARISON OF CYLINDER AND FLUME TESTS

Figure 8 presents a plot of SFR of the feed versus FOFW of the feed, including both cylinder tests and flume tests. Only tests that did not include the addition of gypsum or flocculant are included. Labels next to each data point indicate fines capture in S3 (cylinder tests) or beach (flume tests). This figure has revised the fines captures reported for some tests, as follows:

- Fines captures for the flume tests are the values calculated using the indirect method, as given earlier in Table 2.
- Fines captures for some cylinder tests have been revised from those reported in Table 4.1 of SRC’s report so that all values consistently represent the following:
  - 48 hours of settling.
  - The "volume method" of fines capture calculation.
  - If a re-do test was done, the re-do test result was used.

Figure 8 shows that, although the 2L cylinder tests were much smaller scale tests, the 2L cylinder tests gave results that were generally consistent to the flume tests.
SRC’s report makes the following conclusions:

- Fines capture was governed by feed FOFW.
- Optimum fines capture occurred at a FOFW of 13% for HG and MG sand, with lower fines captures occurring at both lower and higher FOFW.

Using the revised fines captures in Figure 8, Figure 9 plots fines capture versus feed FOFW. Based on this interpretation of the data, it is difficult to make similar conclusions regarding an optimum feed FOFW relative to fines capture. While there is a fair amount of scatter to the data, the results seem to indicate a general decrease in fines capture with increasing feed FOFW and/or decreasing SFR.

Figure 10 plots the overall average fines content of the beach deposit for the 9 flume tests versus feed FOFW, with data labels indicating the feed SFR. This shows that, in general, as the feed FOFW increases and/or the feed SFR decreases, the overall average fines content of the beach deposit also increases.
Table 1. 2011 Laboratory Testing Information Provided by Total for Current Study

<table>
<thead>
<tr>
<th>Category</th>
<th>Document or File Provided</th>
<th>Date Provided</th>
<th>Information Included</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>PDF file entitled &quot;TEPCA Beach Fines Capture 2011 Pilot results Kick off Sept 21 2012&quot;</td>
<td>19 Sep 2012</td>
<td>Presentation made by Total at the project kickoff meeting held on 21 Sep 2012, entitled &quot;Total E&amp;P Canada, Beach Fines Capture 2011 Pilot&quot;</td>
</tr>
<tr>
<td></td>
<td>PDF file entitled &quot;Optimizing the Capture of Oil Sands Fines in Sand Beach Final Version&quot;</td>
<td>24 Sep 2012</td>
<td>Paper submitted to the 2012 IOSTC conference, entitled &quot;Optimizing the Capture of Oil Sand Fines in Sand Beach Areas&quot;, by R. Sun, A. Goldszal and C. Li.</td>
</tr>
<tr>
<td>2011 Laboratory Test Results</td>
<td>PDF file entitled &quot;Final Report for Fines Captured in Sand Beach&quot;</td>
<td>24 Sep 2012</td>
<td>Report prepared by the Saskatchewan Research Council (SRC) entitled &quot;Oil Sand Tailings Fines Captured in Sand Beach Study&quot; and dated November 2011. Excludes Appendix O, which was provided later (see below).</td>
</tr>
<tr>
<td></td>
<td>Excel file entitled &quot;Beach fines capture summary for all results by June 13 2011&quot;</td>
<td>08 Nov 2012</td>
<td>Contains data for tests completed by 13 June 2011. Note: this file does not contain results for all flume tests, as some were completed after June 13, 2011.</td>
</tr>
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<td></td>
<td>Excel file entitled &quot;Data processing Feb 22 2011&quot;</td>
<td>15 Nov 2012</td>
<td>Contains raw data for cylinder tests.</td>
</tr>
<tr>
<td></td>
<td>Six JPG files</td>
<td>15 Nov 2012</td>
<td>Six selected photos of cylinder and flume testing.</td>
</tr>
<tr>
<td></td>
<td>CD containing various supporting data files for all laboratory testing completed, including numerous photos and videos.</td>
<td>19 Nov 2012</td>
<td>Appendix O of the SRC (2011) report – project data library on CD.</td>
</tr>
</tbody>
</table>
Table 2. Flume Test Fines Mass Balance and Fines Capture

<table>
<thead>
<tr>
<th>Test</th>
<th>Mass of fines (^1) (kg)</th>
<th>Fines Capture in Flume Beach</th>
<th>Calculated</th>
<th>Reported</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Feed</td>
<td>Flume</td>
<td>%Closure</td>
<td>Direct (^2)</td>
</tr>
<tr>
<td></td>
<td>Beach</td>
<td>Runoff</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>20.38</td>
<td>9.34</td>
<td>2.46</td>
<td>11.80</td>
</tr>
<tr>
<td>D1</td>
<td>48.67</td>
<td>26.75</td>
<td>28.00</td>
<td>54.75</td>
</tr>
<tr>
<td>D7</td>
<td>51.82</td>
<td>21.06</td>
<td>24.05</td>
<td>45.11</td>
</tr>
<tr>
<td>D8(^b)</td>
<td>43.84</td>
<td>33.72</td>
<td>9.66</td>
<td>43.38</td>
</tr>
<tr>
<td>C2A</td>
<td>27.04</td>
<td>15.33</td>
<td>9.80</td>
<td>25.13</td>
</tr>
<tr>
<td>D2</td>
<td>53.54</td>
<td>34.42</td>
<td>20.10</td>
<td>54.52</td>
</tr>
<tr>
<td>D4</td>
<td>48.43</td>
<td>30.88</td>
<td>18.96</td>
<td>49.84</td>
</tr>
<tr>
<td>D6</td>
<td>66.21</td>
<td>9.69</td>
<td>50.00</td>
<td>59.69</td>
</tr>
<tr>
<td>D5(^b)</td>
<td>50.78</td>
<td>44.89</td>
<td>6.35</td>
<td>51.24</td>
</tr>
<tr>
<td>C3</td>
<td>36.77</td>
<td>19.49</td>
<td>16.41</td>
<td>35.90</td>
</tr>
<tr>
<td>D3</td>
<td>44.71</td>
<td>22.64</td>
<td>21.90</td>
<td>44.54</td>
</tr>
</tbody>
</table>

Notes:
1. From various appendices in SRC (2011) presenting mass balances for the various tests.
2. Direct fines capture = (mass of fines in beach)/(mass of fines in feed).
4. Based on the individual summary table for each test in the main body of SRC (2011).
5. Tests D8 and D5 included the addition of flocculant.
Table 3. Flume Test Slurry and Beach Properties

<table>
<thead>
<tr>
<th>Test</th>
<th>Solids Content</th>
<th>Fines Content</th>
<th>SFRs</th>
<th>FOFW</th>
<th>Mass of Sand (kg)</th>
<th>Mass of Fines (kg)</th>
<th>Fines Content</th>
<th>SFRD</th>
<th>Sand Capture</th>
<th>Fines Capture</th>
<th>SFR Index (SFRs/SFRD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>54.5%</td>
<td>5.7%</td>
<td>16.4</td>
<td>6.4</td>
<td>334.16</td>
<td>17.92</td>
<td>5.1%</td>
<td>18.6</td>
<td>100.0%</td>
<td>87.9%</td>
<td>0.879</td>
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<tr>
<td>D1</td>
<td>51.4%</td>
<td>14.1%</td>
<td>6.1</td>
<td>12.9</td>
<td>287.96</td>
<td>20.67</td>
<td>6.7%</td>
<td>13.9</td>
<td>97.0%</td>
<td>42.5%</td>
<td>0.438</td>
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<tr>
<td>D7</td>
<td>55.4%</td>
<td>14.5%</td>
<td>5.9</td>
<td>15.2</td>
<td>302.49</td>
<td>27.77</td>
<td>8.4%</td>
<td>10.9</td>
<td>98.9%</td>
<td>53.6%</td>
<td>0.542</td>
</tr>
<tr>
<td>C2A</td>
<td>52.0%</td>
<td>9.7%</td>
<td>9.3</td>
<td>9.5</td>
<td>251.18</td>
<td>17.24</td>
<td>6.4%</td>
<td>14.6</td>
<td>99.9%</td>
<td>63.8%</td>
<td>0.638</td>
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<td>D2</td>
<td>52.1%</td>
<td>13.5%</td>
<td>6.4</td>
<td>12.8</td>
<td>331.88</td>
<td>33.44</td>
<td>9.2%</td>
<td>9.9</td>
<td>96.9%</td>
<td>62.5%</td>
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<td>D4</td>
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<td>13.3%</td>
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<td>11.5%</td>
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<td>13.8</td>
<td>99.3%</td>
<td>51.0%</td>
<td>0.514</td>
</tr>
</tbody>
</table>

Notes:
1. Only those tests that did not involve a chemical additive are included in this table; i.e. tests D8 and D5 from Table 2 are excluded here.
2. Determined by subtraction (i.e. mass of sand in beach = mass of sand in slurry feed – mass of sand in runoff) using data from various appendices of SRC (2011) presenting mass balances for the various tests.
3. Determined by subtraction (i.e. mass of fines in beach = mass of fines in slurry feed – mass of fines in runoff) using data from various appendices of SRC (2011) presenting mass balances for the various tests.
Notes:
1. Only cylinder tests that were completed without chemical additives are shown.

Total 2L Cylinders - HG
Total 2L Cylinders - MG
Total 2L Cylinders - LG
CNRL Static Seg/NonSeg Boundary, no CO2 (taken from BARR/Deltares, 2012)

Cylinder Tests - Feed SFR versus Feed FOFW
Notes:
1. Only flume tests that were completed without chemical additives are shown.

Flume Tests - Feed SFR versus Feed FOFW
Notes:

1. Only flume tests that were completed without chemical additives are shown.
Flume Tests - Mineral Solids Content versus Distance from Discharge Point

Notes:
1. Only flume tests that were completed without chemical additives are shown.
Notes:
1. Only flume tests that were completed without chemical additives are shown.
2. Data labels on first point indicate composition of feed (SFR, FOFW).
**Notes:**
1. Only flume tests that were completed without chemical additives are shown.
Notes:
1. Only flume tests that were completed without chemical additives are shown.
Comparison of Cylinder and Flume Tests
Feed SFR versus Feed FOFW

Notes:
1. Only cylinder and flume tests that were completed without chemical additives are shown.
2. Labels next to data points indicate fines capture.
Comparison of Cylinder and Flume Tests
Fines Capture versus Feed FOFW

Notes:
1. Only cylinder and flume tests that were completed without chemical additives are shown.
Notes:
1. Only flume tests that were completed without chemical additives are shown.
2. Data labels indicate SFR of flume feed.
Appendix B

Shell's Muskeg River Mine ETF Case Record
Memo

To:        File          File No:         CG25409
Date:             June 2013
From:  Catherine Fear           Reviewed by:    Ed McRoberts
                        Angela Küpper
Subject:  Muskeg River Mine External Tailings Facility Case Record

1.0      INTRODUCTION

Shell's Muskeg River Mine (MRM) External Tailings Facility (ETF) is an active tailings facility that has been in operation since 2003. Figure 1 presents an aerial photograph of the facility, taken in September 2012. Three types of tailings streams are generated by the MRM extraction plant and discharged at the ETF, as follows:

- Coarse tailings (CST)
- Thickened tailings (TT)
- Tailings solvent recovery unit (TSRU) tailings

At times, such as when primary and/or secondary extraction is bypassed or the thickeners are bypassed and no TT are being produced, a fourth type of tailings, whole tailings, is produced instead of producing CST and TT. When whole tailings are produced, they are discharged into the ETF via the CST lines.

2.0      INFORMATION PROVIDED BY SHELL FOR CURRENT STUDY

Table 1 presents a summary of the information provided by Shell for this study. The summary of the MRM ETF case record presented herein is based on this information as well as some email, telephone and in person discussions with Shell.

3.0      SAMPLING & MEASUREMENT METHODS

Table 2 provides a list of the various sampling and measurement methods used to generate the MRM ETF data provided for this study. AMEC's scope does not include an evaluation of the benefits/limitations of the methods used relative to the accuracy of the resulting data and the calculated fines contents/captures.

4.0      OPERATIONAL HISTORY

4.1      Process Flow Diagram

Figure 2 provides a basic process flow diagram for the MRM extraction plant. As shown in this figure, two main types of tailings are produced by the extraction plant: Coarse Tailings (CST) and Thickened Tailings (TT). CST consists of relatively low fines content cyclone underflow,
while TT is a relatively high fines content stream and is the result of directing the cyclone overflow through thickeners. In addition, a third tailings stream is generated from the tailings solvent recovery unit (TSRU tailings).

As shown in Figure 2, there are four main bypass lines for each train within the extraction plant. When any of these bypasses are activated, the result is that whole tailings are produced rather than separate CST and TT streams. When produced, whole tailings are discharged into the ETF via the CST lines. According to the presentation made by Shell at the project kickoff meeting, historically, whole tailings were discharged 33% of the time, and in 2010, the bypass time was much higher than the historic average.

Oversize rejects at MRM are sent to a waste dump.

4.2 Tailings Lines

4.2.1 Introduction

Figure 3 presents a plan view of the MRM ETF, identifying the various compacted cell areas that comprise the main dykes by cell number. These cell numbers are referenced throughout the rest of this memorandum. All tailings lines come up to the top of the ETF via a ramp located in the Cell 23 corner of the ETF (referred to as Ramp 0).

4.2.2 Coarse Tailings

Coarse Tailings are discharged to the MRM ETF via three 26" lines, as follows:

- CST1 – from Cell 23 and south, down the east side and across the south end to Cell 6 in the SW corner
- CST2 – from Cell 23 and west, across the north end and down the west side to Cell 7 the SW corner
- CST3 – in the NE corner; often on standby, serving as an alternate discharge location

4.2.3 Thickened Tailings

Thickened tailings are discharged to the MRM ETF via a single 26" line with open ended discharge. The specific location of the line would be moved as required operationally, depending on the build up of TT beaches. Initially, the TT line was set up in the Ramp 0 corner, and was active from Cell 23 to Cell 25. Later, it was extended to the south end of Cell 25, and has typically been kept in that general location. On occasion, as required, an alternate short pour location in Cells 24/23 was used.

Upon deposition, the TT tended to build up at the discharge until the material met up with the bottom of the pipe, at which point it would flow down the beach before starting to build up at the pipe again, and eventually the pipe had to be moved. The TT would typically cut shallow channels to the pond and follow the low spots; as the lowest spots filled up, it would re-locate itself to other low spots.
As discussed later in Section 6.1.2, the thickener underflow was typically diluted to lower solids contents by adding water to the line prior to sending the stream to the ETF. Two reasons why water was added to the line were:

- Sending water down the TT line was an option to meet overall water balance requirements for the Extraction plant, if excess water had been sent to the plant from the reclaim barge in the ETF. Sending water down the TT line was preferred over sending water down the CST lines, given that a target density of about 1.56 to 1.57 t/m$^3$ was preferred for CST for cell construction.
- If TT beaches were building up too quickly, and there were no operational resources to move the line, tailings operations could request that water be added to the TT line.

### 4.2.4 TSRU Tailings

TSRU tailings are discharged to the MRM ETF via a single 18" line with open ended discharge. Initially, there was only one discharge point, but a second was added about one to two years after start-up to provide short and long pour locations for more operational flexibility.

### 4.3 Design Basis & Historical Context

Drawing on the final geotechnical and tailings design reports, this section provides a brief overview of the original design and tailings plan for the MRM ETF, for historical context. During its design phase, the MRM ETF evolved from a single pond concept, using a conventional upstream method of construction, to a segmented pond concept. The final design included a Cross Dyke to divide the ETF into two parts: the Main Pond (approximately three quarters of the footprint) and the North Pool (the northeast corner of the ETF).

Around the Main Pond, the perimeter dyke was to be constructed using a conventional upstream method of construction. The remainder of the perimeter dyke (around the North Pool) and the Cross Dyke were to be constructed using a centreline method of construction. All dykes were to have overburden starter dykes, with compacted cell sand used to raise the dykes to their final design crest elevations. Some additional overburden was predicted to be required to supplement cell construction. For foundation stability reasons, the ETF also required a major toe berm at its south end, also to be constructed using an upstream method of construction, with a cell sand perimeter and beaching to the north, towards the ETF.

At the time of the final design, the extraction plant was expected to produce three different tailings streams, as follows: coarse tailings, thickened tailings (TT) and tailings solvent recovery unit (TSRU) tailings. The TT was considered to be a non-segregating stream, while the coarse tailings and TSRU tailings were both considered to be segregating streams. The intent of dividing the ETF into two main areas was to store these three types of tailings as follows:

- **Main Pond** – beach sand & thin/mature fine tailings (TFT/MFT) resulting from the coarse tailings and TSRU tailings.
- **North Pool** – TT, the first 14 months of TSRU tailings, and some small amounts of sand running off from the Centreline Dyke cell construction.

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At the time of the final design, TSRU tailings had to be disposed of and stored subaqueously under a minimum 3 m thick water cap. Since it would take time for a sufficient water cap to develop in the Main Pond, an additional overburden dyke (the Intermediate Dyke) was to be constructed to temporarily sub-divide the North Pool into two parts so that the initial TSRU tailings could be stored in the North Pool, but separately from the TT. TSRU tailings were to be stored on the east side, and TT on the west side. The east side was to have sufficient pre-startup water directed to it, such that the initial TSRU tailings could be disposed of subaqueously under a minimum 3 m water cap.

After the first 14 months of operations, it was expected that a sufficient water cap would have developed in the Main Pond, and TSRU tailings disposal would then be switched permanently from the North Pool to the Main Pond. Subsequent TT deposition would be into the entire North Pool, and the Intermediate Dyke would be overtopped. The original design also included an initial water management strategy that consisted of transferring water from the TSRU pond to the TT pond, and from the North Pool to the Main Pond.

4.4 Dyke Construction & Pond Operations

4.4.1 Overview

Figure 4 presents a series of aerial photographs, showing the evolution of the northeast portion of the ETF from 2002 to 2012. The following items are noted:

- Figure 4(a) shows the overburden starter dykes, constructed as per the original design, including the Cross Dyke, separating the North Pool from the Main Pond, and the Intermediate Dyke, sub-dividing the North Pool into two areas.
- Starting in 2004, a decision was made to no longer raise the Cross Dyke along with ETF perimeter dykes and, eventually, tailings deposited in the North Pool were able to flow over the initial Cross Dyke and into the Main Pond.
- Beaching of CST or Whole Tailings into the NE corner was more than just occasional overboarding during cell construction, as originally envisioned. The NE corner is the closest point to overboard and use as an emergency dump point for the CST lines.
- By 2010, as shown in Figure 4(f), a long above water beach (1000 to 1400 m) had formed in the NE corner of the ETF. For comparison, the above water beach around the Main Pond is in the order of 150 m.

During initial operations, tailings were deposited as per the original design, with TT and TSRU tailings being directed to the west and east sides of the North Pool, respectively, and CST used to raise the perimeter dykes and the Cross Dyke. For a period of time in 2004, deposition of TSRU tailings was temporarily switched back and forth between the Main Pond and the North Pool; however, discharge of TSRU tailings otherwise remained in the NE corner of the ETF, and was never permanently moved to the Main Pond. TSRU tailings were initially deposited subaqueously, as per the original design; however, from 2005 onwards, TSRU tailings were discharged subaerially.
The resulting deposits as of year end 2012 are as follows:

- **NE Beach Area** – TT, TSRU and some CST or Whole Tailings
- **Main Pond** – predominantly CST or Whole Tailings, but any TT or TSRU tailings running off the far end of the NE Beach after the Cross Dyke was no longer raised would have also ended up in the Main Pond

### 4.4.2 Weekly Tailings Planning Reports

Shell’s records for the MRM ETF include detailed weekly tailings planning reports from 2002 to 2012. While these are forecasted weekly plans, not as-built reports, they still give a good indication of where the various tailings lines were discharging over time, and provide other useful comments on overall operations at the ETF.

From 2002 to mid-December 2009, all tailings produced at MRM were discharged into the ETF. Starting in mid-December 2009, some CST were also directed to the South Expansion Area (SEA), at the south end of the ETF proper (see Figure 1). In-pit disposal of CST began in March 2010. With the exception of some TT disposal into In Pit Cell 1 (IPC1) during 2009, all TT and TSRU tailings continued to be directed to the ETF.

Some transfers of fluid fine tailings between storage areas have also occurred over the last few years. While the volumes of transferred fluid have been monitored, the associated mass of mineral solids has not been tracked. Transfers have occurred both out of and into the ETF.

### 4.4.3 Cell Construction

Initial cell construction operations started with 2 m lifts using D7s. A variety of different lift thicknesses were then explored, eventually resulting in 4 m thick lifts using D8s. The following typical practices were followed:

- Perimeter dyke around Main Pond
  - Spillbox and overboarding into Main Pond
  - Pouring all the way to the SW corner of the ETF (Cell 7) was challenging, given long distance and associated pumping requirements
- Perimeter dyke around the North Pool
  - Spillbox – into North Pool
  - Overboarding – attempted to overboard into Main Pond, but not all that successful, resulting in some overboarding into the North Pool
- Cross dyke
  - Spillbox – into Main Pond
  - Overboarding – into Main Pond
- General practices
  - Typical cell dimensions
    - Wider cells used for dykes around the North Pool, as per centreline construction design, than for dyke around Main Pond. Minimum cell widths were driven by operational requirements/restrictions.
    - Shorter cells used in initial operations, and longer cells used later.
    - Longer cells could be used during summer operations, but shorter cells had to be used during winter operations.
    - Maximum cell length of about 500 m (stretch).
Typical cells constructed using 75 ft pipe with 2 legs and a width of about 300 ft. Current minimum width is about 250 ft using 50 ft pipe. The cell lifts placed in the Cross Dyke were wider, and used 3 legs.

- Dayshift and nightshift often followed different approaches, with dayshift typically adding more pipe, resulting in steep slopes to cells, and nightshift letting the feed do the work, resulting in more gentle slopes. This difference in practice didn't appear to have a large impact on spillbox operations or cell capture rates.
- When whole tailings were being produced, instead of CST and TT, operations would still build cell, if possible, depending on the nature of the feed; however, they would switch to overboard when required.

### 4.4.4 Main Pond Beaching

The overboard location was located behind the active cell and moved on an as-needed basis, based on cell construction operations. When placing a new cell lift, the overboard would start at the elevation of the base of the lift, but once it could be advanced, it would be raised to the top of the typically 4 m thick lift. Therefore, when overboarding into the Main Pond, the discharge point typically started with a 4 m drop to the underlying beach.

Some contained beaching was also used in certain areas of the ETF. This consisted of cell construction without an end dyke or spillbox, but with the use of dozers.

A few operational comments of interest include:

- In the initial years, some areas had more beach than others, as it took longer to build up beaches in certain areas.
- CST could be overboarded for extended periods of time in Cell 11 without beaches building up.
- It was rare that the overboard hadn't built up before it had to be moved; typically the overboard had to be moved because the beach had built up to the crest, not because it was causing an issue in cutting beaches back to the dyke.
- As documented in KCB (2010)\(^3\), in November 2009, an upstream movement occurred in the south central region of the Cell 25 area (i.e. within the NE Beach – see Figure 2), while contained beaching operations were underway within the failure footprint. The movement zone was about 230 m long (parallel to the dyke), and formed a graben feature at surface, ranging in width from 40 m to 70 to 80 m (into the pond). In plan view, the graben feature was located over and in line with the Intermediate Dyke that originally sub-divided the North Pool into two parts. KCB (2010) concluded that the most probable mechanism was a deep (about 32 m) translational failure through a weak clayey bituminous layer through the tailings deposit, which caused a graben feature to develop at the head of the sliding mass. As shown in KCB (2010), in cross-section, this likely failure surface would have exited the underwater beach surface at an elevation just a few metres above the crest of the Cross Dyke.

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4.4.5 Water Management

Shortly after start-up, due to a fire, the MRM extraction plant was unexpectedly shut down for about 6 months. As a result, a large volume of water was sent out to the ETF. This resulted in some challenges during the initial years of operations in keeping cell and beach construction ahead of the pond level.

Recycle water is directed back to the plant from a barge located in a bay at the north end of the ETF (see Figure 1). Water is recycled back to the plant at a rate of about 10,000 m$^3$/hr.

From 2002 to about summer/fall 2009, an additional line discharged basal aquifer water into the ETF in the Ramp 0 corner, adjacent to the TT line. Starting in about summer/fall 2009, the line was moved to the base of Ramp 0, and the water was discharged into the seepage ditch.

4.5 Pond Water Chemistry

No specific information regarding pond water chemistry has been provided.

5.0 MASS BALANCE

5.1 2011 Mass Balance

Shell's 2011 annual fluid pond status report for MRM, that was submitted to the ERCB on 31 October 2011 as part of D074 requirements, indicates that, as of 2011, for the MRM site as a whole, the percentage of fines in dykes and beaches is in the order of 70% of all of the fines contained within tailings disposal areas at MRM. The report does not provide the percentage closure for the mass balance (i.e. the report does not compare the total mass of fines accounted for in the tailings deposits to the total mass of fines in the ore, net of rejects). Only a site wide mass balance was completed, which implicitly accounts for the transfers of fluid fine tailings between storage areas; a mass balance specific to the ETF was not completed.

This overall capture rate for MRM as a whole includes tailings contained in the South Expansion Area (SEA) and In-Pit Cell (IPC) 1A and 1B, as well as the ETF. However, as of 2011, the vast majority of the fines in storage (in the order of 90%) were contained within the ETF, as both the SEA and IPC were newer storage areas containing relatively small tailings deposits.

According to one of Shell's 2012 IOSTC papers$^4$, 65% of the fines discharged into the NE corner of the ETF over the four years from 2008 to 2011 were captured in the NE Beach. It is interesting to note that this is similar to the overall site-wide fines capture of 70% reported for MRM in Shell's 2011 ERCB submission (which, as stated above, primarily reflected capture in the ETF as a whole, given the limited discharge to the SEA and in-pit cells as of 2011).

The 2011 pond status report does not provide the details of the mass balance behind the reported numbers, nor were they provided to COSIA for this study. Furthermore, AMEC's scope does not include an audit of the mass balance for the MRM ETF.

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5.2 Historical Context

While the original design pre-dated Directive 074 requirements and, therefore, did not directly consider fines capture per se, the overall intent of the segmented design was to sequester TT in the North Pool, thereby capturing this higher fines content thickened stream in a dedicated deposit area. Therefore, it is considered interesting to assess the fines capture that would have been predicted for the MRM ETF, using the original planning assumptions, had it continued to be raised as a segmented facility.

Although the TSRU was considered to be a segregating stream, given the relative volumes of TT and TSRU stored in the North Pool over the life of the ETF, it seems reasonable to imagine that essentially all of the above fines could be considered "captured" in the primarily dedicated thickened tailings disposal area. Therefore, of the two streams deposited directly into the North Pool (TT and some initial TSRU), 100% of the fines in these two streams would be captured in the North Pool in the original design. The resulting overall average fines content of the contents of the North Pool would have been about 57% in the original design.

Of the three streams directed to the ETF as a whole, the North Pool would capture about 52% of the total fines over the life of the facility, ignoring some fines in the "lost sand" reporting to the North Pool from cell construction activities. In addition to this, the cell sand dykes and beaches in the ETF (including the south toe berm) would also capture some fines. Therefore, at the time of the final design, the overall fines capture for the ETF as a whole would have been predicted to be in the order of about 67% of the fines directed to the ETF.

6.0 SYNTHESIS OF DATA PROVIDED

6.1 Tailings Line Slurry Characteristics

6.1.1 Coarse Tailings

Figure 5, Figure 6 and Figure 7 present flow rate and density data on a 12 hour basis for Coarse Tailings lines CST1, CST2 and CST3, respectively. The plots present all data downloaded from Shell's PI database, and do not attempt to filter out the data that were collected when the lines were down or on flush.

These figures indicate that significant variations in both flow rate and density occurred in all three of the CST lines over short time intervals on an on-going basis. A summary of the typical range in values is as follows:

- Flow rate in each line – typically between about 4,000 and 6,000 m$^3$/hr
  - When operating, CST3 had slightly higher flow rates than CST1 and CST2
- Density in each line – typically between about 1,500 and 1,600 kg/m$^3$

Figure 8 and Figure 9 present solids content and fines content data on a 12 hour basis for CST1 and CST2, respectively. Figure 10 and Figure 11 present the corresponding clay content data, and Figure 12 and Figure 13 present the corresponding $d_{90}$, $d_{50}$ and $d_{10}$ data. Solids content and particle size data were not available for CST3.
A summary of the typical range in solids content, fines content and clay content values for CST1 and CST2 is as follows:

- Dean Stark mineral solids content in each line – typically between about 45 and 65%, but with a gradual overall increase from 2003 to 2012
- Fines content (laser) in each line
  - 2003 to mid-2004 – typically between about 10 and 20%
  - Mid-2004 to 2008 – typically between about 5 and 15%
  - 2009 to 2012 – typically between about 2 and 8%
- Clay content (laser) in each line – varied following a similar pattern over time as fines content, with values all typically less than 1 to 2%

The overall variations in \(d_{90}\), \(d_{50}\) and \(d_{10}\) with time are consistent with the overall variations in fines content and clay content with time. At any given time, the range in \(d_{90}\) was fairly large.

Some periods of higher fines content may represent times during which whole tailings were being produced, and directed down the CST lines, as some component of the Extraction Plant was on bypass. A detailed comparison of the CST data and TT data has not been completed in order to assess the specific time periods during which whole tailings were being produced.

### 6.1.2 Thickened Tailings

Figure 14 presents flow rate and density data on a 12 hour basis for the TT line. The plot presents all data downloaded from Shell’s PI database, and do not attempt to filter out the data that were collected when the lines were down or on flush. This figure indicates that significant variations in both flow rate and density occurred in the TT line over short time intervals on an on-going basis. A summary of the typical range in values is as follows:

- Flow rate – it is difficult to select typical values given the wide range in data; after mid-2004, flow rates were anywhere between about 1,500 and 4,000 m\(^3\)/hr
- Density – followed a somewhat sinusoidal curve over time, with a high of about 1,300 kg/m\(^3\) in mid-2006 to a low of about 1,000 kg/m\(^3\) in late 2010.

Figure 15 presents solids content and fines content data on a 12 hour basis for the TT line. Figure 16 presents the corresponding clay content data, and Figure 17 presents the corresponding \(d_{90}\), \(d_{50}\) and \(d_{10}\) data. A summary of the typical range in solids content, fines content and clay content values is as follows:

- Dean Stark mineral solids content – followed a somewhat sinusoidal curve over time, with a high of about 40% in mid-2006 to a low of about 10% in late 2010.
- Fines content (laser) – followed a somewhat reverse sinusoidal curve over time, with a low of about 30% in mid-2006 to a high of about 80% in late 2010.
- Clay content (laser) – varied following a similar pattern over time as fines content, with a low of about 2% in mid-2006 to a high of about 12% in late 2010.

The overall variations in \(d_{90}\), \(d_{50}\) and \(d_{10}\) with time are consistent with the overall variations in fines content and clay content with time. At any given time, the range in \(d_{90}\) was fairly large.
6.1.3 TSRU Tailings

Figure 18 presents flow rate and density data on a 12 hour basis for the TSRU tailings line. The plot presents all data downloaded from Shell's PI database, and do not attempt to filter out the data that were collected when the lines were down or on flush. This figure indicates that significant variations in both flow rate and density occurred in the TSRU tailings line over short time intervals on an on-going basis. A summary of the typical range in values is as follows:

- Flow rate – typically between about 1,300 and 1,500 m$^3$/hr
- Density
  - 2003 and 2004 – typically between about 800 and 1,025 kg/m$^3$
  - 2005 onwards – typically between about 1,050 and 1,125 kg/m$^3$ 

Figure 19 presents solids content and fines content data on a 12 hour basis for the TSRU tailings line. Other particle size data was not available for the TSRU tailings line. A summary of the typical range in values is as follows:

- Dean Stark mineral solids content in each line (data from 2009 onwards only) – typically between about 10 and 25%
- Fines content (laser; no data before mid-2004)
  - Mid-2004 to late 2005 – typically between about 40 and 70%
  - Late 2005 to mid-2008 – typically between about 40 and 60%
  - Mid-2008 to 2012 – typically between about 50 and 70%

6.1.4 Density versus Flow Rate

Figure 20 to Figure 24 present cross-plots of density versus flow rate for each of the five tailings lines (CST1, CST2, CST3, TT and TSRU). In addition to showing the typical range in flow rate and density, these figures indicate that the total amount of time that the tailings lines are on flush is significant.

For the CST lines, based on the data provided, when each line was operational, the lines had flow rates less than 1100 kg/m$^3$, and were pumping essentially just water, as follows:

- CST1 – about 9% of the time
- CST2 – about 14% of the time
- CST3 (but primarily on backup so often not operational) – about 50% of the time

6.2 Tailings Deposit Characteristics

Figure 25 presents a plan view of the ETF, indicating the locations of 4 cross-sections prepared for the current study, namely Sections A-A', B-B', C-C' and D-D'. Also included in Figure 25 are the 2011 pond bottom contours (taken from Shell's 2011 ERCB submission) and the borehole locations where samples were collected during the 2011 and 2012 site investigations. A few locations drilled in 2009/2010 that were not re-drilled in 2011/2012 are not currently shown.

Figure 26 to Figure 29 present Sections A-A' to D-D', respectively, and show the annual development of the dyke, beaches and pond over time, from start-up to 2012. It is our understanding that the annual surfaces were developed based on all pond bottom data collected; clearly some of the resulting elevations are artificially high compared to the surrounding area and may represent locations where the CT09 tool stopped on a floating mat of muskeg or layer of bitumen/asphaltenes within the otherwise fluid fine tailings.
The laboratory test results from the closest 2011 boreholes to each cross-section are superimposed on the various cross-sections in Figure 30 to Figure 41, as follows (only test data from 2011 samples are currently shown on these cross-sections; test data from samples collected in other years are not currently shown):

- **Section A-A’**
  - Figure 30 – Dean Stark solids content (total mineral content)
  - Figure 31 – fines content (< 44 micron)
  - Figure 32 – clay content (< 2 micron)

- **Section B-B’**
  - Figure 33 – Dean Stark solids content (total mineral content)
  - Figure 34 – fines content (< 44 micron)
  - Figure 35 – clay content (< 2 micron)

- **Section C-C’**
  - Figure 36 – Dean Stark solids content (total mineral content)
  - Figure 37 – fines content (< 44 micron)
  - Figure 38 – clay content (< 2 micron)

- **Section D-D’**
  - Figure 39 – Dean Stark solids content (total mineral content)
  - Figure 40 – fines content (< 44 micron)
  - Figure 41 – clay content (<2 micron)

For each of the boreholes shown on the four cross-sections, an individual plot, using expanded scales, is included in Attachment I, presenting the following 2011 test data on a single plot: Dean Stark solids content, fines content and clay content. At a few of these locations, the 2011 borehole was not drilled to as low an elevation as the earlier 2009 borehole in the same location; for these boreholes, the 2009 test data at lower elevations is also shown. For locations that were re-drilled in 2012, the 2012 data are also shown on the same plot, for comparison. Several new locations were drilled in 2012 for the first time; individual plots are included for these locations as well. All 2011 and 2012 borehole locations are shown in Figure 25.

Attachment II presents a plan view and associated borehole test date for boreholes drilled in site investigations prior to 2009 (taken from Klohn Crippen’s 2009 site investigation report).

Over the course of the various site investigations, at many locations in the Main Pond, the primary focus of the borehole was sampling and testing of the fluid fine tailings, and beach sampling was limited to the uppermost beach just below the pond bottom. At some locations, sampling extended further though the beach and ended closer to the underlying original ground.

Using the 2012 site characterization data for the MRM ETF, Figure 42 presents a plot of fines content versus solids content and Figure 43 presents a plot of clay content versus fines content. Figure 43 indicates that there is a relatively constant ratio between clay content and fines content in the beach deposits, with the ratio increasing in the overlying MFT.
7.0 SUMMARY

The following key summary points can be made, when considering the MRM ETF as a whole:

- MRM produces three tailings streams – cyclone underflow coarse tailings, thickened tailings and tailings solvent recovery unit (TSRU) tailings. At times, during various bypass conditions in the extraction plant, whole tailings are produced instead of separate coarse and thickened tailings.
- The ETF started out as a segmented facility, with a cross dyke separating the northeast corner (NE Pool) from the rest of the facility (Main Pond). TT and TSRU tailings, along with some coarse/whole tailings were discharged in the NE Pool. With the exception of some TSRU disposal in 2004, only coarse/whole tailings were discharged into the Main Pond. The cross dyke was not raised along with the perimeter dykes for the facility as originally planned, but TT and TSRU disposal, along with some coarse/whole tailings, continued to be discharged in the NE corner only, and a long beach developed. The Main Pond continued to receive only coarse/whole tailings.
- For a global assessment of this case record, the ETF can be considered as a whole, and doesn't need to distinguish between the Main Pond and the NE Beach.
- Using information provided at the time of the original design (AMEC, 2001), it is estimated that the fines content of all three of the tailings streams combined (i.e. mined ore net of rejects) is 18.1% (SFR$_S$ of 4.54).
- Based on Shell's 2011 tailings plan submission to the ERCB (Shell, 2011), based on laser diffraction particle size distribution data, the following dry fines could be accounted for in tailings facilities at the MRM site as a whole:
  - 101.8 Mt total
  - 30.1 Mt in fluid tailings
  - 71.7 Mt in dikes and beaches (i.e. 70.4% of all fines that could be accounted for in MRM tailings facilities were captured)
- The above numbers reflect the combined total of fines in the ETF, the South Expansion Area (SEA) and In-Pit Cell 1 (IPC1). However, the vast majority are in the ETF, as tailings disposal into the SEA started in late 2009 and disposal into IPC1 started in 2010. Prior to this, all tailings from start-up in 2003 were discharged into the ETF only. It is difficult to assess the fines capture for the ETF alone, as MFT has been transferred out of and into the ETF, and, while the volumes of transferred MFT were tracked, the specific tonnages of dry fines transferred between facilities have not been tracked.
- A slurry SFR$_S$ of 4.54 and a fines capture of 70.4%, assuming 100% sand capture, infers an overall tailings deposit SFR$_D$ for the whole ETF of 6.48 (or a fines content of 13.3%).
- The fines contents of the tailings deposits vary significantly, depending on location; i.e. NE Beach versus Main Pond beaches and, within the Main Pond, beaches above and below water.
<table>
<thead>
<tr>
<th>Category</th>
<th>Document or File Provided</th>
<th>Date Provided</th>
<th>Information Included</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>PDF file entitled &quot;Shell – Fines Capture at ETF North Pool Beach-Draft-Sep 20&quot;</td>
<td>20 Sep 2012</td>
<td>Presentation made by Shell at the project kickoff meeting held on 21 Sep 2012, entitled &quot;High Fines Capture at MRM ETF North East Tailings Beach: Causes and Opportunities&quot;</td>
</tr>
<tr>
<td></td>
<td>PDF file entitled &quot;121017 Compacted Cell Layout&quot;</td>
<td>17 Oct 2012</td>
<td>Plan drawing dated 03 Oct 2012, showing the numbered compacted cell layout for the MRM ETF.</td>
</tr>
<tr>
<td></td>
<td>Excel file entitled &quot;Abian Tailings PI Tags-For AMEC&quot;</td>
<td>07 Nov 2012</td>
<td>Contained basic process flow diagram sketch for MRM, indiciing sampling and measurement points, as well as a listing of the relevant PI tags.</td>
</tr>
<tr>
<td></td>
<td>Excel file entitled &quot;Thickener PI Data-For AMEC-RN-Additional Data&quot; (replaced earlier versions provided on 06 Feb 2013 and 07 Nov 2012)</td>
<td>12 Feb 2013</td>
<td>Contained results of querying PI database for TT and TSRU data, on a 12 hour basis from start-up to 2012.</td>
</tr>
<tr>
<td>Tailings Slurry Data</td>
<td>Excel file entitled &quot;Shell-CST PI Data-RN&quot; (replaced earlier file provided on 23 Nov 2012)</td>
<td>06 Feb 2013</td>
<td>Contained results of querying PI database for CST data, on a 12 hour basis from start-up to 2012.</td>
</tr>
<tr>
<td>Tailings Pipeline Locations</td>
<td>C0 containing MRM ETF weekly tailings plans (Restricted Use)</td>
<td>12 Dec 2012</td>
<td>Weekly tailings plans for 26 Oct 2002 to 30 Oct 2012.</td>
</tr>
<tr>
<td></td>
<td>Excel file entitled &quot;Shell - TDP 2012 MRM ETF Data&quot; (replaced earlier file provided on 17 Jan 2013)</td>
<td>06 Feb 2013</td>
<td>Laboratory test results in tabular format for tailings samples collected during the 2012 site investigation.</td>
</tr>
<tr>
<td>DWG and PDF files entitled Section A-A', Section B-B', Section C-C' and Section D-D' (replaced earlier versions provided from 21 Dec 2012 to 31 Jan 2013)</td>
<td>06 to 08 Feb 2013</td>
<td>Four detailed cross-sections through the ETF, showing original ground, annual dyke &amp; beach surfaces, and borehole locations.</td>
<td></td>
</tr>
<tr>
<td>CADD files with 3D surfaces for the entire MRM ETF</td>
<td>Mar 2013</td>
<td></td>
<td>3D surfaces for original ground and annual dyke &amp; beach surfaces.</td>
</tr>
</tbody>
</table>
### Table 2. Sampling & Measurement Methods for MRM ETF Data Provided for Current Study

<table>
<thead>
<tr>
<th>Category</th>
<th>Type of Sample / Measurement</th>
<th>Method Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore</td>
<td>Bitumen, mineral and water composition</td>
<td>Dean Stark</td>
</tr>
<tr>
<td></td>
<td>Particle size distribution</td>
<td>Laser diffraction(^1)</td>
</tr>
<tr>
<td>Tailings Slurry</td>
<td>Bitumen, mineral and water composition</td>
<td>Dean Stark</td>
</tr>
<tr>
<td></td>
<td>Particle size distribution</td>
<td>Laser diffraction(^1)</td>
</tr>
<tr>
<td>Tailings Deposit Field Sampling</td>
<td>Tailings beaches</td>
<td>Sonic</td>
</tr>
<tr>
<td>Tailings Deposit Field Measures</td>
<td>Pond bottom surface (interface between fluid fine tailings and beaches)</td>
<td>CT09</td>
</tr>
<tr>
<td>Tailings Deposit Laboratory Testing</td>
<td>Bitumen, mineral and water composition</td>
<td>Dean Stark</td>
</tr>
<tr>
<td></td>
<td>Particle size distribution</td>
<td>Laser diffraction(^1,2)</td>
</tr>
</tbody>
</table>

**Notes:**
1. Using as the dispersant currently available commercial grade Calgon that doesn't include sodium hexametaphosphate.
2. Previously, laser diffraction and different types of sieve hydrometer testing were used to characterize the deposits, and the results were compared. The 2011 ERCB submission reported both clean hydrometer (bitumen free sample; post Dean Stark analysis) results and laser diffraction results. Moving forward, Shell intends to use only laser diffraction. Results used to prepare figures for inclusion in the present memorandum are all based on laser diffraction testing.
1. In this diagram, the term CT means Coarse Tailings.
2. Not shown in this diagram is the additional Tailings Solvent Recovery Unit (TSRU) tailings stream, which is also sent to the ETF.
Compacted Cell Layout at MRM ETF
(provided by Shell)

Exterior Tailings Facility

Main South Toe BERM
(MSTB)
Notes:
1. Images taken from presentation made by Shell at the project kickoff meeting.
2. Images are not all at the identical scale.
Coarse Tailings Line 1 - Flow Rate and Density vs Time - 2003 to 2012 (12h Data)

Flow Rate (m³/hr)
Density (kg/m³)

CST-1 Flow Rate (m³/hr)
CST-1 Density (kg/m³)

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FIGURE 5

P:\Projects\Calgary\CG25409\CG25409 Reports\Figures\FiguresFINAL_June2013.xlsx
Coarse Tailings Line 2 - Flow Rate and Density vs Time - 2003 to 2012 (12h Data)

- CST-2 Flow Rate (m³/hr)
- CST-2 Density (kg/m³)

Flow Rate (m³/hr)

Density (kg/m³)

Time

1-Jan-03 1-Jan-04 31-Dec-04 31-Dec-05 31-Dec-06 31-Dec-07 31-Dec-08 31-Dec-09 31-Dec-10 31-Dec-11 29-Dec-12

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BEACH FINES CAPTURE STUDY

CST2 - Flow Rate & Density vs Time

FIGURE 6
Coarse Tailings Line 3 - Flow Rate and Density vs Time - 2005 to 2012 (12h Data)

- CST-3 Flow Rate (m³/hr)
- CST-3 Density (kg/m³)

FIGURE 7
Figure 9: Coarse Tailings Line 2 - Solids Content and Fines Content vs Time - 2003 to 2012 (12h Data)

- CST-2 Solids Content (%)
- CST-2 Fines Content (%)

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BEACH FINES CAPTURE STUDY

CST2 - Solids Content & Fines Content vs Time
Coarse Tailings Line 1 - Clay Content vs Time - 2003 to 2012 (12h Data)

CST-1 Clay Content [%]

Time

Clay Content [%w/w]

1-Jan-03  1-Jan-04  31-Dec-04  31-Dec-05  31-Dec-06  31-Dec-07  31-Dec-08  31-Dec-09  30-Dec-10  30-Dec-11  29-Dec-12
Coarse Tailings Line 2 - Clay Content vs Time - 2003 to 2012 (12h Data)

Time

Clay Content (%/w/w)

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CST2 - Clay Content vs Time

FIGURE 11
Coarse Tailings Line 2 - d90, d50 and d10 vs Time - 2003 to 2012 (12h Data)

- CST-2 d90 (microns)
- CST-2 d50 (microns)
- CST-2 d10 (microns)

FIGURE 13
FIGURE 15

TT - Solids Content and Fines Content vs Time - 2003 to 2012 (12h Data)

Solids Content or Fines Content (%/w/w)

Time

1-Jan-03 31-Dec-04 31-Dec-05 31-Dec-06 31-Dec-07 31-Dec-08 31-Dec-09 31-Dec-10 31-Dec-11 29-Dec-12

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BEACH FINES CAPTURE STUDY

TT - Solids Content & Fines Content vs Time
**TT - Clay Content vs Time - 2003 to 2012 (12h Data)**

- TT Clay Content (%)

![Graph showing TT Clay Content vs Time between 2003 and 2012 with data points scattered across the timeline.](image-url)
TT - d90, d50 and d10 vs Time - 2003 to 2012 (12h Data)

- TT d90 (microns)
- TT d50 (microns)
- TT d10 (microns)

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BEACH FINES CAPTURE STUDY

TT - d90, d50 & d10 vs Time
TSRU Tailings - Flow Rate and Density vs Time - 2003 to 2012 (12h Data)
TSRU Tailings - Solids Content and Fines Content vs Time - 2003 to 2012 (12h Data)

- TSRU Tailings Solids Content (%)
- TSRU Tailings Fines Content (%)

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BEACH FINES CAPTURE STUDY

TSRU Tailings - Solids Content & Fines Content vs Time
MRM ETF - CST1 - Density vs Flow Rate - 12 h Data

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BEACH FINES CAPTURE STUDY

CST1 - Density vs Flow Rate

FIGURE 20
MRM ETF - CST3 - Density vs Flow Rate - 12 h Data

Flow Rate (m³/hr)

Density (kg/m³)

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BEACH FINES CAPTURE STUDY

CST3 - Density vs Flow Rate

FIGURE 22 AS SHOWN

P:\Projects\Calgary Geo\CG25409 - OSTC Beach Study\300 Reports\FINAL_June2013\Appendix B_Figures_FINAL_June2013.xlsx
MRM ETF - TT - Density vs Flow Rate - 12 h Data

Density (Kg/m³) vs Flow Rate (m³/hr)

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BEACH FINES CAPTURE STUDY

TT - Density vs Flow Rate

FIGURE 23

AMC25409 - OSTC Beach Study/300-Reports/FINAL_June2013/Appendix B_Figures_FINAL_June2013.xlsx
MRM ETF - TSRU - Density vs Flow Rate - 12 h Data

Flow Rate (m$^3$/hr)

Density (kg/m$^3$)

0  2000  4000  6000  8000  10000  12000  14000

0  500  1000  1500  2000  2500

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BEACH FINES CAPTURE STUDY

TSRU Tailings - Density vs Flow Rate

FIGURE 24
Triangulations

- ORIGINAL_GROUND_SURFACE.00T
- STARTER_DYKE_SURFACE.00T
- DCALM_CELL_ABUILT_2004_02_29.00T
- 2004_02_POND_BOTTOM.00T
- BEACH_CELL_ABUILT_2005_09_28.00T
- 2005_10_POND_BOTTOM.00T
- BEACH_CELL_ABUILT_2007_08_14.00T
- 2007_10_POND_BOTTOM.00T
- BEACH_CELL_ABUILT_2007_11_29.00T
- 2007_10_POND_BOTTOM.00T
- BEACH_CELL_ABUILT_2008_06_20.00T
- 2008_08_POND_BOTTOM.00T
- 2009_09_POND_BOTTOM_AND_IIDAR.00T
- 2010_05_POND_BOTTOM_AND_IIDAR.00T
- 2011_04_POND_BOTTOM_AND_IIDAR.00T
- 2013_05_POND_BOTTOM_AND_IIDAR.00T

- Canada's Oil Sands Innovation Alliance

- BEACH FINES CAPTURE STUDY

- Section A-A'

- AMEC Environment & Infrastructure
Cross-Section BB - Solids Content (%)
Cross-Section BB - Fines Content (%)
Cross-Section CC - Solids Content (%)
Cross-Section CC - Fines Content (%)
Cross-Section DD - Solids Content (%)

Elevation (m)

Distance (m)

- MPS01
- S12-D
- MP506
- S4A
- S3B-D
- S2A-A
- Waterline - 2004 to 2012
- June 2011 Pond Bottom

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AMEC Environment & Infrastructure

BEACH FINES CAPTURE STUDY

Section D-D' - Solids Content

FIGURE 39

DATE: JUNE 2013

PROJECT NO: CG25409

REV. NO: 0

FIGURE NO: 39

P:\Projects\Cg\OSIA\CG25409 - OSTC Beach Study\300 Reports\Files\Figure 39_ElevationDistance.png
Fines Content (kg)

Solids Content (%)

Notes:
1. 2012 data only.

- FFFT Data (more than 1 m above reported pond bottom)
- NE Beach Data
- Main Pond Beach Data

Canada's Oil Sands Innovation Alliance

AMEC Environment & Infrastructure
Clay Content vs Fines Content

Notes:
1. 2012 data only.

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AMEC Environment & Infrastructure

BEACH FINES CAPTURE STUDY

Clay Content vs Fines Content

FIGURE 43
ATTACHMENT I – INDIVIDUAL BOREHOLE PLOTS

Note: Each plot includes the following 2011 and/or 2012 test data; on some plots, selected 2009 data from lower elevations are also included:

- Dean Stark solids content
- Fines content (<44 microns)
- Clay content (< 2 microns)

Plots are included in numerical order, by borehole; for 2011 and 2012 borehole locations, refer to Figure 25.

Not included are locations drilled in 2009/2010, but not re-drilled in 2011/2012.
Dean Stark Solids Content (%) or Fines Content, < 44 microns (%)

Sample Elevation (m)

Average Sample Elevation (m)

Clay Content, < 2 microns (%)

MPS07 and S4B

- MPS07 CC - 2011 - MPS07 CC - 2012 - MPS07
- S4B CC - 2011 - S4B CC - 2012 - S4B
- MPS07 FC - 2011 - MPS07 FC - 2012 - MPS07
- S4B FC - 2011 - S4B FC - 2012 - S4B

- May 2012 Waterline
- 2011 Pond Bottom - MPS07
- June 2011 Pond Bottom - S4B
- Original Ground - MPS07
- 2012 Pond Bottom - MPS07
Note: No 2012 pond bottom was reported for MPS08B.
MPS11
Dean Stark Solids Content (%) or Fines Content, < 44 microns (%)

Note: In 2011, two pond bottoms were measured - one as shown and one similar to the one reported for 2012.
MPS15
Dean Stark Solids Content (%) or Fines Content, < 44 microns (%)

Sample Elevation (m)

270
275
280
285
290
295
300
305
310
315
320
325
330
335
340

Average Sample Elevation (m)

Clay Content, < 2 microns (%)

0 10 20 30 40 50 60 70 80 90 100

Note: New location in 2012; no previous data.

CC - 2012
FC - 2012
SC - 2012
May 2012 Waterline
2012 Pond Bottom
Original Ground
Note: New location in 2012; no previous data.
MPS17
Dean Stark Solids Content (%) or Fines Content, < 44 microns (%)

Note: New location in 2012; no previous data.
Note: New location in 2012; no previous data.
Note: New location in 2012; no previous data.
Note: New location in 2012; no previous data.
Note: New location in 2012; no previous data.
Note: New location in 2012; no previous data.
MPS27
Dean Stark Solids Content (%) or Fines Content, < 44 microns (%)

Note: New location in 2012; no previous data.
MPS28
Dean Stark Solids Content (%) or Fines Content, < 44 microns (%)

Note: New location in 2012; no previous data.
Note: New location in 2012; no previous data.
Note:
1. Missing OG for this location.
2. No 2012 data for this location.
S1A-C
Dean Stark Solids Content (%) or Fines Content, < 44 microns (%)

Note:
1. Missing OG for this location.
2. No 2012 data for this location.
S3B-A
Dean Stark Solids Content (%) or Fines Content, < 44 microns (%)

Note:
1. Missing OG for this location.
2. No 2012 data for this location.
Note:
1. Missing OG for this location.
2. No 2012 data for this location.
Note:
1. Missing OG for this location.
2. No 2012 data for this location.
S4A
Dean Stark Solids Content (%) or Fines Content, < 44 microns (%)

Average Sample Elevation (m)

Clay Content, < 2 microns (%)
Note: New location in 2012; no previous data.
Note: New location in 2012; no previous data.
Note: Older data below El. 310 m are from 2009 program.
Note: 2012 pond bottom seems unusually high compared to other adjacent locations. 2011 pond bottom seems more reasonable.
Note: 2012 pond bottom seems unusually high compared to other adjacent locations. 2011 pond bottom seems more reasonable.
Note: 2012 pond bottom seems unusually high compared to other adjacent locations. 2011 pond bottom seems more reasonable.
Note:
1. Missing OG for this location.
2. No 2012 data for this location.
Note: New location in 2012; no previous data.
Note:
1. No 2012 data for this location.
S12A
Dean Stark Solids Content (%) or Fines Content, < 44 microns (%)

Note: Older data below El. 316 m are from 2009 program.
Note: Older data below El. 300 m are from 2009 program.
ATTACHMENT II – PRE-2009 TAILINGS DEPOSIT TEST DATA

Taken from Klohn Crippen's 2009 Site Investigation Report
Note: Data used to produce the following diagrams is from result of LD on samples obtained from Dean Stark method.
Note: Data used to produce the following diagrams is from result of LD on samples obtained from Dean Stark method.
Note: Data used to produce the following diagrams is from result of LD on samples obtained from Dean Stark method.
Note: Data used to produce the following diagrams is from result of LD on samples obtained from Dean Stark method.
Note: Data used to produce the following diagrams is from result of LD on samples obtained from Dean Stark method.
Note: Data used to produce the following diagrams is from result of LD on samples obtained from Dean Stark method.

---

**Shell Canada Energy**

**Klohn Crippen Berger**

---

**PROJECT**
Muskeg River Mine External Tailings Facility
Fine Tailings Model Development

**TITLE**
ETF Pond Surveys
Historic Profiles of Solids content, Fines content, Clay Content and MBI
Main Pond
Sounding point MP - S07

**PROJECT No.**
A02956J10

**DATE**
December, 2010

**Fig. No.**
Figure 2 -7
Note: Data used to produce the following diagrams is from result of LD on samples obtained from Dean Stark method.
Note: Data used to produce the following diagrams is from the result of LD on samples obtained from Dean Stark method.
Note: Data used to produce the following diagrams is from result of LD on samples obtained from Dean Stark method.
Note: Data used to produce the following diagrams is from result of LD on samples obtained from Dean Stark method.
Appendix C

Canadian Natural's Horizon Mine
External Tailings Facility Case Record
Memo

To: File

File No: CG25409

Date: June 2013

From: Catherine Fear

Reviewed by: Ed McRoberts

Subject: Horizon Mine External Tailings Facility Case Record

1.0 INTRODUCTION

Canadian Natural Resource Limited's (Canadian Natural's) Horizon Mine external tailings facility (ETF) is an active tailings facility that has been in operation since Q3 2008. From mine start up to present, the ETF has been the only tailings placement area at the Horizon Mine. Figure 1 presents an October 2012 aerial photograph of the facility. Two types of tailings streams are generated by the Horizon Mine extraction plant and discharged at the ETF, as follows:

- Extraction Tailings
- Froth Treatment Tailings (FTT)

At the Horizon Mine, the quantity of fines reporting to rejects is considered to be negligible, given that any rejects produced are re-fed through the system until they are washed out.

As shown in Figure 1, the Horizon mine ETF is contained by natural ground to the west and a horseshoe shaped dyke (Dyke 10) along the north, east and south sides. Dyke 10 is being constructed entirely of overburden and interburden, using a downstream method of construction. Unlike other ETFs in the oil sands industry, no tailings sand cell construction is being used to raise the dyke.

The ETF is a young facility, with about 4 years of tailings deposition to date. Fluids were first impounded in the ETF in August 2008, and full tailings production rates were reached in May 2009. Due to an unexpected and extended plant shutdown, no tailings were produced over a 7 month period from January to August 2011.

2.0 INFORMATION PROVIDED BY CANADIAN NATURAL FOR CURRENT STUDY

Table 1 presents a summary of the information provided by Canadian Natural for this study. The summary of the Horizon ETF case record presented herein is based on this information as well as some email and telephone discussions with Canadian Natural.

3.0 SAMPLING & MEASUREMENT METHODS

Table 2 provides a list of the various sampling and measurement methods used to generate the Horizon ETF data provided for this study. AMEC's scope does not include an evaluation of the benefits/limitations of the methods used relative to the accuracy of the resulting data and the calculated fines contents/captures.
4.0 OPERATIONAL HISTORY

4.1 Process Flow Diagram

Figure 2 provides a basic process flow diagram for Phase I and Tranche 2 of the Horizon Mine, taken from Canadian Natural's 2010 tailings submission to the ERCB\(^1\). As shown in the figure, two types of tailings are produced: Extraction Tailings and Froth Treatment Tailings (FTT)\(^2\). Extraction tailings are comprised of PSV underflow and flotation underflow, which have been combined in one pumpbox, creating whole tailings. Starting in 2009, CO\(_2\) has been injected into the Extraction Tailings and FTT streams. The purpose of treating the tailings with CO\(_2\) is to increase the fines settling rate by lowering the pH\(^3\).

Figure 2 also shows that the extraction plant is intended to produce no rejects. However, there have been some issues with the secondary crusher, and rejects are re-fed through the system. The rejects are mostly siltstones; "clay balls" have not been observed. After two or three cycles of re-feeding, the remaining "washed out" rejects are directed to waste dumps and/or used for road construction, etc. The quantity/quality of rejects is not monitored, but the quantity of fines reporting to rejects is considered to be negligible.

During initial operations in 2009/2010, high fines ore was being mined, with low \(d_{50}\) (in the order of 90 to 100 microns). Subsequently, the mine moved into lower fines ore, with higher \(d_{50}\) (variable with time, but with average values from late 2010 to 2012 being in the order of 110 to 150 microns, depending on the time period).

4.2 Tailings Lines

4.2.1 Extraction Tailings

From start-up in Q3 2008 through to year end 2012, Extraction Tailings were directed to the ETF via three 30" lines (TL2, TL3 and TL5), with open-ended discharge. At any given time, typically two of the three lines are active. The specific locations of the discharge points over time have not been surveyed or tracked; therefore, there are no detailed records of where the ends of the pipelines were located on any given date. However, Attachment I presents a series of plan view schematics, provided by Canadian Natural, illustrating the general deposition areas for these three lines over time.

Originally, the three Extraction Tailings lines were spread out with Line 2 to the south, Line 3 to the north, and Line 5 in the middle (see Slides 2 and 3 in Attachment 1). Later, all three lines were moved to the north half of the ETF (see Slides 4 and 5 in Attachment 1), and from late 2010 to early 2011, all three lines were moved to the south half of the ETF (see Slides 6 to 8 in Attachment 1).

---

\(^1\) Horizon Tailings Management Plan, Canadian Natural Resources Limited, CNRL Doc. No. 13-RPT-TA-0001, Revision 2, November 2010, available on the ERCB's website.

\(^2\) In Figure 2, FTT are referred to as Naptha Recovery Unit (NRU) tailings; FTT is the current terminology used by Canadian Natural.

\(^3\) Same reference as for Footnote 1.
The current piping and pumping systems allow for Extraction Tailings to be pumped up to 2.5 to 2.7 km from the top of the main tailings ramp (see Figure 1). The three Extraction Tailings lines are typically operated with short/long pours as follows:

- The overall pour length of 2.5 to 2.7 km from the main tailings ramp is divided into about three segments of equal length, with one line assigned to each segment.
- Short pour location stays fixed, closest to the main tailings ramp for the given stretch of dyke assigned to a given line.
- Priority is given to the long pour; the short pour for a given line only operates as the default when the long pour needs to be moved.
- Long pour starts closer to the main tailings ramp and, over time, is moved farther from the main tailings ramp (so farther north when pouring in the north and farther south when pouring in the south).
- Long pour for the first line moves towards short pour for the second line; long pour for the second line moves towards short pour for the third line.
- When a given long pour is kept in a particular location, a cone develops; it is then moved about 150 m and another cone develops; it keeps being moved until it reaches the farthest long pour location for that line.

4.2.2 Froth Treatment Tailings

FTT is a relatively minor stream and only results in about 2 to 3% of the total tailings produced. FTT have been discharged into the ETF via a single 14” line, with open-ended discharge. For the first few years of operations, FTT were discharged at the north end of the ETF in a fixed location (see Slide 5 in Attachment I). More recently, the FTT line has been relocated to the east side of the ETF, at about the mid-point of Dyke 10, where it is being discharged in the same general location as the Extraction Tailings. When FTT were being discharged at the north end of the ETF, the FTT beach was clearly visible and could be distinguished from the adjacent whole tailings beach. However, now that FTT is discharged in the same area as Extraction Tailings, it is no longer distinctly visible, as it is mixing into the Extraction Tailings beach.

4.3 Dyke Construction & Pond Operations

Initially, Dyke 10 was being raised along its entire alignment. However, once the leading edge berm (LEB) along the upstream side of the dyke reached El. 355 m, Canadian Natural adopted a different strategy, in order to keep the dyke raising (mining) and tailings operations separate. The current approach is to raise either the north or south half of Dyke 10 while all three Extraction Tailings lines discharge from the other half of the dyke. As of year end 2012, the north half of Dyke 10 was being raised, and tailings were being discharged from the south half.

This dyke construction and tailings deposition strategy eventually results in a significant amount of beach above water forming at the active pour locations. For example, as of October 2012, Figure 1 shows a large above water beach south of the main tailings ramp. North of the main tailings ramp, where tailings are not actively being discharged, only relatively short beaches are present above the current pond level. For comparison, Slide 5 in Attachment I presents an earlier view of the ETF (at the end of 2010), showing a large above water beach present north of the main tailings ramp, when the active pour locations were in the north. When the three Extraction Tailings lines are eventually all moved back to the north, they will initially discharge into a relatively deep pond, until similar large above water beaches once again form in the north half of the ETF.
Originally, tailings were only overboarded, creating beaches against the upstream side of Dyke 10, with no trackpacking or other compaction of the beaches. However, in the last year or so, the upper beaches became relatively steep (4%) and were burying the discharge points too quickly. Therefore, in order to maximize beach storage volumes and the length of time during which tailings could be discharged in the south while the dyke was still being raised to the north, dozers and excavators were used to move sand around, providing mechanical assistance to generating an overall BAW slope of about 1%. To further assist with sand storage capacity once all of the long pour locations were used, some modified cell construction was also initiated, stepped in over the south above water beaches.

Observations made during tailings beaching operations indicate that the depositional behaviour in a given location can change relatively rapidly over time – from building significant amounts of beach quickly, to cutting a channel, to filling in a channel. Steeper beaches near discharge points have often had large accumulations of 5" cobbles; however, in other steep beach areas, no such rocks have been visible.

The minimum elevation required at any given time for the core of Dyke 10 is driven by the fluid levels in the ETF plus the requirement to store a PMP event, which, at current pond levels, would cause the water level in the pond to rise by about 2.5 m. However, the elevation of the LEB, along the upstream edge of Dyke 10, is driven by BAW containment requirements in one half of the ETF while the other half of Dyke 10 is being raised. Therefore, the LEB, from which tailings are discharged, starts out significantly above the pond level (in the order of up to 12 m) when beaches are first deposited in a given half of the ETF.

Recycle water is returned to the extraction plant via siphons located at the southeast corner of the ETF (see Figure 1). As indicated by the annual tailings submissions to the ERCB, the interpreted thickness of the recycle water zone (based on the ERCB definition of fluid having a solids content less than or equal to 1%) varied with time as follows:

- 2009 – typically about 9 m
- 2010 – typically about 3 m
- 2011 – typically about 4 m

4.4 Pond Water Chemistry

Water chemistry information provided by Canadian Natural for recycle water in the ETF indicates the following:

- TSS increased from July 2009 to November 2009, reaching a maximum of about 20,000 mg/L. During November 2009, levels decreased significantly, to very low values, and have typically remained below about 100 to 200 mg/L through to September 2012. We understand that the significant decrease corresponds to the addition of CO₂.
- Sodium ion concentrations increased from about 200 mg/L to about 700 mg/L from July 2009 to July 2010, at which point raw water was added. From July 2010 onwards, levels have remained relatively constant at about 700 mg/L, with some fluctuations observed, particularly during and after the 7 month shutdown in 2011, and after the introduction of more raw water in December 2011.
- Chloride and bicarbonate concentrations followed similar patterns over time as sodium concentrations, with September 2012 levels being in the order of 500 mg/L and 1000 mg/L, respectively.
5.0 MASS BALANCE

AMEC prepared the annual pond status summary reports for the ETF for 2009, 2010 and 2011 (see list of reports in Table 1). Table 3 summarizes the fines capture for the ETF beaches and the MFT make in the ETF from 2009 to 2011, as reported in the 2011 pond status report. Fines contents for both the ore and tailings are based on washed #325 sieve analyses on bitumen free samples to assess the percentage of the mineral solids passing 44 microns.

The fines captures reported in Table 3 are based on the direct method. Given the relatively tight, but typically negative, fines mass balance closures in Table 3, somewhat higher fines captures would be calculated using the subtraction method, as follows: 61 to 72% in 2009 (depending on whether a layer of MFT in the western portion of the ETF is included or not); 57% in 2010; and 57% in 2011.

As indicated in Table 3, the fines capture decreased from 2009 to 2010, but remained relatively constant from 2010 to 2011. The 2010 pond status report commented that "the difference in beach fines capture rates between the 2009 and 2010 models is likely a reflection of the changed depositional environment in 2010. In 2010, a significant portion of the tailings were deposited as BAW deposits, which typically have low fines capture because of the high energy environment. In 2009, most of the tailings were being deposited subaqueously as BBW tailings where the lower energy environment allows for higher fines capture."

Canadian Natural's 2010 tailings submission to the ERCB states that "... preliminary sampling of the fines capture in the conventional beaches formed from start-up is close to 60%, much higher than the assumed value of 45%" and goes on to say that "both lab and plant testing indicates that the higher fines capture in the beaches is likely the result of CO$_2$ addition to tailings which helps improve settling of fines".

The 2012 mass balance resulted in an overall calculated fines capture from start-up to 2012 of about 62%, using the method of subtraction (personal communication, Mr. Eric Coulombe). AMEC's scope for the beach fines capture project did not include an audit of the 2012 mass balance for the Horizon ETF.

6.0 SYNTHESIS OF DATA PROVIDED

6.1 Tailings Line Slurry Characteristics

6.1.1 Introduction

For the purpose of Directive 074 reporting requirements, Canadian Natural characterizes the fines content of both the ore and the tailings deposits in the ETF using wet #325 sieve tests. However, no wet #325 sieve testing is completed on samples of tailings slurry. The particle size distribution of the tailings slurry in the various tailings lines is assessed using laser diffraction testing. Therefore, the tailings slurry fines content and clay content data provided by Canadian Natural from its PI database, and presented herein, are the results of laser diffraction tests.
6.1.2 Extraction Tailings

Figure 3, Figure 4 and Figure 5 present flow rate data on a 12 hour basis for Extraction Tailings lines TL2, TL3 and TL5, respectively. Figure 6, Figure 7 and Figure 8 present the corresponding density (specific gravity) data, and Figure 9, Figure 10 and Figure 11 present the corresponding Dean Stark mineral solids content data. The plots present all data downloaded from Canadian Natural's PI database, and do not attempt to filter out the data that were collected when the lines were down or on flush.

These figures indicate that significant variations in both flow rate and density occurred in all three of the Extraction lines over short time intervals on an on-going basis. A summary of the typical range in values is as follows:

- Flow rate in each line – typically between about 6,000 and 8,000 m$^3$/hr
- Density (specific gravity) in each line – typically between about 1.2 and 1.4
- Dean Stark mineral solids content in each line – typically between about 35 and 50%

Figure 12, Figure 13 and Figure 14 present the laser diffraction fines content data on a 12 hour basis for Extraction Tailings lines TL2, TL3 and TL5, respectively. Figure 15, Figure 16 and Figure 17 present the corresponding clay content data. A summary of the typical range in value is as follows:

- Fines content (laser) – typically between about 10 and 30%
- Clay content (laser) – typically between about 1 and 4%

Superimposed on Figure 12, Figure 13 and Figure 14, for comparison, are the wet #325 sieve fines contents for the ore on a daily basis. While it can be difficult to make direct comparisons between wet #325 sieve fines contents and laser diffraction fines content, the figures indicate that there are much larger variations in the slurry fines content over time than the ore fines content. This may be a real difference or may represent the different averaging processes used for the ore versus the tailings slurry. In addition, setting aside the effects of measurement methods, the figures indicate that the slurry has a relatively similar average fines content as the ore, as would be expected, given that Extraction Tailings comprise the majority of the tailings produced.

Figure 18, Figure 19 and Figure 20 present the CO$_2$ injection rates on a 12 hour basis for Extraction Tailings lines TL2, TL3 and TL5, respectively. These figures clearly indicate that the CO$_2$ injection rates also varied significantly over short time intervals on an on-going basis.

6.1.3 Froth Treatment Tailings

Figure 21 presents flow rate data on a 12 hour basis for the FTT line. Figure 22 presents the corresponding density (specific gravity) data, and Figure 23 presents the corresponding Dean Stark mineral solids content data. The plots present all data downloaded from Canadian Natural's PI database, and do not attempt to filter out the data that were collected when the lines were down or on flush.
These figures indicate that significant variations in both flow rate and density occurred in the FTT line over short time intervals on an on-going basis. A summary of the typical range in values is as follows:

- Flow rate – typically between about 2,000 and 4,000 m$^3$/hr
- Density (specific gravity) – typically between about 1.05 and 1.25
- Dean Stark mineral solids content – typically between about 10 and 30%

Figure 24 presents the laser diffraction fines content data on a 12 hour basis for the FTT line, and Figure 25 presents the corresponding clay content data. Superimposed on Figure 24, for comparison, are the wet #325 sieve fines contents for the ore on a daily basis. A summary of the typical range in values is as follows:

- Fines content (laser) – typically between about 40 and 80%
- Clay content (laser) – typically between about 3 and 9%

Superimposed on Figure 24, for comparison, are the wet #325 sieve fines contents for the ore on a daily basis. While it can be difficult to make direct comparisons between wet #325 sieve fines contents and laser diffraction fines content, the figure indicates that there are much larger variations in the slurry fines content over time than the ore fines content. This may be a real difference or may represent the different averaging processes used for the ore versus the tailings slurry. In addition, setting aside the effects of measurement methods, the figure indicates that the FTT slurry has a much higher average fines content than the ore, as would be expected for froth treatment tailings.

### 6.1.4 Density versus Flow Rate

Figure 26 to Figure 29 present cross-plots of density versus flow rate for each of the four tailings lines (TL2, TL3, TL5 and FTT). In addition to showing the typical range in flow rate and density, these figures indicate that the total amount of time that the tailings lines are on flush is significant.

For the Extraction Tailings lines, based on the data provided, when each line was operational, the lines had flow rates less than 1100 kg/m$^3$, and were pumping essentially just water, as follows:

- TL2 – about 21% of the time
- TL3 – about 19% of the time
- TL5 – about 22% of the time

### 6.1.5 Clay Content versus Fines Content

Figure 30 presents a plot of laser diffraction clay content versus laser diffraction fines content, for the slurry in each of the Extraction Tailings lines and the FTT line. This figure indicates that there is a relatively constant ratio between MBI and fines content up to a fines content of about 80%, above which the ratio increases.
6.2 Tailings Deposit Characteristics

Figure 31 to Figure 36 present six cross-sections through the ETF, namely Sections 200, 300, 400, 500, 600 and 900 (all plotted looking south, with Dyke 10 to the left). The cross-section locations are shown in Figure 1. These figures show the annual development of the dyke, beaches and pond over time, from 2009 to 2012.

Figure 37 shows all of the tailings sampling locations for the 2009 to 2012 site investigations. The laboratory test results from the closest boreholes to each cross-section are superimposed on the various cross-sections in Figure 38 to Figure 55, as follows:

- **Section 200**
  - Figure 38 – Dean Stark solids content (total mineral content)
  - Figure 39 – fines content (< 44 micron)
  - Figure 40 – MBI
- **Section 300**
  - Figure 41 – Dean Stark solids content (total mineral content)
  - Figure 42 – fines content (< 44 micron)
  - Figure 43 – MBI
- **Section 400**
  - Figure 44 – Dean Stark solids content (total mineral content)
  - Figure 45 – fines content (< 44 micron)
  - Figure 46 – MBI
- **Section 500**
  - Figure 47 – Dean Stark solids content (total mineral content)
  - Figure 48 – fines content (< 44 micron)
  - Figure 49 – MBI
- **Section 600**
  - Figure 50 – Dean Stark solids content (total mineral content)
  - Figure 51 – fines content (< 44 micron)
  - Figure 52 – MBI
- **Section 900**
  - Figure 53 – Dean Stark solids content (total mineral content)
  - Figure 54 – fines content (< 44 micron)
  - Figure 55 – MBI

When looking at these cross-sections, it is important to note the year in which a given borehole was drilled, as indicated in the legends, and then compare it to the appropriate surfaces for that year, in order to distinguish between results for samples of fluid fine tailings versus beach.

For each of the boreholes shown on the six cross-sections, an individual plot, using expanded scales, is included in Attachment II, presenting the following test data on a single plot: Dean Stark solids content, fines content and MBI.

Figure 56 presents a plot of fines content versus solids content and Figure 57 presents a plot of MBI versus fines content. Figure 57 indicates that there is a relatively constant ratio between MBI and fines content in the beach deposits, with the ratio increasing significantly as fines content increases in the overlying MFT, which indicates sorting or segregation in the MFT.
7.0 SUMMARY

The following key summary points can be made, when considering the ETF as a whole:

- The Horizon Mine produces two tailings streams – extraction tailings and froth treatment tailings (FTT). Extraction tailings comprise the vast majority of the tailings produced.
- The Horizon Mine produces essentially no rejects, and those that are produced are considered to be free of fines, as any rejects produced are recycled until they are washed out. Therefore, unlike other oil sand mines, essentially all of the fines mined report to tailings.
- The containment dyke (Dyke 10) for the Horizon ETF is being constructed entirely of overburden and interburden; unlike other ETFs in the oil sand industry, conventional cell construction is not being used. All tailings produced are beached from Dyke 10.
- Tailings disposal and dyke raising activities alternate between the north and south halves of the facility: when the dyke is being raised in the north, tailings are discharged in the south over a significant period of time; when the dyke is being raised in the south, tailings are discharged in the north for a significant period of time. This results in alternating large BBW and BAW zones.
- Based on information provided in the 2011 annual ETF status submission to the ERCB (AMEC, 2012):
  - The overall average SFR of the ore mined to date is 3.53 (i.e. SFR_s of 22.1%, since no fines to rejects).
  - By subtraction, the overall fines capture in the ETF beaches was 57.1%.
- A slurry SFR_s of 3.53 and a fines capture of 57.1%, assuming 100% sand capture, infers an overall beach deposit SFR_D for the whole ETF of 6.19 (or a fines content of 13.9%). The actual sand capture is slightly less than 100% as AMEC (2012) indicated that the MFT had a fines content of 97% and, therefore, contained a small amount of sand.
### Table 1. Horizon ETF Information Provided by Canadian Natural for Current Study

<table>
<thead>
<tr>
<th>Category</th>
<th>Document or File Provided</th>
<th>Date Provided</th>
<th>Information Included</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>PowerPoint file entitled &quot;Info request-Draft&quot;</td>
<td>01 Nov 2012</td>
<td>Overview of ETF operations</td>
</tr>
<tr>
<td></td>
<td>Spring and fall air photos of the ETF from Fall 2009 through to Spring 2012</td>
<td></td>
<td>Fall 2009 to Spring 2012 air photos</td>
</tr>
<tr>
<td></td>
<td>Fall 2012 air photo of the ETF</td>
<td>14 Nov 2012</td>
<td>Fall 2012 air photo</td>
</tr>
<tr>
<td>Ore Data</td>
<td>Excel file entitled &quot;CNRL Tailings Operations Summary_For AMEC_Mar04-2013&quot; (replaced earlier files provided on 12 Nov 2012 and 01 Nov 2012)</td>
<td>04 Mar 2013</td>
<td>File provided is used for planning; therefore, the majority of the data consist of calculated/projected values, not actual measured data. However, the file included some ore data from Canadian Natural’s geological model, Ore Insight, on a daily basis from 02 Jan 2010 to 04 Oct 2012, as follows: total tonnage, bitumen content, D50, fines content, MBI, and some chemical composition data (Na, K, Ca, Mg, Cl and pH). The ore fines content is based on wet #325 sieve. The ore tonnages in this file have not been updated to reflect actual processed values.</td>
</tr>
<tr>
<td>Tailings Slurry Data</td>
<td>Excel file entitled &quot;For AMEC_Tailings Data_March14-2013&quot; (replaced an earlier file provided on 04 Mar 2013)</td>
<td>14 Mar 2013</td>
<td>Contained the following data, on a 12 hour basis, from 01 Jan 2009 to 01 Jan 2013: Extraction Tailings lines TL2, TL3 and TL5 – flow rate; density; velocity; bitumen, solids &amp; water contents; fines content; clay content; C02 injection; suction pressures; discharge pressures. These fines contents and clay contents for the tailings slurry are based on laser diffraction. Froth Treatment Tailings line – flow rate; density; bitumen, solids &amp; water contents; fines content; clay content.</td>
</tr>
<tr>
<td>Pipeline Locations</td>
<td>PDF files entitled &quot;28-PR-PI0001-00_1-0&quot; through to &quot;28-PR-PI0012-00_1-0&quot;</td>
<td>01 Nov 2012</td>
<td>Series of IFC drawings showing tailings line layouts.</td>
</tr>
<tr>
<td></td>
<td>PowerPoint file entitled &quot;Tailings Deposition Areas Over Time_Jan29-2013&quot;</td>
<td>30 Jan 2013</td>
<td>Series of plan view schematics illustrating general discharge locations for each tailings line from start-up to year end 2012.</td>
</tr>
<tr>
<td>Tailings Deposit Data</td>
<td>2009 site investigation data &amp; dyke/beach/pond surfaces</td>
<td>Compiled in Jan/Feb</td>
<td>Laboratory test data for tailings samples include: Dean Stark test results (bitumen, solids and water contents), wet #325 sieve fines content, and MBI. Surfaces include: dyke &amp; above water beach, pond bottom (determined via CT09), and pond levels.</td>
</tr>
<tr>
<td></td>
<td>2010 site investigation data &amp; dyke/beach/pond surfaces</td>
<td>2013 from existing AMEC files</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2011 site investigation data &amp; dyke/beach/pond surfaces</td>
<td>2012 from existing AMEC files</td>
<td></td>
</tr>
<tr>
<td>ETF pond water quality</td>
<td>Excel file entitled &quot;Pond 1 Water Quality_August 22 2012&quot;</td>
<td>01 Nov 2012</td>
<td>Includes data from 01 Jul 2009 to 01 Oct 2012 for the following: TSS, pH, Ca, Mg, K; Na; Cl; Alkalinity; Bicarbonate, Sulphate, Oil/Grease, and EC.</td>
</tr>
</tbody>
</table>

Notes:
1. Documents/information noted as being from existing AMEC files were used for the current COSIA study with Canadian Natural's permission.
## Table 2. Sampling & Measurement Methods for Horizon ETF Data Provided for Current Study

<table>
<thead>
<tr>
<th>Category</th>
<th>Type of Sample / Measurement</th>
<th>Method Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore</td>
<td>Bitumen, mineral and water composition</td>
<td>Dean Stark</td>
</tr>
<tr>
<td></td>
<td>Fines content</td>
<td>Wet #325 sieve</td>
</tr>
<tr>
<td>Rejects</td>
<td>N/A</td>
<td>Not measured; considered to contain a negligible amount of fines.</td>
</tr>
<tr>
<td>Tailings Slurry</td>
<td>Bitumen, mineral and water composition</td>
<td>Dean Stark</td>
</tr>
<tr>
<td></td>
<td>Particle size distribution</td>
<td>Laser diffraction</td>
</tr>
<tr>
<td>Tailings Deposit</td>
<td>Mudline (interface between water and fluid fine tailings)</td>
<td>Sonar</td>
</tr>
<tr>
<td>Field Measurements</td>
<td>Pond bottom surface (interface between fluid fine tailings and beaches)</td>
<td>CT09</td>
</tr>
<tr>
<td>Tailings Deposit</td>
<td>Bitumen, mineral and water composition</td>
<td>Dean Stark</td>
</tr>
<tr>
<td>Laboratory Testing</td>
<td>Particle size distribution</td>
<td>Fines content based on wet #325 sieve Clay content measured indirectly via MBI</td>
</tr>
</tbody>
</table>
Table 3. Horizon ETF Fines Capture and MFT Make – 2009 to 2011

<table>
<thead>
<tr>
<th>Year</th>
<th>Overall Weighted Average Fines Content of Total Ore Mined to Date</th>
<th>Fines Mass Balance Closure</th>
<th>Best Estimate Fines Capture</th>
<th>Average Beach Fines Content</th>
<th>MFT make</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>24%</td>
<td>-11% to +0.8%</td>
<td>62%</td>
<td>BAW 8% BBW 19%</td>
<td>0.06 to 0.12</td>
</tr>
<tr>
<td>2010</td>
<td>22%</td>
<td>-2.4%</td>
<td>54%</td>
<td>BAW 7% BBW 9% HFT 33%</td>
<td>0.30</td>
</tr>
<tr>
<td>2011</td>
<td>20%</td>
<td>-4.9%</td>
<td>52%</td>
<td>BAW 7% BBW 13.5%</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Notes:
1. Information in this table for 2009, 2010 and 2011 is taken from the 2011 pond status report (AMEC, 2012; see Table 1).
2. Overall weighted average fines content of total ore mined to date is to September or October, depending on the year.
4. Fines capture = (mass of fines in beaches) / (mass of fines in ore processed).
5. BAW = beach above water; BBW = beach below water; HFT = high fines tailings – a 2 m thick high fines content layer at the base of the tailings deposit detected in the 2010 investigation.
6. Assumed based on experience with other similar facilities; BAW was not sampled & tested in 2009.
7. Assumed based on results of 2010 investigation; BAW was not sampled & tested in 2011.
8. MFT make = cubic metres of fluid fine tailings per tonne of ore processed since start-up.
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Horizon Process Flow Diagram - Phase I & Tranche 2 (taken from CNRL's 2010 ERCB Submission)

Average Ore Grade
Note 1: CO2 addition to Extraction and NRU Tailings
Note 2: Rates are time dependent and affected by performance of CO2 addition (under review)
TL2 Flow Rate - 2009 to 2012 (12 h Data)

Flow Rate (m³/hr)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Jan-09
1-Jan-10
1-Jan-11
1-Jan-12
31-Dec-12
Date

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Extraction Tailings Line TL2 - Flow Rate vs Time

FIGURE 3
TL3 Flow Rate - 2009 to 2012 (12h Data)
TL5 Flow Rate - 2009 to 2012 (12h Data)

Flow Rate (m³/hr) vs Time (Jan 2009 - Dec 2012)

Date: 1-Jan-09 to 31-Dec-12

Legend:
- TL5 Flow Rate
Figure 6

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BEACH FINES CAPTURE STUDY

Extraction Tailings Line TL2 - Density (Specific Gravity) vs Time

TL2 Density (SG) - 2009 to 2012 (12 h Data)
TL3 Density (SG) - 2009 to 2012 (12 h Data)

* TL3 Density (SG)

Date

1-Jan-09
1-Jan-10
1-Jan-11
1-Jan-12
31-Dec-12

Density (SG)

0.0
0.5
1.0
1.5
2.0
2.5

Extraction Tailings Line TL3 - Density (Specific Gravity) vs Time

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TL2 Solids Content - 2009 to 2012 (12 h Data)

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AMEC Environment & Infrastructure

Extraction Tailings Line TL2 - Solids Content vs Time

FIGURE 9
TL3 Solids Content - 2009 to 2012 (12 h Data)
TL5 Solids Content - 2009 to 2012 (12 h Data)

- TL5 Solids Content

Date

1-Jan-09 1-Jan-10 1-Jan-11 1-Jan-12 31-Dec-12

Solids Content [%]
TL2 Laser Fines Content - 2009 to 2012 (12 h Data)

Graph showing TL2 Laser Fines Content and Ore Daily #325 Sieve Fines Content over the period from January 2009 to December 2012.
TL2 Laser Clay Content - 2009 to 2012 (12 h Data)

- TL2 Laser Clay Content

Date

Laser Clay Content (%)
TL5 Laser Clay Content - 2009 to 2012 (12 h Data)

Extraction Tailings Line TL5 - Clay Content vs Time

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AMEC Environment & Infrastructure

Extraction Tailings Line TL5 - Clay Content vs Time

FIGURE 17
TL2 CO₂ Injection - 2009 to 2012 (12 h Data)

- TL2 CO₂ Injection

Extraction Tailings Line TL2 - CO₂ Injection vs Time

FIGURE 18
TL5 CO₂ Injection - 2009 to 2012 (12 h Data)
Vehicle Logo

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BEACH FINES CAPTURE STUDY

Froth Treatment Tailings Line - Flow Rate vs Time

FIGURE 21

P:\Projects\Calgary\OST\OST вместо\OST вместо\Reports\Finals\Client_dwn\Froth_Treatments_Figures_FINAL_June2013.xlsx
FIGURE 22

Froth Treatment Tailings Line - Density (Specific Gravity) vs Time

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BEACH FINES CAPTURE STUDY
FTT Solids Content - 2009 to 2012 (12 h Data)
FIGURE 24

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BEACH FINES CAPTURE STUDY

Froth Treatment Tailings Line - Fines Content vs Time
Horizon ETF - TL3 - Density (Sp. Grav.) vs Flow Rate - 12 h Data
Horizon ETF - TL5 - Density (Sp. Grav.) vs Flow Rate - 12 h Data
Horizon ETF - FTT - Density (Sp. Grav.) vs Flow Rate - 12 h Data

Flow Rate (m³/hr)

Density (Sp. Grav.)

0 2000 4000 6000 8000 10000 12000 14000

0.5 1 1.5 2 2.5

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BEACH FINES CAPTURE STUDY

FTT - Density vs Flow Rate

FIGURE 29
Clay Content vs Fines Content (both Laser)

Tailings Slurry Clay Content vs Fines Content

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JR2
TL3
TL5
FTT

FIGURE 30 AS SHOWN

BEACH FINES CAPTURE STUDY

Tailings Slurry Clay Content vs Fines Content

PROJECT NO: CG25409
FIGURE NO: 30

DATE: JUNE 2013

SCALE: AS SHOWN

P:\Projects\CalgaryGeo\CG25409 - OSTC Beach Study\300\Reports\FINAL_June2013\Appendix C_Figures_FINAL_June2013.xlsx
Dyke 10

Cross Section - 200 Series (Looking South)

Offset (m) vs Elevation (MASL)

- 2010 Beach (UDAR Oct 2, 2010 CT09 Oct 23-Nov 1, 2010)
- 2011 Beach (UDAR Oct 8, 2011)
- 2011 CT09 (Aug 23-26, 2011)
- 2012 Beach (UDAR Sept 24, 2012)
- DG
- Water Level

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Section 200

P:\Projects\Calgary\CG25409 - OSTC Beach Study\300 Reports\Final\Figures_FINAL_June2013.xlsx
Cross Section - 400 Series (Looking South)

Dyke 10

Elevation (MASL)
Offset [m]

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AMEC Environment & Infrastructure

FIGURE 33

CLIENT LOGO  CLIENT DWN BY:  CHK'D BY:  PROJECTION:  DATUM:  SCALE:
PROJECT  TITLE  DATE:  PROJECT NO:  REV. NO.  FIGURE NO:
P:\Projects\Calgary Geo\CG25409 - OSTC Beach Study\300 Reports\FINAL_June2013\Appendix C_Figures_FINAL_June2013.xlsx
Dyke 10

Cross Section - 600 Series (Looking South)

- 2009 Beach (LiDAR Oct 3, 2009, CT09 Oct 11-13, 2009)
- 2010 Beach (LiDAR Oct 2, 2010 CT09 Oct 23-Nov 1, 2010)
- 2011 Beach (LiDAR Oct 8, 2011)
- 2011 CT09 (Aug 23-26, 2011)
- 2012 Beach (LiDAR Sept 24, 2012)
- 2012 CT09 (Sept 12-15, 2012)
- DG
- Water level

Offset (m)

Elevation (NAG20

0 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 2800 2900 3000 3100 3200 3300 3400

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BEACH FINES CAPTURE STUDY

Section 600
Main tailings ramp

2009 to 2012 Sampling Locations
Cross Section - 200 Series
Solids Content vs. Elevation

Notes:
Values shown at start of point of sample. Beach samples were 1m in length, fluid samples were point samples.
Lab samples identified as unsigned (labeled) were discarded from plot.

Solids Content:
\[
\text{Solids Content} = \frac{W_{0c} + W_{0u}}{W_{0c} + W_{0u} + W_{0m} + W_{0u}}
\]
Cross Section - 200 Series
Fines Content vs. Elevation

Notes:
Values shown at start of sample. Beach samples were 1m in length, fluid samples were joint samples.
Lab samples identified as original ground were excluded from plot.

Fines Content: \[ \frac{W_{f}}{W_{f} + W_{\text{m}} + W_{\text{w}}} \]
Cross Section - 300 Series
Solids Content vs. Elevation

Notes:
Values shown at start of sample. Beach samples were line in length; fluid samples were point samples.
Values shown with an error bar are associated with a water level reading.

Solids Content = \frac{(W_{r.w} + W_{f.w})}{(W_{r.w} + W_{f.w} + W_{w.w} + W_{r.w})}

Offset (m)
368
362
356
350
348
346
340
338
334
332
700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 2800 2900 3000 3100 3200 3300 3400

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Section 300 - Dean Stark Solids Content
Cross Section - 300 Series

Fines Content vs. Elevation

Notes:
Values shown at start of sample. Beach samples were 1m in length, fluid samples were point samples.
Lab samples identified as original ground were excluded from plot.

Fines Content: $W_m - W_l$

FIGURE 42
Cross Section - 300 Series
MBI vs. Elevation

Notes:
Values shown at start of sample. Beach samples were 1 m in length, fluid samples were point samples. Lab samples identified as original ground were excluded from plot.
Cross Section - 400 Series
Solids Content vs. Elevation

Notes:
Values shown at start of samelle. Beach samples were 1m in breadth; fluid samples were oxid.s samples.
Lab samples identified as original ground were excluded from plot.

Solids Content = ΔW
ΔW = Wf - Wl

CLIENT: Canada’s Oil Sands Innovation Alliance

BEACH FINES CAPTURE STUDY

PROJECT: Section 400 - Dean Stark Solids Content

FIGURE 44
Cross Section - 400 Series
Fines Content vs. Elevation

Notations:
Values shown at start of sample. Beach samples were 1m in length, fluid samples were spot samples.
Lab samples identified as original ground were excluded from plot.

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AMEC Environment & Infrastructure
Cross Section - 400 Series

MBI vs. Elevation

Notes:
Values shown at start of sample. Beach samples were 1m in length, fluid samples were point samples. Lab samples identified on original ground were excluded from plot.
Notes:
Values shown at start of sample. Beach samples were 1m in length, fluid samples were point samples.
Lab samples identified as criminal around were excluded from plot.
Cross Section - 600 Series
Solids Content vs. Elevation

Notes:
Values shown at start of sample. Beach samples were 3m in length, fluid samples were point samples.
Azo samples indicate an uncharged or neutral water interface/portion.

Solids Content:
\[
\frac{W_{solid} + W_{fines}}{W_{total} + W_{fines} + W_{solid} + W_{fines}}
\]

Project Title: Section 600 - Dean Stark Solids Content

Client: Canada’s Oil Sands Innovation Alliance

AMEC Environment & Infrastructure
Cross Section - 900 Series
Solids Content vs. Elevation

Notes:
Values shown at start of sample. Beach samples were 1m in length, 7x40 samples were joint sample.
Lacpar samples identified on each graph are included within plot.

Solids Content = (W_{final} + W_{initial}) / (W_{final} + W_{initial} + W_{water} + W_{sand})

FIGURE 53

CLIENT LOGO CLIENT

Canada's Oil Sands Innovation Alliance

AMEC Environment & Infrastructure

BEACH FINES CAPTURE STUDY

Section 900 - Dean Stark Solids Content
Cross Section - 900 Series

Fines Content vs. Elevation

Notes:
Values shown at start of sample. Beach samples were 1m in length, fluid samples were point samples.
Fines Content (Wf) = (Wf1 + Wf2) / 2

Elevation (m ASL)

Offsite (m)

Canada’s Oil Sands Innovation Alliance

AMEC Environment & Infrastructure

Section 900 - Fines Content
Cross Section - 900 Series
MBI vs. Elevation

Notes:
- Vials chosen at start of sample. Beach samples were 5m in length, fluid samples were point samples.
- Lab samples identified as original ground were excluded from plot.
Notes:
1. All data from 2009 to 2012, inclusive.
Notes:
1. All data from 2009 to 2012, inclusive.
2. Most data with MBI > 10 are from 2010 and 2011.
ATTACHMENT I – TAILINGS DEPOSITION AREAS OVER TIME

(Provided by Canadian Natural)
Tailings Deposition Areas Over Time

January 29, 2013

Premium Value | Defined Growth | Independent
Startup (Deposition from 355m N + S)

- TL3
- TL5
- TL2

Fall 2008

Spring 2009
End of 2009 (Deposition from 355m N + S)
2010 (Deposition From 361m N)

Spring 2010

Fall 2010
The transition from 361m N to 368m S occurred between Dec. 15 2010 and Jan. 15, 2011
2011 (Deposition From 368m S)

Spring 2011 (No Production)  Fall 2011
2012 (Deposition From 368m S)

Spring 2012

Fall 2012
End of 2012 (Deposition From 368m S / 370m N)

TL5 moved from 368m S to 370m N in November 2012
ATTACHMENT II – INDIVIDUAL BOREHOLE PLOTS

Note: Each plot includes the following test data:

- Dean Stark solids content
- Wet #325 sieve fines content (<44 microns)
- MBI

<table>
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<th>Section 500</th>
<th>Section 600</th>
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GCPT10-202

Dean Stark Solids Content (%) or Fines Content, <44 microns (%)

Average Sample Elevation (MASL)

MBI Index

Solids Content
Fines Content
2010 Water Level N/A
2010 BAW
OG
GCPT10-205

Dean Stark Solids Content (%) or Fines Content, <44 microns (%)

Average Sample Elevation (MASL)

Solids Content
Fines Content
2010 Water Level N/A
2010 BAW
OG

MBI

+ MBI
+ Solids Content
- Fines Content
--- 2010 Water Level N/A
--- 2010 BAW
--- OG
GCPT11-206

Dean Stark Solids Content (%) or Fines Content, <44 microns (%)
GCPT11-207

Dean Stark Solids Content (%) or Fines Content, <44 microns (%)

Average Sample Elevation (MASL)

Solids Content
Fines Content
2011 Water Level
2011 Pond Bottom
OG
GCPT11-208

Dean Stark Solids Content (%) or Fines Content, <44 microns (%)

Average Sample Elevation (MASL)

MBI Index

Solids Content
Fines Content
2011 Water Level
2011 Pond Bottom
OG

+ MBI
+ Solids Content
+ Fines Content
+ 2011 Water Level
+ 2011 Pond Bottom
+ OG
GCPT10-302

Dean Stark Solids Content (%) or Fines Content, <44 microns (%)

Average Sample Elevation (MASL)

MBI Index

Solids Content
Fines Content
2010 Water Level N/A
2010 BAW
DG
<table>
<thead>
<tr>
<th>Average Sample Elevation (MASL)</th>
<th>MBI</th>
<th>Solids Content</th>
<th>Fines Content</th>
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</table>

**306 (2010)**

Dean Stark Solids Content (%) or Fines Content, <44 microns (%)
305 (2011)

Dean Stark Solids Content (%) or Fines Content, <44 microns (%)

Average Sample Elevation (MASL)

MBI Index

Solids Content
Fines Content
2011 Water Level
2011 Pond Bottom
OG
Dean Stark Solids Content (%) or Fines Content, <44 microns (%)

Average Sample Elevation (MASL)

MBI Index

MBI
Solids Content
Fines Content
2011 Water Level
2011 Pond Bottom
2011 OG
405 (2010)

Dean Stark Solids Content (%) or Fines Content, <44 microns (%)
406 (2010)

Dean Stark Solids Content (%) or Fines Content, <44 microns (%)

Average Sample Elevation (MASL)

MBI Index

- MBI
- Solids Content
- Fines Content
- 2010 Water Level
- 2010 Pond Bottom
- OIS
407 (2010)

Dean Stark Solids Content (%) or Fines Content, <44 microns (%)

Average Sample Elevation (MASL)

MBI Index

- MBI
- Solids Content
- Fines Content
- 2010 Water Level
- 2010 Pond Bottom
- OG
Dean Stark Solids Content (%) or Fines Content, <44 microns (%)

Average Sample Elevation (MASL)

MBI Index

Solids Content
Fines Content

2011 Water Level
2011 Pond Bottom
OG
ETF-718 (2012)

Dean Stark Solids Content (%) or Fines Content, <44 microns (%)

Average Sample Elevation (MASL)

MBI Index

Solids Content

Fines Content

2012 Water Level

2012 Pond Bottom N/A

OG
GCPT10-501
Dean Stark Solids Content (%) or Fines Content, <44 microns (%)

Average Sample Elevation (MASL)

MBI Index

Solids Content
Fines Content
2010 Water Level N/A
2010 Pond Bottom
OG
Hole drilled after LiDAR scan of beach.
602 (2010)

Dean Stark Solids Content (%) or Fines Content, <44 microns (%)

Average Sample Elevation (MASL)

MBI Index

- MBI
- Solids Content
- Fines Content
- 2010 Water Level N/A
- 2010 BAW
- DG
Dean Stark Solids Content (%) or Fines Content, <44 microns (%)

Average Sample Elevation (MASL)

MBI Index

2010 Water Level N/A

2010 BAW

OG

603 (2010)
604 (2010)
Dean Stark Solids Content (%) or Fines Content, <44 microns (%)

Average Sample Elevation (MASL)

MBI Index

Solids Content
Fines Content

2010 Water Level N/A
2010 BAW/Pond Bottom N/A
Dean Stark Solids Content (%) or Fines Content, <44 microns (%)

Average Sample Elevation (MASL)

MBI Index

Solids Content
Fines Content
2009 Water Level
2009 BAW/Pond Bottom N/A
ETF- C-903 (2012)

Dean Stark Solids Content (%) or Fines Content, <44 microns (%)

Average Sample Elevation (MASL)

MBI Index

Solids Content
Fines Content
2012 Water Level N/A
2012 BAW
DG
ETF- C-907 (2012)
Dean Stark Solids Content (%) or Fines Content, <44 microns (%)
09-P1-S050

Dean Stark Solids Content (%) or Fines Content, <44 microns (%)

Average Sample Elevation (MASL)

MBI Index

Solids Content

Fines Content

2009 Water Level

2009 Pond Bottom

OG
Appendix D

Syncrude's Aurora Settling Basin Case Record
Memo

To: File

File No: CG25409

Date: June 2013

From: Catherine Fear

Reviewed by: Ed McRoberts

Subject: Aurora Settling Basin Case Record

1.0 INTRODUCTION

Syncrude’s Aurora Settling Basin (ASB) is an active tailings facility that has been in operation since 2000. Based on the information provided by Syncrude, the current study considers tailings deposited in the ASB up to and including 2009 only. During this time period, the ASB was the only tailings placement area at the Aurora North mine, as in-pit tailings deposition began in Q2 2010. Figure 1 presents a 2009 aerial photograph of the ASB. From 2000 to 2009, two types of tailings streams were generated by the Aurora extraction plant and discharged at the ASB, as follows:

- Coarse tailings (SCT)
- Flotation tailings

Froth produced at Aurora North is pipelined to Syncrude’s Mildred Lake operation, and the solids are deposited in the Mildred Lake Settling Basin (MLSB).

2.0 INFORMATION PROVIDED BY SYNCRUDE FOR CURRENT STUDY

Table 1 presents a list of the ASB information provided by Syncrude for this study. The summary of the ASB case record presented herein is based on this information as well as some email and telephone discussions with Syncrude.

3.0 SAMPLING & MEASUREMENT METHODS

Table 2 provides a list of the various sampling and measurement methods used to generate the ASB data provided for this study.

AMEC’s scope does not include an evaluation of the benefits/limitations of the methods used relative to the accuracy of the resulting data and the calculated fines contents/captures.

---

1 Directive 074, Baseline Survey for Fluid Deposits, Syncrude Mildred Lake and Aurora North, Year: Baseline (2010), report submitted to the ERCB by Syncrude Canada Ltd., dated 30 Sep 2010, and available on the ERCB’s website.
4.0 OPERATIONAL HISTORY

4.1 Process Flow Diagram

Figure 2 provides a basic process flow diagram for Aurora North, provided by Syncrude. The diagram also indicates the locations of sampling points. For the two types of tailings produced, coarse tailings and flotation tailings, the typical slurry data collection is limited to flow rate and density. Slurry samples are not collected for particle size distribution testing during typical operations; however, a limited amount of selected slurry sampling and testing has been completed by Syncrude at specific points in time.

4.2 Tailings Lines

From start-up in 2000 through to October 2005, Coarse Tailings were directed to ASB via one line (Coarse Tailings Line 1). In October 2005, Coarse Tailings Lines 2 and 3 were brought on-line, coinciding with the start up of the second train at Aurora North. The coarse tailings from Train 1 were combined with the coarse tailings from Train 2, sent to a tailings distributor, and then pumped to ASB via three tailings lines (Coarse Tailings Lines 1, 2 and 3).

By 2009, there were two operational Flotation Tailings lines at ASB. Data provided for Flotation Tailings Line 1 starts in July 2000, while data provided for Line 2 starts in January 2004.

Improvements in reliability of the pumping system were made in 2008. Before 2008, it was difficult to predict a pump failure, resulting in large fluctuations in flow rate. After 2008, a strategy was developed to predict and bypass a pump before it failed, resulting in smaller fluctuations in flow rate.

Figure 3 presents the tailings line layout shown in Syncrude's 2009 Directive 074 submission to the ERCB\(^2\). At the time that this figure was prepared, the line coverage was as follows:

- Coarse Tailings Line 1 – East side of ASB (Cell 60 and north to Cell 58)
- Coarse Tailings Line 2 – West side of ASB (to Cell 56)
- Coarse Tailings Line 3 – South side of ASB (to Cell 62)
- Flotation Tailings – Southwest corner of ASB (Cells 52 and 53)

Weekly tailings planning reports for ASB are prepared by Syncrude, but could not be made available in time for the current study. Therefore, it is not possible to know when the various tailings lines were discharging in specific locations around the perimeter of ASB.

4.3 Dyke Construction & Pond Operations

From 2000 to 2009, the perimeter dyke around the east side of ASB was raised via conventional cell construction and beaching techniques, using coarse tailings. The dyke along the west side of ASB includes a combination of overburden and cell construction. Cell construction was typically done in the summer, and winter consisted of beaching. Spoons were used on the ends of the lines, for energy dissipation.

Cell dimensions were typically in the order of 100 m wide (2 legs at 50 m) by 300 m long, with one active spillbox and the next one in place and ready to keep going. Faster rates of cell

---

\(^2\) 2009 Annual Tailings Plan Submission, Syncrude Aurora North (Leases 10, 12 and 34), Submitted to the ERCB by Syncrude Canada Ltd., 30 Sep 2009; report available on the ERCB's website.
construction were possible at ASB, compared to MLSB, given the coarser nature of the tailings stream used for cell construction.

Areas were prioritized for cell construction, with the ability to switch to another location if discharging tailings in the prioritized area was not possible for whatever reason. On the east side of ASB, typically the longest (farthest north) pour was prioritized first (see Ramp 4 to Cell 57/58 in Figure 3), and then tailings would be discharged working back to the south to the shortest pour (see Ramp 1 to Cell 63 in Figure 3). Tailings operations in the longest pour areas were the most challenging.

Flotation Tailings, which have a higher fines content than Coarse Tailings (see Section 6.1), resulted in longer, shallower beaches; e.g., in Figure 3, compare the Flotation Tailings beaches in Cell 53 to the Coarse Tailings beaches in Cell 60.

ASB has a bay constructed into its southwest corner (see Cell 54 in Figure 3). The recycle water system returns water from this bay back to the plant by gravity. Dyke construction had to keep up ahead of the water level in the pond; tailings operations didn’t control the water level within the pond. Cell construction was planned based on fluid predictions. As shown later in some cross-sections presented in Section 6.2 of this memorandum, in 2009, the water cap at ASB was approximately 10 m thick. This water cap is thicker than in most oil sands tailings facilities, in which the water cap is typically in the order of 3 m thick. Whether or not this has an effect on fines capture is not clear, but it might be speculated that a deeper water cap could promote larger BBW slope movements into MFT, which could enhance capture.

5.0  MASS BALANCE

BGC completed an overall fines balance for ASB for tailings deposited from 2000 to 2009, and the work was completed in five phases, with one report per phase (see list of reports in Table 1). Phase 3 consisted of a site investigation in 2009 to collect and test samples of fluid fine tailings and beach from various locations in Cells 53, 58 and 60 (see Figure 1). The results of the 2009 site investigation were incorporated into the fines balance presented in the Phase 4 report. Some additional beach data were collected in 2010, and the fines balance was updated accordingly in the Phase 5 report. Only a fines mass balance was completed for ASB; Syncrude confirmed that a total mineral mass balance has not been completed.

Table ES-1 in the Executive Summary of the Phase 5 report summarizes the results of the Phase 5 fines balance. The table indicates that 77% of all fines estimated to be in the ASB are contained with the compacted cell (shell) and beaches, while 23% are contained in the MFT. The table indicates that the mass of fines in the shell/beaches and MFT is 80.4 Mt and 23.8 Mt, respectively, for a total mass of fines in ASB of 104.2 Mt.

The Executive Summary of the Phase 5 report also states the following:

“To the end of 2009, 690.8Mt of ore, with an average bitumen grade of 11.8% and an average fines content of 22.9% has been mined. Thus 119.2Mt of fines have been sent to ASB; 104.2Mt are accounted in the ASB Pond and Beaches. The cumulative average fines balance in 2009 is within +/- 15% balance; 87% of the fines sent to tailings can be accounted for in the ASB.”
However, AMEC has identified inconsistencies between some of the values cited in the Executive Summary of the Phase 5 report, as well as differences in timing (pond surveys and sampling are completed mid-year and topographic surveys of the dykes and beaches are completed in late fall, but the ore mined is reported to year end). As a result, AMEC concludes that the fines mass balance closure is much better than 87%, and as high as 93 to 97%. While tighter closure on the fines mass balance does not have a significant impact on the overall fines capture that is calculated, it does provide increased confidence in the accuracy of the calculated fines capture for ASB.

The Phase 5 report also indicates that 85.4% of fines mined are sent to ASB, with 6.5% lost to rejects and 8.1% lost to froth. Therefore, if Aurora froth went to ASB, the total capture rate would be lower, somewhere between 70 and 77%, assuming partial capture of froth fines.

AMEC’s scope does not include an audit of the mass balance for ASB.

6.0 SYNTHESIS OF DATA PROVIDED

6.1 Tailings Line Slurry Characteristics

6.1.1 Coarse Tailings

Figure 4, Figure 5 and Figure 6 present flow rate data on a 1 hour basis for ASB Coarse Tailings Lines 1, 2 and 3, respectively. Figure 7, Figure 8 and Figure 9 present the corresponding density (specific gravity) data. The plots present all data downloaded from Syncrude’s PI database, and do not attempt to filter out the data that were collected when the lines were down or on flush.

These figures indicate that significant variations in both flow rate and density occurred in all three of the Coarse Tailings lines over short time intervals on an on-going basis. A summary of the typical range in values is as follows:

- **Flow rate in each line**
  - 2000 to Q3 2005 (Line 1 only) – typically between about 6,000 and 8,000 m$^3$/hr
  - Q4 2005 to 2007 – typically between about 6,500 and 10,000 m$^3$/hr
  - 2008 and 2009 – typically between about 10,000 and 11,000 m$^3$/hr
- **Density (specific gravity) in each line**
  - 2000 to Q3 2005 (Line 1 only) – typically between about 1.4 and 1.6
  - Q4 2005 to Q3 2006 – typically between about 1.2 and 1.4
  - Q4 2006 to 2009 – typically between about 1.3 and 1.55

While the fines content of the slurry in the Coarse Tailings lines is not typically monitored, the following limited fines content (44 micron) information was available from Syncrude:

- 2002 sampling & testing campaign – 10%
  - With an associated total mineral solids content of 53%
- After October 2005 (based on a thickener pilot program in 2007-2008) – 13%
6.1.2 Flotation Tailings

Figure 10 and Figure 11 present flow rate data on a 1 hour basis for ASB Flotation Tailings Lines 1 and 2, respectively. Figure 12 and Figure 13 present the corresponding density (specific gravity) data. The plots present all data downloaded from Syncrude’s PI database, and do not attempt to filter out the data that were collected when the lines were down or on flush.

These figures indicate that significant variations in both flow rate and density occurred in both of the Flotation Tailings lines over short time intervals on an on-going basis. A summary of the typical range in values is as follows:

- Flow rate
  - Line 1 – typically between about 1,000 and 3,000 m$^3$/hr
  - Line 2
    - 2004 to Q2 2006 – typically between about 1,000 and 3,000 m$^3$/hr
    - Q3 2006 to 2009 – typically between about 1,000 and 2,000 m$^3$/hr

- Density (specific gravity)
  - Line 1 – typically between about 1.05 and 1.25
  - Line 2 – typically between about 1.0 and 1.3

While the fines content of the slurry in the Flotation Tailings lines is not typically monitored, the following limited fines content (44 micron) information was available from Syncrude:

- 2002 sampling & testing campaign – 39%
  - With an associated total mineral solids content of 25%
- After October 2005 (based on a thickener pilot program in 2007-2008) – 23%

6.1.3 Density versus Flow Rate

Figure 14 to Figure 18 present cross-plots of density versus flow rate for each of the five tailings lines (Coarse Tailings Lines 1 to 3 and Flotation Tailings Lines 1 and 2). The data for Coarse Tailings Line 1 in Figure 14 are divided into two parts – before and after October 2005 (see the discussion in Section 4.2). In addition to showing the typical range in flow rate and density, these figures indicate that the total amount of time that the tailings lines are on flush is significant.

For the Coarse Tailings lines, based on the data provided, when each line was operational, the lines had flow rates less than 1100 kg/m$^3$, and were pumping essentially just water, as follows:

- Coarse Tailings Line 1 – about 13% of the time
- Coarse Tailings Line 2 – about 11% of the time
- Coarse Tailings Line 3 – about 21% of the time

6.2 Tailings Deposit Characteristics

BGC’s Phase 4 and 5 reports present a series of cross-sections through various cells at ASB, illustrating the annual staging of the dyke shell, beaches and pond over time. However, the only deposit data provided for the current study is from the 2009 site investigation. Therefore, the scope of the current study is limited to three specific cross-sections, through Cells 53, 58 and 60 (see Figure 1). On each cross-section, samples were collected and tested from over the entire beach deposit, from pond bottom through to original ground.
Figure 19, Figure 20 and Figure 21 present cross-sections taken directly from BGC's Phase 4 report, for Cell 53, Cell 58 and Cell 60, respectively. The cross-section locations are shown on inserts in each figure. These figures show the annual development of the dyke shell, beaches and pond over time, from 2000 to 2009. For Cell 53, the cross-section location is slightly different than that in Figure 1 (used for the 2009 site investigation locations).

Superimposed on the three cross-sections, Figure 22 to Figure 30 present the laboratory test results for samples collected during the 2009 site investigation, as follows:

- Cell 53
  - Figure 22 – Dean Stark solids content (total mineral content)
  - Figure 23 – fines content (< 44 micron)
  - Figure 24 – clay content (<1.9 micron)
- Cell 58
  - Figure 25 – Dean Stark solids content (total mineral content)
  - Figure 26 – fines content (< 44 micron)
  - Figure 27 – clay content (<1.9 micron)
- Cell 60
  - Figure 28 – Dean Stark solids content (total mineral content)
  - Figure 29 – fines content (< 44 micron)
  - Figure 30 – clay content (<1.9 micron)

For each of the boreholes shown on the three cross-sections, an individual plot, using expanded scales, is included in Attachment I, presenting the following 2009 test data on a single plot: Dean Stark solids content, fines content and clay content.

Figure 31 presents a plot of fines content versus solids content and Figure 32 presents a plot of clay content versus fines content. Figure 32 indicates that there is a relatively good correlation between clay content and fines content.

### 7.0 SUMMARY

The following key summary points can be made, when considering the ASB as a whole:

- The Aurora North Mine produces two tailings streams – coarse tailings and flotation tailings. Froth produced by the Extraction Plant is directed to Syncrude's Mildred Lake operations and the tailings produced are disposed in MLSB.
- Based on information provided in BGC (2011), based on the fines and sand that can be accounted for within ASB:
  - The overall average slurry fines content of all tailings lines combined would have been about 19.4% (i.e. $SFR_s$ of 4.15).
  - The fines are distributed as follows:
    - 104.2 Mt total
    - 23.8 Mt in MFT
    - 80.4 Mt in shell and beaches (i.e. 77% of all fines that could be accounted for in ASB were captured)
  - The overall average fines content for the tailings deposits (cell, BAW, BBW, and BB-MFT combined) was 15.8% ($SFR_d = 5.34$)
  - Sand capture was 99%.
- A slurry $SFR_s$ of 4.15, a beach deposit $SFR_d$ of 5.33 and 99% sand capture results in a fines capture of 77%, as stated above.
• However, if Aurora froth went to ASB, the total capture rate would be lower, somewhere between 70 and 77%, assuming partial capture of froth fines.

• The fines contents of the tailings deposits vary significantly, depending on the deposit; i.e. cell, BAW, BBW, BB-MFT. Based on the information provided in BGC (2011), the various components of the deposits have the following average characteristics:
  - Cell – average fines content of 12.6%
  - BAW – average fines content of 10.9%
  - BBW – average fines content of 11.4%
  - BB-MFT – average fines content of 39.9%
Table 1. ASB Information Provided by Syncrude for Current Study

<table>
<thead>
<tr>
<th>Category</th>
<th>Document or File Provided</th>
<th>Date Provided</th>
<th>Information Included</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>PowerPoint file entitled &quot;S3P2_SCL_Aurora_Fines_Mass_Balance_N._Wang[1]&quot;</td>
<td>26 Sep 2012</td>
<td>Presentation entitled &quot;Aurora Fines Mass Balance&quot; by N. Wang, R. Lahaie, B. Shaw and J. Lorenz, Syncrude Canada Ltd.</td>
</tr>
<tr>
<td></td>
<td>PowerPoint file entitled &quot;S3P1_SCL_Aurora_Fines_Mass_Balance_B.Shaw[1]&quot;</td>
<td></td>
<td>Presentation made to Syncrude Canada by BGC Engineering, entitled &quot;Aurora Fines Balance, Phase 5 Update: Progress Summary&quot;.</td>
</tr>
<tr>
<td>Tailings Slurry Data</td>
<td>Three Excel files, entitled &quot;Aurora_Tails_PI_OSTC_1&quot;, &quot;Aurora_Tails_PI_OSTC_2&quot; and &quot;Aurora_Tails_PI_OSTC_3&quot;</td>
<td>12 Feb 2013</td>
<td>Contained flow rate and density data, on an hourly basis, from 01 Jan 2000 to 31 Dec 2009, for each Coarse Tailings line and each Flotation Tailings line.</td>
</tr>
<tr>
<td></td>
<td>Excel file entitled &quot;Aurora MFT_Lab_2009&quot;</td>
<td>22 Feb 2013</td>
<td>2009 site investigation laboratory test results for tailings samples collected from selected boreholes used by BGC to create annotated cross-sections through Cells 53, 58 and 60. Included both Dean Stark tests and particle size distribution tests.</td>
</tr>
<tr>
<td></td>
<td>Excel file entitled &quot;OSTC_fine_capture_ASB_2009_MFT&quot;</td>
<td>28 Feb 2013</td>
<td></td>
</tr>
</tbody>
</table>
Table 2. Sampling and Measurement Methods Used for ASB Data Provided for Current Study

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<thead>
<tr>
<th>Category</th>
<th>Type of Sample / Measurement</th>
<th>Method Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore</td>
<td>Mass of ore</td>
<td>Mass of ore in Syncrude's Reconciled Quality Production Database (QPD) is based on actual truck loads to Extraction and BilMat mass balance output</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Connate water assumed to be 3.5%</td>
</tr>
<tr>
<td>Tailings Field</td>
<td>Tailings beaches</td>
<td>Continuous sampling using a 2 m long sonic sampler with a cutting shoe</td>
</tr>
<tr>
<td>Sampling</td>
<td>Native soils</td>
<td>Continuous sampling using a 2 m long sonic sampler with a cutting shoe</td>
</tr>
<tr>
<td>Tailings Field</td>
<td>Pond bottom surface</td>
<td>AK-97 pond soundings on a grid pattern</td>
</tr>
<tr>
<td>Measurements</td>
<td>(interface between fluid fine tailings and beaches)</td>
<td>Topographic surveys</td>
</tr>
<tr>
<td>Tailings Laboratory</td>
<td>Bitumen, mineral and water</td>
<td>Dean Stark test</td>
</tr>
<tr>
<td>Testing</td>
<td>composition</td>
<td>Coulter laser diffraction on clean solids(^1)</td>
</tr>
<tr>
<td></td>
<td>Particle size distribution</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. BGC's Phase 4 report indicates that, to determine grain size, Syncrude generally uses Coulter laser diffraction on dispersed samples; however, some geotechnical grain size tests are done using modified ASTM wet sieve and hydrometer methods.
Notes:
2. Locations shown had tailings samples collected and tested during the 2009 site investigation (Phase 3).
3. Red line represents the assumed flotation tailings boundary.
Location of Sampling Points at Aurora

- Mine Feed to Primary Slurry Preparation
- Hydrotransport Slurry to PSV
- PSV to Flotation
- Flotation to Float Tails and Run-off
- Secondary Slurry Preparation to Rejects
- Rejects to Secondary Slurry Preparation
- Secondary Slurry Preparation to Long/Short Pour Cell/Beach
- Long/Short Pour Cell/Beach to Run-off
- Run-off to Beach

Sampling Point:
- Coarse Tails to Flotation
- Float Tails to Flotation

Basic Process Flow Diagram for Aurora (provided by Syncrude)
Notes:
1. Image taken from Figure 1.2 of Syncrude's 2009 Directive 074 Submission to the ERCB (available on the ERCB's website).
Notes:
1. Data are on a 1 hour basis.
2. This plot presents all data downloaded from Syncrude’s PI database, and does not attempt to filter out data collected when lines were down or on flush.
Notes:
1. Data are on a 1 hour basis.
2. This plot presents all data downloaded from Syncrude's PI database, and does not attempt to filter out data collected when lines were down or on flush.
**Notes:**

1. Data are on a 1-hour basis.
2. This plot presents all data downloaded from Syncrude’s PI database, and does not attempt to filter out data collected when lines were down or on flush.

**Note:** No valid flow rate data from mid-2007 to mid-2009; tag was retired in mid-2009.
For Coarse Tailings Line 1, data plotted are from the following PI tags:
Up to 30 Sep 2005: flow rate - 2401FI210, density - 2401DX180A
From 01 Oct 2005 onwards: flow rate - 2501FI15, density - 2501DI16

Notes:
1. Data are on a 1 hour basis.
2. This plot presents all data downloaded from Syncrude’s PI database, and does not attempt to filter out data collected when lines were down or on flush.
Notes:
1. Data are on a 1 hour basis.
2. This plot presents all data downloaded from Syncrude's PI database, and does not attempt to filter out data collected when lines were down or on flush.
Notes:
1. Data are on a 1 hour basis.
2. This plot presents all data downloaded from Syncrude’s PI database, and does not attempt to filter out data collected when lines were down or on flush.
Notes:
1. Data are on a 1 hour basis.
2. This plot presents all data downloaded from Syncrude’s PI database, and does not attempt to filter out data collected when lines were down on or on flush.
Notes:
1. Data are on a 1 hour basis.
2. This plot presents all data downloaded from Syncrude’s PI database, and does not attempt to filter out data collected when lines were down or on flush.
Notes:
1. Data are on a 1 hour basis.
2. This plot presents all data downloaded from Syncrude’s PI database, and does not attempt to filter out data collected when lines were down or on flush.
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AMEC Environment & Infrastructure
140 Quarry Park Blvd SE, Calgary AB T3C 3G3
Tel 403-248-4331 Fax 403-248-2188

ASB Coarse Tailings Line 1 - Density vs Flow Rate

FIGURE 14
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AMEC Environment & Infrastructure
140 Quarry Park Blvd SE, Calgary AB T2C 3G3
Tel 403-248-4331 Fax 403-248-2188

BEACH FINES CAPTURE STUDY

ASB Coarse Tailings Line 2 - Density vs Flow Rate

Flow Rate (m³/hr)

Density (Sp. Grav.)
Notes:
1. Images taken from Drawing A-03 of BGC’s Phase 4 Final Report, dated 30 Sep 2010.
Notes:
Notes:
Note: Cross-section image shown here is cut at a somewhat different angle than the one on Drawing 4 (which goes directly through the boreholes), but was the only one through Cell 53 without data superimposed.

Notes:
Note: Cross-section image shown here is cut at a somewhat different angle than the one on Drawing 4 (which goes directly through the boreholes), but was the only one through Cell 53 without data superimposed.

Notes:
Note: Cross-section image shown here is cut at a somewhat different angle than the one on Drawing 4 (which goes directly through the boreholes), but was the only one through Cell 53 without data superimposed.

Notes:
Notes:
Notes:
Notes:

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AMEC Environment & Infrastructure

Cell 58 - 2009 Clay Content Data
Notes:

CLIENT LOGO

CLIENT

Canada's Oil Sands Innovation Alliance

AMC Environment & Infrastructure

PROJECT

BEACH FINES CAPTURE STUDY

Cell 60 - 2009 Solids Content Data

DRAWN BY

CHECKED BY

DATE

JUNE 2013

PROJECT NO

CG25409

REV NO

0

FIGURE NO

28

Datum

N/A

Projection

N/A

Scale

AS SHOWN

P:\Projects\Legacy\Cost\528005 - OSTC\Data\from 3D\BGC\Drawings\Phase 4 Final Report\App1 - Beach Fines Capture Study\Cell 60 - Solids Content Data_Figures_FINAL_June2013.xls
Notes:
Notes:
Notes:
1. Data in underlying original ground not yet filtered out.
2. Data for beach and MI 1 not yet separated.

Cells 53, 58 & 60 - Fines Content vs Solids Content
Notes:
1. Data in underlying original ground not yet filtered out.
2. Data for beach and MFT not yet separated.
ATTACHMENT I – INDIVIDUAL BOREHOLE PLOTS

Note: Each plot includes the following 2009 test data:

- Dean Stark solids content
- Fines content (<44 microns)
- Clay content (<1.9 microns)

**Cell 53**
01
02
03
04
05
06
Site 12

**Cell 58**
09
08
07
Site 16
Site 08

**Cell 60**
01
02
03
04
Site 05
Notes:
1. No pond bottom line shown; 2009 borehole started from BAW surface.
2. No original ground line shown; 2009 borehole log indicates that this borehole was terminated in tailings.
Notes:
1. No pond bottom line shown; 2009 borehole started from BAW surface.
Cell 53 - 03
Dean Stark Solids Content (%) or Fines Content, < 44 microns (%)

Notes:
1. No pond bottom line shown; 2009 borehole started from BAW surface.
Cell 53 - 04
Dean Stark Solids Content (%) or Fines Content, < 44 microns (%)

Notes:
1. No pond bottom line shown; 2009 borehole started from BAW surface, just at the waterline.
2. No original ground line shown; 2009 borehole log indicates that this borehole was terminated in tailings.
Note:
1. No original ground line shown; 2009 borehole log indicates that this borehole was terminated in tailings.
Note: Some clay contents > 25% in MFT not shown.
Cell 58 - 08
Dean Stark Solids Content (%) or Fines Content, < 44 microns (%)
Cell 58 - Site 08
Dean Stark Solids Content (%) or Fines Content, < 44 microns (%)

Note: Some clay contents > 25% in MFT not shown.
Note: Some clay contents > 25% in MFT not shown.
Cell 60 - 01
Dean Stark Solids Content (%) or Fines Content, < 44 microns (%)

Notes:
1. No pond bottom line shown; 2009 borehole started from BAW surface.
2. No original ground line shown; 2009 borehole log indicates that this borehole was terminated in tailings.
Notes:
1. No pond bottom line shown; 2009 borehole started from BAW surface, just at the waterline.
Cell 60 - 03
Dean Stark Solids Content (%) or Fines Content, < 44 microns (%)

Note:
1. The last 1.8 m of the 2009 borehole was described as "SILT (ML), some sand, low plastic, firm, black, no particular odour, moist, and homogeneous, moderate cementation, medium strength, trace organics. [CLAY RICH TAILINGS?]". The "possible original ground" line shown on this plot assumes that this material is native soil, but it may be a clay rich tailings layer at the base of the beach deposit.
Note: Some clay contents > 25% in MFT not shown.
Appendix E

Beach Classification by Depositional Environment

Figures E.1 to E.14 – Shell's MRM ETF
Figures E.15 to E.28 – Canadian Natural's Horizon ETF
Figures E.29 to E.39 – Syncrude's ASB
* "Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-10m less for all points.
* "Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-10m less for all points.
"Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-10m less for all points.
"Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-10m less for all points.

- %F FOR L1/ L2 ONLY
  - HR BAW
  - LR BAW
  - U BAW
  - L BAW
  - OTHER BAW

HR - High Rate of Deposition
LR - Low Rate of Deposition
U - Upper BAW
L - Lower BAW

Fines Content (% < 44μm) vs. Approximate Depth at Time of Deposition *(m)
"Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-10m less for all points.

HR - High Rate of Deposition
LR - Low Rate of Deposition
U - Upper BAW
L - Lower BAW
* "Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-10m less for all points.

- %F FOR L1/ L2 ONLY
- HR BBW
- LR BBW
- U BBW
- L BBW
- OTHER BBW

HR - High Rate of Deposition
LR - Low Rate of Deposition
U - Upper BBW
L - Lower BBW

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AMEC Environment & Infrastructure

P:\GEO\PROJECTS\NON-EG\CGI\CG25409 - OSTC Beach Study\500 Analysis\Shell MRM ETF Case Record\Deposit Data\Shell MRM ETF_Categorized Deposit Data_REV0_JUNE2013.xlsx
"Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-10m less for all points.

HR - High Rate of Deposition
LR - Low Rate of Deposition
U - Upper BBW
L - Lower BBW
FCER based on representative average slurry fines contents over time for L1/L2 or TTTS, as applicable. The tailings slurry fines content used for L1/L2 ranged from 6% to 15%, and the tailings slurry fines content used for TTTS was 33.5%.

* "Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-10m less for all points.
FCER based on representative average slurry fines contents over time for L1/L2 or TTTS, as applicable. The tailings slurry fines content used for L1/L2 ranged from 6% to 15%, and the tailings slurry fines content used for TTTS was 33.5%.

* "Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-10m less for all points.
FCER based on representative average slurry fines contents over time for L1/L2 or TTTS, as applicable. The tailings slurry fines content used for L1/L2 ranged from 6% to 15%, and the tailings slurry fines content used for TTTS was 33.5%.

"Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-10m less for all points.

*FCER FOR ALL DATA
- PC
- PC L2
- PC TTTS
- PC L1
†FCER based on representative average slurry fines contents over time for L1/L2 or TTTS, as applicable. The tailings slurry fines content used for L1/L2 ranged from 6% to 15%, and the tailings slurry fines content used for TTTS was 33.5%.
* "Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-10m less for all points.

HR - High Rate of Deposition
LR - Low Rate of Deposition
U - Upper BAW
L - Lower BAW

Approximate Depth at Time of Deposition *(m)

Fines Capture Effectiveness Ratio*
FCER based on representative average slurry fines contents over time for L1/L2 or TTTS, as applicable. The tailings slurry fines content used for L1/L2 ranged from 6% to 15%, and the tailings slurry fines content used for TTTS was 33.5%.

* "Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-10m less for all points.

**Approximate Depth at Time of Deposition** *(m)*

- HR BAW
- LR BAW
- U BAW
- L BAW
- OTHER BAW

**FCER FOR TTTS ONLY**

**HR - High Rate of Deposition**
**LR - Low Rate of Deposition**
**U - Upper BAW**
**L - Lower BAW**
FCER based on representative average slurry fines contents over time for L1/L2 or TTTS, as applicable. The tailings slurry fines content used for L1/L2 ranged from 6% to 15%, and the tailings slurry fines content used for TTTS was 33.5%.

* “Approximate Depth at Time of Deposition” is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-10m less for all points.

- FCER FOR L1/L2 ONLY
  - HR BBW
  - LR BBW
  - U BBW
  - L BBW
  - OTHER BBW

HR - High Rate of Deposition
LR - Low Rate of Deposition
U - Upper BBW
L - Lower BBW

# FIGURE E.13

<table>
<thead>
<tr>
<th>Fines Capture Effectiveness Ratio†</th>
<th>Approximate Depth at Time of Deposition *(m)</th>
</tr>
</thead>
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<tr>
<td>10</td>
<td>-20</td>
</tr>
<tr>
<td>9</td>
<td>-10</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>10</td>
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<td>2</td>
<td>60</td>
</tr>
<tr>
<td>1</td>
<td>70</td>
</tr>
<tr>
<td>0</td>
<td>80</td>
</tr>
</tbody>
</table>

† FCER based on representative average slurry fines contents over time for L1/L2 or TTTS, as applicable. The tailings slurry fines content used for L1/L2 ranged from 6% to 15%, and the tailings slurry fines content used for TTTS was 33.5%.

* "Approximate Depth at Time of Deposition” is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-10m less for all points.
FCER based on representative average slurry fines contents over time for L1/L2 or TTTS, as applicable. The tailings slurry fines content used for L1/L2 ranged from 6% to 15%, and the tailings slurry fines content used for TTTS was 33.5%.

* "Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 5-10m less for all points.
Figure E.16

**Title:** BEACH FINES CAPTURE STUDY

**Title:** HORIZON ETF

**Title:** FINES CONTENT VS DISTANCE FROM DYKE 10 - BAW

**Legend:**
- HR - High Rate of Deposition
- LR - Low Rate of Deposition
- U - Upper BAW
- L - Lower BAW

**Axes:**
- **Y-axis:** Fines Content (% < 44μm)
- **X-axis:** Approximate Distance from Dyke 10 (m)

**Data Points:**
- %F FOR ALL DATA
- BAW HR U
- BAW HR L

**Scale:** NTS

**Dimensions:**
- 0 to 100 on Y-axis
- 0 to 2000 on X-axis

**Notes:**
- P:\GEO\PROJECTS\NON-EG\CG\CG25409 - OSTC Beach Study/500 Analysis\CNRL Horizon ETF Case Record\Deposit Data\Horizon ETF_Categorized Deposit Data_REV0_JUNE2013.xlsx
* "Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 3-4m less for all points.
* *Approximate Depth at Time of Deposition*" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 3-4m less for all points.
"Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 3-4m less for all points.
"Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 3-4m less for all points.

HR - High Rate of Deposition
LR - Low Rate of Deposition
U - Upper BBW
L - Lower BBW

* %F FOR ALL DATA
  BBW HR U
  BBW HR L

Approximate Depth at Time of Deposition (m)

Fines Content (% < 44μm)
† FCER is based on a tailings slurry fines content of 21%
Canada's Oil Sands Innovation Alliance

AMEC Environment & Infrastructure

BEACH FINES CAPTURE STUDY

HORIZON ETF
FCER VS DISTANCE FROM DYKE 10 - BAW

HR - High Rate of Deposition
LR - Low Rate of Deposition
U - Upper BAW
L - Lower BAW

FCER FOR ALL DATA

BAW HR U
BAW HR L

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"Approximate Depth at Time of Deposition" is calculated relative to the pond elevation at the time of the bathymetry following deposition. Consequently, based on the typical annual rate of deposition, the actual depth at the time of deposition would be 3-4m less for all points.
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FCER FOR ALL DATA
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%F FOR BAW ONLY
- HR BAW
- LR BAW
- U BAW
- L BAW

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**Approximate Depth at Time of Deposition *(m)**

**Fines Content (% < 44μm)**

**%F FOR BAW ONLY**
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- **F FOR ALL DATA**
  - FAILED BBW
  - POTENTIALLY FAILED BBW
FCER based on tailings slurry fines content of 23% for Section 53 and 13% for Sections 58 and 60.

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**Approximate Depth at Time of Deposition *(m)*

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FAIRED BBW

POTENTIALLY FAILED BBW