HORIZON OIL SANDS MINE AND PROCESSING PLANT

TAILINGS MEASUREMENT SYSTEM PLAN
REVISION 2

Canadian Natural Report No.

HZN-13-RPT-TA-10006

OSCA Approval No. 9752M, as amended

Submitted On December 23, 2024

Distribution List

Internal: Canadian Natural

Manager, Geotechnical/Geology, Horizon Mine
Manager, Engineering, Horizon Bitumen Production
Lead, Tailings Planning, Horizon Mine - Technical Services
Lead, Mine Engineering, Horizon Mine - Technical Services
VP, Mining, Horizon, Horizon Operations
Regulatory Manager, Oil Sands Mining Operations

External:

Alberta Energy Regulator (AER)

Revision History

Revision	Description	Prepared By	Date
00	Initial Release	Canadian Natural	June 28, 2018
01	Updated to incorporate AER clarification of Fluid Tailings Management reporting requirements for water quality characterization and reporting	Canadian Natural (Chris D, Colin S, Emily P, Katy N, Leah H, Theo P, Scott B, Scott W)	December 31, 2022
02	Updated to reflect new approvals, including ready-to-reclaim criteria and mining alternative ore criteria.	Canadian Natural (refer to Section 9 Authentication)	December 23, 2024

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LIST OF ACRONYMS, ABBREVIATIONS AND UNITS

Acronym, Abbreviation and Unit	Description
%	percent
# or No.	number
3D	three-dimensional
AER	Alberta Energy Regulator
AOC	alternative ore criteria
ASTM	American Society for Testing and Materials
BAW	beach above water
bbl	barrel
BBW	beach below water
BPT or BCPT	ball penetration test or ball cone penetration test
Canadian Natural	Canadian Natural Resources Limited
cm	centimeter
cm^2	squared centimeter
CO_2	carbon dioxide
COSIA	Canada's Oil Sands Innovation Alliance
CPT	cone penetration test
CST	coarse sand tailings
CWZ	clear water zone
D50	median particle size
DDA	Dedicated Disposal Area(s)
DDA2	Dedicated Disposal Area 2
DDMS	drilling data management system
DSA	Dean and Stark Analysis
eNST	enhanced non-segregating tailings
EPEA	*Environmental Protection and Enhancement Act*
esNST	enhanced spiked non-segregating tailings
ETF/DDA1	External Tailings Facility / Dedicated Disposal Area 1
FIS	fixed interval sampling
FT	fluid tailings
g	gram(s)
GBPT or GBCPT	gamma ball penetration test or gamma ball cone penetration test
GCPT	gamma cone penetration test
GoA	Government of Alberta
GPS	Global Positioning System
GSM	gridded seam model
Horizon	Horizon Oil Sands Mine and Processing Plant
in	inch
IPS	inclined plate separators

Acronym, Abbreviation and Unit	Description
IWW	Industrial waste water
kg	kilogram(s)
km	kilometer(s)
lb	pound(s)
LiDAR	light detection and ranging
m	meter(s)
MBI	methylene blue index
mg/L	milligram per liter
Mm^3	millions of cubic meters
n/a	not applicable
NPRI	National Pollutant Release Inventory
NRU	Naphtha Recovery Unit
NST	non-segregating tailings
O/F	over flow
on-spec	on-specification
OSCA	Oil Sands Conservation Act
PSC	primary separation cell
PSD	particle size distribution
psi	pounds per square inch
RDL	recordable detection limit
RFR	ready-for-reclamation
RTR	ready-to-reclaim
SCO	synthetic crude oil
SFR	sand-to-fines ratio
SIR	supplemental information request
SO	sub-objective
TDS	total dissolved solids
t/m^3	tonnes per cubic meter
TMF	Tailings Management Framework
TMP	Tailings Management Plan
TMR	Tailings Management Report
TSS	total suspended solids
TT	thickened tailings
TV:BIP	total value to bitumen in place ratio
U/F	under flow
µm	micrometer
µS/cm	microsiemen(s) per centimeter
WT	whole tailings
wt%	weight or mass %
XRD	x-ray diffraction

1 INTRODUCTION

Canadian Natural Resources Limited's (Canadian Natural) Horizon Oil Sands Mine and Processing Plant (Horizon) is located approximately 70 kilometers (km) north of Fort McMurray, Alberta on Leases 18, 10, 24 and 25. Horizon is an integrated oil sands mining operation that consists of a surface mine, bitumen production, primary and secondary upgrading, and utilities to produce synthetic crude oil (SCO).

1.1 Regulatory Background

The *Application for the Approval of Canadian Natural's Tailings Management Plan (TMP) for the Horizon Oil Sands Processing Plant and Mine* (Canadian Natural 2016), was submitted to the Alberta Energy Regulator (AER) on September 23, 2016 in compliance with *Directive 085: Fluid Tailings Management for Oil Sands Mining Projects* (AER 2022b) and the *Lower Athabasca Region: Tailings Management Framework (TMF) for the Mineable Athabasca Oil Sands* (Government of Alberta or GoA 2015). The Horizon TMP (Canadian Natural 2016) was approved by the AER on December 18, 2017 in Decision 20171218A (AER 2017a). Amendments to the approved 2016 Horizon TMP (Canadian Natural 2016) (e.g., in-pit configuration and extension of the end of mine life) were made in the *Horizon South Lease 24 Integration Application* (Canadian Natural 2019).

The *Horizon Tailings Measurement System Plan* (Canadian Natural 2018) was submitted to the AER on June 28, 2018 and was approved in March 2021 after supplemental information request (SIR) responses were provided to the AER in January 2020, November 2020 and February 2021. An update to the *Horizon Tailings Measurement System Plan: Revision 1* (Canadian Natural 2022c) was submitted on December 31, 2022, and is currently under review by the AER. This update to the Horizon Tailings Measurement System Plan is submitted in response to updated approvals for the Horizon site, including the *Horizon Oil Sands Processing Plant and Mine Proposed Amendment to Non-Segregating Tailings Ready-to-Reclaim Sub-Objective 1 Performance Criteria* (Canadian Natural 2023a) and *Horizon Oil Sands Processing Plant and Mine Proposed Amendment to Non-Segregating Tailings Ready-to-Reclaim Sub-Objective 2 Performance Criteria* (Canadian Natural 2024a).

Revision 2 of the Horizon Tailings Measurement System Plan is submitted in accordance to the requirements outlined in Directive 085 (AER 2022b), the *Measurement System Plan Requirements letter* (AER 2017b), Decision 20171218A (AER 2017a), the *Notice of Reporting Requirement Clarification: Directive 085 – Fluid Tailings Management Reporting Requirements Water quality characterization and Reporting Letter and clarification letter* (AER 2022a and 2022c). Concordance tables are provided in Appendix A.

1.2 Nomenclature

Directive 085 (AER 2022b) defines fluid tailings (FT) as "*any fluid discard from bitumen extraction facilities containing more than 5 mass per cent* [mass %, weight % or wt%] *suspended solids and having less than an undrained shear strength of 5 kilopascals*". This definition is inclusive of all tailings production streams at Horizon, including non-segregating tailings (NST), NST enhancements (i.e., enhanced NST [eNST] and enhanced spiked NST [esNST]) and Naphtha Recovery Unit (NRU) tailings. This differs from the definition of 'FT inventory' defined by Directive 085 (AER 2022b) as being "*the total volume of FT measured in treated tailings deposits or FT ponds, excluding any volume that meets specific ready-to-reclaim (RTR) performance criteria at the time of measurement*".

To simplify, Canadian Natural uses the term ‘treated Tailings’ or ‘treated FT’ to mean any tailings stream which has been treated and is discharged into a tailings pond. The term FT is reserved to indicate the materials within the FT deposition zone of the tailings pond, as described in Section 6.2 and illustrated in Figure 6-2.

2 MEASUREMENT SYSTEMS

In order to report on tailings performance, Canadian Natural’s tailings measurement plan consists of the collection of both quantitative (i.e., numerical) and qualitative (i.e., categorical or attribute) data. Both of these data types are collected from the *in-situ* oil sand ore body, across the mining and extraction processes and in the resultant tailings deposits, as illustrated in Figure 2-1.

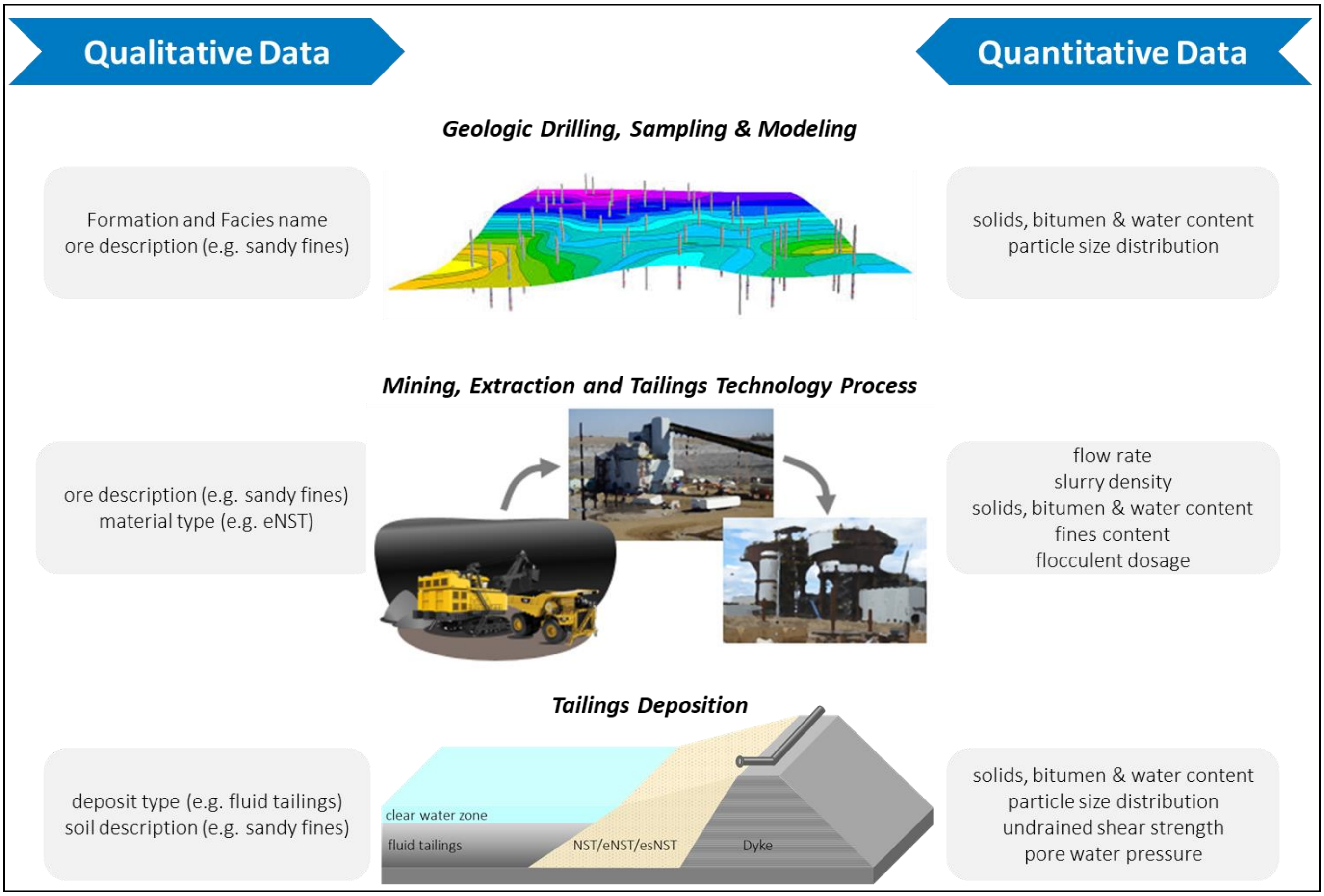


Figure 2-1: Examples of Data Collected at Horizon

Canadian Natural’s measurements, calculations, models and data management are designed to provide information that is used to support operational decisions, planning and regulatory reporting. Data collection and assessments, where possible, will be based on measured values and not on projected values. Measured values will provide an accurate and representative assessment of the oil sands processed and deposited between evaluation periods. Where required, Canadian Natural will provide forecasts and/or estimations based on calculations that are projected from a measured date and utilize available geologic, mining and tailings process measurements.

The milestones illustrated in Table 2-1 outline the key activities used to develop a Tailings Management Report (TMR) that is an accurate representation of annual tailings performance at the Horizon site. It should be noted that some surveys and measurements are completed more often than shown, and the milestones shown on Table 2-2 are depicted for assessment of the reporting period. The survey sample locations and tailings pond investigation timing will continue to be optimized during annual scope development.

Table 2-1: Tailings Management Report Development Milestones

Activity	Year X												Year X+1			
	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April
geology coring & laboratory testing																
mining data collection																
tailings process data collection																
groundwater monitoring program																
tailings pond investigation – scope development*1																
tailings pond investigation – field program*1*2																
tailings pond investigation – laboratory testing*1*2																
data analysis and modeling																
annual TMR development																

**1 spring survey timing shown is estimated for illustration and is only completed as required for Horizon operational and planning requirements.*
**2 quality assurance and control procedures are completed to ensure measurements are as accurate as possible, and that no apparent bias exists.*
where: light grey illustrates expected timing of optional spring tailings pond investigation for Year X; grey illustrates expected timing of surveys and measurements to support TMR for Year X; and dark grey illustrates timing of surveys and measurements to support TMR for Year X+1.

2.1 Data Management System

Canadian Natural's tailings measurement system activities encompass several operating units at Horizon, including Geotechnical and Geology, Mine Technical Services (includes mine and tailings planning teams), Bitumen Production Process Engineering, Technology Development, Tailings Operations, and Environment and Regulatory teams. For all research and field activities (e.g., environmental monitoring and tailings measurement activities), data are saved to dedicated drives owned by each of these operating units. Canadian Natural servers are backed up in accordance with corporate policies. Table 2-2 presents a summary of Canadian Natural's data backup policy.

Table 2-2: Data Backup Policy Summary

Type of Backup	Frequency	Storage Location	Retention Period
full	daily	in alternate data center	7 days
full	weekly	in alternate data center	4 weeks
full	monthly	in alternate data center	3 months
full	yearly	in alternate data center	3 years
emergency (full)	monthly	offsite records center	3 months
application specific	as requested	in alternate data center or offsite records center	as requested (typically 1 day)

The Bitumen Production Extraction and NST plant at Horizon are fully instrumented and the tagged signals are fed to the Historian system. The data are saved on a dedicated server and backed-up every 12 hours. Official reports and documentation are saved in a document control system (i.e., McLaren).

3 GEOLOGY

The Horizon oil sand deposit is dominated by the Cretaceous McMurray Formation which was deposited 120 to 90 million years ago. Deposition occurred during an overall rise in sea level, where initial placement of the McMurray Formation was controlled by the Devonian topography at the time of deposition. During pre-McMurray time, millions of years of deposition and erosion affected the landscape; deep valleys were cut into the underlying Devonian carbonates, which later confined McMurray depositional systems.

McMurray depositional environments are complex and consist mainly of fluvial channel deposits that are commonly preserved in the deepest parts of the Devonian valley systems. The Lower McMurray consists of fluvial coarse-grained pebbly/gravelly sand channels deposited within the erosional valley complexes. Middle McMurray deposition is a more transgressive estuarine system. The tidally-influenced estuaries were dominated by fluvial-tidal estuarine point bar deposits with changes of the sand grain sizes that range from fine to medium, and lithology such as mudstones breccias, low-angle inclined heterolytic stratification deposits of mud and sand.

As sea level continued to rise, and the Devonian valleys filled, there became more room for the fluvial systems to meander and estuarine systems to incise resulting in greater preservation of coarsening-upwards shoreface deposits of the Upper McMurray. Finally, at a point of maximum transgression, thick laterally continuous shales and mudstones of the Wabiskaw Member and Lower Clearwater Formation were deposited.

3.1 Coring and Sampling

Oil sand cores extracted from the drilling programs are kept frozen in plastic sleeves to preserve their moisture content and structure. The cores are shipped to Calgary where they are photographed, and lithological, structural, and geotechnical features are logged (i.e., described). The cores are cut in half (slabbed) and a 300 gram (g) sample is collected at sample intervals varying between 0.3 meters (m) to 1.5 m along the core. The samples collected are then sent for laboratory tests as outlined in Table 3-1.

Table 3-1: Summary of Procedures Completed on Geology Oil Sand Ore Samples

Parameter	Lab Procedure Name	Procedure Summary
bitumen content	Dean and Stark Analysis (DSA) (by weight difference)	refer to Appendix C – Section 2
water content	DSA (by weight difference)	refer to Appendix C – Section 2
mineral (i.e., solids) content	DSA (by weight difference)	refer to Appendix C – Section 2
particle size distribution (PSD)	dry sieve/hydrometer/laser diffraction	refer to Appendix C – Section 3
clay content	dry sieve/hydrometer/laser diffraction	refer to Appendix C – Section 3
clay content	Methylene Blue Index (MBI)	refer to Appendix C – Section 4
connate water quality (i.e,. oil sand pore water)	soluble ions	refer to Appendix C – Section 5

The most recent exploration program at Horizon was conducted during the winter of 2023, which included 191 core holes within the 5-year mine footprint to support applications for planned future expansions (South and North Pit), as shown in Figure 3-1.

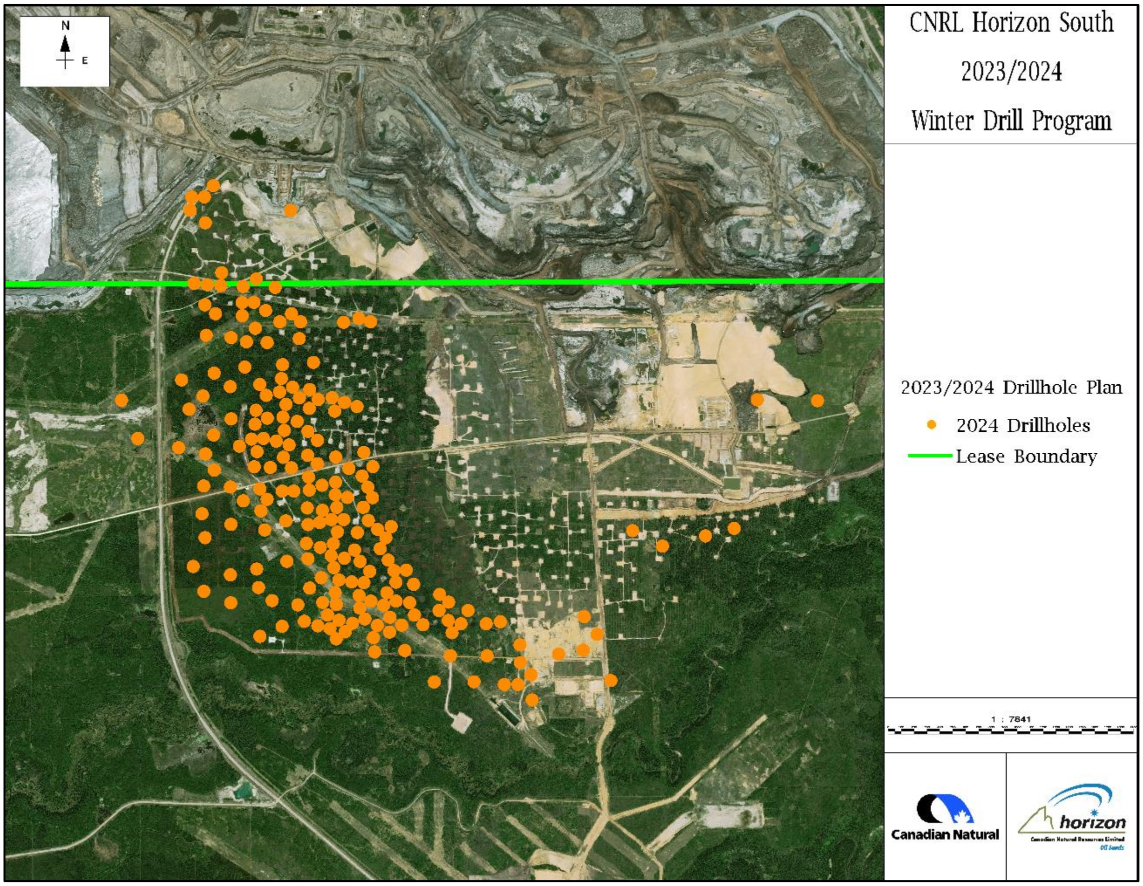


Figure 3-1: Geology Drillhole Location to Support Current Geology Model

Additional information regarding field and laboratory procedures are provided in Appendix B and C, respectively.

3.2 Geology Block Model

The geology block model is constructed using the tools within the modelling package MineSight. A 1 m three-dimensional (3D) block model which uses block dimension of 25 m by 25 m by 1 m is created annually. The user can view drillhole data, interpret and create geologic surfaces, and interpolate grades into the 3D blocks. The geology models in MineSight contains four key files:

1) Drillhole file (11): contains downhole assay and geologic information by depth interval,
2) Drillhole file (12): contains survey information,
3) Gridded surface file (13): 25 m by 25 m grid with stored values in the center of each grid. Values can include: elevations, thickness, ratio of total value to bitumen in place (TV:BIP), and

4) 3D block model file (15): same grid plan as the gridded surface file, with a 1 m vertical block height. Each block contains values that represent the block characteristics such as: bitumen content, median particle size (i.e., D50), fines content, soluble ions, formation, facies, and facies association group.

The following key steps are performed on the drillhole data before 3D block model interpolation:

1) Drillhole data is loaded into 'hs11.dat',
2) Drillhole intervals are composited into 1 m lengths for the 1 m model. A new composite begins at every change of a geologic unit,
3) Model blocks are interpolated with formation, facies, bitumen content and PSD data, and
4) Mineable intervals are tagged using a minimum thickness of 2 m, bitumen and fines content.

The 1 m model, as illustrated in Figure 3-2, is a detailed model where geologic interpretations have been made, characterizing the McMurray into genetically related geological units.

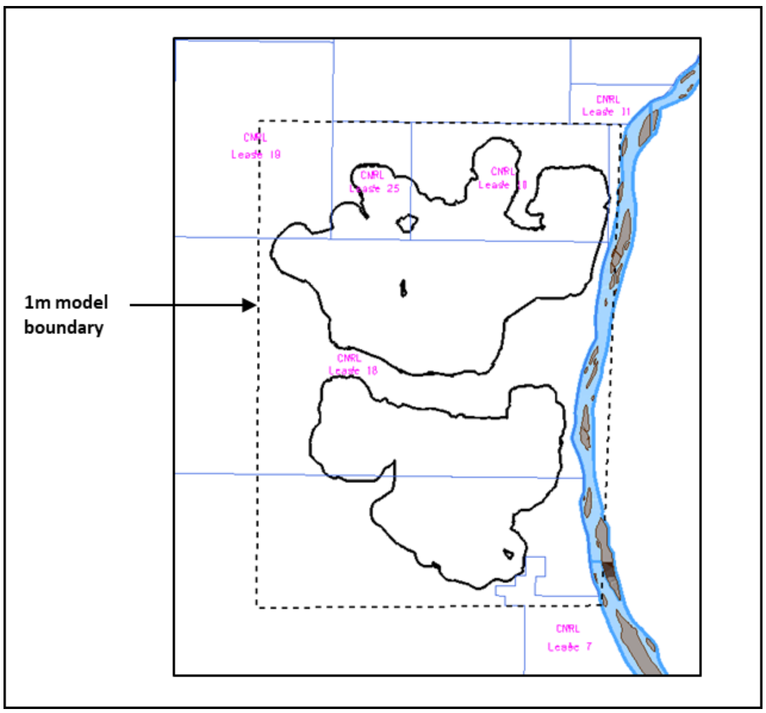


Figure 3-2: 1 m Geology Model Boundary

Major geologic surfaces that are gridded in the 1 m model include the top of Paleozoic, Lower McMurray, Middle McMurray, Upper McMurray, Wabiskaw, Clearwater and Pleistocene. Topography is gridded from the high-resolution light detection and ranging (LiDAR) data. In addition to these major surfaces which are generated automatically in MineSight, the 1 m model contains finer subdivisions within the Pleistocene and McMurray.

Extensive work has been made to characterize the McMurray in the 1 m model into genetically-related geologic units called facies associations. Facies association surfaces represent the top of that unit and include the 100's, 300's, 360's, 400's and 500's facies associations. These surfaces are generated from the drillhole data by creating polylines/points in two dimensions, guided by geologic criteria and interpretations. The facies associations are interpreted in the south pit and north pit, using 50m ± 25 m sections in MineSight.

To prepare the 1 m model for interpolation, the model blocks are first interpolated with the formation codes that are constrained by the surfaces. These geologic surfaces act as containers, and interpolation of drillhole data is constrained within the individual McMurray formations for the 1 m model. Facies association code and facies association group used to interpolate a grade item into that block interpolation from the Lower McMurray will not communicate with drillhole data from the Middle McMurray.

3.3 Quality Assurance and Quality Control

Canadian Natural created a web-hosted quality assurance and quality control tool called Drilling Data Management System (DDMS) for all drilling, wireline logging, auger/sonic, core logging and laboratory assay data. The key benefits of the DDMS include:

- vendors became accountable for importing error free data with DDMS relaying back to users the required data changes,
- each user able to upload/download data easily,
- user friendly interface – no training, and
- data quality assurance and quality control, data storage and data manipulation system.

One of the main goals of Canadian Natural's quality assurance and quality control program is to ensure that the laboratory provides consistent results on a year-to-year basis. The program also helps to confirm systematic trends that might be revealed in the Horizon-specific database as being real trends rather than issues with laboratory performance.

Statistic quality control practices allow Canadian Natural to maintain the necessary level of consistency and include:

- separate programs to differentiate between random error and bias error, and
- monitoring of the accuracy and precision of all physical and chemical tests.

Bias errors can be identified by regularly submitting test samples of reference material with pre-established "consensus" values into the analytical queue. By submitting the original sample, the bias associated with any of the sample preparation steps (disaggregation in the case of particle size distribution) as well as the bias associated with the final measurement step are identified.

Repeatability (random error) is monitored by analysis of blind duplicate samples that are submitted by the operator of the lease.

4 MINING

Oil sand ore at the Horizon site is mined using a truck and shovel open pit mining method. Oil sand is transported to the ore preparation plant, crushed and conveyed to the ore slurry plant, where it is blended with hot water, steam and caustic to form a slurry that is then transported via pipeline to extraction (i.e., hydrotransport feed).

4.1 Mine Planning

The 3D geology block model(s), as outlined in Section 3.2, are provided to the mine planning group where they are converted into a gridded seam model (GSM) format to support mine planning. The first step of this process involves differentiating ore from waste using a discrimination algorithm that is based on the recently approved alternative ore criteria (AOC) (Canadian Natural 2022b) and the subsequent *AOC Pilot Application* (Canadian Natural 2023). Oil sand ore is differentiated from waste using the following criteria:

- bitumen content ≥ 6 and ≤ 7 wt%,
- fines content ≥ 30 and ≤ 35 wt%, and
- vertical mining selectivity ≥ 2m thickness.

Once ore and waste units are identified throughout the deposit, surface mining pits are created based on predetermined TV:BIP criteria. The final geometry of the pit designs are further refined to ensure that the pit limits comply with water course and infrastructure, land tenure and regulatory approval limits. The slopes of pit walls are preliminarily designed based on predetermined geotechnical criteria for the various stratigraphic units they intersect.

The GSM for each pit are further refined into ore and waste bench plans for mining. These bench plans are then scheduled at various scales throughout the life of mine. The schedules produced determine the time-scaled metrics, including ore tonnage, ore grade, PSD, clay content and soluble ions that will be delivered to the processing facility.

One of the most important components of the mine plan is to ensure that there is adequate tailings containment throughout the life of mine by ensuring that dykes are built and tailings ponds or dedicated disposal areas (DDA) are available when needed. Waste tonnages and their respective qualities are scheduled in order to meet the geotechnical design requirements of various in-pit and out-of-pit waste structures. The waste to ore strip ratio and haul distances are used to determine equipment and infrastructure needs.

4.2 Ore Production and Reconciliation

Ore and waste assignments to each modeled GSM bench grid are imported into the mine dispatch system. This 3D library of spatial locations for each ore and waste unit, as well as their respective characteristics, is digitally transferred to the excavation equipment throughout the mine. Global positioning system (GPS) spatial location technology, installed on the excavators, is used to determine what bench grids are being mined in real time. The characteristics of the modeled ore and waste grids are then transferred to the trucks being loaded. The trucks then haul these loads to dispatch assigned locations where the material is placed. These material characteristics (e.g., ore/waste, grade, particle size fractions, D50, soluble ions, etc.) are then transferred from the haul truck to the final dump location. This dispatch technology allows for accurate accounting of material as it is moved throughout the mine.

The mine survey department is continually surveying the mine advance to develop a 3D structure of the lowest mined *in-situ* and as-built surface in real time. At the end of each week, these surveyed results are reconciled to the dispatch results to ensure they are well aligned.

The survey reconciled dispatch results for all ore material hauled to either ore stockpiles or the processing facility are used to determine the ore tonnage and respective characteristic that entered the bitumen extraction plant. A detailed mass balance reconciliation effort is completed at the end of each month to ensure that the mine and processing teams are aligned on the quantities and qualities of the ore supplied to the extraction facility. A component of these results are then provided each month to the AER (i.e., S-23 OS3 and OS4 values).

4.3 Geology, Mining and Tailings Reconciliation Process

The pond investigation and tailing modeling process are discussed in detail in Section 6. Upon completion of the annual tailings pond investigation model(s), an in depth mass balance reconciliation process is completed to determine if the dry mineral sand and fines estimates within the original geological model are aligned with the material mined, processed and then deposited into the DDAs. With the introduction of Dedicated Disposal Area 2 (DDA2) tailings deposition in 2020, this process has become more detailed. To complete the mass balance process, the mineral solids (i.e., sand and fines) that are transferred from DDA2 to the External Tailings Facility / Dedicated Disposal Area 1 (ETF/DDA1) through the fluid transfer system and transferred from the ETF/DDA1 to DDA2 via the esNST process were quantified.

A more detailed description of this process is provided in the annual TMR submitted. Furthermore, a table is also provided in the annual TMR comparing the as-mined and tailings model dry mineral balance results. Typically the annual dry mineral tonnage differences are within the range of 1-3 %. In Canadian Natural's opinion, this mass balance difference is within an acceptable range.

Quantifying water movement throughout each DDA is a byproduct of the mineral mass balance reconciliation process discussed above. Water movement throughout each DDA is tracked and quantified and incorporated into the site wide water balance results that are also reported to the AER in the annual TMR and discussed further in Section 7.

5 BITUMEN PRODUCTION

A simplified schematic of the extraction and tailings processes at the Horizon site is shown in Figure 5-1. Bitumen Production incorporates all activities for processing oil sand ore including the ore preparation plant, where oil sand is crushed and conveyed to the ore slurry plant then blended with hot water and caustic to form a slurry that is then transported via pipeline to the extraction. In extraction, the ore slurry is fed into a primary separation cell (PSC), where the ore slurry is separated into three layers:

- The bitumen froth consists of mainly bitumen, water, and small amounts of solids (sand, silts and clays). The bitumen froth floats to the top of the PSC, is collected and transported to froth treatment.
- PSC middlings consist of water, solids (sand, silts and clays) and some bitumen. The PSC middlings are withdrawn from the side of the PSC and are further processed in secondary separation or flotation cells where air is added to separate an additional 2 % to 4 % of bitumen froth, which is returned to the PSC. The remaining water, solids and some unrecovered bitumen are transported to the thickeners.
- The PSC underflow or whole tailings (WT) consists of mainly water and solids (sand, silts and clay) and some residual bitumen and is transported to the hydro-cyclones to separate the fines and the coarse material for further dewatering.

The WT stream is pumped to the hydro-cyclones, where the underflow creates a tailings stream that has less water and fines than WT and is referred to as coarse sand tailings (CST). The overflow, which contains mainly fines and water, are pumped and flocculated at the thickener to agglomerate the fine materials into larger particles that settle out as thickened tailings (TT) and release warm water for re-use in the extraction process. The CST and TT are then recombined in the plant at the NST pump box to make a non-segregating sand-and-fines mixture and are transported hydraulically to tailings containment facilities. Carbon dioxide (CO_2) is injected into the process as a rheology modifier to increase the yield strength of the slurry and decrease the potential for mixture segregation.

Canadian Natural's extraction process is capable of producing NST, eNST, and esNST. Enhanced NST (eNST) has in-line polymer injection prior to deposition into the tailings pond. Enhanced spiked NST (esNST) has FT injection upstream of the NST pumpbox at the cyclone underflow launders and polymer injection prior to deposition into the tailings pond. Canadian Natural will continue to use CO_2 as a supplemental technology enhancement to promote fines capture and settlement in the recycle water.

In Froth Treatment, the bitumen froth is diluted with naphtha to reduce viscosity and increase the density differential between the hydrocarbon and water phases. Diluted bitumen froth is processed through a combination of inclined plate separators (IPS) which allow solid particles and water droplets to settle by gravity. Diluted bitumen product collected from the IPS is stored in diluted bitumen tanks, and is then sent to the Horizon Upgrader where naphtha is recovered in the diluent recovery unit for reuse in the Froth Treatment Plant. Froth treatment tailings are then sent to the NRU where naphtha is removed by steam stripping before tailings are sent to the tailing pond. The recovered naphtha diluent is recycled back to the Froth Treatment Plant. The recovered bitumen product is pumped to the upgrader for treatment to produce SCO. The NRU tailings are injected with CO_2 and pumped to the ETF/DDA1 for containment.

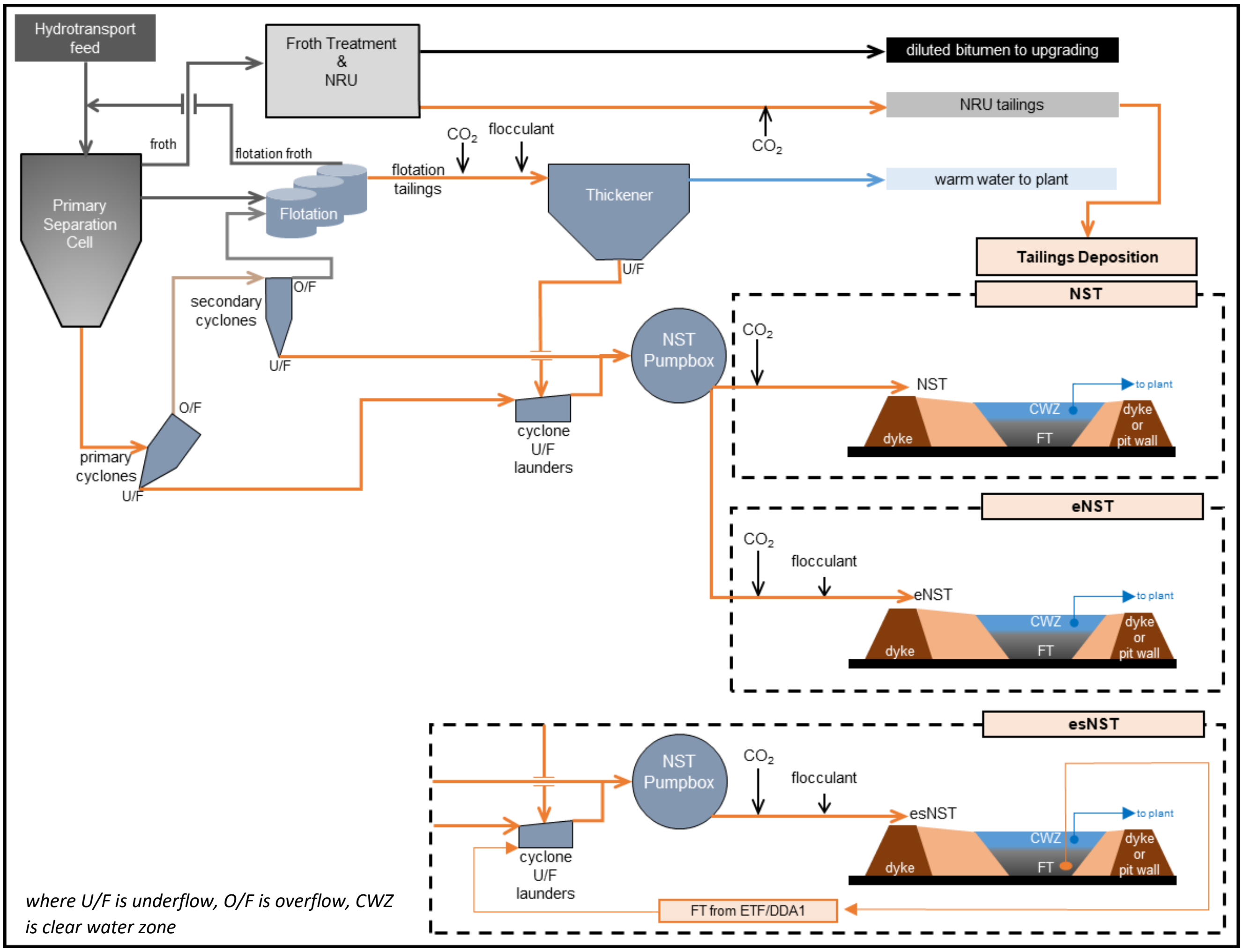


Figure 5-1: Simplified Horizon Process Flow Diagram

5.1 NST Process Measurements

The plan for monitoring and measuring the performance of the NST process is multi-facetted and comprise of flow-meters, density-meters, in-line samplers, and physical observations at the tailings discharge point. NST on-specification (on-spec) slurry density is defined as greater than 1.6 tonnes per cubic meter (t/m^3); on-spec NST management specifications are provided in Section 7.2.1 of the 2016 Horizon TMP Application (Canadian Natural 2016). The key indicators to determine on-spec performance of eNST and esNST processes are outlined in Table 5-1.

Operational factors such as the ore body fines content, equipment availability, and deposit geometry will influence which NST product (or combination of products) is produced at any given time. At Horizon, tailings deposits referenced as 'NST' contain a combination of all three NST products.

To meet extraction requirements, the *in-situ* ore body is blended by the mine for bitumen and fines content, which results in the production of NST or eNST with a sand-to-fines ratio (SFR) similar to the ore processed. Whenever the blended ore has an SFR higher than the esNST slurry SFR target of 3.75, Canadian Natural produces esNST (i.e., FT spiking) to increase the fines content in the esNST slurry and reduce the FT inventory. Canadian Natural reduced the esNST minimum slurry SFR target from 4.0 to 3.75 due to expected fines run-off, which results in a NST deposit with a higher SFR than the slurry SFR (i.e., SFR > 4:1) thereby improving overall fines capture. The flocculation dosage rate for eNST and esNST is based on data regression models that were developed using in-line sample results and multiple plant variables.

Table 5-1: NST Process Key Parameter Measurements

Parameter	Units	NST	eNST	esNST
flocculant addition*1	on / off	off	on	on
eNST and esNST polymer run times	%	n/a	≥ 85%	≥ 85%
slurry SFR	n/a	variable*2	variable*2	≥ 3.75
FT spiking density*3	t/m^3	n/a	n/a	> 1.03

**1 flocculant addition measured in grams (g) of polymer per tonne of fines*
**2 final product SFR dependent on ore feed SFR*
**3 density of water (i.e., no solids) is 1.0 t/m^3*
n/a means not applicable

In addition to the key parameter measurements listed above, Canadian Natural also monitors other parameters to provide additional information to allow for a better understanding of the process, including:

- slurry density of the feed materials (thickener underflow, PSC underflow, secondary cyclone feed and FT used for spiking) using in-line measurements,
- CO_2 injection rates,
- stream flowrates,
- physical observation of deposition behavior (e.g., channelized erosion on the beach, weekly beach scans),
- routine laboratory testing of the feed materials and NST, and
- annual tailings pond investigation results.

5.2 NRU Tailings Process Measurements

The NRU is designed to ensure that NRU tailings meet the diluent loss requirements as outlined in Table 5-2, from clause 14a) of Oil Sands Conservation Act (OSCA) Approval No. 9752M, as amended.

Table 5-2: NRU Process Key Parameter Measurements

Parameter	Units	Criterion
diluent losses	bbl of diluent per 1000 bbl of produced bitumen	< 4.0

where bbl means barrel

Monitoring and measuring the performance of the NRU tailings process is multi-facetted and comprise of the following activities:

- slurry density of the NRU tailings using in-line measurements (e.g., flow-meters, density-meters, in-line samplers),

- CO_2 injection rates,
- weekly beach scans,
- physical observation of deposition behavior,
- routine laboratory testing of the feed materials and NRU tailings, and
- annual tailings pond investigation results.

5.3 Quality Assurance and Quality Control

Sections 7.1 and 8 of the *S-23 – Monthly Oil Sands Plant Statement Production Accounting Manual* (i.e., S-23 Manual) outline the instrumentation and sampling requirements in terms of measurement accuracy, preventative maintenance, service factors, sampling frequency, and lab analyses. Equipment criteria compliance is reviewed monthly, and any potential changes first require AER approval, prior to field implementation. The S-23 Manual is required to be updated annually to the AER prior to December 31st to capture known changes prior of the start of the year, so that the manual is up-to-date.

6 TAILINGS DEPOSITION

The objective of tailings management at Horizon is to minimize the accumulation of FT by ensuring that FT are treated and tailings deposits are reclaimed progressively during the life of the operation while balancing environmental, social and economic needs. Canadian Natural has developed RTR performance criteria and measurement system plans for tailings deposits to support reclamation and closure of tailings facilities. Canadian Natural has implemented several strategies to manage and reduce FT inventory at the Horizon site, including:

- Implementation of the AOC (Canadian Natural 2022b) and AOC pilot (Canadian Natural 2023b) which were approved by the AER on November 14, 2022 and December 11, 2023, respectively. This alternate mining methodology reduces the fines content (i.e., less than 44 micrometer [μm]) in the ore feed being processed thereby reducing the total volume of fines in tailings.
- In 2015, Canadian Natural commissioned NST treatment technology to manage and reduce FT volumes at the Horizon site. **Error! Reference source not found.** provides a simplified schematic of the extraction a nd tailings processes at Horizon, including NST, eNST and esNST. Canadian Natural will continue to evaluate the feasibility of modifying NST composition and improving NST processes to maximize fines capture and overall solids capture, as well as developing supplemental and alternate technologies to ensure the approved FT inventory profile and progressive reclamation goals are met.
- Injection of CO_2 into the NST and NRU tailings process as a rheology modifier to increase yield strength of the slurry, decrease the potential for mixture segregation and improve fines settling.
- Plan for the use of water-capped tailings in a pit lake in the final closure landscape.

In addition to the commercially implemented strategies noted above, Canadian Natural continues to participate in additional tailings research and is an active member of the Canada's Oil Sands Innovation Alliance (COSIA) a division of Pathways Alliance.

6.1 Current Tailings Management Plan Approval

Canadian Natural's approved FT inventory is provided in Appendix B of OSCA Approval No. 9752M, as amended, and the legacy and new FT inventory profiles are illustrated as stacked line graphs in Figure 6-1. The approved total FT volume limit of 277 millions of cubic meters (Mm^3) and the FT trigger limit of 198 Mm^3 are also shown. Performance reporting on FT inventory is provided in the TMR, submitted annually by April 30.

Canadian Natural's approved RTR performance criteria for NST (i.e., including eNST and esNST), as a result of the updated approvals for the Horizon site, including the *Horizon Oil Sands Processing Plant and Mine Proposed Amendment to Non-Segregating Tailings Ready-to-Reclaim Sub-Objective 1 Performance Criteria* (Canadian Natural 2023a) and *Horizon Oil Sands Processing Plant and Mine Proposed Amendment to Non-Segregating Tailings Ready-to-Reclaim Sub-Objective 2 Performance Criteria* (Canadian Natural 2024a), is provided in Table 6-1.

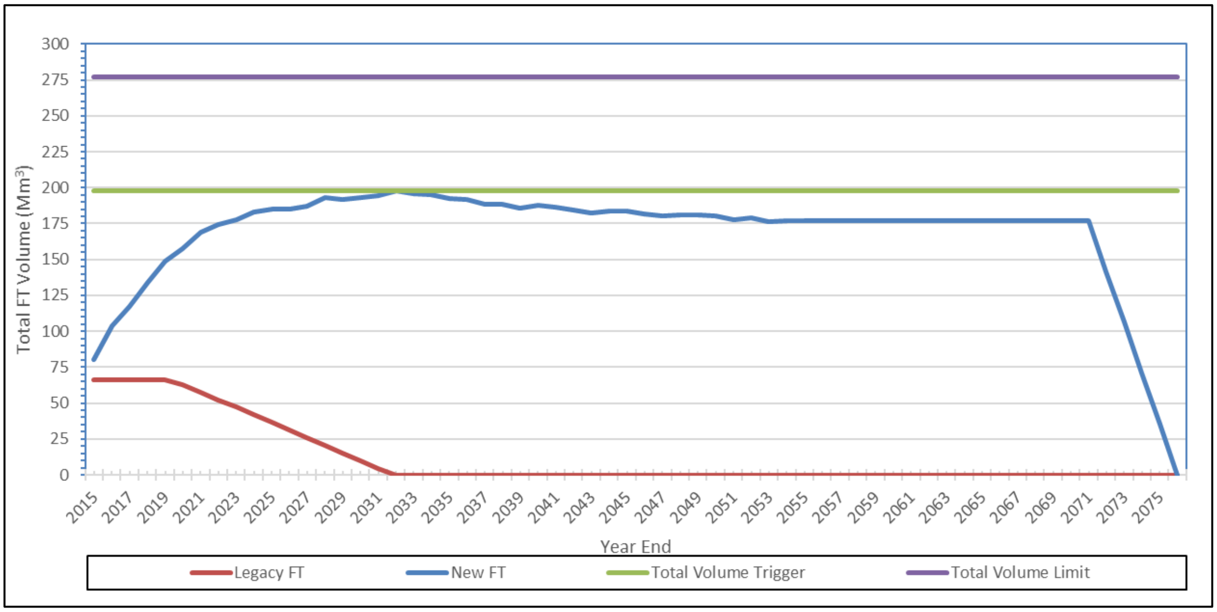


Figure 6-1: Horizon Approved Fluid Tailings Profile

Table 6-1: Current Approved RTR Criteria

Material	RTR Criteria	
Non-Segregating Tailings (NST, eNST, esNST)	Sub-Objective 1	1. 70 percent solids by weight (w/w) within 1 year of tailings placement, and
		2. 75 percent solids by weight (w/w) within 5 years of commencement of pond backfilling*
	Sub-Objective 2	Groundwater is monitored as required by Environmental Protection and Enhancement Act (EPEA) Approval No. 149968, as amended or renewed

** backfilling is defined as the approximate final 5% of the planned NST deposition for each DDA*

6.2 Tailings Deposition Zones

Tailings operations at Horizon includes the discharge of treated tailings streams (i.e., NST, eNST, esNST and NRU tailings) into a DDA, as illustrated in Figure 6-2. A large portion of the mineral content of the treated tailings is deposited on the beach as the tailings migrate towards the pond. All remaining mineral content, not contained within the beach (beach above water [BAW] and beach below water [BBW]), becomes a part of the FT inventory.

The deposition zones used in the annual TMR are described below:

- Tailings beach is comprised of both the BAW and BBW deposition zones.
    - The top of the BAW deposition zone is above the pond shoreline and the lower bound is defined by the post-mining surface or the previous year's top of BAW for an incremental volume calculation.

- The top of the BBW deposition zone is the hard-bottom surface, and the lower bound is defined by the post-mining surface, or the previous year's top of BBW for an incremental volume calculation.

- The fluid portions of the tailings pond develop when water, sand (i.e., > 44µm), fines (i.e., ≤ 44µm) and some residual bitumen from the treated tailings discharge are not captured in the beaches and flow into the pond to create the clear water zone (CWZ) and FT deposition zones.
  - The CWZ is created at the surface of the tailings pond as the solids settle. The CWZ contains water with less than 5 wt% solids that is recycled to the plant (refer to Section 7.1 for more details on the site wide water balance). The CWZ is bounded by the pond surface and the mudline.
  - The remaining material in the pond is FT (i.e., below the mudline and above the hard-bottom). Some portions of the FT deposition zones in the ETF/DDA1 and DDA2 meet approved RTR performance criteria and are therefore removed from the FT inventory.

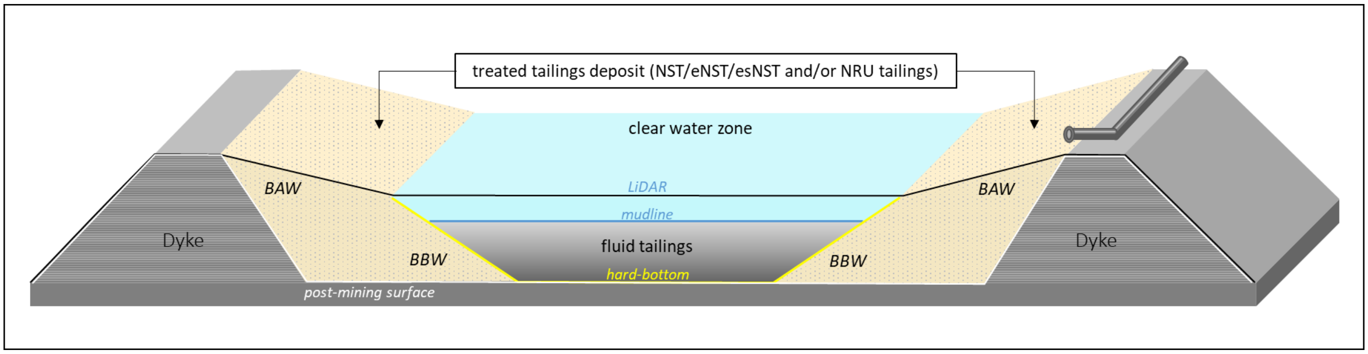


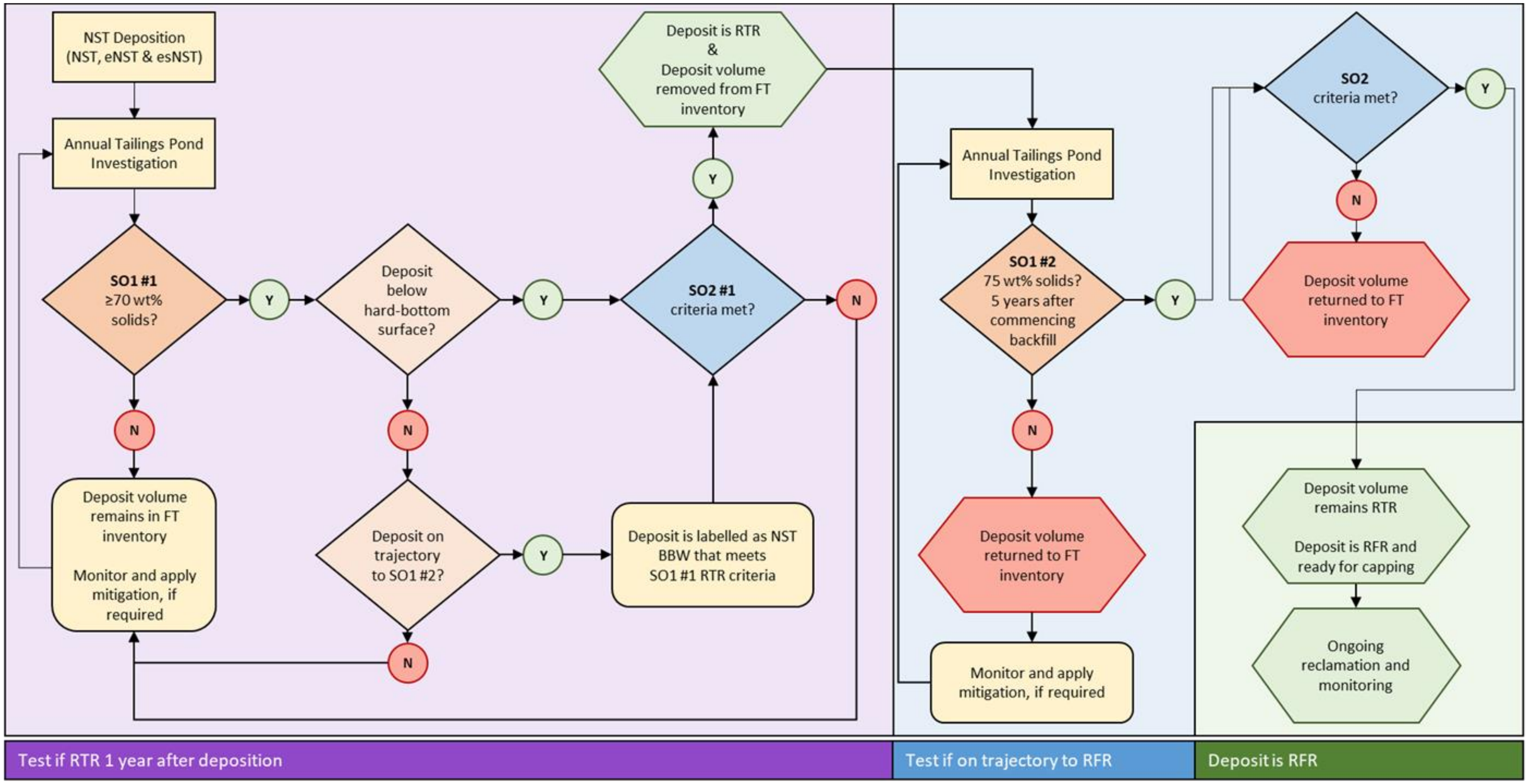
Figure 6-2: Tailings Deposition Zones

6.3 Method Determination of Fluid Tailings and Ready-to-Reclaim Deposits

The Horizon Measurement System Plan is designed to outline how measurements and data are collected and managed to provide reporting on FT inventory and RTR performance criteria.

Any NST deposit that is sampled and does not meet RTR criteria is included in the FT inventory volume for that year as illustrated in Figure 6-3. However, since the beach deposits are not homogenous, smaller pockets that do not meet the approved RTR criteria may still exist. Any NST beaches that were sampled and do not meet approved RTR criteria will be sampled again the following year. If the NST beach meets approved RTR criteria at that time, then they are considered as meeting RTR and are removed from the FT inventory. The process flow by which Canadian Natural reports on NST performance from initial deposition to RTR and ready-for-reclamation (RFR), as approved, is illustrated in Figure 6-2.

As per clause 201 of Decision 20171218A (AER 2017a) and clause 34 of OSCA Approval No. 9752M, as amended, Canadian Natural may not remove NRU tailings from the FT inventory until RTR sub-objective 1 and sub-objective 2 performance criteria for NRU tailings (Appendix C of OSCA Approval No. 9752M, as amended) is applied for and is approved by the AER. Until such time that NRU tailings has an approved RTR criteria, Canadian Natural will add NRU tailings deposit volume to the FT inventory. Any FT that is created from the deposition of NRU tailings is already counted as part of the FT inventory.



Note: NST is non-segregating tailings; eNST is enhanced NST; esNST is enhanced spiked NST; SO is sub-objective 1 and/or 2; FT is fluid tailings; RTR is ready-to-reclaim; RFR is ready-for-reclamation; BBW is beach below water.

Figure 6-3: NST RTR & RFR Flow Chart (Current Approval Basis)

6.4 Tailings Pond Investigations

The Horizon tailings pond investigation is designed to meet the requirements of both ongoing tailings and geotechnical planning activities and annual regulatory reporting (i.e., as shown in Table 2-1). Canadian Natural currently plans for at least one tailings pond investigation per year, which is typically completed in the fall, prior to the pond freezing. Canadian Natural will occasionally conduct a smaller scope tailings pond investigation in the spring to develop a high-level understanding of performance to ensure that planning and operational objectives are being met, and/or to collect samples for various research initiatives.

The methodologies used in the tailings pond investigations follow the *Guidelines for Determining Oil Sands Fluid Tailings Volumes* (COSIA 2015b) and the approved Horizon TMP (Canadian Natural 2016 & 2019). The key objectives of the tailings pond investigations include:

- to map the top of pond (i.e., water surface) and BAW,
- to identify and map the mudline,
- to identify and map the hard bottom (i.e., FT and beach interface),
- To develop 3D geometric shapes (wireframes) and calculate volumes of the CWZ, FT and the incremental beach deposited since the previous tailings pond investigation,
- to characterize the physical properties of the tailings deposition zones, and
- to determine soil stratigraphy, density, strength and pore pressure properties.

The main objective of the tailings pond investigation is to collect a sufficient population/distribution of the various datasets listed above to allow for the adequate characterization of the deposition zones to support regulatory reporting, planning and operational requirements.

Table 6-1 and 6-2 outline the measurement type, density and frequency of tailings deposition zone surface delineation and deposit physical characteristics to support regulatory reporting.

Table 6-2: Measurement of Tailings Deposition Zone Volumes for Regulatory Reporting

Parameter	Tool/Method	Density	Frequency*1	Reference
water surface	LiDAR, other survey methods*2	continuous	semi annually	Appendix B – Section 1.1
BAW surface	LiDAR, other survey methods*2	continuous	annually	Appendix B – Section 1.1
mudline	sonar survey	continuous	annually	Appendix B – Section 1.2
mudline	fixed interval sampling (FIS)	minimum 3/pond (COSIA 2015b)	annually	Appendix B – Section 2.2
hard-bottom	CT09	100 m to 200 m grid	annually	Appendix B – Section 1.3
hard-bottom	ball or cone penetration test (BPTor BCPT/CPT)	minimum 3/pond	annually	Appendix B – Section 1.4-1.6

*1 minimum frequency required on deposits 1-2 years old to support operational, planning and regulatory reporting
*2 other survey techniques may include GPS, where accessible, and/or digitized air photos or satellite imagery

Table 6-3: Measurement of Tailings Deposition Physical Characteristics for Regulatory Reporting

Parameter	Test/Method	Density	Frequency[*1]	Reference
solids content (wt%)	DSA (weight difference)	variable[*2]	annually	Appendix C – Section 2
water content (wt%)	DSA (weight difference)	variable[*2]	annually	Appendix C – Section 2
bitumen content (wt%)	DSA (weight difference)	variable[*2]	annually	Appendix C – Section 2
fines content (wt%)	PSD of post DSA sample by wet/dry sieve and laser diffraction	variable[*2]	annually	Appendix C – Section 3
particle size distribution	PSD of post DSA sample by wet/dry sieve and laser diffraction	variable[*2]	as required	Appendix C – Section 3
clay content (wt%)	PSD of post DSA sample by wet/dry sieve and laser diffraction	variable[*2]	as required	Appendix C – Section 3
clay type/content	x-ray diffraction (XRD)	variable[*2]	as required	n/a
clay type/content	MBI test	variable[*2]	annually	Appendix C – Section 4
BAW and BBW undrained shear strength	cone or gamma cone penetration test (CPT/GCPT)	minimum 3/pond	annually	Appendix B – Section 1.4-1.6
FT undrained shear strength	ball or gamma ball penetration test (BCPT/GBCPT)	minimum 3/pond	annually	Appendix B – Section 1.4-1.6
FT undrained shear strength	vane shear test	variable[*2]	as required	Appendix B – Section 1.7

[*1] minimum frequency required on deposits 1-2 years old to support operational, planning and regulatory reporting
[*2] the number of tests in any deposit will depend on the variability of the deposit, which is assessed after the previous tailings pond investigation, and reviewing active deposition areas since last tailings pond investigation.

Although RTR is based on solids content, many other performance tests are completed and relied upon to validate deposition zone surfaces and volumes. The 2023 tailings pond investigation sample results from all DSA for ETF/DDA1 and DDA2 are plotted in the geotechnical ternary diagram in Figures 6-4 and 6-5, respectively, which are based on Figure 1 of the *"Measuring Undrained Shear Strength of Oil Sands Tailings Deposits"* (COSIA 2015a) report. Comparing Figures 6-4 and 6-5 to Figures 2 and 3 of COSIA (2015a) illustrates that the undrained shear strength of tailings deposits produced at Horizon (i.e., beach deposits and/or deposits that are consolidating) are suitably measured by CPT, BPT and/or vane shear tests.

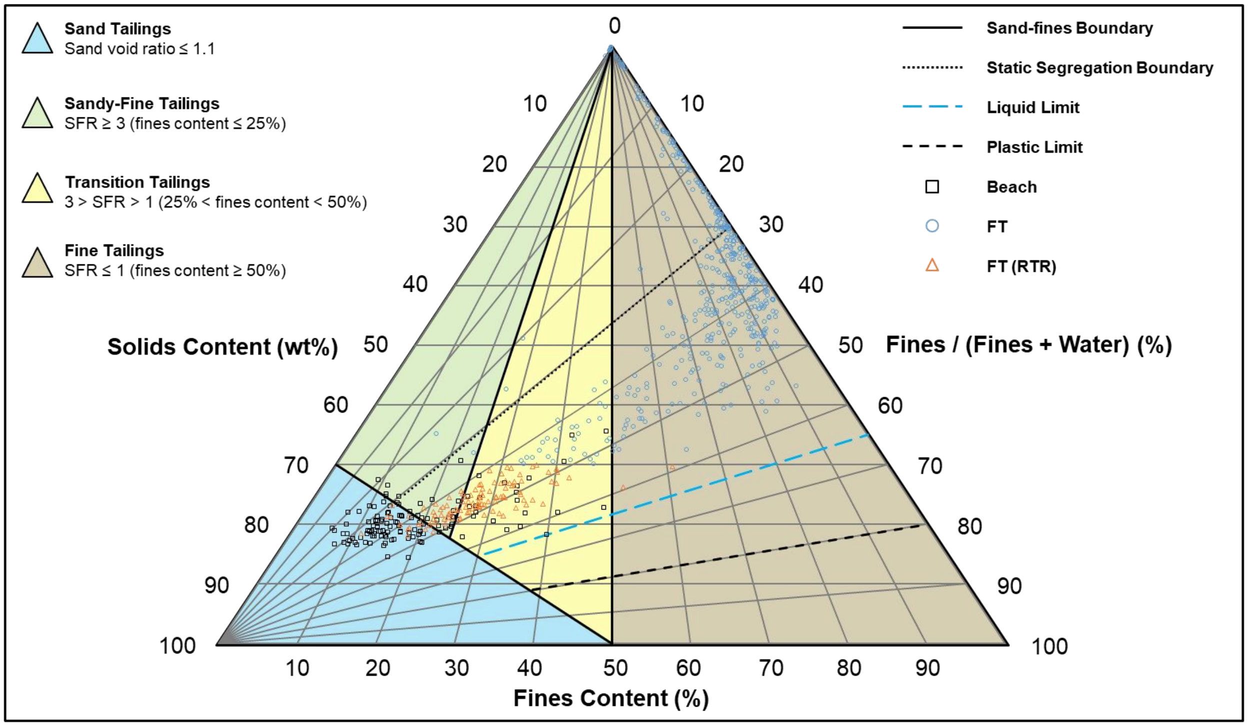


Figure 6-4: Geotechnical Ternary Diagram, 2023 ETF/DDA1 Sample Results (adapted from COSIA 2014a)

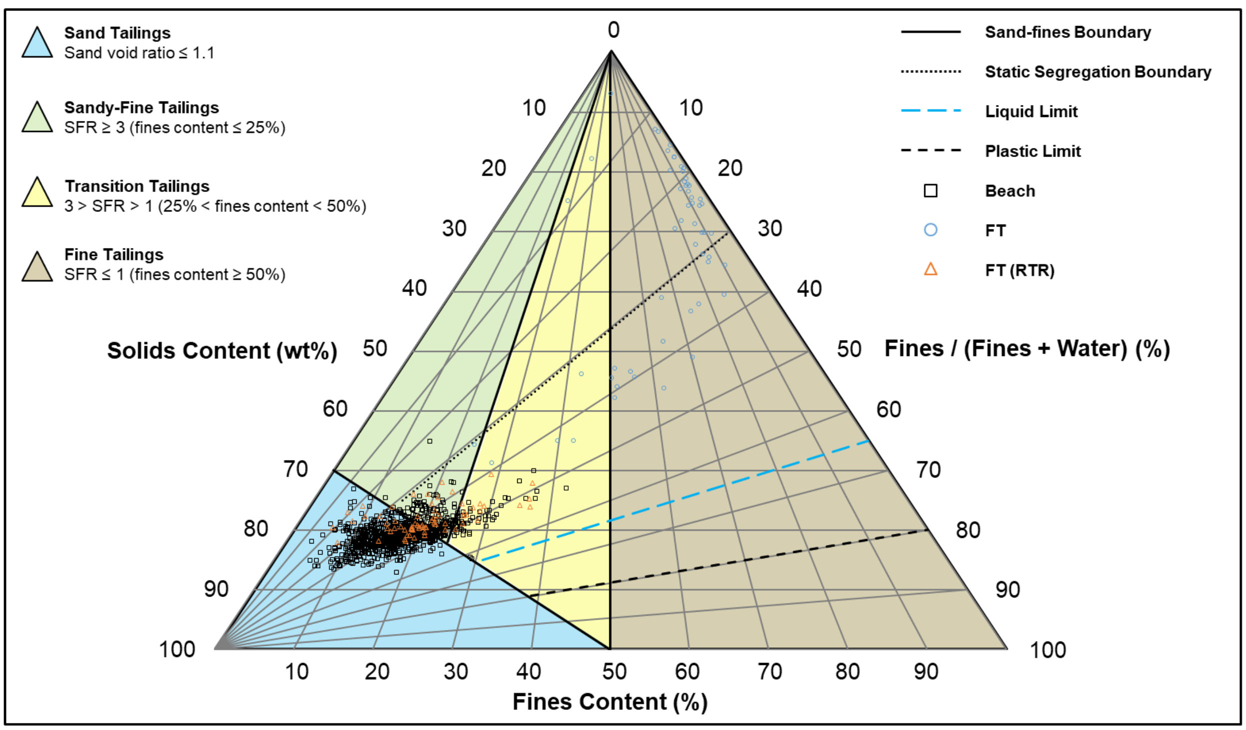


Figure 6-5: Geotechnical Ternary Diagram, 2023 DDA2 Sample Results (adapted from COSIA 2014a)

6.4.1 Survey Program Analysis

The topographic survey (i.e., LiDAR), sonar, FIS, CT09 and pond elevation surveys conducted during the tailings pond investigations are used to define the 3D geometry for each depositional zone within the DDA. The survey data obtained from the tailings pond investigations are used to generate the pond surface, the BAW, mudline and hard bottom surfaces for each DDA. Original ground (i.e., post-mining surface), LiDAR and surfaces derived from prior investigations are used to supplement the pond survey data as required.

6.4.1.1 Accuracy of Survey Dataset

A series of checks are completed to validate the boundary of the deposition zones with several types of survey data. Most of the survey data collected can be validated against other survey data or sample point data. These checks include:

- Ensure the accuracy of the LiDAR survey, by comparing to pond elevation survey and manual survey data collected from the beach and containment dykes. In addition, the LiDAR data can be compared to the collar elevations of the sonic core hole drill program;
- Check that the change in the top of pond elevations (i.e., top of CWZ), which are taken weekly, are reasonable and can be reconciled with tailings deposition, FT removal and the tailings pond water balance (refer to Section 7 for additional details on the site wide water balance);
- Compare the sonar derived mudline (i.e., CWZ and FT interface) surface to the FIS derived mudline to ensure consistency; and
- Ensure the accuracy of the BBW surface by comparing the CT09 data to the BCPT, CPT and sample results.

If any of the above checks result in discrepancies in the surfaces that define each deposition zone, then the differences need to be reconciled and rechecked, and reported in the annual TMR.

6.4.2 Distribution of Sample Locations

The number and distribution of sampling locations required to adequately characterize each depositional zone are based on a combination of previous statistical analyses and engineering judgment. The annual tailings pond investigation at Horizon is holistic in scale (i.e., not as concerned about localized over and underestimation events within each depositional zone as long as the averages are representative and without bias in one direction or the other). As a result, the sample location spacing requirements are less dense in relation to what is required in an active mining scenario.

Canadian Natural completed pond drill spacing decimation studies to develop relationships between depositional variability and estimation accuracy. To do this, an area was intentionally oversampled and surveyed during a tailings pond investigation to determine appropriate future sample point densities. The primary consideration in quantifying uncertainty is the scale of investigation, or specifically, the scale at which to quantify the error in the estimate. As an example, for reserves estimation, a 400 m by 400 m drill spacing (16 core holes/section), over the pit area of interest, is typically sufficient for reconciling within 1 - 3% of the equivalent pit area drilled at 100 m by 100 m spacing (256 core holes/section). This means only 6% of the sample points distributed over the life-of-mine pit are required to generate a model estimate consistent with a model constructed using a 100 m by 100 m production level drill spacing dataset. The purpose for the increased drill density is specifically related to the scale of investigation. Reserves are based on the accuracy of the global scale estimate for the life-of-mine pit, whereas production level drill spacing is necessary to determine the localized level of accuracy required for predicting what's in front of a mining shovel at a given moment in time. Two vastly different sampling densities are therefore required to meet the estimation accuracy needs for each particular scale of interest.

For reporting purposes, global estimates for total volumes, dry tonnages and average characteristics (solids, water, bitumen, MBI, sand/fines/clay content, etc.) of each tailings deposition zones are required. Current sampling and surveying density acquired from each tailings pond investigation are developed to meet planning requirements, which is more than sufficient to meet the global estimation accuracy requirements of the regulator.

Geostatistical analysis of prior tailings pond investigations demonstrated that areas with the most depositional variability typically take place within the BBW footprint for both FT and BBW deposits. Based on these findings, additional drilling and optimized borehole placement strategies have been undertaken to improve model characterization accuracy in this area.

As discussed in the annual TMRs, a mass balance reconciliation exercise is completed to ensure the dry mineral (i.e., solids) and fines mined and processed is consistent with the modeled dry tonnages deposited in the various zones within each DDA. The mass balance differences between the S-23 reported processed ore (refer to Section 4) and modeled ETF/DDA1 depositional increments typically ranges between ± 3 to 5 % annually.

Based on experience reconciling annual tailings pond investigation data, Canadian Natural generally considers FT volumes in the ETF/DDA1 to be within 5 % or better of surveyed values.

Canadian Natural is continuing with ongoing engineering analysis of the various deposition zones within each DDA to evaluate the drill spacing and sample location requirements for each deposition zone. The appropriate spacing will be dependent on the expected variability of the deposit for each deposition zone. Figure 6-6 provides an example of the sampling density used in ETF/DDA1 and DDA2 as reported in the 2023 TMR (Canadian Natural 2024b).

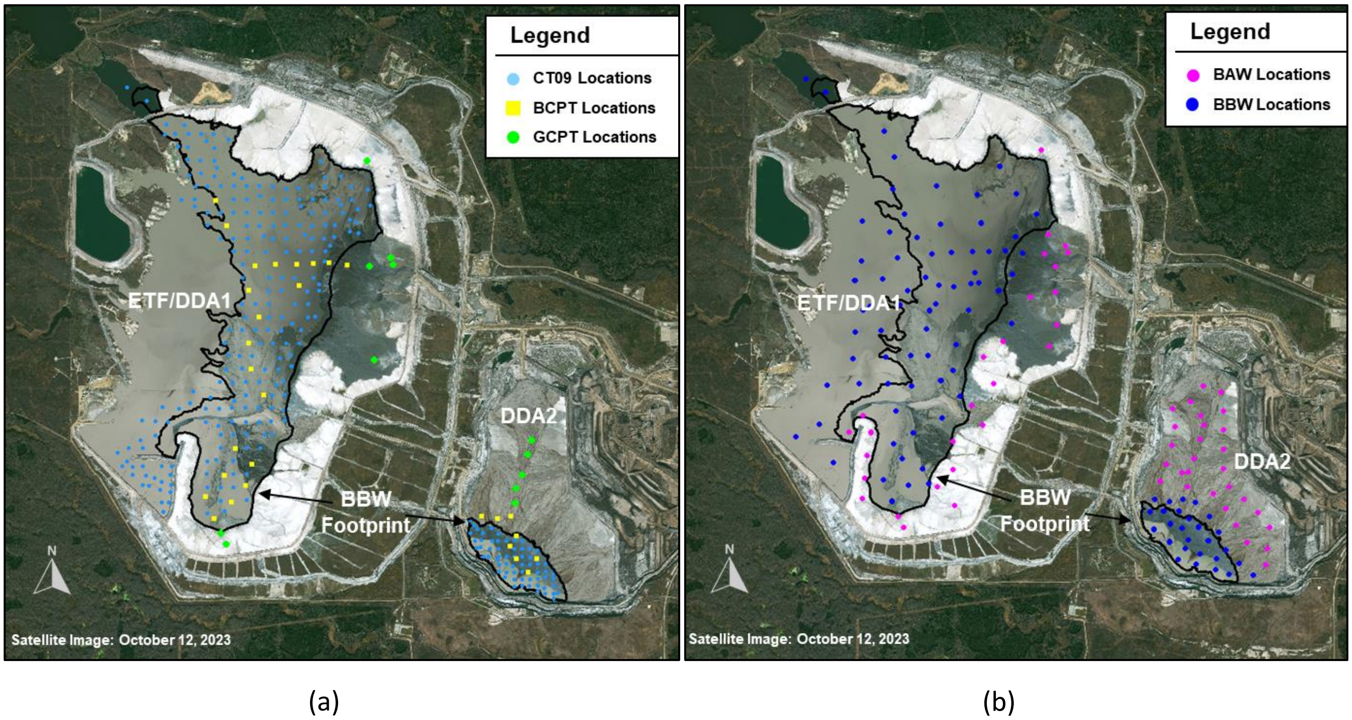


Figure 6-6: 2023 Tailings Pond Investigation (a) Geotechnical Test Locations and (b) Sampling Locations

All BAW and BBW drilling collect vertically contiguous samples that are sent to the laboratory for additional testing. Sampling through a portion of the previous investigation depositional zones allows for the validation of the previously modeled depositional increment, as well as map any changes observed.

6.4.3 Laboratory Testing

A laboratory testing program is conducted on the samples collected from the DDAs during the annual tailings pond investigation. The laboratory testing components were outlined in Table 6-2 and include:

- DSA (by weight difference) which provides solids, water and bitumen content as a wt% of the total sample mass (refer to Appendix C – Section 2),
- PSD of post DSA sample by wet/dry sieve and laser diffraction provides fines content (% passing 44 µm sieve size) as a wt% of the total solids mass (refer to Appendix C – Section 3),
- % clay as determined by MBI, (refer to Appendix C – Section 4), and
- total suspended solids (TSS) and water chemistry on CWZ samples (refer to Section 7 and Appendix C – Section 6).

Lab results are used to characterize, confirm and validate the extents of the various depositional zones within the block model.

The standard for measuring clay characteristics is x-ray diffraction (XRD). When this is used, both the mineralogy and available surface area are determined. This process is expensive and can be time consuming. The methylene blue "stain" test is an acceptable alternative and is a reasonable quantitative evaluation method to determine the activity of a material based on the type and quantity of clay minerals contained in it.

6.4.3.1 Accuracy of the Sample Results

One of the main goals of the quality assurance and quality control program is to ensure that the laboratory provides consistent results on a year-to year basis and to verify that the systematic trends that might be revealed in the Horizon-specific database as being real trends rather than issues with laboratory performance.

Statistic quality control practices allow Canadian Natural to maintain the necessary level of consistency and include:

- Separate programs to differentiate between random error and bias error, and
- Monitoring of the accuracy and precision of all physical and chemical tests.

Bias errors can be identified by regularly submitting test samples of reference material with pre-established “consensus” values into the analytical queue. By submitting the original sample, the bias associated with any of the sample preparation steps (disaggregation in the case of particle size distribution) as well as the bias associated with the final measurement step are identified.

Repeatability (random error) is monitored by analysis of blind duplicate samples that are submitted by the operator of the lease.

The accuracy of the results from DSA, fines content and clay content (MBI) are essential to adequately characterize the depositional zones within the tailings ponds. To ensure that an accurate material balance reconciliation can take place between ore mined and tailings produced; consistent sample collection, preparation and analyses are essential.

To confirm the accuracy and reproducibility of the sampling results, a blind re-testing program of the spring 2018 samples was completed in March of 2019. Approximately 34 % of FT and RTR beach samples were independently re-labeled and re-tested. The average difference in the results was ±0.2 wt% (absolute) for both the DSA and the fines content results. This blind test demonstrated the accuracy and reproducibility of the spring 2018 assay results. Going forward, the tailings pond investigation sample lab results are validated using a blind duplicate retesting process similar to the one used for the annual mine core hole drilling program. In 2021 and 2022, approximately 10% of samples were validated using a blind duplicate process. The test results were within an acceptable range of variability (i.e., criteria for fines in FT and beach is ± 1.5 wt% [absolute]). The difference between bitumen duplicates were in the range of 0.1% (absolute). Based on reference sample results, there were no bias in lab results between 2021 and 2022 programs both in bitumen and fines data.

6.4.4 Modelling

Three-dimensional digital wireframes are created to define the CWZ, FT and incremental beach deposited since the previous tailings pond investigation. Total volumes for the CWZ, FT, BBW and BAW are calculated using these wireframes. Incremental volume changes from prior investigations are also calculated.

In the event that active deposition is taking place during the various survey activities, efforts are made to ensure that the mid-point date of the CT09 survey is scheduled to align with the LiDAR survey dates. This ensures the time stamp for the data collected to construct both the BAW and BBW surfaces are consistent.

To characterize the depositional zones, assay data results from the laboratory testing (as per Section 6.3) are used to create a block model, allowing for the spatial characterization of each respective depositional zone. The key modelled attributes of interest include: solids, water, bitumen, fines and clay content (i.e., as approximated using MBI results).

The surveyed zone wireframes discussed above are used to populate each model block with codes to differentiate which deposition zone each block is contained within. Model blocks and assay samples with the same zone code can then be used to interact with one another during the interpolation process. The assay samples within each zone are used to interpolate DSA, fines content and MBI into the model blocks. The spatial characteristics of each zone are evaluated to determine the most appropriate interpolation parameters. Following the population of the attributes listed above, a variety of additional block characteristics are then calculated including wet density, dry density, mass of dry sand and fines, clay content and SFR. A series of cross sections throughout the model showing solids content, SFR and clay content (based on MBI) are provided in the annual TMR.

Summary statistics from the DDA tailings block models are evaluated to ensure the mass of dry sand and fines reporting to the processing facility are well aligned with the incremental model results between two successive tailings pond investigations. Additional information regarding the reconciliation process were provided in Sections 3, 4 and 5.

6.4.4.1 Fluid Tailings Accounting

The FT inventory for each reporting period is calculated using the methodologies which are consistent with those outlined in the *Guidelines for Determining Oil Sands Fluid Tailings Volumes* (COSIA 2015). Directive 085 (AER 2022) defines RTR as the "*state achieved when FT have been processed through an accepted technology, have been placed in their final landscape position, and have achieved necessary performance criteria*". The geometry of the FT deposition zone is constrained between the mudline and hard bottom surfaces. In an effort to produce a representative FT inventory, hard bottom surfaces are modelled and reviewed against previous surveys, lab sampling, satellite imagery, and any additional available data. Commentaries relating to the interpretation of the survey data are provided below.

<u>Mudline Interpretation</u>

The mudline surface (i.e., CWZ and FT interface) is created from the sonar survey dataset, which includes measured mudline elevations overlain by a grid of Northings and Eastings that can then be used to create a surface. As discussed in Sections 6.2 and 6.4 and in Table 6-2, the accuracy of the mudline is determined by comparing the sonar derived mudline surface to the FIS fluid sample results.

<u>Hard Bottom Interpretation</u>

The hard bottom surface is developed by combining the original ground as-built surface with the BBW surface, as determined from the CT09 survey. As discussed in Sections 6.2 and 6.4 and in Table 6-2, the accuracy of the hard bottom is confirmed by comparing the CT09 data to the BCPT, GCPT and sample assay results. The BAW and BBW zones within the DDAs are composed of material with strengths indicating non-fluid behaviour with an average solids content range of approximately 78 wt% to 79 wt% in the ETF/DDA1 and 80 wt% to 81 wt% in the DDA2 (Canadian Natural 2022a and 2024b). Furthermore, several years of assay and BCPT data is showing this zone to be increasing in strength and solids content with depth in both cells.

Fluid Tailings that meet RTR Criteria

Canadian Natural identified an area of the FT inventory with a solids content greater than 70 wt% in the ETF/DDA1 starting in 2019 and in DDA2 starting in 2020. Initially, Canadian Natural did not remove any of this volume from the FT inventory, as more time was required to evaluate this zone. Upon further investigation of this area over multiple pond investigations, Canadian Natural has determined that a significant portion of the FT with a solids content greater than 70 wt% has since refused CT09 and is now part of the BBW deposition zone as defined by the hard-bottom surface. This indicates that this zone is consolidating and/or settling in place, being covered or mixing with the advancing BBW and improving in solids content and strength over time.

Starting in the 2023 Horizon TMR (Canadian Natural 2024b), Canadian Natural allocated the portion of the FT that has a solids content greater than 70 wt% as meeting RTR sub-objective 1 performance criteria and is therefore removed from the FT inventory, as outlined by the process illustrated in Figure 6-3. The decision to remove this volume from the FT inventory was based on the fact that this deposit met condition 1 of the approved RTR sub-objective 1 performance criteria (i.e met 70 wt% solids content within 1 year of deposition) and is on trajectory to meeting condition 2 (i.e., 75 wt% solids) as per Table 6-1.

This zone will continue to be surveyed, mapped, sampled, lab analyzed and strength tested in forthcoming investigations to build on the current library of data.

Naphtha Recovery Unit Tailings Deposits

Naphtha Recovery Unit tailings have been produced at Horizon since startup, and have always been deposited into the ETF/DDA1 in alignment with clause 31 of OSCA Approval No. 9752M, as amended. Naphtha Recovery Unit tailings beach deposits do not currently have approved RTR performance criteria, and therefore have been added to the FT inventory in alignment with clause 34 of OSCA Approval No. 9752M, as amended.

Naphtha Recovery Unit tailings were co-deposited with WT from 2009 to 2015, were co-deposited with NST starting in 2015, and were co-deposited with enhancements to NST (i.e., eNST and esNST) in 2019 and 2020. Since the fall of 2020, the NST lines directly north and south of the NRU tailings pour point were moved to DDA2, and a NRU dominated tailings deposit has since been created on the east side of the ETF/DDA1.

Differentiating NRU tailings from within the NST/ NRU tailings co-deposit is not feasible. Therefore, Canadian Natural has allocated a portion of the total co- deposit to the FT inventory based on the relative proportion of NRU tailings deposited in the ETF/DDA1 co- deposit (i.e., approximately 12%) between the 2018 and 2020 tailings pond investigations. The BAW and BBW surface from the fall 2020 tailings pond investigation is used as a surface to represent the boundary between the NRU dominated tailings deposit and the underlying co-deposit. The total volume of NRU tailings beach that has developed in the eastern ETF/DDA1 (i.e., volume above the fall 2020 tailings pond investigation BAW and BBW) is added to the FT inventory.

6.4.5 Model Reconciliation to Ore Processed

The modelling process described in Section 6.4.4 outlines how the model blocks within each depositional zone are populated with atribute data. These estimates are then used to determine the dry mass of the total mineral solids (i.e., mass of sand and fines) within each individual model block.

The total mass of sand and fines, water and bitumen in the FT deposition zone is determined by accumulating the masses contained within each model block. The incremental FT deposited, for a given period of time can then be calculated by subtracting the FT inventory components from the model of the previous investigation. The RTR beach, on the other hand, is modeled as a depositional increment (between two successive beach surfaces).

The incremental mass of sand and fines that are estimated between two consecutive tailings pond investigations, can then be compared and reconciled against those respective components reporting to the various tailings streams for the equivalent time period. This reconciliation is reported in the annual TMR. Section 4 of this document provided additional context on how mined and processed material is reconciled tailing modeling results.

6.4.5.1 Adequacy of Dataset

There are a variety of components used to determine the adequacy of the pond investigation dataset. Survey data defines the geometric shapes of the various depositional zones. Survey inaccuracies will result in erroneous zone volumes. Regardless of how accurately the material is characterized within each zone, the result will likely be an over or under estimation, relative to what was actually deposited.

Conversely, an accurate survey dataset may create a representative 3D model for each depositional zone, but inaccuracies in the core and fluid sample dataset, or an insufficient spatial distribution of data, may result in an inaccurate characterization within any, or all, of the zones being modeled.

An important component of the modeling process is the mass balance comparison to the hydro-transport estimates discussed further in Section 4. If there is reasonable alignment between the tailings model mass estimates and the hydro-transport estimates, this is a good indicator that the global estimates contained within the model are representative. Validation of the survey, assay dataset and modeling assumptions are still required. Ongoing analyses are used to continuously improve all aspects of sampling and survey density, drillhole placement and modeling inputs and assumptions.

6.4.6 Quality Assurance and Quality Control

6.4.6.1 Equipment Verification

All equipment used (CPT, BCPT, GCPT and/or GBCPT, CTO9, sonic, vain shear) must be well maintained and calibrated to available standards (i.e., American Society for Testing and Materials or ASTM) as required. Additional quality assurance and quality control methodologies for specific field surveys, in-situ measurements and sampling procedures are provided in Appendix B and E.

6.4.6.2 Field Data Confirmation

Training of operators and the correct execution of procedures are vital to obtaining representative field data. Repeatability and confirmation using different tools is done as required during measuring and monitoring. The contractor provides verification records on these efforts. Additional quality assurance and quality control methodologies for specific field surveys, in-situ measurements and sampling procedures are provided in Appendix B and E.

6.4.6.3 Validation of Laboratory Data

One of the main goals of the quality assurance and quality control program is to ensure that laboratory provides consistent results on year-to year basis and to justify the systematic trends that might be revealed in the database as real trends rather than issues with a laboratory performance.

Statistic quality control practices allow to maintain the necessary level of consistency and Include:

- Separate programs to differentiate between random error and bias error, and
- Monitoring of the accuracy and precision of all physical and chemical tests.

Bias errors can be identified by regularly submitting test samples of reference material with pre-established “consensus” values into the analytical queue. By submitting the original sample, the bias associated with any of the sample preparation steps (disaggregation in the case of particle size distribution) as well as the bias associated with the final measurement step are identified.

Repeatability (random error) is monitored by analysis of blind duplicate samples that are submitted by the operator of the lease.

6.4.6.4 3D Model Confirmation

As discussed, once the data has been collected, checked and confirmed it is turned into a 3D block model using the geological modelling software MineSight. Once the model is built the tailings deposition data is checked statistically to ensure the accuracy of the interpretation.

7 TAILINGS WATER

The tailings water measurement plan consists of 2 main parts, the plant and tailings pond water balance and the plant chemistry measurements. The block flow diagrams shown in Figure 7-1 and Figure 7-2 illustrate the Horizon plant and tailings pond water balance where stream volumes are reported in the annual TMR. The various streams are colored based on the type of measurement, such as:

- metered streams (shown in orange),
- calculated streams (shown in yellow), and
- environmental modelled streams (shown in blue).

7.1 Plant and Tailings Ponds Water Balance

The stream volumes reported in the annual TMR are not reconciled and reflect the actual measured, calculated and/or modelled values. The reported error of the blocks must be less than the error of the measurements in order to show that the balance is as accurate as possible. Where possible, physical samples (e.g., in-line samplers) are also taken to confirm metered and calculated values.

7.1.1 Metered Streams

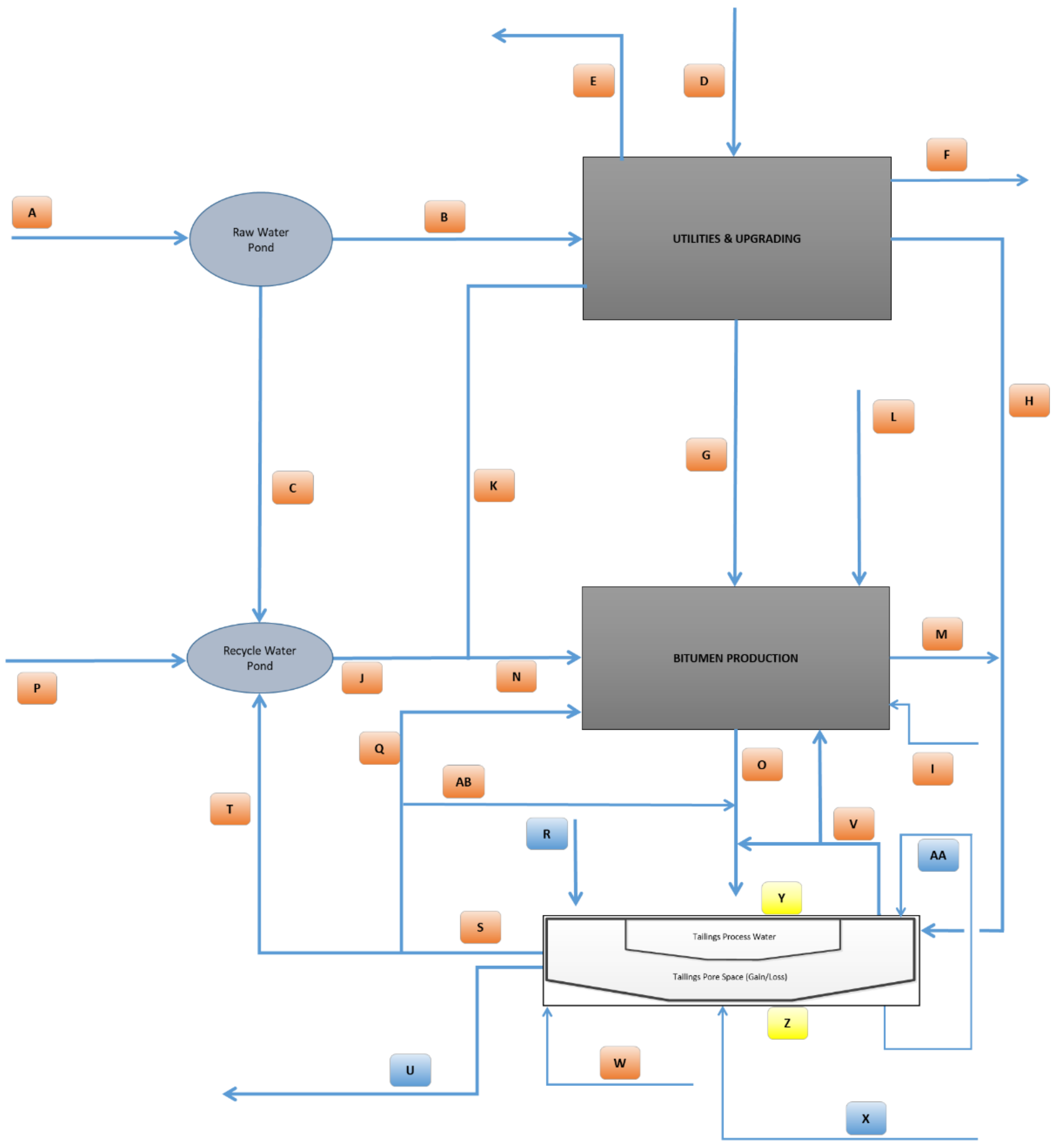
Flow-meters and density-meters are installed on several slurry pipelines throughout the Horizon Plant and on all tailings lines. Flow meters are used to measure flow rates, typically in meters per hour, and take continuous readings which are uploaded to the data historian. Density meters are used to measure the density of the slurry in the pipeline, typically in tonnes per cubic meter, and take continuous readings which are uploaded to the data historian.

Physical samples are taken from each tailings line using in-line samplers, which collect 12-hour composite samples that are analyzed at the Horizon site laboratory using DSA to determine the bitumen, solids and water content.

Since the water and bitumen in these streams are similar in density the lab data is used to subtract the bitumen from the total liquid volume to report the volume of water. There are other streams in which the addition of multiple lines or the difference between lines is the reported number.

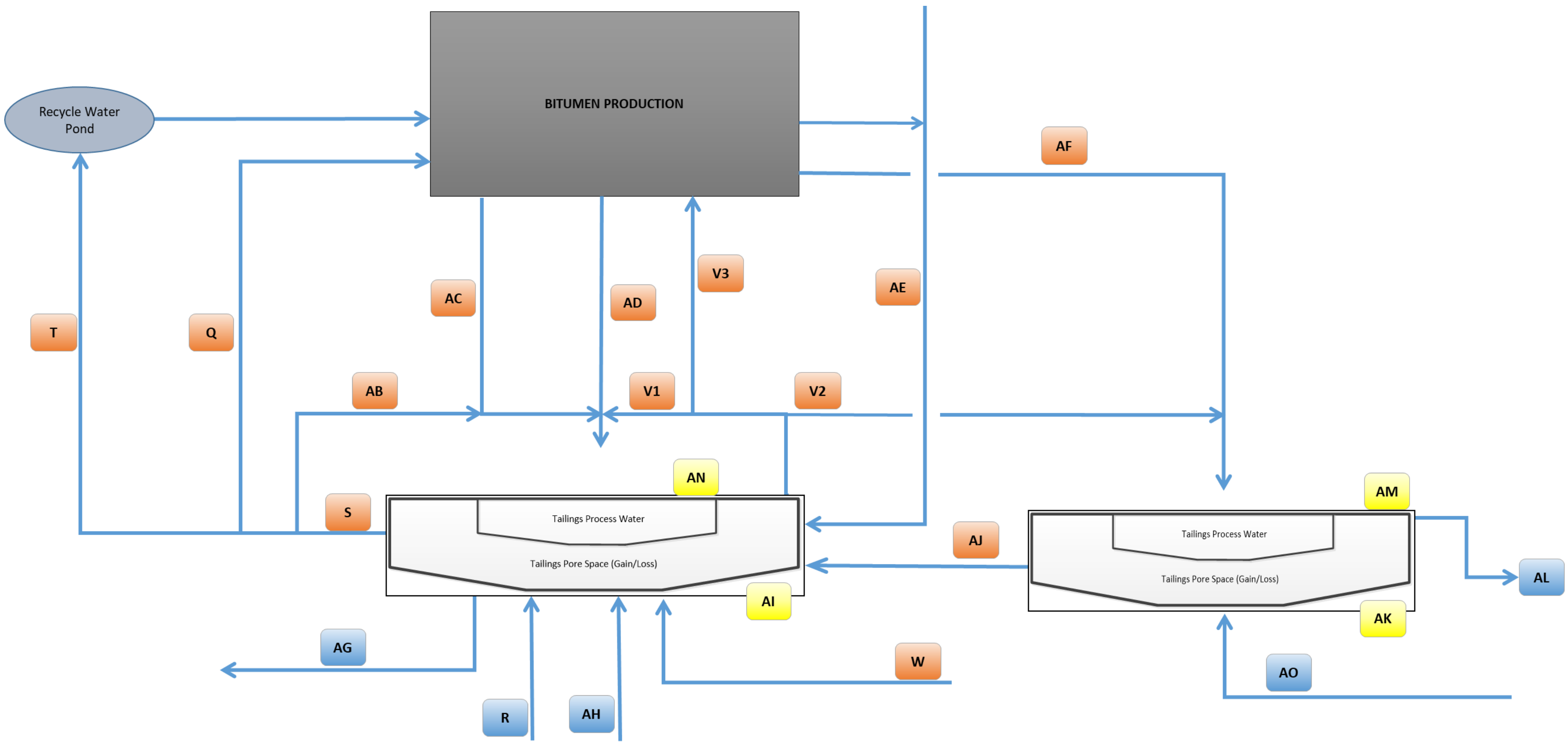
The error for streams of water that have a flow meter is ± 0.1 %. All flows that may need to be calculated or inferred have an error of ± 1 %.

Figure 7-1: Horizon Mine Water Block Flow Diagram



A	Athabasca River water
B	Raw water to Upgrading
C	Raw water to RCW Pond
D	Plant site run-off water
E	Storm water pond to RCW Pond (included in "P")
F	Cooling tower water losses
G	HPW, utility water & steam
H	Upgrading waste water
I	Caustic & site run-off
J	Recycle water
K	Recycle water to heat Integration
L	Ore conate water
M	Thickener WPW & HPW
N	CPW to Bitumen Production
O	Water in NST & NRU tailings slurry
P	Surface and Mining water sources
Q	Ore Preparation water
R	Tar River Diversion to ETF/DDA1
S	Reclaim water from ETF/DDA1
T	Reclaim water to RCW Pond
U (1)	Tailings pipeline steam evaporation
U (2)	ETF/DDA1 pond evaporation
U (3)	DDA2 pond evaporation
V	Water in FT from FT spiking
W	Dyke Run-Off Pond (DROP) water to ETF/DDA1
X (1)	ETF/DDA1 precipitation
X (2)	DDA2 precipitation
X (3)	ETF/DDA1 run-off
X (4)	DDA2 run-off
X (5)	Horizon South surface water to DDA2
Y	Tailings pond(s) water cap delta
Z	Water in pore spaces (FT & beaches)
AA	Dyke seepage
AB	Tailings pump gland water and polymer water

Figure 7-2: Horizon Tailings Pond Water Block Flow Diagram



Q	R	S	T	W	AB	V1	V2	V3	AC	AD	AE	AF	AG (1)	AG (2)	AH (1)	AH (2)	AI	AJ	AK	AL (1)	AL (2)	AM	AN	AO (1)	AO (2)	AO (3)
Ore Preparation water	Tar River Diversion to ETF/DDA1	Reclaim water from ETF/DDA1	Reclaim water to RCW Pond	Dyke Run-Off Pond (DROP) water to ETF/DDA1	Tailings pump gland water and polymer water	Water in FT from FT spiking to ETF/DDA1	Water in FT from FT spiking to DDA2	Water in FT from FT spiking to Extraction	Polymer HPW	Water in NST & NRU tailings slurry to ETF/DDA1	Waste water to ETF/DDA1	Water in NST slurry to DDA2	ETF/DDA1 pipeline steam evaporation	ETF/DDA1 pond evaporation	ETF/DDA1 run-off	ETF/DDA1 precipitation	Water in ETF/DDA1 pore spaces (FT & beaches)	Water from DDA2 to ETF/DDA1	Water in DDA2 pore spaces (FT & beaches)	DDA2 pipeline steam evaporation	DDA2 pond evaporation	DDA2 water cap delta	ETF/DDA1 water cap delta	DDA2 precipitation	DDA2 run-off	Horizon South surface water to DDA2

7.2 Water Quality

The tailings pond water quality is influenced by four key factors: ore connate water chemistry, plant chemical addition (e.g., caustic and CO_2), ice, and fresh water additions. The ice during the winter months has a low salt content therefore the salt content in the remaining CWZ increases. Once spring melt and runoff occurs, the CWZ is diluted and the salt content decreases. There are currently five datasets collected (refer to Figure 7-3 for sample locations) to monitor on-site tailings water quality, including:

- ETF/DDA1 return water quality (i.e., water sampled from the siphon intake system which draws water from approximately 2 m below the surface) sampled weekly for cation analysis,
- ETF/DDA1 return water quality (i.e., from the siphon intake system) sampled quarterly for complete chemistry,
- fluids transferred from DDA2 to ETF/DDA1 are sampled biweekly for cation (i.e., water and FT are sampled after the pump on the DDA2 dredges which is taken anywhere between 4 and 8 m below the water surface depending on the dredge cutting head location),
- FT water dredged from the ETF/DDA1 (i.e., used to make esNST) sampled quarterly for complete chemistry, and
- ETF/DDA1 and DDA2 sampled CWZ chemistry in open water between May to October. This data set is analyzed as per the *Notice of Reporting Requirement Clarification Directive 085 - Fluid Tailings Management Reporting Requirements Water Quality Characterization and Reporting* (AER 2022b and c).

All water released from tailings deposition flows into the tailings pond and is recycled back to the Extraction plant, as illustrated in Figures 7-1 and 7-2. The volume and quality of water measured in the tailings pond, as described above, is representative of the water in the NST slurry lines, water run-off from the beaches and the water trapped in the pore spaces of beach and FT deposition zones. All NST lines are actively depositing in DDA2 and the DDA2 dredges maintain a low fluid inventory in the pond. Sampled water from the DDA2 dredges is the closest representation to NST, eNST and/or esNST expressed pore water chemistry. Pore water from the FT pumped from Plant 29 (FT Harvesting Facility) is sampled quarterly.

7.2.1 Plant Operations

Plant operations requires frequent sampling for cations that may affect the plant performance. Each tailings pond water cap is sampled at minimum once a month. See Appendix D - Table D-2 for the list of substances measured and the lower or recordable detection limit (RDL).

7.2.2 Quarterly Samples

As required by the Federal Government National Pollutant Release Inventory (NPRI) the tailings pond water cap is sampled quarterly to calculate the NPRI values. Only the ETF/DDA1 water cap is sampled (i.e., water from DDA2 is continuously being pumped into the ETF/DDA1 and is mixed) the measured values are also reported in the annual TMR and the Industrial Waste Water (IWW) reports. See Appendix D - Table D-3 for the list of substances measured and the RDL.

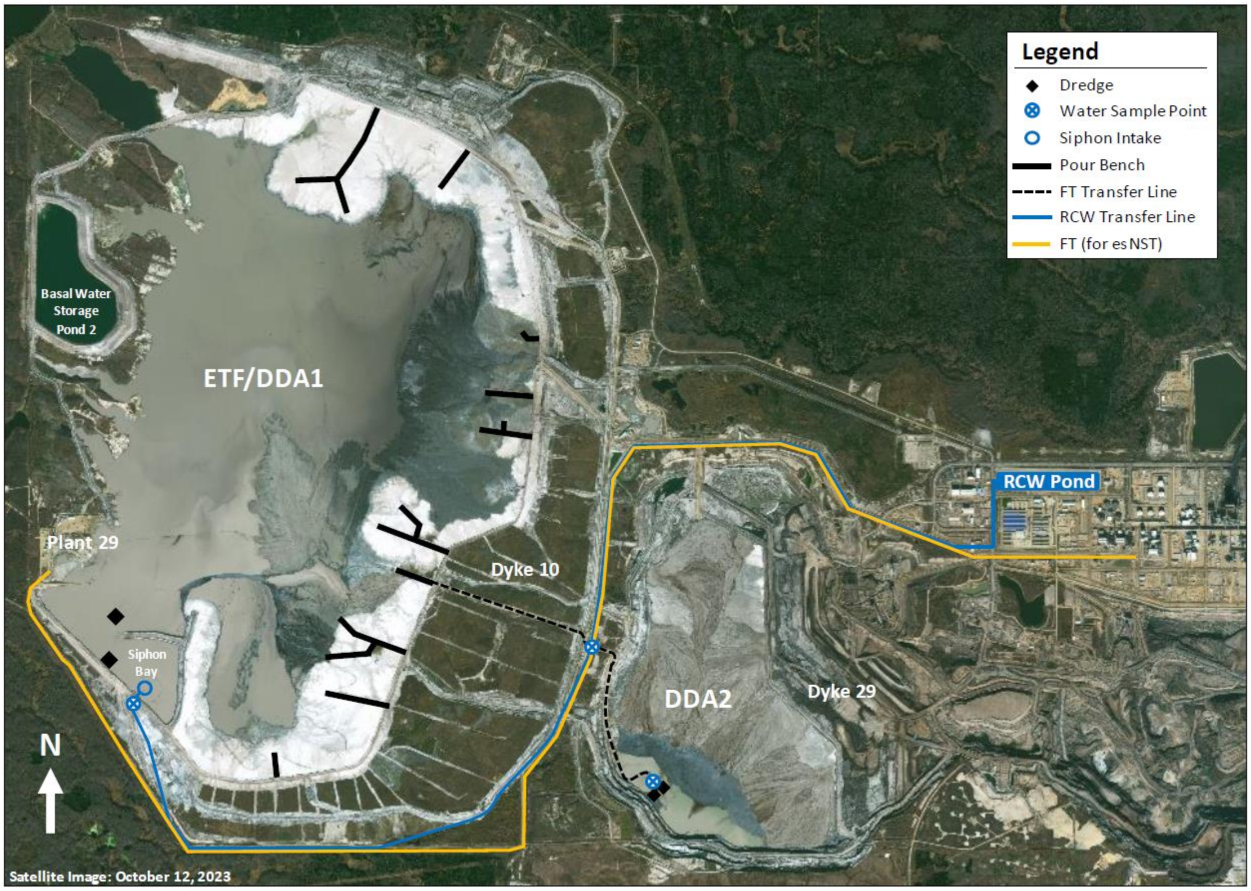


Figure 7-3: Water Quality Sampling Locations (2023)

7.2.3 AER Samples

As requested by the regulator (AER 2022a and AER 2022c), each tailings pond water cap is sampled, from locations shown on Figure 7-3, once per year during the open ice season. The parameter list is similar to the NPRI samples but are more inclusive. See Appendix D - Table D-4 for the list of substances measured and an approximate RDL, for reference.

7.2.4 FT Pore Water Samples

Canadian Natural samples the pore water in the FT that is used to make esNST, as shown on Figure 7-3 and occasionally filters pore water from beach deposits and FT using the sampling and testing protocol found in Section 6 of Appendix C. Refer to Appendix D for the list of substances measured and an approximate RDL, for reference.

8 SUB-OBJECTIVE 2

As outlined in Section 6.1 and Figure 6-3, in order for treated FT (i.e., NST, eNST and esNST beaches) to be considered as RTR and to remain off the FT inventory, then the approved sub-objective 2 performance criteria must also be met. Canadian Natural must monitor the groundwater as required by *EPEA* Approval No. 149968, as amended.

8.1 Groundwater Monitoring

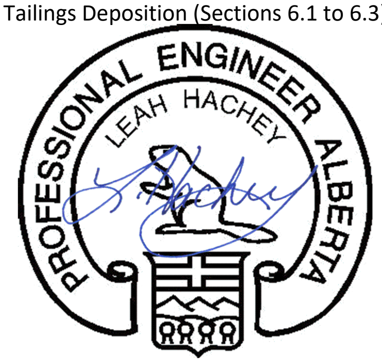
Canadian Natural conducts a bi-annual sampling frequency for the majority of monitoring locations. Newly installed monitoring wells around ETF/DDA1 and DDA2 have a tri-annual sampling frequency. Once eight representative samples have been obtained, monitoring locations will transition to an annual sampling frequency. Groundwater monitoring well locations and the analytical schedule are listed in Appendix 4 of the annual groundwater monitoring report. A description of the sampling methodologies can be found in Appendix 5 of the annual groundwater monitoring report. The details of any additional groundwater monitoring wells or decommissioning of groundwater monitoring wells are described within Section 7 of the annual groundwater report.

Canadian Natural uses a statistical approach to develop site-specific, risk-based performance standards to evaluate groundwater monitoring results. The description of these methodologies can be found in Appendix 6 of the annual groundwater monitoring report. The results of these methodologies are shown in Appendix 9, and the laboratory quality assurance and quality control information is in Appendix 8 of the annual groundwater monitoring report.

Canadian Natural reports on the groundwater monitoring results in Section 9 of the annual groundwater monitoring report. Should any changes be identified in groundwater levels or quality, actions will be taken as per the response plan described in Section 9 of the groundwater monitoring program proposal submitted in 2022.

9 AUTHENTICATION

Introduction (Section 1); Measurement Systems (Section 2); and Tailings Deposition (Sections 6.1 to 6.3) authenticated by:



APEGA ID# 76750
December 23, 2024

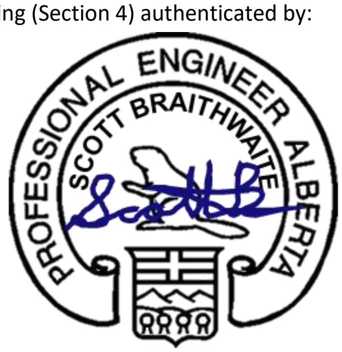
Leah Hachey, P .Eng.
Supervisor, Tailings Research and Reporting

Geology (Section 3) authenticated by:

ID# 126108
December 23, 2024

Katy Nattesheim, P. Geo.
Geologist, Mining

Mining (Section 4) authenticated by:



ID# 75524
December 23, 2024

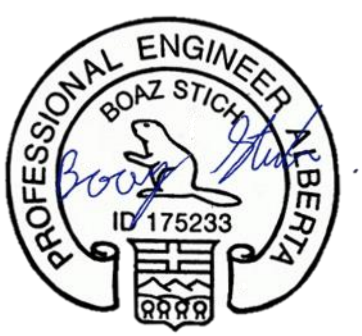
Scott Braithwaite, P. Eng.
Lead, Long Range Planning, Mining

Bitumen Production (Section 5) authenticated by:

December 20, 2024

Sepideh Samiei, P. Eng.
Manager, Engineering, Bitumen Production

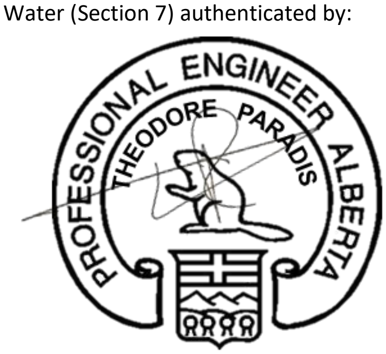
Tailings Deposition (Section 6.4) and Appendix B (Field Procedures) authenticated by:



December 23, 2024

Bo Stich, P.Eng.
Supervisor, Tailings Planning

Tailings Water (Section 7) authenticated by:



ID# 90406
December 23, 2024

Theo Paradis, P. Eng.
Engineer, Process

Sub-Objective 2 (Section 8) authenticated by:	Appendix C (Laboratory Testing Procedures) authenticated by:
PROFESSIONAL GEOSCIENTIST ALBERTA EMILY PRICE ID 158190 December 23, 2024	PROFESSIONAL GEOSCIENTIST ALBERTA TEA MALKOVA ID 94783 December 23, 2024
Emily Price, P.Geo. Supervisor, Hydrogeology	Tea Malkova, P. Geo. Geologist, Mining

Document reviewed and validated by:

PERMIT TO PRACTICE
CANADIAN NATURAL RESOURCES LIMITED

RM SIGNATURE: ______

RM APEGA ID #: 125250

DATE: December 23, 2024

PERMIT NUMBER: P006872
The Association of Professional Engineers and Geoscientists of Alberta (APEGA)

Chris Dobek, P.Geo., Lead Geologist, Mining; Responsible Member, Permit to Practice P006872

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Appendix A Concordance tables

1 Directive 085 (AER 2022b) Concordance Table

Requirement			Reference
5. Measurement Outcomes			
17	Operators must provide quality information and ensure that the measurement system used for fluid tailings management achieves the following outcomes to the satisfaction of the AER:		n/a
17	a)	Accuracy: the degree to which the measurement matches the correct value.	Sections 3 to 8, Appendices B, C, D & E
17	b)	Precision: the measure of agreement among repeated measurements of an indicator.	Sections 3 to 8, Appendices B, C, D & E
17	c)	Sensitivity: the degree of ability to discriminate differences in performance of indicators.	Sections 3 to 8, Appendices B, C, D & E
17	d)	Representativeness: the degree that the data is suitable measure of the condition being examined.	Sections 3 to 8, Appendices B, C, D & E
17	e)	Comparability: a qualitative expression of the confidence that the quality of data is sufficient to contribute to analysis, even when measurement methods differ.	Sections 3 to 8, Appendices B, C, D & E
17	f)	Completeness: the measure of the amount of valid data not omitted.	Sections 3 to 8, Appendices B, C, D & E
17	g)	Bias: the measure of systematic distortion of measurements.	Sections 3 to 8, Appendices B, C, D & E
18	Operators must maintain a data management system that supports the following outcomes to the satisfaction of the AER:		Section 2 to 8 Appendices B, C, D & E
18	a)	Verification: the process to ensure that data are evaluated for accuracy, errors, and inconsistencies after data migration is done.	Section 2 to 8 Appendices B, C, D & E
18	b)	Validation: follows verification; a process to compare data to documented acceptance of criteria.	Section 2 to 8 Appendices B, C, D & E
18	c)	Integrity: maintaining and assuring the accuracy and consistency of data over its entire life cycle.	Section 2 to 8 Appendices B, C, D & E
19	Operators must submit their measurement system plan to the AER within six months following approval of the fluid tailings management plan.		Submitted on June 28, 2018. Updated in this document.
20	Operators must address deficiencies in their measurement system plan identified by the AER.		noted
If an operator monitors for any substances or parameters that are the subject of monitoring requirements set out in EPEA approvals, the operator must use procedures, methods, or protocols authorized in those approvals.			Section 8

2 Decision Report 20171218A (AER 2017a)

Requirement			Reference
Measurement and Averaging (pg.27-28; AER 2017)			
[156]	Each treated tailings deposit will have approved indicators that must be measured to determine if the RTR criteria has been achieved.		Sections 6.1 and 6.3; Appendix B and C
[156]	Directive 085 requires operators to submit a measurement system plan six months from the date of an approved TMP.		Submitted on June 28, 2018. Updated in this document.
[157]	Details on RTR criteria measurement will be included in Canadian Natural’s measurement system plan (Appendix 6). The measurement system plan must include:		n/a
[157]	•	definitions of parameters for fluid tailings and RTR criteria measurements;	Sections 1.2, 6.1, 6.2 and 6.3
[157]	•	reference to standards and procedures used to measure fluid tailings and treated tailings and RTR criteria;	Section 6; Appendix B, C, D and E
[157]	•	an explanation of and justification for measurement procedures that are unique to Canadian Natural and its plan;	Sections 2, 3, 4, 5 and 6; Appendix B, C, D and E

Requirement		Reference
[157]	• evidence that the plan will address the measurement outcomes as per section 5 of Directive 085;	Section 6, Appendix B, C, D and E
[157]	• an explanation of how each of the deposit's RTR criteria will be measured, calculated, and reported;	Sections 6.3 and 6.4
[157]	• a description of the deposit sampling, measurement, and survey program; and	Sections 6.3 and 6.4, Appendix B, C, D and E
[157]	• justification of how measurement, sampling, and spacing intervals will – show the variation of the deposit properties, – verify that the tailings deposit is achieving RTR criteria, and – identify if any material in the deposit is not achieving RTR criteria.	Sections 6.3 and 6.4 Appendix B, C, D and E
[158]	Canadian Natural is required to measure the volume of treated tailings that meets the RTR criteria based on deposit sampling and cannot use annual average solids content for the entire deposit. Treated tailings can only be removed from the fluid tailings inventory if the RTR criteria are achieved.	Sections 6.3 and 6.4 Appendix B, C, D and E
[159]	RTR criteria alone do not explain how Canadian Natural will determine the volumes of treated tailings that are no longer meeting RTR criteria and must be returned to the inventory. Canadian Natural did not propose how it would determine the volume of fluid tailings to be returned to the fluid tailings inventory where subobjective 1 or subobjective 2 RTR criteria were not met. As such, *Canadian Natural's measurement system plan is required to describe how Canadian Natural will measure the volume of treated tailings that do not meet RTR criteria and that must be returned to the inventory.*	Sections 6.3 and 6.4 Appendix B, C, D and E
[160]	A key issue of the measurement system is the use of averaging or deposit sampling. Canadian Natural's proposed use of using an averaging process for solids content of a deposit as an RTR criterion does not provide sufficient information to identify variations in tailings characteristics across a deposit. The use of an average, in particular, limits the ability to assess risks and liabilities for underperforming treated tailings and the effect on a deposit's performance towards the targeted ecosites. A deposit may show excellent performance on average while a significant portion of the tailings deposit is underperforming and compromising the ability to reclaim. The averaging process obscures understanding of the deposit volumes that have been treated unsuccessfully or are failing to improve as expected. *Therefore, Canadian Natural is required to measure the volume of fluid tailings and treated tailings that meets the RTR criteria based on deposit sampling and may not use an annual average for the entire deposit*.	Sections 6.3 and 6.4 Appendix B, C, D and E
[161]	The AER recognizes that sampling of a tailings deposit is challenging and that Canadian Natural may use some form of 3-D modelling or spatial statistics to determine the volume not meeting the performance criteria, and the degree of inadequate performance. *The AER expects that the frequency and spatial extent of monitoring, and the statistical methods applied, will minimize the margin of error.*	Sections 6.3 and 6.4

3 Measurement System Plan Requirements Letter (AER 2017b)

Requirement	Reference
In accordance with Directive 085: Fluid Tailings Management for Oil Sands Mining Projects, the Alberta Energy Regulatory (AER) requires Canadian Natural Resources Limited (Canadian Natural) to submit by June 30, 2018, or on such other date stipulated by the AER, a measurement plan for fluid tailings, treated tailings volumes and ready to reclaim (RTR) criteria (subobjective 1 and subobjective 2 in Appendix C) in Approval No. 9752E.	Submitted on June 28, 2018. Updated in this document.
The measurement plan must include the following:	n/a
• Key definition of parameters for fluid tailings and RTR criteria measurements.	Sections 1.2 and 6.2
• Reference of standards and procedures used to measure fluid tailings, treated tailings, and RTR criteria.	Sections 6.3 and 6.4, Appendices B, C D and E

Requirement	Reference
• An explanation of and justification for measurement procedures that are unique to Canadian Natural and this plan	Sections 2, 3, 4, 5 and 6
• Evidence that the plan will address the measurement outcomes as per section 5 of Directive 085, as amended	Section 6, Appendix B, C, D and E
• An explanation of how each of the tailings deposit's RTR criteria will be measured, calculated and reported	Section 6.3 and 6.4
• A description of the tailings deposit survey program	Section 6.4, Appendix B, C, D and E
• Justification of how measurement, sampling, and spacing intervals will show the variation of the deposit properties, and verify that the tailings deposit is achieving RTR criteria.	Section 6.3 and 6.4 Appendix B, C, D and E
• Identify if any material in the deposit is not achieving RTR criteria	Section 6.3 and 6.4 Appendix B, C, D and E
• Any other information the AER may require.	Appendix A – Section 4
Where measurement plans exist for either sub-objective, Canadian Natural may incorporate references to other plans, such as the groundwater monitoring program.	Sections 3, 4, 5, 6, 7 and 8
Canadian Natural must also ensure that the measurement system plan developed aligns with the Groundwater Monitoring Program authorized under its EPEA approval.	Section 8.1

4 Notice of Reporting Requirement Clarification: Directive 085 – Fluid Tailings Management Reporting Requirements Water quality characterization and Reporting Letter (AER 2022a)

Requirement	Reference
Prior to December 31, 2022, operators are required to update and resubmit their Measurement System Plans with water quality sampling methods, locations, and sampling frequency.	This document. Water quality test methods, locations and sampling frequency provided in Section 7 and Appendix D.
Sampling and characterization are required for inclusion in the 2022 Tailings Management Reports, due April 30, 2023.	noted

5 Directive 085 Reporting Requirement Clarification – Water Quality Characterization (AER 2022c)

Requirement	Reference
Prior to December 31, 2022, operators are required to update and resubmit their Measurement System Plans with water quality sampling methods, locations, and sampling frequency.	This document. Water quality test methods, locations and sampling frequency provided in Section 7 and Appendix D.
Sampling and characterization are required for inclusion in the 2022 Tailings Management Reports, due April 30, 2023.	noted

Appendix B Field Procedures

1 *In-situ* Tailings Measurement Procedures

Canadian Natural collects field measurements of tailings materials utilizing topographic surveys, sonar surveys, hard-bottom survey, cone penetration tests, ball penetration tests, passive gamma testing and vane shear testing, as outline in the following sections.

1.1 Topographic Survey

Topographic LiDAR surveys are conducted on the Horizon site, as required, to support ongoing mine, tailings and reclamation planning. Canadian Natural will, at a minimum, will conduct a LiDAR topographic survey of the tailings ponds as close to the same time as the annual tailings pond investigation as possible. The LiDAR topographic survey is piloted by specialized contractors using accepted industry measurement methods. In essence it is a technology that uses the pulse of a laser to collect measurements which can be used to create 3D topographic models.

1.2 Mudline Survey

The sonar survey is conducted to determine the CWZ and FT interface (i.e., mudline) using a Sonar-GPS sounder located on a boat. The sonar system sends a sound pulse into the pond and then measures the amount of time for the pulse to be reflected back, using that time to calculate distance. Corresponding GPS coordinates are recorded at each reading location.

An electronic echo sounding device is used in accordance with ASTM D5073 to identify the interface between the CWZ and FT. The mudline is compared to analytical data to assess the solids content of the delineated mudline, as determined by sonar.

1.2.1 Procedure

1) The device is a fathometer, single beam sonar and/or swath (i.e., multi-beam) bathymetry that uses active sonar to detect an interface. A transmitter creates an electrical impulse that is converted into a sound wave and sent into the water via a hydrophone.
2) When the wave strikes an interface it is reflected back and recorded.
3) The distance to the interface is then calculated based on the measured time between the impulse and the reflected wave and the known wave velocity through water.

There are two main components to the sonar survey.

- The first is a shoreline survey of the pond. This survey is conducted by travelling around the pond's edge, making one pass as close to the shoreline as possible, followed by another pass offset from the first.
- The second component covers the interior regions of the pond; this region is surveyed using a grid pattern, making passes back and forth across the pond in both the North-South and East-West directions.

1.2.2 Quality Assurance and Quality Control

The purpose of the sonar survey is to develop the mudline surface. Repeatability and confirmation using different tools is done during measuring and monitoring. The sonar survey results are checked and confirmed with the results of the FIS sampler (Appendix B – Section 2.2) and FT Sampling (Appendix B - Section 2.3), and subsequent lab analyses (Appendix C).

The contractor (i.e., Mikisew-ConeTec) provides quality assurance and control records for the mudline survey, as outlined in Appendix E.

1.3 Hard-Bottom Survey

The CT09 is a drop sounding tool, as illustrated in Figure B-1, which consists of a weight, a cone penetrometer, and a data acquisition system. The total length of the tool is 3.35 m (132 inches or in) and it weighs 136 kilogram (kg) (300 pounds or lb). An ASTM 15 squared centimeters (cm^2) cone is attached below the weight.

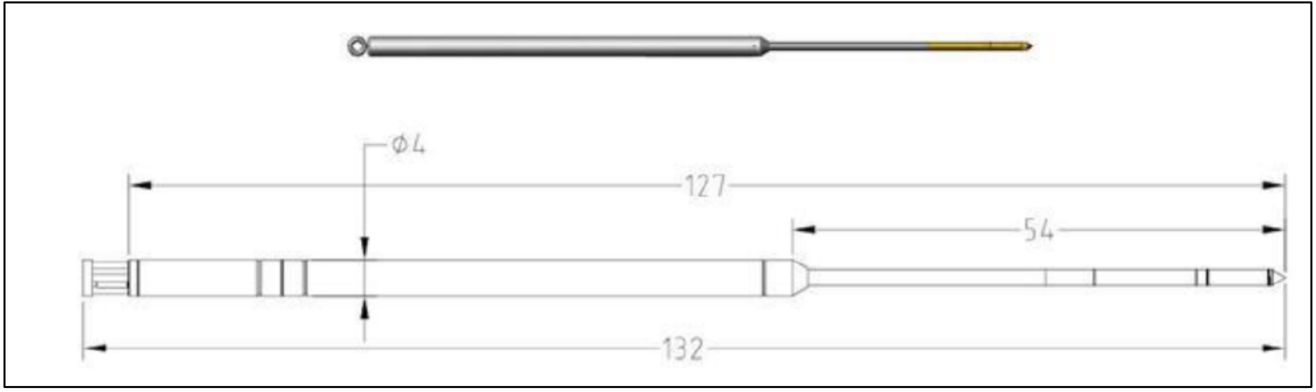

Figure B-1: CT09 Schematic and dimensions in inches

The cone measures tip resistance, dynamic pore pressure, and inclination with maximum capacities of 1500 bar and 500 psi (34.5 bar) for the tip and pore pressure transducers respectively.

1.3.1 Procedure Summary

1) The CT09 is dropped via a winch line at the slowest of either the winch speed or the free fall speed of the CT09 through the FT until it refuses, either in BBW, consolidated FT or the post-mining surface.
2) The inclination, pore pressure, and tip resistance are recorded throughout the drop, allowing the refusal depth or pond bottom to be evaluated.

1.3.2 Quality Control & Data Management

Training of operators and the correct execution of procedures are vital to obtaining representative field data. Repeatability and confirmation using different tools is done as required during measuring and monitoring. The contractor provides verification records on these efforts.

The purpose of the sonar survey is to develop the hard-bottom surface. This is checked and confirmed with the results of FT sampling (Appendix B – Section 2.3) and BBW sampling using either piston sampling (Appendix B – Section 2.5) and/or sonic piston sampling (Appendix B – Section 2.6) methodologies, and subsequent lab analyses (Appendix C).

1.4 Cone Penetration Test (CPT or CPT_u)

Cone penetration testing (CPT_u) is performed by advancing an instrumented probe (Figure B-2) into the soil at a rate of 2 cm/s. The standard CPT_u probe includes sensors to obtain the tip resistance (q_c), sleeve friction (f_s), dynamic fluid pressure (u_2), inclination, and temperature every 2.5 or 5 cm of depth. The cone tip resistance requires a systematic correction from qc to a corrected value of qt using $q_t = q_c + u_2(1 – a)$. The net tip resistance, q_t-sv0, depends primarily on the soil type, density, and in-situ effective stress. The in-situ effective stress and density around the cone-probe depends on the generation and dissipation of excess pore pressure during penetration. The dynamic fluid pressure, u_2, depends on the ambient fluid pressure, the induced fluid pressure due to cavity expansion and soil shear to accommodate the cone probe, and rate dependent pressure dissipation during pushing. The CPTu is a reproducible and efficient site investigation technique for profiling soil deposits and estimating soil properties.

Cone probes include an internal temperature sensor for quality assurance on the CPT measurements. It can be used to temperature-correct sensors when required. The temperature sensor is positioned near the load-cells used to obtain the cone tip resistance and sleeve friction; it is not in direct contact with the soil.

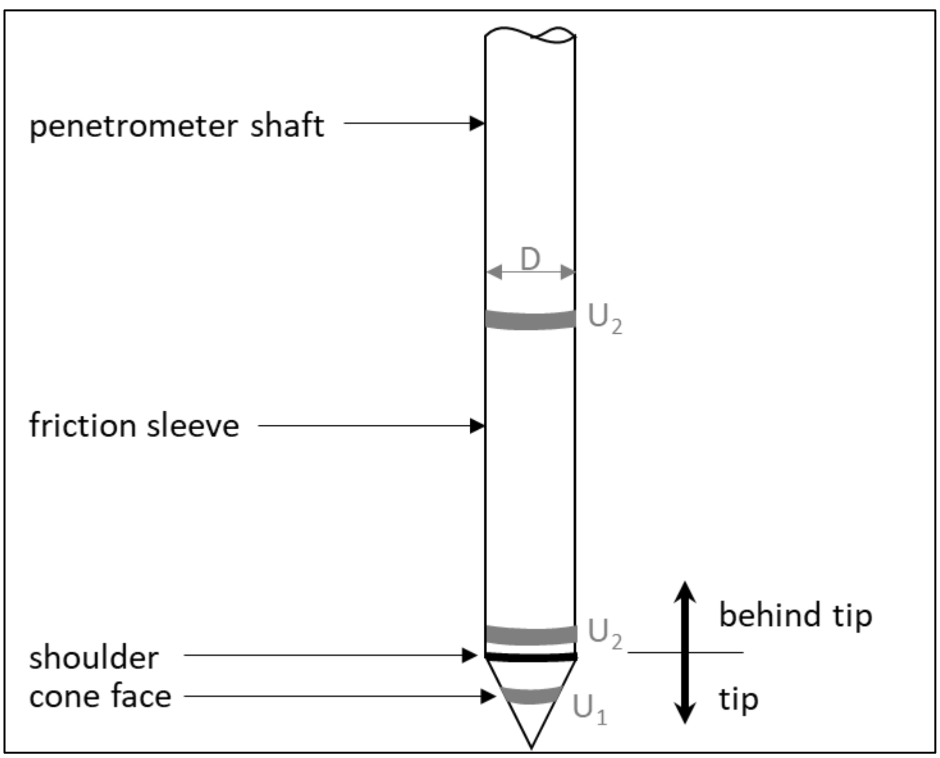

Figure B-2: Schematics of Cone Penetrometer

The CPT is carried out in general accordance with ASTM D5778-07 using a medium-capacity compression type cone (MC-375).

1.4.1 Procedure Summary

1) The cone is pushed into the deposits at a steady rate of 2 cm/s until the bottom of the tailings or refusal is reached. The cone has a tip area of 15 cm^2, and a tip capacity of 375 bar (37.5 MPa).
2) The cone tip is represented by a cone net area ratio of 0.80 to correct for unequal cone stress.
3) A saturated 5 mm thick porous filter is located directly behind the cone tip in the “u2” position transmitting fluid pressure to the pore pressure transducer. This measures porewater pressure response.
4) The friction sleeve has a surface area of 225 cm^2 and is designed to have equal end areas.
5) Tip resistance, sleeve friction, and porewater pressure response are measured at 2.5 cm depth intervals.
6) Naturally occurring gamma radiation is measured by a gamma module installed 75 cm above the cone tip.
7) The gamma data is collected through a separate data acquisition system at 10 cm depth increments.
8) A complete set of baseline readings is taken before and after each sounding to allow corrections due to temperature change, if required.

1.4.2 Quality Control & Data Management

Training of operators and the correct execution of procedures are vital to obtaining representative field data. Repeatability and confirmation using different tools is done as required during measuring and monitoring. The contractor provides verification records on these efforts.

The purpose of the CPT measurements is to determine the apparent undrained shear strength of the tailings materials. This is checked and compared with the results of tailings sampling (Appendix B – Sections 2.5, 2.6 and 2.7) and subsequent lab analyses (Appendix C).

1.5 Ball Penetration Testing (BPT or BPTu)

The ball penetrometer test (BPT) is used to assess the undrained shear strength (su) of very soft to soft materials. This in-situ test was originally developed to test very soft offshore sediments. The test incorporates a standard cone penetrometer body (typically 10 cm^2 plan area) and a spherical attachment that replaces the standard 60 degree conical tip, as shown in Figure B-3 below. The shape of the penetrometer lends itself to theoretical interpretations of undrained strength due to spherical cavity expansion. The larger diameter of the ball also increases the penetration resistance and uses more of the load-cell capacity in very soft soils.

The undrained shear strength derived from the full flow penetration test is related to the net penetration resistance using the following relationship:

$$s_u = q_{net} / N \text{ (where N is typically 11.0)}$$

Although the N factor is generally considered to be unique across soil deposits, experience has shown that some minor variation does exist. Hence the BPT is usually conducted along with VST to obtain an appropriate N factor for the soil tested.

Figure B-3: Flow Penetrometer Rod with Ball Attachment

1.5.1 Quality Control & Data Management

Training of operators and the correct execution of procedures are vital to obtaining representative field data. Repeatability and confirmation using different tools is done as required during measuring and monitoring. The contractor provides verification records on these efforts.

The purpose of the BPT measurements is to determine the apparent undrained shear strength of the FT materials. This is checked and compared with the results of FT sampling (Appendix B - Section 2.3) and subsequent lab analyses (Appendix C).

1.6 Passive Gamma Testing

Passive gamma modules can be attached behind the cone probe or ball probe to create the GCPTu or GBPTu test. The passive gamma module housing contains a scintillating crystal that glows when it is struck by gamma rays. The gamma-module uses a photo-multiplier-tube and associated internal electronics to monitor this scintillating crystal. The observed gamma-ray incidents are counted up and used to calculate the gamma counts-per-second, which is reported in the GCPTu logs.

There are three common natural gamma ray sources that can be found in terrestrial minerals. These are natural radioisotopes of potassium (^{40}K), thorium (^{232}Th), and uranium (^{238}U). These three radioisotopes exist in nature due to exceptionally long half-life times that are a similar magnitude to the age of Earth. Potassium can be found in Illite and Feldspar minerals, thorium is associated with heavy minerals, and uranium can be found in uranium salts and organic shale. The mineralogical constituents of the bitumen ore remain in the tailings by-product and gamma profiling can identify different tailings units.

The generated gamma rays from these natural sources will interact with matter. This interaction makes it possible to observe gamma rays in-situ. The propagating gamma rays can re-coil, lose energy, and change direction in a process known as Compton scattering. When the gamma ray energy drops below 100 keV it can be extinguished by photoelectric absorption. Gamma rays with energies higher than 1022 keV can split into two rays of 511 keV in a process known as pair-production. For a typical density of tailings, a generated gamma ray may travel up to 15-25 cm. This means that the GCPTu gamma profile responds to the same soil measured by the cone penetration test.

The GCPTu and GBPTu measurements depend on the in-situ tailings density, effective stress, and composition. Empirical relationships between the in-situ tests and laboratory characterized oil sand composition have been developed using a database of paired results. These relationships have been termed a Tailings Behavior Type (TBT) interpretation of the in-situ tests. The TBT infers the percent solids, fines content, and MBI from the GCPTu or GBPTu measurements.

The GCPTu and GBPTu soundings add information relevant to tailings characterization programs that cannot be easily obtained through sampling and laboratory testing. The in-situ test data include measurements every 2.5 cm of depth penetration, which permits the identification of depths to tailings layer boundaries. These boundaries include the mud-line, hard-bottom, and any other boundaries that develop due to the tailing deposition. In-situ testing using the GCPTu and GBTPu probes is consistent and reproducible year over year. The test equipment and procedures conform to international standards (ASTM) and rigorous internal quality assurance and quality control protocols. This permits the use of repeated soundings at the same location to track changes in the layer boundary depths due to sedimentation and consolidation of the tailings. The in-situ measurements are the same, whereas laboratory sample data is sensitive to changes in laboratories and specimen preparation procedures.

Sampling campaigns obtain samples at discrete depths or over depth ranges. Collected samples can bracket a layer change or bridge a layer change but may not be able to easily identify the exact depth of the layer change. It is also not clear how to compare samples collected at the same location over time. If samples are collected at the same elevation and an adjacent layer boundary decreases due to consolidation, then the solids content could appear to decrease. If samples are collected at the same elevation and the layer boundary raises due to sedimentation, then the solids content would appear to increase.

1.6.1 Quality Control & Data Management

Training of operators and the correct execution of procedures are vital to obtaining representative field data. Repeatability and confirmation using different tools is done as required during measuring and monitoring. The contractor provides verification records on these efforts.

The purpose of the passive gamma measurements, either as a GCPT or CBPT) is to determine the apparent undrained shear strength of the tailings materials. This is compared to the results of FT sampling (Appendix B - Section 2.3), tailings sampling (Appendix B – Sections 2.5, 2.6 and 2.7) and subsequent lab analyses (Appendix C).

1.7 Vane Shear Testing

The vane shear test (VST) is used to obtain an in-situ index measure of the undrained soil strength. A four-bladed vane is attached to the end of a string of drill-rods and pushed through the bottom of a borehole to the target test depth. The torque required to slowly rotate the drill-rods at a constant rate is measured and used to calculate $(s_u)f_v$, the field vane undrained shear strength. The vane testing is performed in general accordance with ASTM D2573-08.

The VST was introduced to North America in 1950. It quickly replaced unconsolidated and undrained triaxial testing characterizations of undrained shear strength. The VST was easily standardized and did not suffer from sample disturbance errors. Geotechnical engineering has a long history of successful application of VST undrained strengths in design.

The VST is typically limited to soft-soil investigations. The vane blades can be damaged on insertion by striking rocks. The vane blade can be damaged on rotation if the soil-strength is too high. VST results can also be misleading in soils with high coefficients of consolidation that may be affected by partial-consolidation during the test. The VST has been used to obtain $(s_u)f_v$ from 0.0033 kPa to over 634 kPa and to depths in excess of 160 m. Fast vanes tests with rotation rates over 15°/sec can also be performed to obtain $(s_u)f_v$ in silty soils that may be partially drained during conventional vane testing.

The VST can be combined with adjacent cone penetration test profiles and/or ball penetration test profiles to efficiently characterize $(s_u)f_v$ across a site. These combinations are used to calibrate site-specific empirical factors between the net cone tip resistance or net ball resistance.

Electronic Vane Systems (eVST) are a modern alternative to the mechanical vane systems used in the past. Mechanical vane systems are sensitive to ambient pressures and temperatures at the ground surface. The eVST includes an electronic torque motor with accurate control and measurement of the uphole rotation. It includes an electronic torque load cell sensor providing high resolution torque measurements. It includes a data acquisition system that records full torque versus rotation curves observed during the vane shear test. Electronic vane systems provide higher resolution, more consistent and more reliable VST results than mechanical systems.

1.7.1 Test Procedure:

1) The vane is advanced to the test depth by pushing the cone rods into the ground.
2) Once the vane has reached the correct depth an electrical motor is used to rotate the vane and rods at a constant rate.
3) The rods and vane are both rotated until the surrounding soil has yielded.
4) After yielding occurs, the vane continues to be rotated in order to characterize the soil's post-yielding shear resistance.
5) The vane is then released from the motor and is rotated clockwise approximately ten times to completely remold the soil.
6) Once the soil is remolded, the motor is used to rotate the vane and rods to record the remolded strength of the soil.

2 Sampling Procedures

Canadian Natural collects field samples of tailings materials utilizing fluid wireline samplers, FIS, FT sampling, piston sampling, sonic piston sampling and sonic drilling and sampling as outlined in the following sections.

2.1 Fluid Wireline

Wireline samplers are used for efficiency in FT. This is a piston type sampler and has a sample volume of about 3 liters. Weights are fitted to the top of the sampler such that it sinks vertically in FT. The sampler has a closed bottom end with a small diameter opening to permit fluids to enter the sampler. During deployment, the piston is held in the closed position using pressurized gas such that no tailings or water can enter the sampler. When the target depth is reached, the gas pressure is released to atmosphere and fluid pressures cause the sampler to fill. The sampler is then retrieved, and gas is again used to push the piston back to the face of the sampler, thus extruding the sample and preparing it for next use. A photograph of the collected sample, the sample container, and the sample container label is taken for quality assurance.

2.2 Fixed Interval Sampler (FIS)

Fixed Interval Sampling (FIS) is used to assess the depth of mudline and to verify the mudline information obtained using sonar survey. Fixed interval sampling is comprised of modules of banks of sample cylinders. This sampler includes 10 sampling points spaced at 10 cm intervals. Compressed gas is used to keep all ten of the sample cylinders closed.

2.2.1 Procedure Summary

1) The FIS is attached to a winch line in preparation for the sampling.
2) The nitrogen is turned on which forces the piston inside the sample chamber to the bottom.
3) The sampler is lowered to the desired sampling depth, typically from 1 to 3 m above the mudline to 1 to 3 m below the mudline.
4) Once the sampler is at the desired depth the nitrogen gas is turned off.
5) Fluid pressure displaces the gas inside the sampler and the gas is replaced by the fluid.
6) As the fluid fills the sample chamber the piston inside moves through the cylinder which expels the nitrogen gas.
7) Once the cylinder is filled, the sampler is winched back to the rig deck for collection.
8) The sample is extruded into properly labelled sample containers by turning the nitrogen back on which pushes the piston in the sampler to the bottom while at the same time extruding the sample.

2.2.2 Quality Control

A photograph of the collected samples, the sample containers, and the sample container labels is taken for quality assurance.

2.3 Fluid Tailings Sampling

Specialized fluid sampling procedures are used to sample low solids content material such as FT. The sampler is comprised of two parts: a lower portion consisting of a cylindrical chamber, which collects the sample, and an upper weight, which keeps the sampler in an upright position as it is lowered to the sample depth.

2.3.1 Procedure Summary

1) While the sampler is lowered, compressed nitrogen is used to keep the sample chamber closed until the desired sample depth is reached.
2) To obtain a sample, the Fluid Sampler is lowered via a winch line with the nitrogen on forcing the piston to the bottom of the sampler.
3) Once the sampler is at the desired depth, the nitrogen gas is turned off. As the tailings fill the sample chamber, the piston inside rises expelling the nitrogen gas. The sampler therefore remains stationary while the sample is collected.
4) Once the operator deems that all the gas has been expelled, the sampler is winched back up to surface and the sample is extruded by turning the nitrogen back on. This pushes the piston in the sampler to the bottom, extruding the sample into a 4L sample container.
5) At shallow depths a suction sampler is used to collect samples. It is similar to the fluid sampler except a manual rod is used to move the piston rather than compressed gas.

2.3.2 Quality Control

Samples are visually described, photographed and sent to the laboratory for further testing.

2.4 Parky Sampler

This is a push-in cone-shaped sampler that can be used in soft soils. Once at the target depth you stop pushing the cone-tip. A 2-metre-long casing is pushed over and past the cone tip into the soft soil. The sample is brought to the surface and the cone-tip is driven through the sampler to push the soil into a collection tray.

2.4.1 Quality Control

A photograph of the collected sample, the sample container, and the sample container label is taken for quality assurance.

2.5 Piston Sampling

Piston sampling is used to sample relatively soft and/or shallow deposits within the ETF/DDA1. It is used primarily to sample BBW deposits from an amphibious carrier. It can also obtain samples of higher solids content FT. The piston sample is 1 m in length and 38 mm (1.5”) in diameter.

2.5.1 Procedure Summary

1) Prior to sample collection, the sampler is cleaned and the piston is mechanically extended to remain in place, flush with the leading edge of the sample.
2) The sampler is attached to a series of rods and pushed to the desired sample depth.
3) A lock on the inner rods is released allowing the barrel to be pushed ahead of the piston, collecting the sample.
4) Passive suction and friction cause the sample to remain in the barrel as the sampler is raised.
5) Samples are placed into a 4 L sample container.

2.6 Sonic Piston Sampling

Compact sonic aqualock piston sampling is used when an open borehole is not required for additional testing. The sampler is advanced with a piston at the face or shoe to the target depth. The pressure holding the piston is then released and the sampler is advanced to collect a 2 m long 50 mm diameter sample of tailings. The sampler may be advanced using a combination of pushing and vibration. A sand-trap is used in the cutting shoe to prevent sample loss during retrieval. Compact sonic aqualock sampling can be an efficient sampling tool when the sampler can be advanced quickly to the target depth

Piston sampling is used to sample relatively soft and/or shallow deposits within the ETF/DDA1. It is used primarily to sample BBW deposits from an amphibious carrier. It can also obtain samples of higher solids content FT. The piston sample is 1 m in length and 38 mm (1.5”) in diameter.

2.6.1 Procedure Summary

1) Prior to sample collection, the sampler is cleaned and the piston is mechanically extended to remain in place, flush with the leading edge of the sample.
2) The sampler is attached to a series of rods and pushed to the desired sample depth.
3) A lock on the inner rods is released allowing the barrel to be pushed ahead of the piston, collecting the sample.
4) Passive suction and friction cause the sample to remain in the barrel as the sampler is raised.
5) Samples are placed into a 4 L sample container.

2.6.2 Quality Control

A photograph of the collected sample, the sample container, and the sample container label is taken for quality assurance.

2.7 Sonic Drilling and Sampling

Sonic drilling is used to obtain continuous samples of tailings beach deposits in BAW areas (i.e., where land access is possible). Conventional sonic drilling methods are used to obtain 50 mm diameter, 2 m long samples over the full depth of the tailings beach.

2.7.1 Procedure Summary

1) The sonic drill head induces 150 Hz vibration directly to the rods and sampler, causing the sampler to advance.
2) Prior to retrieving each sample, water pressure is used to push the piston flush to the leading edge of the sampler.
3) The sampler is then lowered to the sample depth and the water valve unlocked.
4) The piston remains in place while the sample barrel is advanced by vibration collecting the sample.
5) The 2 m sample is split into 1 m lengths.
6) Each 1 m length is placed into a 4 L container, labelled and shipped to the laboratory.
7) No sample is disposed of. Each sample is visually described and photographed in the field.

Appendix C Laboratory Testing Procedures

1 Laboratory Testing

Over the years a series of tests have become standard to characterize and then predict the behavior of tailings materials. These tests include:

- DSA is used to determine and characterize the bitumen, mineral and water content of oil sand, petroleum products or other bituminous materials. As described in Section 6.4.3, all samples are measured using DSA (by weight difference), the results of which are checked against the results from the DSA (by closure) on reference samples to determine bias errors.
- PSD procedure utilizes wet sieve test to determine the fines content (≤ 44 μm), and laser diffraction (LD) on the solids minerals of a post DSA sample to determine the fines content
- Standard MBI are combined with other tests to quantify the clay within the sample. The standard for measuring clay characteristics is X-Ray Diffraction (XRD). When this is used, the mineralogy of the sample is determined. However, XRD is semi-quantitative and does not measure the particle size. Additionally, this process is expensive and can be time consuming. As an alternative, the methylene blue "stain" test method can be used to approximate clay content. The methylene blue test is a quantitative evaluation method to determine the cation exchange capacity and surface area of a material based on the type and quantity of clay minerals contained in it.
- Water quality including soluble ions, dissolved metals, TDS and TSS, pH, etc.

1.1 Sample Preparation

1) Field samples are received at the laboratory in 4 L containers which are a maximum of ¾ full.
2) The samples are homogenized using an industrial shaker.
3) Shaking is carried out for a minimum of 5 minutes or until a probe at the bottom of the container indicates any settled material has been liberated.

Specific details of the homogenization process vary depending on the material being tested and may involve manual mixing and longer time periods to fully homogenize the samples, based on the experience and judgment of the operator. A representative sample of the homogenized material is then sub-sampled for analysis. For high solids content material (i.e., beach samples), sub-samples are removed during the mixing process.

1.2 Validation of Laboratory Data

One of the main goals of Canadian Natural's quality assurance and quality control program is to ensure that the laboratory provides consistent results on year-to year basis and to justify the systematic trends that might be revealed in Horizon-specific database as real trends rather than issues with a laboratory performance.

Statistic quality control practices allow to maintain the necessary level of consistency and include:

- Separate programs to differentiate between random error and bias error, and

- Monitoring of the accuracy and precision of all physical and chemical tests.

Bias errors can be identified by regularly submitting test samples of reference material with pre-established “consensus” values into the analytical queue. By submitting the original sample, the bias associated with any of the sample preparation steps (disaggregation in the case of particle size distribution) as well as the bias associated with the final measurement step are identified.

Repeatability (random error) is monitored by analysis of blind duplicate samples that are submitted by the operator of the lease.

2 Determination of Water, Mineral and Bitumen by DSA (by Weight Difference)

2.1 Scope and Application

This method covers the determination of sediment (mineral) and water in crude oils and fuels by extraction with toluene. The characteristics of the water and sediment (mineral) in oil are important. The refining process will use the mass percentage of water and sediment (mineral) to determine the steps used in refining the oil.

2.2 Method Summary

A test portion of a sample contained in a cellulose thimble is extracted with hot toluene until the residue reaches a constant mass. The mass of residue, calculated as percentage, is reported as sediment by extraction.

2.3 Health and Safety Warnings

- Toluene is extremely flammable, and maybe fatal by inhalation or ingestion
- Chemical resistant gloves and lab coat must be worn
- Wear lab coat and safety glasses at all times
- Wear a respirator at all times while in Dean and Stark and Vapor Phase rooms
- No smoking and open fire are allowed

Note*: When working in Vapor Phase room use buddy system to ensure safety procedures are met.*

2.4 Handling and Preservation

- Use Safety-can to store small amount of toluene
- Toluene drum and safety-can must be grounded all the time

2.5 Detection Limits and Method Validation

Please consult ASTM Method D473 – B1 (1995) Section 11.

2.6 Interferences

- Duration of extraction process is too short
- Water contamination in glassware
- Using reagent grade toluene which may contain water
- Improper alignment of sample flow into thimble
- Thimble having toluene overflow
- FeS in sediment may cause combustion of thimble

2.7 Sample Requirements

Approximately 100g of sample is required to perform a single run of this test

Samples must be kept frozen

2.8 Equipment and Supplies

- 8500mL round-bottom flask, water trap (25mL capacity) and water-cooled reflux condenser
- cellulose extraction thimble (33 x 94mm)
- analytical balance
- thimble cage
- 125ml glass jars
- fiber glass filter paper
- 500ml measurement flask
- conventional oven
- toluene, UN 1294
- ~250ml of toluene per sample
- qualitative filter papers
- phase separators

2.9 Quality Control

For the test to be considered valid, duplicates should be included with every run. If there are many samples, a duplicate is included after every ten samples. This must be recorded on the well information form and the bitumen value between duplicates should be within 0.2% absolute.

2.10 Procedures

2.10.1 Sample Preparation

1) Label thimbles.
2) Label thimble cage.
3) Weigh thimble and qualitative filter paper.
4) Measure 100 g of sample onto the filter paper, roll it up by folding the bottom third of the filter towards the top then fold each side towards the center of the filter. Finally, roll the filter paper around the sample and place it in the thimble.
5) Add ~250ml (to the top of the jar) of toluene to Erlenmeyer flask.
6) Place thimble in Erlenmeyer flask on top of the metal ring apparatus such that the toluene will drip into the thimble. Ensure the level of toluene does not meet the bottom of the thimble when placed in flask.
7) Ensure all cockstops are closed.
8) Turn oil bath (no more than two at a time) on and reflux with hot toluene to extract hydrocarbons from sample until solvent dropping from the thimble is colorless. A minimum of eight hours is required for each extraction process.
9) After one hour, check all Erlenmeyer flasks to ensure toluene is dripping into the thimbles.
10) Label individual water jars to match the number of samples in the well. Weigh each bottle and lid, empty, and enter bottle weight in the appropriate cell of the well information form.
11) When the emulsion solution in the water trap becomes clear (about 4 hours of extraction), the water from the oil sands sample is completely extracted. Read water volume in each water trap to the nearest scale division. Double-check the water reading and record the data into the Logbook.
12) Continue the extraction process for another 4 hours until the solvent dripping from the thimble becomes colorless. Switch heating mantle power off. Turn off the cooling water system.
13) Let the samples cool in the Erlenmeyer flasks about sixty (60) minutes.
14) Remove thimble from Erlenmeyer flask (being careful not to make contact with bitumen) and place in thimble cage.

    Note*: Should a thimble absorb any bitumen while removing from flask, record the event on the well information form.*

    Place the thimble for re-cleaning at the end of the next well to be DSA'd.
15) Place thimbles in conventional oven (95ºC) for eight (8) hours.
16) Remove thimbles from oven, place in front of cooling fan. When cooled, record weight of samples.

2.11 Calibration and Measurement

1) The analytical balance should be calibrated before each use.
   ***Note**: Record all calibrations in the balance logbook*.

2) All measurements will be done on an analytical balance.

   Record the weight of water collected in the water trap. If the trap fills with water, it may drained into a sample cup and weighed at room temperature (only to be done if sample water volume becomes larger than the graduations on water trap).

   After the extraction is completed, and the thimble dries, cool in a desiccator and record the mineral weight.

2.12 Data Analysis and Calculations

Use following formulas to calculate the contents of water, oil and residue in the oil sands sample:

Mineral, wt % = Wt. Mineral (g) / (Sample Weight (g)) * 100

Water, wt % = Wt Water (g) / (Sample Weight (g)) * 100

Hydrocarbon, wt % = 100% - (%Water + %Sediment)

3 Evaluation of Particle Size Distribution of Post-DSA Oil Sand Samples by Wet/Dry Sieving and Laser Diffraction

3.1 Scope and Application

This standard operating procedure (SOP) describes a method for the evaluation of PSD for post-DSA oil sands samples using wet/dry sieving method. The particle size ranges from 44 to 2000 µm. For PSD under 44 µm, laser diffraction method is used. By combining the results from these two methods, a complete PSD is obtained.

3.2 Method Summary

Oil sand samples are stripped of bitumen and dried by the Dean and Stark extraction method, and dry solids are soaked in Calgon solution (sodium hexametaphosphate dispersing agent) solution and boiled. After cooling down overnight, the aqueous sample is washed thoroughly with de-ionized water on top of two 325 mesh US standard sieves. The washed liquid (containing fines < 44 µm) is collected for PSD analysis by the laser diffraction method.

The retained sample left on the sieve is collected and dried in the oven. The dried sample (> 44 µm) is used for the evaluation of PSD by dry sieving method. The overall PSD is obtained by combining the results from the wet/dry sieve and laser diffraction methods.

3.3 Health and Safety Warnings

- General Safety requirements for laboratory work are provided by the Loring Tarcore Health, Safety and Environment Manual.
- Personal protection measures, such as gloves and lab coats must be used.
- Material safety data sheets for all chemical reagents are available to and understood by all personnel using this method, and reviewed during analyst training.

3.4 Interferences

Oily residue in the sample may skew the PSD to larger particle sizes, so return the sample for further Dean and Stark extraction if received sample is not clean.

3.5 Handling and Preservation

About 100 g samples are received in the labeled plastic bag as clean, dry solids that have been processed through Dean and Stark extraction. The plastic bag is labeled with the well number and the sample number on UPC barcode. Approximately 75 g (± 5 g) of sample is required for this test method.

3.6 Equipment and Supplies

- stereo microscope
- sample splitter (riffler)
- analytical balance
- sonicator
- vacuum filtration apparatus
- oven
- hot plate
- 3D-vibratory sifter (model AS200-Retsch)
- computer with test data recorder program and scanner (optional)
- stainless steel 325-mesh sieve and pan
- 600 mL beakers
- shark-skin filter paper (Refined cellulose, Whatman)
- U.S. standard series sieves (10, 18, 35, 45, 60, 80, 120, 200, and 325 mesh)
- sieve stack cover
- rubber pestles
- porcelain mortar
- plastic funnel

- rubber policeman
- certified standard weight set (for analytical scale verification)
- sieve calibration standard, mesh 80, 120, 200, 325 (purchased from Cole Parmer)
- sieve cleaning brushes
- de-ionized (DI) water
- methanol
- Calgon solution (prepared by dissolving 20 g of Sodium Hexametaphosphate in 1 Liter of DI water)

3.7 Quality Control

1) Perform duplicate analysis on one sample for every ten samples analyzed. Duplicate results for D50 should agree within ± 10% RPD of the average value. The lab coordinator/supervisor must be informed if this quality criterion is not met. Repeat analysis may be required.
2) One reference sample is analyzed per well and this is determined by the client. Client will determine the acceptance criteria for the reference sample and may request repeat analysis.

3.8 Procedures

3.8.1 Calibration

1) Verify analytical scale calibration by checking with certified weights before starting the work. Record the results of scale calibrations in the logbook.
2) Dry sieves are verified at least monthly using Sieve Calibration Standards. These verifications are recorded in the logbook.
3) Sieves are visually inspected daily and inspected with a microscope weekly; both observations are recorded in the logbook.

3.8.2 Sample Preparation

Disaggregation

1) Size the solids in a 3.35 mm (No. 6 mesh) sieve with a receiving pan below.
2) Massage the material retained by the sieve with a rubber pestle or break the aggregates apart using your fingers. Softer materials will fall apart and pass through the sieve and collected in the receiving pan.
3) Pieces of unconsolidated sandstone (easily reduced) that do not pass through the sieve are disaggregated with a mortar and rubber pestle. This step may not be required depending on the nature of the samples.
4) The remaining material that did not pass through the sieve is manually sorted into two piles (fibrous material such as cotton or pieces of filter paper should be removed and discarded).
    (i) Non-Ablatable Material
    Remove this material from the sample: (1) Pyrite, pebbles, cemented material (siltstone), and (2) Non-ablatable cemented material (siltstone) will "streak" if scratched with a pointy object such as a nail.

(ii) Ablatable Material
This material is retained in the sample: (1) Siltstone, shale, silty shale and cemented material (sandstone); (2) Ablatable cemented material (sandstone) will "peel" as sand by rubbing with the fingers. Siltstone, shale and silty shale can be "carved" by a pointy object such as a nail; and (3) Coal and wood.

5) Ablatable material (>3.35 mm) is disaggregated using a mortar and rubber pestle and retained in the sample.

Sub-sampling (Sample splitting)

1) The disaggregated sample is split using a riffle splitter to obtain one representative sample of 75 % of total sample for PSD analysis and one sample of 25% for MBI analysis. The sub-samples are recombined and repeatedly split using the riffle splitter until representative sub-samples are obtained. The sample should be inspected during this step to visually ensure an even and homogenous split. If original sample is less than 75 g, make sure to leave at least 10 g sample for MBI.
2) Place a labeled (with barcode) 600 mL beaker on the scale and "Tare" the weight. Weigh a sub-sample for PSD analysis into the beaker and press the "Print" button on the scale to automatically enter the sample weight into the Test Data Recorder program.
3) Place the beaker (with sample) onto the cart labeled "For Boiling".

Boiling

1) 'Wet' the sample with just enough Methanol to make the sample moist. Then add 300 mL of Calgon solution to the beaker.
2) Place beaker on hot plate and bring to boil. Continue boiling for 15 minutes. Watch sample and stir if necessary, always rinsing the stirring rod with de-ionized water to avoid loss of sample.
3) Turn the hot plate "Off" and allow beaker to sit for 30 minutes until cool.
4) Remove beaker from the hot plate and allow to sit for at least 12 hours at room temperature.

3.8.3 Wet Sieving

1) Visually inspect under magnifying lens, two 325-mesh sieves to ensure that they are in good condition (not too many holes are blocked by looking through it to the lights) and not damaged or punctured. Stack the two sieves with sieve labeled "TOP" on the top and place a receiving pan under the stack. ALWAYS stack "TOP" sieve on the top.
2) Label 1 L plastic bottle and Shark-skin filter paper (using pencil or marker) with RC number and sample ID.
3) Stir the sample thoroughly using a police man or glass rod and then sonicate for 15 seconds using the sonicating Probe with AMPL at 20%. Wash the probe with DI water while collecting the washings into the beaker.
4) Transfer the slurry from the beaker to the top of sieve stack. Wash beaker and police man/glass rod with DI water to ensure complete transfer of solids.
5) Filling 1 L bottle with about 700 mL DI water. Wash the sample with DI water by showering from the 1 L plastic bottle with perforated lid. Use police man or fingers to gently move the samples around on top of the sieve. Squish any soft lumps with a rubber police man or fingers

being careful not to spill the mixture. Once in a while, use washing bottle to wash down any samples clinging to the sieve wall.

6) Continue washing in this manner until the water flowing into the receiving pan is CLEAR. Try to limit the volume of DI water for the washing to no more than 700 mL. If more than 700 mL of water is required to achieve a clear wash, notify the Lab Coordinator, and continue with washing. Collect washings from the receiving pan into the 1 L plastic bottle with corresponding sample ID. If necessary, use another bottle. Collect all washings and ensure that no fines are discarded.
7) Check the water in the receiving pan to make sure that very little fine sands exist in the water or on the bottom of the pan. If there is no or very little fine sand in the water, then the final wash is NOT collected and is allowed to run into the sink drain. If there are some fine sands in the water or at the bottom of the pan, allow the sand to precipitate for about 5 minutes. Then pour out the top clean water and wash the fine sands to the 1 L bottle.
8) Place a labeled shark skin filter paper into a Buchner funnel, press down fully to the bottom of the funnel. Attach funnel to the vacuum filtration apparatus. Wet the filter with DI water and then transfer the solids retained in the two 325-mesh sieves onto the filter using DI water in a wash bottle. Turn “On” vacuum pump to drain the water. When the water is completely drained, turn “Off” vacuum pump.
9) Remove the filter paper containing the solids from funnel to a flat surface. Fold the filter paper with the solids (make sure no sample lost) and place this into an aluminum tray.
10) Drying the filter paper roll with samples in the oven at 105-110 °C for at least 3 hours until completely dry.
11) Send the labeled 1 L bottles containing washed fines (<44 µm) for PSD analysis by laser diffraction.
12) Take out the dried sample from the oven and leave it in the air to cool down.

3.8.4 Dry Sieve

1) Inspect standard sieves (mesh 10, 18, 35, 45, 60, 80, 120, 200, 325) and receiving pan to ensure that they are not damaged or punctured. The sieves are identified using a letter designation (i.e., A, B, C, etc.) and the sieve size (i.e., 10, 18, 35, etc.).
   Note*: It is critical that sieves with different letter designations are not interchanged with other sieve stacks.*
2) Stack the sieves on top of each other with the largest mesh size (10) at the top and progressively smaller size (325) below, with the receiving pan at the bottom of the sieve stack.
3) Scan and weigh each sieve on the scale, in order, beginning with sieve 10 through 325, and ending with the receiving pan. Press the “Print” button after each weighing to automatically record the weights into the Test Data Record program. Ensure that the weights are captured into the appropriate data input cells. Flip over the sieve and pan after each weighting and stack one on top of each other, with Sieve 10 at the bottom, and then Sieve 18, Sieve 35, to Sieve 325 and receiving pan at the top.
4) Weigh out the dried filter and solids and record this weight in the program.
5) Flip over the sieve stack. Now you have Sieve 10 at the top and the receiving pan at the bottom. Place the wrapped sample with filter paper on top sieve. Carefully open the wrapped filter

paper and make sure the solids can fall into the sieves directly. Ensure that the entire solids are transferred to the top sieve by rubbing the filter surface together.

6) Re-weigh the filter (minus solids) and record this weight in the program.
7) Place the sieve stack on the shaker and clamp the stack together with the sieve holder.
8) Set the sieving time at 5 min, amplitude at 58 and 0 for the interval. Press the “Start” button to begin shaking. Make sure the vibration height is at 1.36, adjust the amplitude knob position if necessary.
9) When the shaking is done, remove the sieve stack (with pan) from the shaker. Place the stack on the lab bench and rotate the stack 90°, 4 times; each time slightly tapping the sieve with the hand from top to the bottom to ensure that all particles smaller than the openings of the mesh pass through.
10) Re-weigh each sieve (with retains) on the scale and record each weight in the program. Ensure that the weights are captured into the appropriate data input cells.
11) Upload all the data onto Server by click “Upload to Server” button in the Test Data Recorder so back up the data into computer by click “Backup” button.
12) Collect samples from all sieves into a labeled (with RC number and sample ID) plastic bags for checking later (if necessary)

3.8.5 Sieve Cleanup

1) If mesh 325 sieves for wet sieving are not in good condition (many holes were blocked), put them in the water bath sonicator. Turn on the sonication for an hour. Continue washing if sieve is still not good. After washing, rinse with water and dry in air.
2) All sieves used after dry sieving should be cleaned with a designated brush. Always clean the sieve from the back side. Use rectangular brass brush for Mesh 100 and coarser. Use round nylon brush for 120 mesh sieve and finer. After cleaning with brushes, use air jet to clean them again.
3) The weight of cleaned sieve should be within 0.2 gr as comparing to its previous weight. If not, report to lab coordinator immediately.
4) When the sieves for dry sieving are not in good condition (many holes are blocked by visual inspection, even after brush and air jet cleaning), put them in the water bath sonicator and wash for at least one hour. Visual check them again. If they are in good condition, dry them in the over at 50-60 °C for at least 2 hours. Then take them out and cool down in the air. Check under microscope again to make sure they are in good condition.

3.9 Data Analysis and Calculations

1) Calculations and reports for PSD are performed automatically on the server.
2) The wet/dry sieving results will be combined with results from laser diffraction for fines and fed into PSD reporting template from the client for final reporting. The quality of test results are verified prior to reporting.

4 Determination of the Methylene Blue Index (MBI) of Post-DSA Oil Sand Samples

4.1 Scope and Application

This method covers the determination of the MBI from dry and clean solid oil sands samples that have been processed through Dean and Stark extraction.

4.2 Method Summary

Methylene blue solution is added to a sample retained in the thimble after DSA. The dye is absorbed onto the clay mineral surface by a cation exchange reaction. Because non-clay minerals have a low cation exchange capacity, the dye absorbed by a sample is an indication of the clay content of that sample.

When the dye is initially added to the sample suspension, it is completely absorbed. Dye is continually added and continually absorbed until all cation exchange sites are used up. When all of the ion exchange sites have been occupied, the excess dye will cause a faint halo stain on filter paper when a drop from the suspension is applied, which indicates that the endpoint is reached. Based on this endpoint, the MBI for the sample is determined.

4.3 Health and Safety Warnings

- General Safety requirements for laboratory work are provided by the contract laboratory Health, Safety and Environment Manual.
- Personal protection measures, such as gloves and lab coats must be used.
- Material safety data sheets for all chemical reagents are available to and understood by all personnel using this method, and reviewed during analyst training

4.4 Interferences

Materials that react with methylene blue may affect the results.

4.5 Handling and Preservation

Safety glasses and chemical resistant gloves must be worn when making H_2SO_4 and NaOH solutions.

4.6 Equipment and Supplies

- balance (at least 0.01 g resolution)
- pH meter (at least 0.1 pH resolution)
- water bath with thermometer
- ultrasonic bath
- magnetic stirrer and stir bar
- sample racks for 50 mL centrifuge tubes

- metal spatula
- burette (50 mL) and stand with auto-fill attachment
- pasteur pipette
- Black Ray display lamp
- porcelain mortar and pestle
- filter paper, #1 Whatman
- 50 mL disposable centrifuge tubes with caps
- wash bottle
- 200 - 250 mL beakers

4.7 Reagents

1) De-ionized (DI) water.
2) Standard pH buffer solutions of pH 4.00, 7.00, 10.00 for the calibration of pH meter (commercially obtained).
3) 10% v/v sulfuric acid (H_2SO_4) solution.
   To a 1000 mL volumetric flask, add at least 250mL of DI water. Slowly, with mixing add 100 mL of pure ACS grade sulfuric acid with class A graduated cylinder. Bring to volume with DI water. Let it cool to room temperature.
4) 10% w/v sodium hydroxide (NaOH) solution.
   In a 1000 mL volumetric flask add 100g (± 1 g) of sodium hydroxide pellets and dissolve with DI water then bring to volume with DI water. Mix well.
5) 61.26 g/L sodium bicarbonate (Na_2CO_3) solution.
   In a 2.0 L volumetric flask add 2.52 g (± 0.5 g) of sodium bicarbonate, dissolve with DI water then bring to volume with DI water. Mix the solution, and adjust the pH to 9.7 using 10% w/v sodium hydroxide solution (about 2 mL).
6) 0.006 N Methylene Blue Trihydrate Solution.
   In a 2.0 L volumetric flask add 4.486 g (± 0.001 g) of methylene blue trihydrate, dissolve with DI water then bring to volume with DI water. Always mix the solution and protect it from light using tinfoil, the solution expires in 48 hrs. Store at room temperature. The solution must be verified using Bentonite standard before use.
7) Bentonite Standard.
   Dry 5 g at a time in a glass bottle at 110 ± 5°C overnight. Place in a desiccator to cool, and use immediately after cooling to prevent absorption of moisture from air. Replace the vial, with Bentonite, in the oven overnight for the following day.
   ***Note**: Regent grade chemicals must be used.*

4.8 Quality Control

One blind sample is also provided for each well and these are determined by the client. The client will determine the acceptance criteria for the blind samples and may request repeat analysis.

4.9 Procedures

4.9.1 Calibration

1) Calibrate the pH meter with pH 7.00 and pH 10.00 buffer solutions.
2) Use certified weighs of 50, 100, 200 and 300 g to calibrate the balance. The readings should be within ±0.005 g of the certified weight. If not, report to lab coordinator immediately.

4.9.2 Sample Preparation

1) Lightly grind solids until aggregates are no larger than 1 mm. Be careful not to place too many solids into the mortar at one time, but grind in small batches to ensure that grinding is even. Grind all solids supplied for each sample. Combine all batches from the grinding process and mix well to homogenize the sample. Return these solids to the original sample container.
2) Clean the mortar and pestle by wiping with a dry paper towel and brushing across the surfaces to remove any residual solids.
3) Place a 50 mL plastic centrifuge tube in a beaker or suitable bottle, and put them on the scale and tare this weight. Weigh 2 to 10 g (2 g for samples high in clay, and 10 g for samples low in clay) of dried, ground sample into the tared centrifuge tube. Record the weight in MBI Logbook.
4) Add about 40 mL of $NaHCO_3$/NaOH solution to the centrifuge tube (with sample) and mix well by hand-shaking (do not use a stick to mix). Heat the sample slurry in a 80°C water bath for 20 minutes or longer. Take the sample out of the water bath and allow slurry to stand overnight.
5) The following day, sonicate the sample for 20 minutes in the ultrasonic water bath (room temperature)
6) After ultrasonic dispersion, transfer sample to a 200 or 250 mL beaker and wash the centrifuge tube with $NaHCO_3$/NaOH solution to recover any residual solids on the sides of the tube. The total volume of suspension should be about 100 mL, add more $NaHCO_3$ solution if required to reach this volume.
7) Add a stirring bar to the beaker and put the beaker on a magnetic stirrer. Insert the probe of pH meter into the solution. Adjust the pH of the suspension to just below pH 4 (pH 3.6 – 4.0) by adding drop-wise 10% (v/v) sulfuric acid solution. Use 10% NaOH or Na_2CO_3 solution to bring pH up if excess H_2SO_4 was added. Rinse the pH probe with de-ionized water to ensure that no solids are removed by the pH probe. Titration with MB solution should be performed directly.

4.9.3 Verification of Methylene Blue Titrant

1) In a tared 50 mL plastic centrifuge tube, weigh out a 0.2 g (to 0.1 mg) of dried Bentonite standard. Record the weight in MBI Logbook. Process as described in sample preparation items 4 to 7. Titrate with MB titrant as described in Sample Analysis. This titration endpoint must be between 25 - 27 mL for the batch of MB to be accepted. If the titration endpoint is out of this range, re-analysis or re-preparation of MB solution must be conducted.
2) Two standard samples (bentonite) must be run before running samples. Report the standard sample titration in the logbook.

3) When a new batch of MB titrant solution is prepared, it must be checked with the Bentonite standard, and recorded in the Logbook.

4.9.4 Sample Analysis

1) Label a Whatman #2 filter paper with well name, sample ID, date and the analyst's initial.
2) Fill the bottle with MB solution. The bottle of MB solution should be wrapped completely in tinfoil to avoid light. Fill the burette with MB solution by squeezing the MB bottle.
3) While stirring the sample slurry, add 0.5 mL to 2 mL of MB solution from a burette (Check with PSD results as provided. 2 mL only for samples with very high fine contents). Stir for 1-2 minutes on the magnetic stir plate. Record the amount of MB on the filter paper.
4) Using a Pasteur pipette, place a drop of the slurry on the surface of the filter paper.
5) Observe the appearance of the drop. The endpoint is indicated when a blue halo forms around the drop.
6) If no halo appears, continue adding MB solution to the slurry in 0.5 mL or 1 mL or 2 mL increments (Check with PSD results as provided. DO NOT use a titration increment larger than 2 mL), with 1-2 minutes of stirring after each addition.
   - Write the volume of MB added for each addition on the filter paper. When the endpoint is nearing (again check with PSD results as provided), reduce the titrant volume to 0.5 mL and continue until the endpoint is reached. Make sure that the halo persists after one minute of additional stirring.
7) Let the filter paper dry, reverse it and determine where the light blue halo exists surrounding the inner dark blue. This is the endpoint of the titration. Continue adding 0.5 mL MB solution two or three times to confirm the stability of the light blue halo.
8) Once the endpoint is determined, record the total amount of MB titrant (mL) used to reach the endpoint in the MBI Logbook.
9) Input sample weight and total amount of MB titrant (mL) used into MBI data process program.

4.9.5 Clean-up

1) All used MB solution (with/without samples) should be collected and damped in the “MBI WASTE” drum.
2) Retain all MBI filter papers in a plastic bag. Label the bag with company name and Well ID.
3) Wash all the beakers, centrifugal tubes and burette with tap water, and rinse with DI water. Leave them to air dry.

   Turn off the scales, pH meters, and magnetic stir plates when no longer in use

4.10 Data Analysis and Calculations

1) Use following formula to calculate MBI:

   MBI = 0.006 x V x 100/W

   Where:

MBI = Methylene Blue Index in meq/100 g sample

V = volume (mL) of Methylene Blue solution (0.006 N) used W = weight (g) of dry sample used

W = weight (g) of dry sample used

2) Duplicate Relative Percent Difference (RPD):

RPD (%) = | A_1-A_2|/((A_1+A_2)/2)*100%

Where:

A_1, A_2 = Final MBI results (meq/100 g) of the duplicates

3) The relative percent difference (RPD) of the repeat measurements should be within 10% of the mean value. If this criterion is not satisfied, re-analyze the failed repeats and samples, as appropriate. Record these instances in the MBI logbook and report to the lab coordinator or supervisor.

5 Extraction of Oil Sands Samples for the Determination of Soluble Ions and pH/EC

5.1 Scope and Application

This method covers the method of extracting aqueous solutions from frozen oil sands samples for the determination of pH/EC, concentrations of cations (Na, K, Ca and Mg) and anions (Cl and SO_4). The measurement of cations by ICP-AES and anions by IC is described by separate SOPs.

5.2 Method Summary

The oil sand sample is extracted with boiling, de-ionized water (1:1 w/w extraction) and stirred for 5 minutes with an impeller stirrer. The slurry is filtered using a mud press. A portion of the filtrate is analyzed for pH and electrical conductivity (EC) by electrode probes. The remaining filtrate is filtered again through 0.1 µm Millipore filter and the final extract is analyzed for anions (Cl^-, SO_4^{2-}) by IC, and cations (K^+, Na^+, Mg^{2+} and Ca^{2+}) by ICP-AES.

5.3 Health and Safety Warnings

General Safety requirements for laboratory work are provided by the Loring Tarcore Health, Safety and Environment Manual.

Personal protection measures, such as gloves and lab coats must be used.

Material safety data sheets for all chemical reagents are available to and understood by all personnel using this method, and reviewed during analyst training.

5.4 Interferences

Not applicable

5.5 Handling and Preservation

1) The pH and EC probes must be cleaned with DI water after each use, and then kept hydrated in storage solution (pH probe) and DI water (EC probe), respectively.
2) The filtration and micro-filtration cells must be cleaned after each use with soap and water. If necessary, toluene may be used to remove oily residue, followed by soap and water. The cells should be post-rinsed with DI water prior to use.
3) When cleaning the filtration cells with toluene, safety glasses, chemical resistant gloves, and respirator must be worn. Operate in a fume hood only.
4) If the sample extracts cannot be analyzed within 2 days, store the extracts in the refrigerator at 4-10°C until time of analysis. Ensure that sample bottles are tightly capped during storage to prevent volume loss by evaporation.
5) Store any unused portions of the sample extracts in the refrigerator for 2 weeks after the analytical report is issued in case repeat testing is required.

5.6 Equipment and Supplies

- electric kettle
- impeller mixer
- stopwatch or timer
- stand and support ring
- mud press with sample filter apparatus (100-120 psi air pressure)
- micro-filtration apparatus (40 - 45 psi air pressure)
- pH/EC meter
- scale (0.1 g resolution)
- 100 mL plastic graduated cylinder
- 450-480 mL disposable plastic cups
- 125 mL narrow mouth plastic bottles with caps
- 25 mL Dram 7 plastic vials with caps.
- mud press filters (Canamara PIN EN8700; 3.5 inch diameter)
- Millipore Durapore 0.1 pm VVPP membrane filters (47 mm diameter)
- de-ionized water
- toluene
- paper towel
- standard pH buffer solution (7.00, 9.80 and 10.00).

- calibration standards of electrical conductivity, 1000, 1500 and 2070 µS.

5.7 Quality Control

1) A duplicate sample is, prepared for every ten samples analyzed. Duplicate analytical results should agree within ±10 % RPD of the average value. The lab coordinator/supervisor must be informed if this quality criterion is not met.
2) One reference sample is analyzed per well and this is determined by the client. The client will determine the acceptance criteria for the reference sample and may request repeat analysis.
3) One blind sample is also provided for each well and this is determined by the client. The client will determine the acceptance criteria for the blind sample and may request repeat analysis.

5.8 Procedures

5.8.1 Calibration

1) Calibrate the balance using 50 and 100 g certified weights. The readings of balance must be within ± 0.1 g. If not, report to lab coordinator immediately.
2) Calibrate pH meter using standard buffer solutions of pH 7.00 and 10.00, following the instructions of the pH meter manual. Check the slope of the probe after calibration (MUST be at least 90 %). After calibration, measure the standard buffer solution of pH 9.80. The reading should be within ± 0.2 pH units. If not, report to lab coordinator immediately.
3) Calibrate EC meter using EC calibration solutions of 1000 µS. After calibration, measure EC check solutions (1500 and 2070 µS). The reading should be within ± 2 % of the certified values.

5.8.2 Preparation

1) Assemble the filter cell, and sit it on the rack.
2) Add DI water into electrical kettle and boil.
3) Label 25 mL and 125 mL plastic vials with well name and sample ID.

5.8.3 Extraction

1) Weigh 100 g (± 1 g) of sample into a 480 mL disposable plastic cup and add 100 mL of boiling de-ionized (DI) water. If the available sample weight is less than 100 g, prepare an appropriate 1:1 extract using the available amount of sample with the corresponding volume of boiling DI water. Record sample weight and water volume in SI Logbook.
2) Sit the cup on the support ring of the stirrer stand. Lift the ring all the way up to the stirring blade. Then lower the ring a down (5-10 mm). Turn on the stirrer and stir for 5 minutes (using timer) with the impeller stirrer (ensure a good mixing).
3) Turn off the stirrer. Lower the support ring all the way down. Immediately pour the top portion (liquid) of the mixture (oil sands and water) into the filter cell until a drop-wise flow is obtained.
4) Secure the cell to the rack. Open the compressed air valve (100 -120 psi air pressure) and collect the filtrate. When enough sample (15-20 mL) out of the filtration cell, transfer them into a 25 mL plastic vial for pH and EC determinations immediately.

5) Measure pH with pH-meter and EC with EC probe and record pH and EC in SI Logbook. Keep this portion of the sample in the refrigerator after pH and EC have been determined until SI (pH & EC) reports are approved. Wash the pH and EC probes with DI water and wipe with Kimwipe after each measurement.
6) Continue filtering until enough sample is collected (25-30 mL).
   ***Note**: the extraction process should be as short as possible. If the filtration speed is too slow (not reaching 25 mL in 120 minutes), take out the mud cake at 60 minutes and extend the process to 150 minutes*.
7) While waiting for the filtration, clean the impeller blade with paper towel after each use. If necessary, the impeller blade may be cleaned with toluene to remove oily residue, then rinsed with DI water.
8) Switch off the air supply to the filtration cell. Switch the toggle valve to release air pressure in the filtration cell.
9) Prepare the second-stage filtration assembly.
10) The 25-30 mL extract from first-stage filtration is subsequently filtered through a Durapore 0.1 µm Millipore membrane filter at 40 - 45 psi air pressure. The filtrate is collected into a labeled 50mL plastic bottle and then submitted for SI analysis by IC and ICP/AES.

5.8.4 Clean-up

1) Loose the handle above the filtration cell. Remove the top of filtration cell. Take out the filtration cell (body and base) from the rack.
2) Separate the cell body and base. Dump the filter paper (with solids) into a designated trash bag. Use a paper towel to clean the cup wall.
3) Use tweezers to take out the mesh screen, O-ring and gasket from the filtration cell base.
4) Clean the cell body with toluene under fume hood. Wait for toluene to evaporate. Then clean under tap water following by rinsing with DI water. Allow to air dry.
5) Clean the filtration unit base with tap water followed by rinsing with DI water.
6) Put the mesh screen, O-ring and gasket into a container, add boiling water and carefully shake for a few minutes. Clean with soap and tap water, rinse with DI water and allow to air dry.

For second-stage filtration cells, take apart after filtration, dispose of the filter paper. Rinse with tap water followed by DI water.

5.9 Data Analysis and Calculations

All data (pH, EC and ion concentrations) are reported in a specific spreadsheet template, and uploaded to the server for final reporting to the client.

6 Extraction of Oil Sands Tailings Samples for the Determination pH/EC/ORP and Soluble Ions.

6.1 Scope and Application

This method details how to extract 'first flush' solutions from dry or semi-dry tailings samples that do not contain enough water for direct filtration using micro-filtration cells. Extracts obtained using this method can then be used to measure potential hydrogen (pH), electrical conductivity (EC), oxygen reduction potential (ORP), alkalinity and soluble cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) and anions (Cl^- and SO_4^{2-}). Tailings samples already containing sufficient fluid for the direct filtration process should not have additional water added and can be directly filtered (micro-filtration and 0.1 µm Millipore filter) then sent for analysis.

6.2 Method Summary

Tailings samples will be received in 5L pails. Each containing around 400g tailings; 100g is for Dean and Stark Analysis (DSA) and the remainder can be processed for pH, EC, ORP, alkalinity and soluble ions.

The tailings sample is visually assessed for fluid content. Samples too dry to directly filter should have 40 ml room temperature DI water added to 100g sample and stirred for 5 minutes using an impeller stirrer. The tailings slurry is then filtered using a mud press.

A portion of the filtrate is then analyzed for pH, EC and ORP using electrodes. The remaining filtrate is subsequently filtered through a 0.1 µm Millipore filter and the final extract then sent to analysis of alkalinity by titration, anions (Cl^-, SO_4^{2-}) using IC, and cations (K^+, Na^+, Mg^{2+} and Ca^{2+}) using ICP-AES. For each batch of tailings, one sample of DI water needs to be analyzed using both IC and ICP-AES, to determine background levels of soluble ions that were added to the sample.

6.3 Health and Safety Warnings

General Safety requirements for laboratory work are provided by the Loring Tarcore Health, Safety and Environment Manual.

Personal protection measures, such as gloves and lab coats must be used.

Material safety data sheets for all chemical reagents are available to and understood by all personnel using this method, and reviewed during analyst training.

6.4 Analytical Interferences

Soluble ions may be present in the DI water and could potentially affect analysis. One sample of DI water needs to be analyzed using both IC and ICP-AES, to determine the potential of adding soluble ions to the samples.

6.5 Handling and Preservation

7) The pH, EC and ORP probes must be cleaned with DI water after each use, and then kept hydrated in manufacturer recommended solutions.
8) Filtration and micro-filtration cells must be cleaned after each use with soap and water. If necessary, toluene may be used to remove oily residue, followed by soap and water. The cells should be post-rinsed with DI water prior to use.
9) When cleaning the filtration cells with toluene, safety glasses, chemical resistant gloves, and respirator must be worn. Procedure only to be carried out in the fume hood.
10) If sample extracts cannot be analyzed within 2 days, store the extracts in the refrigerator at 4-10°C until time of analysis. Ensure that sample bottles are tightly capped during storage to prevent volume loss by evaporation.
11) Store any unused portions of the sample extracts in the refrigerator for 2 weeks after the analytical report is issued in case repeat testing is required.

6.6 Equipment and Supplies

- impeller mixer
- stopwatch or timer
- stand and support ring
- mud press with filter apparatus (100-120 psi air pressure)
- micro-filtration apparatus (40 - 45 psi air pressure)
- pH/EC/ORP meter
- weighing scales (0.1g resolution)
- 100 mL plastic graduated cylinder
- 450-480 mL disposable plastic cups
- 125mL narrow mouth plastic bottles with caps
- 25mL Polypropylene 7 Dram plastic vials with caps
- mud press filters (Canamara PIN EN8700; 35 mm in dimeter)
- Millipore Durapore 0.1 µm VVPP membrane filters (47 mm diameter)
- de-ionized water
- toluene
- paper towel
- standard pH buffer solution (7.00, 9.80 and 10.00)
- calibration standards of electrical conductivity, 1000, 1500 and 2070 µS

6.7 Quality Control

12) A duplicate sample is, prepared for every ten samples for analysis. Duplicate analytical results should agree within ± 10% deviation of the average value. The lab coordinator/supervisor must be informed if this quality criteria is not met.

13) One reference sample is analyzed per well and this is determined by the client. The client will determine the acceptance criteria for the reference sample and may request repeat analysis.
14) One blind sample is also provided for each well and this is determined by the client. The client will determine the acceptance criteria for the blind sample and may request repeat analysis.

6.8 Procedures

6.8.1 Calibration

15) Calibrate the balance using 50 and 100 g certified weights. The readings of balance must be within ± 0.1g, if not, report to lab coordinator immediately.
16) Calibrate pH meter using standard buffer solutions of pH 7.00 and 10.00, following the instructions of the pH meter manual. Check the slope of the probe after calibration (MUST be at least 90%). After calibration, measure the standard buffer solution of pH 9.80. The reading should be within ± 0.2pH. If not, report to lab coordinator immediately.
17) Calibrate EC meter using EC calibration solutions of 1000 µS. After calibration, measure EC check solutions (1500 and 2070 µS). The reading should be within ± 2% of the certified values.
18) Calibrate ORP meter following manufactures instructions.

6.8.2 Preparation

19) Assembly the filter cell, and sit it on the rack.
20) Label 25mL and 125mL plastic vials with well name and sample ID.

6.8.3 Extraction

11) Weigh 100 g (± 1g) of sample into a 480 mL disposable plastic cup and add 40 g of room temperature de-ionized (DI) water. If the available sample weight is less than 100 g, prepare an appropriate ratio of (10:4) sample: water using the available amount of sample (e.g., for 50g of tailings sample add 20 ml DI water). Record sample weight and water volume in SI Logbook.
12) Sit the cup on the support ring of the stirrer stand. Lift the ring all the way up to the stirring blade. Then lower the ring down 5-10mm. Turn on the impeller mixer and fully mix for 5 minutes.
13) Turn off the stirrer. Lower the support ring all the way down. Immediately pour the top portion (liquid) of the mixture (oil sands and water) into the filter cell until drop-wise flow is achieved.
14) Secure the cell to the rack. Open the compressed air valve (100 -120 psi air pressure) and collect the filtrate. When 15-20 mL of sample is obtained from the filtration cell, then directly transfer the extract into a 25mL plastic vial for pH, EC and ORP analysis.
15) Measure pH, EC and ORP and record the data in the SI Logbook. Keep this portion of the sample in the refrigerator after pH and EC have been determined until SI (pH & EC) reports are approved. Wash the pH and EC probes with DI water and gently wipe with Kimwipe after each measurement.
16) Continuing filtering until >50mL sample is collected.
    Note*: The extraction process should be as short as possible. If the filtration speed is very slow (25 mL extract is not obtained in 120 minutes), remove the mud cake at 60 minutes and finish processing the rest of the sample in 150 minutes.*

17) After each use, clean the impeller blade with paper towel. If necessary, the impeller blade may be cleaned with toluene to remove oily residue, and rinsed with DI water.
18) Switch off the air. Switch the toggle valve to relieve air pressure in the filtration cell.
19) Prepare second-stage filtration assembly.
20) The 25-30 mL extract from first-stage filtration is filtered through a Durapore 0.1 µm Millipore membrane filter at 40 - 45 psi air pressure. The filtrate is collected into a labeled 50 mL plastic bottle and then submitted for ions analysis by IC and ICP/AES.

6.8.4 Clean-up

21) Loosen the handle above the filtration cell and remove the top. Take the filtration cell out of the rack.
22) Separate the filtration cell body and bottom sections. Dispose of the filter paper (with solids) into designated waste disposal. Use a paper towel to clean the cup wall.
23) Take out the mesh screen with tweezers and remove the O-ring and gasket from the bottom.
24) Clean the body with toluene in the fume hood. Wait for the toluene to evaporate then clean the parts under tap water and rinse with DI water. Air dry the parts before re-using.
25) Clean the bottom with tap water then rinse in DI water.
26) Place the mesh screen, O-ring and gasket into a container and add boiling water. Soak the parts then clean with soap and tap water, final rinse with DI water and air dry.
27) Dismantle the second-stage filtration cells after filtration. Dispose of the filter paper into the correct waste disposal. Rinse with tap water, rinse with DI water and air dry before re-assembly.

6.9 Data Analysis and Calculations

All data (pH, EC, ORP alkalinity and ion concentrations) are reported using the CNRL spreadsheet template, and upload to the server for final delivery to the client.

Appendix D Water Quality RDL Tables

Bureau Veritas is accredited to ISO/IEC 17025 for specific parameters on scopes of accreditation. Unless otherwise noted, procedures used by Bureau Veritas are based upon recognized Provincial, Federal or US method compendia such as CCME, MELCC, EPA, and APHA.

All work recorded herein has been done in accordance with procedures and practices ordinarily exercised by professionals in Bureau Veritas' profession using accepted testing methodologies, quality assurance and quality control procedures (except where otherwise agreed by the client and Bureau Veritas in writing). All data is in statistical control and has met quality control and method performance criteria unless otherwise noted. All method blanks are reported; unless indicated otherwise, associated sample data are not blank corrected. Where applicable, unless otherwise noted, measurement uncertainty has not been accounted for when stating conformity to the referenced standard.

Table D-1: Summary of Water Quality Lab Standard Operating Procedures.

Analyses	Laboratory Method	Analytical Method
Alkalinity @25C (pp, total), CO_3,HCO_3,OH	AB SOP-00005	SM 23 2320 B m
Biochemical Oxygen Demand	AB SOP-00017	SM 23 5210B m
BTEX/F1 in Water by HS GC/MS/FID	AB SOP-00039	CCME CWS/EPA 8260d m
F1-BTEX		Auto Calc
Chloride/Sulphate by Auto Colourimetry	AB SOP-00020	SM23-4500-Cl/SO4-E m
Cyanide (total)	CAL SOP-00270	SM 23 4500-CN m
COD by Colorimeter	AB SOP-00016	SM 23 5220D m
Dissolved Hexavalent Chromium	AB SOP-00063	SM 23 3500-Cr B m
Total Hexavalent Chromium	AB SOP-00063	SM 23 3500-Cr B m
Conductivity @25C	AB SOP-00005	SM 23 2510 B m
Fluoride	AB SOP-00005	SM 23 4500-F C m
CCME Hydrocarbons (F2-F4 in water) (2)	AB SOP-00037	CCME PHC-CWS m
Sulphide (as H_2S)		Auto Calc
Hardness Total (calculated as $CaCO_3$) (1, 3)	BBY WI-00033	Auto Calc
Hardness (calculated as $CaCO_3$) (1)	BBY WI-00033	Auto Calc
Ultra Low Mercury - Diss, lab filtered (1)	BBY7SOP-00022	EPA 1631E m
Ultra Low Level Mercury - Total (1)	BBY7SOP-00022	EPA 1631E m
Iodide, Thiosulphate, Thiocyanate	CAL SOP-00057	Dionex #034035 R09 m
Ion Balance		Auto Calc
Methyl Mercury (Total) in Water (1)	BBY7SOP-00028	EPA 1630 m
Na, K, Ca, Mg, S by CRC ICPMS (diss.) (1)	BBY WI-00033	Auto Calc
Elements by ICPMS Low Level (dissolved) (1, 4)	BBY7SOP-00002	EPA 6020b R2 m
Elements by ICPMS Digested LL (total) (1)	BBY7SOP-00003 / BBY7SOP-00002	EPA 6020b R2 m
Na, K, Ca, Mg, S by CRC ICPMS (total) (1)	BBY WI-00033	Auto Calc
Naphthenic Acids by IR (DCM)	AB SOP-00070	Syncrude 1995 m
Ammonia-N (Total)	AB SOP-00007	SM 23 4500 NH3 A G m
Nitrate and Nitrite		Auto Calc
NO_2 (N); NO_2 (N) + NO_3 (N) in Water	AB SOP-00091	SM 23 4500 NO3m

Table D-1: Summary of Water Quality Lab Standard Operating Procedures.

Analyses	Laboratory Method	Analytical Method
Nitrate (as N)		Auto Calc
Target & Alkylated PAH in Water by GC/MS (5)	AB SOP-00037 - CAL SOP-00250	EPA 8270e m
Benzo[a]pyrene Equivalency (6)		Auto Calc
Filter and HNO_3 Preserve for Metals (1)	BBY7 WI-00004	SM 23 3030B m
pH @25°C (7)	AB SOP-00005	SM 23 4500-H+B m
Phenols (4-AAP)	AB SOP-00088	EPA 9066 R0 m
Orthophosphate by Konelab (8)	AB SOP-00025	SM 23 4500-P A,F m
Total Sulphide	AB SOP-00080	SM 23 4500 S2-A D Fm
Sulphite by IC	AB SOP-00026 / CAL SOP-00071	SM 23 4110 B m
Total Dissolved Solids (Calculated)		Auto Calc
Total Trihalomethanes Calculation		Auto Calc
Carbon (Inorganic)	CAL SOP-00076	Modified AE 2411
Total Kjeldahl Nitrogen (Total)	BBY WI-00033	Auto Calc
Nitrogen (Total)	AB SOP-00093	SM 23 4500-N C m
Carbon (Total Organic) (9)	AB SOP-00087	MMCW 119 1996 m
Total Phosphorus	AB SOP-00024	SM 23 4500-P A,B,F m
Total Suspended Solids (NFR)	AB SOP-00061	SM 23 2540 D m
Turbidity	CAL SOP-00081	SM 23 2130 B m
VOCs in Water by HS GC/MS (Std List)	AB SOP-00056	EPA 5021a/8260d m

Reference Method suffix “m” indicates test methods incorporate validated modifications from specific reference methods to improve performance.
** RPDs calculated using raw data. The rounding of final results may result in the apparent difference.*
(1) This test was performed by Bureau Veritas Vancouver, 4606 Canada Way , Burnaby, BC, V5G 1K5
(2) Silica gel clean up employed.
(3) "Total Hardness" was calculated from Total Ca and Mg concentrations and may be biased high (Hardness, or Dissolved Hardness, calculated from Dissolved Ca and Mg, should be used for compliance if available).
(4) Dissolved > Total Imbalance: When applicable, Dissolved and Total results were reviewed and data quality meets acceptable levels unless otherwise noted.
(5) Alkylated PAH results are semi-quantitative
(6) B[a]P TPE is calculated using 1/2 of the RDL for non-detect results as per Alberta Environment instructions. This protocol may not apply in other jurisdictions.
(7) The CCME method requires pH to be analysed within 15 minutes of sampling and therefore field analysis is required for compliance. All Laboratory pH analyses in this report are reported past the CCME holding time. Bureau Veritas endeavours to analyze samples as soon as possible after receipt.
(8) Orthophosphate > Total Phosphorus Imbalance: When applicable, Orthophosphate, Total Phosphorus and dissolved Phosphorus results were reviewed and data quality meets acceptable levels unless otherwise noted.
(9) TOC present in the sample should be considered as non-purgeable TOC.

Table D-2: Plant Operations Measured Substances and Recordable Detection Limit (RDL)

ELEMENTS BY INDUCTIVLEY COUPLED MASS SPECTROMETRY (WATER)

Total Metals	Units	RDL
Total Calcium (Ca)	mg/L	0.3
Total Magnesium (Mg)	mg/L	0.2
Total Potassium (K)	mg/L	0.3
Total Sodium (Na)	mg/L	2.5

RESULTS OF CHEMICAL ANALYSIS OF WATER

Miscellaneous Inorganics	Units	RDL
Conductivity	uS/cm	2.0
pH	pH	n/a
total suspended solids (TSS)	mg/L	1.4
Anions	**Units**	**RDL**
Alkalinity (total as $CaCO_3$)	mg/L	1.0
Bicarbonate (HCO_3)	mg/L	1.0
Chloride (Cl)	mg/L	25
Sulphate (SO_4)	mg/L	5.0
Calculated Parameters	**Units**	**RDL**
total hardness	mg/L	0.50
calculated total dissolved solids (TDS)	mg/L	26

ICPMS means inductively coupled plasma mass spectrometry
RDL means recordable detection limit
mg/L means milligram(s) per liter
TDS means total dissolved solids
n/a means not applicable

Table D-3: NPRI Measured Substances and Recordable Detection Limit (RDL)

REGULATED METALS (CCME/AT1) - DISSOLVED

Element	Units	RDL
Dissolved Cadmium (Cd)	µg/L	0.020
Dissolved Aluminum (Al)	mg/L	0.0030
Dissolved Antimony (Sb)	mg/L	0.00060
Dissolved Arsenic (As)	mg/L	0.00020
Dissolved Barium (Ba)	mg/L	0.010
Dissolved Beryllium (Be)	mg/L	0.0010
Dissolved Boron (B)	mg/L	0.10
Dissolved Calcium (Ca)	mg/L	0.30
Dissolved Chromium (Cr)	mg/L	0.0010
Dissolved Cobalt (Co)	mg/L	0.00030
Dissolved Copper (Cu)	mg/L	0.0010
Dissolved Iron (Fe)	mg/L	0.060
Dissolved Lead (Pb)	mg/L	0.00020
Dissolved Lithium (Li)	mg/L	0.020
Dissolved Magnesium (Mg)	mg/L	0.20
Dissolved Manganese (Mn)	mg/L	0.0040
Dissolved Molybdenum (Mo)	mg/L	0.00020
Dissolved Nickel (Ni)	mg/L	0.00050
Dissolved Phosphorus (P)	mg/L	0.10
Dissolved Potassium (K)	mg/L	0.30
Dissolved Selenium (Se)	mg/L	0.00020
Dissolved Silicon (Si)	mg/L	0.50
Dissolved Silver (Ag)	mg/L	0.00010
Dissolved Sodium (Na)	mg/L	2.5
Dissolved Strontium (Sr)	mg/L	0.020
Dissolved Sulphur (S)	mg/L	0.20
Dissolved Thallium (Tl)	mg/L	0.00020
Dissolved Tin (Sn)	mg/L	0.0010
Dissolved Titanium (Ti)	mg/L	0.0010
Dissolved Uranium (U)	mg/L	0.00010
Dissolved Vanadium (V)	mg/L	0.0010
Dissolved Zinc (Zn)	mg/L	0.0030

REGULATED METALS (CCME/AT1) - TOTAL

Element	Units	RDL
Total Cadmium (Cd)	µg/L	0.020
Total Aluminum (Al)	mg/L	0.0030
Total Antimony (Sb)	mg/L	0.00060
Total Arsenic (As)	mg/L	0.00020
Total Barium (Ba)	mg/L	0.010
Total Beryllium (Be)	mg/L	0.0010
Total Boron (B)	mg/L	0.10
Total Calcium (Ca)	mg/L	0.30
Total Chromium (Cr)	mg/L	0.0010
Total Cobalt (Co)	mg/L	0.00030
Total Copper (Cu)	mg/L	0.0010
Total Iron (Fe)	mg/L	0.060
Total Lead (Pb)	mg/L	0.00020
Total Lithium (Li)	mg/L	0.020
Total Magnesium (Mg)	mg/L	0.20
Total Manganese (Mn)	mg/L	0.0040
Total Molybdenum (Mo)	mg/L	0.00020
Total Nickel (Ni)	mg/L	0.00050
Total Phosphorus (P)	mg/L	0.10
Total Potassium (K)	mg/L	0.30
Total Selenium (Se)	mg/L	0.00020
Total Silicon (Si)	mg/L	0.50
Total Silver (Ag)	mg/L	0.00010
Total Sodium (Na)	mg/L	2.5
Total Strontium (Sr)	mg/L	0.020
Total Sulphur (S)	mg/L	0.20
Total Thallium (Tl)	mg/L	0.00020
Total Tin (Sn)	mg/L	0.0010
Total Titanium (Ti)	mg/L	0.0010
Total Uranium (U)	mg/L	0.00010
Total Vanadium (V)	mg/L	0.0010
Total Zinc (Zn)	mg/L	0.0030

RESULTS OF CHEMICAL ANALYSES OF WATER

Miscellaneous Inorganics	Units	RDL
Strong Acid Dissoc. Cyanide (CN)	mg/L	0.00050
Nutrients	**Units**	**RDL**
Total Ammonia (N)	mg/L	0.075
Miscellaneous Organics	**Units**	**RDL**
Naphthenic Acids	mg/L	1.0
Phenols	mg/L	0.005

MERCURY BY COLD VAPOR (WATER)

Elements	Units	RDL
Total Mercury (Hg)	ug/L	0.00010

VOLATILE ORGANICS BY GC-MS (WATER)

Volatiles	Units	
Benzene	µg/L	0.40
Toluene	µg/L	0.40
Ethylbenzene	µg/L	0.40
m & p-Xylene	µg/L	0.80
o-Xylene	µg/L	0.40
Xylenes (Total)	µg/L	0.89
F1 (C6-C10) - BTEX	µg/L	100
F1 (C6-C10)	µg/L	100

SEMIVOLATILE ORGANICS BY GC-MS (WATER)

Polycyclic Aromatics	Units	RDL
B[a]P TPE Total Potency Equivalents	µg/L	0.010
Acenaphthene	µg/L	0.10
Acenaphthylene	µg/L	0.10
Acridine	µg/L	0.040
Anthracene	µg/L	0.010
Benzo(a)anthracene	µg/L	0.0085
Benzo(b&j)fluoranthene	µg/L	0.0085
Benzo(k)fluoranthene	µg/L	0.0085
Benzo(g,h,i)perylene	µg/L	0.0085
Benzo(c)phenanthrene	µg/L	0.050
Benzo(a)pyrene	µg/L	0.0075
Benzo(e)pyrene	µg/L	0.050
Chrysene	µg/L	0.0085
Dibenz(a,h)anthracene	µg/L	0.0075
Fluoranthene	µg/L	0.010
Fluorene	µg/L	0.050
Indeno(1,2,3-cd)pyrene	µg/L	0.0085
1-Methylnaphthalene	µg/L	0.10
2-Methylnaphthalene	µg/L	0.10
Naphthalene	µg/L	0.10
Phenanthrene	µg/L	0.050
Perylene	µg/L	0.050
Pyrene	µg/L	0.020
Quinoline	µg/L	0.20

Table D-4: AER Requested substances and recordable detection Limit

AT1 BTEX AND F1-F4 IN WATER (WATER)

Ext. Pet. Hydrocarbon	Units	RDL
F2 (C10-C16 Hydrocarbons)	mg/L	0.10
F3 (C16-C34 Hydrocarbons)	mg/L	0.10
F4 (C34-C50 Hydrocarbons)	mg/L	0.20
Volatiles	**Units**	**RDL**
Benzene	ug/L	0.40
Toluene	ug/L	0.40
Ethylbenzene	ug/L	0.40
m & p-Xylene	ug/L	0.80
o-Xylene	ug/L	0.40
Xylenes (Total)	ug/L	0.89
F1 (C6-C10) - BTEX	ug/L	100
F1 (C6-C10)	ug/L	100

RESULTS OF CHEMICAL ANALYSES OF WATER

Calculated Parameters	Units	RDL
Filter and HNO_3 Preservation	n/a	n/a
Dissolved Hardness ($CaCO_3$)	mg/L	0.50
Total Hardness ($CaCO_3$)	mg/L	0.50
Ion Balance (% Difference)	%	n/a
Sulphide (as H_2S)	mg/L	0.0020
Calculated Total Dissolved Solids	mg/L	26
Demand Parameters	**Units**	**RDL**
Biochemical Oxygen Demand	mg/L	2.0
Chemical Oxygen Demand	mg/L	10
Misc. Inorganics	**Units**	**RDL**
Conductivity	uS/cm	2.0
Strong Acid Dissoc. Cyanide (CN)	mg/L	0.00050
pH	pH	n/a
total organic carbon (C)	mg/L	1.0
total suspended solids	mg/L	1.4
Polyacrylamide	mg/L	10
Anions	**Units**	**RDL**
Alkalinity (PP as $CaCO_3$)	mg/L	1.0
Alkalinity (Total as $CaCO_3$)	mg/L	1.0
Bicarbonate (HCO_3)	mg/L	1.0
Carbonate (CO_3)	mg/L	1.0
Dissolved Fluoride (F)	mg/L	0.050
Hydroxide (OH)	mg/L	1.0

SEMIVOLATILE ORGANICS BY GC-MS (WATER)

Polycyclic Aromatics	Units	RDL
B[a]P TPE Total Potency Equivalents	µg/L	0.010
Acenaphthene	µg/L	0.10
Acenaphthylene	µg/L	0.10
Acridine	µg/L	0.040
Anthracene	µg/L	0.010
Benzo(a)anthracene	µg/L	0.0085
Benzo(b&j)fluoranthene	µg/L	0.0085
Benzo(k)fluoranthene	µg/L	0.0085
Benzo(g,h,i)perylene	µg/L	0.0085
Benzo(c)phenanthrene	µg/L	0.050
Benzo(a)pyrene	µg/L	0.0075
Benzo(e)pyrene	µg/L	0.050
Chrysene	ug/L	0.0085
Dibenz(a,h)anthracene	ug/L	0.0075
Fluoranthene	ug/L	0.010
Fluorene	ug/L	0.050
Indeno(1,2,3-cd)pyrene	ug/L	0.0085
Indeno(1,2,3-cd)fluoranthene	ug/L	0.0085
2-Methylnaphthalene	ug/L	0.10
Naphthalene	ug/L	0.10
Phenanthrene	ug/L	0.050
Perylene	ug/L	0.050
Pyrene	ug/L	0.020
Quinoline	ug/L	0.20
Retene	ug/L	0.20
C1-Naphthalene	ug/L	0.10
C3-Naphthalene	ug/L	0.10
C4-Naphthalene	ug/L	0.10
C2-Naphthalene	ug/L	0.10
Biphenyl	ug/L	0.020
C1-biphenyl	ug/L	0.020
C2-biphenyl	ug/L	0.020
C1-fluorene	ug/L	0.050
C2-fluorene	ug/L	0.050
C3-fluorene	ug/L	0.050
Dibenzothiophene	ug/L	0.020
C1-dibenzothiophene	ug/L	0.020
C2-dibenzothiophene	ug/L	0.020

Table D-4: AER Requested substances and recordable detection Limit

Iodide (I)	mg/L	1.0
Total Sulphide	mg/L	0.0018
Dissolved Sulphite (SO_3)	mg/L	20
Thiocyanate	mg/L	0.20
Thiosulphate	mg/L	0.20
Chloride (Cl)	mg/L	25
Sulphate (SO_4)	mg/L	5.0
Metals	**Units**	**RDL**
Dissolved Hex. Chromium (Cr 6+)	mg/L	0.00099
Total Hex. Chromium (Cr 6+)	mg/L	0.00099
Nutrients	**Units**	**RDL**
Total Ammonia (N)	mg/L	0.075
Total Inorganic Carbon (C)	mg/L	4.0
Orthophosphate (P)	mg/L	0.0030
Total Phosphorus (P)	mg/L	0.030
Misc. Organics	**Units**	**RDL**
Naphthenic Acids	mg/L	1.0
Phenols	mg/L	0.0015
Physical Properties	**Units**	**RDL**
Turbidity	NTU	0.1

ELEMENTS BY ICPMS (WATER)

Dissolved Metals by ICPMS	Units	RDL
Dissolved Aluminum (Al)	mg/L	0.0030
Dissolved Antimony (Sb)	mg/L	0.00060
Dissolved Arsenic (As)	mg/L	0.00020
Dissolved Barium (Ba)	mg/L	0.010
Dissolved Beryllium (Be)	mg/L	0.0010
Dissolved Boron (B)	mg/L	0.10
Dissolved Calcium (Ca)	mg/L	0.30
Dissolved Chromium (Cr)	mg/L	0.0010
Dissolved Cobalt (Co)	mg/L	0.00030
Dissolved Copper (Cu)	mg/L	0.0010
Dissolved Iron (Fe)	mg/L	0.060
Dissolved Lead (Pb)	mg/L	0.00020
Dissolved Lithium (Li)	mg/L	0.020
Dissolved Magnesium (Mg)	mg/L	0.20
Dissolved Manganese (Mn)	mg/L	0.0040
Dissolved Molybdenum (Mo)	mg/L	0.00020
Dissolved Nickel (Ni)	mg/L	0.00050

C3-dibenzothiophene	ug/L	0.020
C4-dibenzothiophene	ug/L	0.020
C1 phenanthrene/anthracene	ug/L	0.050
C2 phenanthrene/anthracene	ug/L	0.050
C3 phenanthrene/anthracene	ug/L	0.050
C4 phenanthrene/anthracene	ug/L	0.050
C1 fluoranthene/pyrene	ug/L	0.020
C2 fluoranthene/pyrene	ug/L	0.020
C3 fluoranthene/pyrene	ug/L	0.020
C4 fluoranthene/pyrene	ug/L	0.020
C1 benzo(a)anthracene/chrysene	ug/L	0.0085
C2 benzo(a)anthracene/chrysene	ug/L	0.0085
C3 benzo(a)anthracene/chrysene	ug/L	0.0085
C4 benzo(a)anthracene/chrysene	ug/L	0.0085
C1benzobjkfluoranthene/benzoapyrene	ug/L	0.0075
C2benzobjkfluoranthene/benzoapyrene	ug/L	0.0075
C1-Acenaphthene	ug/L	0.10
1-Methylnaphthalene	ug/L	0.10

VOLATILE ORGANICS BY GC-MS (WATER)

Volatiles	Units	RDL
Total Trihalomethanes	ug/L	1.3
Bromodichloromethane	ug/L	0.50
Bromoform	ug/L	0.50
Bromomethane	ug/L	2.0
Carbon tetrachloride	ug/L	0.50
Chlorobenzene	ug/L	0.50
Dibromochloromethane	ug/L	1.0
Chloroethane	ug/L	1.0
Chloroform	ug/L	0.50
Chloromethane	ug/L	2.0
1,2-dibromoethane	ug/L	0.20
1,2-dichlorobenzene	ug/L	0.50
1,3-dichlorobenzene	ug/L	0.50
1,4-dichlorobenzene	ug/L	0.50
1,1-dichloroethane	ug/L	0.50
1,2-dichloroethane	ug/L	0.50
1,1-dichloroethene	ug/L	0.50
cis-1,2-dichloroethene	ug/L	0.50
trans-1,2-dichloroethene	ug/L	0.50

Table D-4: AER Requested substances and recordable detection Limit

Dissolved Phosphorus (P)	mg/L	0.10
Dissolved Potassium (K)	mg/L	0.30
Dissolved Selenium (Se)	mg/L	0.00020
Dissolved Silicon (Si)	mg/L	0.50
Dissolved Silver (Ag)	mg/L	0.00010
Dissolved Sodium (Na)	mg/L	2.5
Dissolved Strontium (Sr)	mg/L	0.020
Dissolved Sulphur (S)	mg/L	0.20
Dissolved Thallium (Tl)	mg/L	0.00020
Dissolved Tin (Sn)	mg/L	0.0010
Dissolved Titanium (Ti)	mg/L	0.0010
Dissolved Uranium (U)	mg/L	0.00010
Dissolved Vanadium (V)	mg/L	0.0010
Dissolved Zinc (Zn)	mg/L	0.0030
Dissolved Phosphorus (P)	mg/L	0.10
Dissolved Potassium (K)	mg/L	0.30
Dissolved Selenium (Se)	mg/L	0.00020
Dissolved Silicon (Si)	mg/L	0.50
Dissolved Silver (Ag)	mg/L	0.00010
Dissolved Sodium (Na)	mg/L	2.5
Dissolved Strontium (Sr)	mg/L	0.020
Total Metals by ICPMS	**Units**	**RDL**
Total Aluminum (Al)	mg/L	0.0030
Total Antimony (Sb)	mg/L	0.00060
Total Arsenic (As)	mg/L	0.00020
Total Barium (Ba)	mg/L	0.010
Total Beryllium (Be)	mg/L	0.0010
Total Boron (B)	mg/L	0.10
Total Calcium (Ca)	mg/L	0.30
Total Chromium (Cr)	mg/L	0.0010
Total Cobalt (Co)	mg/L	0.00030
Total Copper (Cu)	mg/L	0.0010
Total Iron (Fe)	mg/L	0.060
Total Lead (Pb)	mg/L	0.00020
Total Lithium (Li)	mg/L	0.020
Total Magnesium (Mg)	mg/L	0.20
Total Manganese (Mn)	mg/L	0.0040
Total Molybdenum (Mo)	mg/L	0.00020
Total Nickel (Ni)	mg/L	0.00050
Total Phosphorus (P)	mg/L	0.10

Dichloromethane	ug/L	2.0
1,2-dichloropropane	ug/L	0.50
cis-1,3-dichloropropene	ug/L	0.50
trans-1,3-dichloropropene	ug/L	0.50
Methyl methacrylate	ug/L	0.50
Methyl-tert-butylether (MTBE)	ug/L	0.50
Styrene	ug/L	0.50
1,1,1,2-tetrachloroethane	ug/L	1.0
1,1,2,2-tetrachloroethane	ug/L	2.0
Tetrachloroethene	ug/L	0.50
1,2,3-trichlorobenzene	ug/L	1.0
1,2,4-trichlorobenzene	ug/L	1.0
1,3,5-trichlorobenzene	ug/L	0.50
1,1,1-trichloroethane	ug/L	0.50
1,1,2-trichloroethane	ug/L	0.50
Trichloroethene	ug/L	0.20
Trichlorofluoromethane	ug/L	0.50
1,2,4-trimethylbenzene	ug/L	0.50
1,3,5-trimethylbenzene	ug/L	0.50
Vinyl chloride	ug/L	0.50

MERCURY BY COLD VAPOR (WATER)

Elements	Units	RDL
Total Methyl Mercury	ng/L	0.050
Total Mercury (Hg)	ug/L	0.00010
Lab Filtered Elements	**Units**	**RDL**
Dissolved Mercury (Hg)	ug/L	0.00010

TOTAL KJELDAHL NITROGEN

Calculated Parameters	Units	RDL
Nitrate (N)	mg/L	0.010
Nitrate (NO_3)	mg/L	0.044
Nitrite (NO_2)	mg/L	0.033

Table D-4: AER Requested substances and recordable detection Limit

Total Potassium (K)	mg/L	0.30
Total Selenium (Se)	mg/L	0.00020
Total Silicon (Si)	mg/L	0.50
Total Silver (Ag)	mg/L	0.00010
Total Sodium (Na)	mg/L	2.5
Total Strontium (Sr)	mg/L	0.020
Total Sulphur (S)	mg/L	0.20
Total Thallium (Tl)	mg/L	0.00020
Total Tin (Sn)	mg/L	0.0010
Total Titanium (Ti)	mg/L	0.0010
Total Uranium (U)	mg/L	0.00010
Total Vanadium (V)	mg/L	0.0010
Total Zinc (Zn)	mg/L	0.0030

Total Kjeldahl Nitrogen (Calc)	mg/L	0.40
Nutrients	**Units**	**RDL**
Nitrite (N)	mg/L	0.010
Nitrate plus Nitrite (N)	mg/L	0.010
Total Nitrogen (N)	mg/L	0.40

Table D-5: FT Water Measured substances and recordable detection Limit

REGULATED METALS (CCME/AT1) - DISSOLVED

Elements	Units	RDL
Dissolved Cadmium (Cd)	ug/L	0.020
Dissolved Aluminum (Al)	mg/L	0.0030
Dissolved Antimony (Sb)	mg/L	0.00060
Dissolved Arsenic (As)	mg/L	0.00020
Dissolved Barium (Ba)	mg/L	0.010
Dissolved Beryllium (Be)	mg/L	0.0010
Dissolved Boron (B)	mg/L	0.020
Dissolved Calcium (Ca)	mg/L	0.30
Dissolved Chromium (Cr)	mg/L	0.0010
Dissolved Cobalt (Co)	mg/L	0.00030
Dissolved Copper (Cu)	mg/L	0.0010
Dissolved Iron (Fe)	mg/L	0.060
Dissolved Lead (Pb)	mg/L	0.00020
Dissolved Lithium (Li)	mg/L	0.020
Dissolved Magnesium (Mg)	mg/L	0.20
Dissolved Manganese (Mn)	mg/L	0.0040
Dissolved Molybdenum (Mo)	mg/L	0.00020
Dissolved Nickel (Ni)	mg/L	0.00050
Dissolved Phosphorus (P)	mg/L	0.10
Dissolved Potassium (K)	mg/L	0.30
Dissolved Selenium (Se)	mg/L	0.00020

SEMIVOLATILE ORGANICS BY GC-MS (WATER)

Polycyclic Aromatics	Units	RDL
B[a]P TPE Total Potency Equivalents	ug/L	0.010
Acenaphthene	ug/L	0.10
Acenaphthylene	ug/L	0.10
Acridine	ug/L	0.040
Anthracene	ug/L	0.010
Benzo(a)anthracene	ug/L	0.0085
Benzo(b&j)fluoranthene	ug/L	0.0085
Benzo(k)fluoranthene	ug/L	0.0085
Benzo(g,h,i)perylene	ug/L	0.0085
Benzo(c)phenanthrene	ug/L	0.050
Benzo(a)pyrene	ug/L	0.0075
Benzo(e)pyrene	ug/L	0.050
Chrysene	ug/L	0.0085
Dibenz(a,h)anthracene	ug/L	0.0075
Fluoranthene	ug/L	0.010
Fluorene	ug/L	0.050
Indeno(1,2,3-cd)pyrene	ug/L	0.0085
1-Methylnaphthalene	ug/L	0.10
2-Methylnaphthalene	ug/L	0.10
Naphthalene	ug/L	0.10
Phenanthrene	ug/L	0.050

Table D-5: FT Water Measured substances and recordable detection Limit

Dissolved Silicon (Si)	mg/L	0.50
Dissolved Silver (Ag)	mg/L	0.00010
Dissolved Sodium (Na)	mg/L	2.5
Dissolved Strontium (Sr)	mg/L	0.020
Dissolved Sulphur (S)	mg/L	0.20
Dissolved Thallium (Tl)	mg/L	0.00020
Dissolved Tin (Sn)	mg/L	0.0010
Dissolved Titanium (Ti)	mg/L	0.0010
Dissolved Uranium (U)	mg/L	0.00010
Dissolved Vanadium (V)	mg/L	0.0010
Dissolved Zinc (Zn)	mg/L	0.0030

Perylene	ug/L	0.050
Pyrene	ug/L	0.020
Quinoline	ug/L	0.20

RESULTS OF CHEMICAL ANALYSES OF WATER

Misc. Inorganics	Units	RDL
Strong Acid Dissoc. Cyanide (CN)	mg/L	0.00050
Nutrients	**Units**	**RDL**
Total Ammonia (N)	mg/L	0.075
Misc. Organics	**Units**	**RDL**
Phenols	mg/L	0.0015

VOLATILE ORGANICS BY GC-MS (WATER)

Volatiles	Units	RDL
Benzene	ug/L	0.40
Toluene	ug/L	0.40
Ethylbenzene	ug/L	0.40
m & p-Xylene	ug/L	0.80
o-Xylene	ug/L	0.40
Xylenes (Total)	ug/L	0.89
F1 (C6-C10) - BTEX	ug/L	100
F1 (C6-C10)	ug/L	100

MERCURY BY COLD VAPOR (WATER)

Elements	Units	RDL
Dissolved Mercury (Hg)	ug/L	0.0019

Appendix E Outline of Mikisew-ConeTec Quality Assurance and Control Programs for Annual Tailings Pond Assessments

MIKISEW CONETEC

Mikisew ConeTec Limited Partnership
2820 Ellwood Drive SW, Edmonton, AB, T6X 0A9
+1 780-485-1095 (Office) | +1 780-485-1097 (Fax)
mikisew-conetec@conetec.com | conetec.com/mikisew

Chris Dobek, P.Geo.
Lead, Tailings Planning
Canadian Natural Resources Ltd.
855 2 St SW #2100
Calgary, AB T2P 4J8

December 7, 2022

Re: **Discussion Memo: Outline of ConeTec quality assurance and control programs for annual tailings pond assessments**

Dear Mr. Dobek,

Mikisew-ConeTec Limited Partnership (Mikisew-ConeTec) is a partnership between the Mikisew Group of Companies (Mikisew) and ConeTec Investigations Ltd. (ConeTec). Mikisew-ConeTec is proud to offer site investigation services to the Oil Sands industry, while also providing direct economic benefit to the Mikisew-Cree First Nation (MCFN), and employment opportunities with ConeTec to MCFN members. ConeTec retains ownership of all equipment, intellectual property, and employment relationships while working through Mikisew-ConeTec to execute projects in the region. Mikisew-ConeTec is the contracted entity, ConeTec in its capacity as the Operating Partner maintains responsibility for the execution of all services and provision of Professional Work Products (PWP's) as defined by the Association of Professional Engineers and Geoscientists of Alberta (APEGA).

In response to the Alberta Energy Regulator's (AER) requirement for error quantification in annual Directive 85 reporting, Mikisew-ConeTec has outlined Directive 85 specific and standardized field testing and quality assurance and control processes to meet this objective.

Quality control is defined as a series of procedures put in place to ensure the performed services adheres to a defined set of quality criteria, such as:

- Quality criteria
  - the data must be correct and complete
- Control procedures
  - Ensure equipment is working properly through instrument calibration, field checks (including instrument baseline verification and monitoring, depth verification, data quality checks)
  - Non-conformance tags attached to equipment not functioning properly and sent for assessment and repair
  - Data analysis team performs checks and verification on data collected using specialized software and standardized processes
  - Senior review of data and data reports
  - Post processing checklists for data review process
  - Quality memos generated and communicated to all personnel

Mikisew ConeTec Limited Partnership
2820 Ellwood Drive SW, Edmonton, AB, T6X 0A9
+1 780-485-1095 (Office) | +1 780-485-1097 (Fax)
mikisew-conetec@conetec.com | conetec.com/mikisew

Quality assurance is defined as a process or protocols to maintain a desired level of quality, such as:

- Training conducted with all personnel on procedures and protocols
    - Yearly company training
    - New hire training
    - On the job training
- On site field visits by project managers for verification of field procedures and quality checks
- Manuals and protocol documents generated, maintained and available to all personnel for reference and review

ConeTec is committed to meeting the APEGA standard for Authenticating Professional Work Products. ConeTec is a Permit Holder with APEGA. After comprehensive analysis and review, each report is authenticated by an APEGA registered Professional Engineer or Professional Geoscientist and validated by a Responsible Member. ConeTec has quality assurance documentation, and a Professional Practice Management Plan (PPMP) as required by APEGA.

Contents

MIKISEW CONETEC

Mikisew ConeTec Limited Partnership
2820 Ellwood Drive SW, Edmonton, AB, T6X 0A9
+1 780-485-1095 (Office) | +1 780-485-1097 (Fax)
mikisew-conetec@conetec.com | conetec.com/mikisew

CT09™

Objective of a CT09 survey: Define the bottom bounding surface (termed "hard bottom") for modelling fluid volume. AER Directive 85 specific quality assurance activities that could be used to quantify or minimize measurement errors:

- Provide individual cone penetrometer calibration records used on the project.
    - Provides the appropriate data to show that the penetrometer has been properly calibrated within a timely manner in general accordance with ASTM standard D5778.
- On a per-sounding basis, highlight hard bottom selection criteria, manual or automated, hard bottom achieved or not.
- Conduct multiple CT09s in a cluster to assess repeatability in each pond in multiple areas (shallow, deep, hard refusal areas, frictional refusal areas). Recommended 8 in a cluster (small offsets), multiple clusters in pond centered about a cone penetration test profile, ideally paired with sample data. Use the data to determine the repeatability of CT09 hard bottom measurement versus GCPTu or BGCPTu and sample results. Where this is done, generate a statistical analysis on a per-pond basis that evaluates the accuracy and precision of CT09 measurements in the facility.
- In tailings facilities where hard bottom is not achieved with the CT09 due to a frictional refusal, suggest using GCPTu or BGCPTu as a more representative test.
- When the boat is not fixed (dynamic positioning), suggest collecting high quality coordinates throughout the test sounding. Guidelines for tailings deposit sampling and measuring tools (2015) report to COSIA recommends that horizontal deviation does not exceed 5% of sounding depth. Currently this is not always possible due to weather conditions and the depth to mudline. In ponds where the mudline is deeper than 8m, efficient anchoring is not possible with the current equipment. Suggest measuring and reporting deviations. Opportunities for equipment improvement include:
    - Longer (telescopic) anchoring spuds
    - RTK GNSS system on workboat (centimeter accuracy) for positioning and coordinate measurement pre/post/during sounding

Standardized quality activities

- Cone calibration date is within 1 year of testing date
- When dynamically positioned, collect pre and post sounding coordinates, report horizontal deviation, it should never exceed 5% of sounding depth.
- Up/down difference does not exceed 0.4m for soundings where depth is greater than 10 meters.
- Up/down difference does not exceed 0.2m for soundings where depth is less than 10 meters.
- Cone penetrometer cleaned at the end of each day
- Cone penetrometer saturated prior to each sounding

Mikisew ConeTec Limited Partnership
2820 Ellwood Drive SW, Edmonton, AB, T6X 0A9
+1 780-485-1095 (Office) | +1 780-485-1097 (Fax)
mikisew-conetec@conetec.com | conetec.com/mikisew

GCPTu

Objective of Gamma Cone Penetration Test with Pore Pressure Measurement (GCPTu): Provide detailed stratigraphic log of tailings deposit with direct measurements of tip resistance, sleeve friction, pore pressure and passive gamma. Use measured data to calculate geotechnical parameters such as shear strength and tailings constituents using a Tailings Behaviour Type (TBT) model. AER Directive 85 specific quality assurance activities that could be used to quantify or minimize measurement errors:

- Provide individual cone penetrometer calibration records used on the project.
    - Provides the appropriate data to show that the penetrometer has been properly calibrated within a timely manner in general accordance with ASTM standard D5778
- Provide dimension verifications for CPTu wear parts. This procedure is common in natural soils and compacted soils but will provide limited value in fluid tailings besides operational transparency.
- Provide zero load readings for each sounding.
    - Zero load readings between soundings should be similar for the same cone
    - Provide the cone calibration check record for instruments that have undergone a shift in zero load readings.
- Provide a table summarizing the point reading resolution for each capacity of penetrometer used on the project.
- Assess the variance between paired adjacent GCPTu soundings in beach and fluid tailings to assess the repeatability and implicit spatial variability of the deposit in the measurements.
- TBT interpretations to be compared with sample results collected adjacent to the sounding. A statistical analysis of TBT variance from lab data will be presented with each report.
- Recommend twinning a minimum of one sounding or approximately 1/10 of GCPTu holes with electric downhole vane shear testing to confirm assumptions in undrained shear strength interpretations in each tailings facility. Provided basis for Nkt factor used in calculating the data.
- Report on methodology of unit weight assumptions and method of determination. Unit weights are determined from either from PPD tests (in fluid slurries) and SBT zones (in materials generating effective stress), or from the lab data with the following assumptions; SG_{fines}=2.62, SG_{san}d=2.57, SG_{oil}/water=1 and unit UW_{water}=9.81kN/m^3 or TBT.
    - $G_{S\,total\,sample} = \left[\dfrac{\frac{Total\ Sample\ Percent}{100\%}}{\left(\frac{(sand\ wt\%)}{G_{S\,sand}\ x\ 100\%}+\frac{(fines\ wt\%)}{G_{S\,fines}\ x\ 100\%}+\frac{(Oil\ wt\%+\ water\ wt\%)}{G_{S\,oil+water}\ x\ 100\%}\right)}\right]$
    - $\gamma_{material} = \gamma_{water}\ x\ G_{S\,total\,sample}$

Standardized quality activities:

- Testing procedures generally meet or exceeds ASTM D5778
- Cone calibration date is within 1 year of testing date
- Each filter is saturated in silicone oil under vacuum pressure prior to use
- Recorded cone penetrometer zero load measurements are checked with an independent multi-meter (applicable to analog systems only)
- Baseline readings are compared to previous readings

Mikisew ConeTec Limited Partnership
2820 Ellwood Drive SW, Edmonton, AB, T6X 0A9
+1 780-485-1095 (Office) | +1 780-485-1097 (Fax)
mikisew-conetec@conetec.com | conetec.com/mikisew

- Soundings are terminated at the client's target depth or at a depth where an obstruction is encountered, excessive rod flex occurs, excessive inclination occurs, equipment damage is likely to take place, or a dangerous working environment arises
- Differences between initial and final zero load measurements are calculated to ensure zero load offsets have not occurred and to ensure compliance with ASTM standards
- Cone penetrometer is cleaned between soundings
- Before and after each sounding, gamma modules are verified against reference values from materials having consistent output. These values are recorded for inspection during data processing. Data scaling may be conducted using pre and post calibration values.
- There are certain geotechnical properties or physical laws that cannot be violated and as such are used for detailed quality control checks. The review procedure identifies any such violations and recommends small adjustments to the data or a re-collection of field data.
    - $f_s >= 0$, $q_t >= 0$
        - Sleeve friction cannot be negative (because of the design, a ConeTec cone sleeve load cell cannot go into tension) nor should the tip resistance.
    - $q_t >= u_d$
        - Because the tip is a total stress sensing device the tip resistance (q_t) cannot be less than the total overburden stress. In typical geotechnical testing the unit weight of the material must be estimated to determine the total overburden stress, however, in fluid tailings the total stress is a result of the fluid pressure which is directly measured by the dynamic pore pressure (u_d) channel.
    - $\sigma_v' >= 0.0$
        - Effective vertical stress must not be negative. ConeTec software independently calculates the total stress and the fluid pressure, slightly negative effective stresses may be computed.

BGCPTu

Objective of Ball Gamma Cone Penetration Test with Pore Pressure Measurement (BGCPTu): Assess the undrained shear strength (Su) of tailings that flow around the penetrometer. BGCPTu testing collects direct measurements of ball tip resistance, pore pressure and passive gamma. The calculated undrained shear strength and passive gamma data is used to provide tailings constituents (TBT). AER Directive 85 specific quality assurance activities that could be used to quantify or minimize measurement errors:

- Provide individual cone penetrometer calibration records used on the project.
    - Provides the appropriate data to show that the penetrometer has been properly calibrated within a timely manner in general accordance with ASTM standard D5778
- Provide dimension verifications for BGCPTu wear parts. This procedure is common in natural soils and compacted soils but will provide limited value in fluid tailings besides operational transparency.
- Provide zero load readings for each sounding.
    - Zero load readings between soundings should be similar for the same instrument

MIKISEW CONETEC

Mikisew ConeTec Limited Partnership
2820 Ellwood Drive SW, Edmonton, AB, T6X 0A9
+1 780-485-1095 (Office) | +1 780-485-1097 (Fax)
mikisew-conetec@conetec.com | conetec.com/mikisew

   - Provide the cone calibration check record for cones that have undergone a shift in zero load measurements.
- Provide a table summarizing the point reading resolution for each capacity of penetrometer used on the project.
- Assess the variance between paired adjacent BGCPTu soundings in fluid tailings to assess the repeatability and implicit spatial variability of the deposit in the measurements.
- TBT interpretations to be compared with sample results collected adjacent to the sounding. A statistical analysis of TBT variance from lab data will be presented with each report.
- Recommend twinning a minimum of one sounding or approximately 1/10 of BGCPTu holes with electric downhole vane shear testing to confirm assumptions in undrained shear strength interpretations in each tailings facility. Provided basis for N_{ball} factor used in calculating undrained shear strength.

Standardized quality activities:

- Cone calibration date is within 1 year of testing date
- Testing procedures generally meet or exceeds ASTM D5778
- Each filter is saturated in silicone oil under vacuum pressure prior to use
- Recorded cone penetrometer baselines are checked with an independent multi-meter (applicable to analog systems only)
- Zero load readings are compared to previous readings
- Soundings are terminated at the client's target depth or at a depth where an obstruction is encountered, excessive rod flex occurs, excessive inclination occurs, equipment damage is likely to take place, or a dangerous working environment arises
- Differences between initial and final baselines are calculated to ensure zero load offsets have not occurred and to ensure compliance with ASTM standards
- Cone penetrometer is cleaned between soundings
- Before and after each sounding, gamma modules are verified against reference values from materials having consistent output. These values are recorded for inspection during data processing. Data scaling may be conducted using pre and post calibration values.

Mikisew ConeTec Limited Partnership
2820 Ellwood Drive SW, Edmonton, AB, T6X 0A9
+1 780-485-1095 (Office) | +1 780-485-1097 (Fax)
mikisew-conetec@conetec.com | conetec.com/mikisew

Sampling

Objective of tailings sampling: Collect profiles of physical samples for analysis, providing solids content, fines content, bitumen content, and Methylene Blue Index (MBI) testing by lab or HyperScan.

Sample Collection & Laboratory Analysis

AER Directive 85 specific quality assurance activities that could be used to quantify or minimize measurement errors:

- Collect one duplicate sample per fifty. Analyze duplicate pairs for repeatability and provide summary statistics per deposit. Duplicate sampling density may need to be increased in smaller tailings facilities to get a statistically meaningful dataset for each deposit. This error analysis will contain components of field collection error, spatial variability error and laboratory analysis error.
    - Lab services provider to select certain samples to duplicate testing for their own QA/QC
    - Utilize blind splits to assess lab measurement error
    - ConeTec can include lab duplicate testing with our duplicate samples for statistical analysis
    - Industry could commission a study to determine the repeatability and reproducibility of lab reported tailings constituents
- Assess the variance between paired adjacent fluid, Fixed Interval Sampler (FIS) and sonic soundings in fluid and/or beach tailings to assess the repeatability and implicit spatial variability of the deposit in the measurements.
- Instruct the lab to split occasional samples and report the laboratory split data. Analyze laboratory duplicate pairs for repeatability and provide summary statistics per deposit. Duplicate lab sampling density will need to provide a statistically meaningful set of data pairs. The error analysis will contain components of sub-sampling error and laboratory process error.
- Compare laboratory splits to field duplicates to approximate field error versus laboratory error.

Standardized quality activities:

- Record gas pressure during deployment of gas actuated piston samplers (verify that gas pressure exceeds deposit pressure)
- Collect photographs of all samples
- Mudline from sonar reading is within 10cm of the mudline from FIS samples
- Locations with paired sampling/GCPT/CT09:
    - Mudlines should be within 10cm
    - Fluid sampler refusal is within 1m of CT09 refusal

HyperScan (Hyperspectral Sensing Technology for Oil Sands Tailings Constituent Analysis)

Proposed AER Directive 85 specific quality assurance activities that could be used to quantify or minimize measurement errors:

- Utilize HyperScan and Tailings Behaviour Type results to identify potential poor quality laboratory results for retesting.

Mikisew ConeTec Limited Partnership
2820 Ellwood Drive SW, Edmonton, AB, T6X 0A9
+1 780-485-1095 (Office) | +1 780-485-1097 (Fax)
mikisew-conetec@conetec.com | conetec.com/mikisew

- Report the sum of total mass percent bitumen, total mass percent solids, and total mass percent water predictions produced by HyperScan models.
- Report the homogenization methodology, such as no homogenization (point scans on core), mechanically mixed, manual, or sand suspending polymer utilized.
- Report a tabular summary of samples that required polymer amendments to homogenize the sample for HyperScan testing, including the mass used and name of product.
- Report the confidence interval of model predictions
- Conduct a third-party validation using data collected during the 2023 tailings assessment

Standardized quality activities:

- Perform confirmatory laboratory testing on a subset of HyperScan tested samples
- Conduct baseline scans on the Spectralon white reference discs every 15 minutes
- Conduct daily reference tests on a mylar card for wavelength verification of the instrument
- Conduct weekly inspection of fiber optic cables
- Conduct daily tests on control samples to verify model performance is within control limits

Vane Shear Testing

Objective of vane shear testing (VST): Provide a direct measurement of undrained shear strength in-situ. Proposed Oil Sands Directive 85 specific quality assurance activities that could be used to quantify or minimize measurement errors:

- Provide calibration records for each vane load cell used on project. Calibrations comply with ASTM D2573/D2573M.
- Provide zero load readings for each sounding (baseline counts)
- Provide a table of point reading resolution for each capacity of downhole load cell used on the project.
- Provide proof or record of elapsed time from insertion to rotation. From remolding to remold testing.
- In sand/fine mixtures (CT, high SFR MFT) evaluate drained versus undrained behaviour to assure VST is representative of an undrained shear strength. This is achieved by performing an adjacent CPT pore pressure dissipation test to obtain the coefficient of consolidation (c_{vh}). A non-dimensional vane test time factor is then calculated based on the time elapsed between vane insertion and failure (t_f) and the vane diameter (D) such that $T = c_{vh}*t_f/D^2$. If T is less than 1.3 we can assume undrained conditions. A recent paper by Reid (2016) evaluated T from VST in silty Australian mine tailings and showed the need to perform faster VST to avoid partially drained vane strength measurements.

Standardized quality activities:

- Torque is measured downhole, negating the need for rod string friction measurements. In the case of uphole torque measurement, rod friction must be recorded for each test.
- Testing procedures generally meet or exceeds ASTM D2573. Variances from standard:
    - Extra-large vane for profiling fluid tailings (150x300mm)

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Mikisew ConeTec Limited Partnership
2820 Ellwood Drive SW, Edmonton, AB, T6X 0A9
+1 780-485-1095 (Office) | +1 780-485-1097 (Fax)
mikisew-conetec@conetec.com | conetec.com/mikisew

    - Depths referenced to the middle of the vane blade, not to the vane tip
    - Rate of remolding is not recorded
    - We do not plot torque versus rotation we plot shear stress versus rotation
- Appropriate vane selected for testing based on adjacent GCPTu or BGCPTu calculated undrained shear strength assuming an N_{kt} factor of 15 or N_{ball} factor of 11.
- Vane load cell calibration date is within 1 year of testing date
- Zero load readings between soundings are similar (within 1% of the measured Su value)
- Peak test starts within 5 minutes of reaching the required test depth
- Remold test starts within 1 minute after remolding process
- Vane is inspected for damage before use. Vane blade thickness and stem diameter are measured and recorded.

Acoustic Mudline Measurements

Objective of testing: Delineate the upper boundary surface (mudline) for fluid tailings volume and constituent modelling.

Single Beam Sonar

Proposed Oil Sands Directive 85 specific quality assurance activities that could be used to quantify or minimize measurement errors:

- Provide measurement uncertainty value for each reported elevation
- Provide a table in the report that outlines equipment precision, equipment uncertainty and offset measurements

Standardized quality activities:

- Measure and document the transducer depth below water and verify keel offset settings in software
- Verify sonar depth measurement versus an area with physically verified depth each day to verify setup
- Sonar transducer mounted to an outrigger barge for dynamic surveying, verifies that transducer elevation does not change as boat pitch and draft change due to travel velocity and turning
- Static sonar readings at sampling locations should agree within 10cm of collected FIS mudline

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Swath Bathymetry (3DSS)

Proposed Oil Sands Directive 85 specific quality assurance activities that could be used to quantify or minimize measurement errors:

- Provide measurement uncertainty value for each reported elevation
- Provide a table in the report that outlines equipment precision, GNSS uncertainty and equipment offset measurements (transducer depth, offset from GNSS antenna)
- Provide any equipment calibration reports (Sound Velocity Probe)

Standardized quality activities:

- Compare sonar mudline measurements with Fixed Interval Sampler mudline measurements to ensure they agree within the measurement uncertainties
- Perform 'Patch Test' calibration for 3DSS equipment each time the equipment is deployed on a vessel.
- Ensure 3DSS Sound Velocity Probe is calibrated yearly
- Sound velocity profiles are used to transform time series data to distance
- Data is compensated for pitch, roll, and vector of the survey vessel

GNSS Survey

Objective of testing: Define a pond surface datum to reference tests against.

Standardized quality activities:

- Fixed versus float solutions
- Provide detailed error report
- Verification of rod length used (staff length + deck to ground from CPT)
- Verify against independently surveyed elevations or monuments

Planned and Proposed Deliverables

1. Field Data Report (within 2 weeks of completing each field project)
    - Factual report of field data
    - Authenticated by a Professional Engineer or Geoscientist
2. Field Data Error Analysis (within 2 weeks of receipt of lab data)
    - Statistical summary of repeatability and variance observed
    - Reported for each tailings deposit
3. Pond Assessment Quality Report (Q1 of the following year, after receiving all laboratory data)
    - Comprehensive report outlining the QA processes used

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Contributors

Alexis Maddaloni, Training and QA/QC Manager, ConeTec Investigations Ltd.
Chris Hermiston, Geophysics Project Manager, ConeTec Investigations Ltd.
David Parkinson, P.Eng., Project Manager, ConeTec Investigations Ltd.
Iman Entezari, PhD, Research Engineer, ConeTec Investigations Ltd.
Mary Nguyen, Data Analyst, ConeTec Investigations Ltd.

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Closing

Mikisew-ConeTec has robust quality assurance and control processes involving all aspects of data collection, analysis, release, and archiving – the data must be right! The summarized additional reporting will quantify the degree of accuracy, representativeness, bias, and precision of the collected field data. This information will enable Canadian Natural Resources Ltd. to determine the accuracy of inputs to modelling and regulatory reports.

This memo is provided for discussion and is intended to give an overview of options available to improve statistical analysis of accuracy, reliability, representativeness and precision of testing tools and methods used to characterize Canadian Natural's tailings facilities. This additional data will help modelling experts in quantifying error in their reports.

If you have any questions, please contact the undersigned.

Sincerely,

Dallas McGowan, P.Eng.
Vice President, Mikisew-ConeTec Limited Partnership
Vice President - Oil Sands, ConeTec Investigations Ltd.
(780)-381-9753
dmcgowan@conetec.com