Long Term In-Situ Behaviour of Oil Sands Fine Tailings in Suncor's Pond 1A

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Abstract

Suncor Energy Inc's oil sands operation north of Fort McMurray, Alberta, has been in production since 1966. Pond 1A, a fluid fine tailings (FFT) storage and flow-through recycle water pond, began infilling in the 1970's. The first sampling programme of the FFT was conducted in 1977, with periodic follow-up programmes through to 2010. This pond has been used to store volumes of FFT in the form of Mature Fine Tailings (MFT) at significant depths in relatively undisturbed conditions for over 25 years. This site, unique in the industry, is important to understanding the long-term behaviour of fluid fine tailings in the oil sands landscapes. The observed behaviour provides insights into potential storage and material strength gain projections. Several decades worth of sample profiles are provided, along with general observations on the potential implications to the industry.

Pond History

Pond Construction

Suncor's oil sands site, situated in north-eastern Alberta near the city of Fort McMurray, began operations in the mid 1960's. Immediately west of Pond 1, the first tailings pond in the oil sands now known as Wapisiw Lookout, was one of the first open pit mining areas on the site. Once mining was completed the pit was converted to a fluid storage pond in 1976, with transfers of Mature Fine Tailings (MFT) and water from Pond 1. The pond bottom remains primarily in-situ ground with what is assumed to be very low permeabilities. The pond was filled to capacity over the following three years, with dyke construction consisting of hydraulically placed tailings sand in areas to the south and east of the pond.

Pond Operations

Once filled with MFT and process water, Pond 1A became a flow-through water storage pond. Up to 2.5m^3/s of recycle water passes through the pond, supplied from an upstream settling pond known as Pond 2/3 shown in Figure 1. This same volume is transferred through a decant system directly to extraction processing plants, maintaining the overall pond at a static elevation around 1055ft (as measured in Suncor's historical Imperial-based grid system). This high flow rate, together with the low solids content of the input stream, mean that very little additional solids are added to Pond 1A and as such there have been no transfers of MFT out of the pond in over 20 years. Initial small volumes of MFT were pumped out in the late 1970's and early 1980's during the MFT transfer operations from Pond 1, but this was done only to maintain a viable watercap and an acceptable pond elevation. In addition, any withdrawals from the pond were conducted at shallow depths and were not likely to affect any material below approximately 12m in depth. The MFT below the watercap has remained untouched for up to 35 years, and this condition provides an exceptional opportunity to obtain long-term behaviour data for these fluid fine tailings.

Pond Statistics

Pond 1A has remained relatively static, with very little input or release of material other than process water. As such, its total storage volume and surface areas have also remained the same. It has a total wet surface area of 51.7ha, and a total storage volume of 12,942km^3 (1000's of cubic metres). Of this, 10,346 km^3 is fluid fine tailings in the form of MFT, and 2,596 km^3 is recycle water.

The deepest area of the pond is at 870ft elevation, with the top of the fluid material around 1055ft, giving a total maximum depth of the pond of approximately 185ft or 56.4m.

Sample profiles in the pond have been taken periodically as part of Suncor's annual pond assessment programme. The location of these sites is provided in Table 1, quoted in the original Imperial Suncor grid system.

Table 1 - Sample Profile Site Locations (Suncor Grid)

Hole ID	**Easting (ft)** ***Suncor Grid***	**Northing (ft)** ***Suncor Grid***	**Top Elevation (ft)** ***Suncor Grid***
01P1AS1	52,998	50,999	1055.5
06P1AS1	52,987	51,018	1055.4
77P1AS11	53,000	51,000	1034.0
82P1AS1	52,907	50,867	1056.0
90P1AS1	52,965	50,920	1055.0
10P1AS1	52,475	50,568	1055.8

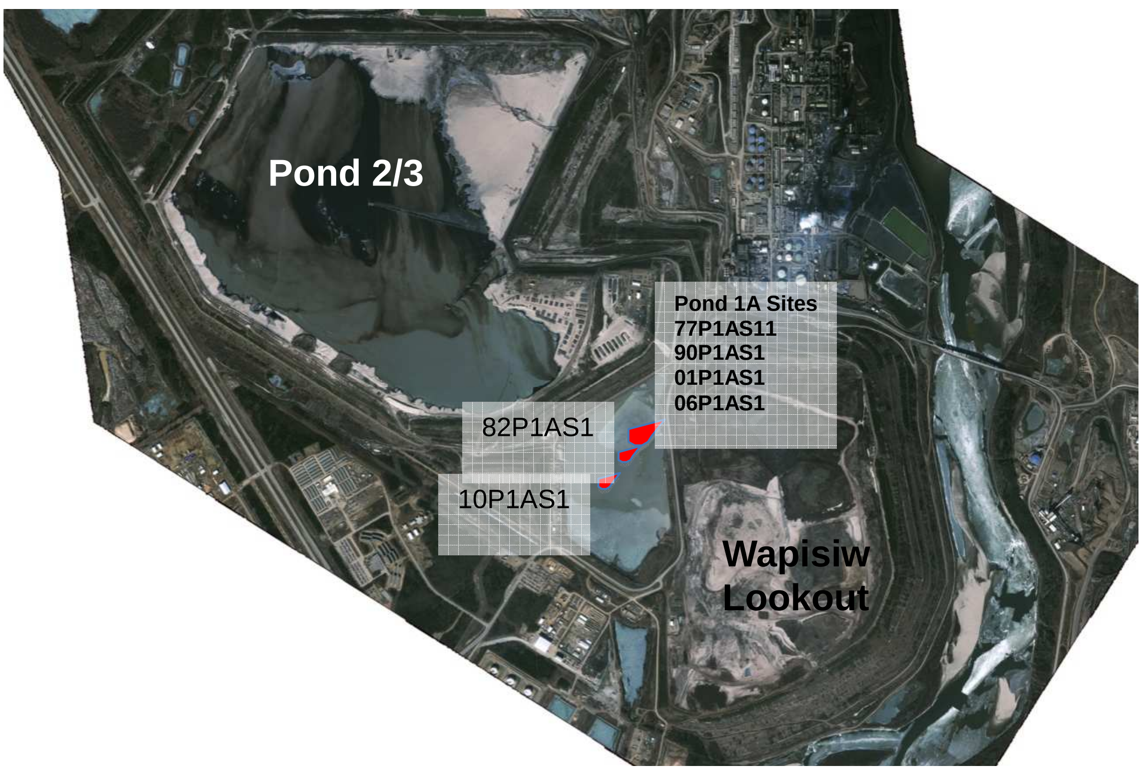

Figure 1 - Pond 1A Site Locations

Solids Content

Figure 2 shows the evolution of solids contents over time. Site 1 has been selected for comparison purposes, although it does not represent the deepest area of the pond. It should be noted that the traditional method of reporting density on site has been as a percent solids by weight. Oil sands tailings have utilised technologies that have resulted in stored materials remaining at full saturation. As such, this method of measurement is sufficiently consistent to indicate dewatering processes as long as full saturation is maintained and the fines contents remain known.

Table 2 provides a reference between percent solids by weight (%sbw) and void ratio (e), with an assumption of a solids density of 2.6t/m3 and 100% saturation.

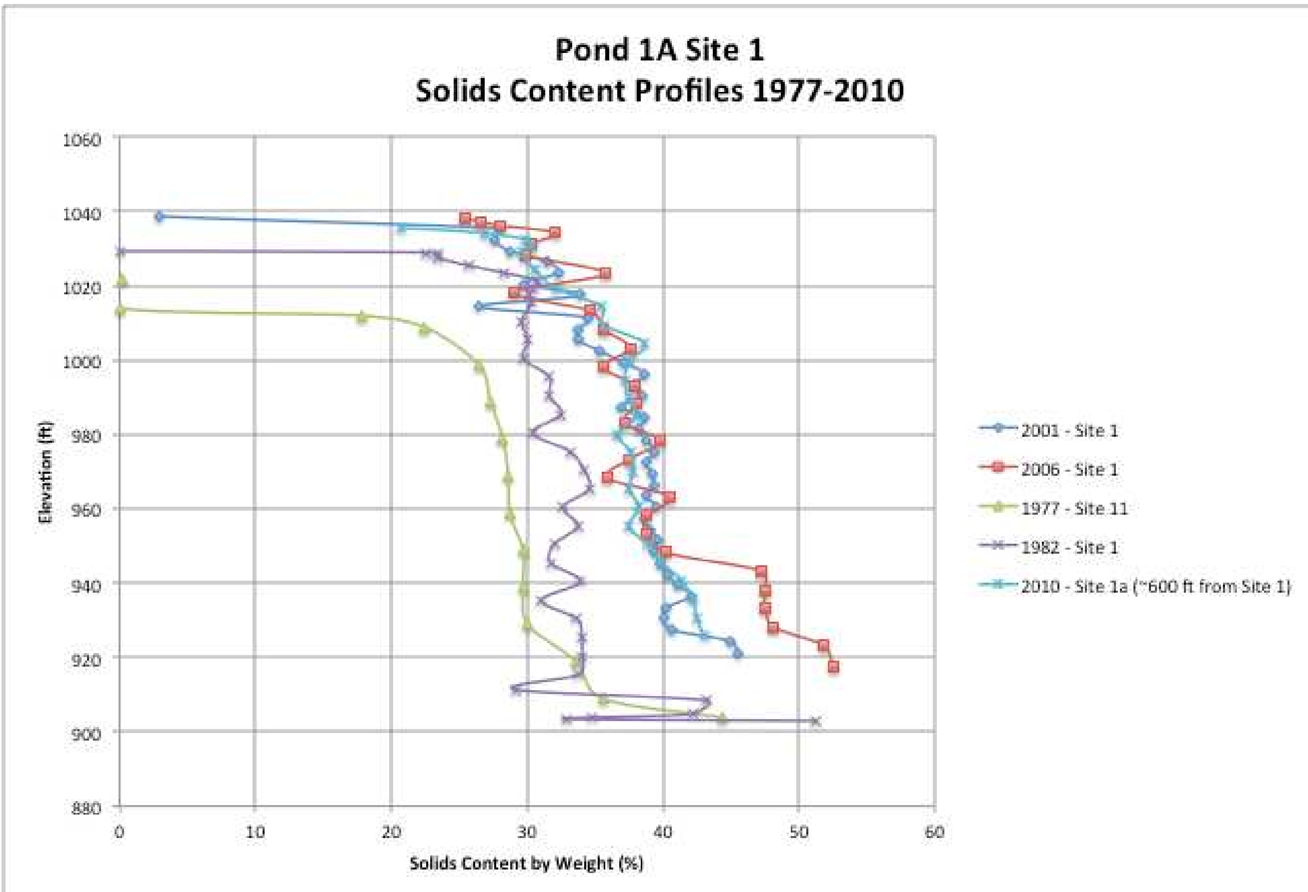

Figure 2 - Pond 1A Site 1 Solids Content Profiles 1977-2010

Table 2 - %Solids by Weight to Void Ratio (2.6t/m3 solids density)

Solids by Weight (%)	Void Ratio (e)
10%	23.4
20%	10.4
30%	6.1
40%	3.9
50%	2.6
60%	1.7
70%	1.1
80%	0.7
90%	0.3
100%	0.0

Starting from an initial solids content range of between 18-30%sbw in 1977, the column increased to a range of 22-34.5%sbw by 1982 in areas above 903ft elevation. Increases in solids content below this depth are likely to be the result of intermixing with the underlying in-situ ground, although some amount of dewatering from underdrainage effects cannot be ruled out. Since 1982, samples have not been taken below the 917ft elevation.

By 2001, the column had reached a relatively static state. Percent solids did not noticeably increase from 2001-2010, with the one notable exception found near the bottom of the column in 2006 and discussed below. In order to differentiate increases in solids content due to dewatering from increases due to other conditions, an additional measure is required. One common dewatering measure is shown in Figure 3.

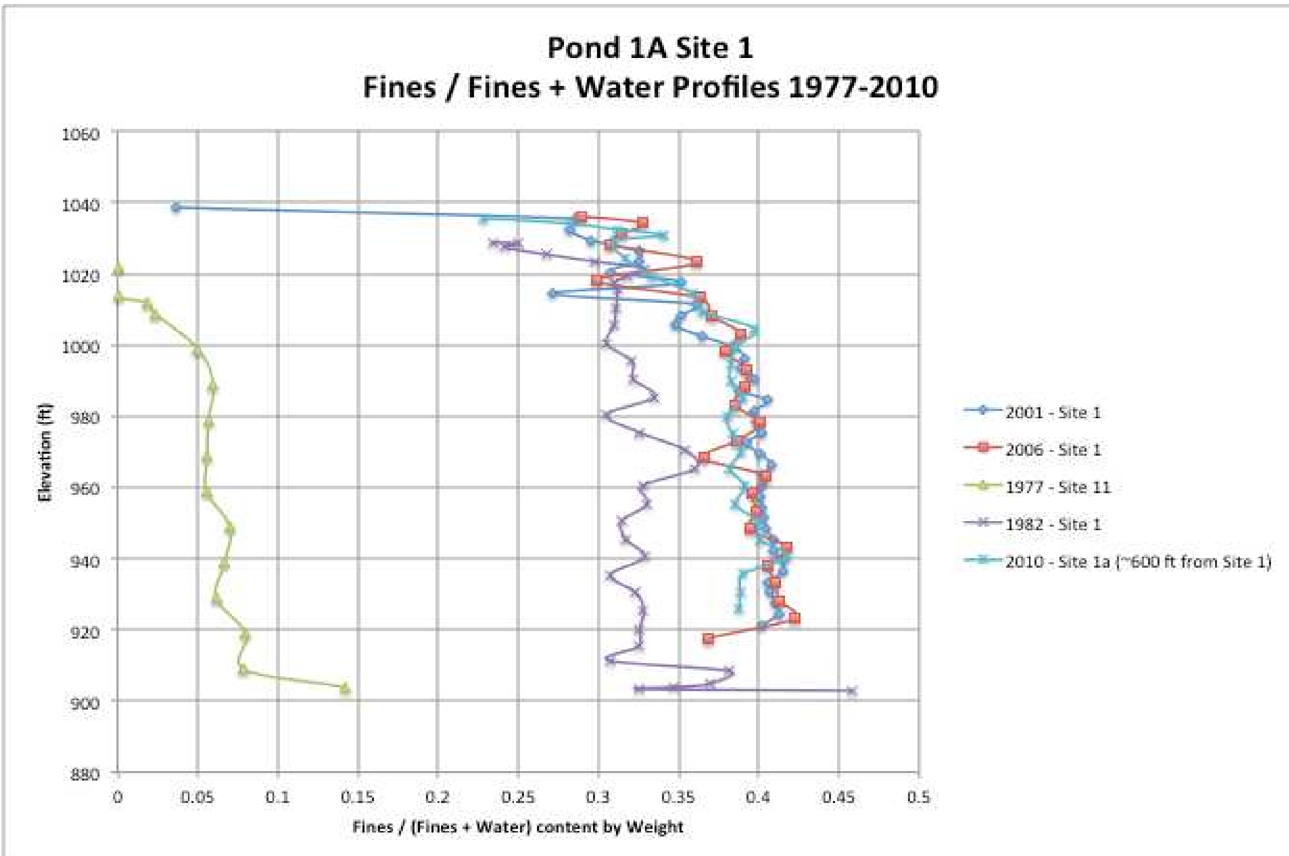

Figure 3 - Pond 1A Site 1 f/(f+w) Profiles 1977-2010

This chart shows a ratio known as "fines over fines plus water" or f/(f+w). This is defined as the ratio of the weight of fines in a sample divided by the weight of fines plus water. It is a better measure of dewatering when compared to %sbw, as certain conditions such as the addition of sand to a column of MFT can increase the measured solids content without any actual additional dewatering.

After the initial rapid densification from 1977-1982, the MFT has appeared to reach effective plateaus for densities, at least in the areas with low sand contents (defined here as having > 90% of the solids passing 325 mesh wet sieve or <44 micron size fraction). Reviewing the fines content provided in Figure 4, this plateau for the low sand content MFT appears to be around 40-42%sbw, or void ratios (e) of 3.6-3.9. Even so, these higher values still appear to be somewhat dependent on elevated sand contents and may be slightly high. These densities have f/(f+w) levels of 0.39-0.41, and were first measured in 2001. Allowing for some sample specific variations, these maximums do not appear to have increased significantly since. In short, it appears that the column of MFT in Pond 1A rapidly settled to an apparent dewatering limit after a maximum of 25 years in place, with little to no change final the last 10 years.

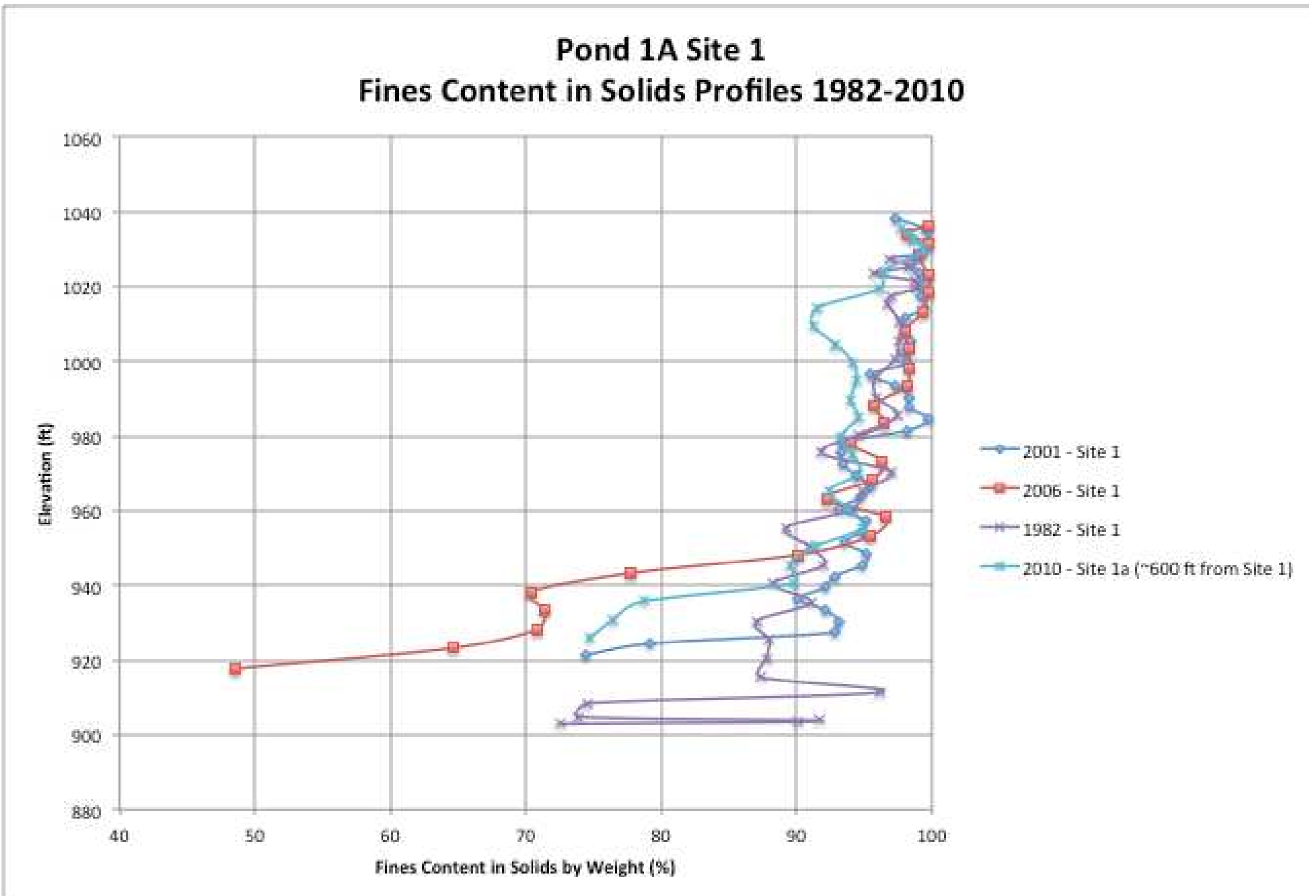

Figure 4 - Pond 1A Site 1 Fines Content Profiles 1982-2010

One exception to this plateau effect appears in the 2006 profile below the 945ft elevation. In this region the solids content increased 7-10% in 5 years. However this increase can be attributed to increases in sand content at that depth, as the f/(f+w) values do not change. It is likely that sand was introduced to the column sometime between 2001 and 2006 and was in the process of settling through the MFT. While the 2010 profile does not show this density and sand content increase, the 2010 site is some 600ft away and may have not been impacted by the settling sand. Alternately the sand may have settled through the tested column and now form part of the pond bottom.

Additional details on the 2010 Profile are provided in Table 3, and include details on the methylene blue results. These values are used to estimate the clay contents in oil sands tailings, and can be a better measure of dewatering than either %sbw or f/(f+w). However, these values were not available for 1977 and 1982, and as such were not used here.

Table 3 - 2010 Site 1 Profile Details

Elevation	Redox (Oxidation-reduction - ORP)	Cond.	In-Situ Temp. (°C)	Comments	Solids Properties					
					Bitumen	Solids	Water	Methylene Blue 0.006 N Measured	<45 micron	Total Dissolved Solids (Measured)
(ft)	mV	µS	°C		(wt%)	Solids (wt%)	(wt%)	(meq/100 grams)	(wt%)	mg/L
1039.3	-121.6	2684.0	24.6	Water	0.08	<0.01	99.87	Insufficient Sample	Insufficient Sample	900
1029.5	-102.9	1597.0	14.5	MFT	4.51	29.66	65.76	11	97.7	760
1019.7	-115.1	806.0	13.1	MFT	5.49	32.13	61.83	9.1	94.4	600
1009.8	-121.3	1558.0	15.7	MFT	5.99	35.59	56.43	9.3	90.0	610
990.1	-149.5	816.0	16.4	MFT	5.46	37.47	56.91	9.6	92.6	600
970.4	-153.6	1124.0	15.7	MFT	5.22	37.78	56.14	10	93.1	640
950.8	-153.5	726.0	15.8	MFT	6.18	38.89	53.55	9.5	90.3	640
931.1	-152.7	952.0	17.0	MFT	5.63	42.45	51.09	8.2	75.2	560

Pore Water Chemistry

In 2010, analysis of the pore water chemistry in the MFT was conducted. Some of the results are provided in Table 4.

Examining the data, some general observations can be made:

- Chloride levels are significantly lower in the MFT pore water compared with those found in the overlying recycle water
- pH remains relatively consistent with depth, ranging between 8.0-8.5, and having little to no depth dependence
- Conductivity of the pore water is around 1600uS/cm in the recycle watercap, reducing to a consistent 1100uS/cm below 1020ft elevation
- Total Dissolved Solids (TDS) is also reduced from that in the watercap at 900mg/L, to below 700mg/L in the MFT

Table 4 - 2010 Site 1 Pore Water Chemistry

Elevation	Comments	PORE WATER ANALYSIS										
		Alkalinity (Total as CaCO3)	Alkalinity (PP as CaCO3)	Bicarbonate (HCO3)	Carbonate (CO3)	Dissolved Chloride (Cl)	Conductivity	pH	Dissolved Sulphate (SO4)	Dissolved Potassium (K)	Dissolved Sodium (Na)	Dissolved Calcium (Ca)
(ft)		mg/L	mg/L	mg/L	mg/L	mg/L	uS/cm	N/A	mg/L	mg/L	mg/L	mg/L
1039.3	Water	370	0	460	0	180	1600	8.03	120	6	290	9.7
1029.5	MFT	640	2.8	770	3.3	16	1300	8.33	11	15	240	11
1019.7	MFT	530	11	620	14	10	1100	8.48	8	11	190	8.4
1009.8	MFT	520	0	640	0	8	1000	8.3	7	12	190	8.2
990.1	MFT	540	9.7	630	12	8	1100	8.45	6	11	190	9.5
970.4	MFT	550	2.6	660	3.1	8	1100	8.34	8	11	190	9.5
950.8	MFT	520	6	620	7.1	9	1100	8.4	9	11	180	8.5
931.1	MFT	520	5.1	630	6.1	9	1100	8.38	6	11	190	9.6

Conclusions

Long-term storage of oil sands MFT is a central component of many operation's tailings plans in the region. Understanding how this material behaves, both physically and chemically, is key to ensuring these plans are based on well-understood parameters. Material properties of stored MFT can be impacted by on-going tailings operations, through mixing with underlying ground or with newly introduced materials such as sand. Many models require a detailed understanding of the consolidation behaviour of MFT, but this can be difficult if the monitored behaviour includes impacts from external tailings operations. It is only with a long term, relatively undisturbed site that the actual self-weight settlement and consolidation parameters can be determined.

The MFT in Pond 1A, with the exception of some minor sand addition to the profile, has remained static for nearly 35 years. It is apparent that, after the initial densification over the first quarter century, very little to no additional dewatering has occurred, or that the self weight settling and consolidation is too slow to measure. Further work is required to determine the long term behaviour of this material, and this site will become an important component in the on-going efforts to improve tailings operations for the industry.