Tailings2018

5th International Seminar on Tailings Management

Advances in Tailings surveying using optical satellites

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GECAMIN

Summary

- Case study
  - Practical implementation of satellite surveying at a large operating mine
- Satellite survey technology evolution 2010-2018
- What is special about TSF surveying ?
  - What we have learned and special requirements.
  - Examples from other mines (including Chile)
- Current limitations
- Future trends

Satellite surveying at Suncor Millennium mine 2012 - 2018

2013 goal for survey department was to provide monthly surveys of all TSF areas.

<u>Safety above all else.</u>

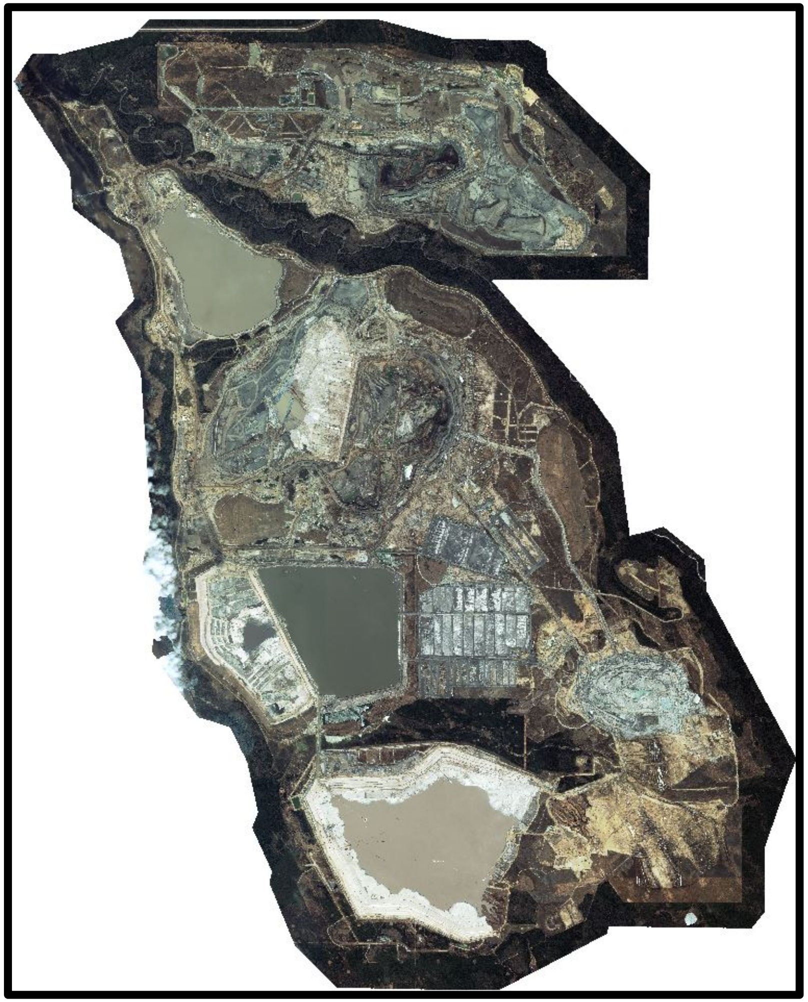
Any new technology should:

- Increase safety
- Reduce risk

Suncor Millennium mine

Oil Sands, Northern Alberta

– 271 km2 (66,974 acres)
– 1M t/day
– 350,000 bbls/day
  Synthetic crude oil

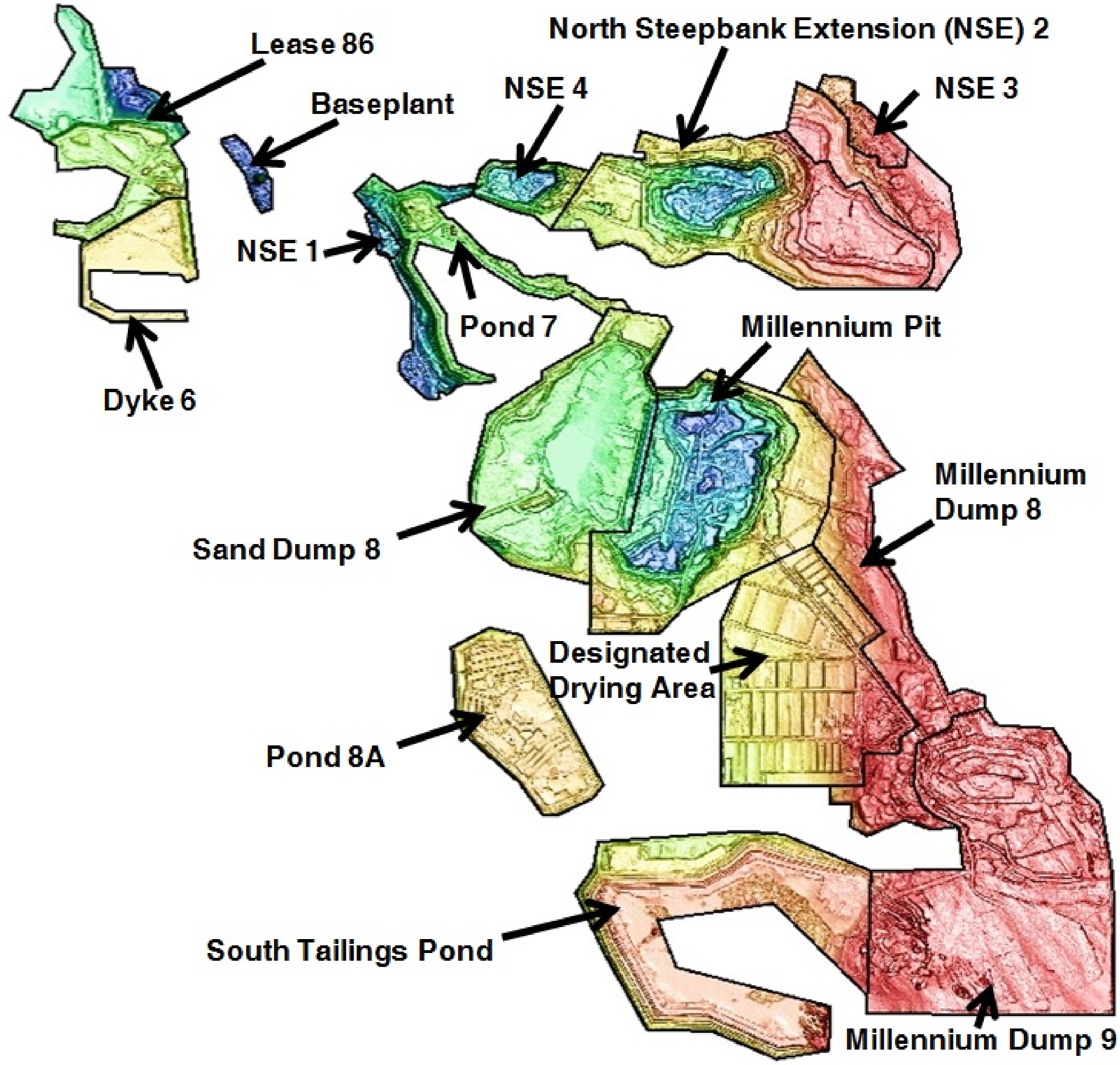


Slide courtesy Suncor

Millennium mine 2013

15 operational areas

4 main tailings areas.



Slide courtesy Suncor

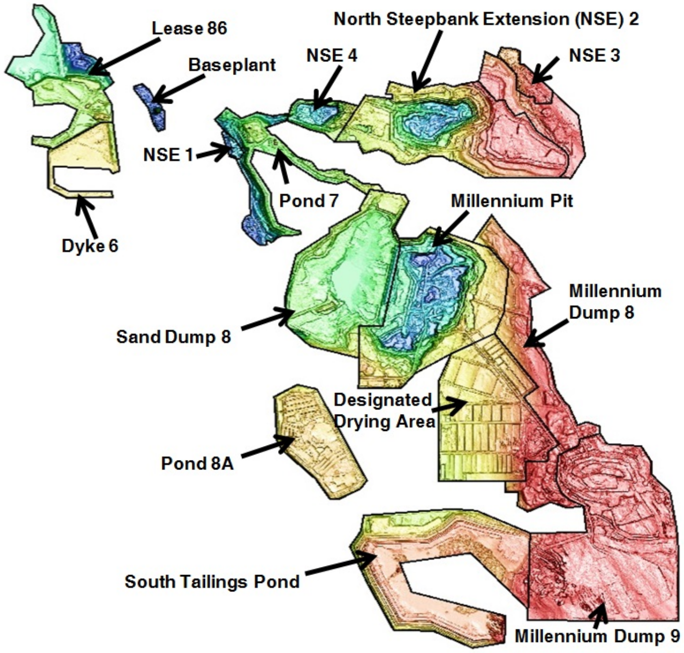
Survey requirements

Suncor defined approximately 20 polygons based on users requirements.

- Tailings and Pit surveyed once or twice monthly
- Other areas monthly, quarterly or annually.

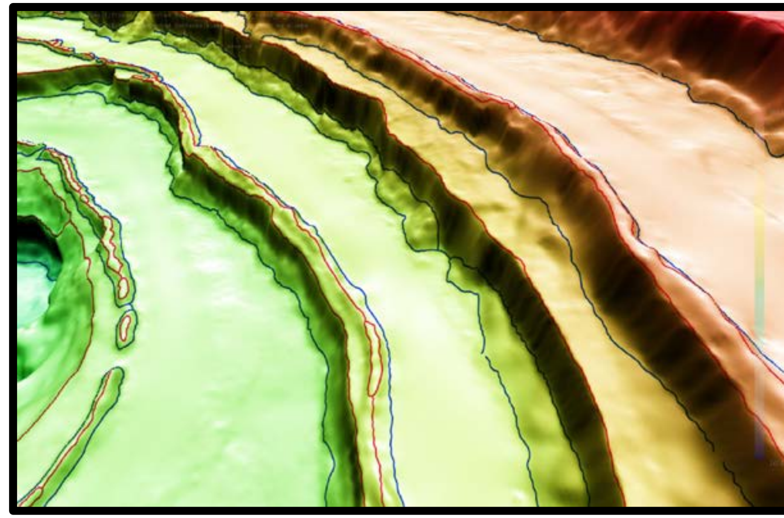
Occasional need for surveys elsewhere (contractor verification).

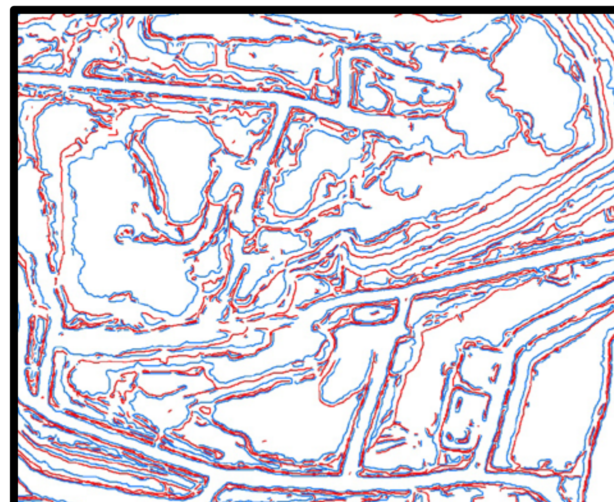
Satellite photo's cover entire lease area (273 sq km). Within that area surveys can be produced anywhere at any time in the future.



Survey deliverables

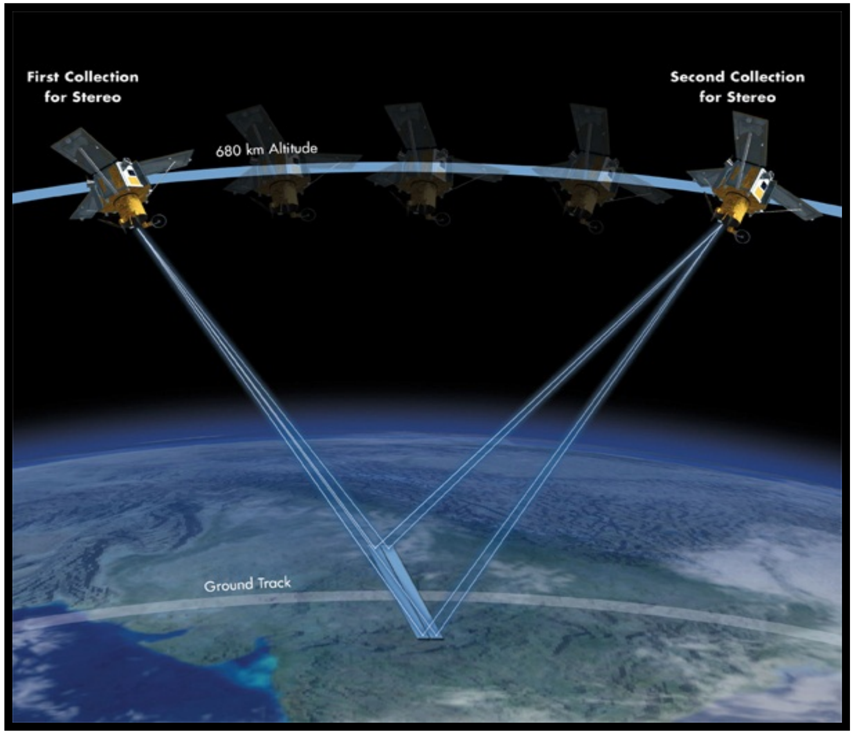
- Many users including contractors and consultants.
- Several formats – AutoCAD, ArcGIS, Vulcan, Minescape, Muck3D.
- Two coordinate systems
  (both custom mine grids)
- Toes and crests
- Waterbodies
- Various infrastructure surveys





Satellite deployment at Suncor

- Four satellites simultaneously
  - DigitalGlobe WV1-3 + GeoEye
- Automatic notification
- QC within 4-6 hours
- Main TSF in 24 hours



Sand Dump 8

Total Surface Area
4 million m^2

Tailings Sand Deposit
39 million m^3 /year

74 Tailings Cells,
74 Discharge Locations

Operates 12 months / year

Average vertical displacement for cells range from less than 10cm per month to more than 3m per month

Slide courtesy Suncor

Suncor Tailings Reduction Program

Mature Fine Tailings

Designated Drying Areas

Total surface area 7.5 M m^2 (1,866 acres)

697 tailings cells

2788 discharge locations

Slide courtesy Suncor

Mature Fine Tailings Designated Drying Areas

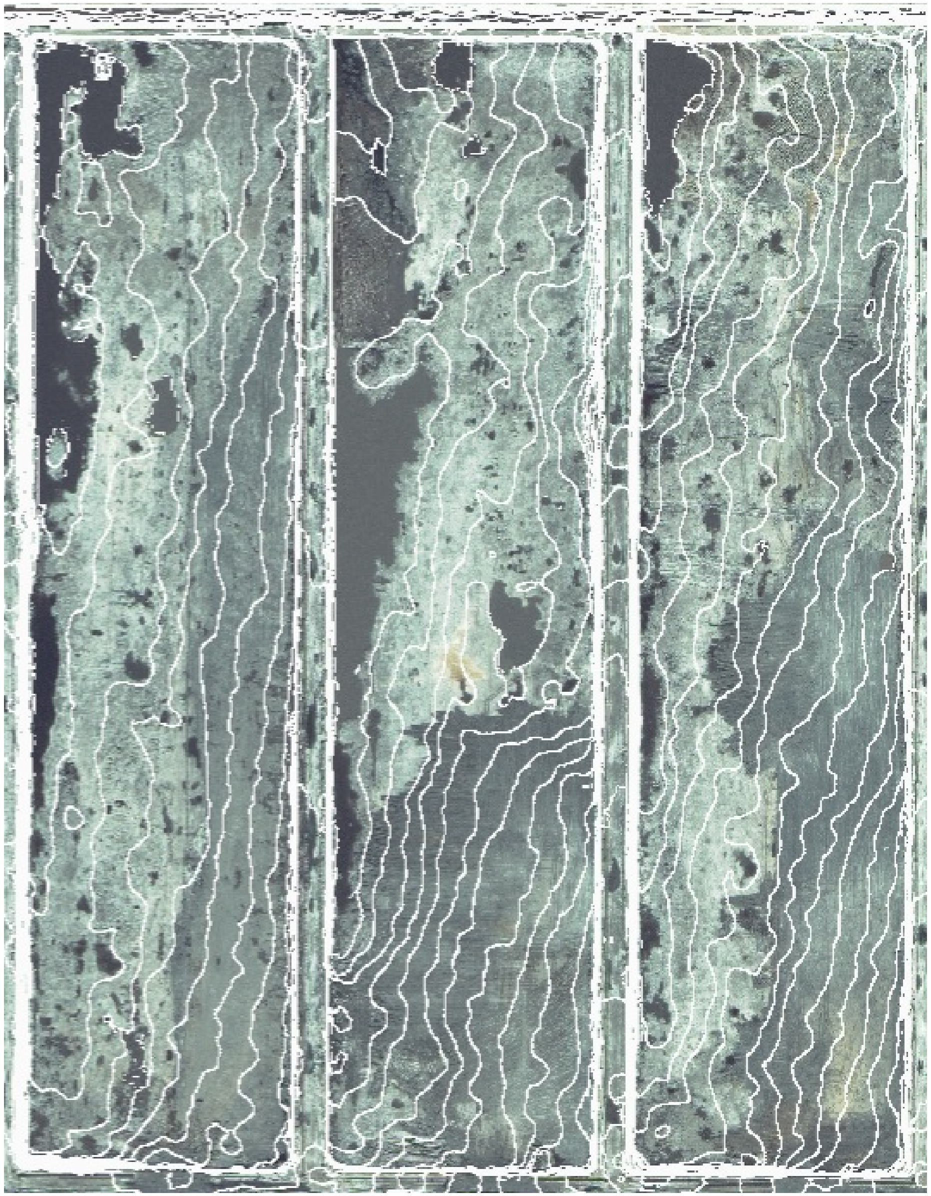
Slide courtesy Suncor

Mature Fine Tailings
Designated Drying Areas

Volumes and thickness of deposits

Performance measurement

Contractor billing validation



WV3 photo with 50cm contours

Survey Technology comparison for monthly TSF surveys

Technologies that were compared:

- Trimble GNSS – GPS ground surveying
- Trimble VX – Laser scanning
- Drones
- Airborne LiDAR
- Satellite surveying

Head of survey – Paul Lomond

- Published at Trimble Dimensions conference

2013 comparison summary

Trimble dozer mounted precision GPS equipment was used on compacted areas of Sand Dump 8.

- Less than 20% of total area was safely accessible

Trimble VX was tested on DDA Cells.

- Very slow, multiple set-ups, sparse data
- Not good on smooth horizontal surfaces

Drones

- Suitable for small areas in the summer
- Logistics (safety, site access, weather)
- Data error – matching

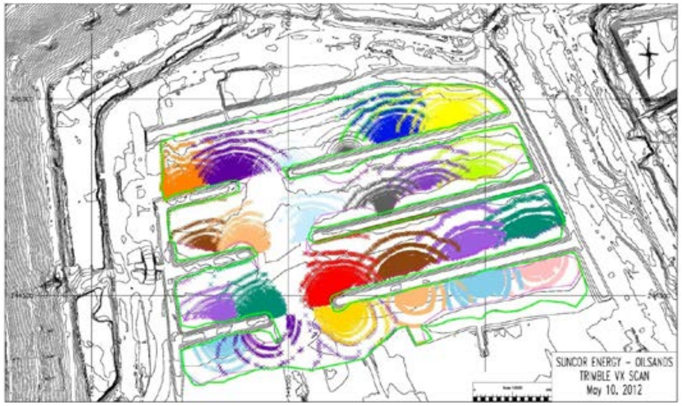
Airborne LiDAR was tested for TRO Cells.

- Huge point-clouds, once errors were fixed, good data
- Slow data delivery

Satellite surveying

- Improved safety
- Entire site coverage – archive.
- Consistent accuracy across the site and between dates
- Limitations as noted later

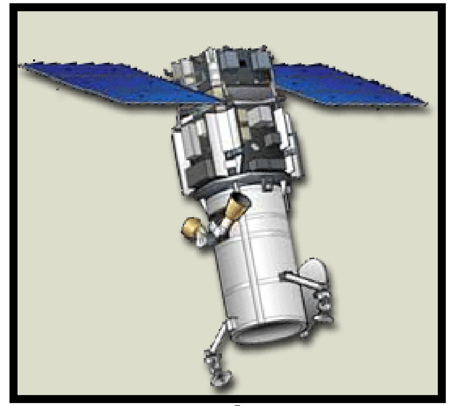
Comparison to contractor survey data. Satellite survey used as independent 3rd party survey to reconcile volume differences between surveys.



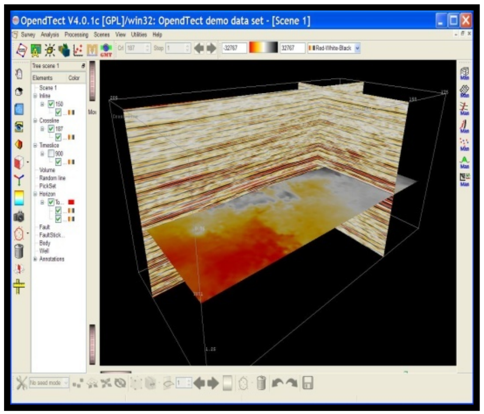
Evolution of satellite surveying

Four key technical components

High resolution stereo satellite photos



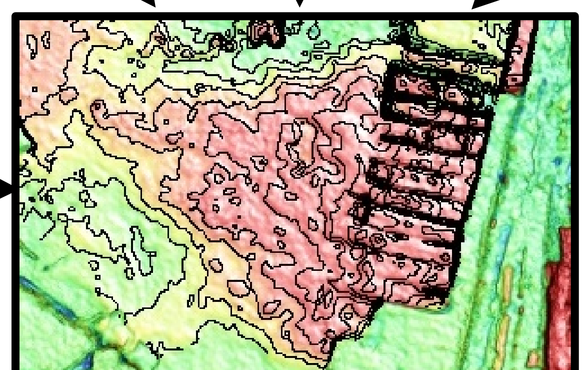
Adaptation of seismic processing algorithms



Graphics Processing Units (GPUs)

Characterize the satellites and optimize the process

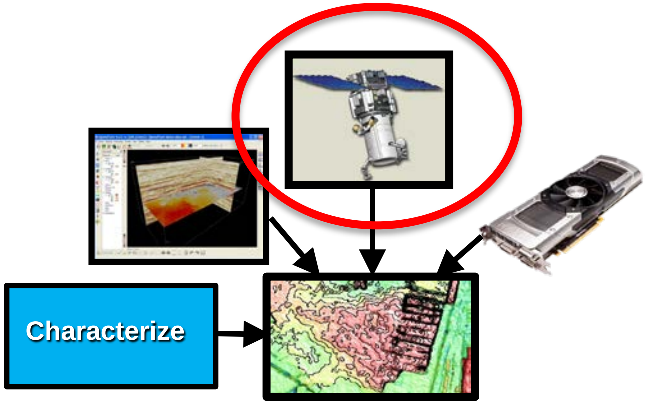
Oil sands surveying and 900+ other projects



1. Optical Satellite evolution

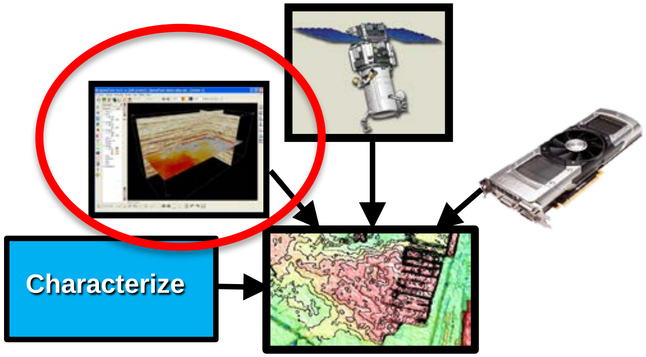
- Military optical satellites since early 1960's
- First commercial survey for mining volume measurement 2010 (GoldCorp)
- Currently 50+ satellites from which some kind of elevations can be produced

- Only some of these have sufficient accuracy for TSF surveys.



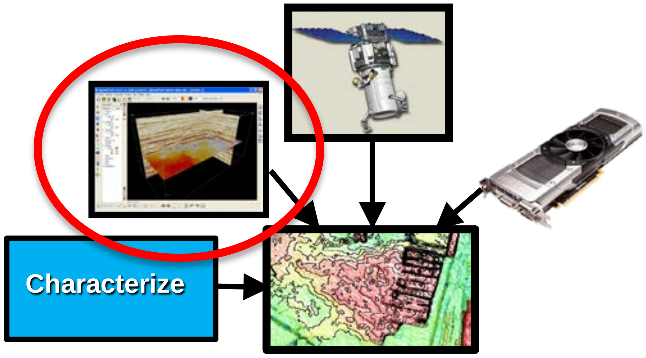
2. Algorithm evolution

- Photogrammetry since 1950's
  - Still used today
  - Best vertical accuracy with satellite images is 1.5 - 2m.
- Mathematics "breakthrough" by Oil and Gas industry for seismic processing – late 1990's
- Geophysical (seismic) algorithms demonstrated for processing satellite data in early 2010.



2. Accuracy evolution

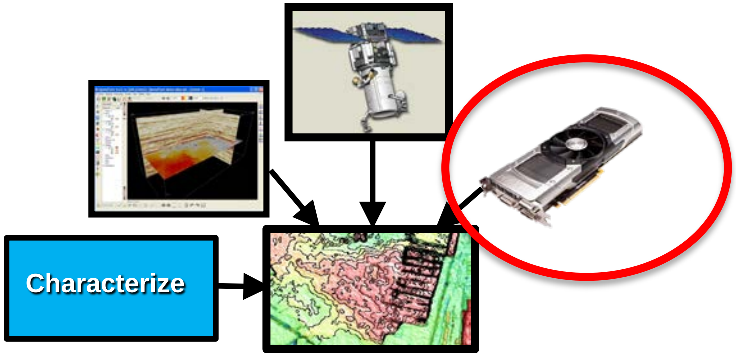
- 2011 – new algorithms achieve 50cm vertical accuracy commercially
  - 20cm required for TSF surveying
- 2011-2014 - Accuracy studies for many satellite using new algorithms
  - 12cm RMSE accuracy possible
- 2014 – COSIA defines 15cm RMSE as suitable vertical accuracy for TSF measurements for Oil Sands.



3. Processing technology evolution

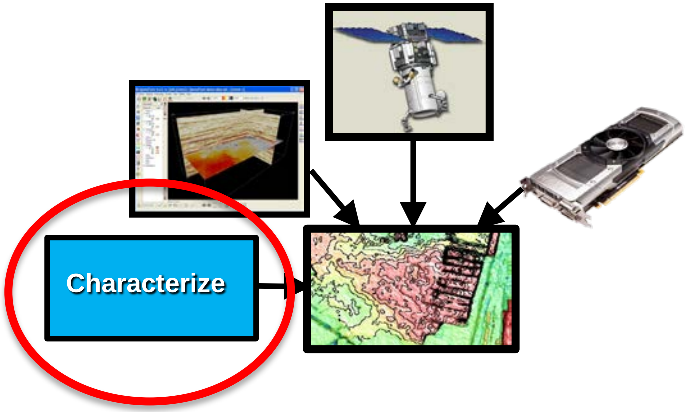
- Geophysical algorithms produce best current accuracy but are computationally intensive.

- Graphics processors allow 10,000's of cores hence 20x improvement in processing time but require a code re-write.



4. Calibration / Optimization

- Information about camera characteristics of optical satellites is classified.
- 900+ surveys of mine sites allows the development of libraries of corrections for specific satellite cameras.
- 2013 / 2014 – 15cm RMSE on TSF was reliable and repeatable.



Current status and lessons learned

Twice monthly surveys continue at Suncor Millennium and Fort Hills.

- Main TSF deliveries in 24 hours
- Experimenting with weekly updates in small areas.

Three main “lessons”:

1. “Time to use” is what is important
2. Special deliverables for TSF measurements.
3. Automate everywhere

"Special deliverables" for TSF surveying

- Time sensitive surveys
- Consistent accuracy and quality
  - across areas and
  - between surveys

- Beach profiles
- Water body outlines
- Thinned data sets

Chile Beach profile example - Sierra Gorda

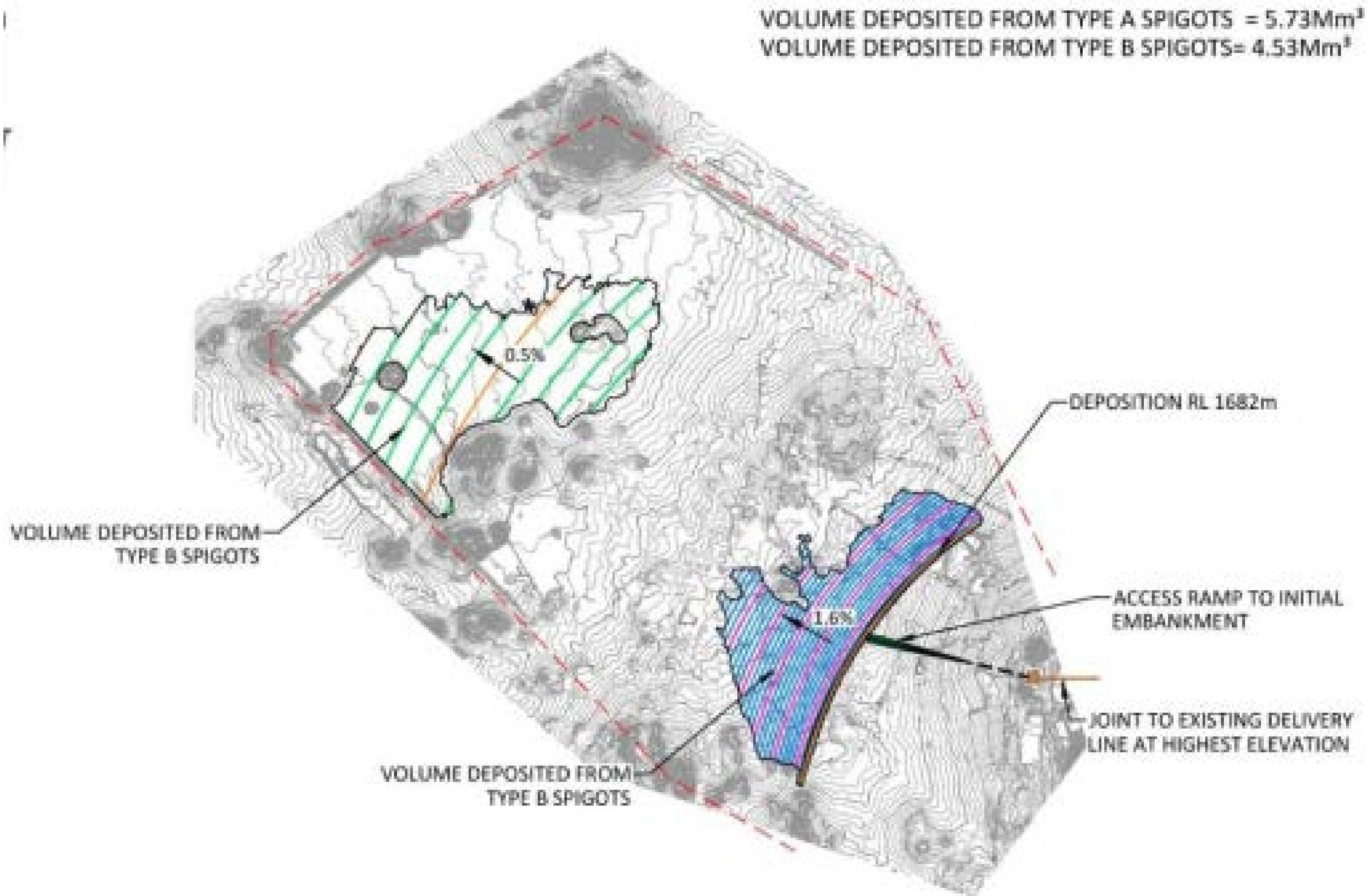
Used to monitor modification of discharge system.

Monthly or bi-monthly surveys between April 2016 and April 2018.

Published at PASTE 2018 – Engels, Gonzales, Aedo, McPhail.

Figure 8 Plan of TSF showing N1 and N2, and S1 and S2 spigot distribution systems

WorldView 2 satellite image



PASTE 2018 – Engels, Gonzales, Aedo, McPhail.

Beach profile example

Sierra Gorda

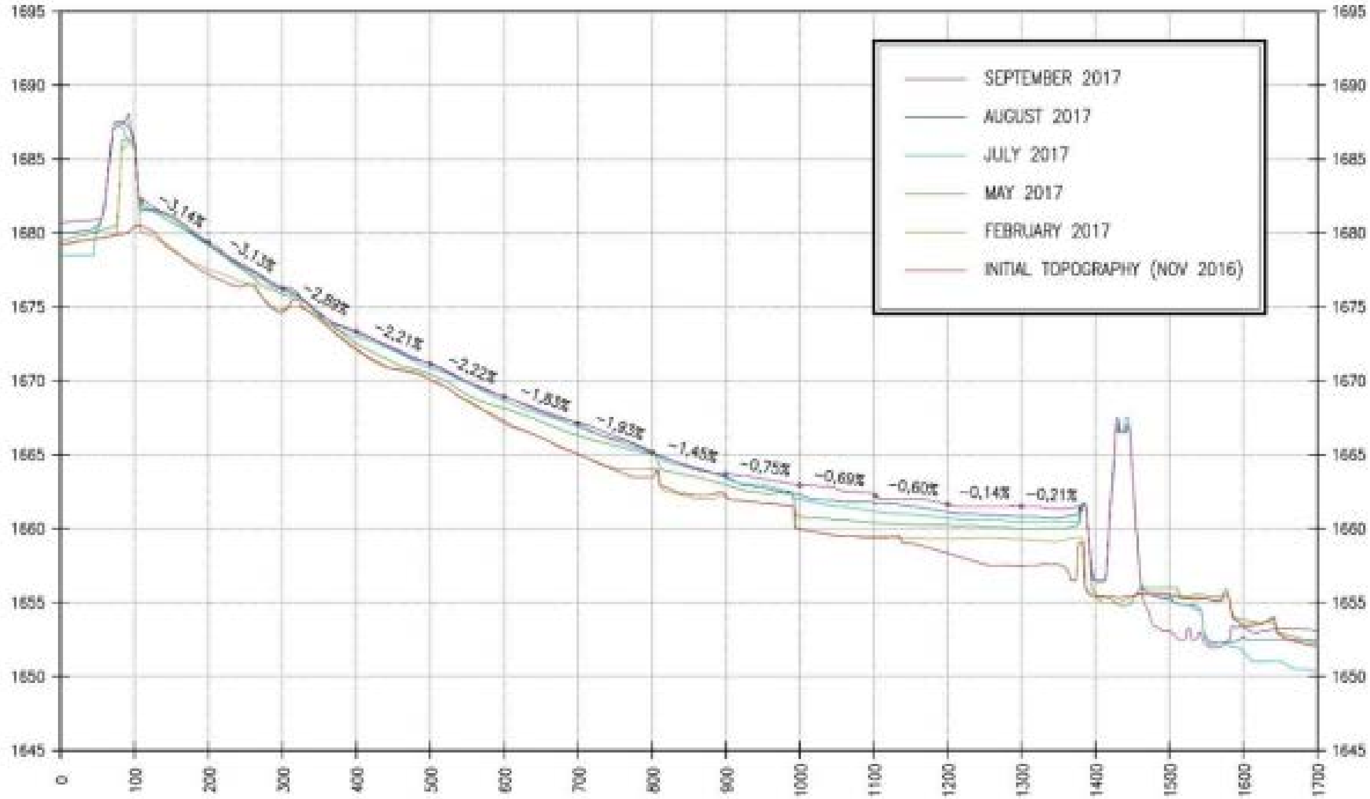


Figure 9 S1 beach development (February to September 2017) – vertical scale twice exaggerated

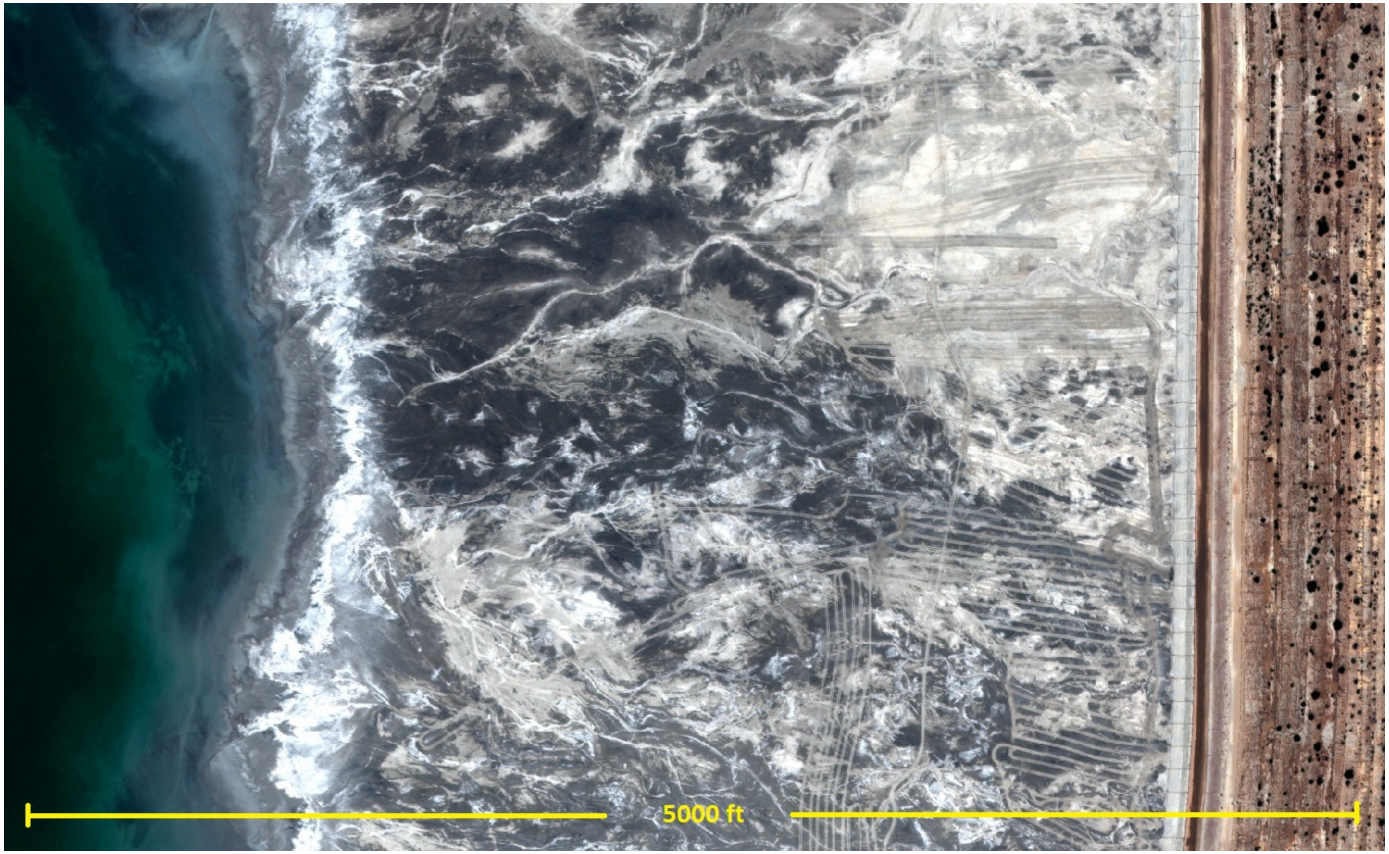
PASTE 2018 – Engels, Gonzales, Aedo, McPhail.

Beach profiles and volumes by TailPro Consulting.

Waterbody outlines

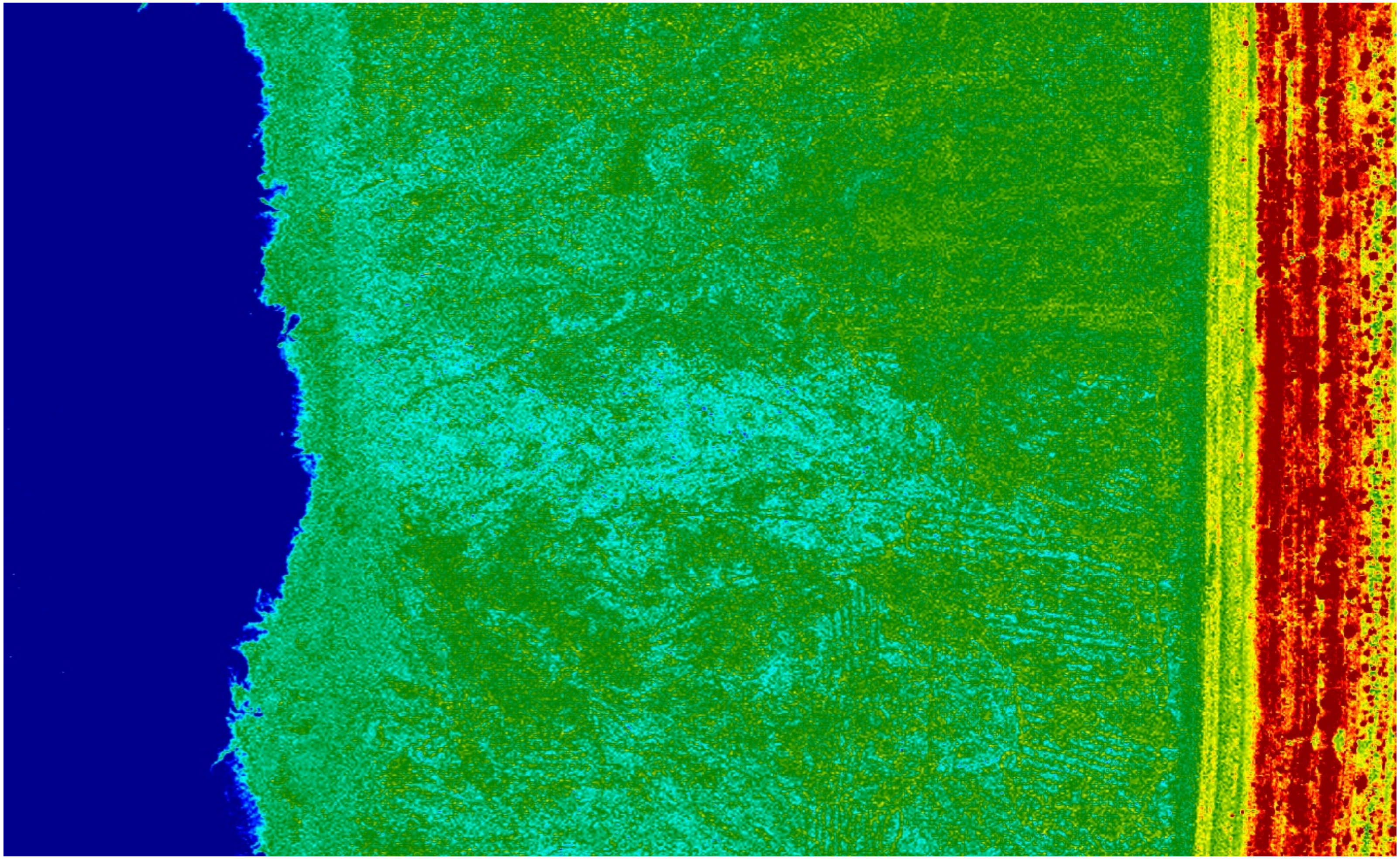
It is often difficult to determine the edge of the pond in a TSF.

Visible distinction between the waters edge and "damp tailings" on the beach.



WorldView 2 satellite image

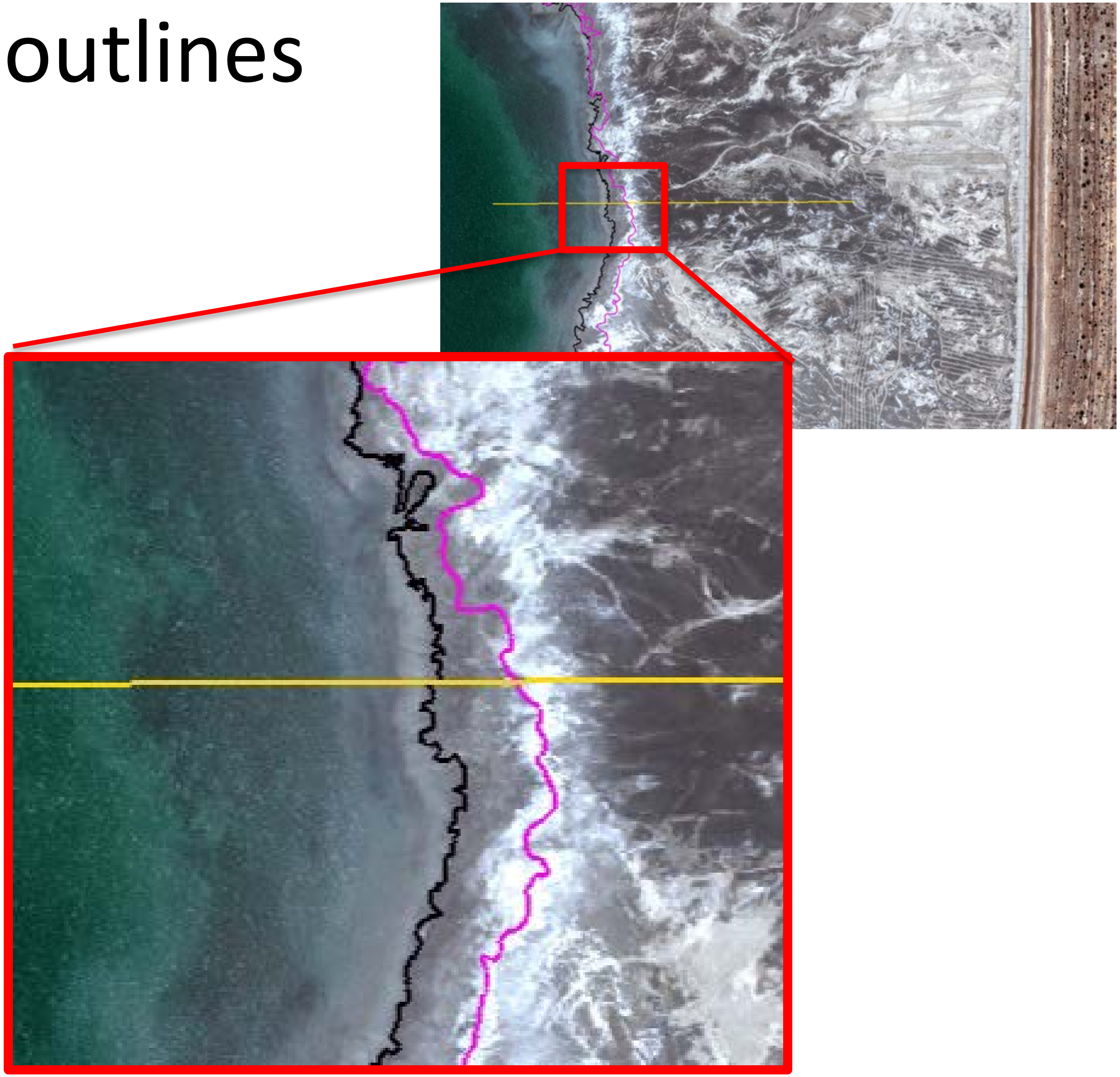
Waterbody outlines



Satellite cameras have detectors in the Infra-red. Infra-red is absorbed by water. Using a ratio of various wavelengths an accurate and repeatable location of the waters edge can be determined.

Waterbody outlines

Pond edge location as determined by band ratio is often significantly better that the location determined by other methods.



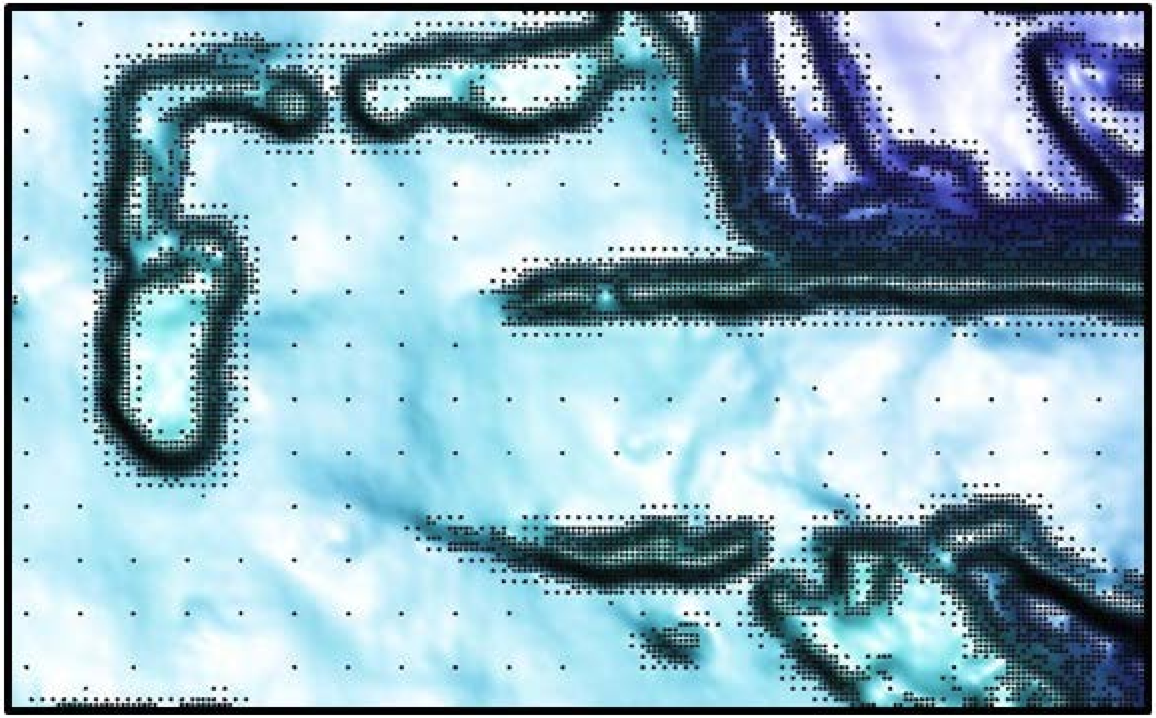
Thinned grids

TSF areas are large and flat which means that high resolution datasets can result in very large data files.

“Standard” grid resolution for a TSF is 50cm.

Normal data thinning changes this to (say) 10m which results in loss of resolution.

TSF thinning keeps points in areas of elevation change while reducing file size by up to 90%.



Example of
"automate
everywhere"

Millennium MFT
System 1, July 27
2014

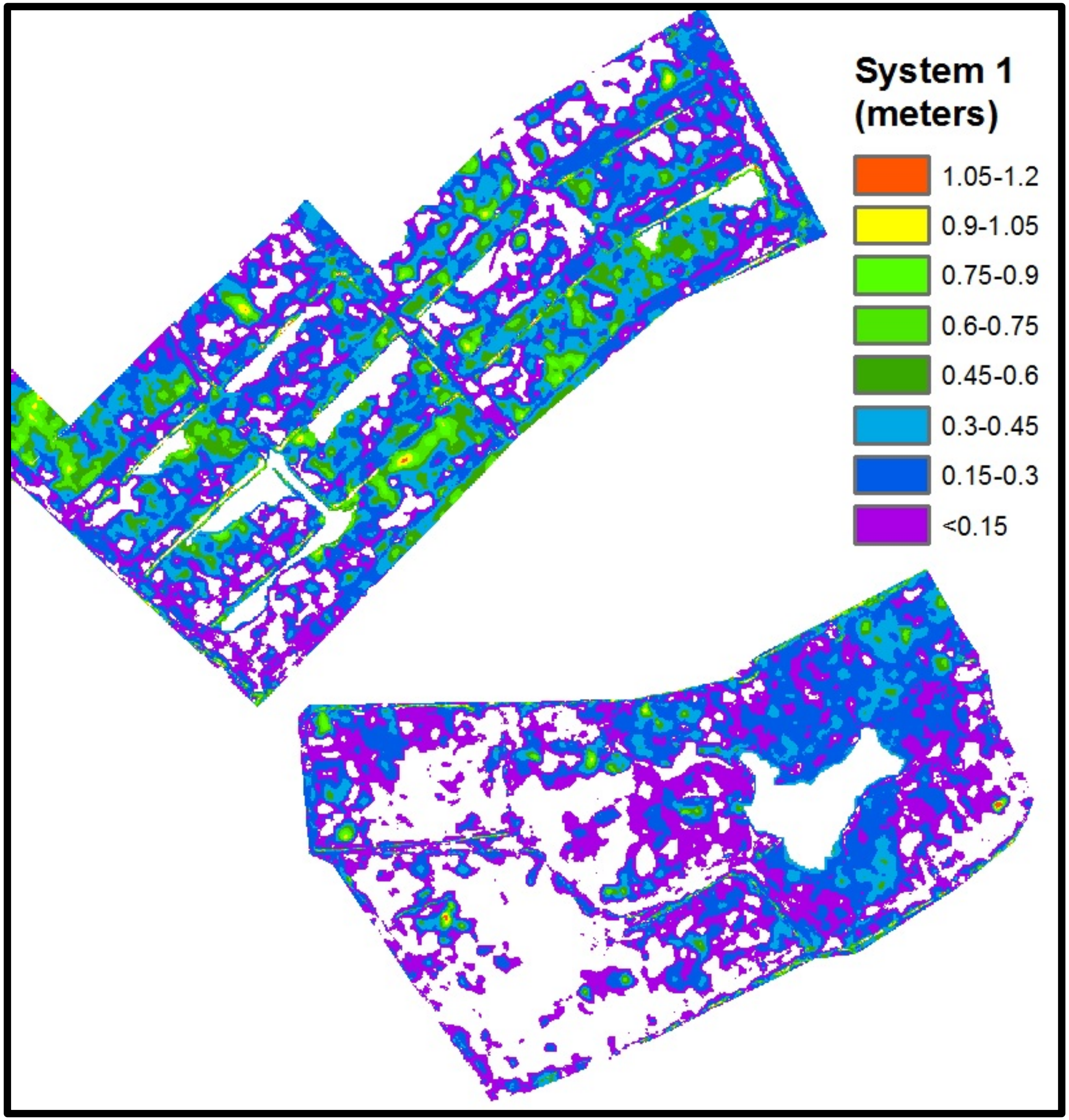
Slide courtesy Suncor

System 1:
MFT thickness change
June 29 to July 13

- Volume change in cell
- Lift thickness
- Utilization area
- Utilization volume

Annual volume removed (contractor check).

Slide courtesy Suncor



“automated”
Excel version

System	Field	MFT Volume Since Last Pour (m3)	Area Covered by MFT (m2)	Area of Polygon (m2)	Utilization of Polygon (%)	MFT Lift Thickness (m)
Sys 1	A1-14	23,324	61,981	86,984	71%	0.38
Sys 1	B1-15	22,293	59,950	89,079	67%	0.37
Sys 1	C1-15	21,989	66,900	89,048	75%	0.33
Sys 1	D1-7	12,645	37,452	42,584	88%	0.34
Sys 1	S1-5	3,329	19,630	46,820	42%	0.17
Sys 1	S6-12	13,378	60,755	113,475	54%	0.22
Sys 1	S13-17	18,885	94,623	204,231	46%	0.20
Total for System 1		**115,842**	**401,291**	**672,220**	**60%**	**0.29**
Sys 2	N1-9	58,721	145,033	151,871	95%	0.40
Sys 2	S1-9	15,721	57,060	144,136	40%	0.28
Sys 2	W1-12	27,650	87,358	139,579	63%	0.32
Sys 2	E0-21	33,741	120,560	223,960	54%	0.28
Total for System 2		**135,832**	**410,011**	**659,546**	**62%**	**0.33**
Sys 4	A1-6	14,175	63,356	98,944	64%	0.22
Sys 4	B1-9	30,123	165,885	197,783	84%	0.18
Sys 4	C1-11	16,604	53,853	233,376	23%	0.31
Sys 4	D1-11	39,097	121,359	211,518	57%	0.32
Sys 4	E1-11	41,970	99,726	214,359	47%	0.42
Sys 4	F1-11	41,862	115,043	246,705	47%	0.36
Total for System 4		**183,832**	**619,222**	**1,202,684**	**51%**	**0.30**
Sys 5	A1-8	41,658	118,689	138,678	86%	0.35
Sys 5	B1-8	27,514	95,335	149,348	64%	0.29
Sys 5	C1-8	28,427	74,215	143,552	52%	0.38
Sys 5	D1-8	25,899	58,937	147,195	40%	0.44
Sys 5	E1-8	1,553	9,847	127,964	8%	0.16
Sys 5	I and F	20,445	57,548	113,218	51%	0.36
Sys 5	J - odd	11,061	39,702	60,493	66%	0.28
Sys 5	J - even	13,887	42,858	60,664	71%	0.32
Sys 5	K1-8	6,780	31,144	62,452	50%	0.22
Sys 5	L1-4	1,215	7,113	29,191	24%	0.17
Sys 5	M1-3	2,408	10,388	19,470	53%	0.23
Sys 5	G1-11	43,297	119,642	148,068	81%	0.36
Sys 5	H1-11	25,057	97,291	149,136	65%	0.26
Total for System 5		**249,201**	**762,707**	**1,349,428**	**57%**	**0.33**
Sys 6	A1-7	7,734	28,561	53,271	54%	0.27
Sys 6	B1-6	1,274	8,727	60,785	14%	0.15
Sys 6	C1-3	7,732	24,951	39,096	64%	0.31
Sys 6	D1-9	12,381	51,942	109,828	47%	0.24
Sys 6	E1-3	7,668	33,254	44,759	74%	0.23
Sys 6	F1-9	19,959	79,596	105,697	75%	0.25
Sys 6	G1-3	15,616	47,077	52,248	90%	0.33
Sys 6	H1-9	26,756	79,206	91,329	87%	0.34
Sys 6	I1-25	35,366	87,276	133,967	65%	0.41
Sys 6	J1-10	13,984	40,729	57,615	71%	0.34
Sys 6	K1-6	9,515	27,792	35,239	79%	0.34
Sys 6	L1-5	8,213	24,929	33,926	73%	0.33
Total for System 6		**166,195**	**534,039**	**817,759**	**65%**	**0.31**
Sys 7	A1-14	23,813	111,248	223,229	50%	0.21
Sys 7	B1-14	24,065	113,568	174,024	65%	0.21
Sys 7	C1-14	19,546	94,461	193,955	49%	0.21
Sys 7	D1-14	23,103	87,268	193,598	45%	0.26
Sys 7	E1-14	32,743	138,020	191,318	72%	0.24
Sys 7	F1-14	41,285	136,067	183,666	74%	0.30
Sys 7	G1-15	20,539	92,089	141,504	65%	0.22
Sys 7	Jacking Header 1-3	6,840	35,065	59,335	59%	0.20
Sys 7	I1-8	9,691	35,778	61,625	58%	0.27
Sys 7	J1-8	24,601	55,645	67,336	83%	0.44
Total for System 7		**226,227**	**899,208**	**1,489,589**	**60%**	**0.25**

Slide courtesy Suncor

Current technology limitations

Major limitation is weather

- Satellites don't "see" through clouds.
- Keep trying at no additional cost until suitable photos are acquired.

Processing time

- Computation time has been reduced.
- Formatting and data transfer time is the major limitation.

Satellite company "spec" collect.

- Limited archive collection outside North America.

The future of satellite surveying

"Big data" Processing

- PhotoSat on Amazon servers now.
- More to come ?
- AI for enhancement – PhotoSat

More satellites

- WorldView 4 in orbit now
- 4-8 additional "big sats" planned by 2020
- Digital Globe Legion program – 30-60 minute revisit 2021-
- Small sats.

WorldView-4 artist rendering

Conclusions

Current vertical accuracy <15cm RMSE meets industry requirements.

Monthly TSF surveys are now routine.

Major mine operators are accumulating archive "elevation ready" images showing monthly mine development.

Expect greater satellite availability, faster processing and lower cost in the future.

Over 100 mine surveys
in Chile, Argentina, Peru