Integration of Field Investigations and an Innovative Modelling Tool in the Prioritization of Mitigation Strategies for an Abandoned Uranium Mine

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EcoMetrix Incorporated

20th BC MEND ML-ARD Workshop Vancouver, 4-5 December 2013

Site Location

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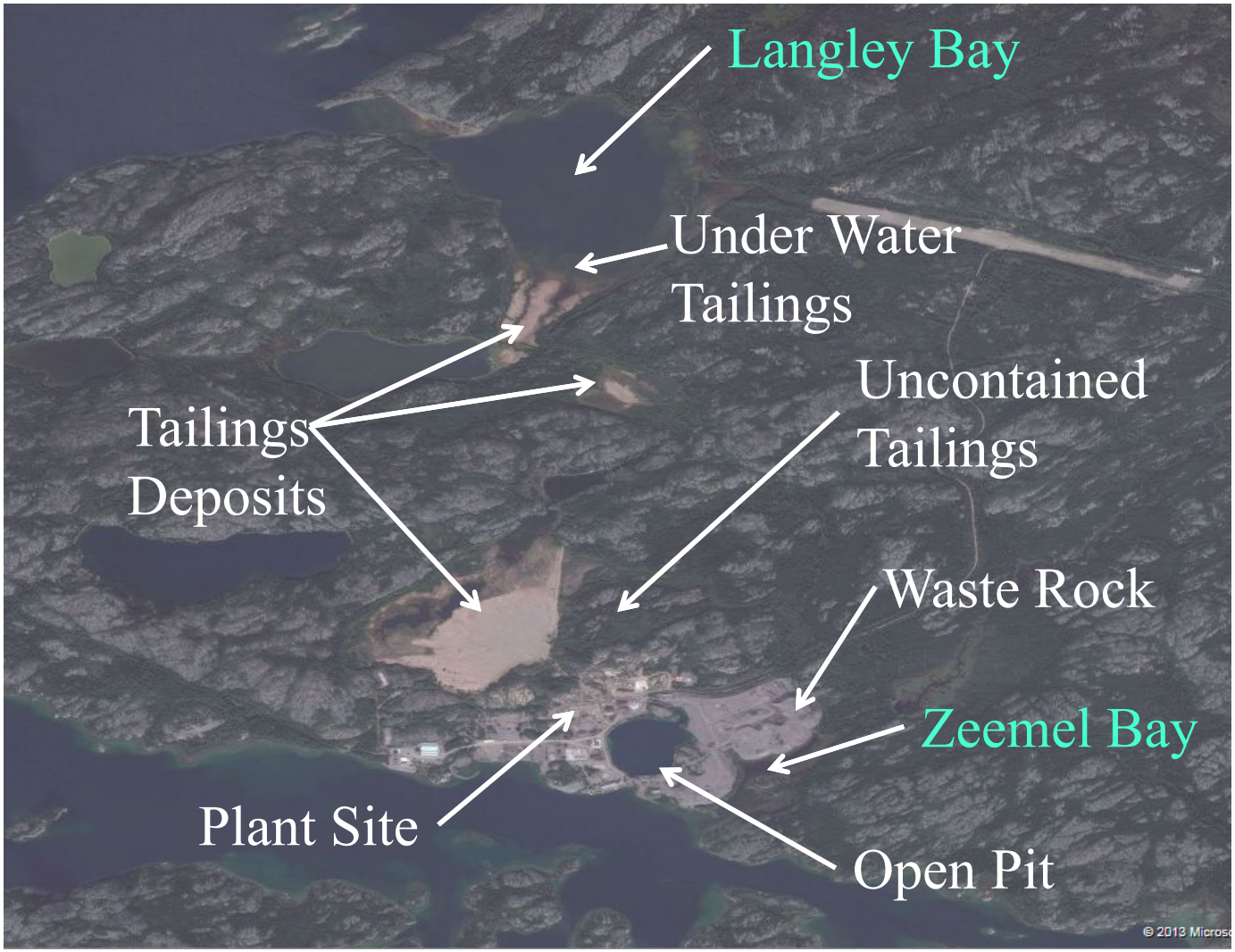
Site Overview



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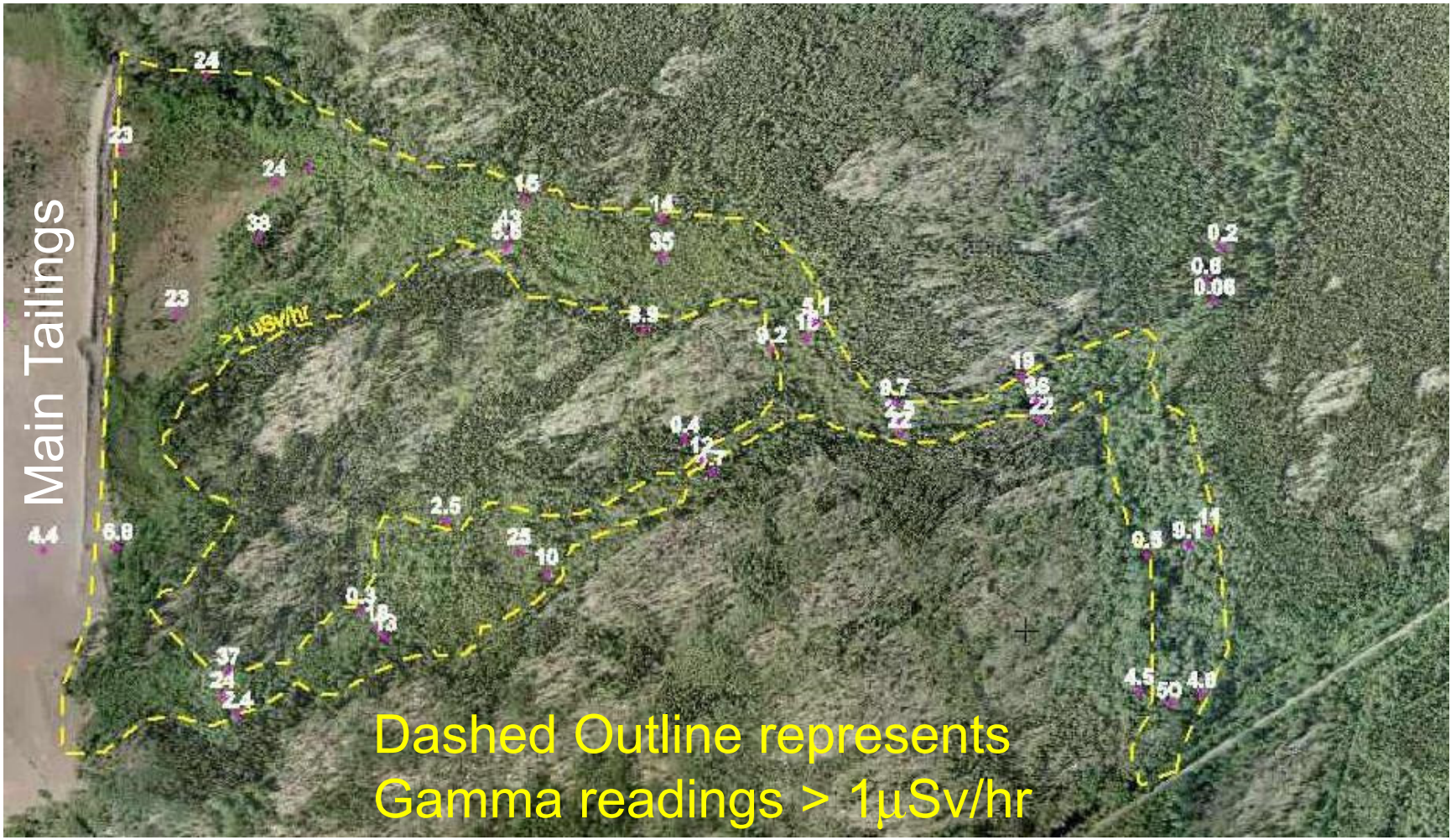
Uncontained Tailings



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Background - History

- Uranium Mine opened in 1955 with Open pit and went Underground in 1961
- Produced 6900 tons of U at a grade of 0.15%
- 3.5 Mm^3 of tailings
- 2.2 Mm^3 of waste rock

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Background - History

- Mill Process – sulphuric acid leach (pH=1) – tailings NOT neutralized before discharge

- Sulphuric Acid produced on site using elemental Sulphur

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Ground Fires Around the Sulphur Storage Pad

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Background - Studies

- Detailed assessment in 1980s – *National Uranium Tailings Program (NUTP)*
- Environmental Impact Statement (EIS) studies for reclamation (2010)
- Risk assessment identified constituents of potential concern (COPC) in surface water as potential risks;
  - » Uranium (eco-risk – Zeemel Bay)
  - » Radium-226 (human and eco radiation dose – Langley Bay)
  - » Arsenic (human food-chain risk)
  - » Cadmium (aquatic risk)

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Objectives of this Study

- Identify and quantify sources and pathways of COPCs
- Apply loadings model to assess current conditions and evaluate mitigation strategies

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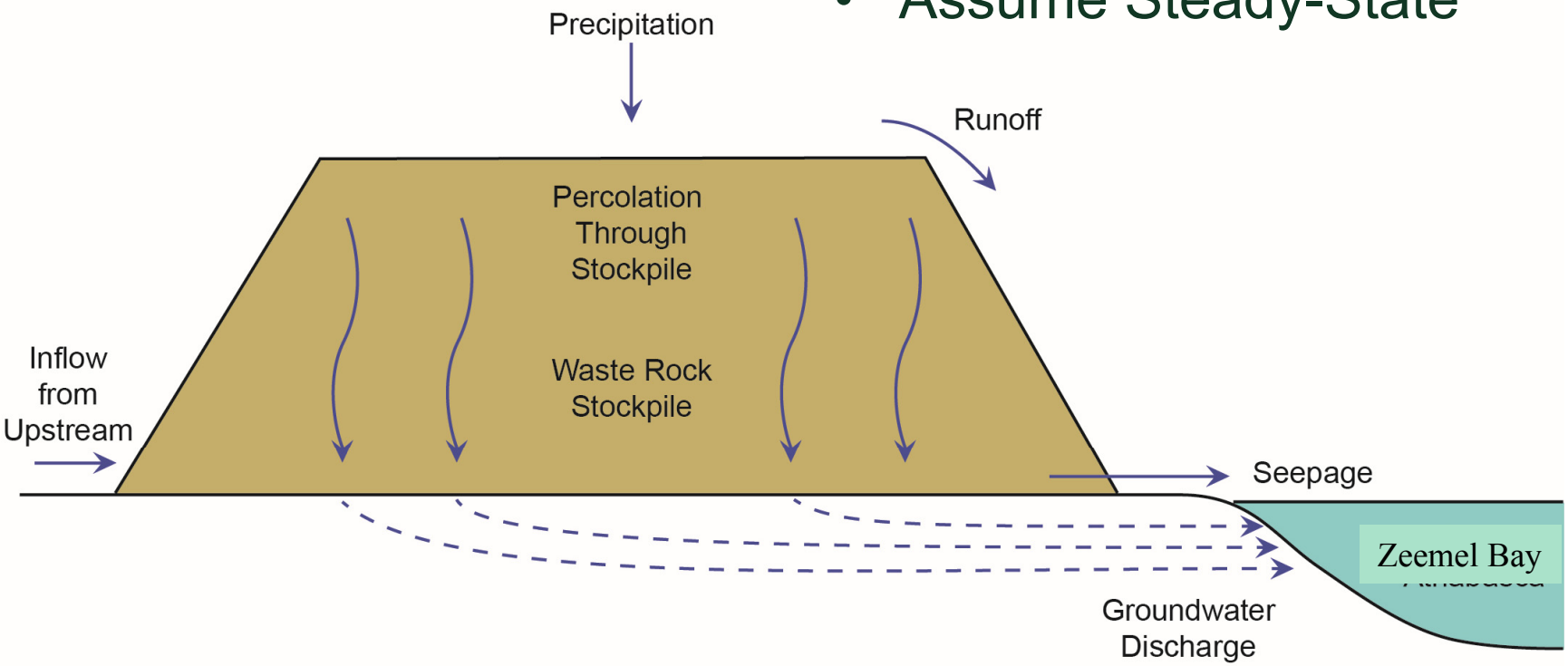
Waste Rock - Conceptual Model

- 50 Years of weathering
- Not acidic
- Assume Steady-State



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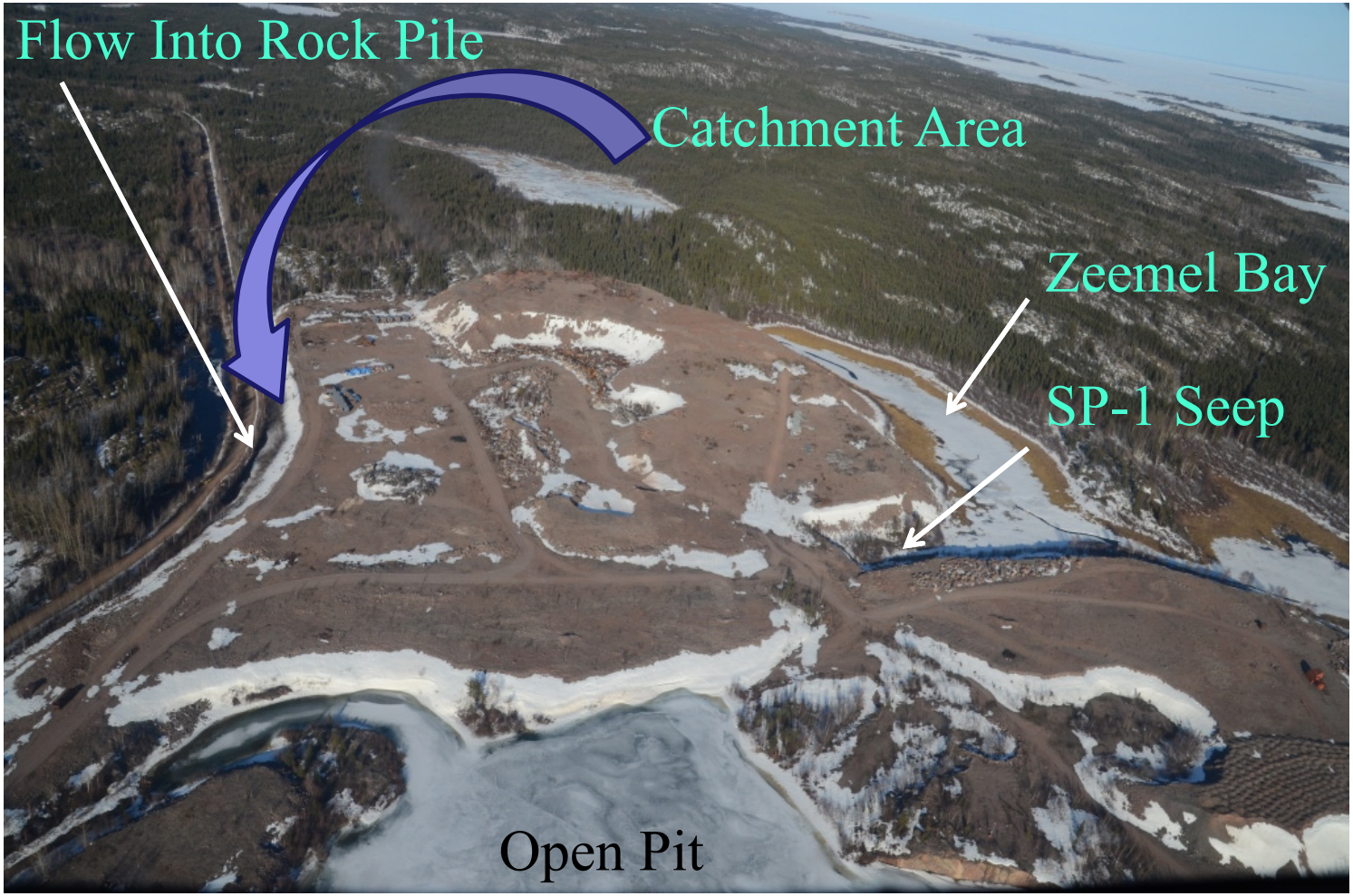
East Waste Rock Pile



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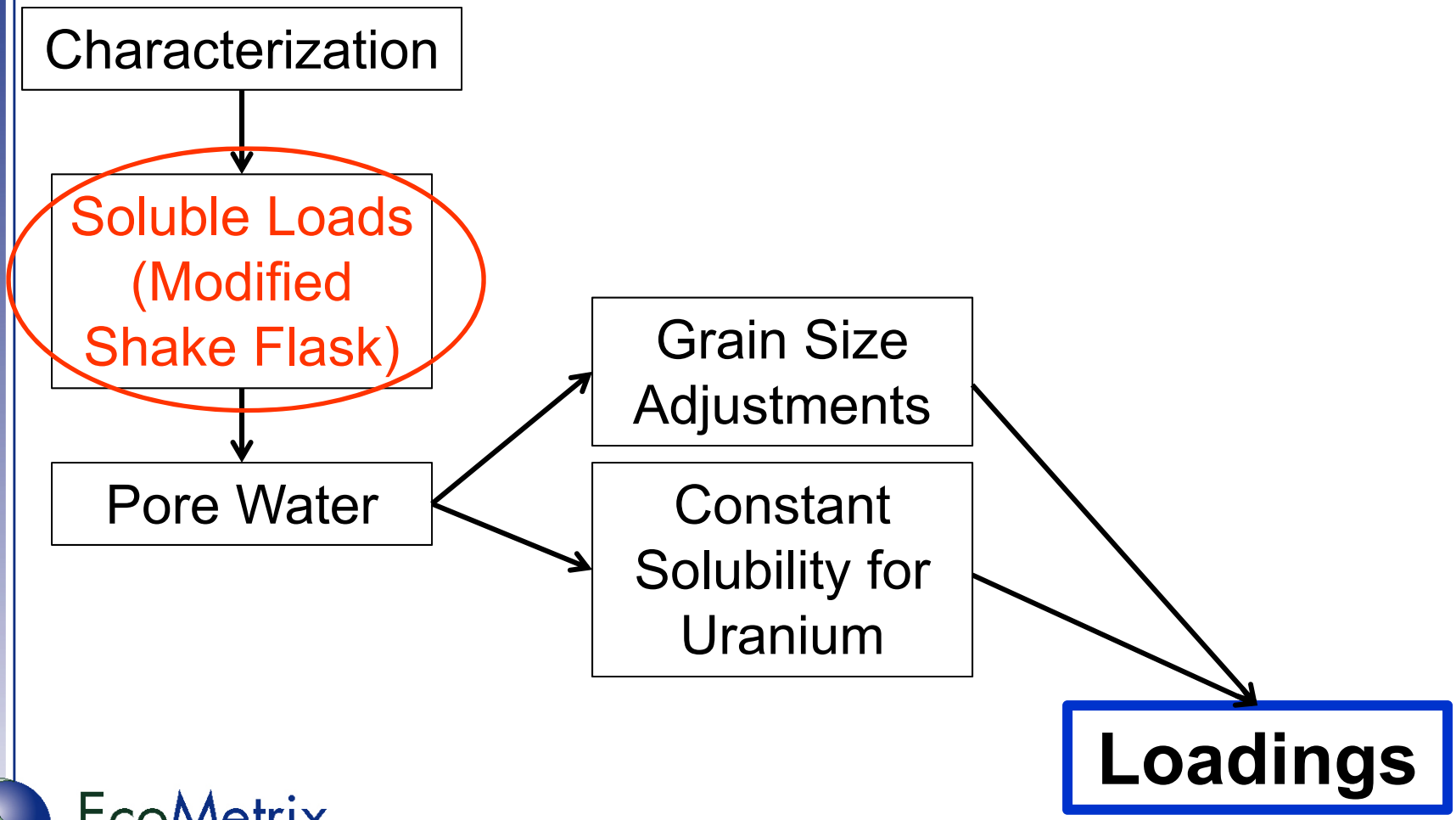
Waste Rock Characterization – Conceptual Model



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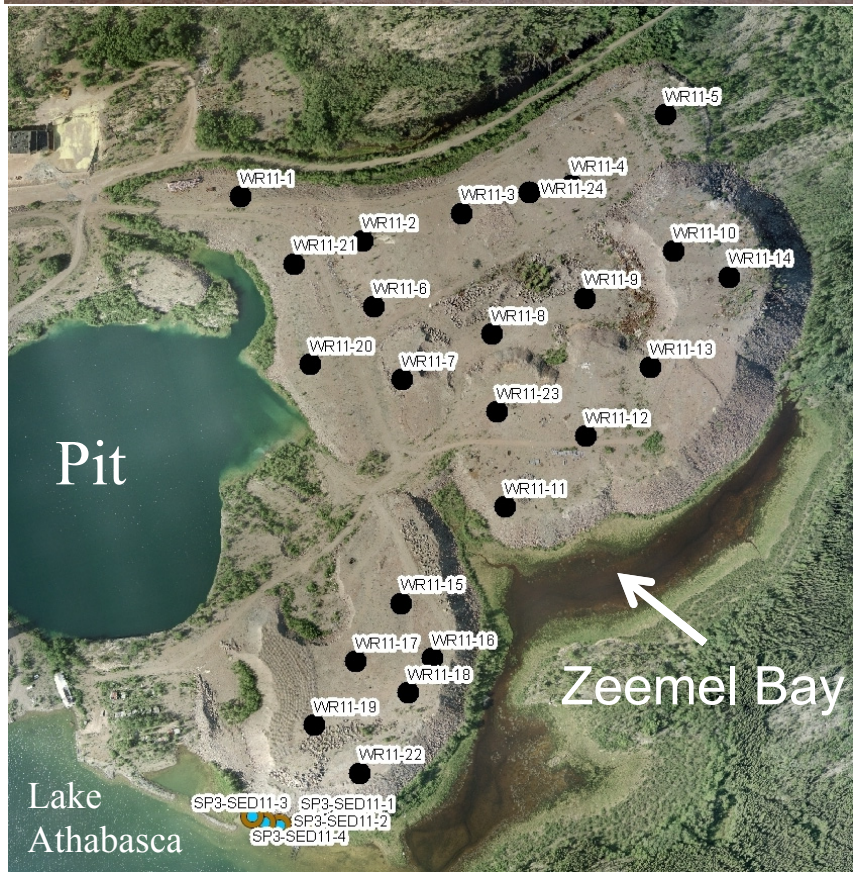
Characterization Program – Waste Rock

- Test pits with excavator - 124 Samples
- 1m intervals to depths of about 5m
- Typical samples less than 75 mm (3”) grain sizes
- Select samples for grain-size assessment;
    - Less than 50 mm
    - 50 to 150 mm
    - Greater than 150 mm



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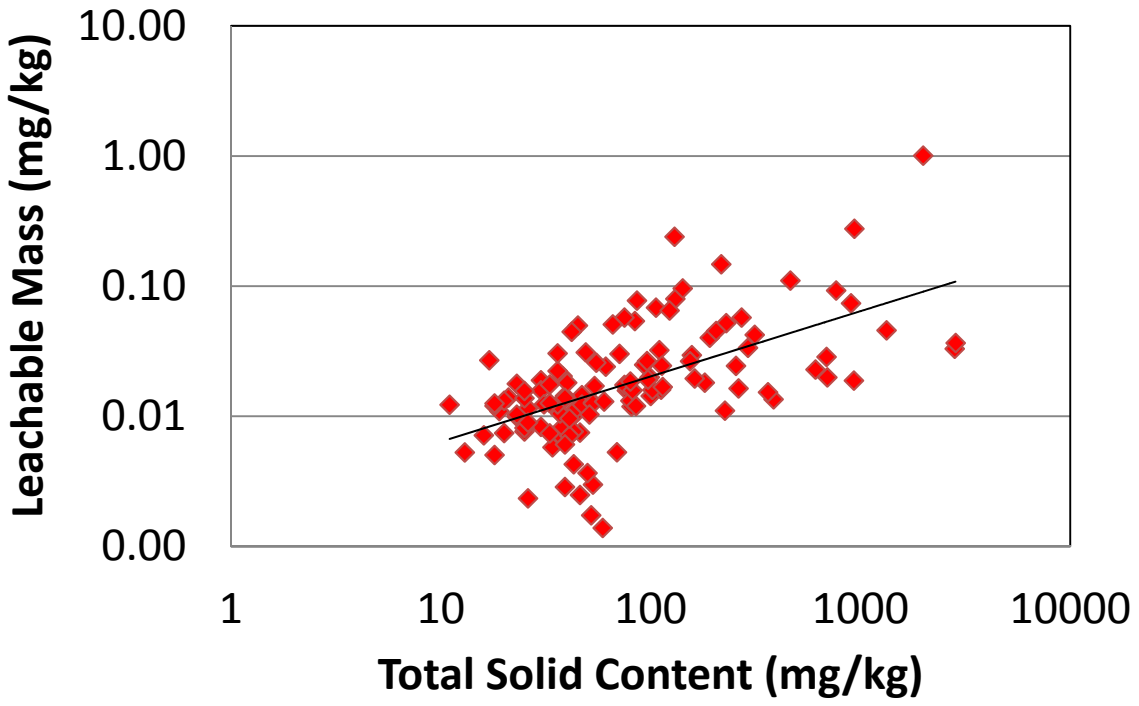
Characterization Program – Waste Rock

Laboratory analysis:

- Metal contents
- Radiological content
- Leachable Mass – Shake Flask (modified SWEP)
- ABA



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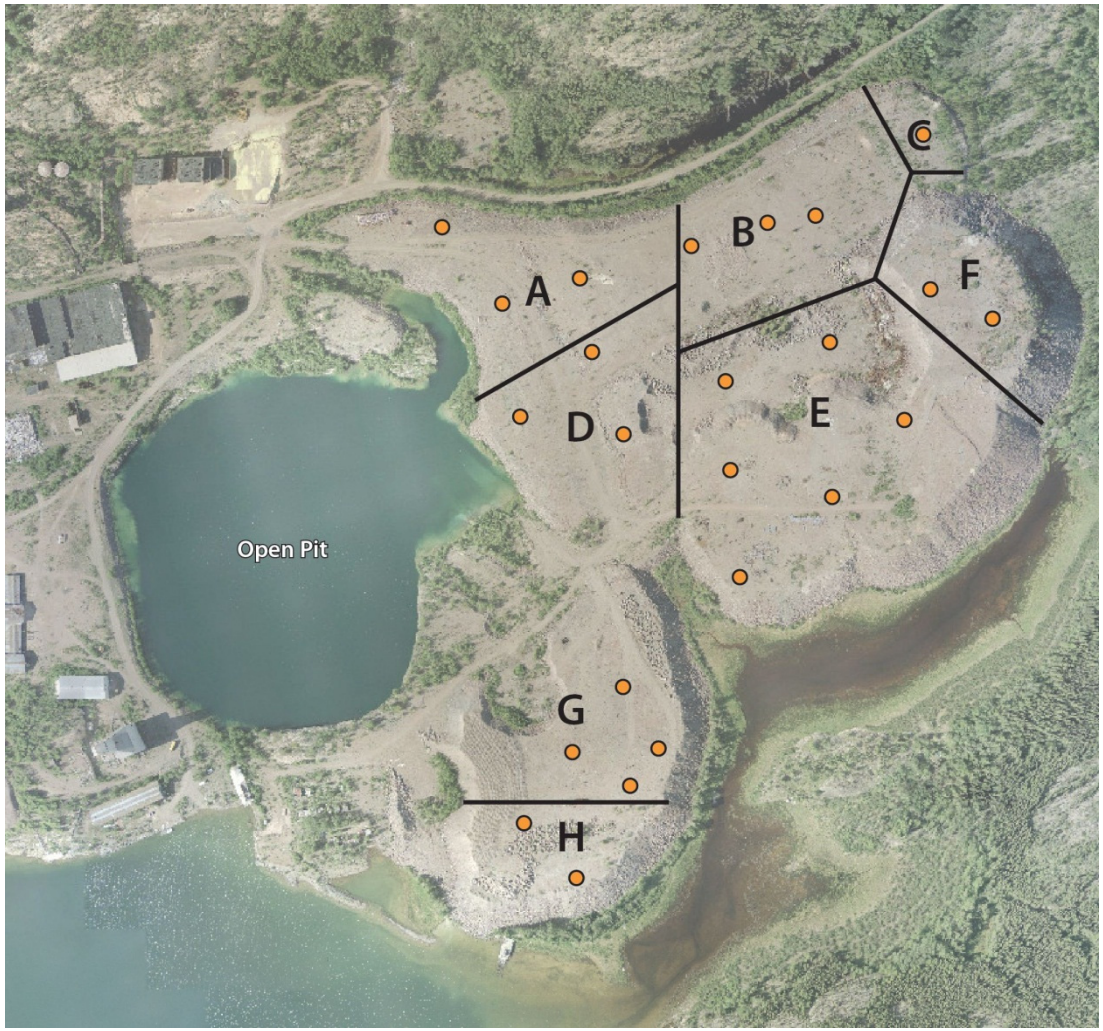
Pore Water Concentrations in Waste Rock



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Pore Water Concentrations in Waste Rock

Parameter	Units	Waste Rock Stockpile Zone								Median
		A	B	C	D	E	F	G	H	
Radium-226	Bq/L	11	75	351	115	151	267	60	45	134
Sulphate (SO_4)	mg/L	392	1812	2765	1239	1294	2693	2190	3609	1924
Arsenic (As)	mg/L	0.03	1.72	2.46	0.74	0.73	1.50	1.29	1.39	1.22
Lead (Pb)	mg/L	0.18	0.86	2.22	1.10	0.77	6.03	1.73	3.26	1.91
Uranium (U)	mg/L	8.9	10.3	15.1	4.3	5.4	21.1	3.4	7.4	8.9

- Back calculation from shake flask results (mg/kg) and measured moisture contents

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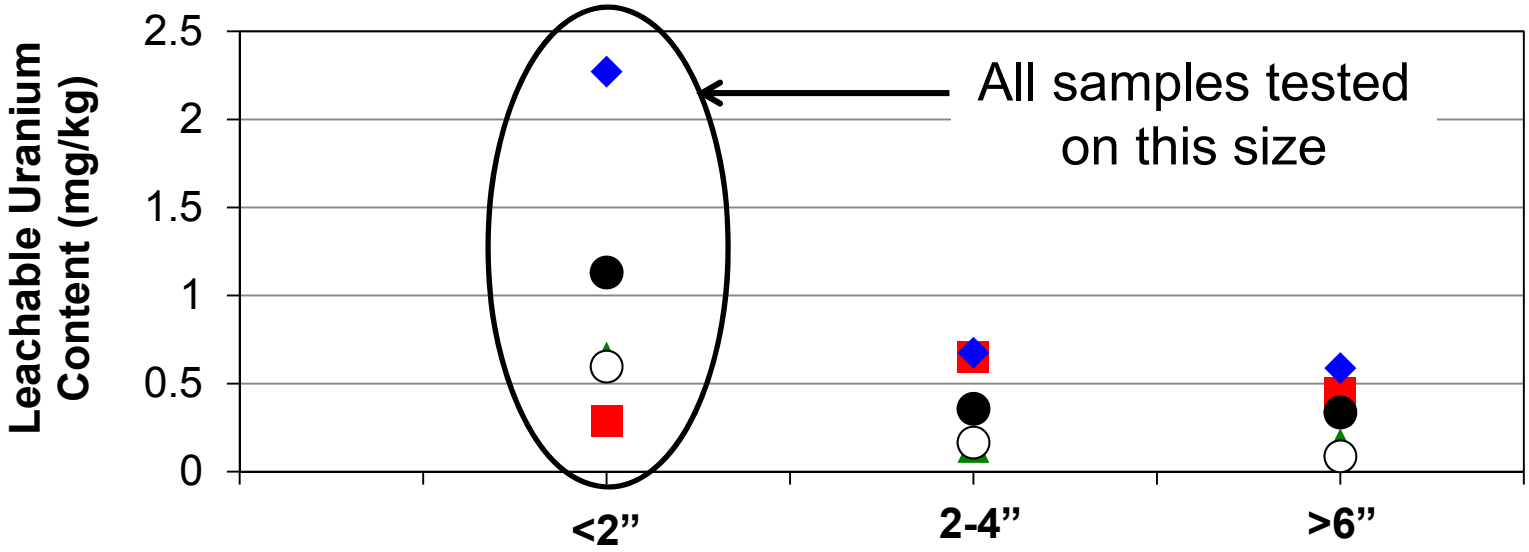
Grain Size Considerations



- Rock was 30 to 40% finer than 2”
- Typical decrease with increasing particle size

Parameter	Ratio Leachable Content <2-inch Dia. to >6-inch Dia.
Radium (Ra-226)	2.3
Sulphate (SO_4) [2]	3.6
Arsenic (As)	5.8
Lead (Pb)	5.5
Uranium (U)	4.6

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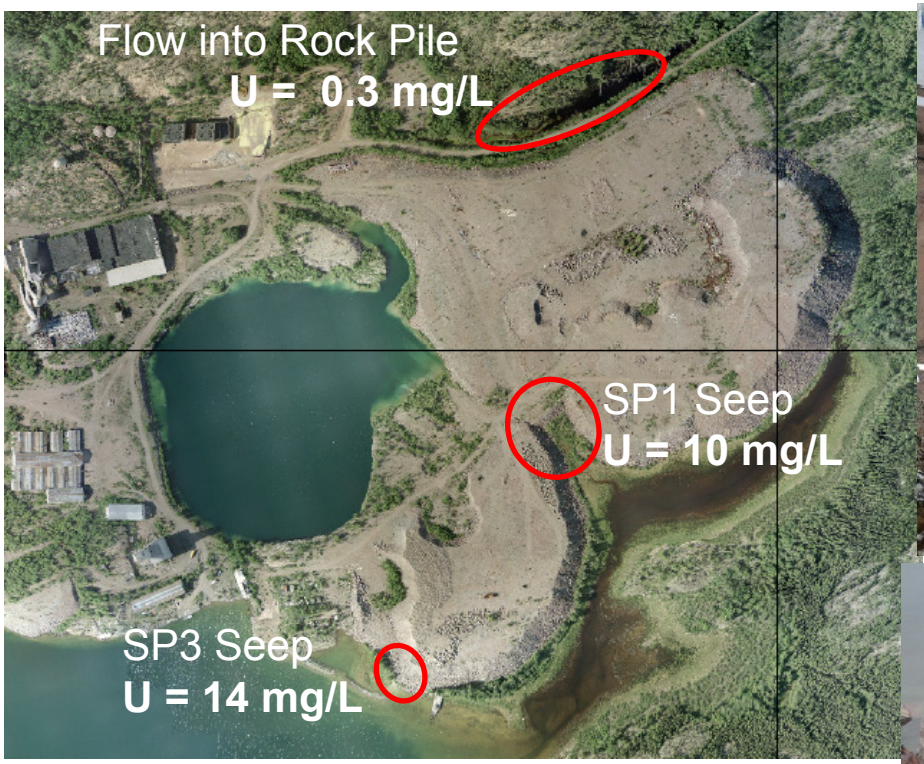
Waste Rock Seepage – SP1 and SP 3



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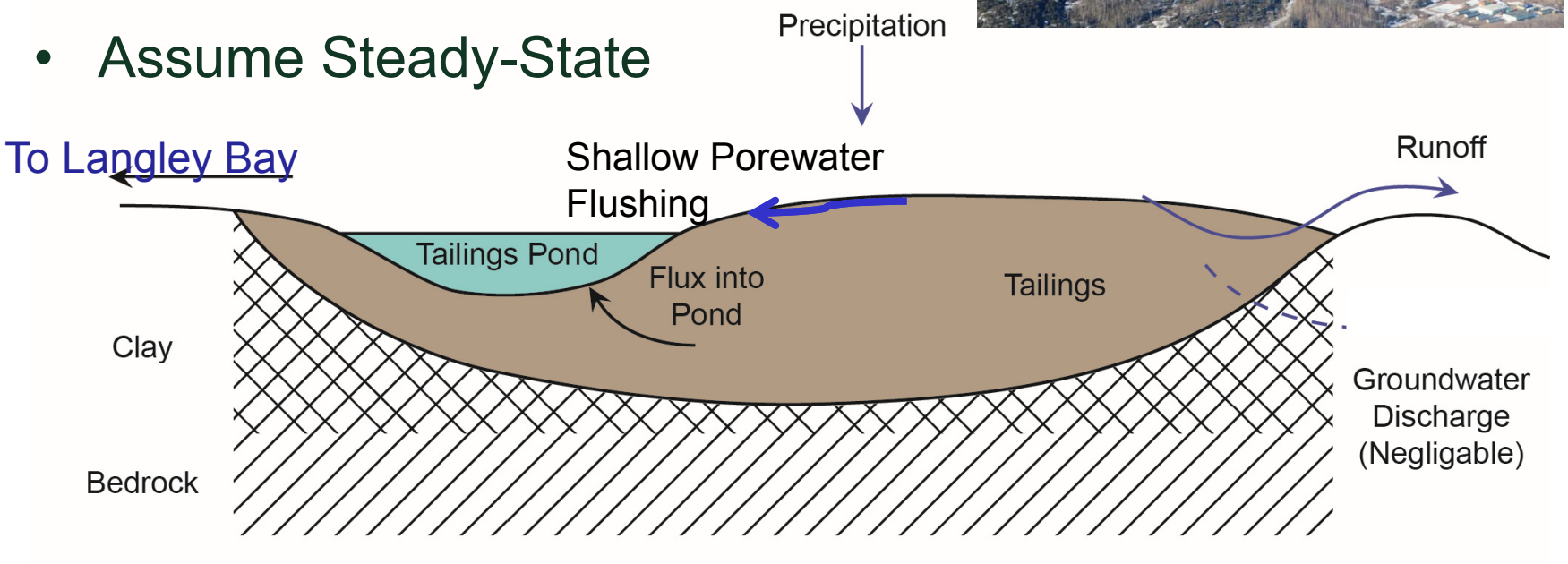
Main Tailings – Conceptual Model

- 50 Years of weathering
- Not acidic
- Assume Steady-State



- Majority of precipitation reports as runoff
- Key loadings out of tailings:
  - surface flushing of upper 10(s) of cm of tailings
  - Subsurface (groundwater) flow

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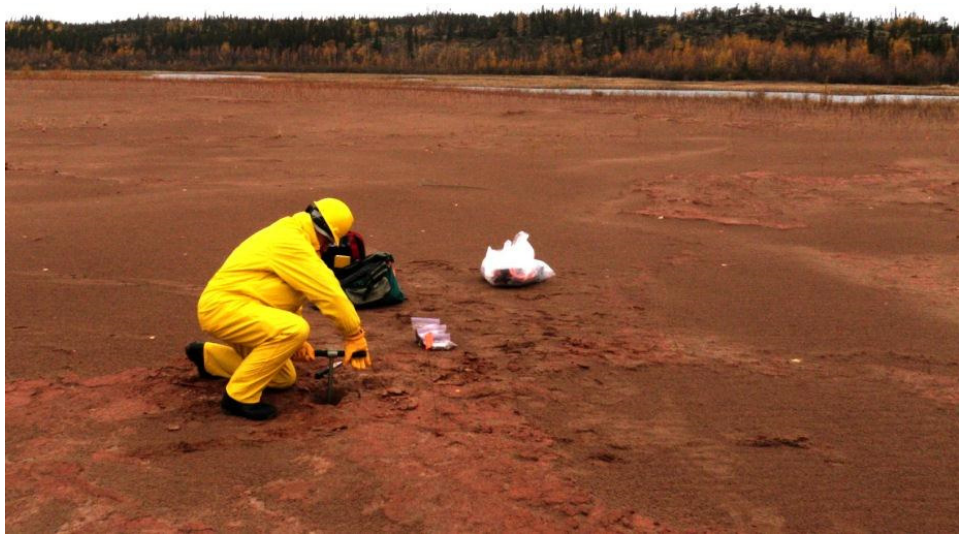
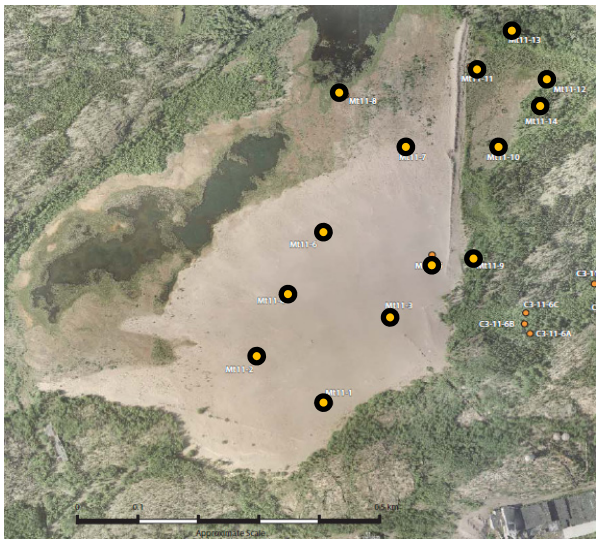
Gunnar Main Tailings – Solids Sampling

- Sampling by hand auger
- Depth intervals (bgs) of
  - 0-10 cm
  - 10-20 cm
  - 40-50 cm
  - 70-80 cm.
- Drive-point Piezos 1.5 mbgs





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Pore Water Concentrations in Gunnar Tailings

PARAMETER	Units	Main Tailings Area				Uncontained Tailings			
		Average	Minimum	Maximum	Median	Average	Minimum	Maximum	Median
Radium 226	**Bq/L**	80	18	218	80	85	2	375	43
Sulphate (SO_4)	**mg/L**	65,888	4,628	167,355	62,339	28,712	223	98,497	28,558
Arsenic (As)	**mg/L**	0.49	0.061	1.51	0.38	0.54	0.0029	5.19	0.10
Lead (Pb)	**mg/L**	0.15	0.0019	2.02	0.03	2.24	0.0029	18.51	0.13
Uranium (U)	**mg/L**	22.6	1.3	74.4	18.8	3.8	0.002	26.0	0.6

- Back calculation from SFE (mg/kg)
- Measured moisture content on each sample
- Sulphate over-estimated – artifact of Gypsum dissolution

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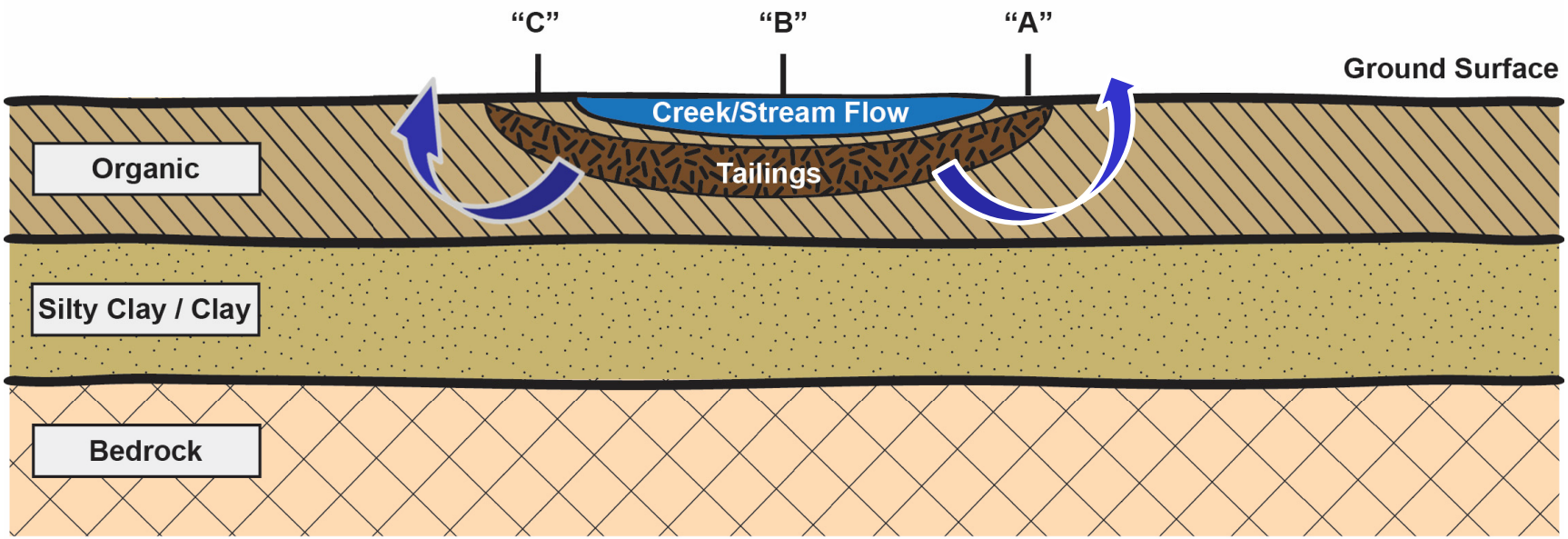
Uncontained Tailings – Conceptual Model

Generalized Cross Section



Drawing Not to Scale

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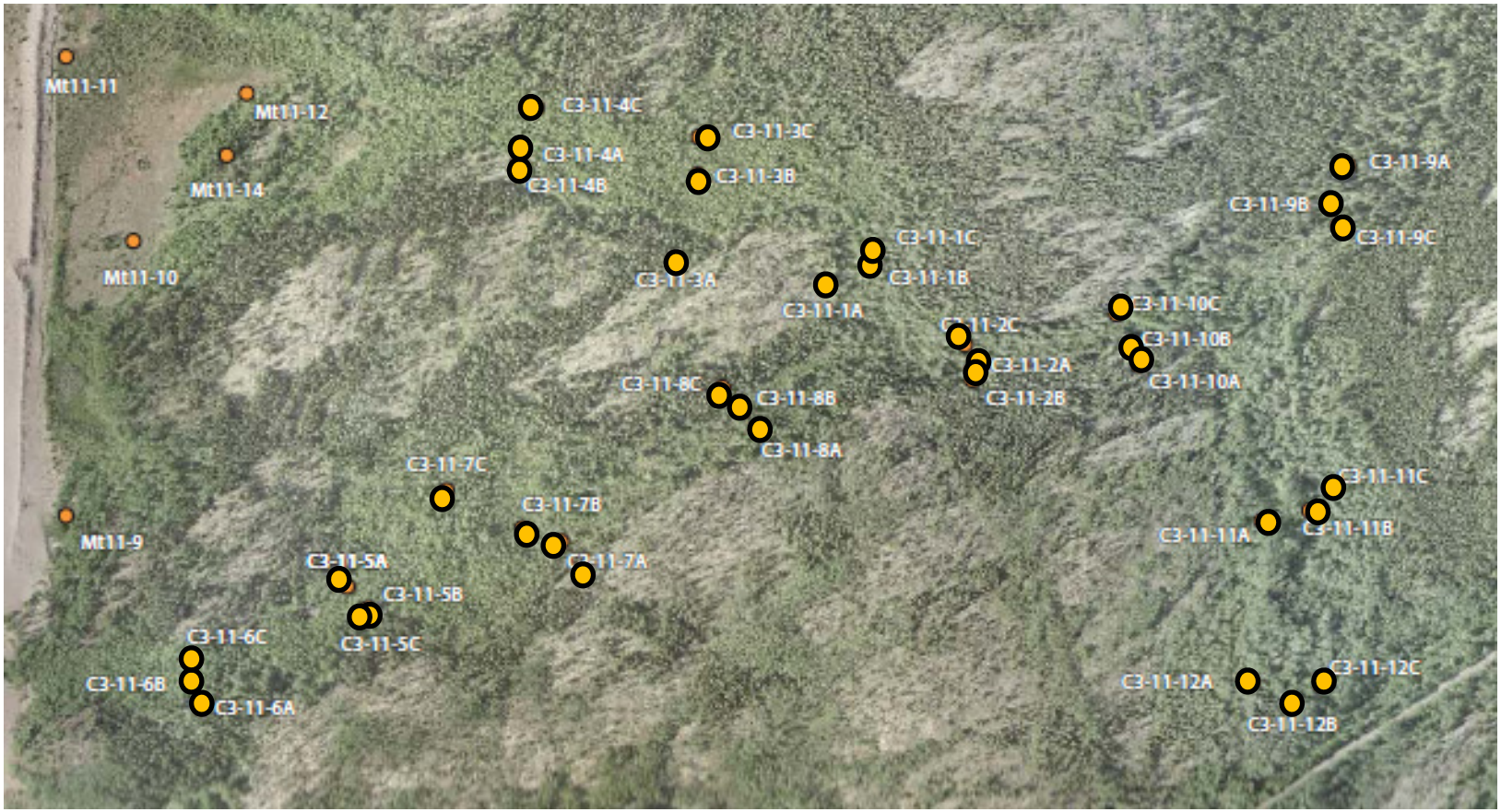
Uncontained Tailings – Sampling

- Samples collected at 12 stations along drainage path



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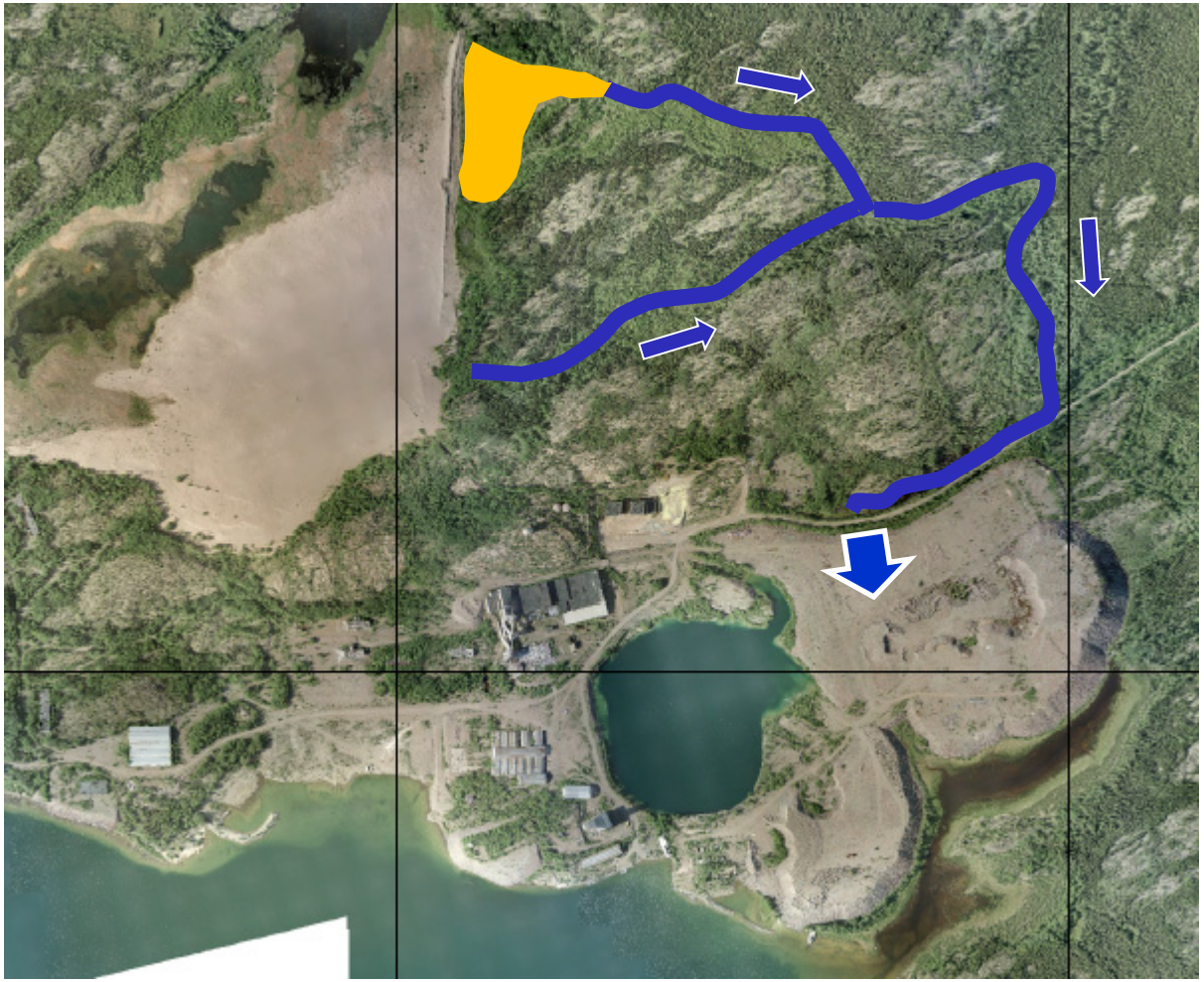
Uncontained Tailings – Flow Directions



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Pore Water Concentrations Uncontained Tailings

PARAMETER	Units	Uncontained Tailings			
		Average	Minimum	Maximum	Median
Radium 226	Bq/L	21.1	0.73	229	6.91
Sulphate (SO_4)	mg/L	3,464	40	62,359	565
Arsenic (As)	mg/L	0.054	0.002	0.42	0.020
Lead (Pb)	mg/L	0.50	0.005	8.97	0.068
Uranium (U)	mg/L	0.28	0.004	4.05	0.120

- Back calculation from SFE (mg/kg)
- Measured moisture content on each sample

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Loadings Assessment

Waste Rock:

- Load = Porewater Concentration x Infiltration Rate
  - » Corrected for grain size (except uranium)

Main Tailings:

- Load = Soluble Mass (top 10 cm) flushed each year
  - + Deep Porewater flow x Concentrations

Uncontained Tailings:

- Load = Soluble Mass Flushed each year

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Loadings Assessment - Median Concentrations

Parameter	Units	Waste Rock	Main Tailings (Runoff only)	Uncontained Tailings
Radium (Ra-226)	MBq/a	2,718	202	349
Arsenic (As)	kg/a	17	2.4	1.0
Lead (Pb)	kg/a	27	0.1	3.4
Uranium (U)	kg/a	295	58	6.1

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Integration Into Loadings Model

- Independent source term loadings estimates
- Combine with site flow rates
- **Validate** with extensive monitoring data

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MineMod™

- Mine-Mod developed in house in C++ and Graphic interface
- Provides a real time platform to facilitate proactive closure planning, review reclamation options and to ensure the most appropriate strategies are implemented
- Valuable tool for the mine design process (provides a means to assess operational/management practices)

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MineMod™

- Model is a combination of a database management system and calculation tool
- GIS-based in order to relate model and data components to geographical and site features
- User flexibility for the definition of source-term loading rates, site features and data import
- Time varied flows, loading rates, concentrations
- Real time processing of scenarios for round table meetings and regulator discussions/presentations

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Model Inputs

- Loadings model combined the quantified releases from individual sources at the site with flows (surface and subsurface)
- Inputs included
  - Results from mine waste geochemistry
  - Groundwater monitoring data
  - Surface water monitoring data
  - Seepage data
  - Baseline surface water chemistry
  - Hydrology
  - Hydraulic exchange rate between the Lake and the Bays

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Source Term Overview

- 4 surface tailings deposits and 1 submerged
- Uncontained (spilled) tailings and floodplain deposits in drainage creek
- Two large waste rock stockpiles, as well as fill material present throughout the property
- Flooded pit

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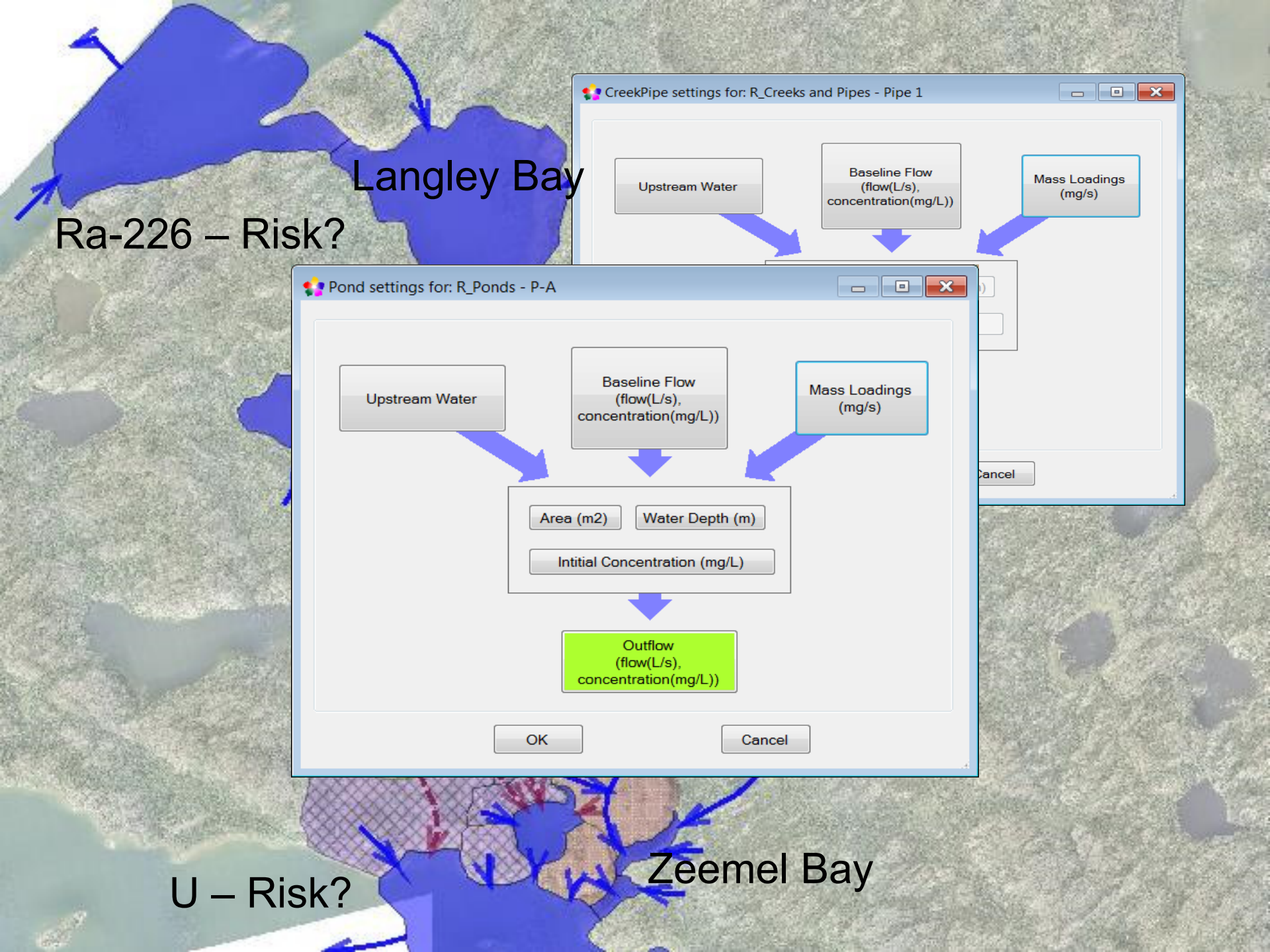
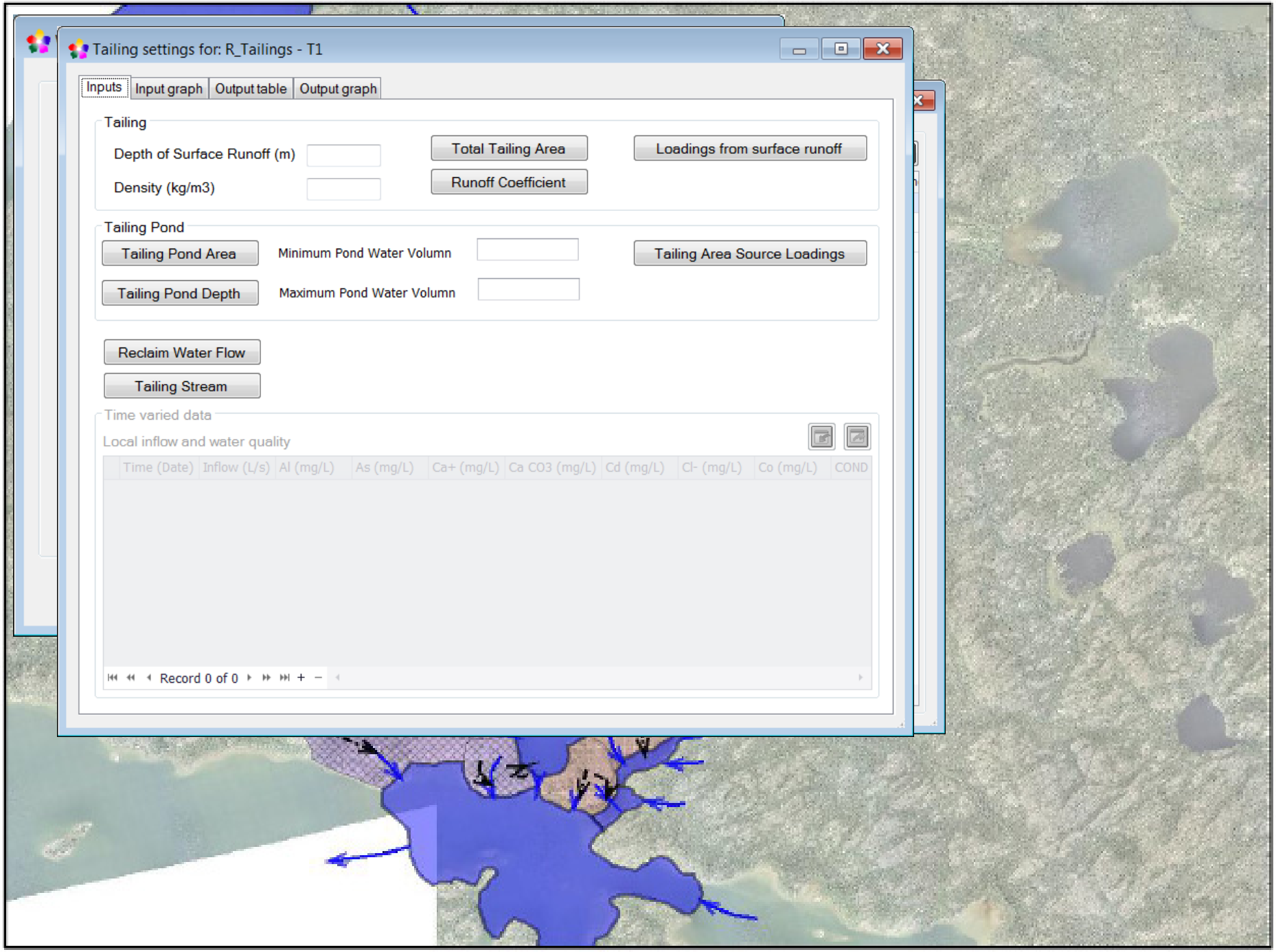

Langley Bay
Ra-226 – Risk?
CreekPipe settings for: R_Creeks and Pipes - Pipe 1
Upstream Water
Baseline Flow (flow(L/s), concentration(mg/L))
Mass Loadings (mg/s)
Cancel
Pond settings for: R_Ponds - P-A
Upstream Water
Baseline Flow (flow(L/s), concentration(mg/L))
Mass Loadings (mg/s)
Area (m2)
Water Depth (m)
Intitial Concentration (mg/L)
Outflow (flow(L/s), concentration(mg/L))
OK
Cancel
Zeemel Bay
U – Risk?


Tailing settings for: R_Tailings - T1
Inputs
Input graph
Output table
Output graph
Tailing
Depth of Surface Runoff (m)
Density (kg/m3)
Total Tailing Area
Runoff Coefficient
Loadings from surface runoff
Tailing Pond
Tailing Pond Area
Tailing Pond Depth
Minimum Pond Water Volumn
Maximum Pond Water Volumn
Tailing Area Source Loadings
Reclaim Water Flow
Tailing Stream
Time varied data
Local inflow and water quality
Time (Date)
Inflow (L/s)
Al (mg/L)
As (mg/L)
Ca+ (mg/L)
Ca CO3 (mg/L)
Cd (mg/L)
Cl- (mg/L)
Co (mg/L)
COND
Record 0 of 0

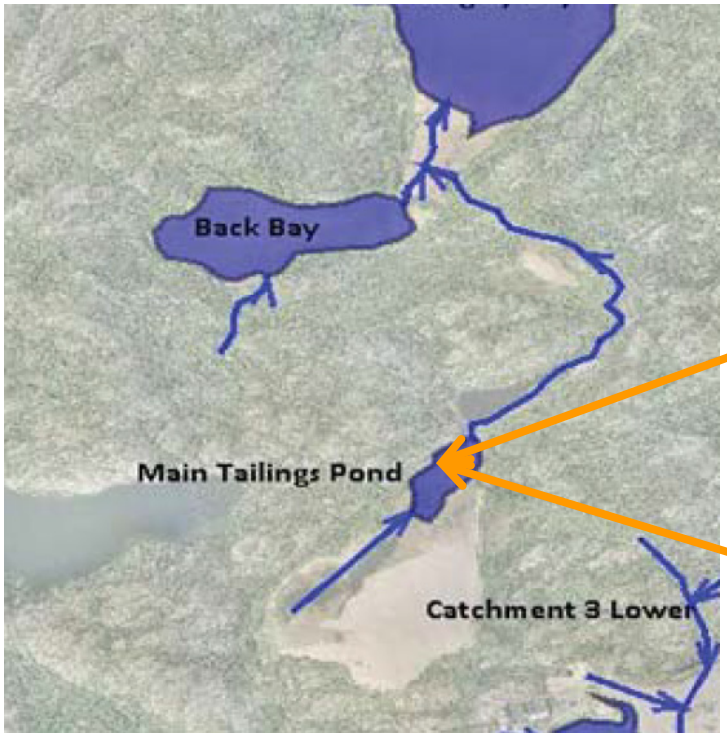
Basecase Scenario

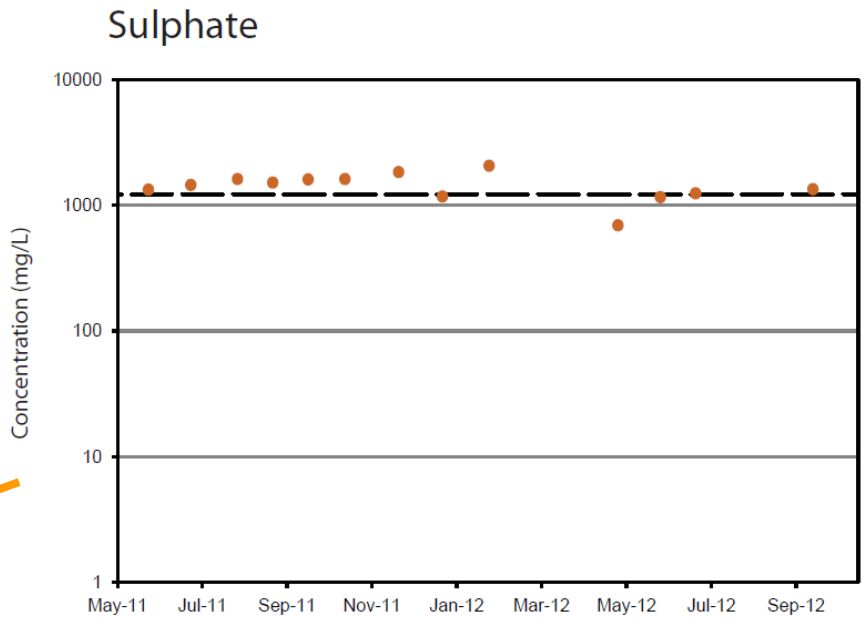
- Primary objective to evaluate loading rates to key receiving waterbodies
- Basecase developed for the status quo and used as a benchmark for sensitivity analyses
- Used the 50th percentile of loadings values
- Validated using extensive monitoring data for the site
- Reasonable prediction of observed water quality when independently derived sources incorporated

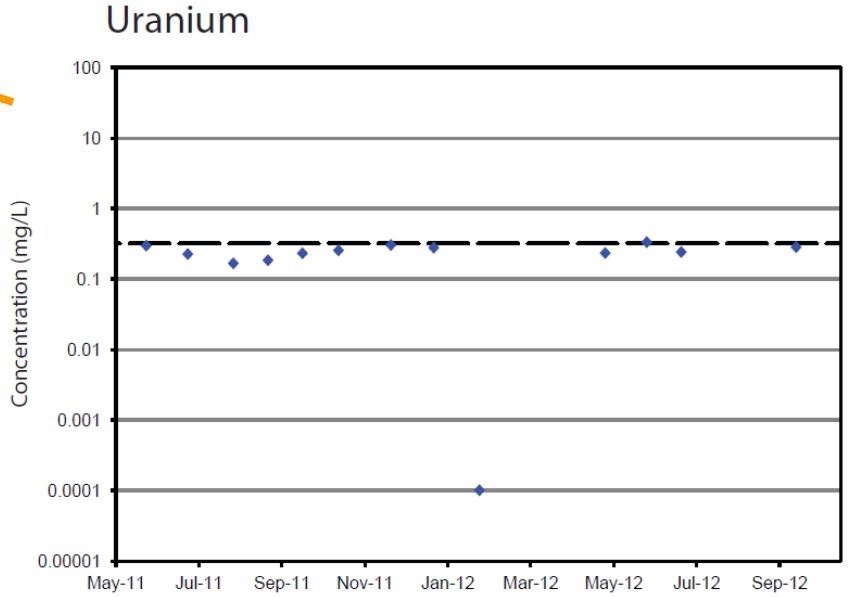
Parameter	Concentration (mg/L; Bq/L)						
	Water Quality Guideline [1]	Site-specific Remedial Objective[2]	Minimum [3]	Geometric Mean [3]	Median [3]	Maximum [3]	Predicted
Arsenic (As)	0.005	0.1	0.0002	0.00027	0.0003	0.0003	0.0002
Cadmium (Cd) [4]	0.000014	0.0003	0.00001	0.000037	0.00001	0.001	0.0001
Lead (Pb) [4]	0.0010	0.013	0.0001	0.00017	0.00010	0.0020	0.0001
Radium-226 (Ra-226) [5]	0.11	-	0.090	0.12	0.12	0.17	0.11
Sulphate (SO_4) [6]	100	-	6	7	7	14	7
Uranium (U)	0.015	0.09	0.0006	0.001	0.001	0.002	0.001

Basecase Scenario

Comparison of Predicted Results to Measured SW Values







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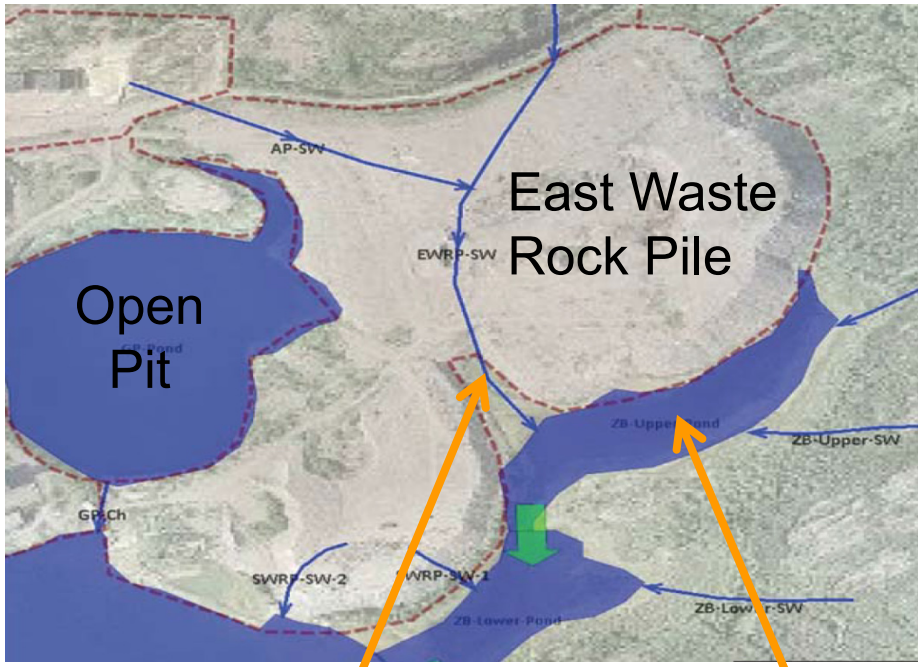
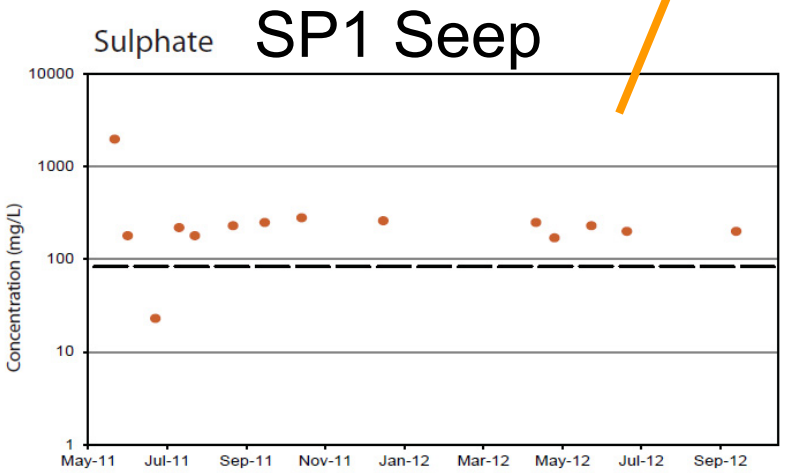
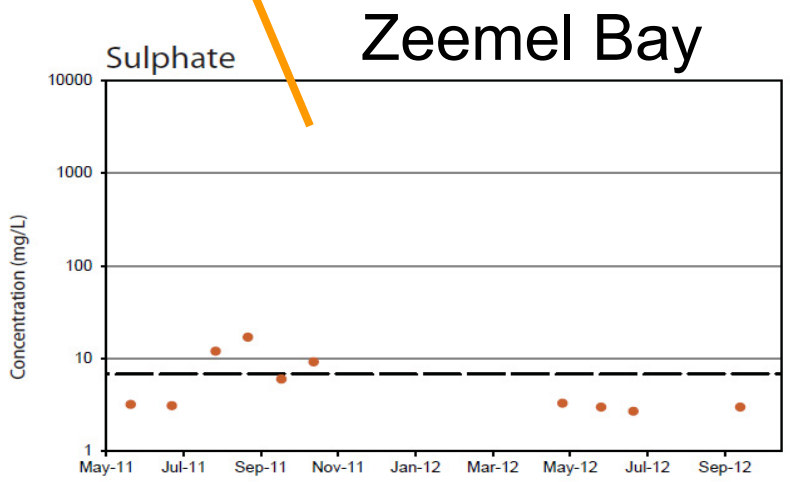
Basecase Scenario

Comparison of Predicted Results to Measured SW Values

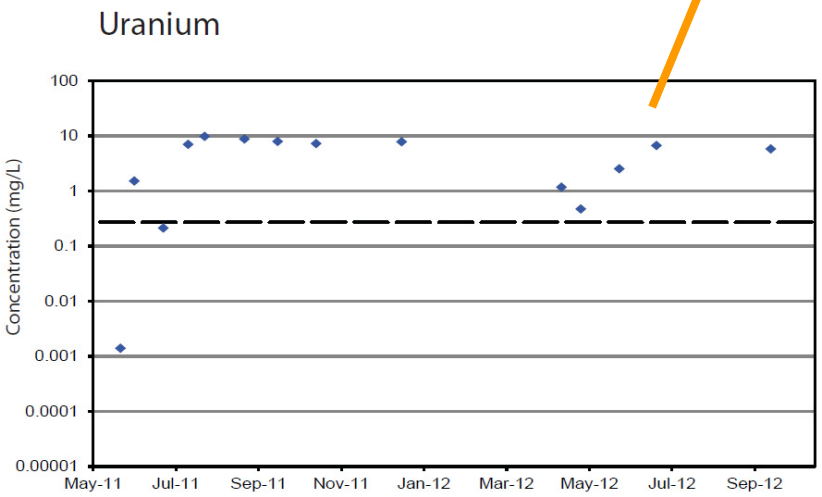


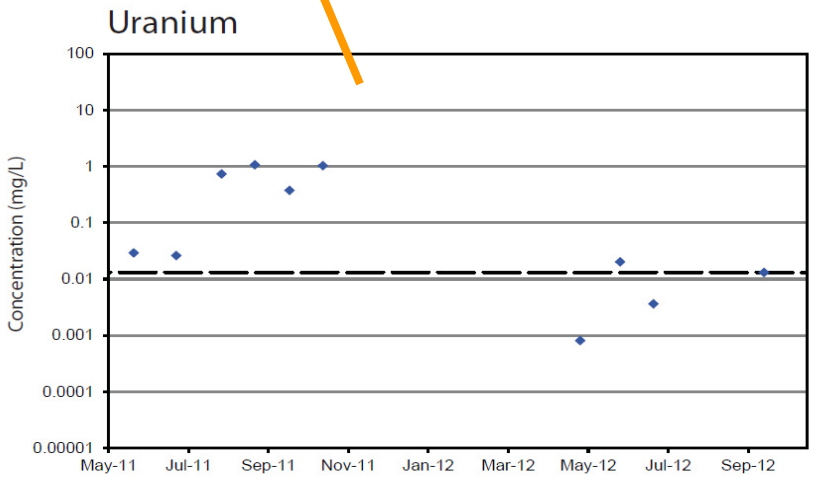




Basecase Scenario

Comparison of Predicted Results to Measured WR Seepage





Sensitivity Scenarios
Waste Rock Piles

- Several scenarios developed to investigate the under-estimation of uranium in surface water down-gradient from the WRPs

Loading rates from the WRP's were adjusted using:

- 10th percentile porewater concentrations
- 90th percentile porewater concentrations
- Arithmetic average porewater concentrations

- 50th percentile porewater concentrations, ***no grain size correction***
- 10th percentile porewater concentrations, ***no grain size correction***
- 90th percentile porewater concentrations, ***no grain size correction***

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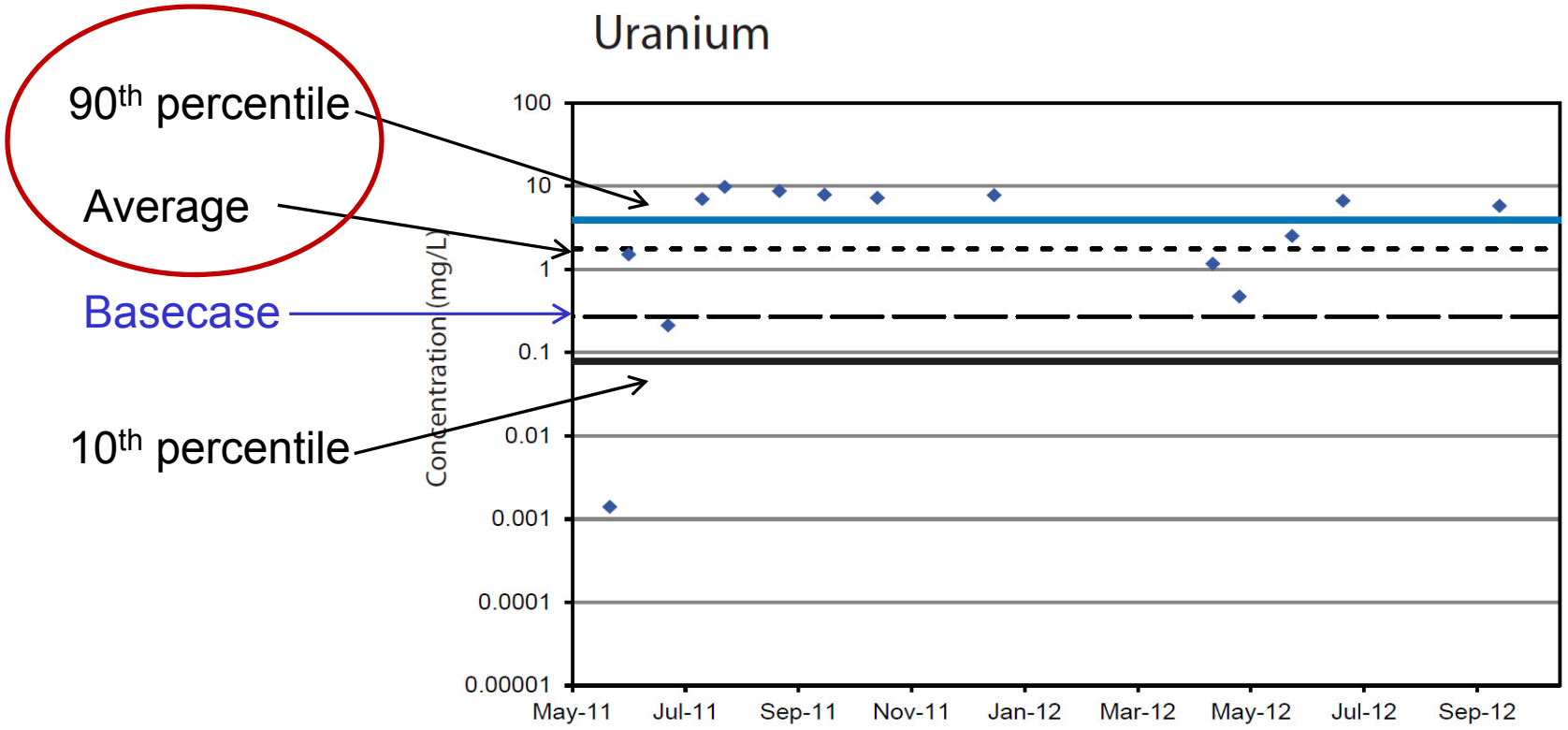
Sensitivity Scenarios

Waste Rock Piles – Loading Rates



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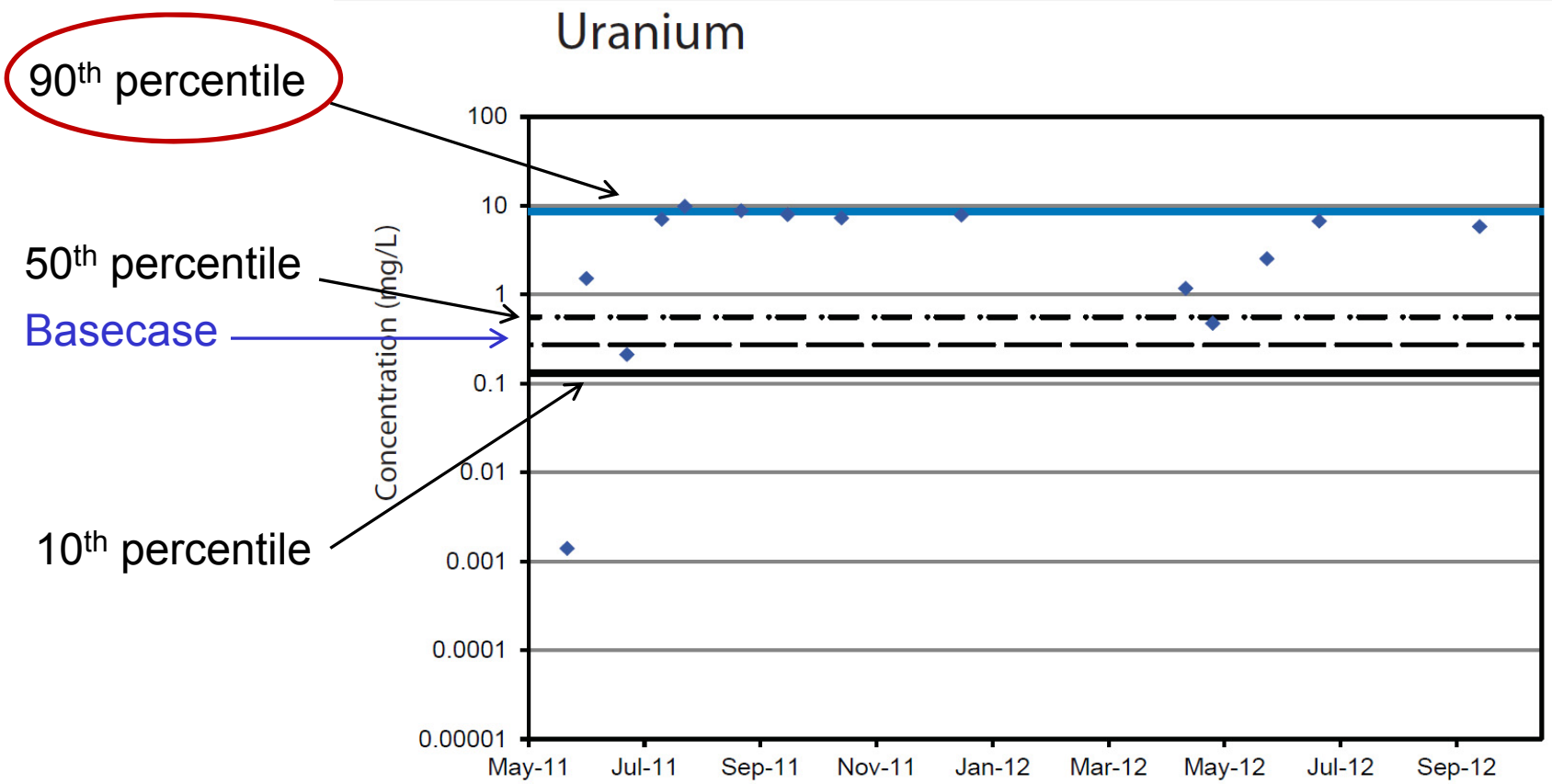
Sensitivity Scenarios

Waste Rock Piles – Grain Size Correction



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Sensitivity Scenarios

Waste Rock Piles

- Results indicate that upper bound loading rates are required to resolve measured surface water values
- Uranium may be controlled by an equilibrium reaction within the WRP
- Solubility of uranium is not expected to be a function of particle size

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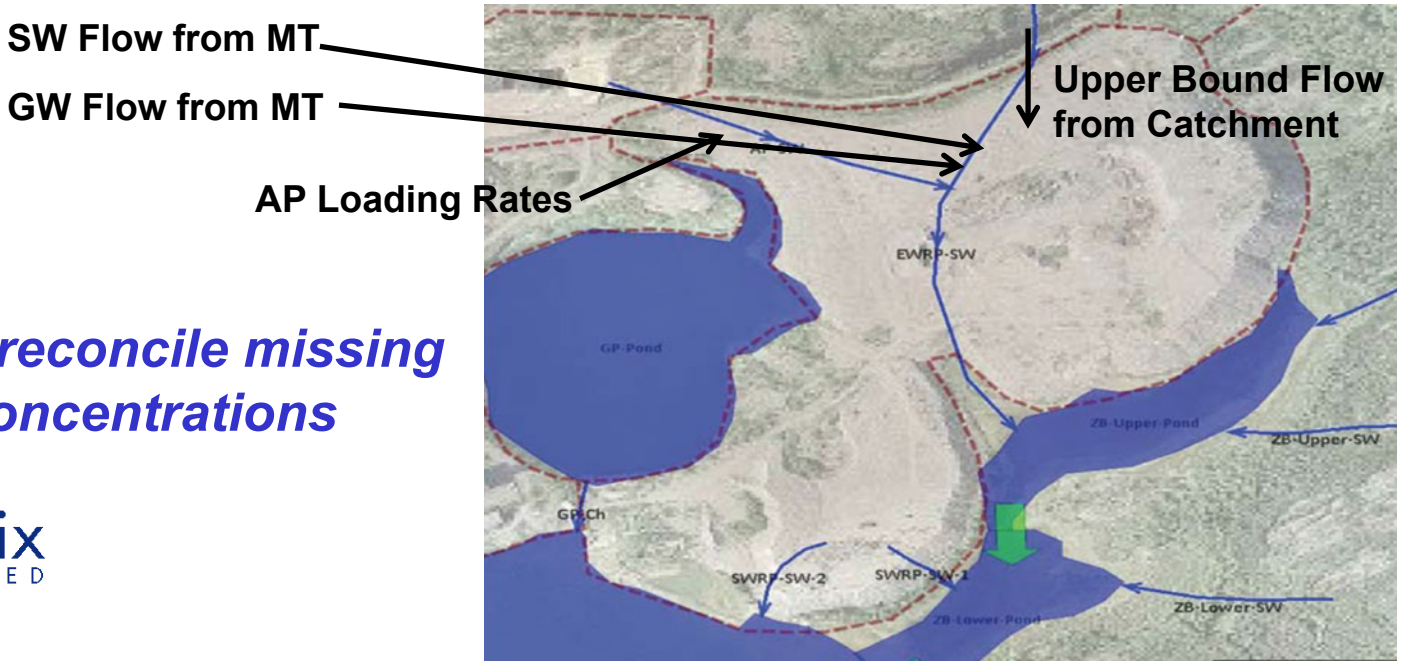
Sensitivity Scenarios

Several *additional scenarios* were developed to investigate sources of uranium in surface water down-gradient from the WRPs:

- Upper bound SW flow rates reporting to the WRP
- Upper/Lower bound loading rates from the Acid Plant area
- Surface water flow pathway from the Main Tailings
- Upper bound GW flow rate from the MT to the AP



Could not reconcile missing uranium concentrations

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Summary

- Loadings model was able to reasonably predict the observed concentrations of COPCs in receiving waterbodies when *independently derived sources incorporated*
- Provides a path forward in assessing potential remediation strategies and subsequent trade off studies
- However, data suggest that there may be uranium loadings that are unaccounted for in the recognized sources on site
- The uranium load from the WRP's is likely underestimated by the median porewater concentrations
- Potential solubility control and/or source within or up-gradient of the footprint of the WRP

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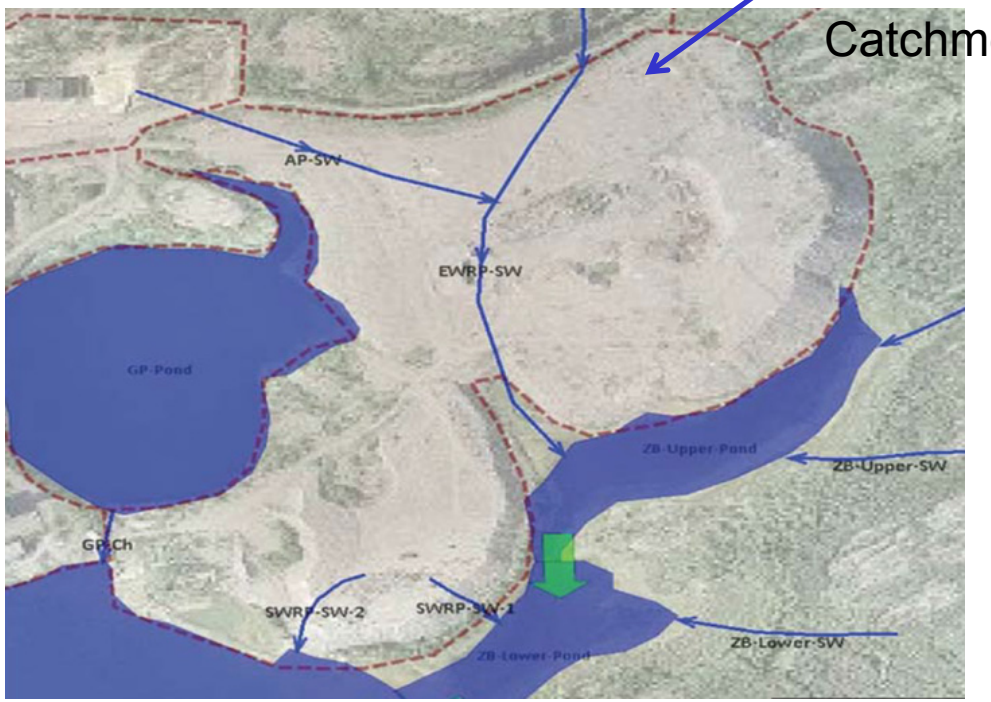
Recommendations

- Flows reporting to the seepage locations surrounding the WRP's be further quantified
- Flow originating from the catchment up gradient of the WRP be investigated
- Acid Plant site be further investigated wrt flow direction and chemistry

~200,000 m^3/a report to the WRP from Catchment above



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Conclusions

- Appropriate data collection and interpretation is necessary to characterize mine sources
- Holistic approach to site wide loadings allows for focus on priority sources and closure measures
- Becomes a useful communication tool when evaluating site aspects with regulators/industry

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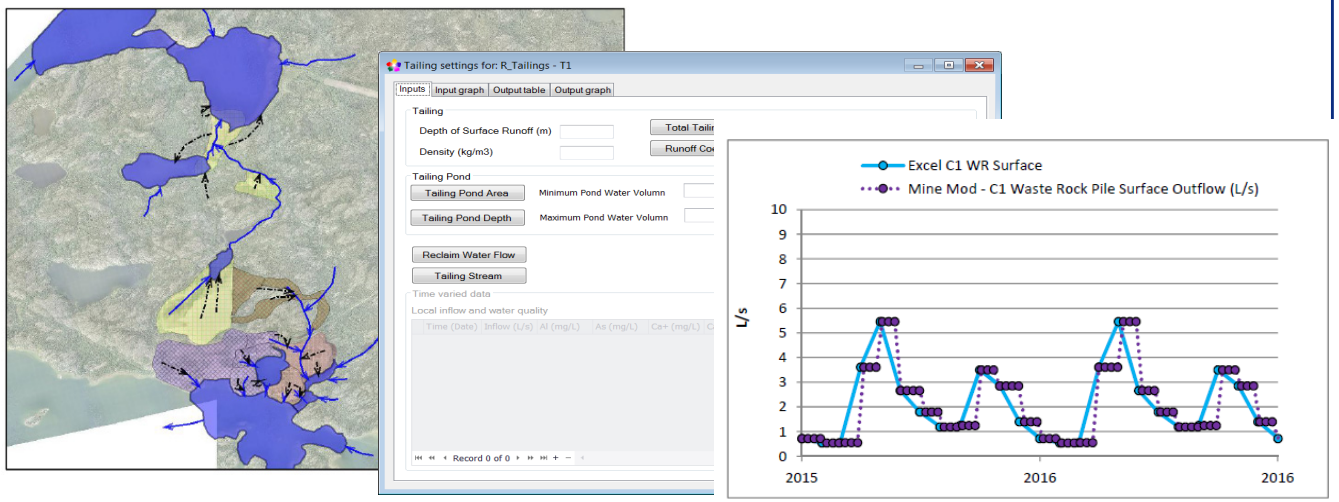
Thank you for you attention!

Questions?



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