Case Studies that Illustrate the Benefits, Limitations and Information Requirements of Geochemical Modelling

Jeff Martin
Gerd Wiatzka
Jeno Scharer
Bruce Halbert
of
SENES Consultants Limited

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Background

- Ontario Mine Rehabilitation Code states that BC Guidelines are to be followed for ML/ARD assessment
- CANMET requested comments for update to *Guidelines and Recommended Methods for the Prediction of Metal Leaching and Acid Rock Drainage*
- SENES commented with respect to geochemical modelling, as 1998 guideline gave didn't fully address benefits
- This presentation will address benefits and limitations

Geochemical Modelling - SENES

- 1986 UTAP – Uranium Tailings Assessment Program for NUTP
- 1989 RATAP – Reactive Acid Tailings Assessment Program for MEND
- 1992 ACIDROCK and ROCKSTAR
  - SENES models
  - Updated periodically
- ROCKSTAR – dynamic geochemical model – multi-nodal – up to 20 interconnected, layered compartments
  - Waste rock, tailings, pits, underground mines

ROCKSTAR

- Considers:
  - Acid generation due to biological and chemical oxidation of sulphides
  - Diffusion of oxygen into wastes
  - Convection of oxygen into wastes
  - Production and transport of heat
  - Metal leaching
  - Transport of dissolved chemical species
  - Dissolution of buffering minerals
  - Formation of secondary minerals
  - Solubility of solid phases (precipitates, minerals)
  - Speciation of dissolved constituents
  - pH
  - Solid solutions, adsorption of metals, co-precipitation

ROCKSTAR

- Monthly time steps
- Initial inventory module
- Kinetics module
  - Sulphide oxidation and dissolution of buffering
- Transport module
  - Oxygen, temperature, solute
- pH calculation and aqueous ions speciation module
  - pH, buffering minerals, co-precipitates, solid solutions
- Trace metals and radionuclides module
- Material balance module
- Acidity module

General Approach to Mathematical Prediction

- Identify objectives
- Collect and review data
- Select models
- Prepare inputs
- Calibrate model to field data
- Perform simulations
- Interpret
  - Identify controlling processes
  - Compare to concentrations at similar sites
  - Compare to estimates using alternate approach

Benefits

- provide insight into potential future conditions
- determine which variables are most important in determining future conditions
- assess the effects of alternative approaches to decommissioning
- assess the potential effects of not knowing one or more parameters very well (sensitivity and uncertainty analysis)
- direct field and laboratory studies to provide the information necessary to make decisions, for example, regarding the effects of alternative closure options
- Integrates available information to predict what could happen
  - EAs

Limitations

- Insufficient data
- Can be challenging and can be misinterpreted
  - What is the alternative?
  - Essential that limitations of the predictive methods be clearly described and that model predictions be evaluated
- Uncertainty and variability
  - Deterministic vs. probabilistic modelling – Monte Carlo analysis
- Important that potential sources of uncertainty in predictive models be described and where practical evaluated quantitatively
- Guidance for practitioners, industry and regulators on alternative methods of evaluation, when they might be applied and how to address uncertainties is needed.
- Model versus actual conditions

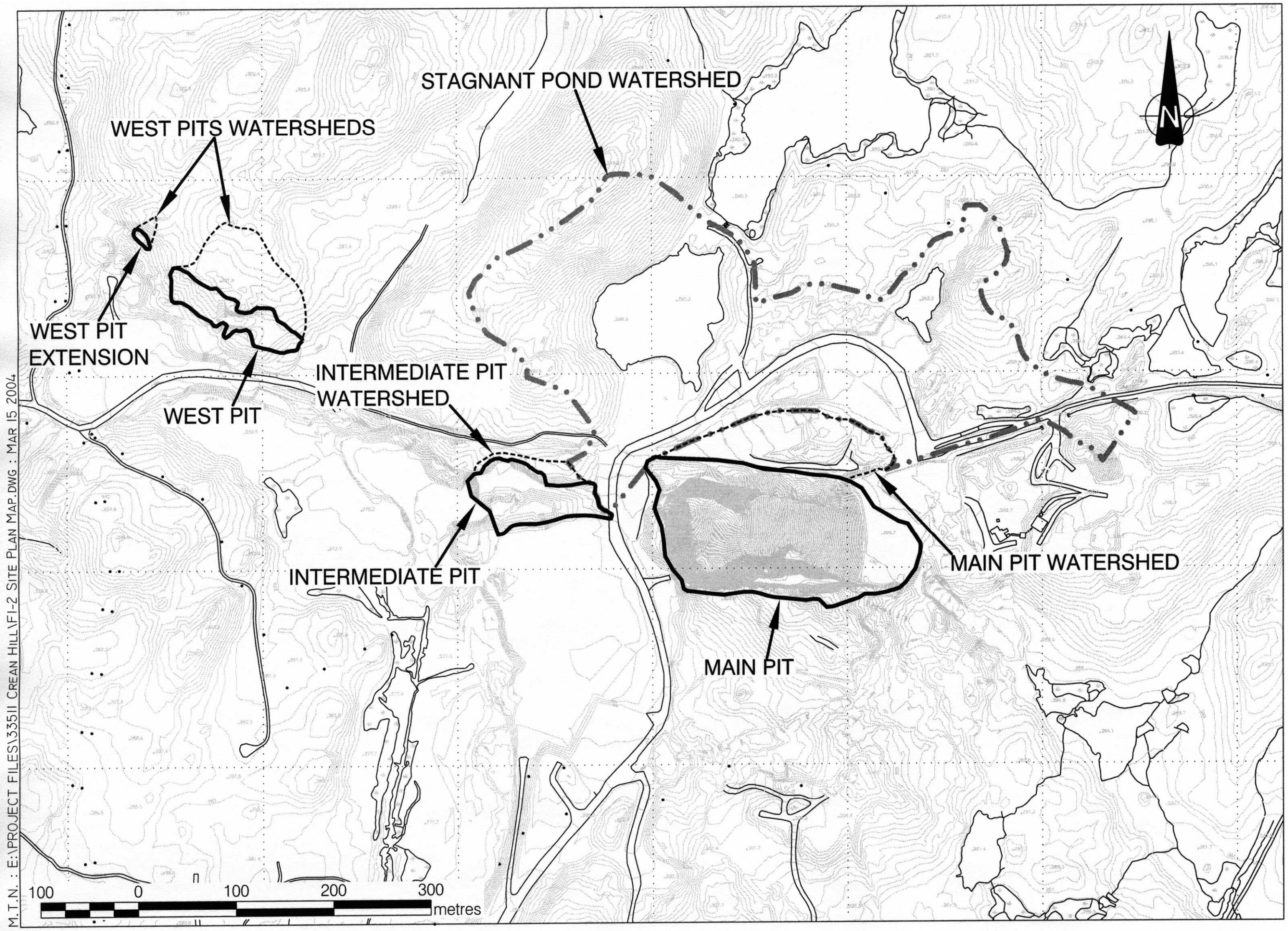
Information Requirements

- Climate
- Hydrology
- Hydrogeology
- Water Quality
- Physical Layout
- Waste characteristics
- Cover characteristics
- Management alternatives

Case Study – Crean Hill Mine

- Located 28 km west of Sudbury, Ontario
- Mined from 1970s to 2002
- South Range nickel-copper contact deposit, underground and open pits
- 3 pits connected to underground workings: West, Main, and Intermediate
- Pits being backfilled with acidic waste rock from various sources – lime added

CREAN HILL MINE SITE AND PIT WATERSHEDS



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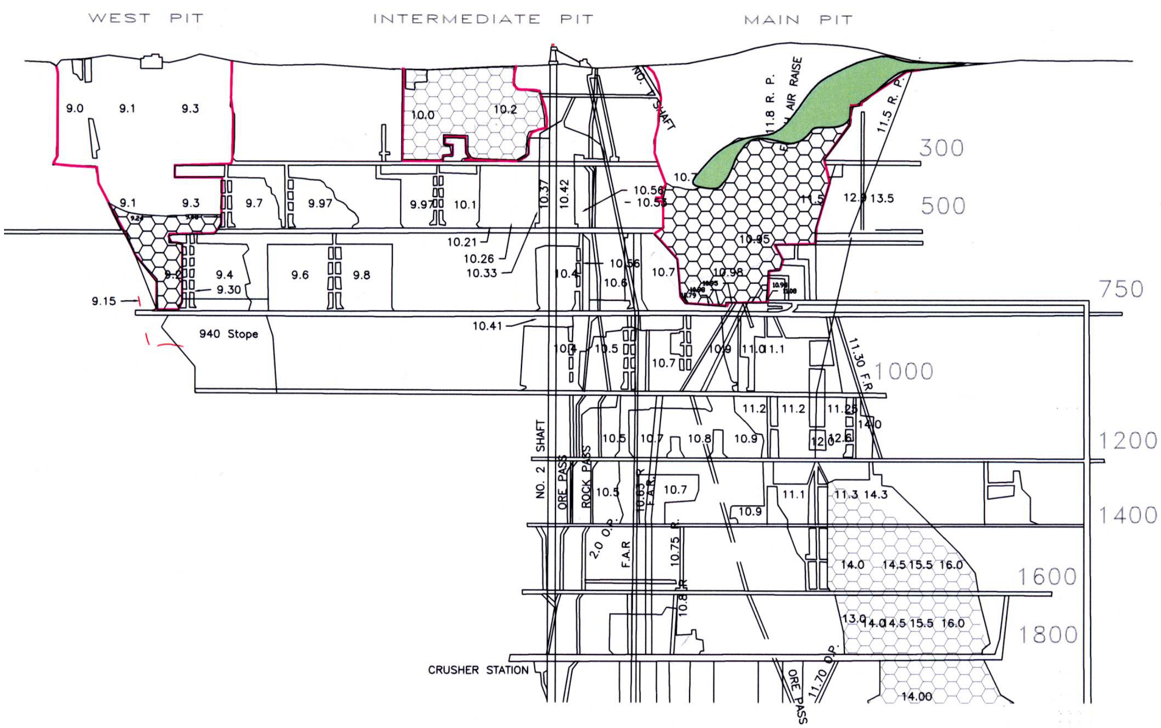
Crean Hill waste rock relocation

Crean Hill waste rock relocation



LEGEND:

OPEN PIT/GLORY HOLE OUTLINES PROVIDED BY INCO LIMITED

FILLED LEVELS PROVIDED BY INCO LIMITED
(FROM MAY 2001 BASE AERIAL PHOTOGRAPH)

FILL LEVELS TAKEN FROM ENGINEERING SECTIONS
(UPDATED JANUARY 2002)

REFERENCES:

THIS DRAWING IS BASED ON CREAN HILL MINE SURFACE PITS LONGITUDINAL CROSS-SECTION, DATED APRIL 29, 1993, (CH-OPIT.DWG).

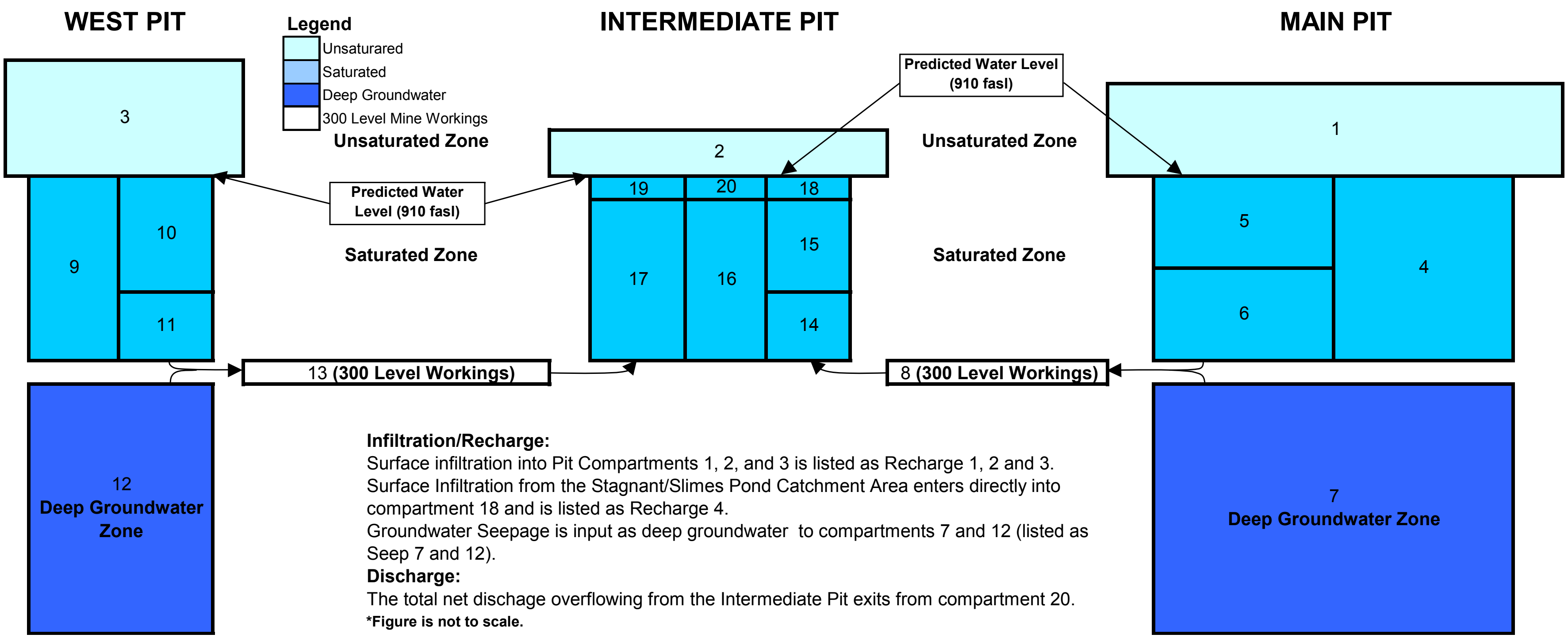
500 0 500 1000

SCALE: 1" to 500' FEET

Modelling Approach

- 3 pits and 3+ compartments in each: unsaturated zone, hydraulically active saturated zone, and inactive deep groundwater zone
- Flow from West and Main pits to Intermediate pit at 300 Level (bottom of active zone
- Minimal contribution below 300 Level

CONCEPTUAL FLOW MODEL OF THE CREAN HILL MINE: CROSS-SECTION OF THREE PITS LOOKING NORTH



Infiltration/Recharge:
Surface infiltration into Pit Compartments 1, 2, and 3 is listed as Recharge 1, 2 and 3.
Surface Infiltration from the Stagnant/Slimes Pond Catchment Area enters directly into compartment 18 and is listed as Recharge 4.
Groundwater Seepage is input as deep groundwater to compartments 7 and 12 (listed as Seep 7 and 12).
Discharge:
The total net dischage overflowing from the Intermediate Pit exits from compartment 20.
***Figure is not to scale.**

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Waste Characterization

- physical characteristics: grain-size distribution, porosity, unsaturated water content, and oxygen diffusion coefficient
- Geochemical characteristics:
  - whole rock
  - Nitric acid and hydrogen peroxide extraction with hydrochloric acid: indication of the total leachable metals, including metals associated with secondary precipitates and primary sulphides
  - Acid base accounting (ABA): interpreted to estimate the sulphide content, sulphate content, carbonate content, and net neutralization potential
  - Hydroxylamine hydrochloride (HHCl) extraction: data provide a relative measure of the readily leachable metals associated with reducible oxides such as iron and manganese-oxyhydroxides
  - Distilled water extraction (DWE): extracted metals and sulphate data provide an estimate of the pore-water conditions prevalent in the waste rock prior to liming as well as the leachability of metals and sulphate
  - Rinse pH: used to assess the geochemical conditions of the waste rock during sampling in the field, prior to liming
  - Mineralogy
  - Could also use dynamic test results

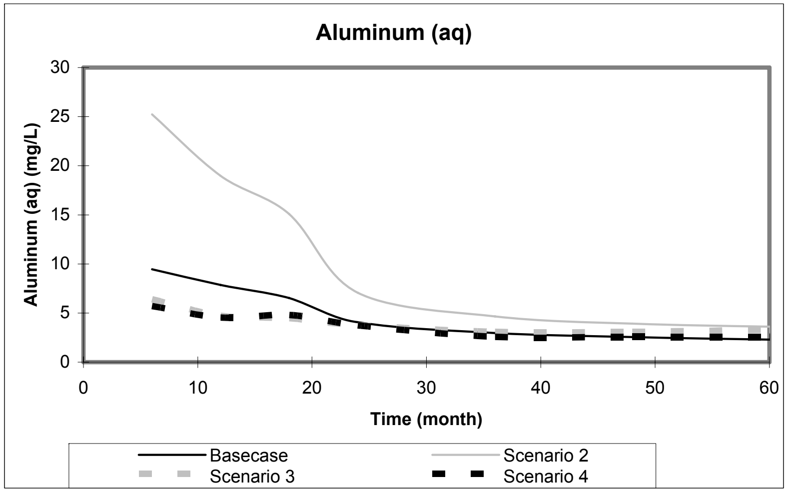
Scenarios Modelled

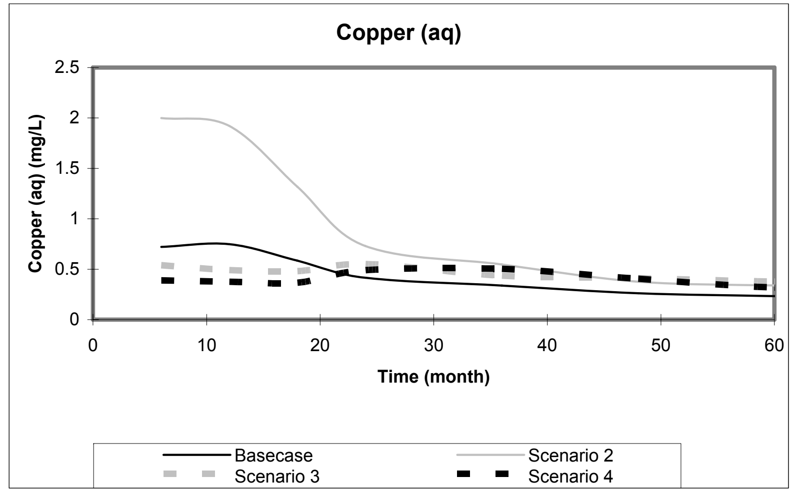
- 4 scenarios modelled to consider effects of run-off diversion and cover options on water quality
- Scenarios chosen to cover a range of infiltration rates that are reasonably achievable

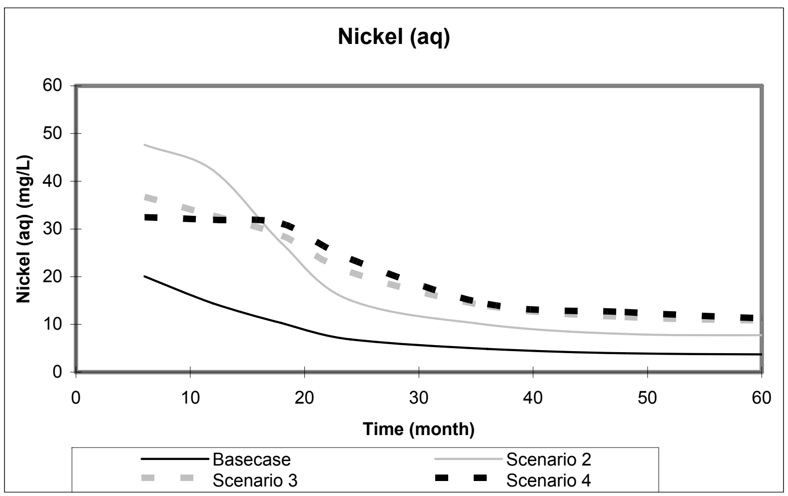
Scenarios – Crean Hill

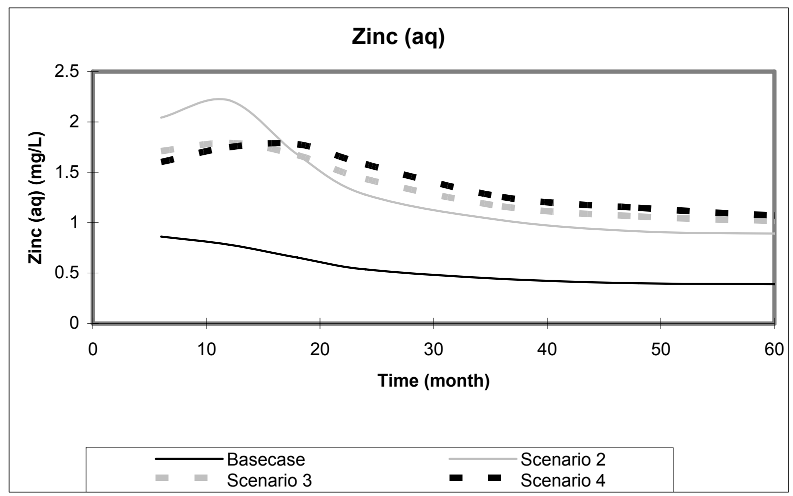
1. Uncovered pits with no diversion of runoff. It was assumed that 60% of precipitation falling directly on the uncovered pits will infiltrate, and that 60% of precipitation on the pit catchments will flow into the pits. It is assumed that no runoff would be diverted from the pits.
2. Same as Scenario 1, however 100% of the Stagnant-Slimes Pond Catchment was assumed to be diverted away from the Intermediate Pit.
3. Cover Scenario 1: Stagnant-Slimes Pond Catchment diverted 100%. 50% diversion of runoff from each pit catchment. Infiltration through the pit surface area reduced by 50% (equivalent to 30% of precipitation).
4. Cover Scenario 2: Stagnant-Slimes Pond Catchment diverted 100%. 50% diversion of runoff from each pit catchment. Infiltration through the pit surface area reduced by 75% (equivalent to 15% of precipitation).

PREDICTED WATER QUALITY FOR THE INTERMEDIATE PIT OVERFLOW SHORT TERM









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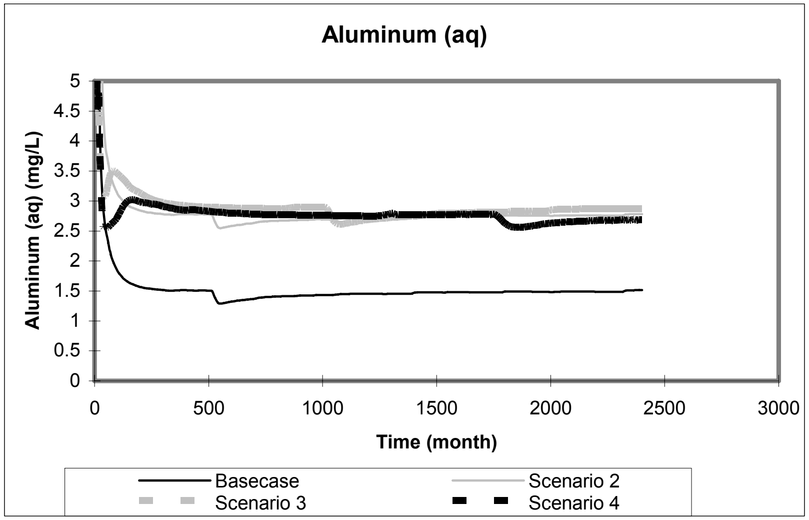
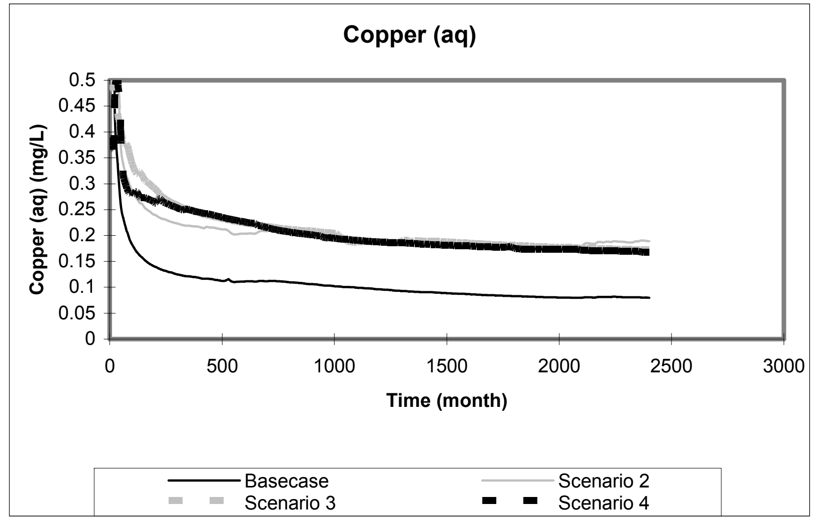
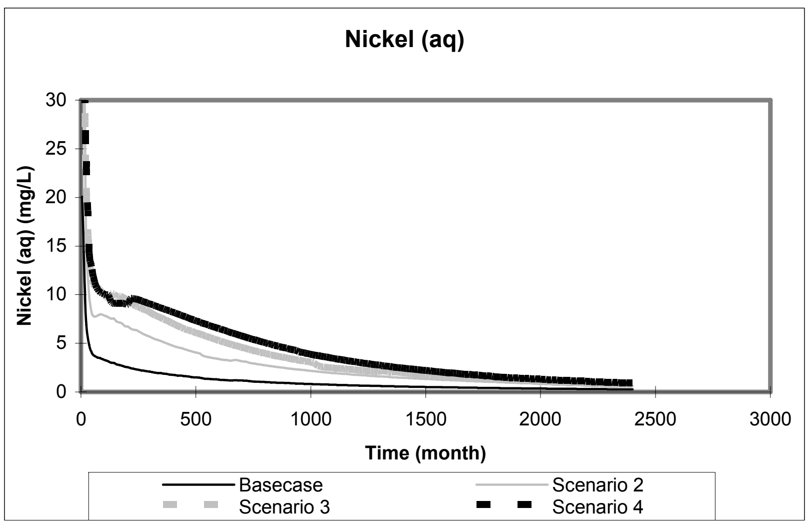
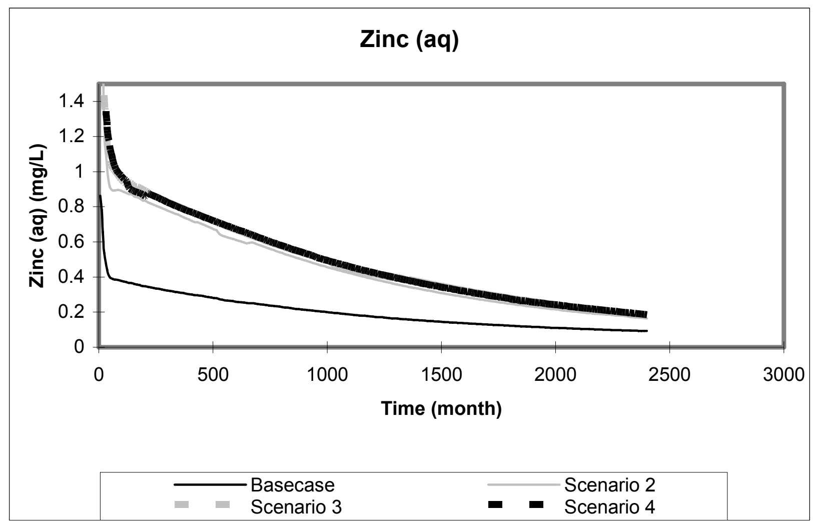
PREDICTED WATER QUALITY FOR THE INTERMEDIATE PIT OVERFLOW LONG TERM









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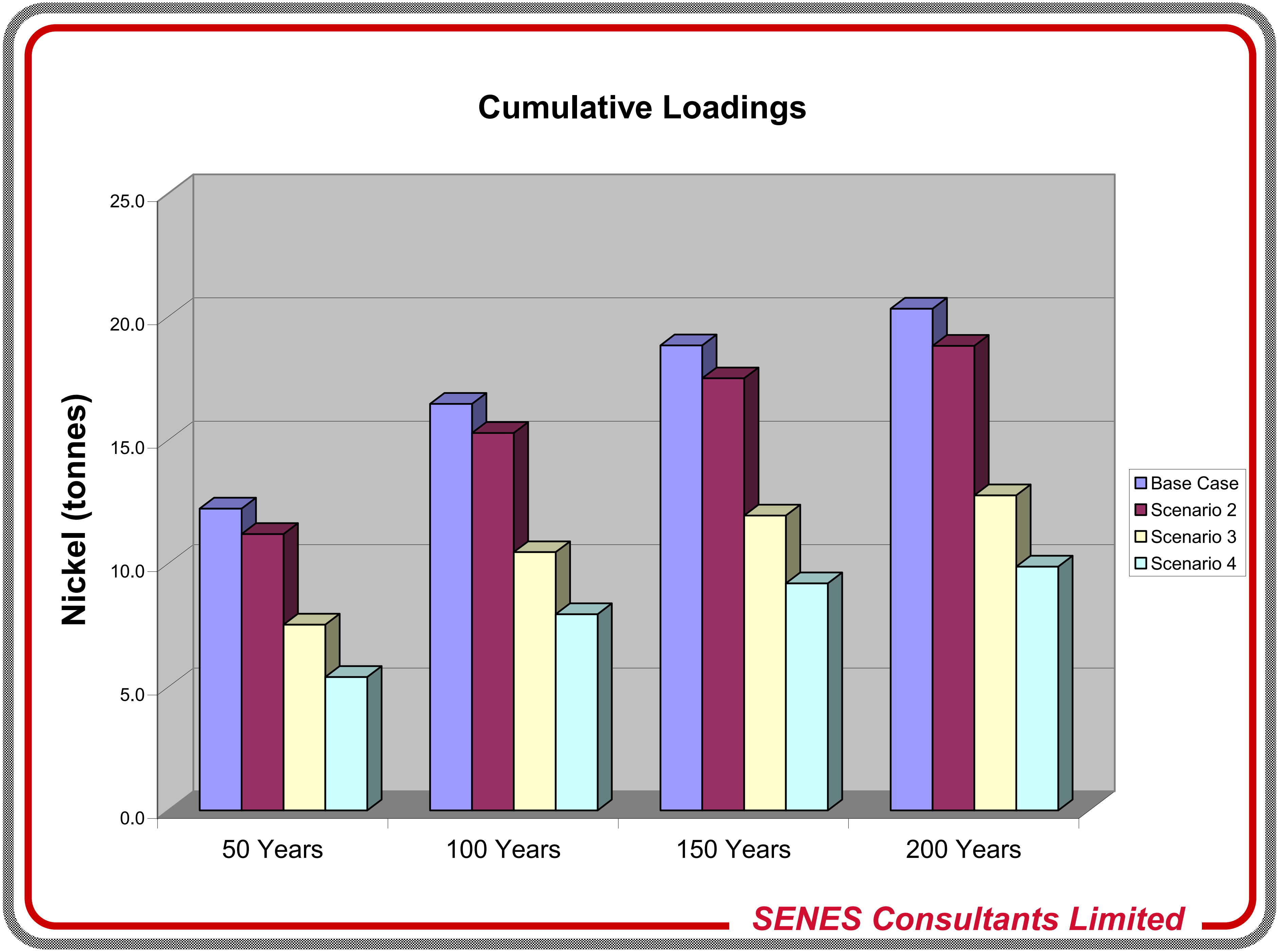

Cumulative Loadings
Nickel (tonnes)
25.0
20.0
15.0
10.0
5.0
0.0
50 Years
100 Years
150 Years
200 Years
Base Case
Scenario 2
Scenario 3
Scenario 4
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Conclusions

- Diversion of Stagnant Pond will reduce loadings, but not proportionately
- Diversion of runoff and reduction of infiltration to Main Pit and West Pit had greatest impact on loadings
- Model relatively insensitive to oxygen diffusion coefficient for cover over unsaturated waste rock layer

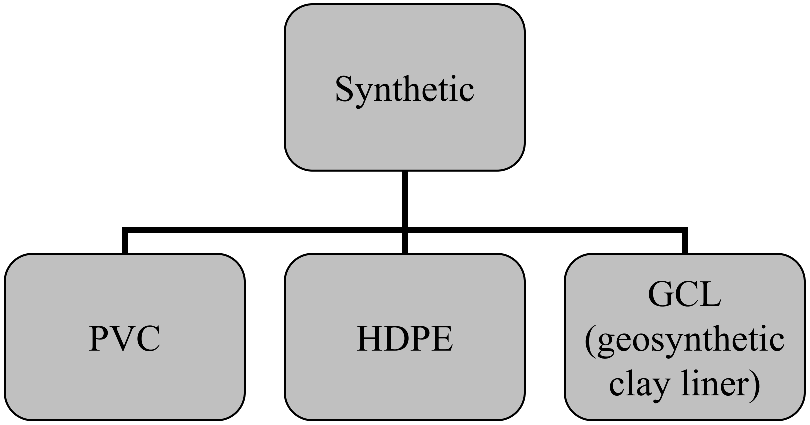
Case Study – Kam Kotia

- Copper, zinc, gold & silver producer
- Intermittent production from 40s to 70s
- Ontario MNDM conducting phased rehabilitation of this abandoned mine site

Kam Kotia North Impounded Tailings Design / Modelling of Composite Cover

- Objective – Select cover to:
  - Minimize infiltration to tailings to reduce volumes requiring treatment
  - Inhibit further ARD by minimizing oxygen ingress
  - Use native materials (if acceptable performance)

Available Cover Materials



Geochemical Modelling - Urantail

- Detailed geochemical model developed by SENES to examine the generation of acid mine drainage and the release of contaminants from tailings
- Theoretical basis similar to Acidrock and Rockstar
- Can be applied to simulate geochemical processes occurring with acid-generating tailings, and to examine wet and dry closure alternatives, such as flooded tailings versus simple to complex engineered covers.

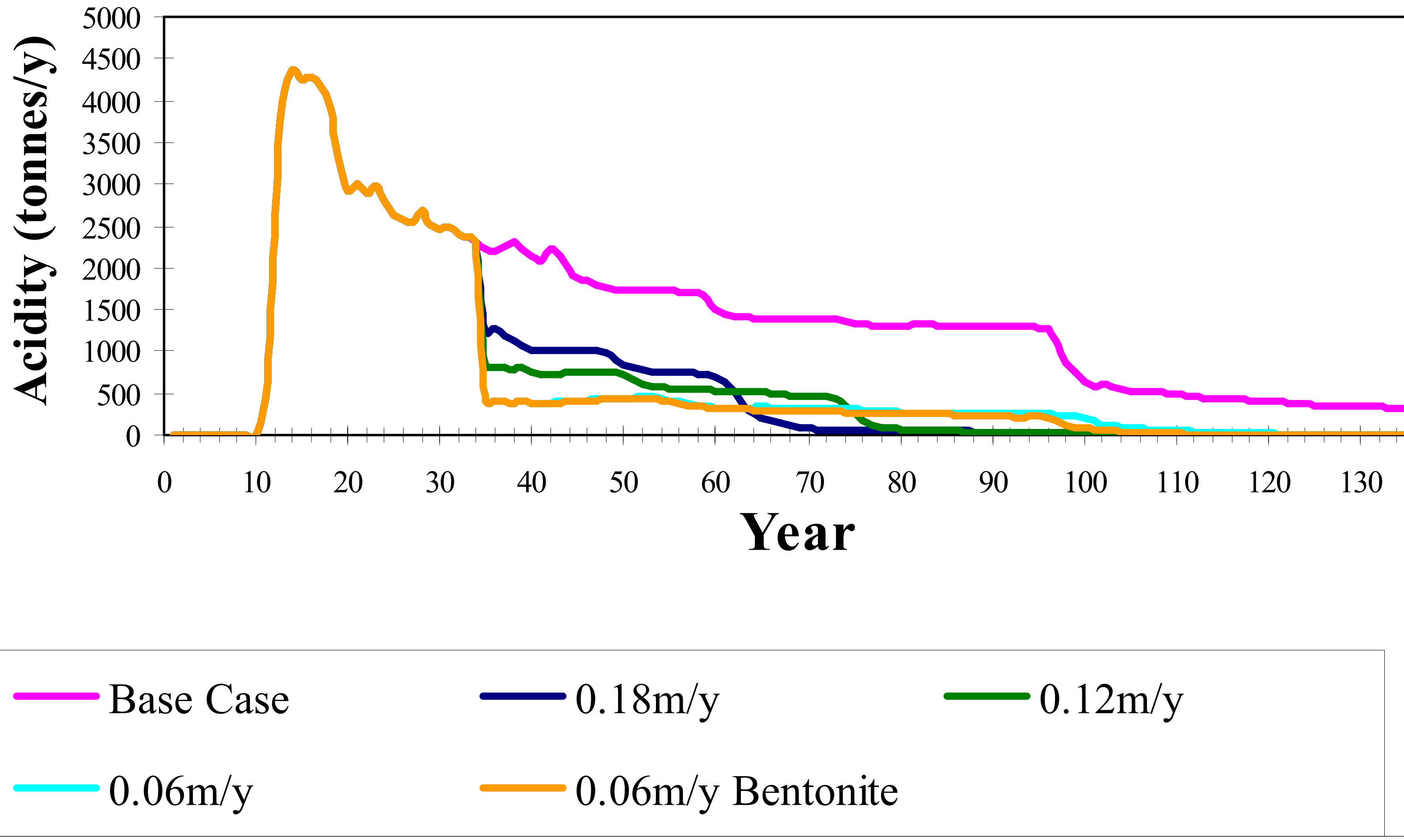
Preliminary Geochemical Modelling

- Initial Phase – 4 covers modelled
  - Clay Cover 1 - 0.3 m Rock/0.3 m Granular/0.5 m Clay/0.5 m Granular
  - Clay Cover 2 - 0.3 m Rock/0.3 m Granular/1.0 m Clay/0.5 m Granular
  - GCL Cover - 0.3 m Rock/0.3 m Granular/GCL/0.5 m Granular Cover
  - Polymer Liner Cover - 0.3 m Rock/0.3 m Granular/PVC Liner/0.5 m Granular Cover
- Conclusion - all covers would significantly reduce treatment requirements, <u>based on assumptions</u>

Detailed Material Characterization and Follow-up Modelling

- Clay
  - permeability higher than initially estimated
  - permeability increased additional 2 orders of magnitude with freeze-thaw action
- Uncertainty in clay performance modelled by assuming a range of infiltration and oxygen diffusion coefficients
  - Deterministic, could have also modelled probabilistically

Predicted Seepage Load from NIT - Acidity



Final Proposed Design

- 0.1 m Topsoil
- 0.5 m Granular
- 0.3 m Clay
- GCL with polyethylene coating
- 0.3 m Granular
- 0.3 m Waste Rock

Conclusion – Geochemical Modelling

Benefits

- insight into potential future conditions
- determine which variables are most important in determining future conditions
- assess the effects of alternative approaches to decommissioning
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- direct field and laboratory studies
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  - Important that potential sources of uncertainty in predictive models be described and where practicable evaluated quantitatively
- Guidance on alternative methods of evaluation, when they might be applied and how to address uncertainties is needed
- Model versus actual conditions

Additional Information

- Technical Description – Rockstar Reactive Transport Model
  - included on Workshop CD
- Contact:
  - jmartin@senes.ca
  - 905 764 9389 x 349

Acknowledgements

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