Prediction of Groundwater Recovery and Post-Flooding Groundwater Quality

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Outline

- Site Background & Study Objectives
- Prediction of Groundwater Rebound
- Prediction of Post-flooding Water Quality
- Implications for Closure Planning
- Conclusions

Site Background

- Mine located in tropical savannah region with distinct wet season producing ~1,600 mm/year
- Mine exploited a lead-zinc deposit from 1985 – 1998
  - o 100m deep open pit
  - o 750m deep underground workings
- Mine produced 4.5 Mt of waste rock and 2 Mt of tailings
- Open Pit & Underground Workings located in structural zone resulting in very "wet" mine with significant dewatering during operations (up to 350 L/s)

ARD Potential & Early Decommissioning

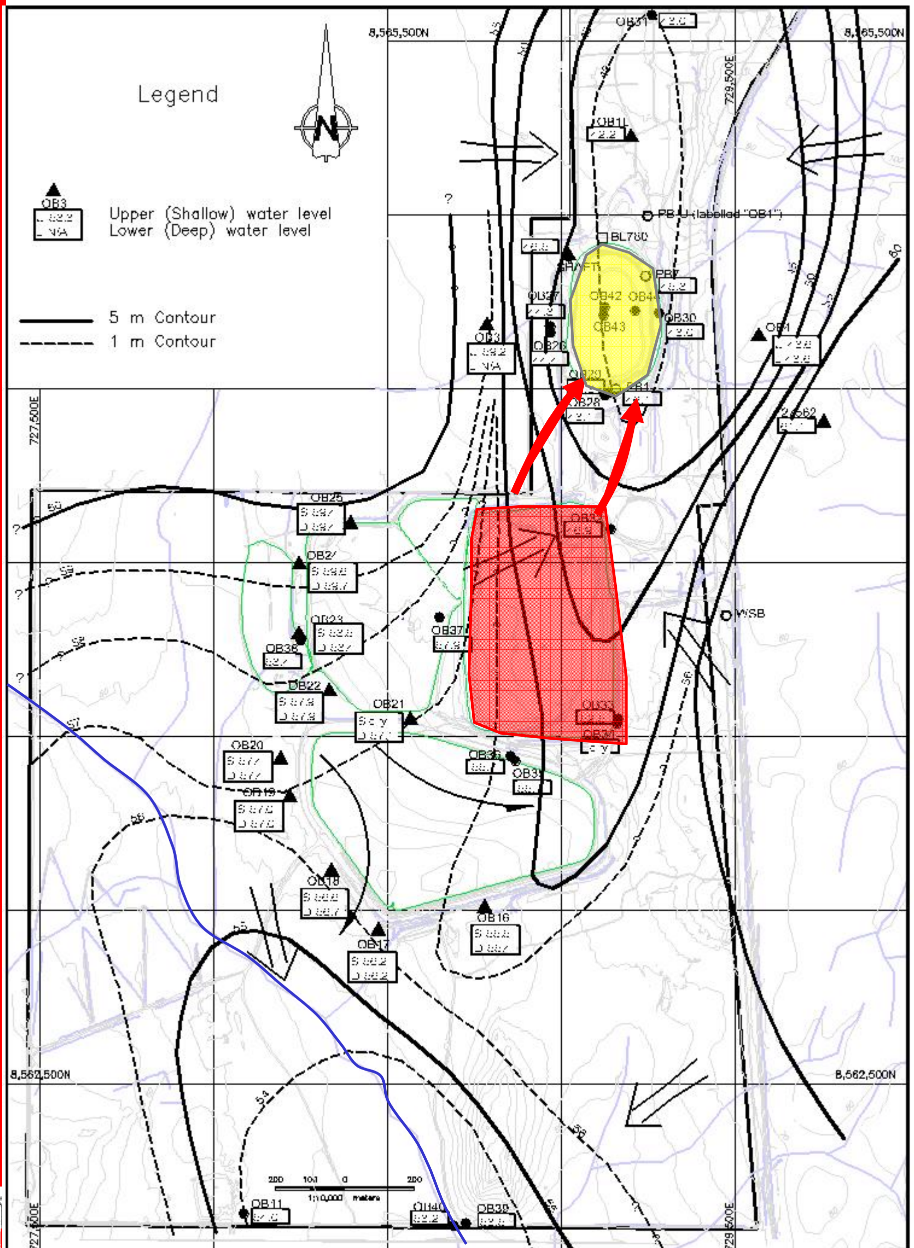
- Tailings have a high sulphide content (~20%) and are net acid generating (NAG ~300 kg H_2SO_4 per tonne)
- WRD consists of a mixture of oxidized waste rock and primary waste rock with pyrite contents ranging from 3-25%
- Groundwater monitoring suggested that seepage from tailings and WRD is neutralized in local groundwater
- Zinc is the primary contaminant of concern (mobile at neutral pH)

- Between 1999-2000, high-sulphide waste rock and all tailings were backfilled into the open pit and mine allowed to reflood

Hydrogeological Study

Overview

- Hydrogeological Study initiated in 2001 in response to rapid flooding of underground workings
- Study Objectives:
  - Update prediction of groundwater recovery (time and final pit water level)
  - Predict contaminant transport (SO4 and zinc)
  - Assess closure options for WRD
  - Assist in development of closure criteria
- Study Components:
  - Field Investigation (Well Installation, hydraulic testing)
  - Groundwater Flow Model
  - Solute Transport Model



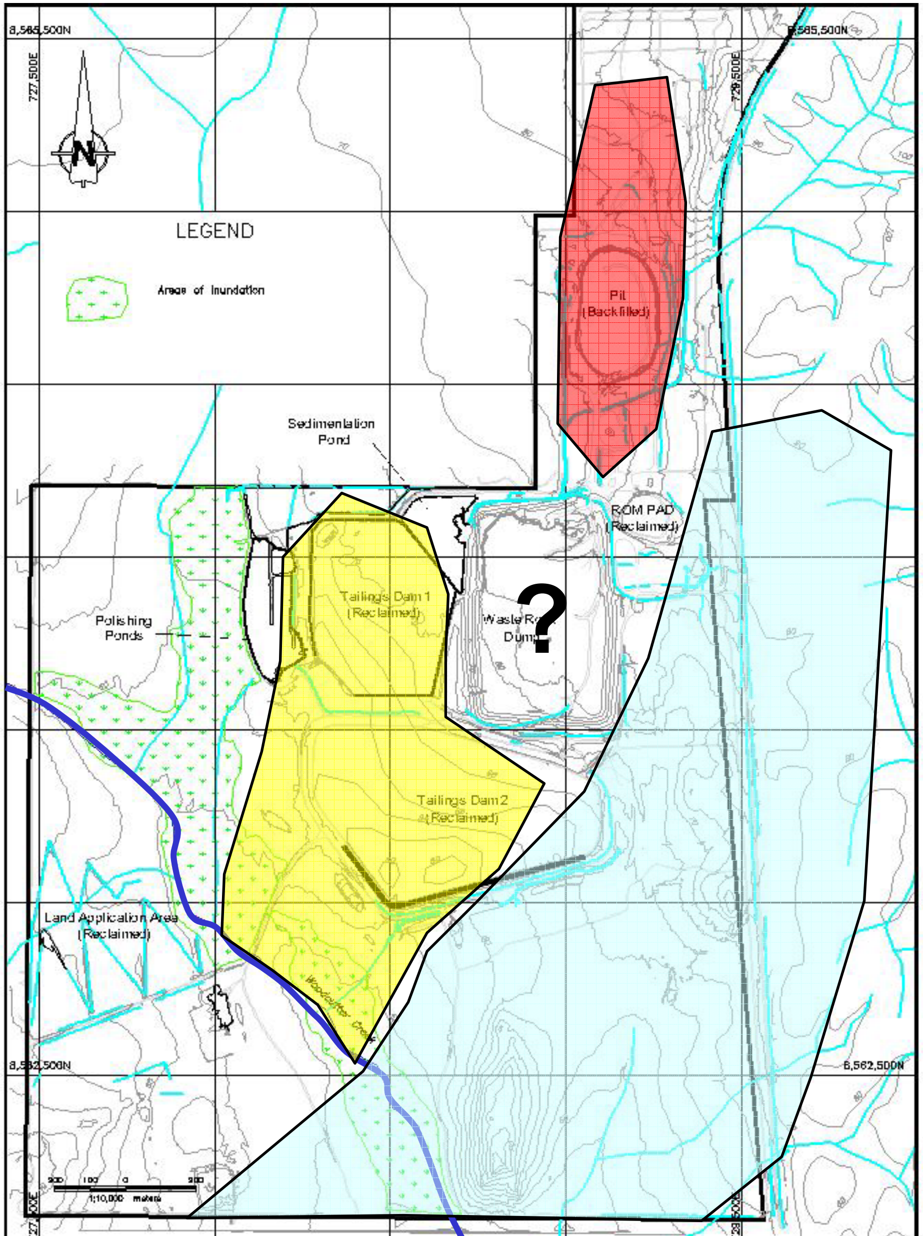
Field Investigation I

Observed Water Levels - Feb 2001

- Mine dewatering has created a cone of depression which is aligned N-S along major structure;
- Open pit and u/g are a major sink for groundwater
- WRD seepage still draining into cone of depression

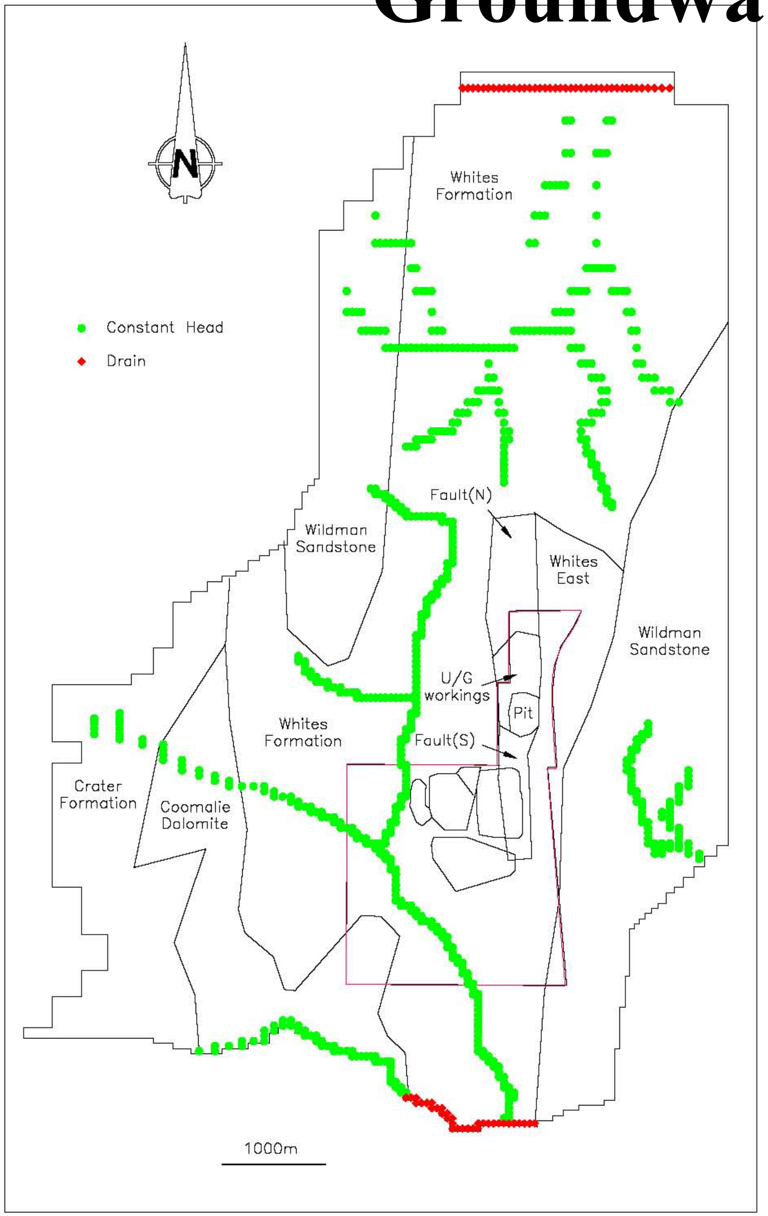
Field Investigation II

Groundwater Quality Feb 2001



- GW in pit area highly impacted (SO4, TDS, Mn, Fe, Zn etc.)
- GW in tailings area shows highly variable impact
- GW at downstream boundary (Creek) shows very low impact
- High localised ARD load (Zn~400 mg/L) in seepage from WRD; however, no clear evidence of impact on groundwater quality

Groundwater Flow Model



Methods

- Model domain subdivided into major lithologies
- Bedrock profile subdivided into 4 model layers representing:
  - Weathered bedrock (saprolite)
  - Partially weathered, fractured bedrock
  - Fresh, less fractured bedrock
  - Deep, tight bedrock
- Major structures represented implicitly by using anisotropy
- Underground workings represented as drain nodes

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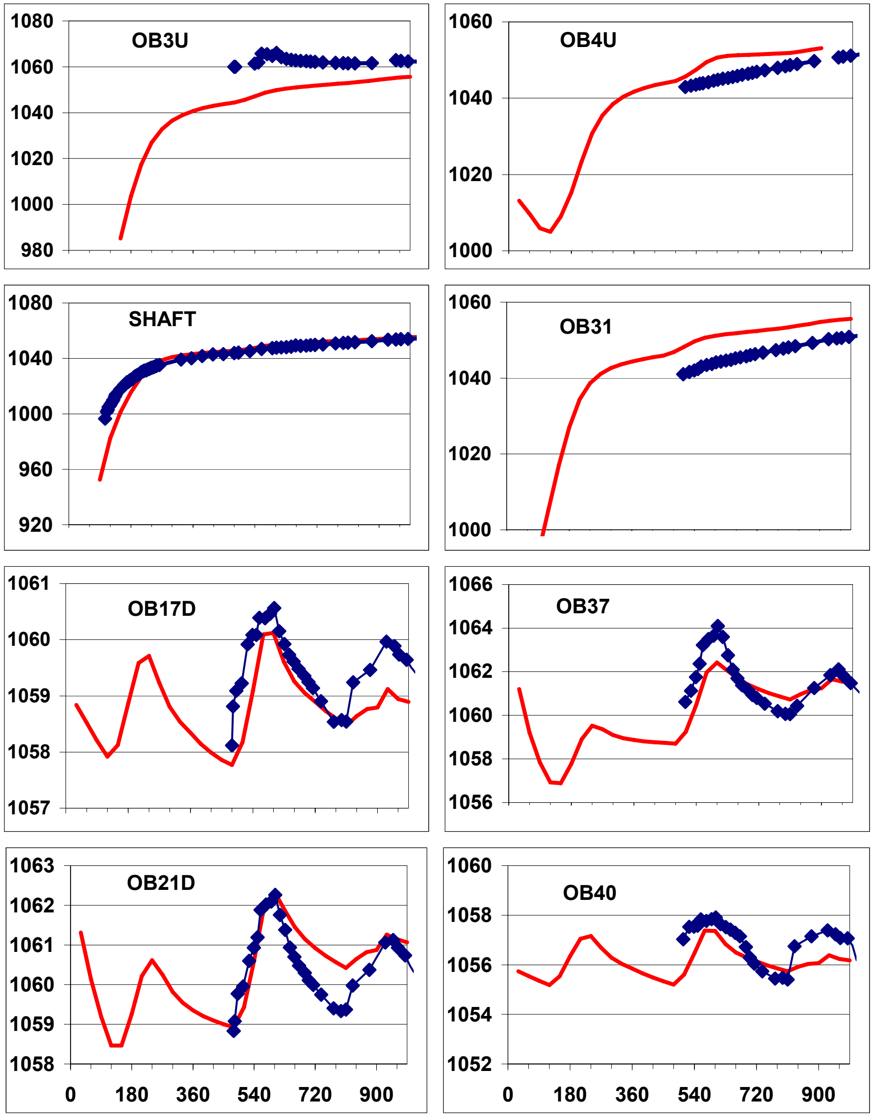
Calibration of GW Flow Model



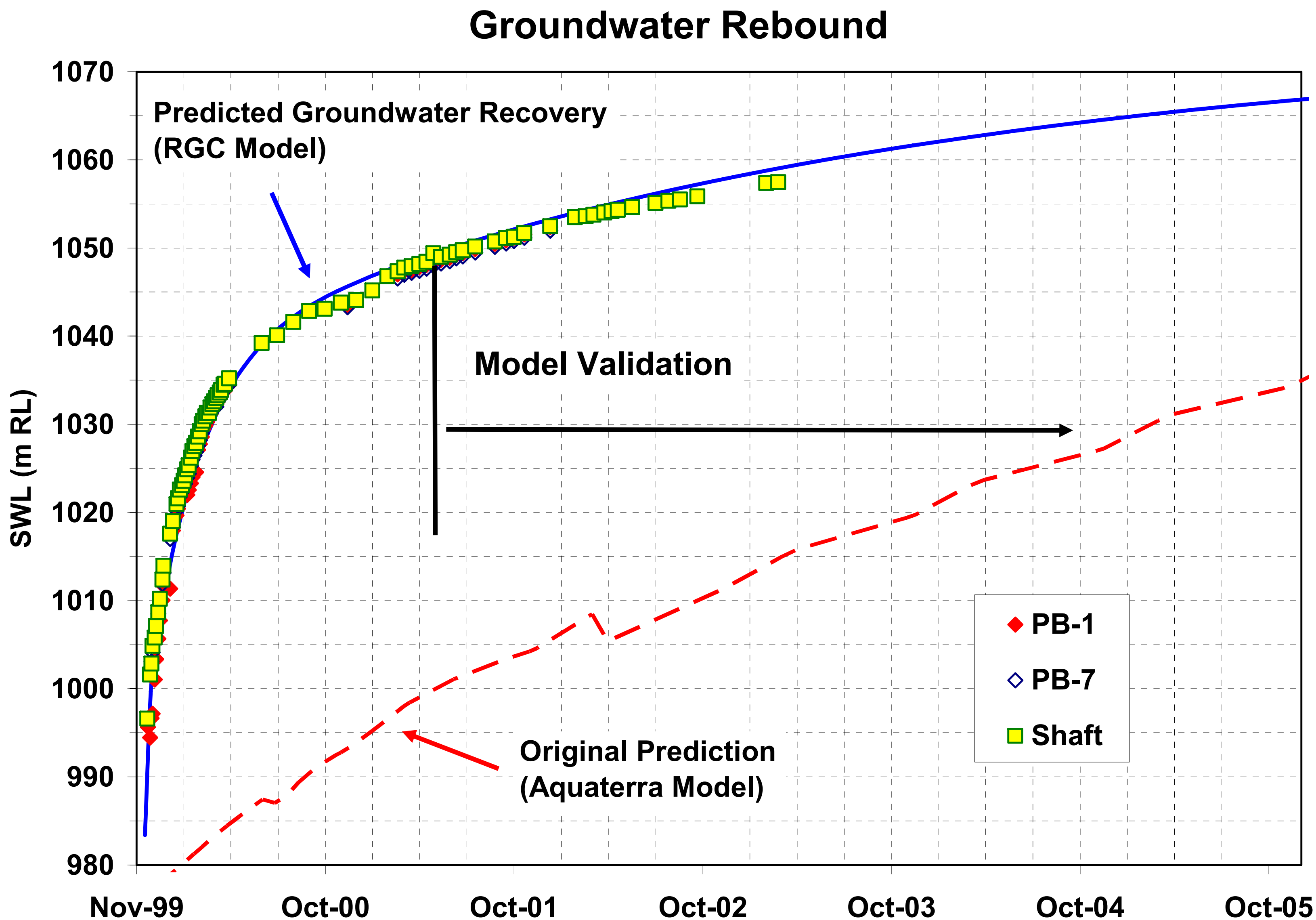
Four calibration periods:

- Pre-mining conditions
- Open Pit Dewatering
- Underground Dewatering
- Early Reflooding

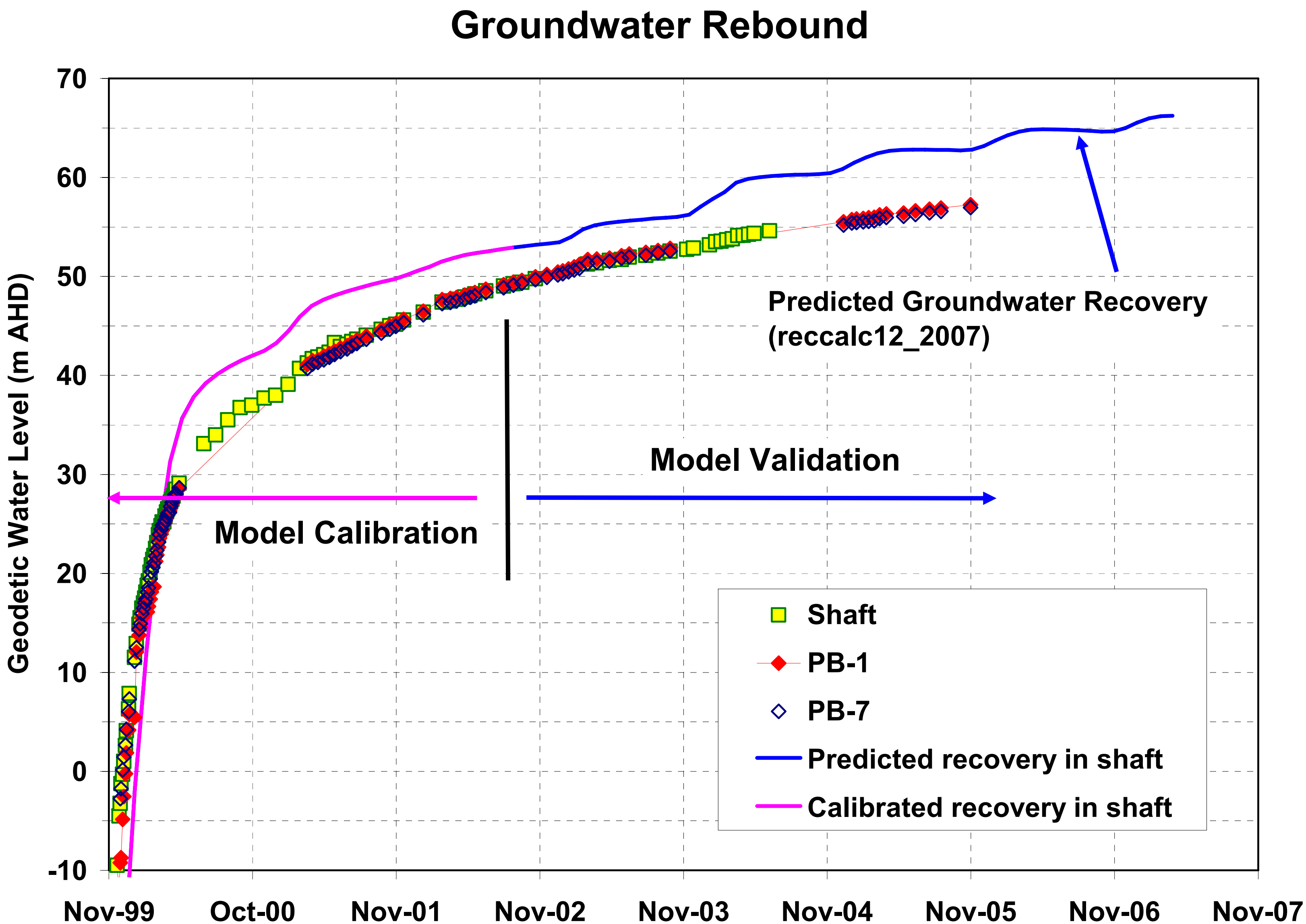
⇒ Both GW levels & mine dewatering rates used for calibration

⇒ Critical that all four mining periods be modeled to predict recovery

Validation of GW Flow Model



Updated Validation of GW Flow Model



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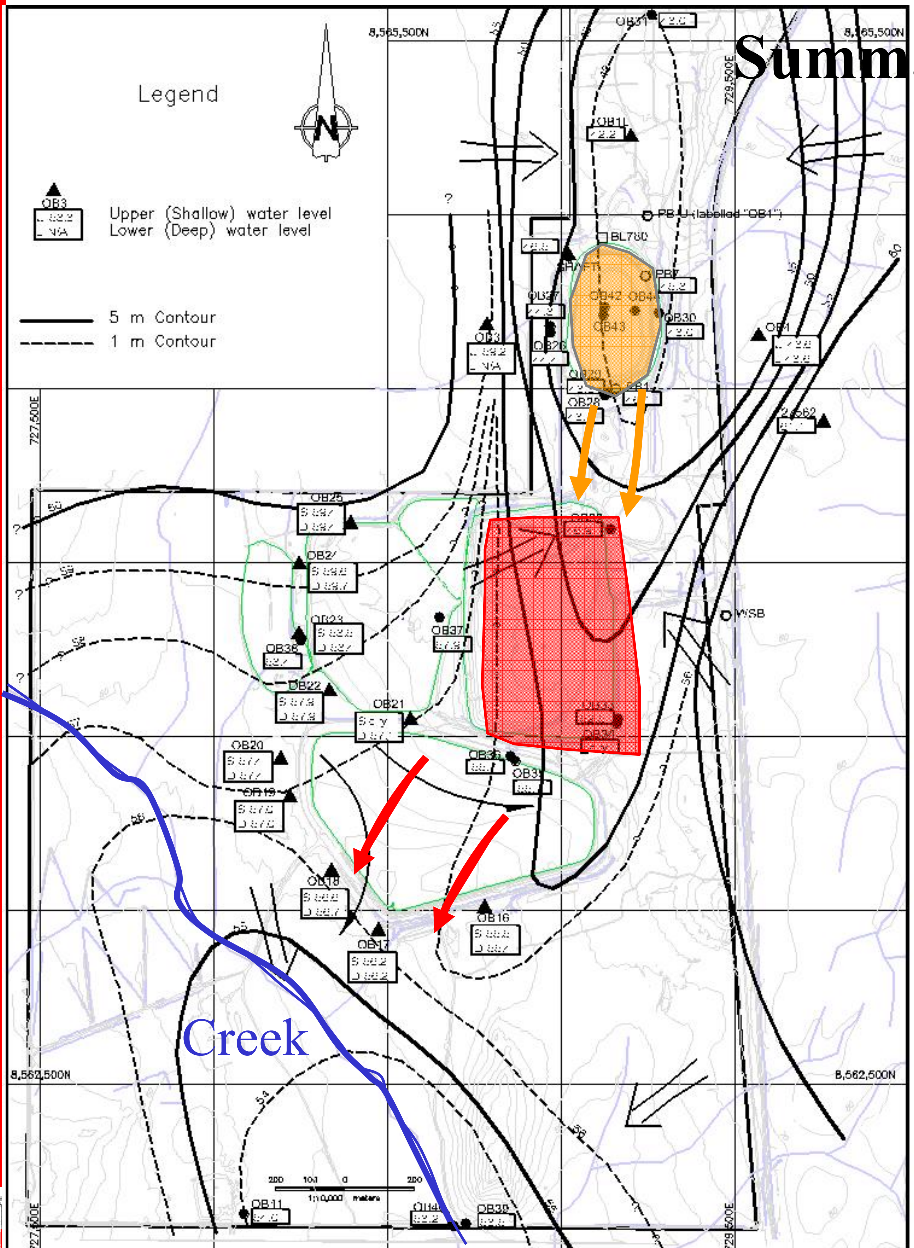
Prediction of Reflooding

Summary of Results



- The model predicts that the backfilled tailings will be completely reflooded by 2010-2012
- The model predicts that groundwater levels will recover to pre-mining levels (likely by 2020-2025)
- The model predicts a reversal of hydraulic gradients over time such that the entire mine site (including open pit & WRD) will drain towards the Creek after complete reflooding

=> Impact to local Creek??

Prediction of Post-Flooding Groundwater Quality

- Predict contaminant transport using solute transport model (MT3D) and calibrated groundwater flow model

- Phase 1: Predict future migration of SO_4 plume for initial cover design
- Phase 2: Predict future loading of zinc to Creek for detailed cover design (incl. ecological risk assessment)

Phase 1: Closure Alternatives

Sulphate Transport

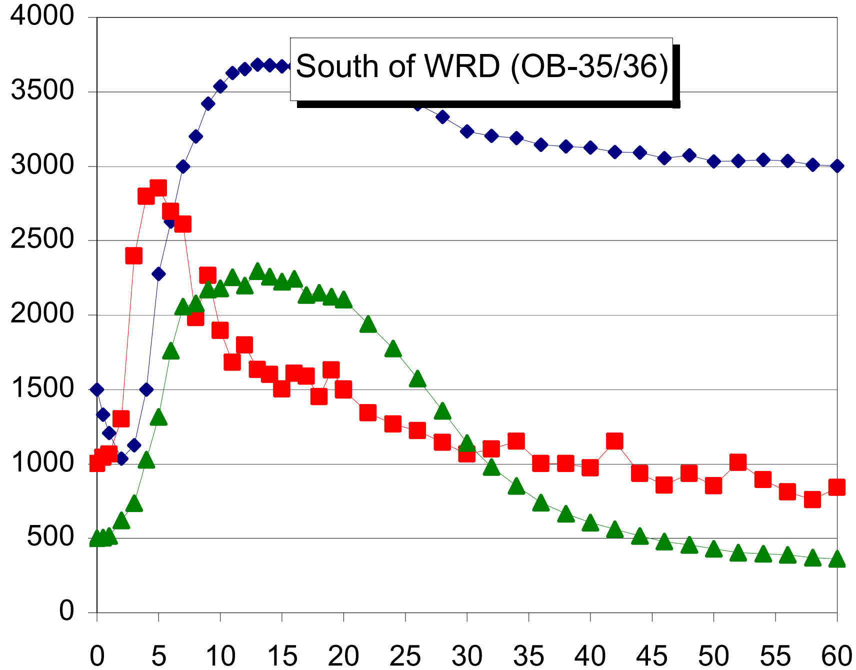
- Alternative 1: Tailings backfilled in pit & no cover on WRD (2001 conditions)
- Alternative 2: Tailings backfilled in pit & "high quality" cover on WRD

Alternative	WRD Seepage Rate	WRD Seepage Quality (mg/L)	
		Initial SO4	Future SO4
1	33% of MAP	4,000	4,000
2	1% of MAP	4,000	4,000

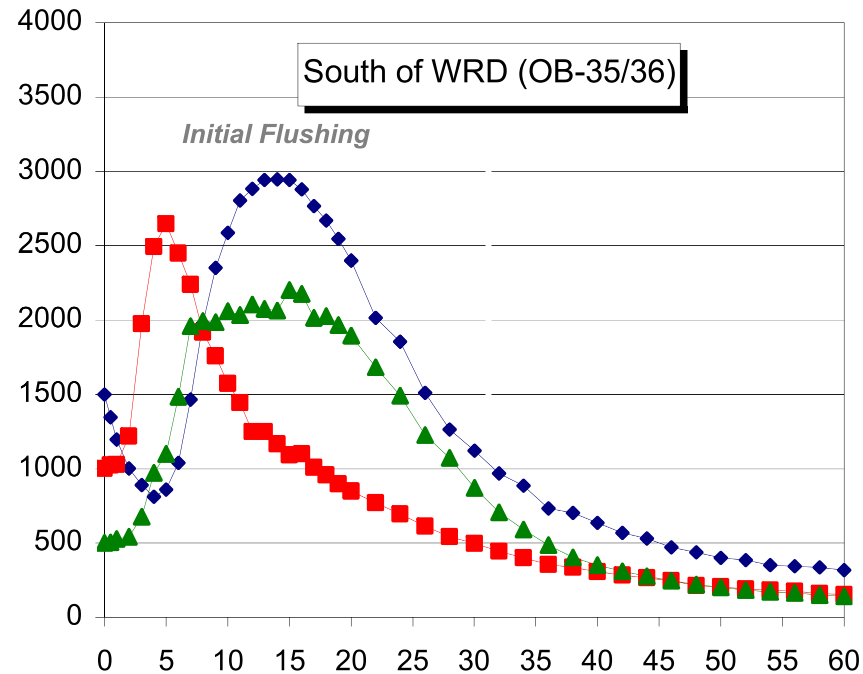
Note: SO_4 in backfilled tailings assumed to remain constant (1,500 mg/L)

Predicted SO4 Transport

No Cover on WRD



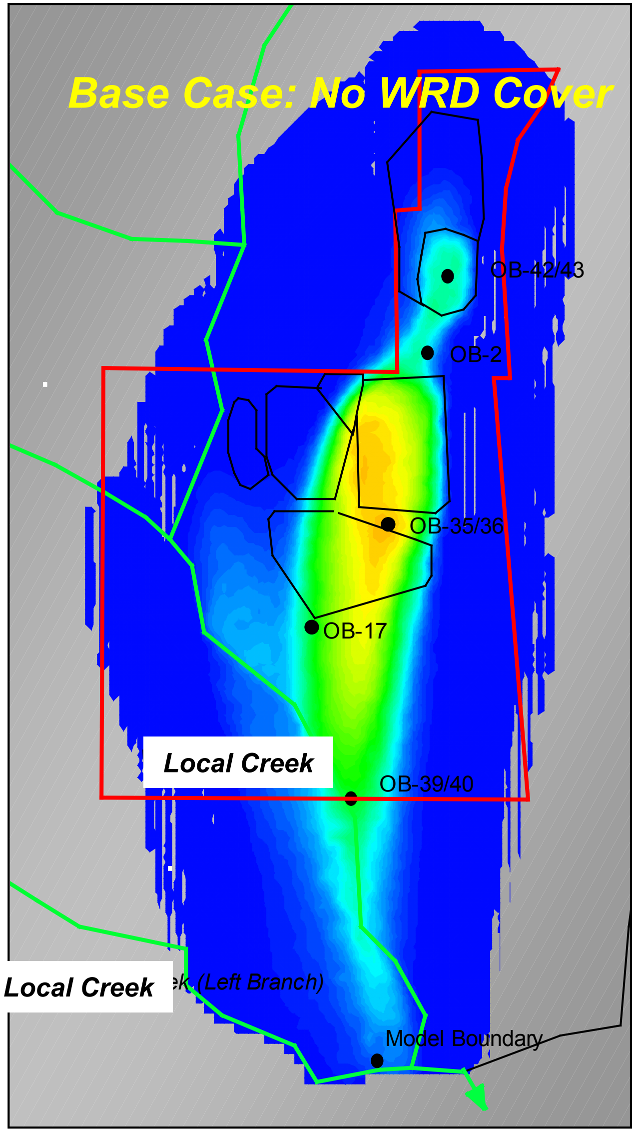
High Quality Cover on WRD



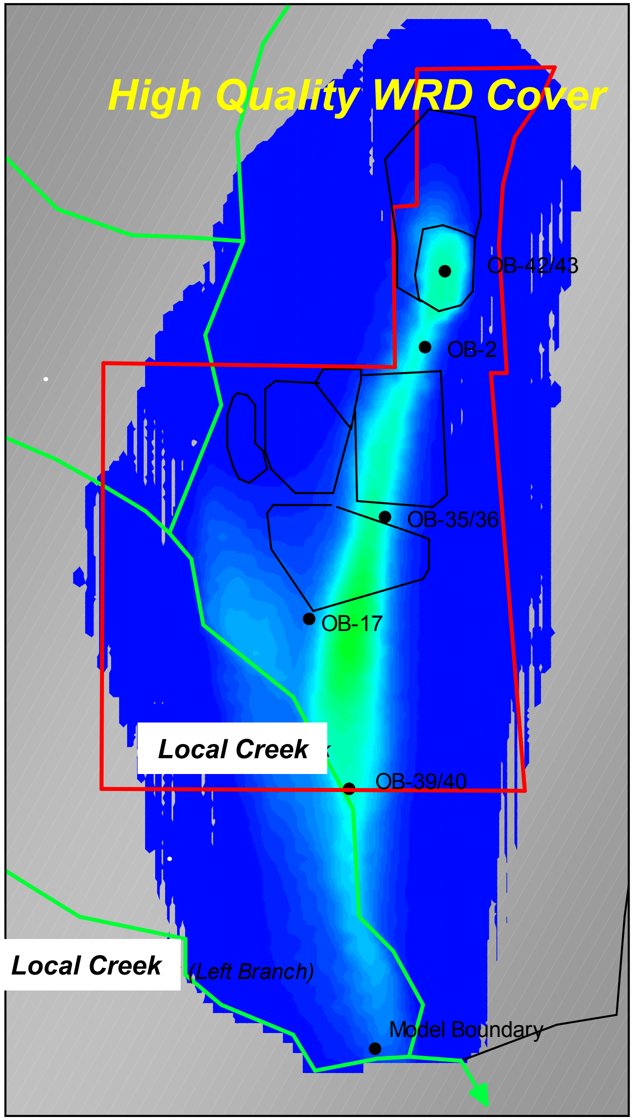
⇒ ~30 years required to flush existing SO_4^{2-} plume

⇒ High Quality Cover reduces long-term SO_4^{2-} concentrations more than 10 times

Predicted SO4 Transport



T=30 yrs



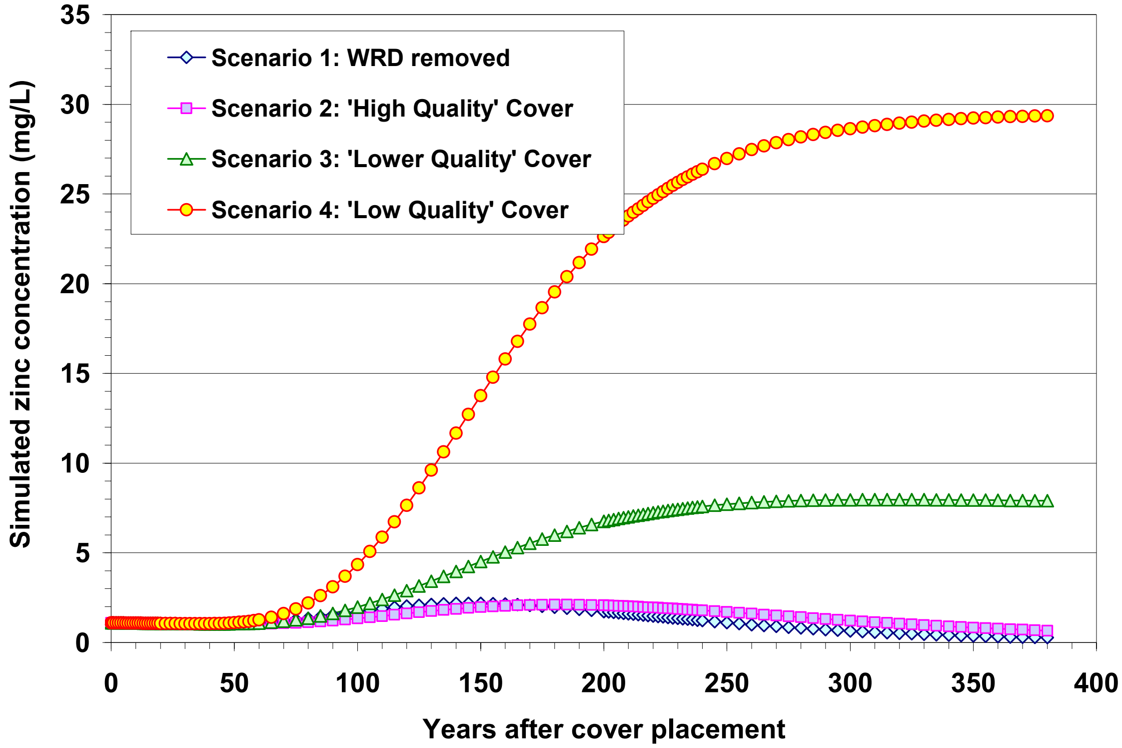
Phase 2: Cover Scenarios

Zinc Transport

Scenario	Description	WRD Seepage Rate	WRD Seepage Quality (mg/L)	
			Initial Zn	Future Zn
1	No cover (WRD removed)	0% of MAP	10	0
2	High Quality Cover	1% of MAP	10	10
3	Lower Quality Cover	10% of MAP	10	50
4	Low Quality Cover	20% of MAP	10	100

Notes:
Assume Zn in backfilled tailings remains constant (13 mg/L)
Assume retardation of zinc in aquifer (Rf = 2 to 6)

Predicted Zinc Transport



- Significant increase in zinc loading to Creek predicted over next 100-200 years for "low quality" cover on WRD (Scenario 4)
- No significant increase in Zn loading to Creek predicted for "high quality" cover on WRD (Scenario 2)

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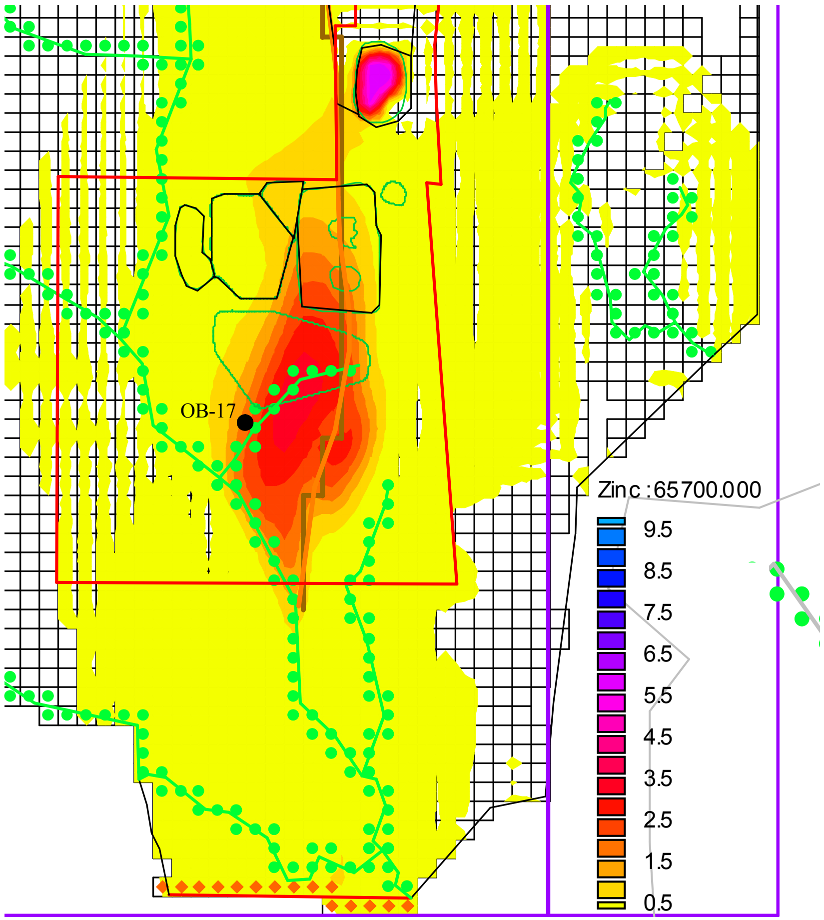
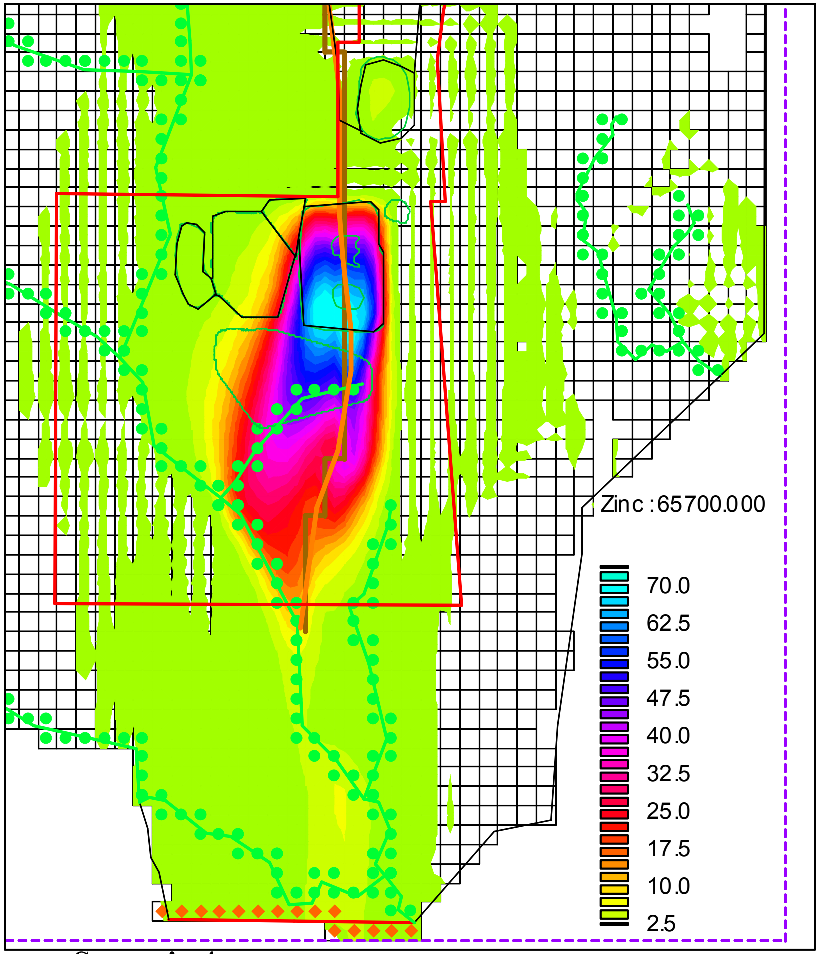
Predicted Zinc Transport

after 300 years



Scenario 2:
Backfilled Pit & High Quality Cover



Scenario 4:
Backfilled Pit & Low Quality Cover

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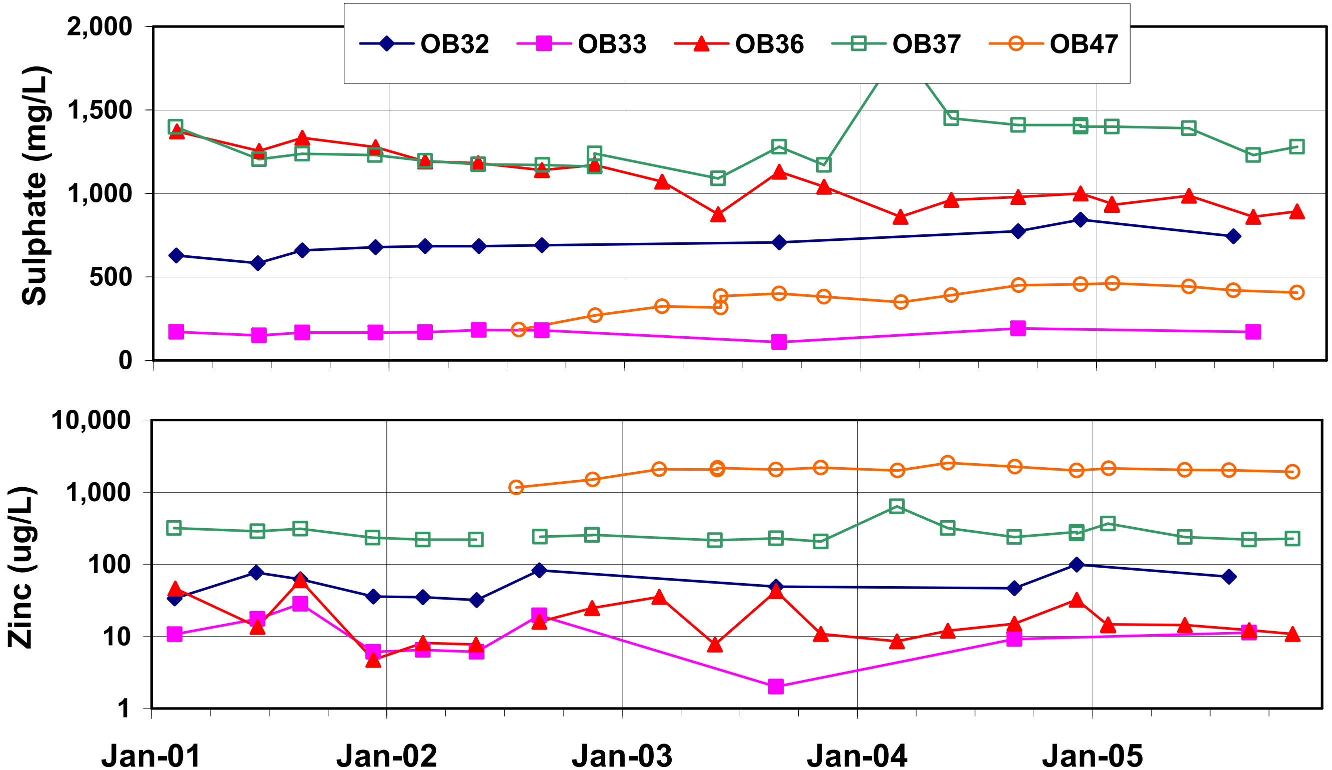
Validation of Transport Model ?



- No significant increase in SO4 and Zn has yet been observed in monitoring wells downstream of the WRD and backfilled pit
- At least 10-15 years of monitoring will be required before the transport model can be validated with any degree of confidence

Implications for Closure

- Modeling exercise created awareness of potential long-term deterioration in groundwater quality and contaminant loading to local Creek
- Model predictions assisted in setting more realistic expectations of time horizon for lease relinquishment
- High quality cover was selected for WRD to minimize future ARD seepage and potential long-term metal loading to creek (constructed in 2003/04)
- Groundwater model assisted in communication with local stakeholders & development of closure criteria

Lessons Learned

- Prediction of groundwater rebound very sensitive to aquifer parameters (T, S); successful prediction requires very good calibration data (incl. pre-mining water levels, dewatering rates, early recovery)
- Solute transport models are much more difficult to calibrate and validate due to the very slow rates of contaminant transport in groundwater systems
- Despite these limitations groundwater modeling provides a powerful tool for closure planning and may assist in developing closure performance criteria
- Groundwater flow and transport models should be updated as new monitoring data become available


Thank You !