Dependence of Predicted Dewatering on Size of Hydraulic Stress Used for Groundwater Model Calibration

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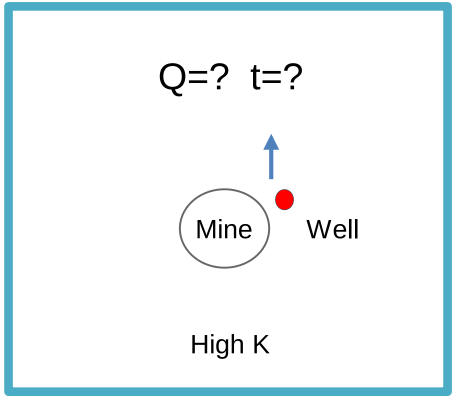
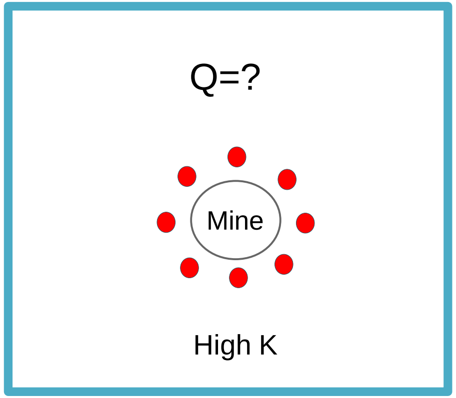
Introduction

Hydrogeologic Testing



Mine Dewatering



Unknown boundaries:

- Unbounded
- Impermeable
- Leaky

Magnitude of hydraulic stress
vs
Calibration for a reliably long-term mine dewatering prediction

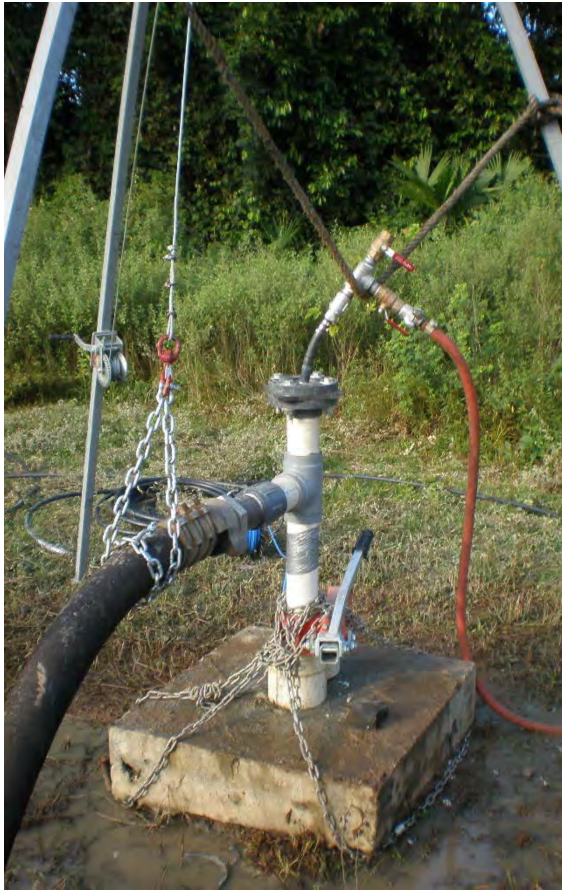
How important are the unknown lateral boundaries in a highly permeable groundwater system?

Hydrogeologic Studies by SRK

- 2010 to 2011 – Scoping Study for Two Block Cave Operations
- 2013 to 2014 – Pre-Feasibility Study for One Block Cave
- 2014 to 2015 – Feasibility Studies for Open Pit

Short Term Testing:

- 11 Packer Tests (pumping & injection)
- 95 Falling/ Rising Head Tests



Long Term Testing (2013 to 2014 Field Program):

- 3 pumping tests in large diameter wells
- 5 to 14 day duration
- 5 to 60 L/s pumping rate

One Year Decline Pumping Test (Q up to 350 L/s) with Water Level Monitoring

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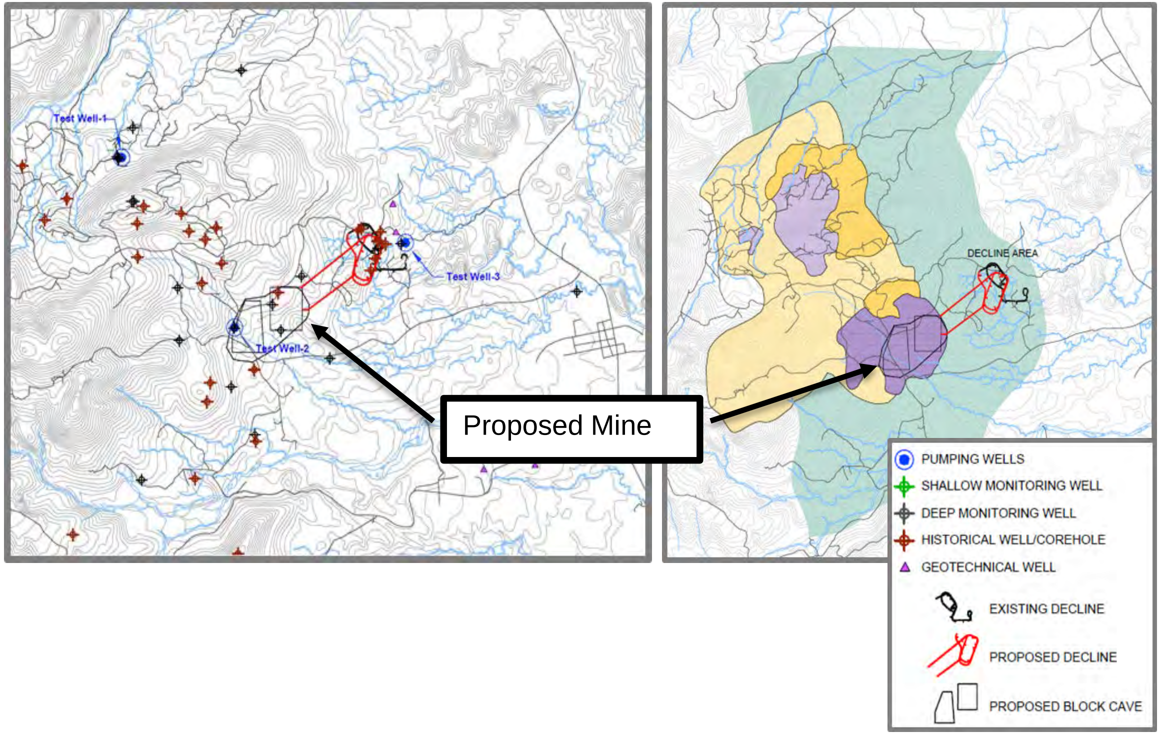
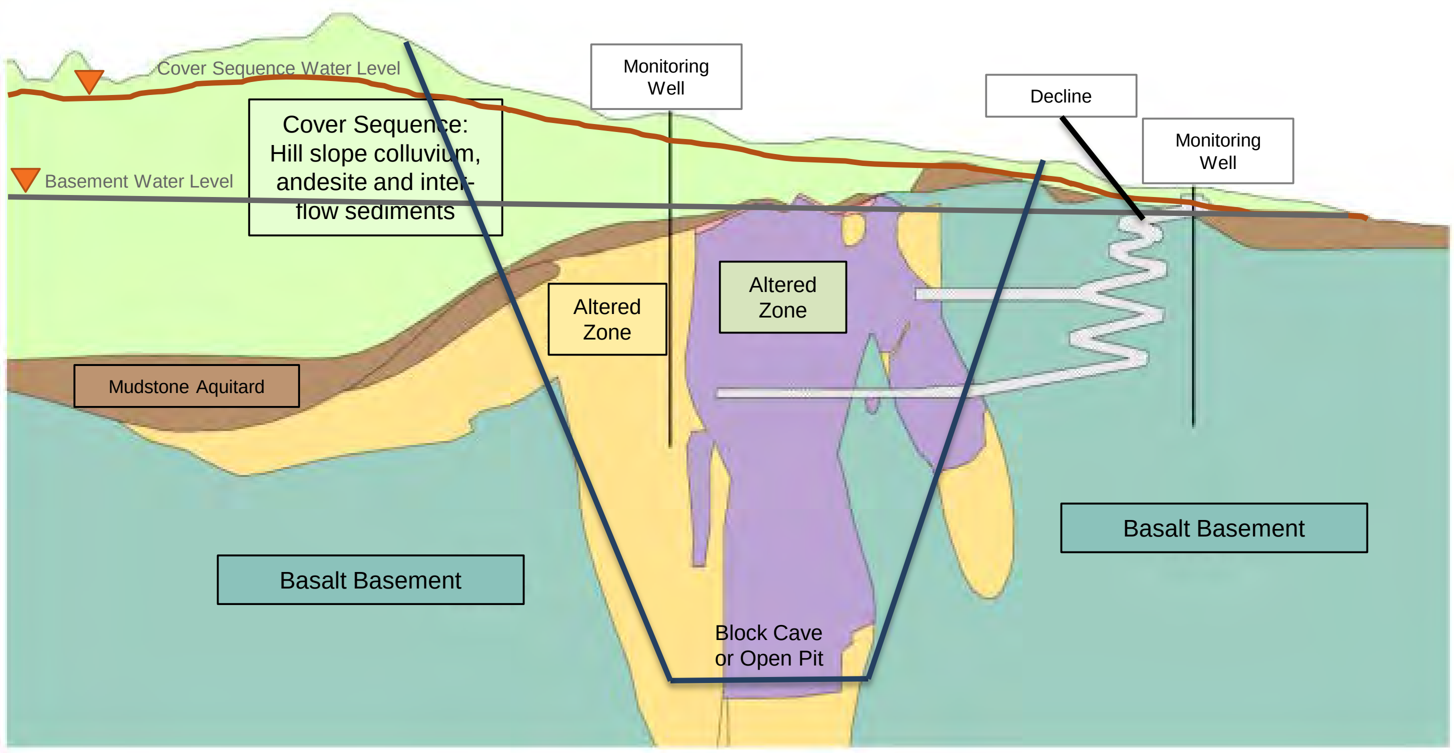
Hydrogeologic Study Area



- 3 pumping tests were completed during decline installation in proximity of orebody
- Majority of monitoring wells are located within 1.5 km of site

Conceptual Hydrogeologic Cross Section

Q=?



Q=?

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Conceptual Hydrogeologic Cross Section

- Two groundwater systems with limited vertical hydraulic connection
- High K basement fractured rock, low K cover sequence except first 100 m of upper part, intermediate to high K orebody
- Exploration decline started before hydrogeological studies with significant groundwater inflow
- Unknown effect of lateral boundaries at beginning of study
- Necessary to implement large scale, active dewatering

Long Term Stress to the Groundwater System Used for Model Calibration

PHASE 1

Pre-Decline Exploration
Short Term Testing
No Decline Active Dewatering

PHASE 2

3 Pumping Tests
10 Days of Active Decline Dewatering
Max Q total – up 100 L/s

PHASE 3

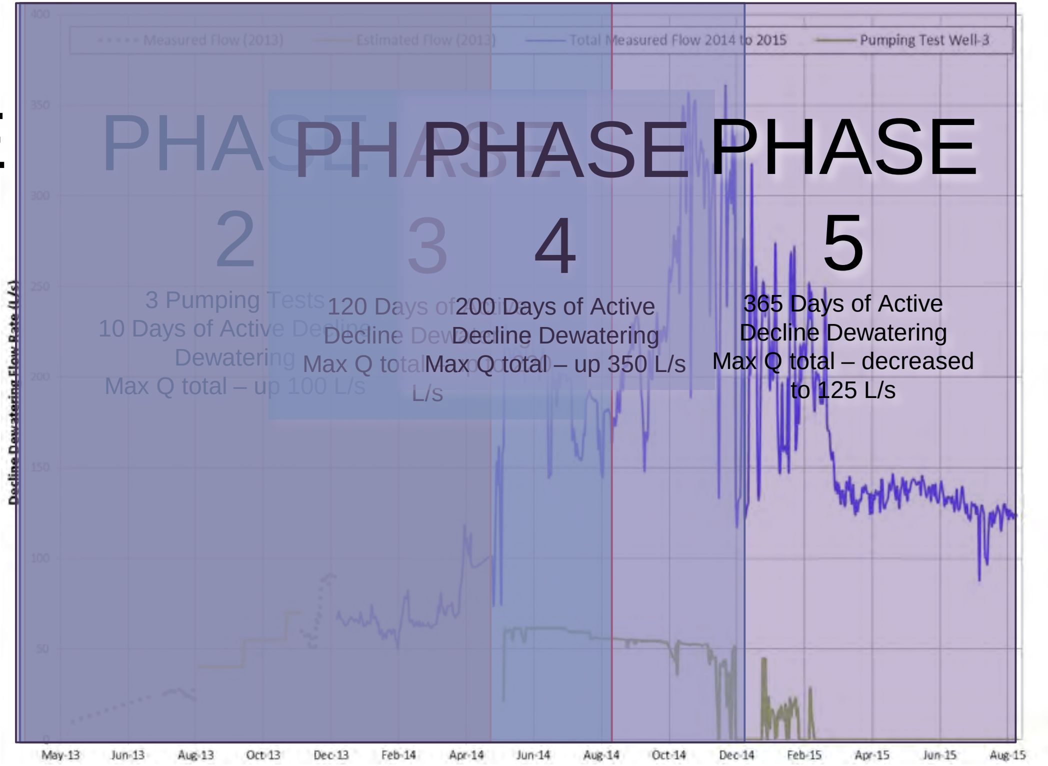
120 Days of
Decline Dew
Max Q total
L/s

PHASE 4

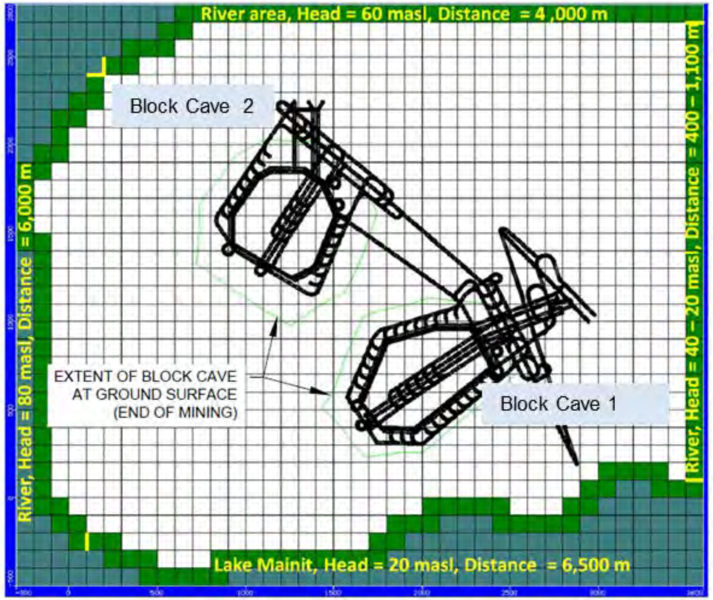
200 Days of Active
Decline Dewatering
Max Q total – up 350 L/s

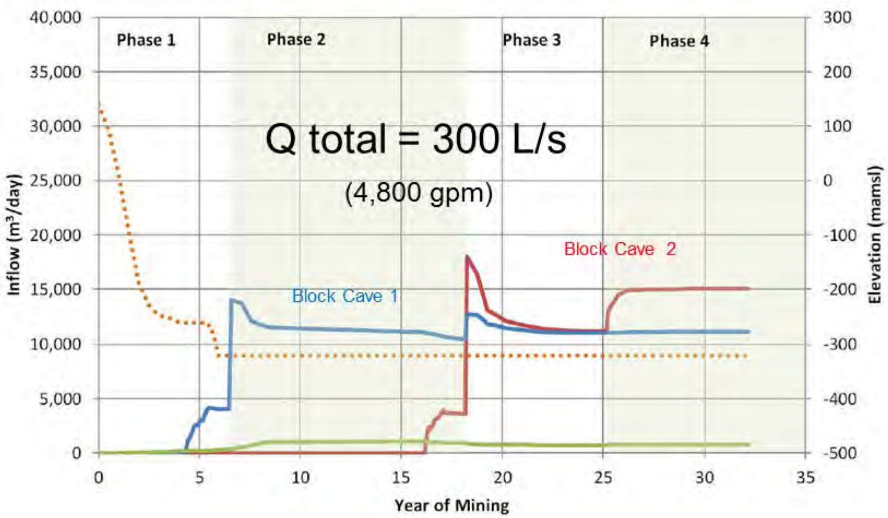
PHASE 5

365 Days of Active
Decline Dewatering
Max Q total – decreased to 125 L/s



Phase 1: Scoping Study Dewatering Predictions





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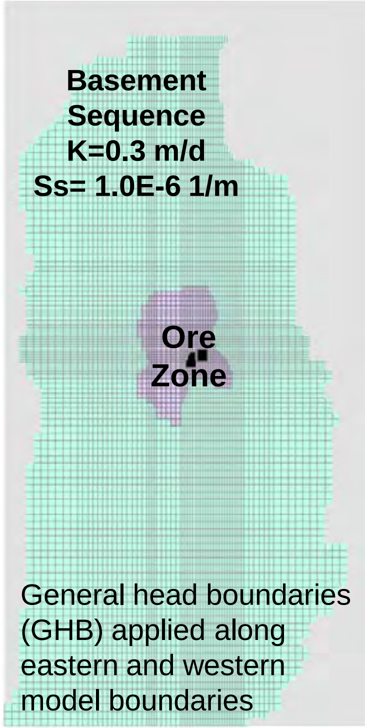
Phase 1: Scoping Study Dewatering Predictions

- Local scale groundwater model
- Packer testing in 2 deep geotechnical boreholes
- Simple numerical model calibrated to water levels in shallow piezometers
- Assumed hydrogeological conditions – high K Cover Sequence and Low K Basement (not confirmed during Phases 2 to 5 of Studies)
- Predicted pumping rate 300 L/s

Phase 2: Permeable and Unbounded Conceptual Model



- Pre-Feasibility Study
- Single Block Cave with Continued Decline Excavation
- Additional Field Data Including:
  - 3 pumping tests in large diameter wells
  - 10 days of active dewatering
  - Max Q total is 100 L/s
  - Approximately 7 months of water level data

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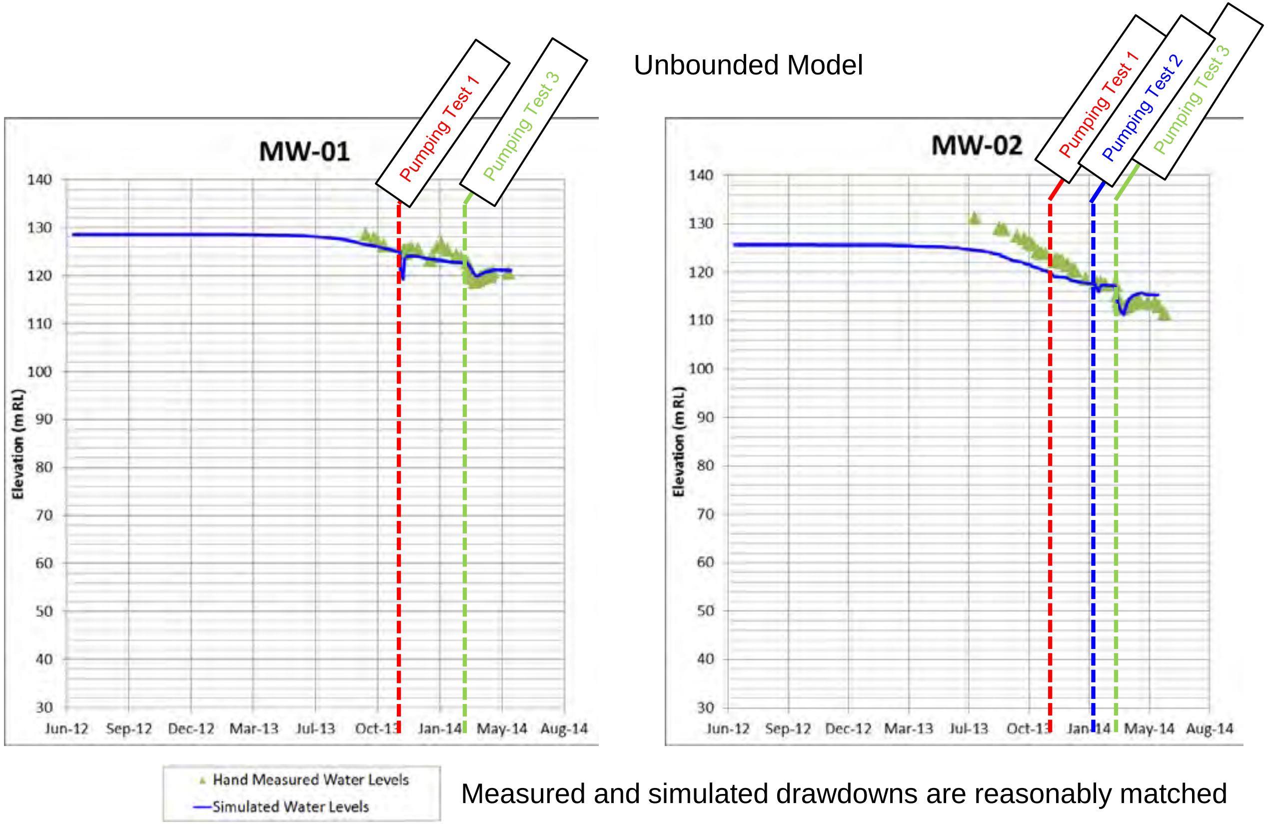
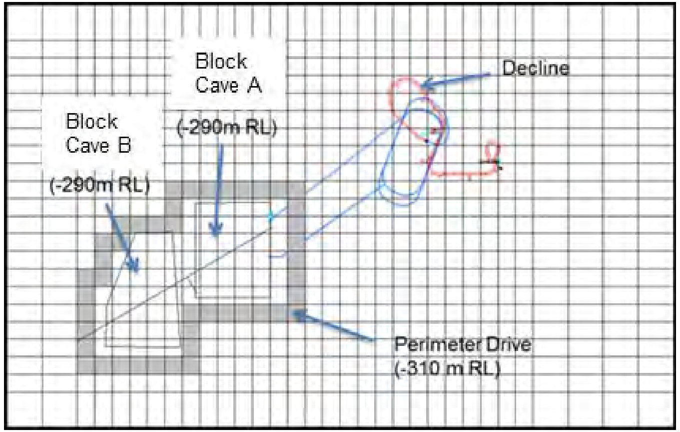
Phase 2: Calibration Results (based on 3 pumping tests and pumping from Decline)

Unbounded Model

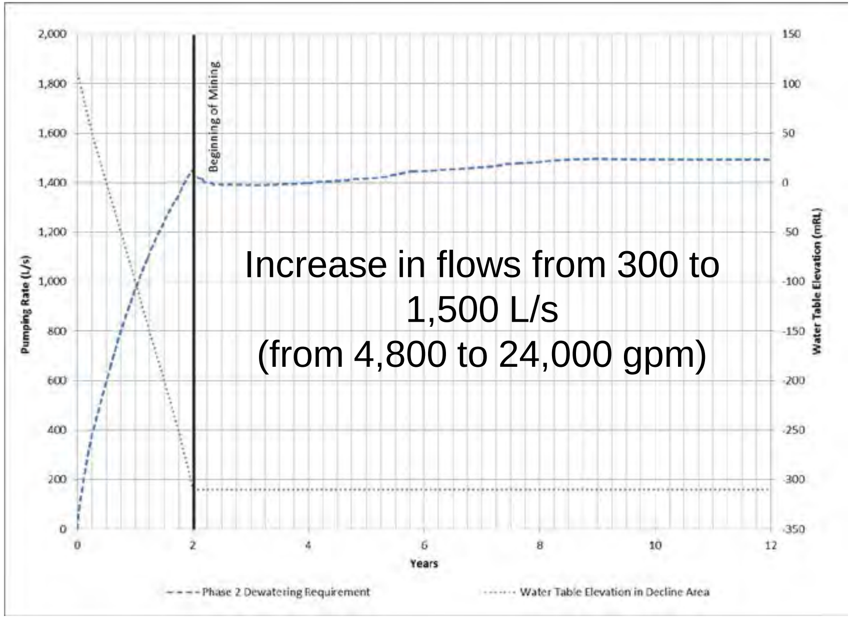


Measured and simulated drawdowns are reasonably matched

Phase 2: Block Cave Dewatering Predictions– Pre-Feasibility Study

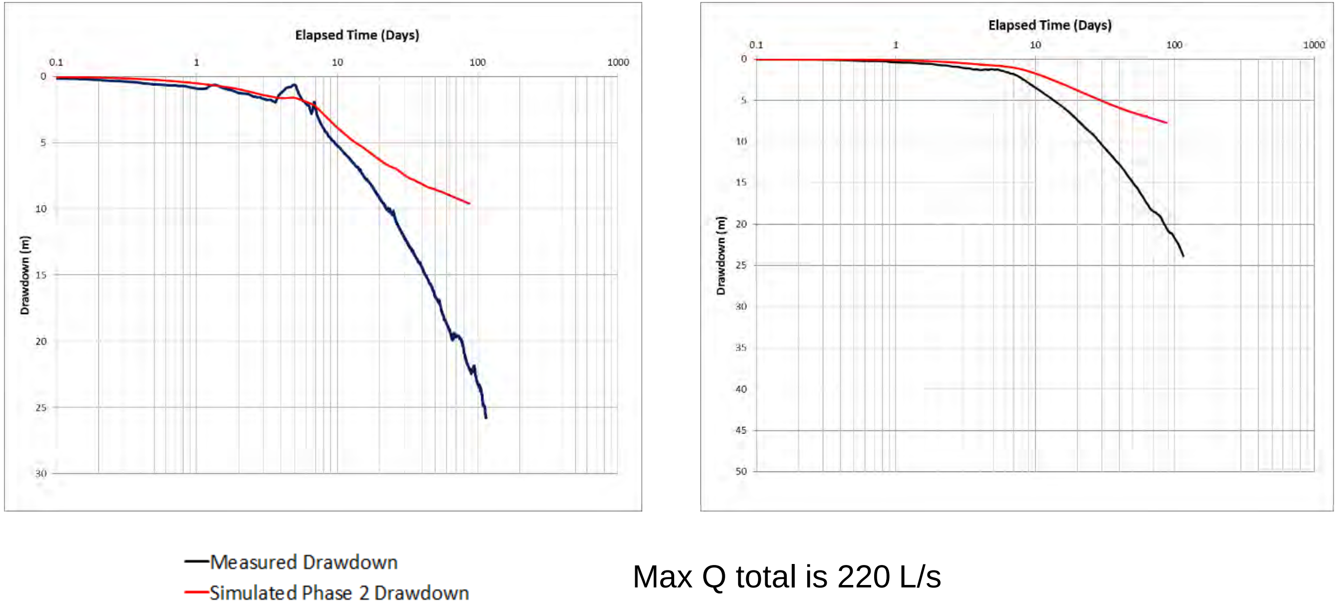


Unbounded Model



Increase in flows from 300 to 1,500 L/s
(from 4,800 to 24,000 gpm)

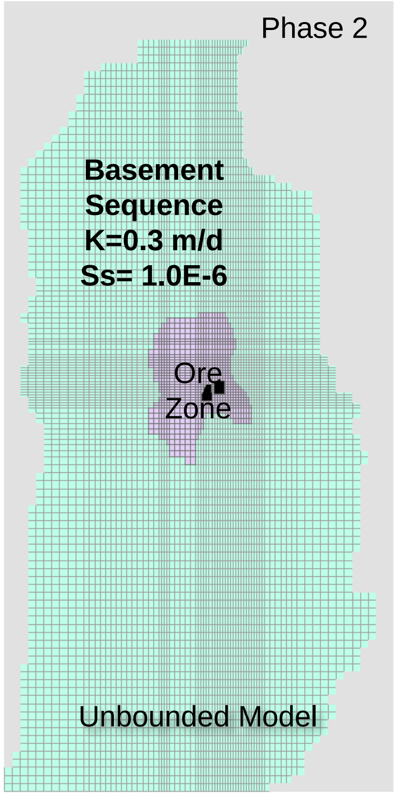
Phase 2: Calibration to 120 Days of Pumping- Drawdown



Max Q total is 220 L/s

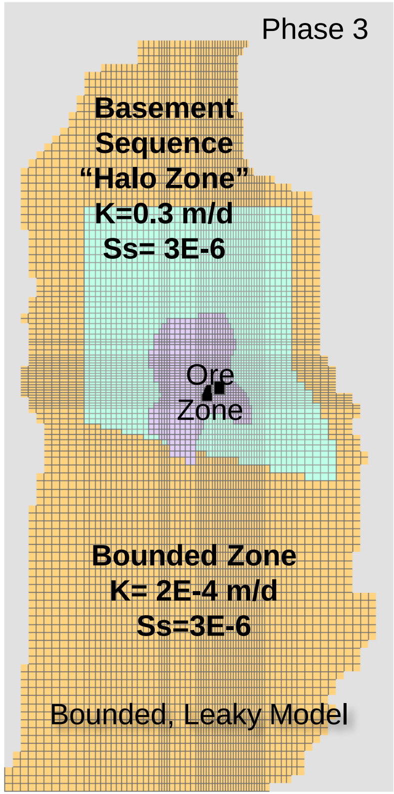
Measured drawdowns exceed simulated - groundwater system is bounded but most likely leaky.

Phase 2 to Phase 3: Change in Conceptual Model



GHB applied along eastern and western model boundaries

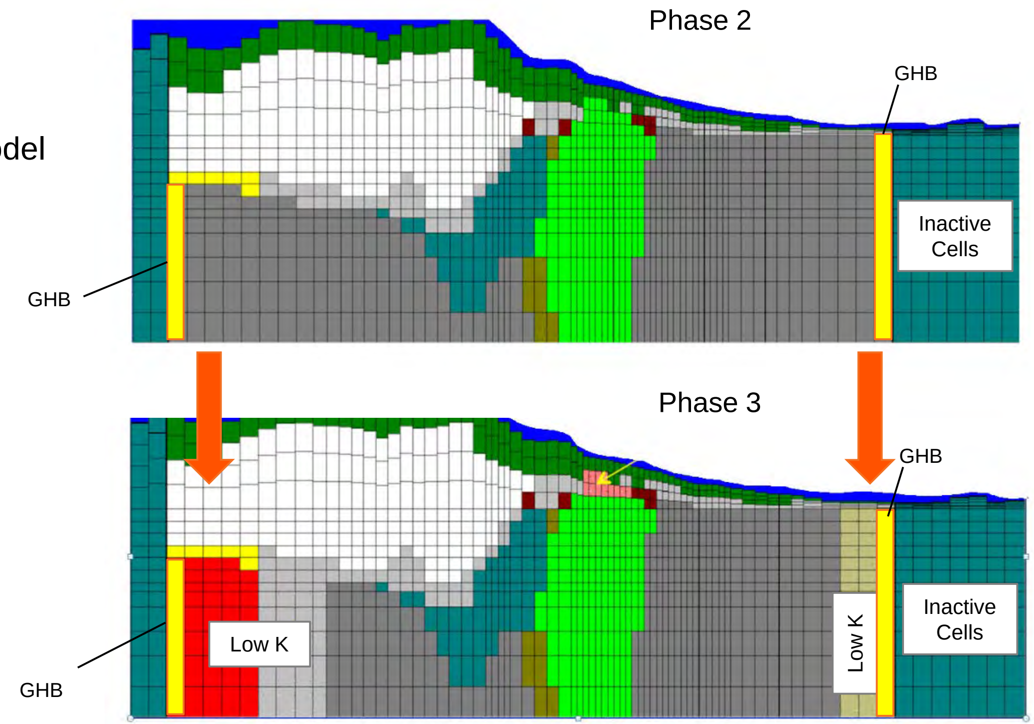
K Values of bedrock outside of Halo Zone were obtained during calibration to measured drawdown



Phase 3: Change in Conceptual Model– Cross Section (West-East)

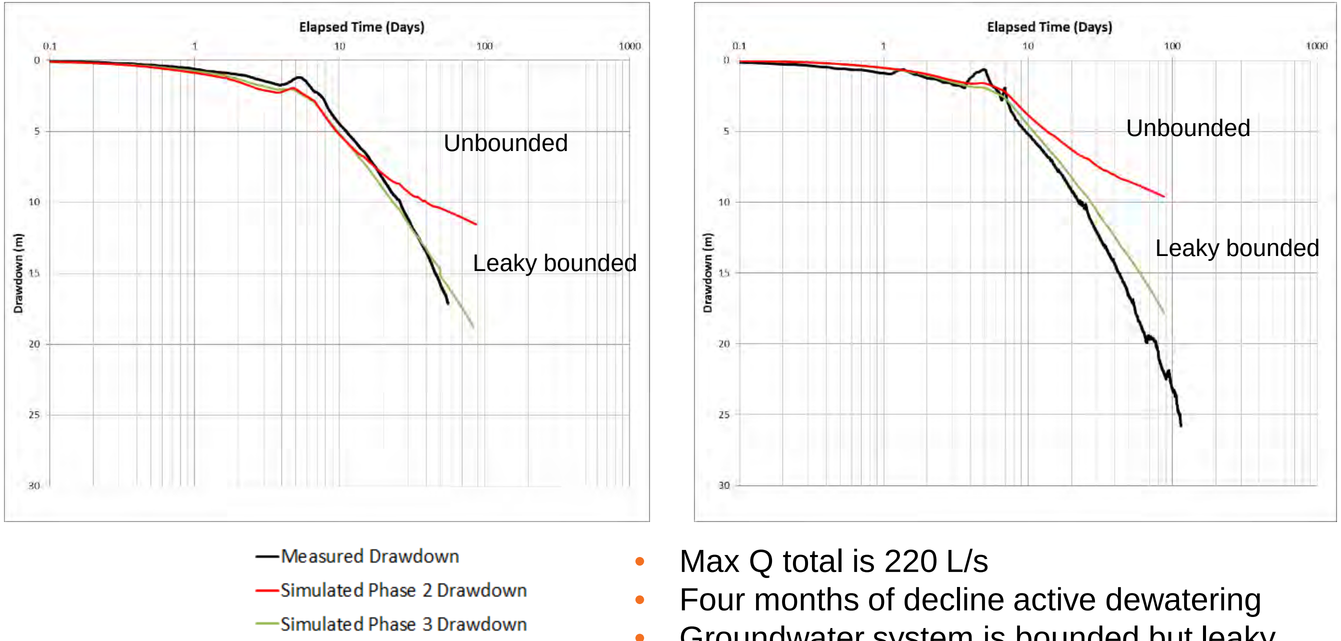
Unbounded Model

Bounded "Leaky Bucket" Model



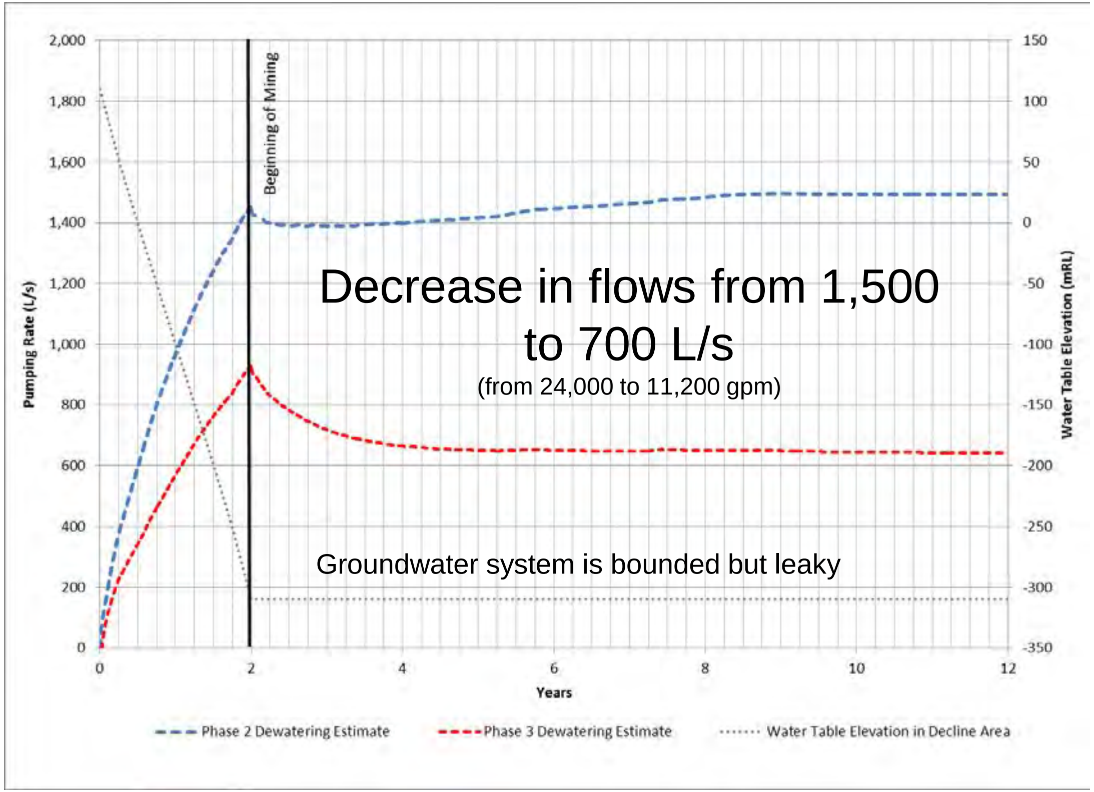
GHBs applied along eastern and western model boundaries

Phase 3: Calibration to 120 Day Pumping using Bounded, Leaky Model



- Max Q total is 220 L/s
- Four months of decline active dewatering
- Groundwater system is bounded but leaky

Phase 3: Block Cave Dewatering Estimate

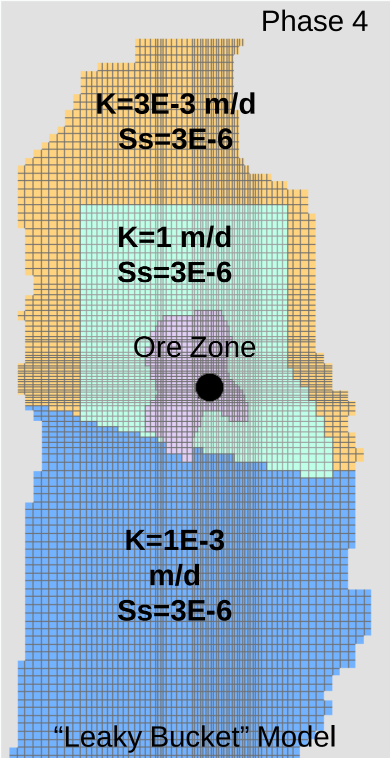


Phase 4: 200 Days of Pumping

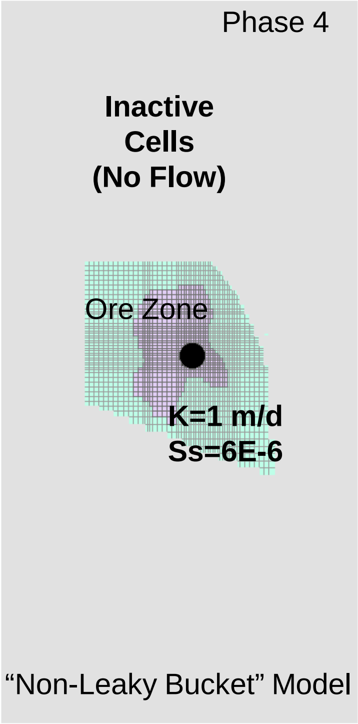
- Large scale pumping from exploration decline, max Q=350 L/s
- 7 months of transient water level data since decline active dewatering started
- Significant increase in measured drawdown
- Change from Block Cave to Open Pit
- Alternative conceptual models

Groundwater system is bounded but
LEAKY OR NON-LEAKY?

Phase 4: Alternative Conceptual Models



OR



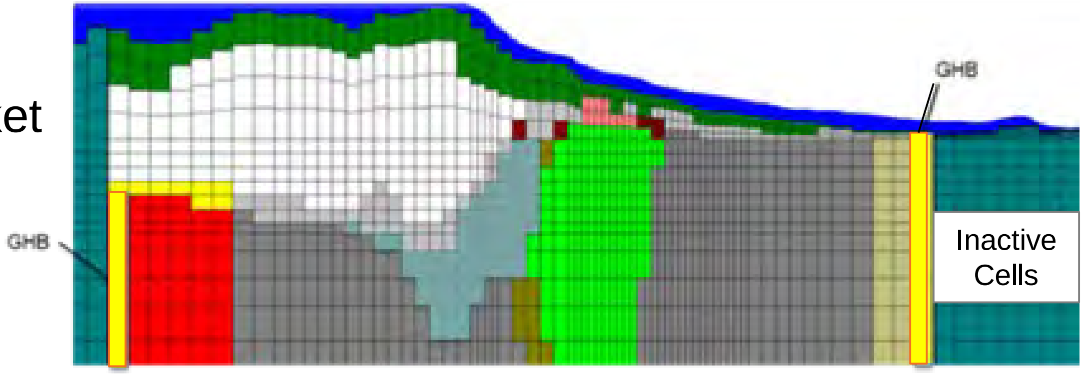
?

GHBs applied along eastern and western model boundaries

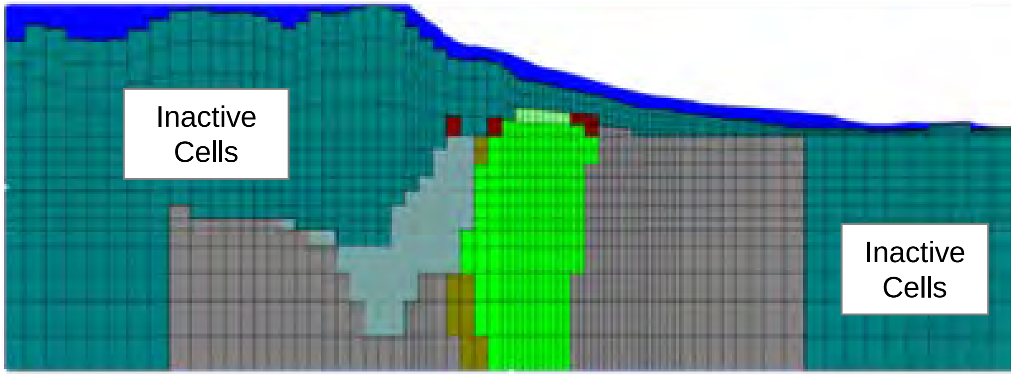
Phase 4: Alternative Models – Cross – Section (West- East)

“Leaky” Bucket

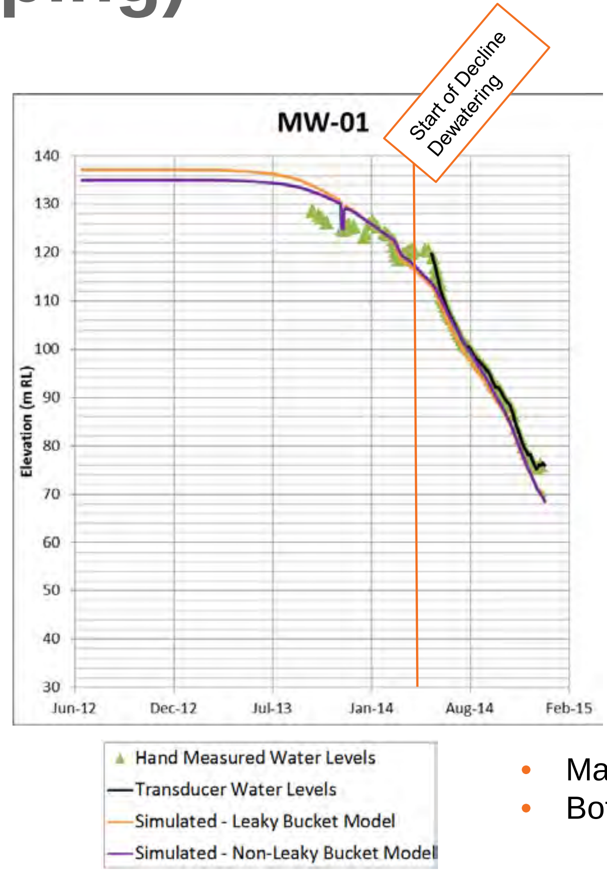
GHBs applied along eastern and western model boundaries

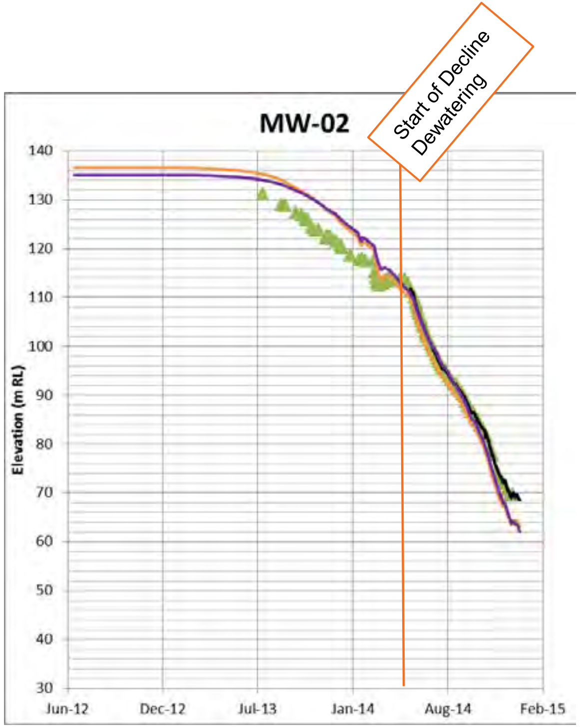


“Non-Leaky” Bucket



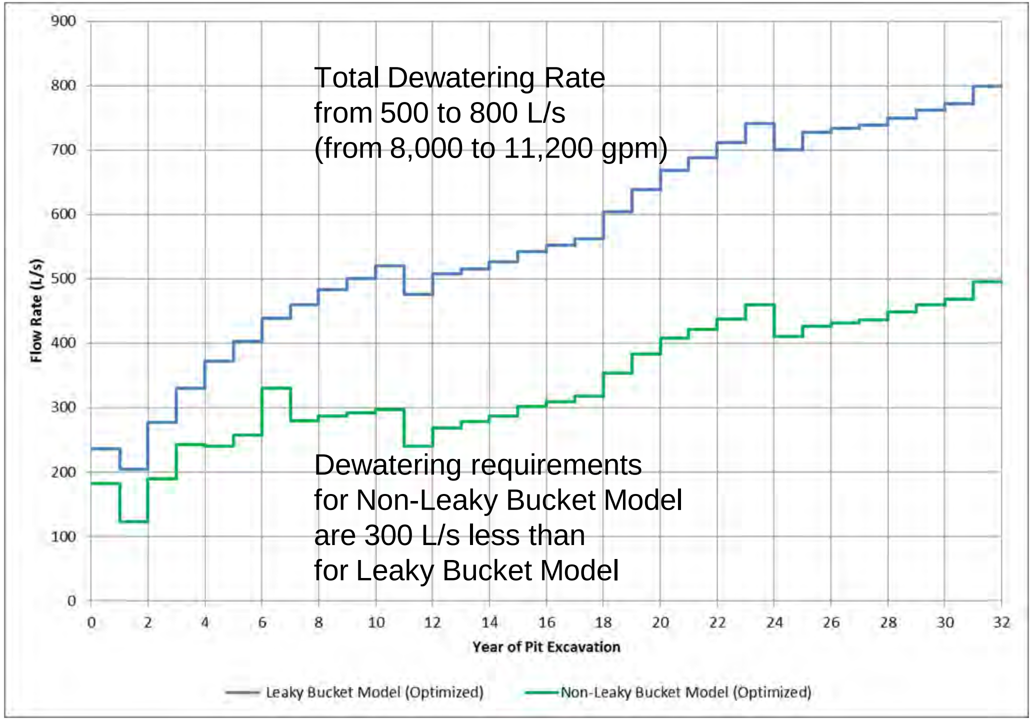
Phase 4: Calibration Results (200 Days of Pumping)





- Max Q is 350 L/s
- Both models can reproduce measured drawdowns

Phase 4: Open Pit Dewatering – Intermediate Results



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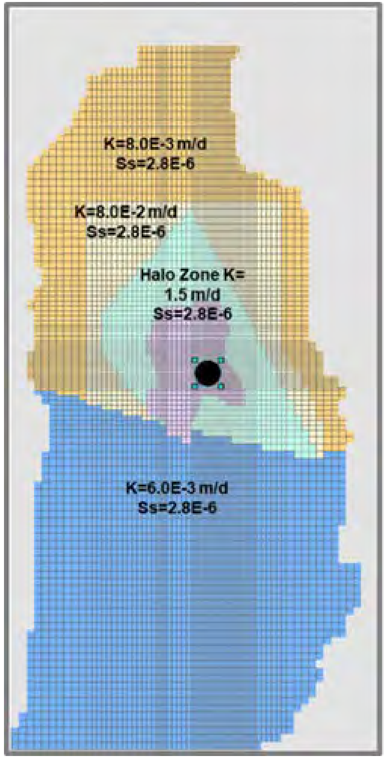
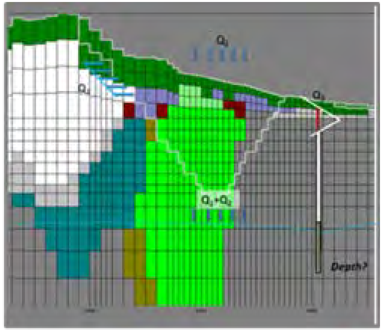
Which Conceptual Model Is Correct?

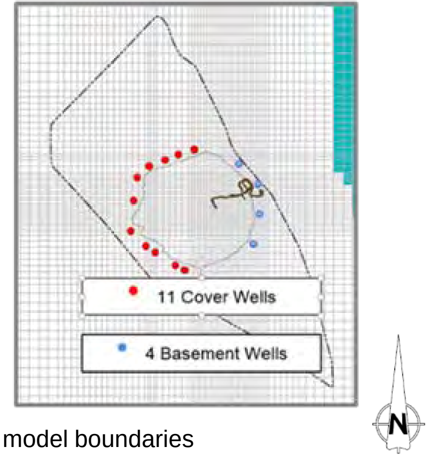
- One year of monitoring well water level and decline discharge data
- Maximum drawdown of about 70 m
- Decrease in decline dewatering to 125 L/s and observation of initial stage of water level recovery

Phase 5: “Leaky Bucket” Model, 365 Days Dewatering

- “Leaky Bucket” model consisting of a high-permeability fractured rock
- bounded at intermediate distance by low-permeability barriers and receiving limited vertical recharge from the overlying andesite aquifer

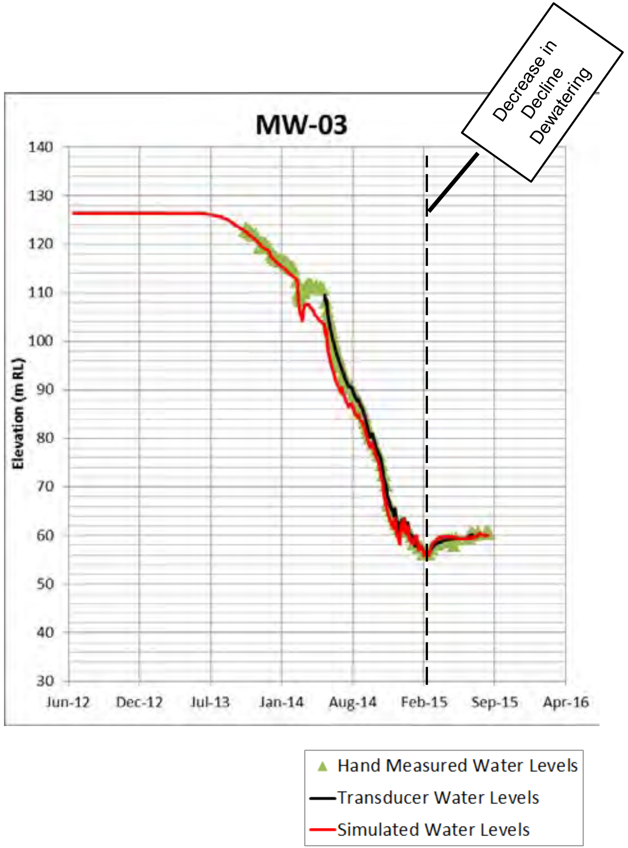


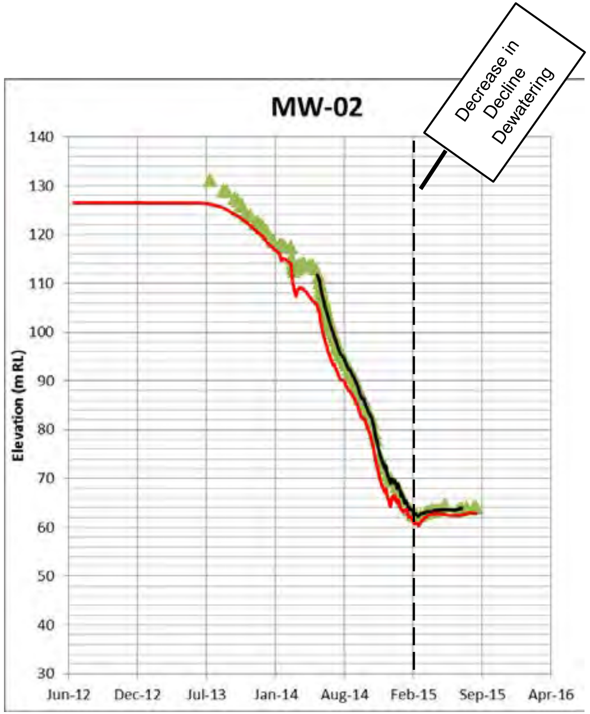




GHBs applied along eastern and western model boundaries

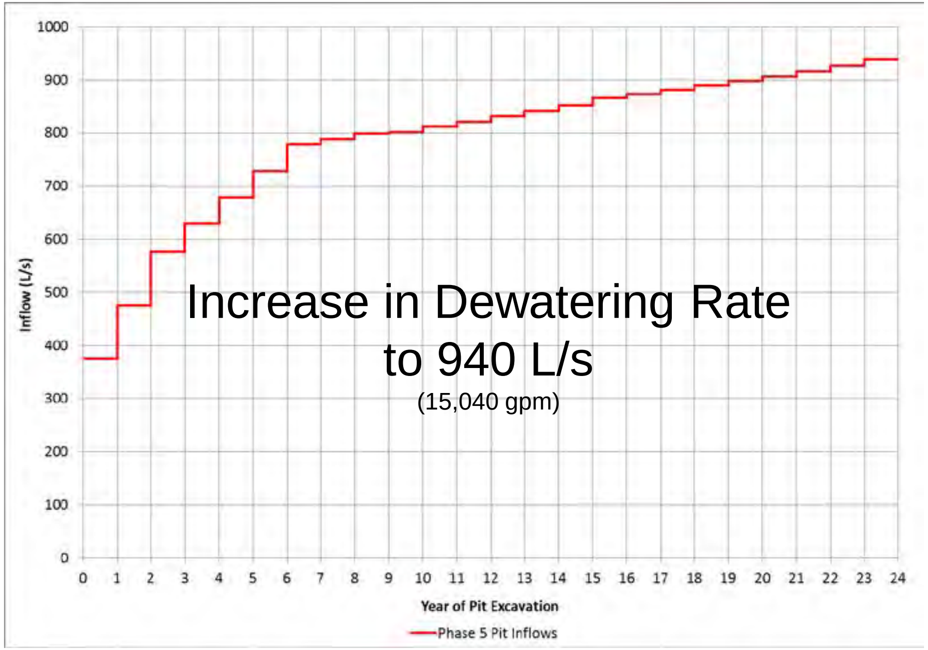
Phase 5:Calibration Results to 365 Decline Pumping





- Max Q decreased to 125 L/s
- “Leaky Bucket” Model

Phase 5: Open Pit Dewatering – Feasibility Study Predictions

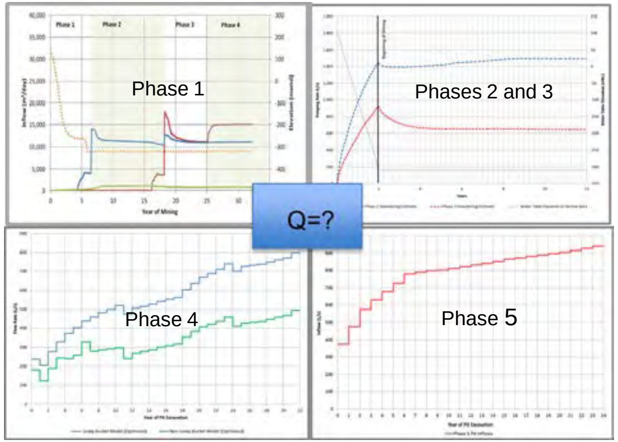


Phase 6: Model Verification

Five phases of model calibration with predicted dewatering rates from 300 to 1,500 L/s

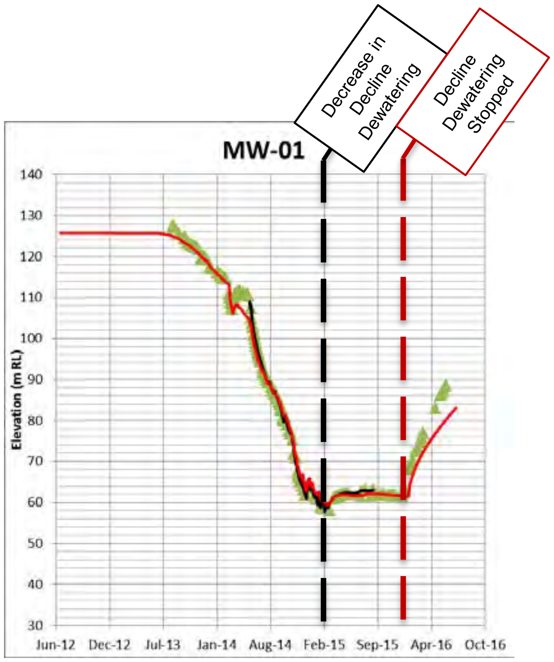
Are our predictions correct?

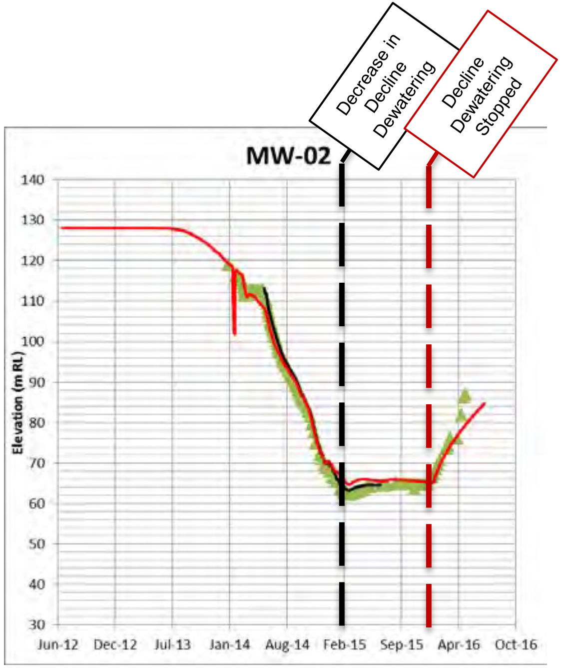
Phase 5 calibrated model was verified based on water level recovery data after shut down of decline dewatering



Phase 6: Model Verification

Groundwater level recovery after shutdown of dewatering confirmed correctness of "Leaky Bucket" conceptual model

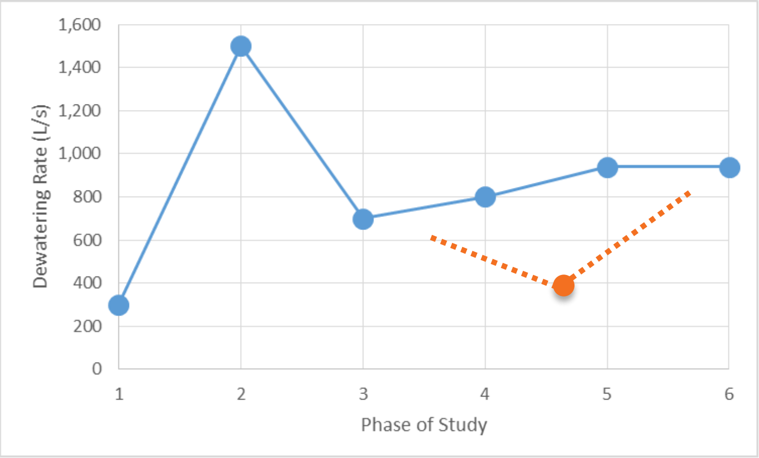




Hand Measured Water Levels
Transducer Water Levels
Phase 5 Simulated Water Levels

- Groundwater recovery (Q total = 0 L/s)

Predicted Dewatering Rates vs. Phase of Study



Phase of Study	Days Since Active Decline Dewatering Began	Predicted Dewatering Rate (L/s)	Conceptual Model	Type of Dewatering
1	0	300	Unbounded, Low K	Passive inflow to two block caves
2	10	1,500	Unbounded, High K	Active dewatering of one block cave
3	120	700	"Leaky Bucket"	
4	200	500-800	"Leaky Bucket"/Bounded	Active/passive dewatering of open pit
5	365	940	"Leaky Bucket"	Active dewatering of open pit
6	730	940		

Conclusions

- Dewatering predictions significantly depend on the hydrogeologic role of lateral boundaries and vertical recharge to the groundwater system.
- These two factors cannot be precisely evaluated during short to intermediate-term hydraulic testing in case of highly permeable “bucket” groundwater system and “leaky" conditions.
- Long-term testing data provide more support to conceptual models and accurate mine dewatering predictions.

Conclusions

- Groundwater level recovery data allow to improve/confirm model predictability in case of “leaky bucket” groundwater system.
- Water level monitoring data outside of highly permeable “bucket” can significantly help in defining “leaky/non leaky” conditions but are not usually available during initial stage of the mining project.

THANKS FOR YOUR ATTENTION

QUESTIONS?