Numerical Simulation of Basal Aquifer Depressurization in the Presence of Dissolved Gas – An Update

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What to Take Away From this Presentation

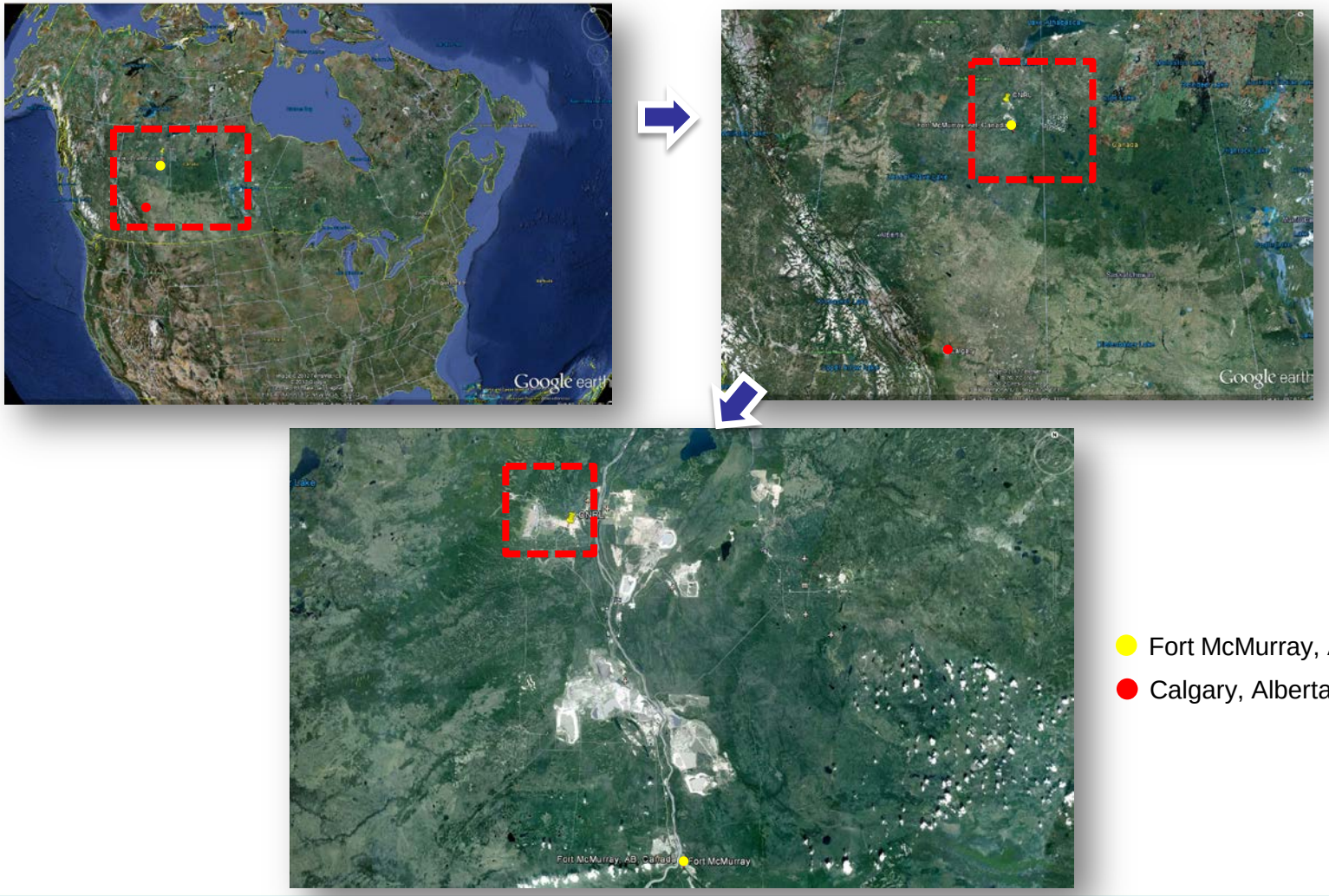
- Reservoir modelling typically considers multiphase flow;
- Groundwater modelling has only dealt with single phase flow;
- A regional scale reservoir model is required to address the dissolved gas issues during basal aquifer depressurization in advance of mining;
- Originally, this challenge was addressed through a modified application of MODFLOW (finite difference approach);
- This presentation provides the results of a better approach developed using FEFLOW (finite element approach).

Outline

- Background
- Key Questions to be Answered
- Ground Water Modelling Approach
  - Model Construction
  - Model Calibration
  - Prediction Results
- Summary and Conclusions

Background

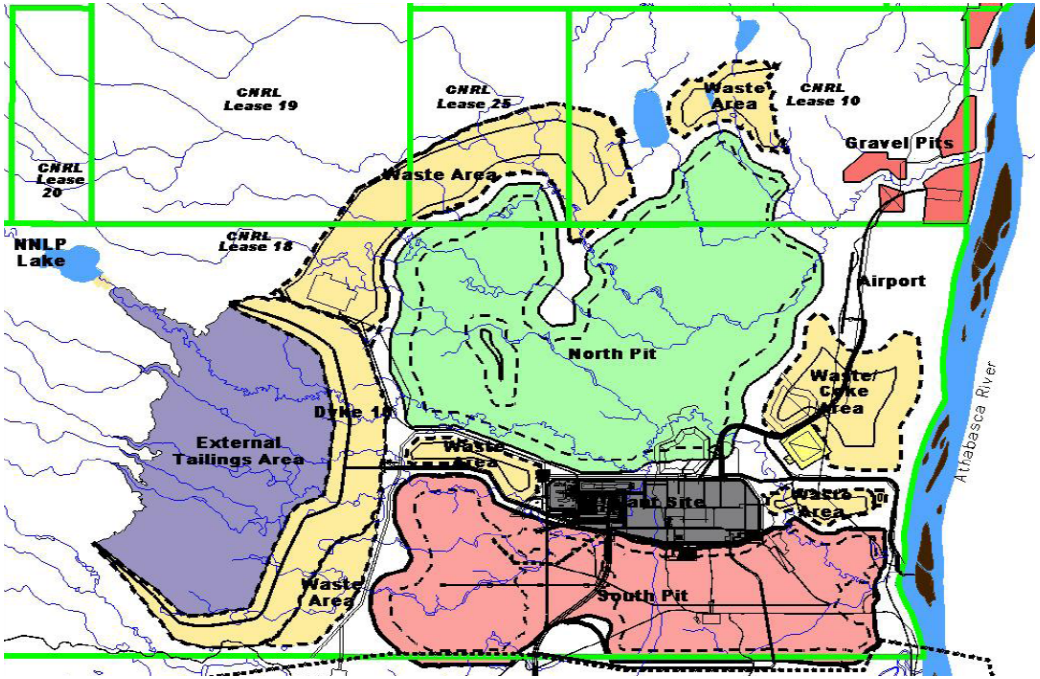
Background – Project Location



- Fort McMurray, Alberta, Canada
- Calgary, Alberta, Canada

Background - CNRL Horizon Oil Sands Project

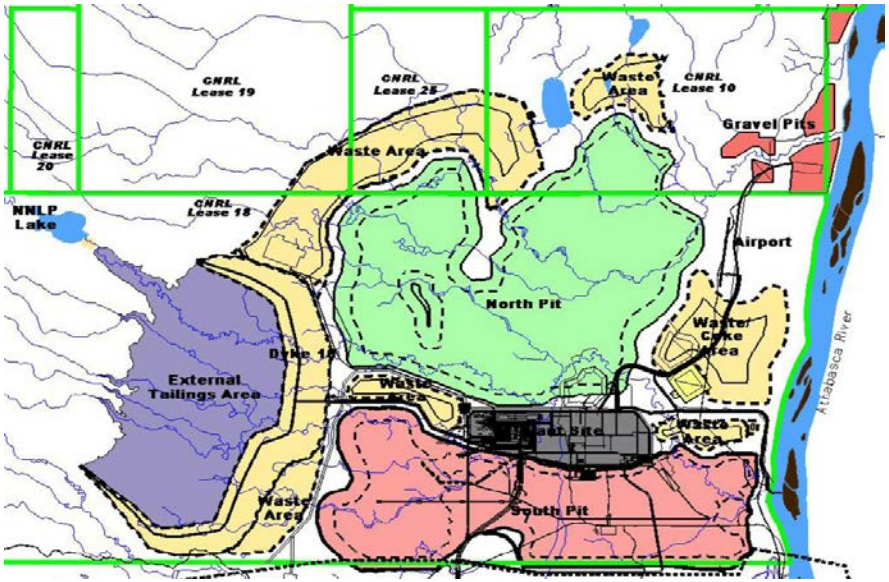
- Located about 75 km north of Fort McMurray in northeastern Alberta
- Open pit mining operation and oil sands plant for extracting and upgrading bitumen from the McMurray Oil sands deposit.



Background - CNRL Horizon Oil Sands Project

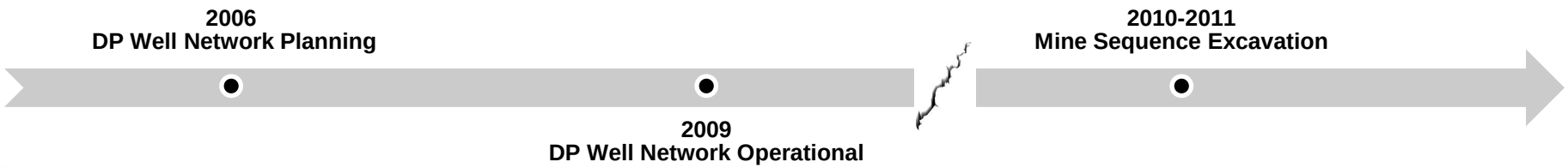
- Prior to mining the piezometric elevations within primary aquifer varied between 276 m to 280 m asl

- An aquifer depressurization plan consisting of 6 pumping wells were planned around the South Pit to depressurize the basal aquifer



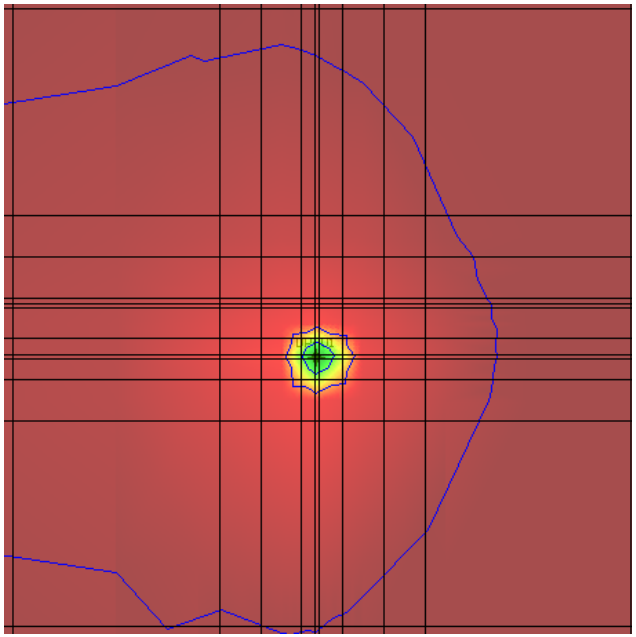
Background - CNRL Horizon Oil Sands Project

- DP network operational since 2009
- In early 2012, the DP well network consisted of 35 vertical in-pit pumping wells and 2 horizontal pumping wells
- Depressurization has been achieved in the area of active mining.



Background – Why? Gas Locking

- If there are substantial amounts of dissolved gas in the groundwater, “gas-locking” may occur during the depressurization of aquifer
  - Pore pressure reductions lower the gas solubility;
  - When pressure reduces below critical value (“bubble pressure point”), exsolution occurs;
  - Presence of gas ↑ effective specific storage or ↓ effective permeability;
  - Permeability reduction results in steeper drawdown curves and reduced depressurization extent.



Background – Effects of Gas Locking

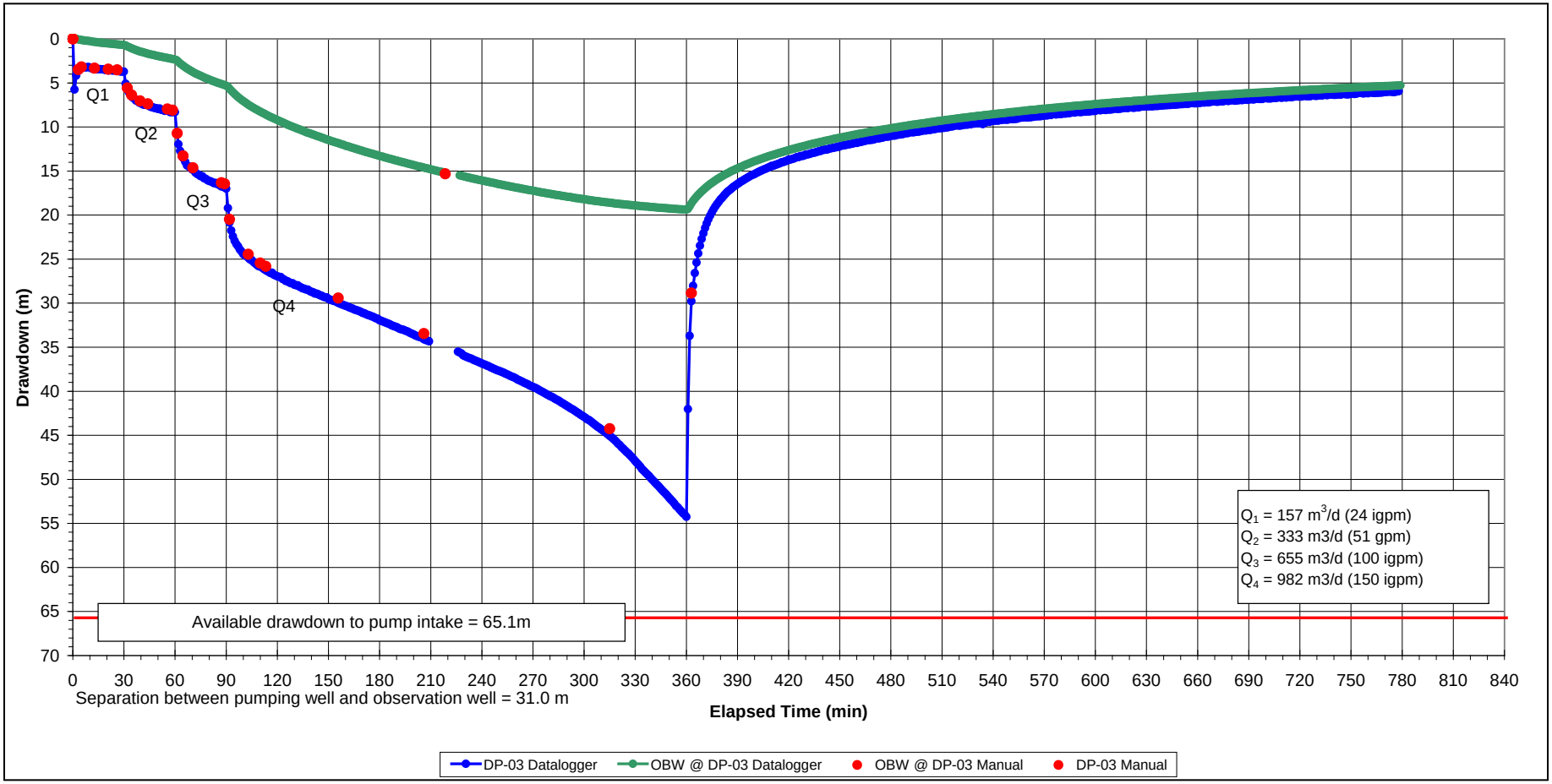
- Reduction in DP well efficiency – depressurization is limited locally;
- Additional DP wells may be required to achieve the target water level elevations.
- Cost and schedule implications.

Background – Basal Aquifer Isopach

- Mining starts from the west edge of the pit

South Pit Contours

Background – Key Indicators



Key Questions

Key Questions to be Answered

- How many wells are required to be installed in the DP network?
- How much water to be handled?

Modelling Approaches

Groundwater Modelling Approaches

- Develop Regional Model in Multiphase Flow Modelling Framework.
  - Numerically complex;
  - Computationally memory extensive.

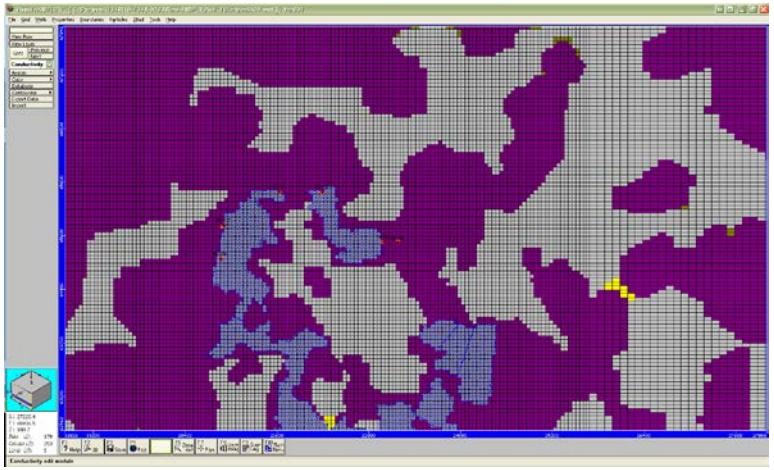
- Develop Alternative Model to Build the Solution for Gas Locking Problem in the Single-Phase Modelling Framework;
  - Easy to solve using an existing regional model;
  - Computationally less intense.

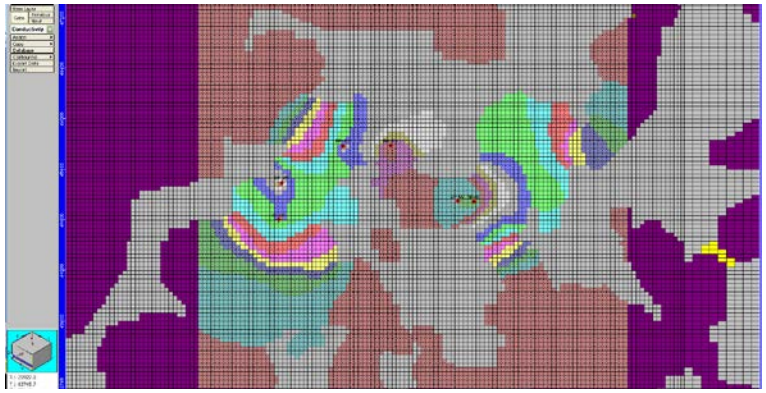
    - Regional Model in Visual MODFLOW;
    - Regional Model in FEFLOW.

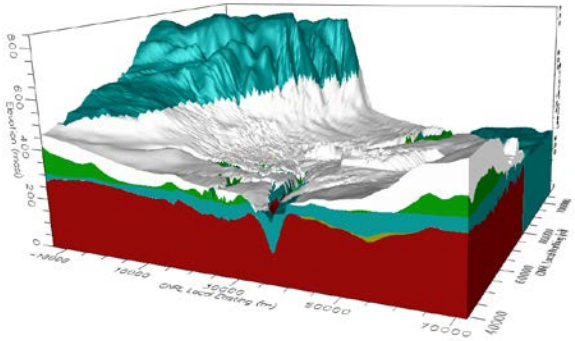
Single Phase Flow Modelling - MODFLOW

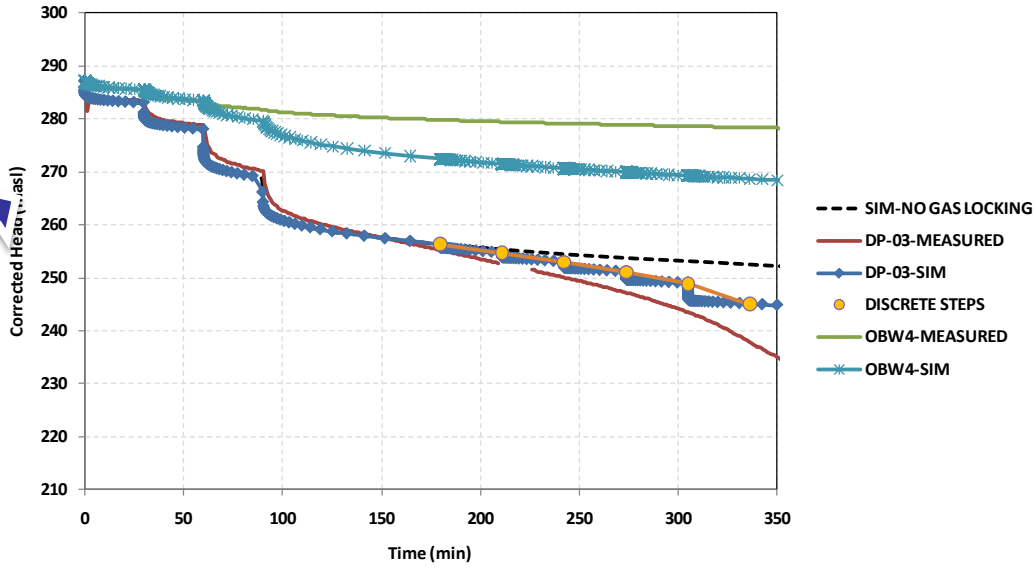
- MODFLOW model was revised to account for dissolved gas issues
  - The hydraulic conductivity values were revised based on the simulated pressure at discrete time steps.

MODFLOW Approach – Discrete Reduction





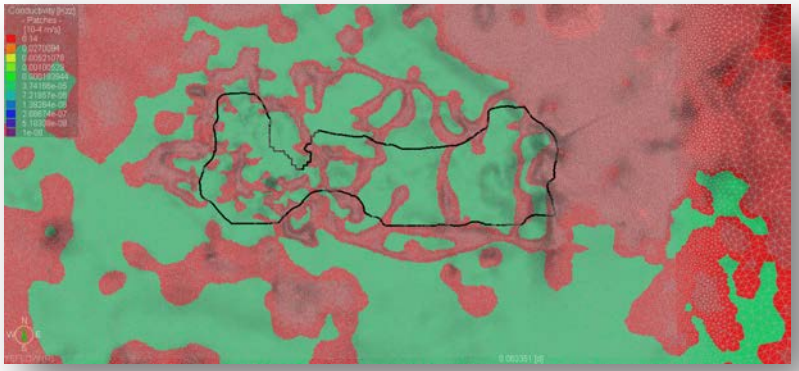


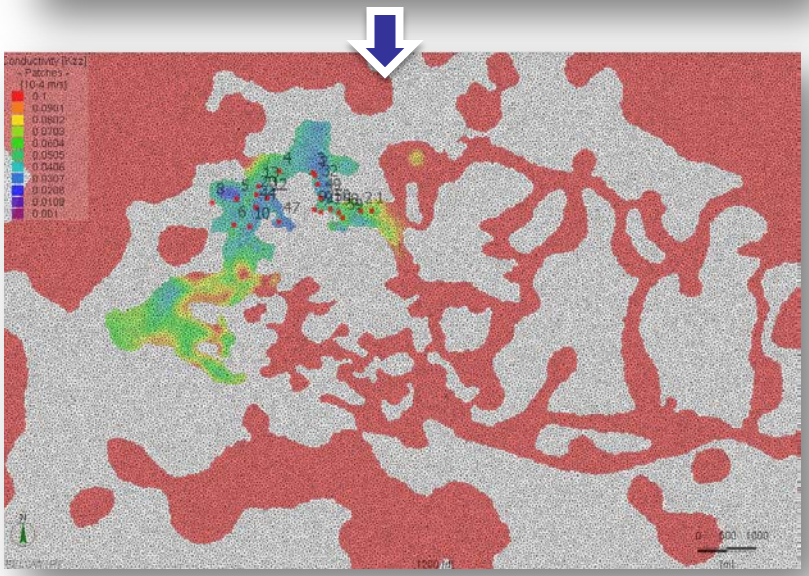


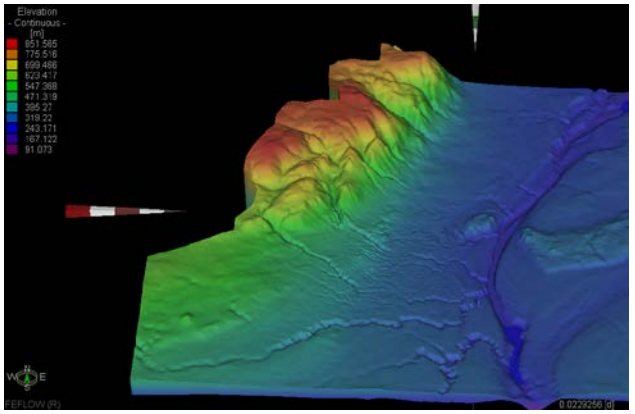
Single Phase Flow Modelling - FEFLOW

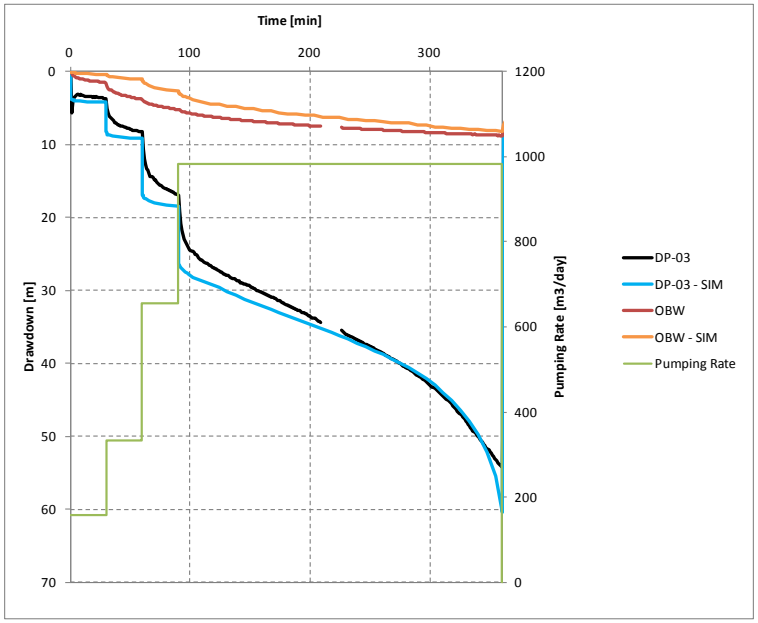
- An external module was developed in FEFLOW
  - Automated update of hydraulic conductivity during each timestep based on:
    - Aquifer pressures; and
    - Relative permeability relationship.

FEFLOW Approach - Continuous Reduction









Single Phase Flow Modelling - FEFLOW

- Gas characterization
  - Pressurized sampling
  - Multi-phase flow (reservoir) modelling CNRL

    ➔ Relative permeability relationship

    ➔ 30% reduction in permeability for every 10 m reduction in head below the bubble point pressure (BPP)

Single Phase Flow Modelling - FEFLOW

- $K' = (1-p)^{\frac{H-h}{D}} \times K$ … obtained from the relative permeability and pressure saturation relationship

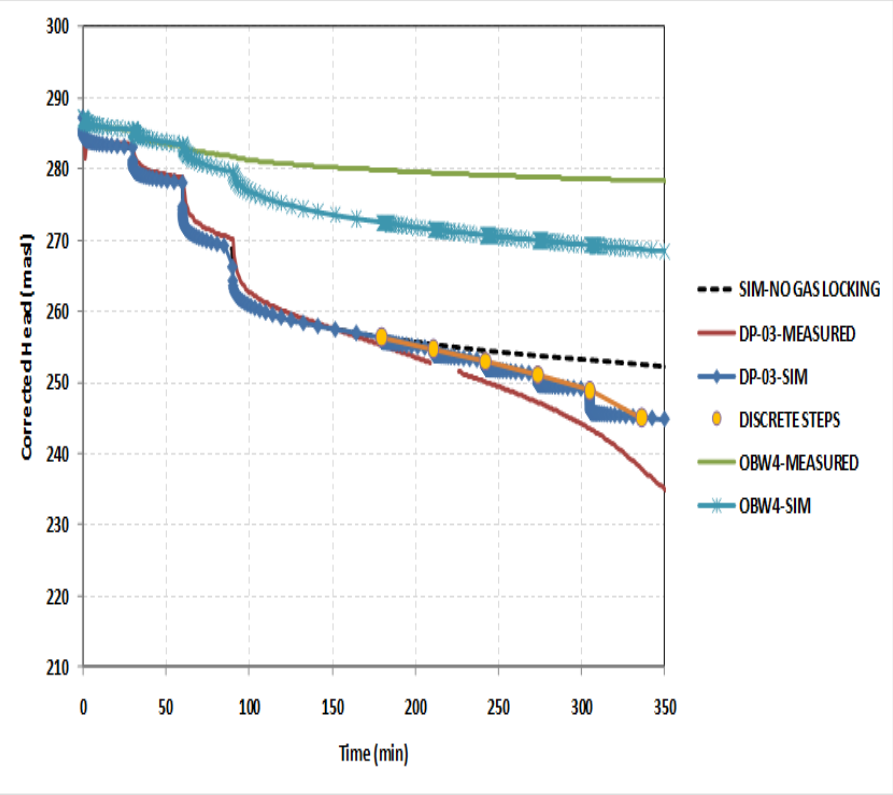
- p% of permeability reduction was found for D m of pressure drop

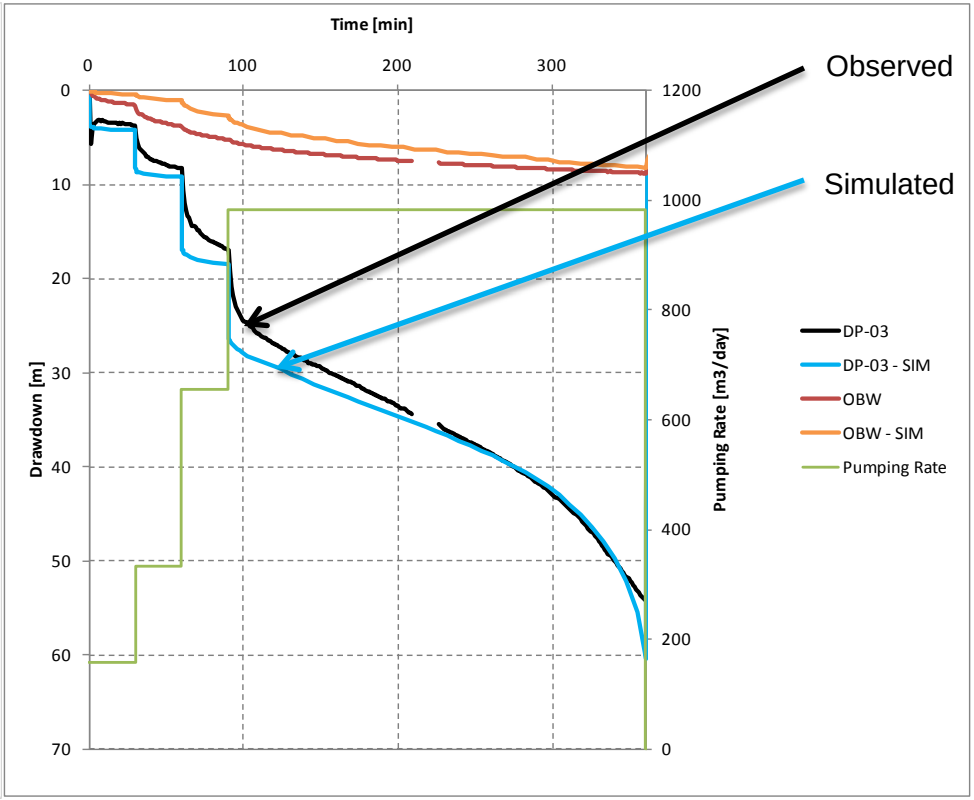
- H = 240 masl (BPP)
- h = head in each node
- K = Original Hydraulic Conductivity

Calibration to a Pumping Test

- With Gas-Locking – 30% reduction in K per 10 m

Calibration (Well Head)





Comparison Between Approaches

- *FEFLOW Model*

- Reduction in effective permeability is continuous (i.e. at every timestep)

  Implemented through external module (IFM) which is linked to FEFLOW at run-time

  - separate module created to reduce K
  - shorter runtimes
  - minor user interaction (only need specify K reduction function)

- *Visual MODFLOW Model*

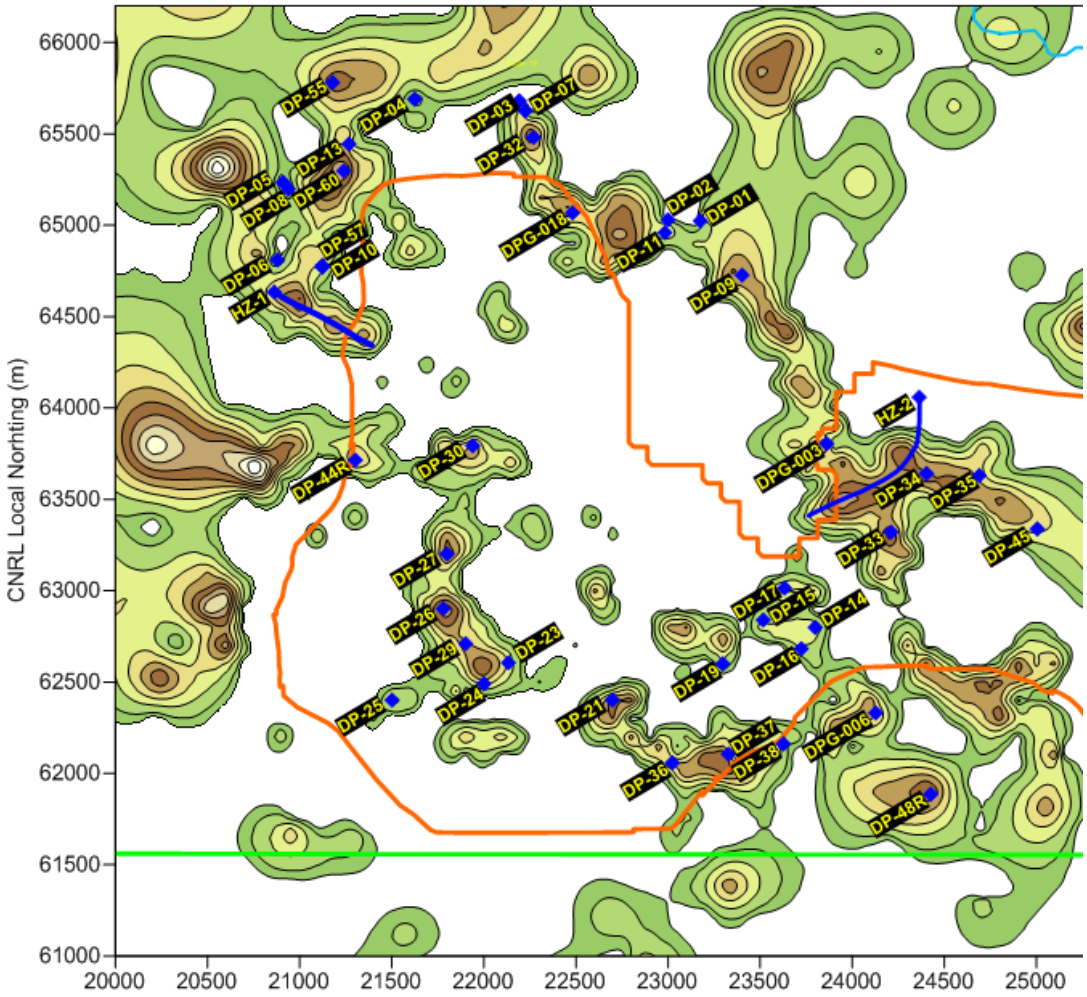
- Reduction in effective permeability is discrete (i.e. not at every timestep)

  The K field was revised at discrete timesteps based on the simulated heads and bubble point pressure

  - model run was interrupted to reduce K
  - longer runtimes
  - major user interaction

History Match

History Match – Pumping Wells



- Pumping schedule irregular
- Horizontal wells *<u>are</u>* modelled
- 40 scheduled stress (pumping) periods
- 43 pumping wells

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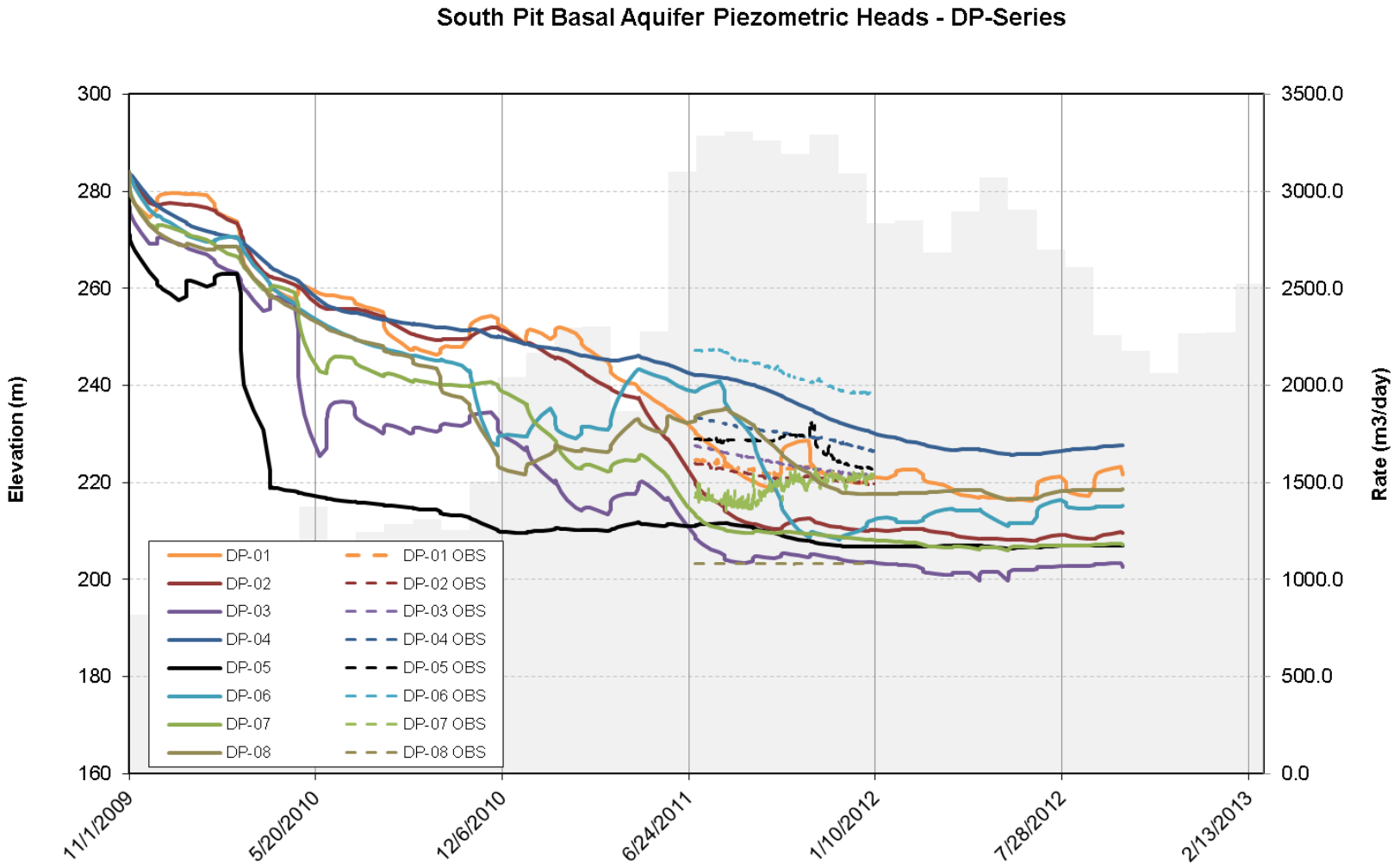
History Match – DP Obs Wells (with gas-lock)



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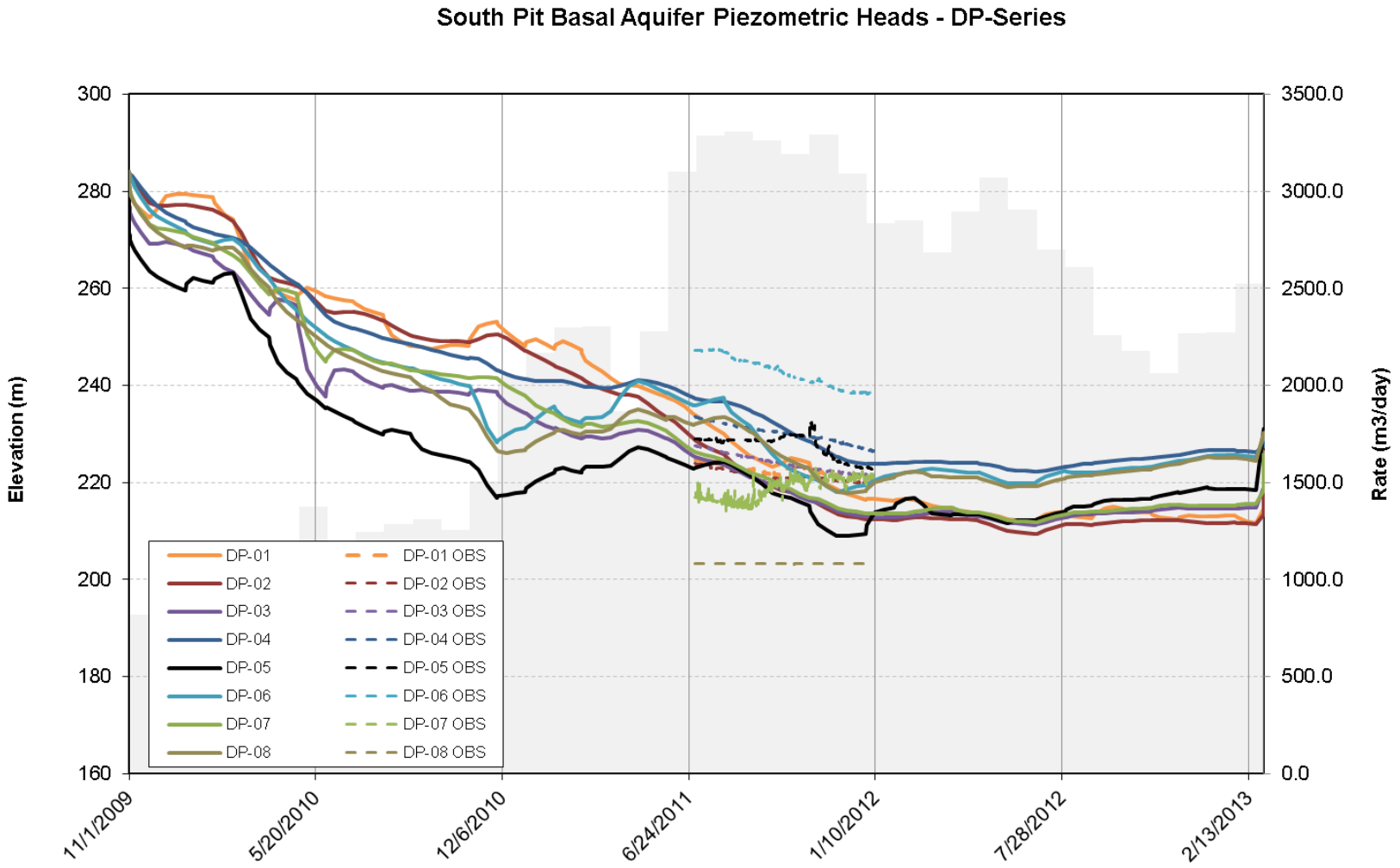
History Match – DP Obs Wells (no gas-lock)



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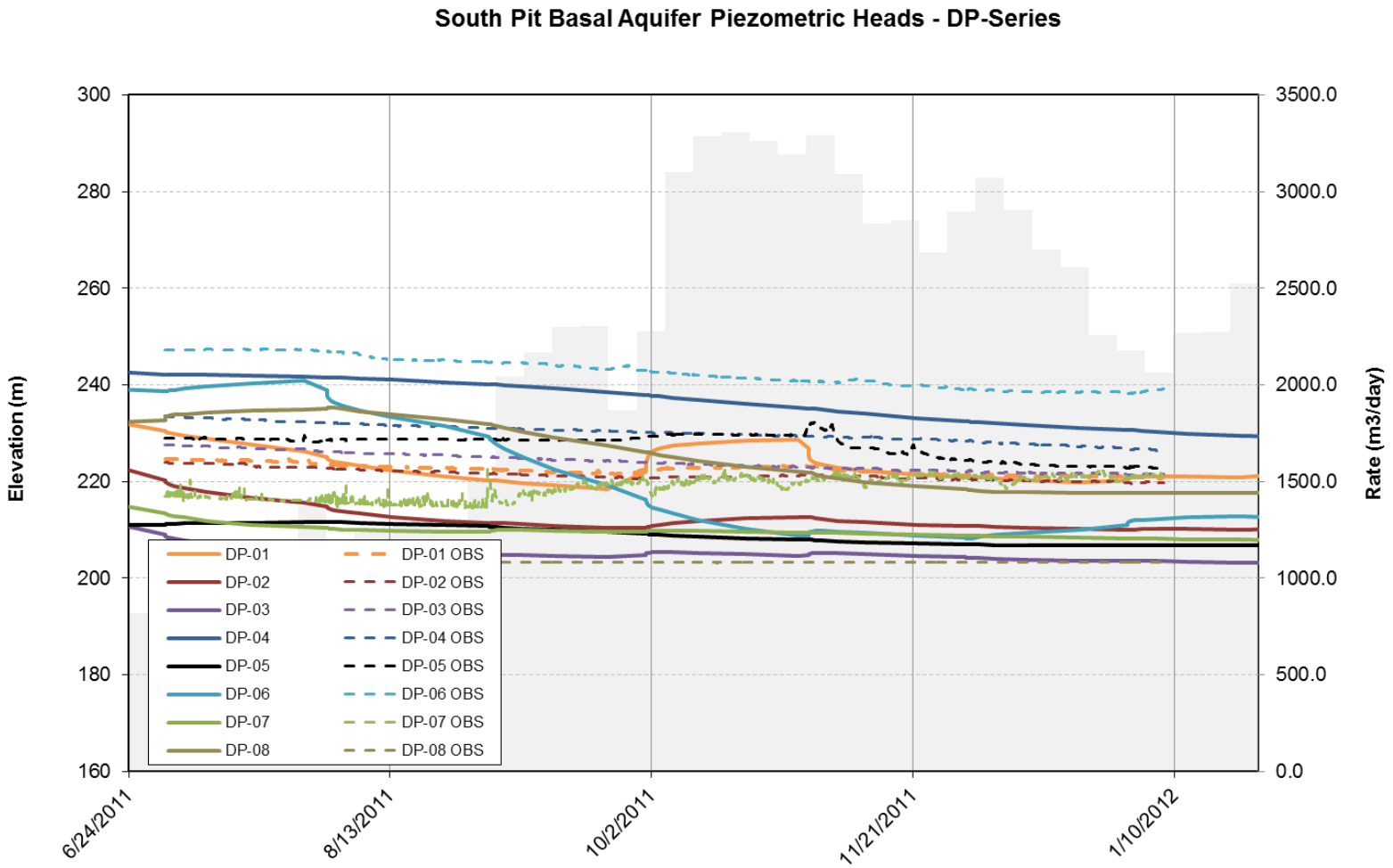
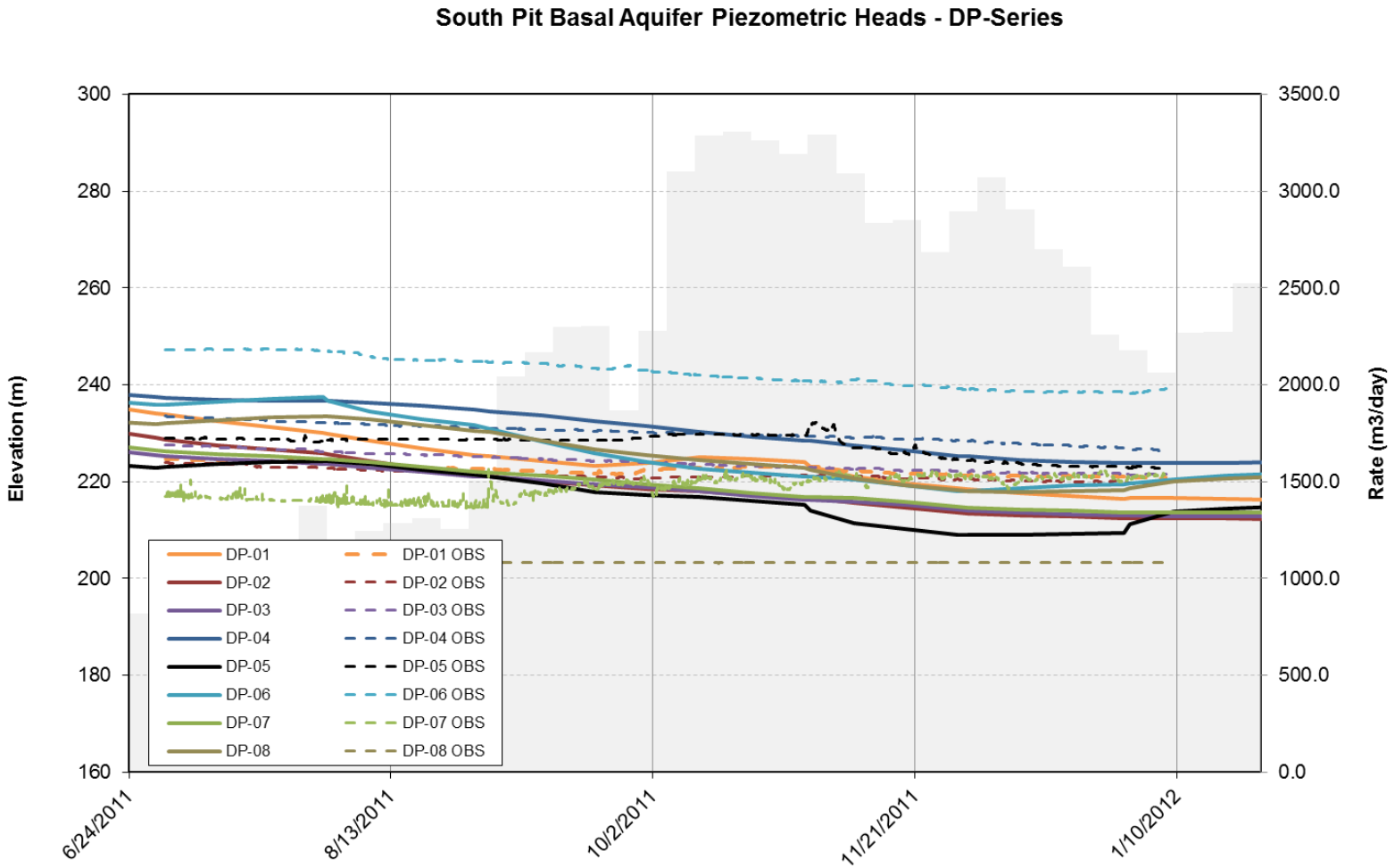


History Match – DP Obs Wells (no gas-lock)



History Match - Summary

- Detailed history match of operational volumes completed with
  - irregular pumping schedule;
  - 2 horizontal wells; 41 vertical wells;
  - 40 scheduled stress (pumping) periods

- Suitable match obtained given approach and uncertainties

Prediction Results

Estimation of Flow Volumes and Number of Wells

No Gas Locking

	North [m^3/day	South [m^3/day	Total [m^3/day
2012	711.23	98.46	809.69
2013	655.55	292.44	947.99
2014	482.81	555.90	1038.71
2015	457.22	662.96	1120.18

No Gas Locking – Estimate # Wells

Number of Wells Operating		
North	**South**	**Total**
8	1	9
7	3	11
5	6	12
5	7	12

With Gas Locking – Estimate # Wells

Number of Wells Operating		
North	**South**	**Total**
24	3	27
22	10	32
16	19	35
15	22	37

Summary and Conclusions

Summary and Conclusions

- Characterization of dissolved gas during the early stage of the project is critical;
- A predictive tool has been developed to design the DP well network for gassy aquifers;
- Greater number of wells are required to depressurize a given aquifer in the presence of dissolved gas;
- The presence of dissolved gas could significantly impact the overall project schedule and budget.