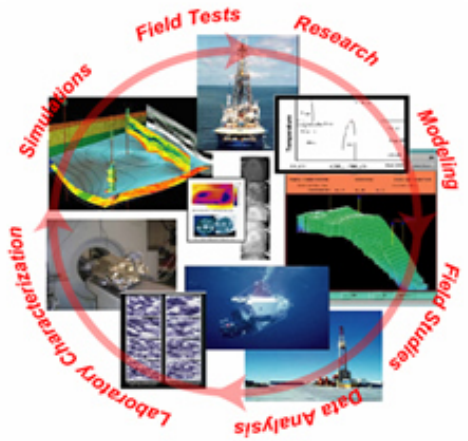
NATIONAL ENERGY TECHNOLOGY LABORATORY

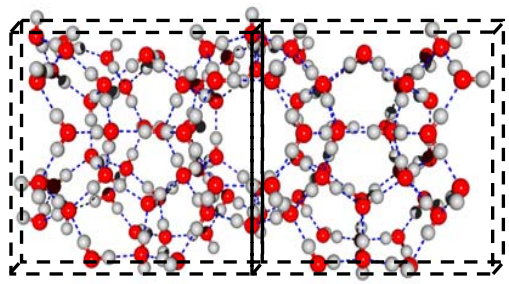
Methane Hydrate Reservoir Code Comparison and Reservoir Simulation Sensitivity Analyses



Brian J. Anderson

National Energy Technology Laboratory

West Virginia University



This technical effort was performed in support of the National Energy Technology Laboratory's on-going research in Gas Hydrates Under the RDS contract DE-AC26-04NT41817

West Virginia University
Department of Chemical Engineering

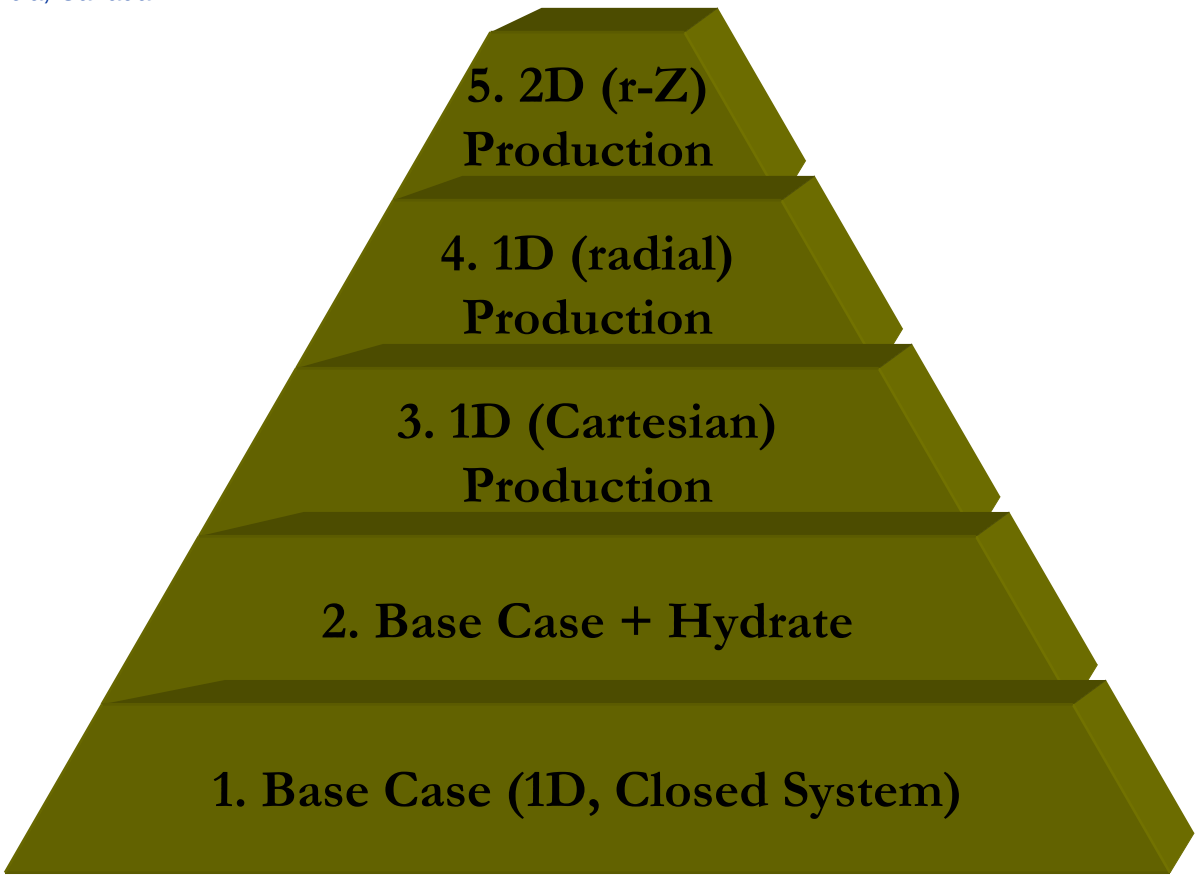
Reservoir Simulator Comparison Study

Goals

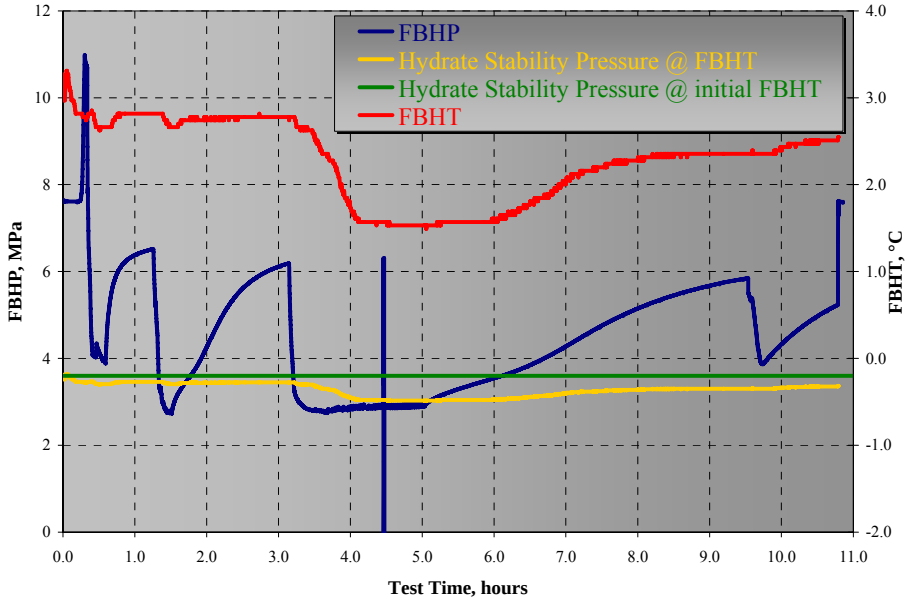
- **To exchange information regarding gas hydrate dissociation and physical properties enabling improvements in reservoir modeling**
- **To build confidence in all the leading simulators through exchange of ideas and cross-validation of simulator results on common datasets of escalating complexity; and**
- **To establish a depository of gas hydrate related experiment/production scenarios with the associated predictions of these established simulators that can be used for comparison purposes .**

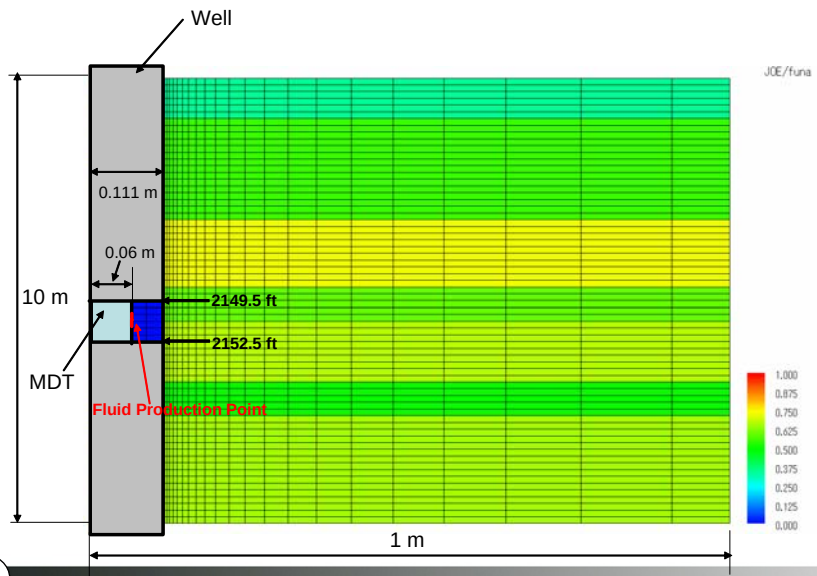
Progression of Problems 1-5

Wilder, J., et al. An International Effort to Compare Gas Hydrate Reservoir Simulators. in Proceedings of the 6th International Conference on Gas Hydrates. 2008. Vancouver, British Columbia, Canada.



Problem 6





- **History Matching**
  - Participants charged with matching the MDT test results – particularly the C2 test
    - Pressure response
    - Temperature response
    - Fluid flow rates
  - Compared fit parameter sets for differences and agree on common inputs for Problem 7
  - Anderson, B., et al. *Analysis of Modular Dynamic Formation Test Results from the "Mount Elbert" Stratigraphic Test Well, Milne Point, Alaska.* in *Proceedings of the 6th International Conference on Gas Hydrates.* 2008. Vancouver, British Columbia, Canada.

Key Findings

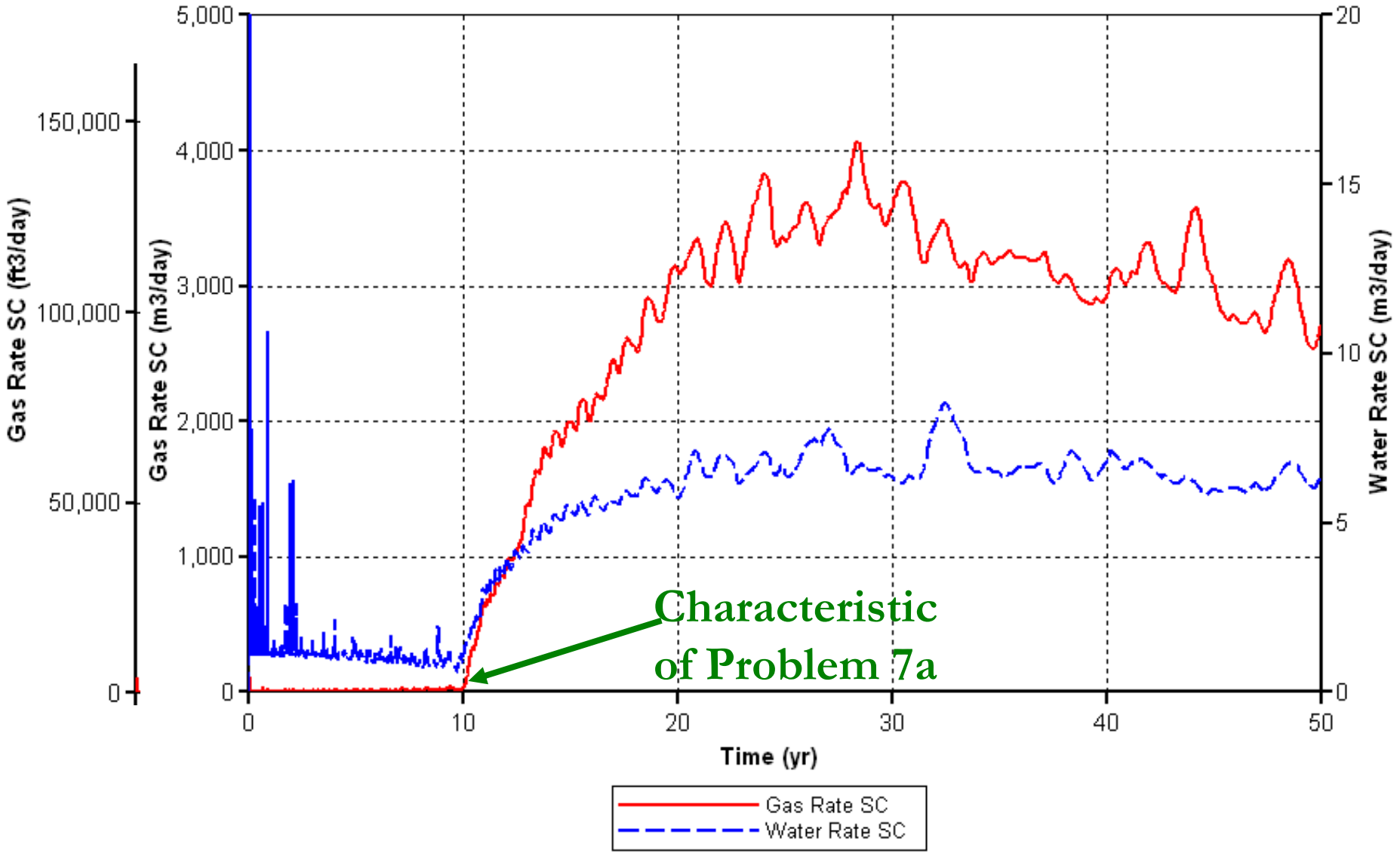
- **1st Drawdown**
  - *in situ* perm. 0.12 – 0.17 mD

- **Subsequent Flow Periods**
  - Wellbore storage necessary for reproducing pressure curves
    - Fluid segregation in this annular space plays a key role in the general shape of the recovery curves
    - No models explicitly represent open space – overall fitted parameters may reflect this error
  - Formation kinetics *may* affect the shape of the recovery curve

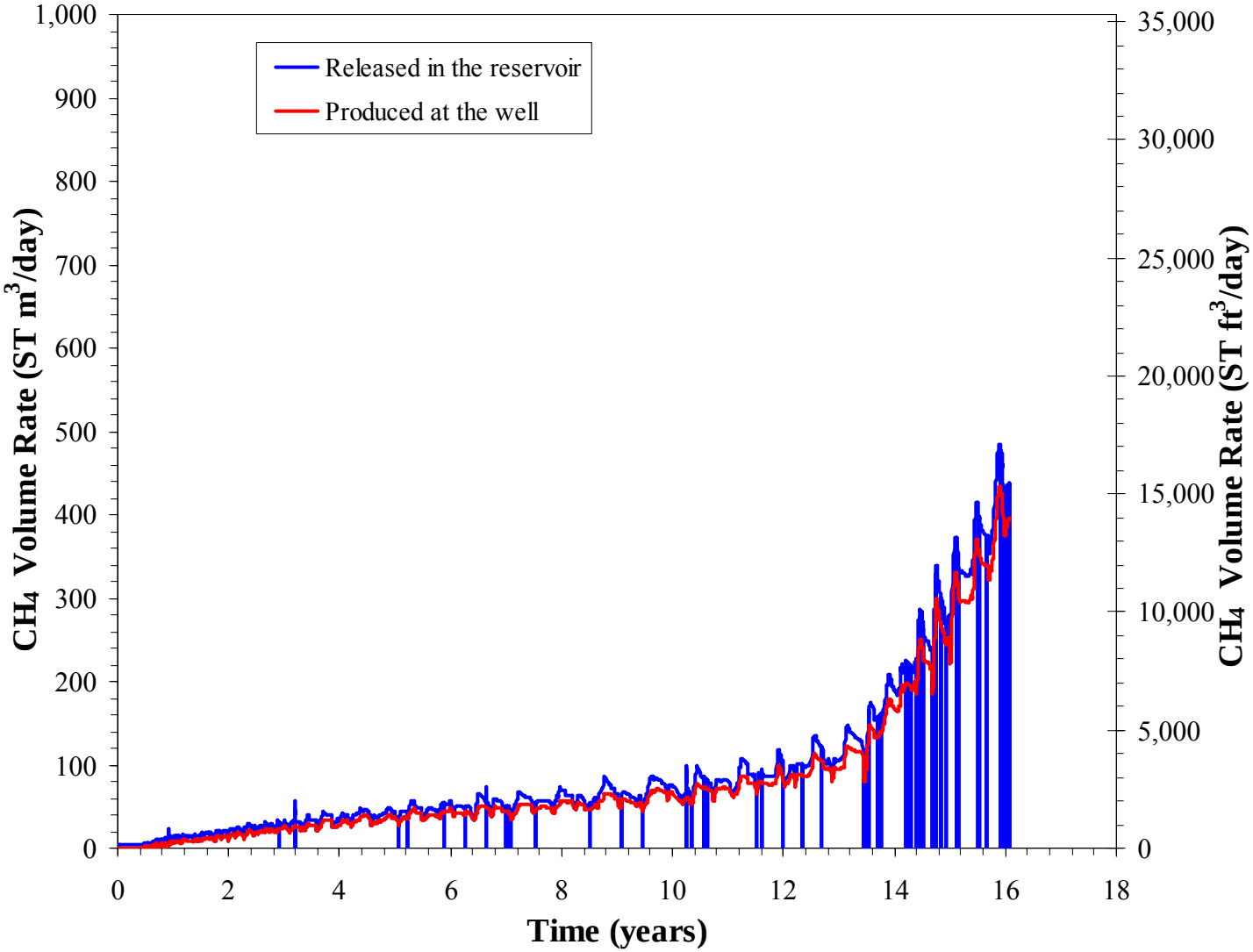
Problem 7 – Three production scenarios

- **3 different hydrate accumulation scenarios – 50-yr production**
  - Mt. Elbert-like formation
    - 2.5-3.0°C, S_H = 65%, P ~ 6.7 MPa
  - PBU L-Pad
    - 5.0-6.5°C, S_H = 75%, P ~ 7.3-7.7 MPa, two hydrate zones
  - Down-dip formation
    - 10-12°C, S_H = 75%, P ~ 8-9 MPa, two hydrate zones, near base of HSZ

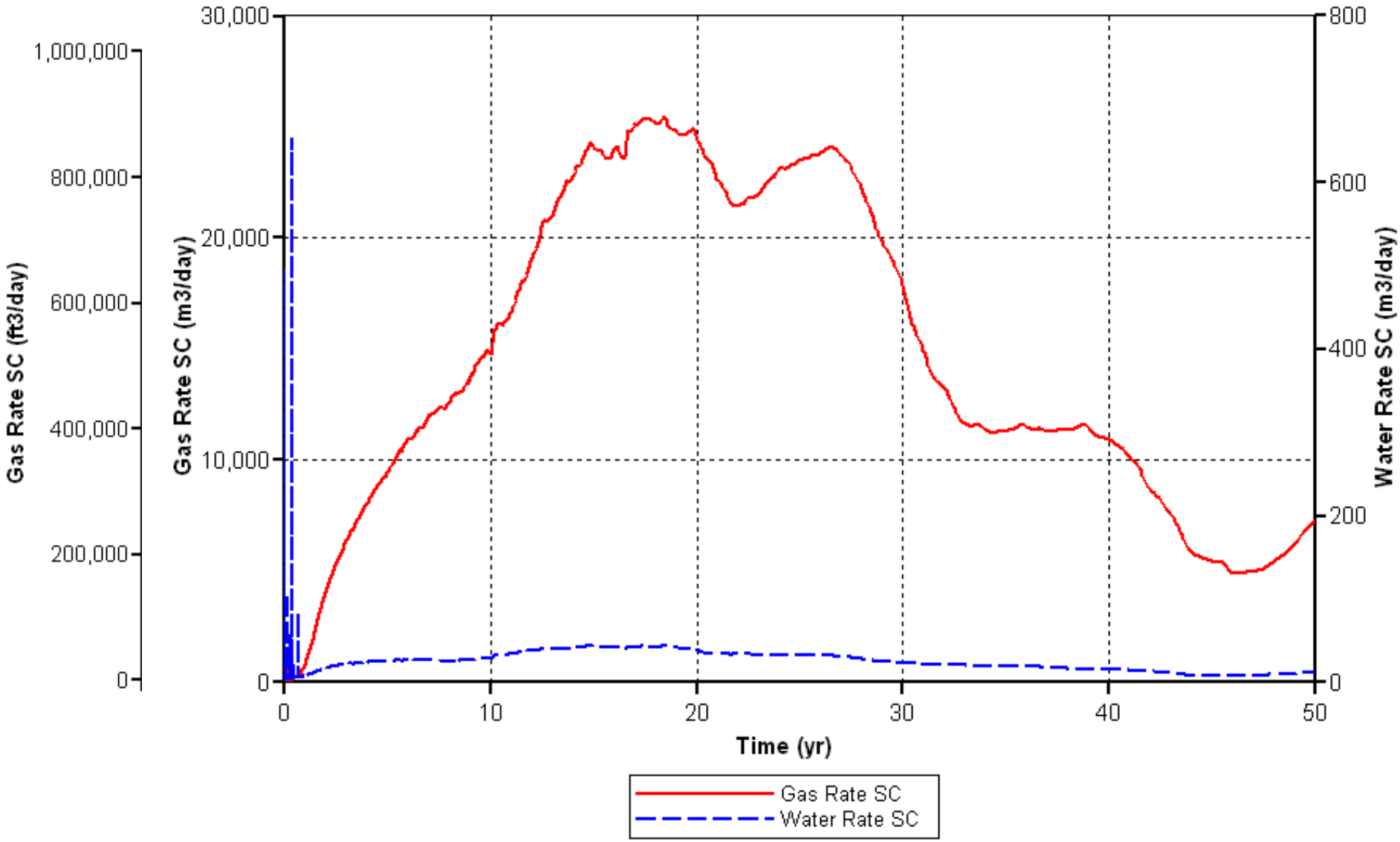
Problem 7a: CMG STARS



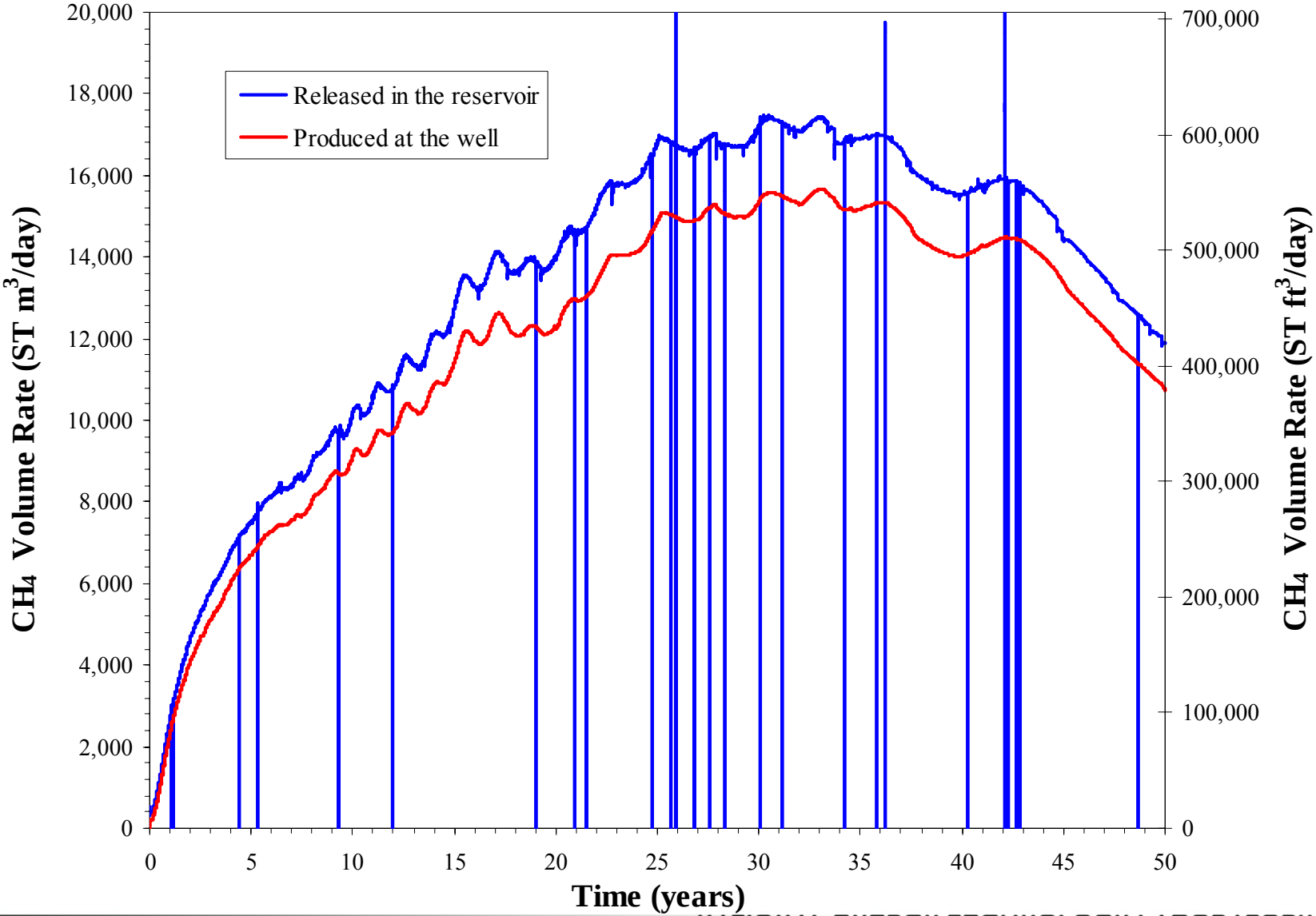
Problem 7a: HydrateResSim



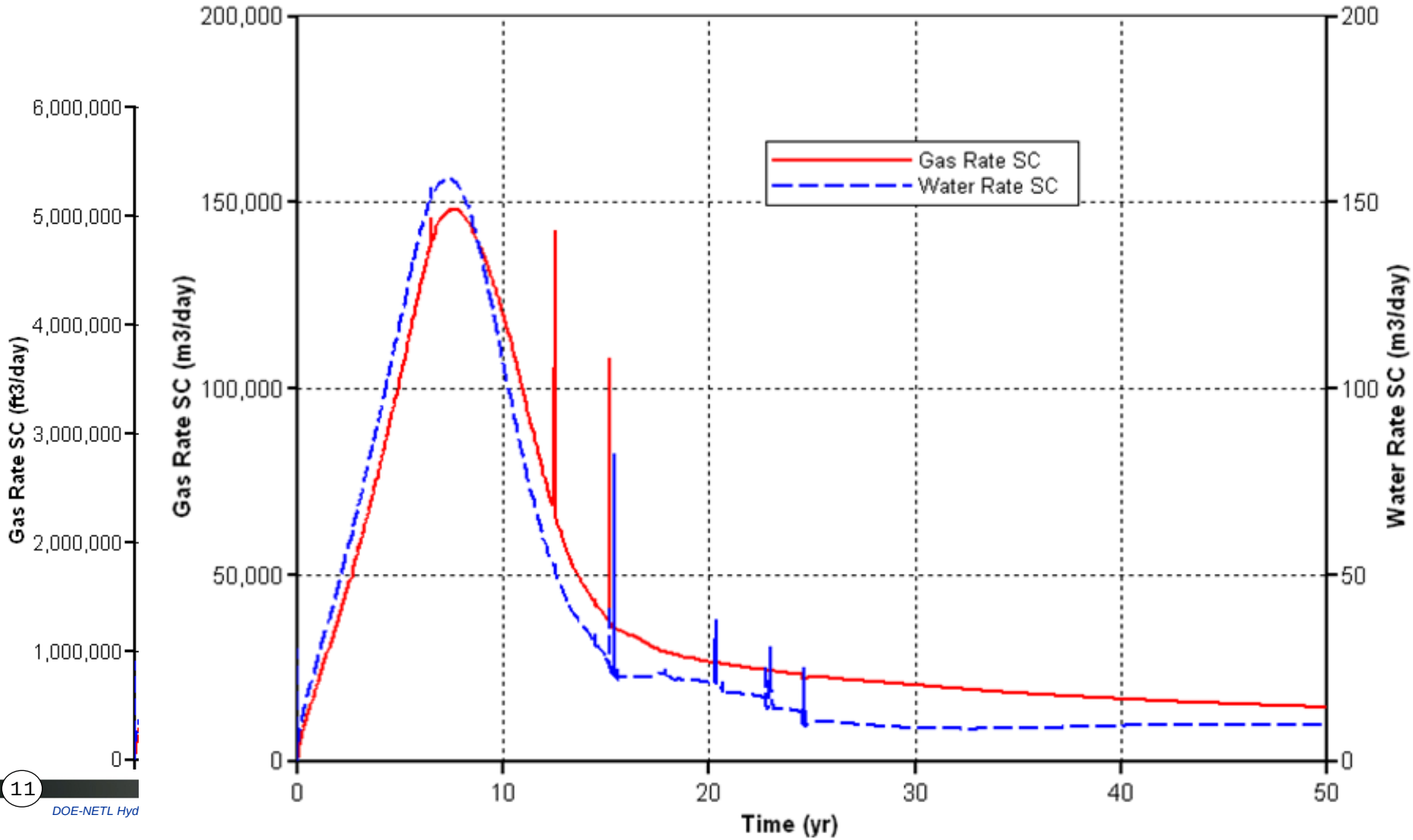
Problem 7b: CMG STARS



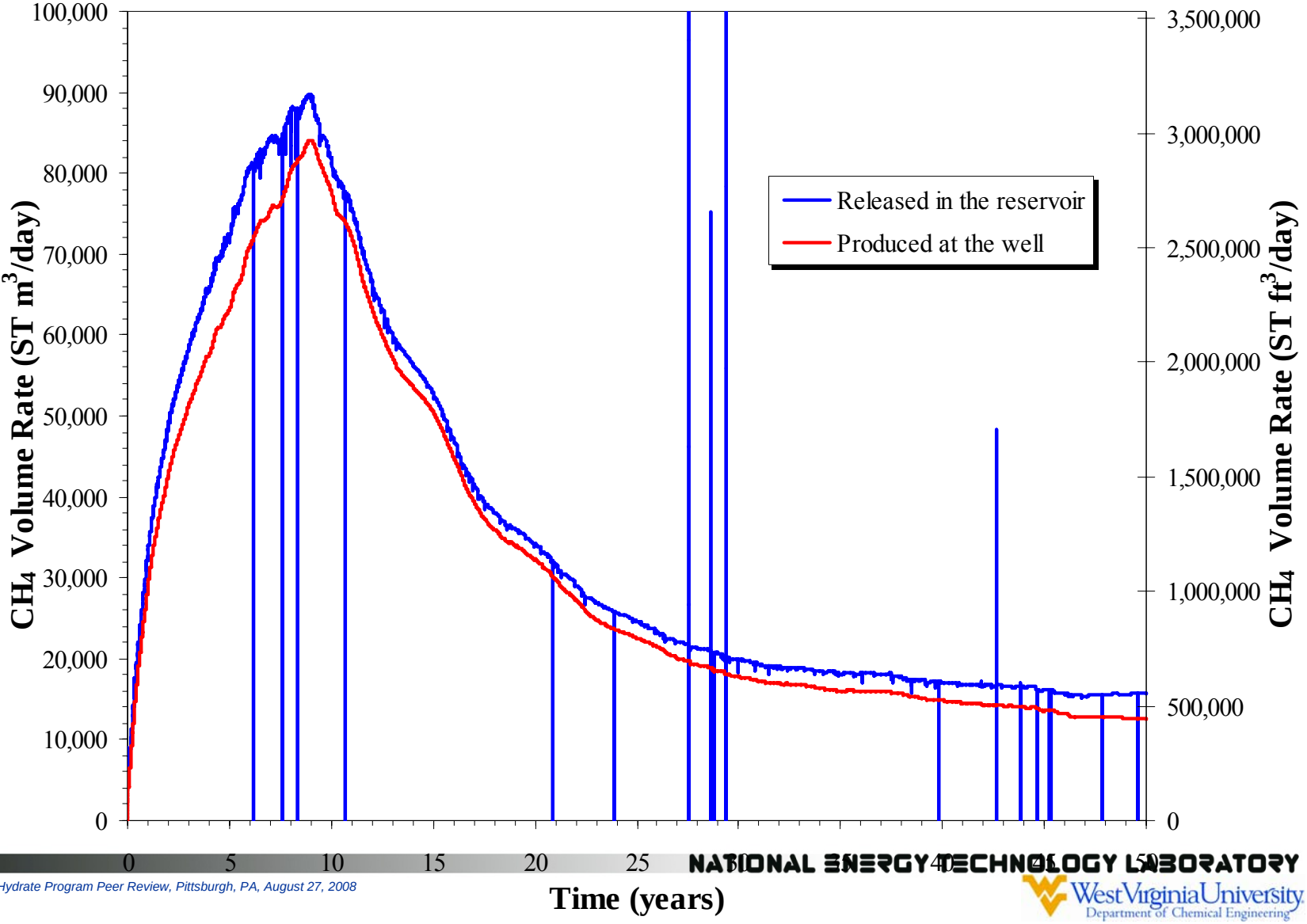
Problem 7b: HydrateResSim

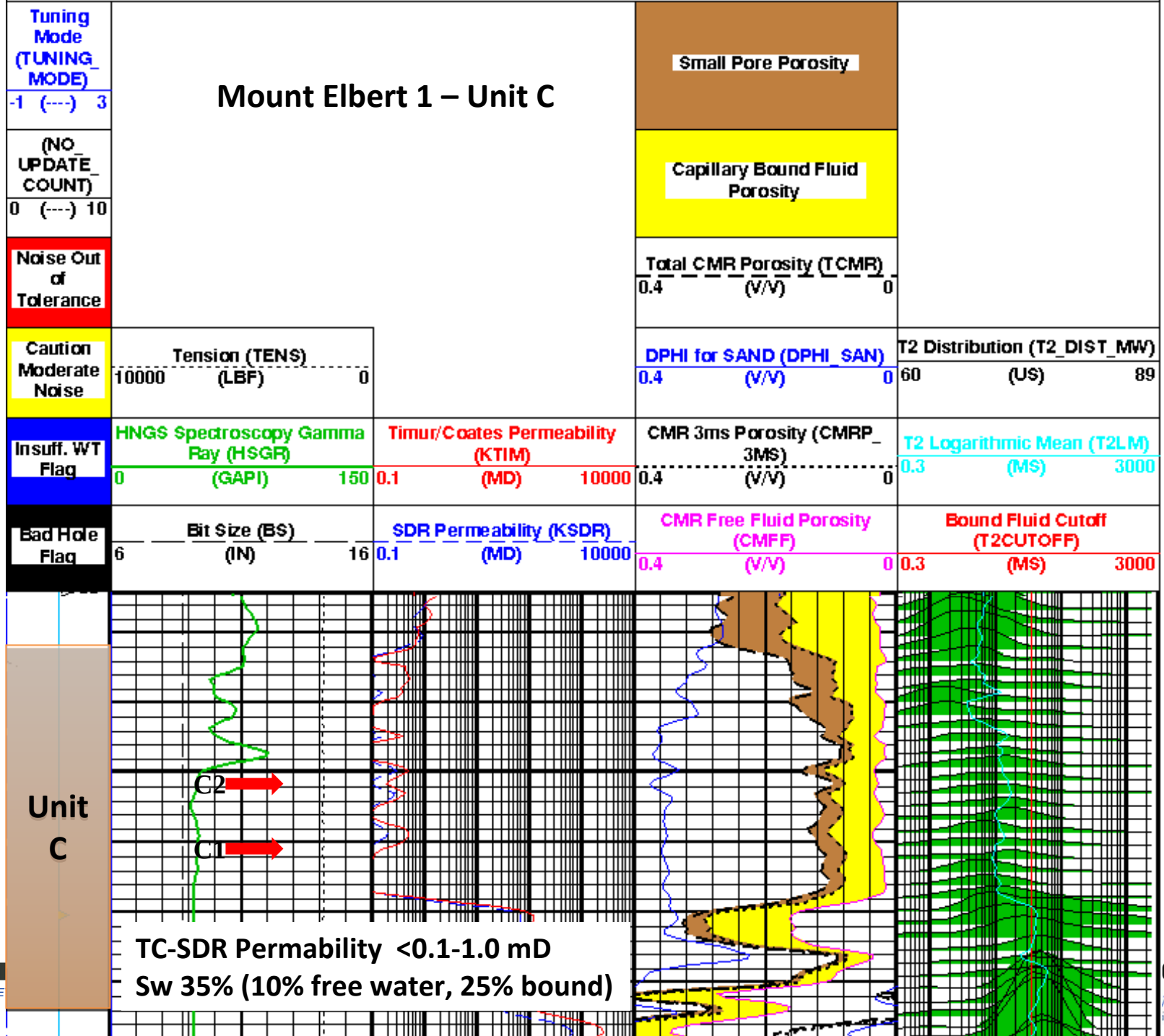


Problem 7c: CMG STARS

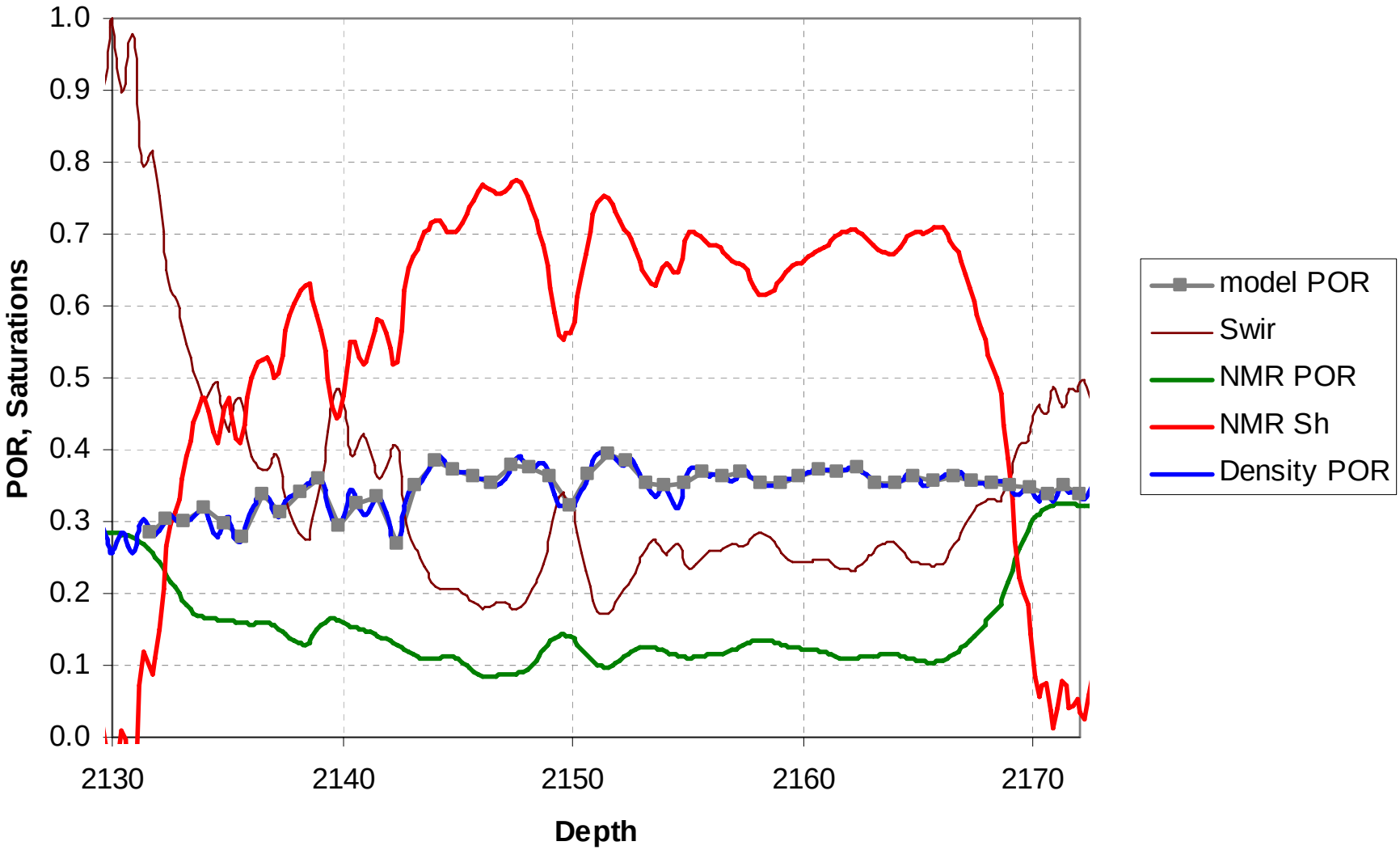


Problem 7c: HydrateResSim

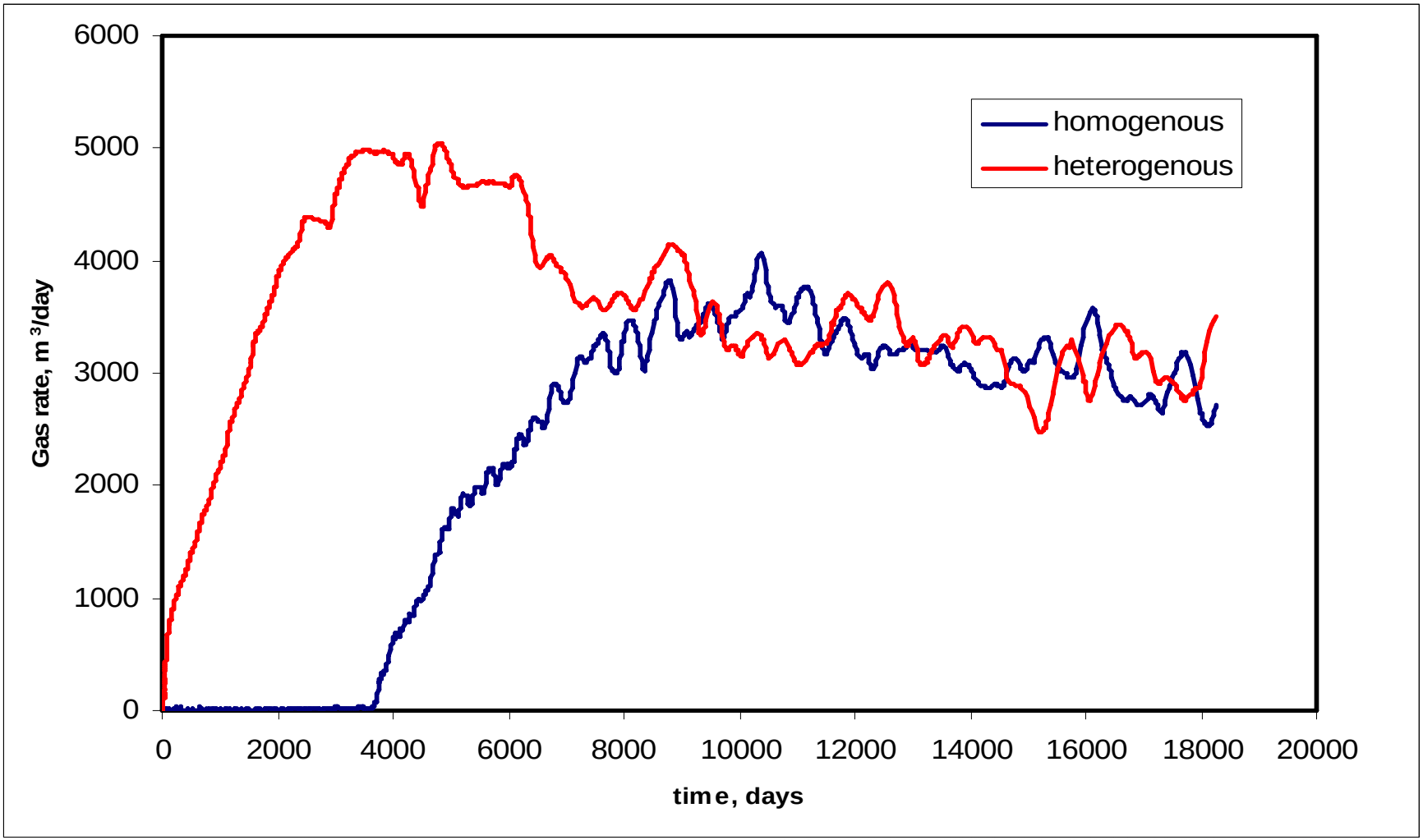



Mount Elbert 1 – Unit C
Tuning Mode (TUNING_MODE)
-1 (----) 3
(NO_UPDATE_COUNT)
0 (----) 10
Noise Out of Tolerance
Caution Moderate Noise
Insuff. WT Flag
Bad Hole Flag
Tension (TENS)
10000 (LBF) 0
HNGS Spectroscopy Gamma Ray (HSGR)
0 (GAPI) 150
Bit Size (BS)
6 (IN) 16
Timur/Coates Permeability (KTIM)
0.1 (MD) 10000
SDR Permeability (KSDR)
0.1 (MD) 10000
Small Pore Porosity
Capillary Bound Fluid Porosity
Total CMR Porosity (TCMR)
0.4 (V/V) 0
DPHI for SAND (DPHI_SAN)
0.4 (V/V) 0
CMR 3ms Porosity (CMRP_3MS)
0.4 (V/V) 0
CMR Free Fluid Porosity (CMFF)
0.4 (V/V) 0
T2 Distribution (T2_DIST_MW)
60 (US) 89
T2 Logarithmic Mean (T2LM)
0.3 (MS) 3000
Bound Fluid Cutoff (T2CUTOFF)
0.3 (MS) 3000
Unit C
C2
C1
TC-SDR Permability <0.1-1.0 mD
Sw 35% (10% free water, 25% bound)

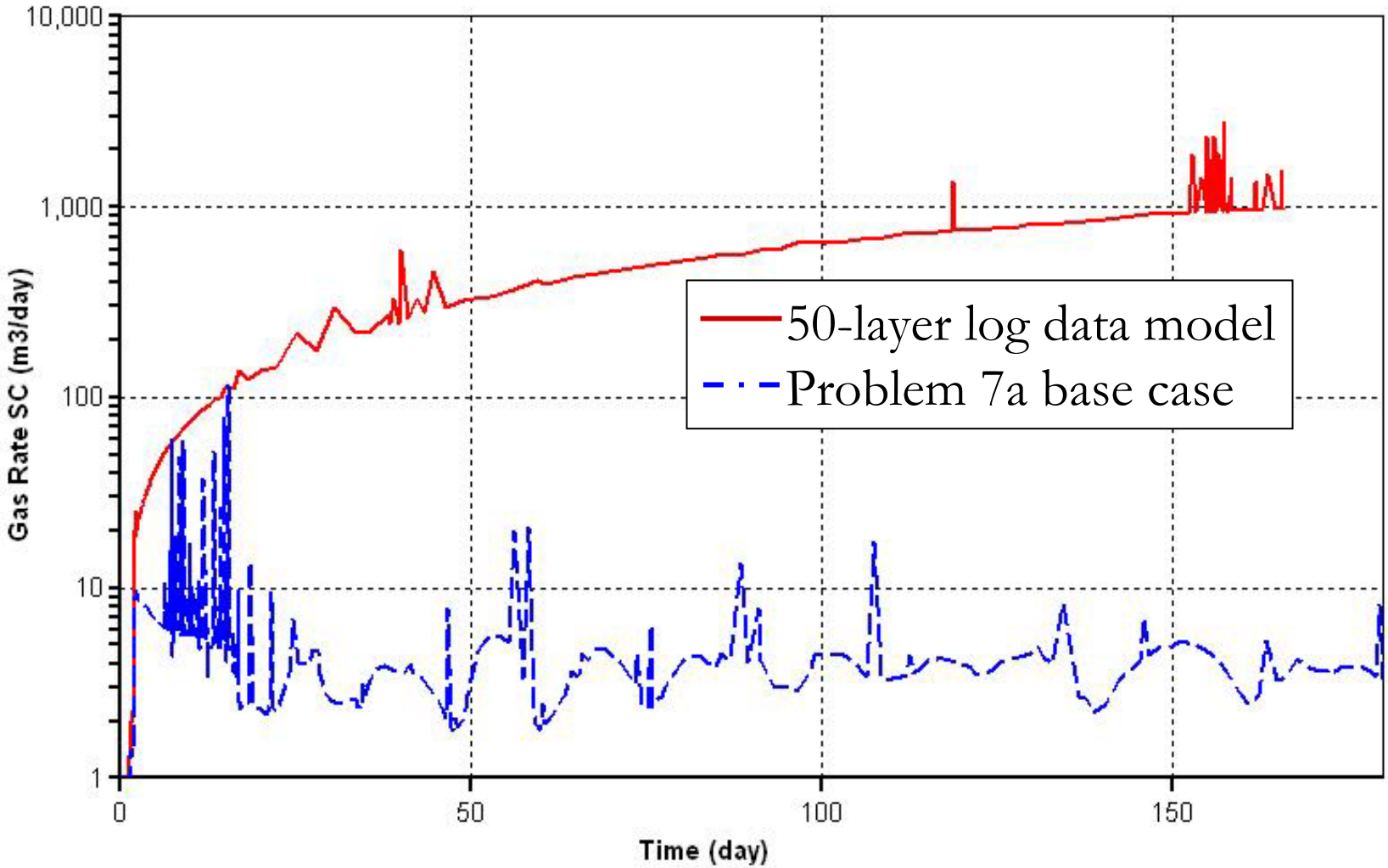
C-Unit Heterogeneity



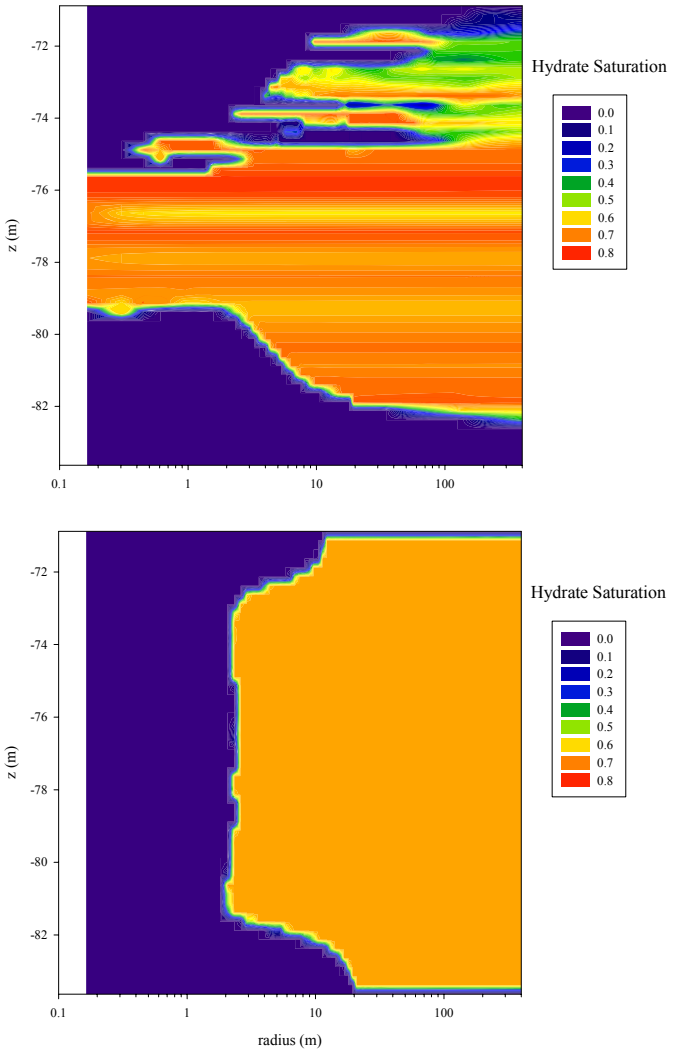
Effect of heterogeneity of permeability and porosity on production rates

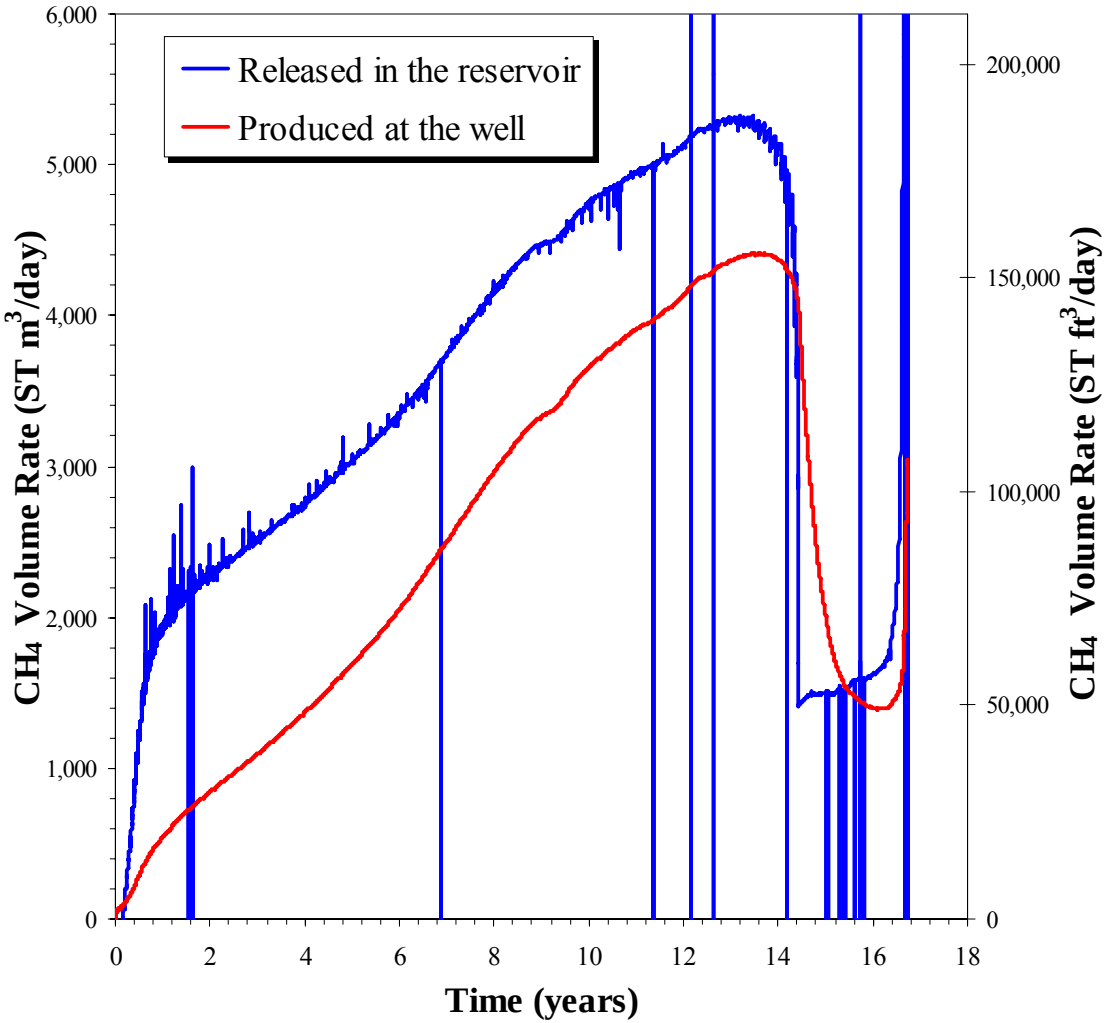


Affects of Reservoir Heterogeneity



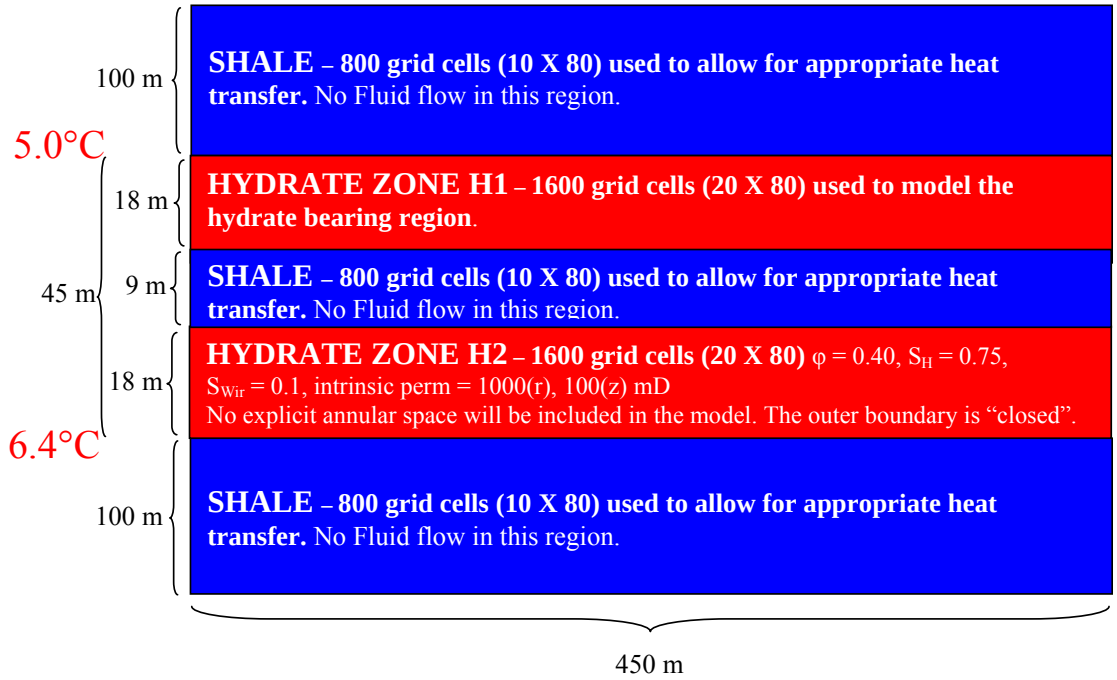
HydrateResSim Heterogeneity Results – Problem 7a





Sensitivity Analysis

A uniform reservoir consisting of two shale bounded hydrate layers is considered.

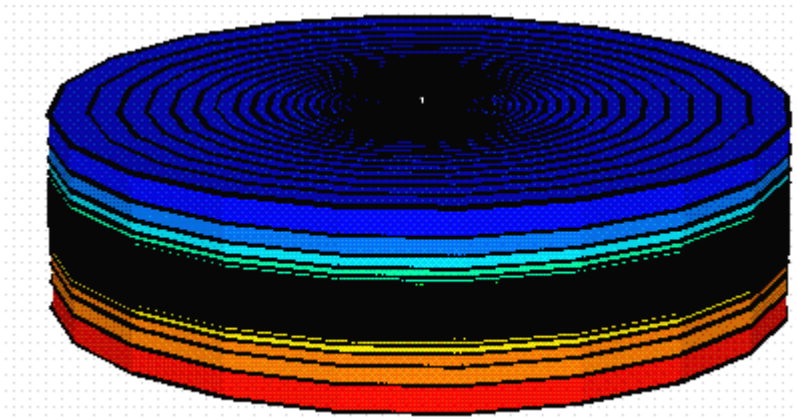


Discretization:

- r direction-80 cells logarithmically distributed from r_w=0.111 to r_{80}=450m
- z direction-70 cells (10 x various m,50 x 0.9 m, 10 x various m)

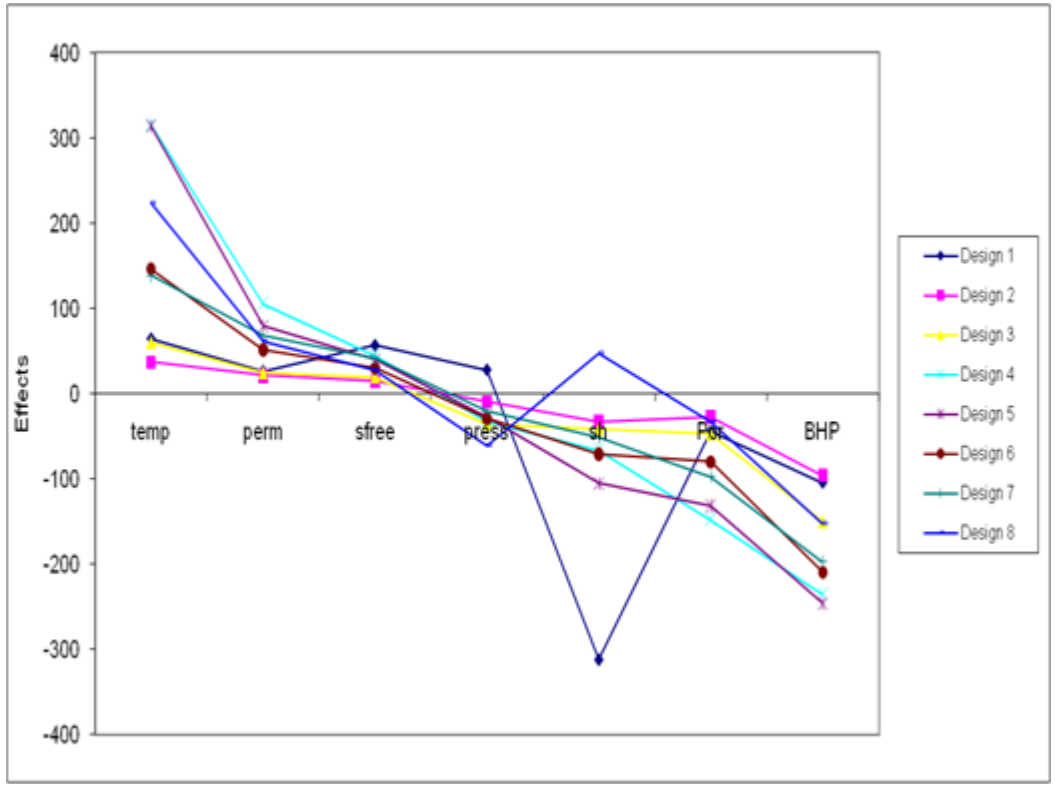
Reservoir properties:

- Gas hydrate saturation 75%
- Porosity 40%
- Intrinsic permeability 1000 mD
- Reservoir temperature, regional gradient 5.0-6.5ºC



Sensitivity Analysis

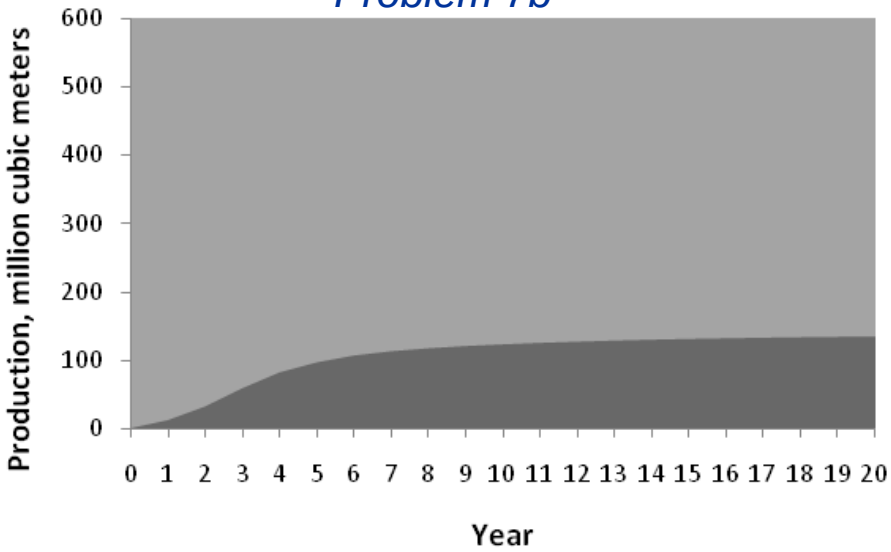
- Reservoir parameters considered in this analysis are pressure, temperature, hydrate saturation, Bottom Hole pressure,
- porosity, permeability and free water saturation.
- A Plackett-Burman design of size 8 is considered.
- Eight design tests are conducted and the effects are shown in the plot.
- Discount rate of 15% is incorporated

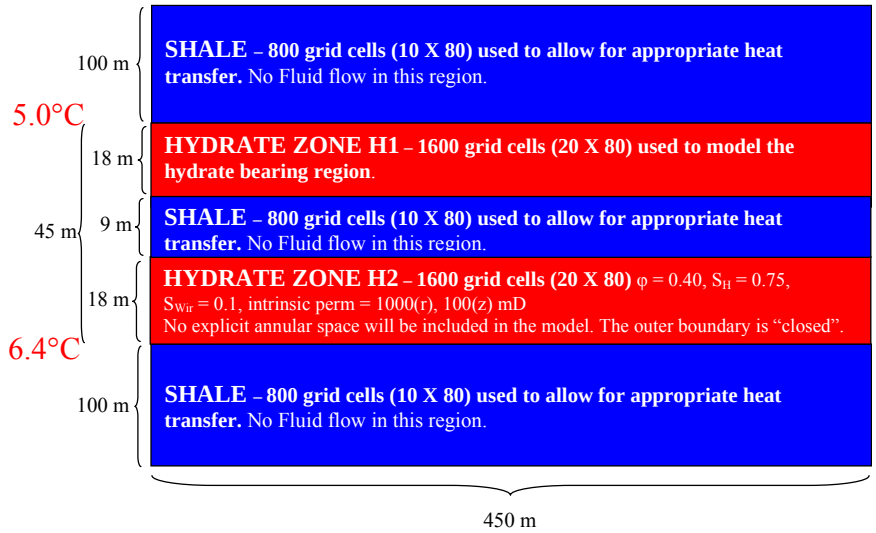


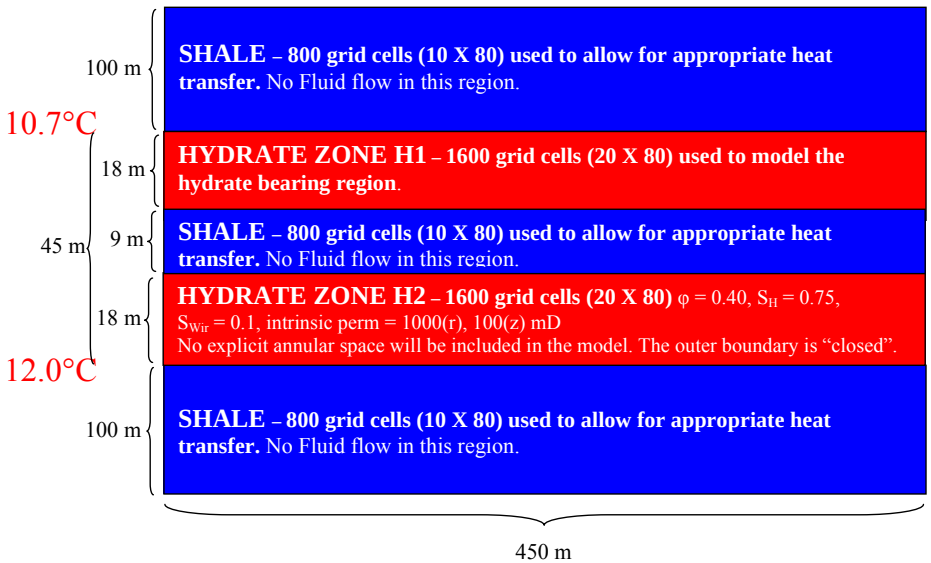
	Rankings							
Design / **Parameters**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Pressure	6	7	5	7	7	6	7	4
Temp	3	2	2	1	1	2	2	1
S_H	1	3	4	4	4	4	5	5
Perm	7	5	6	5	5	5	4	3
BHP	2	1	1	2	2	1	1	2
Porosity	5	4	3	3	3	3	3	6
Free water	4	6	7	6	6	7	6	7

Sensitivity Analyses

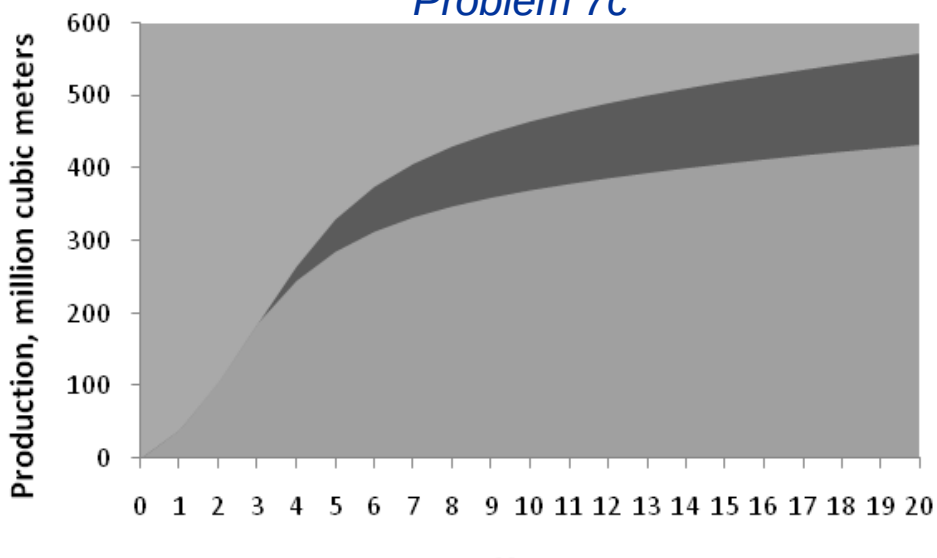
Problem 7b



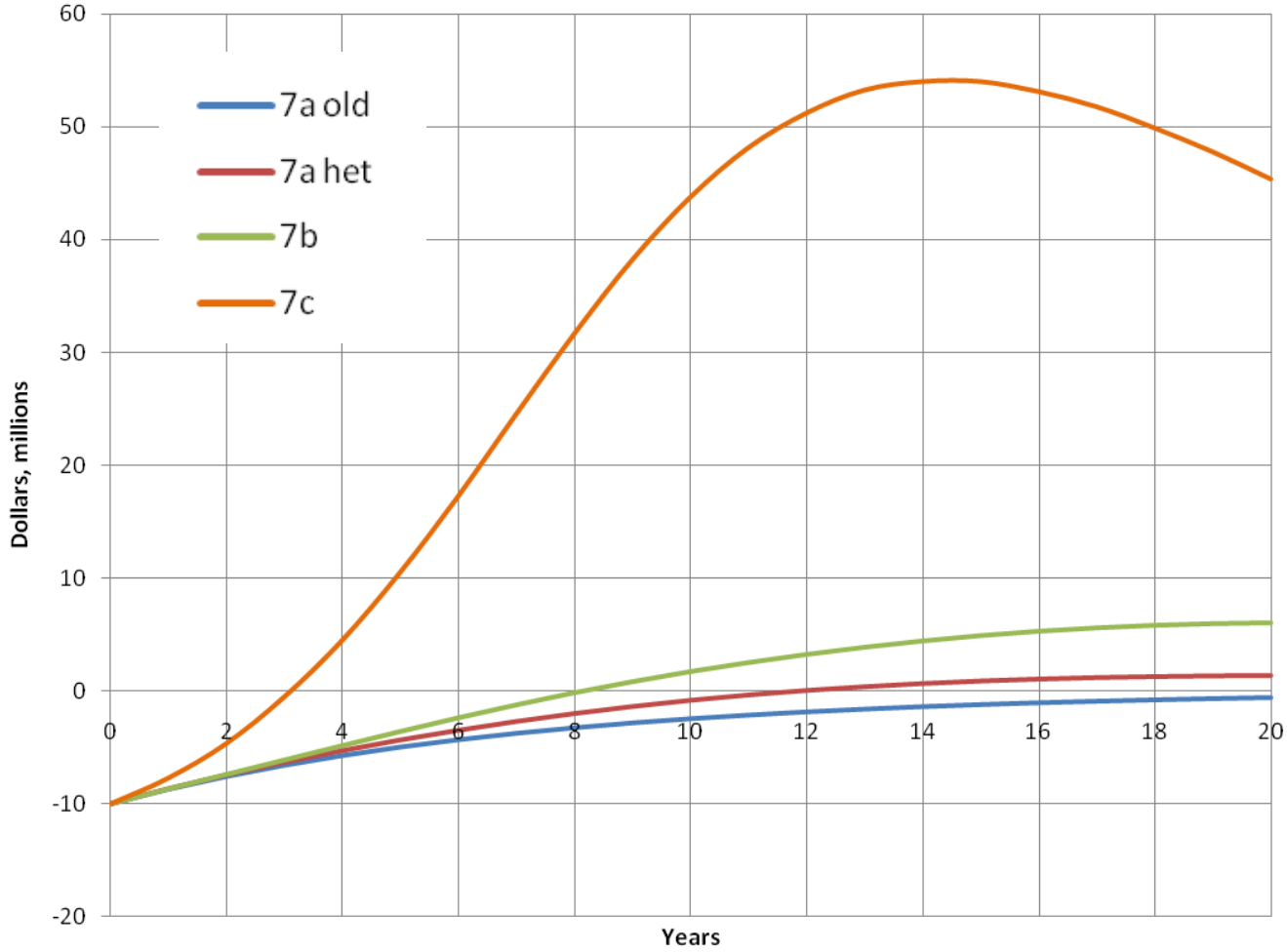




Problem 7c



Preliminary Cash Flow at the Well



- Comparison of 7a base case, heterogeneous 7a, 7b, and 7c reservoir conditions
- Based on $7/MCF wellhead price neglecting transportation costs
- Includes well cost, O&M, royalties, taxes, lease costs

Conclusions

- **All of the participating simulators show remarkable agreement**
  - Gas rates
  - Characteristic times
- **As expected, warmer and deeper hydrates are likely more productive**
  - 7a: 250 mcf/d, 7b: 8 mcf/d, 7c: 4.3 mmcf/d
- **Still much to be learned from coupling the log data to reservoir simulations**

Thank You

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