

# Geo-mechanical and Flow Modeling for Paradox Valley Unit

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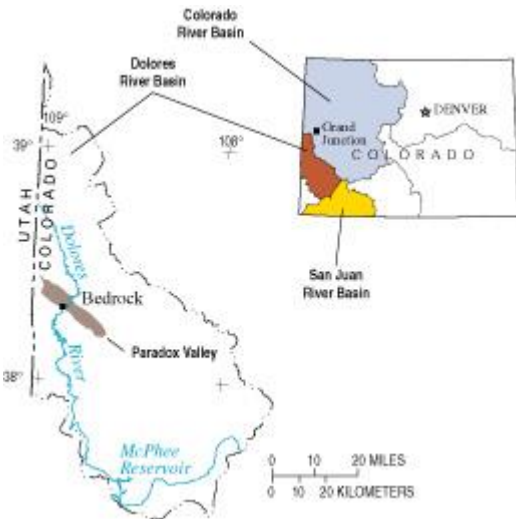
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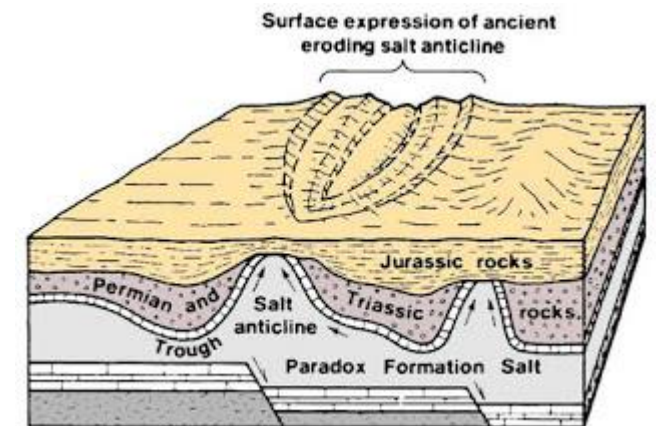
# Context

## Paradox Valley desalinization project



330px-Paradox\_Valley\_NASA.jpg

Valley  
caused by salt fault collapse



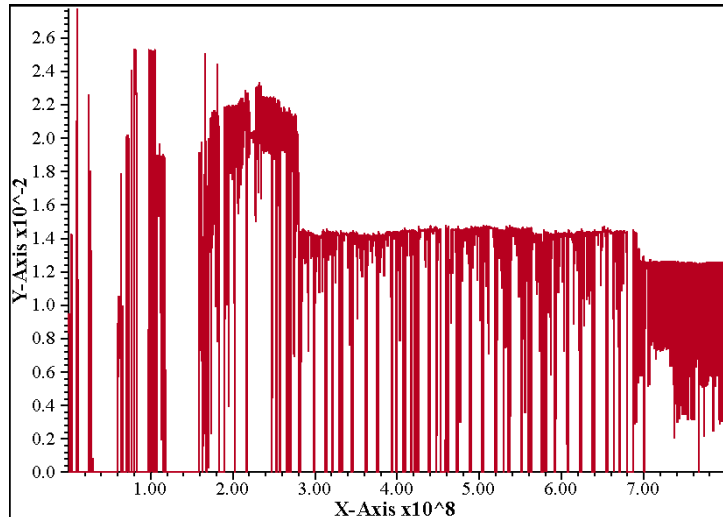
Dolores River

**Brine injection at depth**

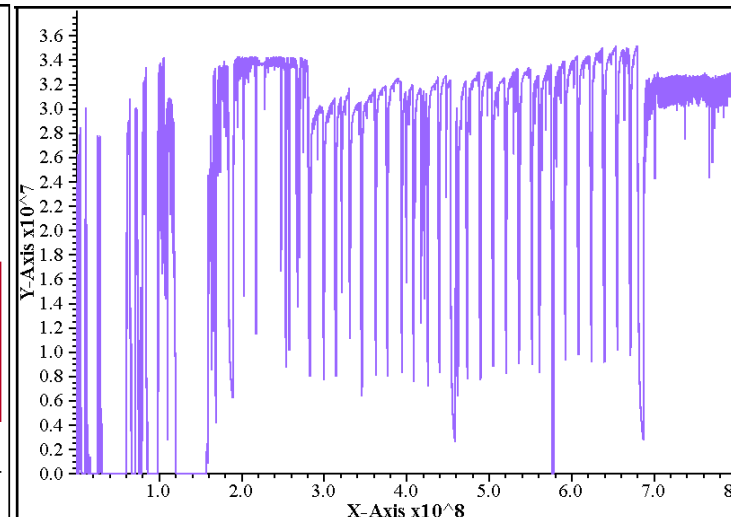
# Project background

- Existing PVU-1 well with 25 years history of brine reinjection
  - Injection in Leadville:  $\sim 4.8$  km depth,  $<20$ md, 7,000 barrels per day (719 l/min)
  - Induced seismicity
- ➡ Evaluation of five potential well sites for additional injection

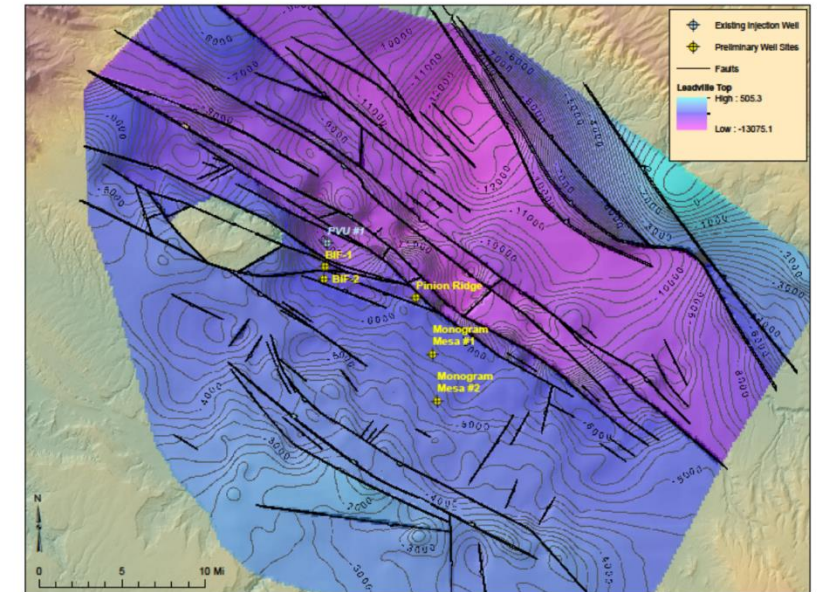
PVU-1 data



Injection rate [ $\text{m}^3/\text{sec}$ ] vs time [sec]



Wellhead pressure [Pa] vs time [sec]



Well locations (USBR)

# Project objectives

Appraise and rank, using numerical simulations, five potential well sites :  
BIF-1, BIF-2, Mesa-1, Mesa-2, Pinion Ridge.

$Q = 0.0112 \text{ m}^3/\text{s}$  used to resume injection in PVU-1

$Q = 0.0151 \text{ m}^3/\text{s}$  used in 5 additional wells

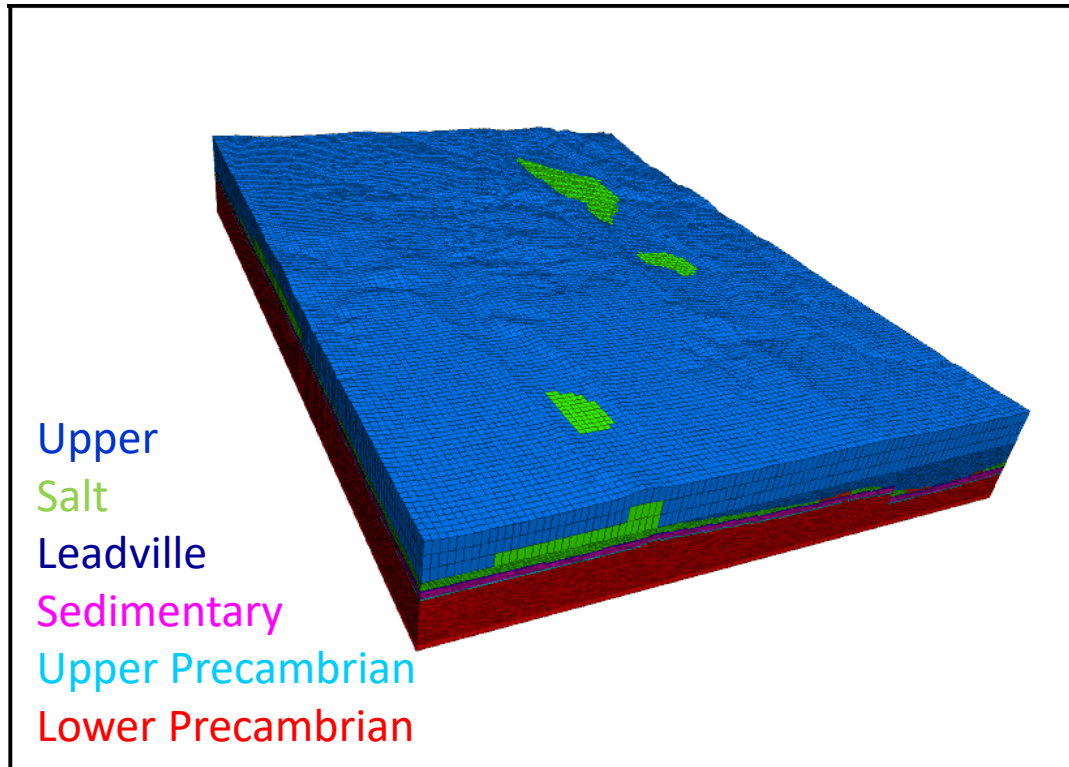
Three criteria for appraisal set by USBR at 50 years of injection:

1. Potential for simulated wellhead pressure to reach a critical **Target pressure**
2. Potential for **surface heave**
3. Risk of **induced seismicity** in the injection layer (Leadville)  
... based on elastic stress state in the model (USBR)  
Quantified using FoS index with respect to fluid pressure  
 $\text{FoS} < 1$  indicates possible yield in Leadville



# FLAC3D model

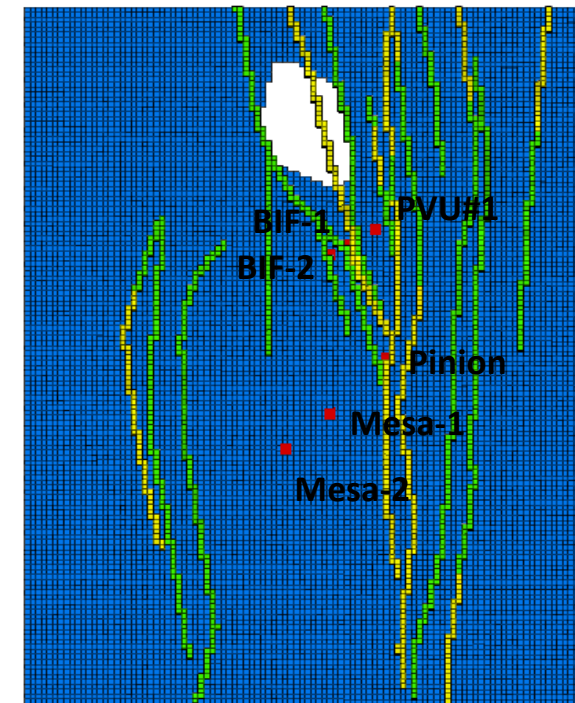
6 Layer model + Welds + Faults



40 km x 56 km x 7.5 km

616,000 zones – 640,845 nodes

Faults and well location in FLAC3D model



Leadville background – Impermeable Faults in yellow

# Formation Properties (USBR)

Layer	1	2	3	4	5	6
Layer description	Formations above salt	Salt	Leadville	Sedimentary layers below Leadville	Precambrian	Lower Precambrian
Density	2.53 g/cm <sup>3</sup>	2.16 g/cm <sup>3</sup>	2.69 g/cm <sup>3</sup>	2.56 g/cm <sup>3</sup>	2.65 g/cm <sup>3</sup>	2.65 g/cm <sup>3</sup>
Bulk modulus	29.8 GPa	25.3 GPa	64.8 GPa	50.6 GPa	50.1 GPa	50.1 GPa
Young's modulus	43.1 GPa	35.8 GPa	76.2 GPa	66.8 GPa	83.0 GPa	83.0 GPa
Shear modulus	17.1 GPa	14.2 GPa	29.2 GPa	26.1 GPa	33.9 GPa	33.9 GPa
Poisson's ratio	0.260	0.264	0.304	0.280	0.224	0.224
Permeability	0.1 mD	0 mD	6 mD	0.1 mD	1.5 mD	0 mD
Porosity	0.06	0	0.05	0.01	0.03	0
Diffusivity (before 1/8/02)	0.0019 m <sup>2</sup> /s	0 m <sup>2</sup> /s	0.20 m <sup>2</sup> /s	0.0043 m <sup>2</sup> /s	0.051 m <sup>2</sup> /s	0 m <sup>2</sup> /s
Diffusivity (after 1/8/02)	0.0020 m <sup>2</sup> /s	0 m <sup>2</sup> /s	0.21 m <sup>2</sup> /s	0.0044 m <sup>2</sup> /s	0.053 m <sup>2</sup> /s	0 m <sup>2</sup> /s

# Workflow

## 1. Flow model calibration and validation – PVU-1

- Preliminary calibration of reference permeability model using 25y of wellhead pressure data

**Calibration parameter:** coefficient of well pressure correction  
(applied to account for large zone size compared to well diameter)

- Reference model used to test permeability hypotheses
- Permeability model selection and recalibration

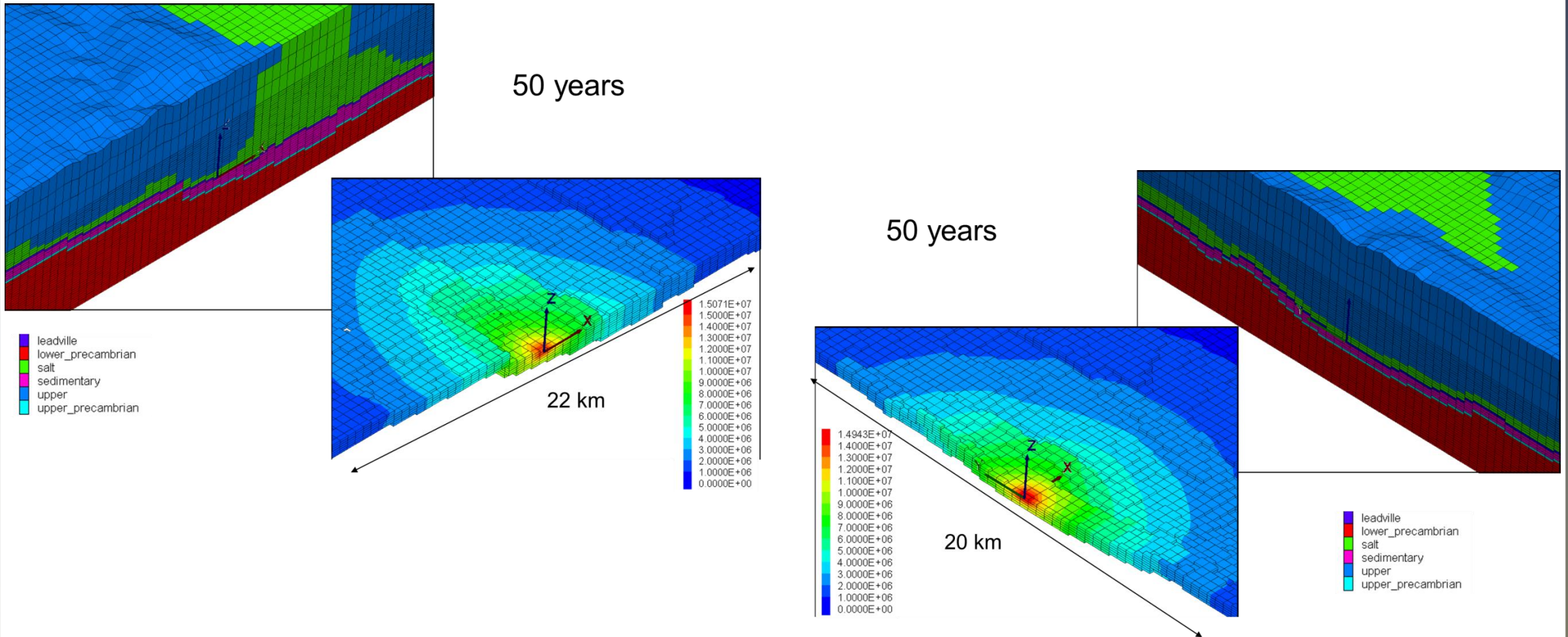
## 2. Model predictions

- at PVU and 5 potential wells
- for up to 50 years of injection
- a) Fluid flow only : Comparison of Well-head pressure with target value
- b) Fluid-mechanical coupling: Surface heave  
Potential for slip



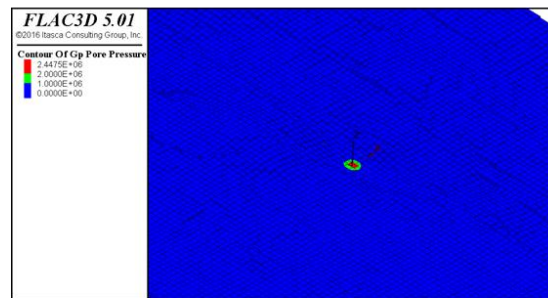
# MODEL CALIBRATION AND VALIDATION – PVU-1

# Stratigraphy & induced fluid pressure in Leadville

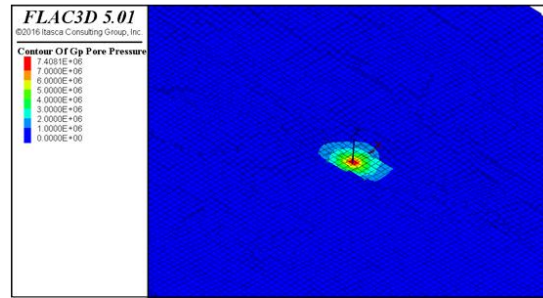


# Evolution of induced pressure

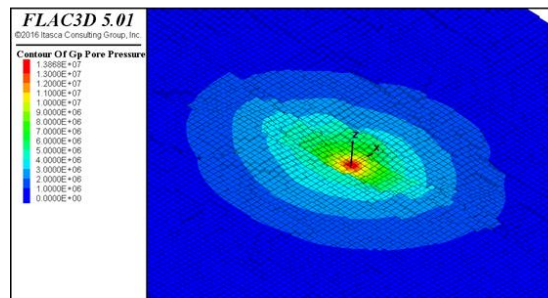
## Leadville



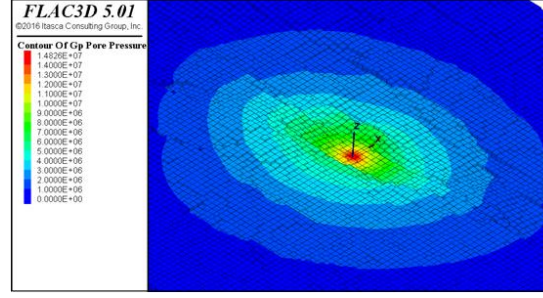
1 week (max: 2.4 Mpa)



1 year (max: 7.4 MPa)



20 years (max 13.9 Mpa)



Induced fluid pressure contours in the Leadville

# Permeability models- PVU-1

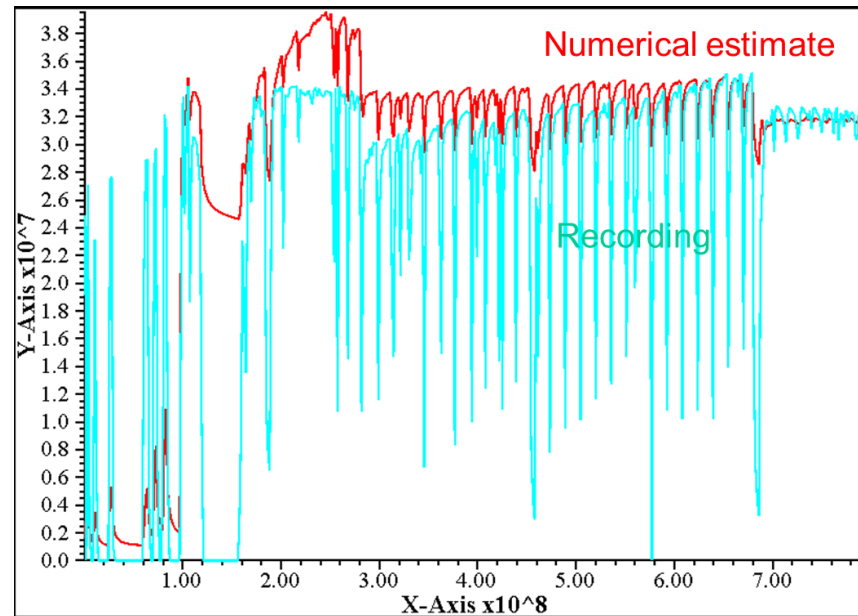
↩ Preliminary calibration

Permeable	Model 1	Model 2	Model 3	Model 4	Model 5
Upper			yes	yes	yes
Salt					
Welds				yes	yes
Leadville	yes	yes	yes	yes	yes
Sedimentary	yes		yes	yes	yes
Upper-precamb	yes		yes	yes	yes
Lower-precamb					
Imperm. Faults		all			some

# Model 1

Three permeable layers: L-S-U

Upper  
Salt  
Leadville  
Sedimentary  
Upper Precambrian  
Lower Precambrian

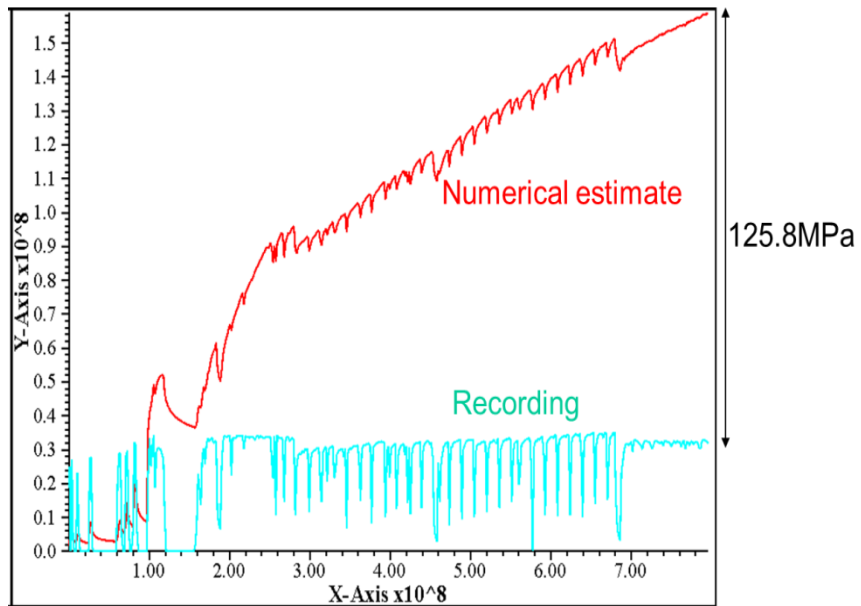


Wellhead pressure [Pa] versus time [sec]

Reference case

# Model 2 - Model 3

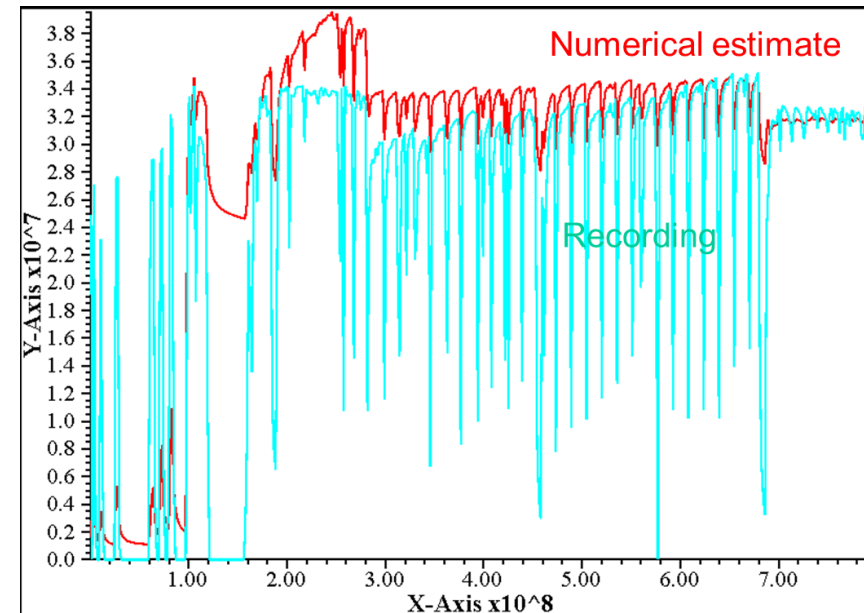
Permeable L + Imperm. Faults



Wellhead pressure [Pa] versus time [sec]

Rejected

Model 1 + Permeable Upper



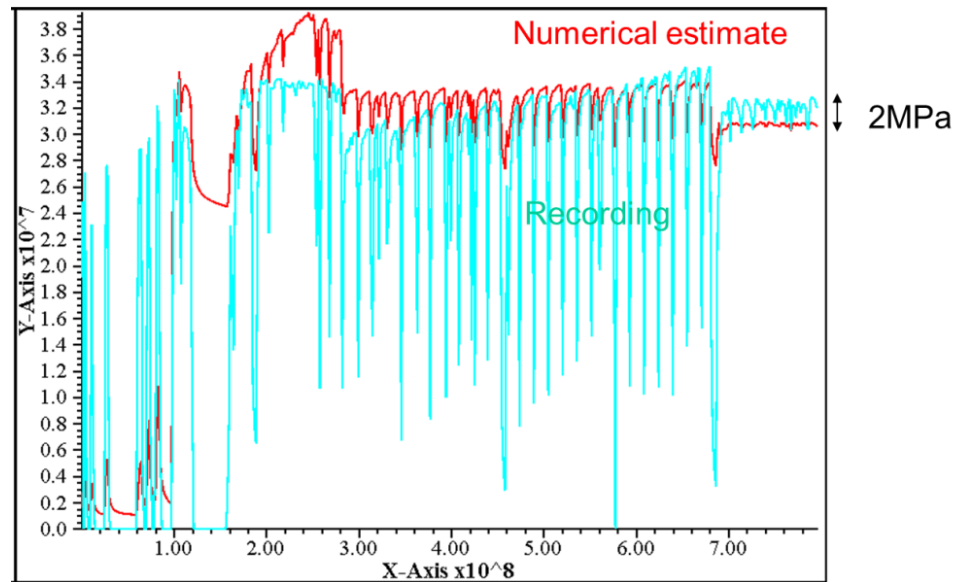
Wellhead pressure [Pa] versus time [sec]

Similar to Model 1



# Model 4 - Model 5

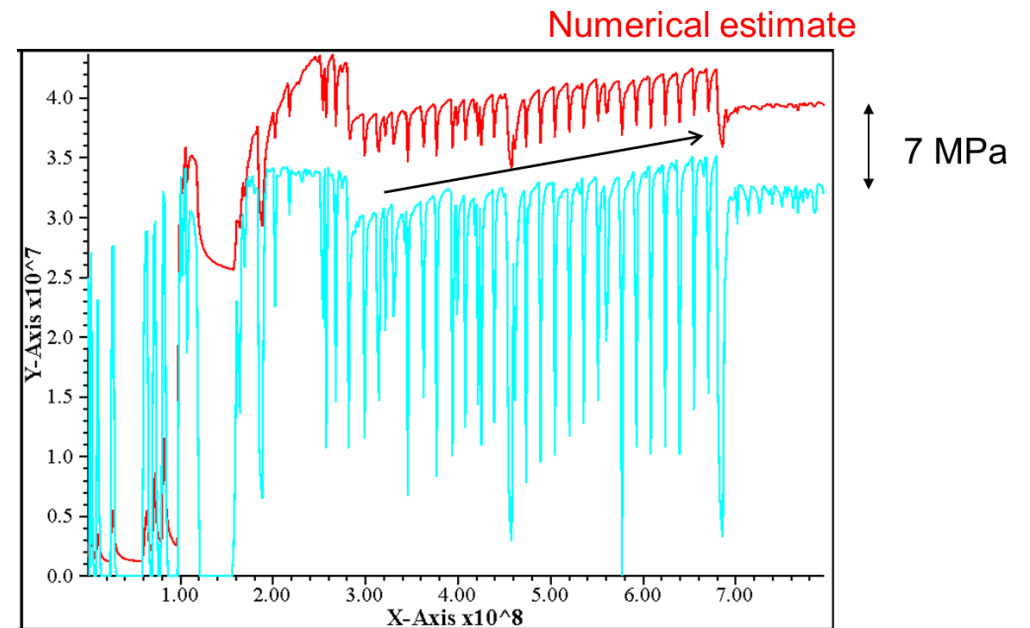
Model 3 + Permeable welds



Wellhead pressure [Pa] versus time [sec]

Cannot be discounted

Model 4 + some Imperm. Faults



Wellhead pressure [Pa] versus time [sec]

Good trend – recalibration needed

# Outcome

1. Model 5 is selected
  - 4 permeable layers + welds
  - Faults with large vertical offset (>152m), impermeable
2. Recalibration:  
PVU-1 location

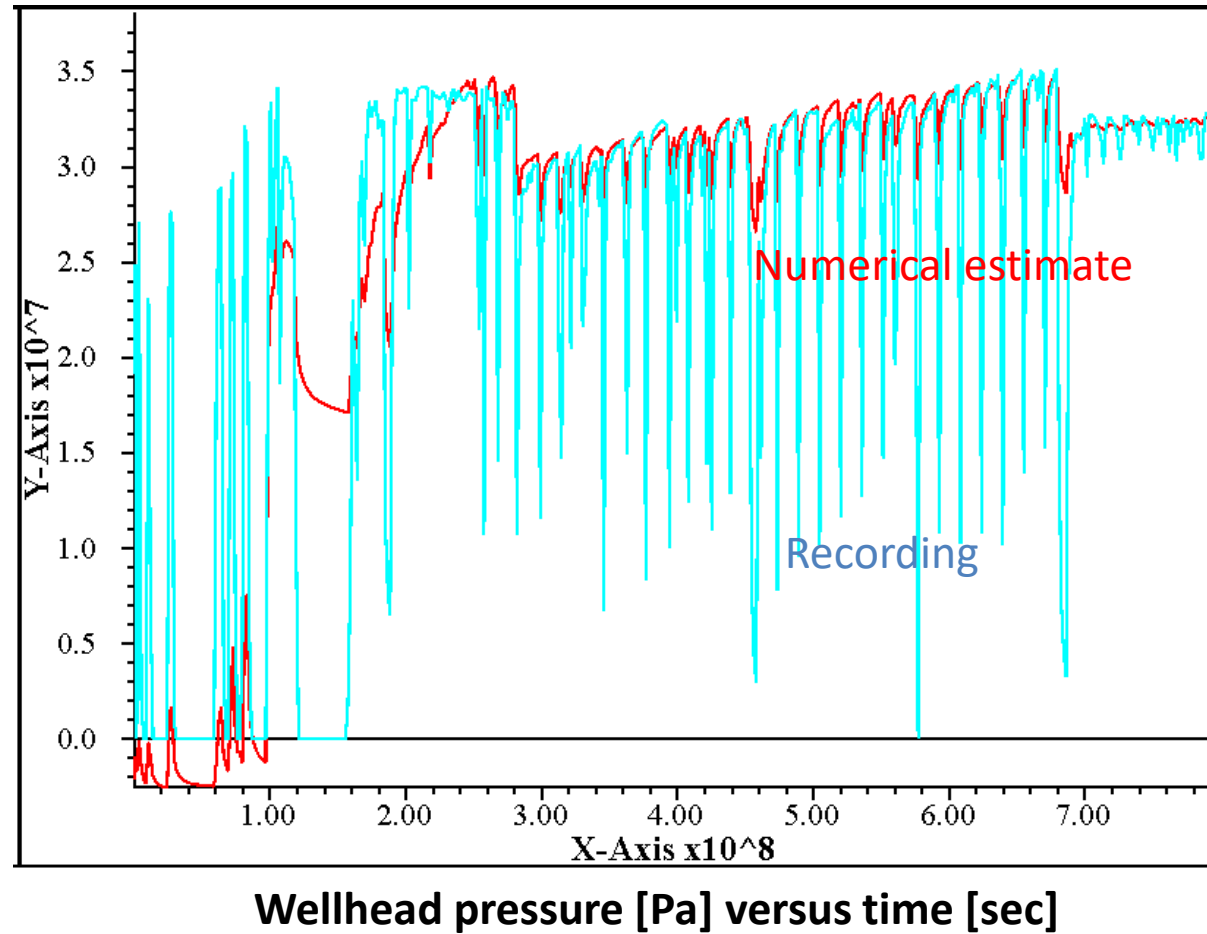
$$p_{wh} = p_{induced} + p_{correction} + p_{insitu} - p_{brine}$$



$$\beta = 0.78$$

(diversion from radial flow in Leadville)

# Recalibration results – PVU-1



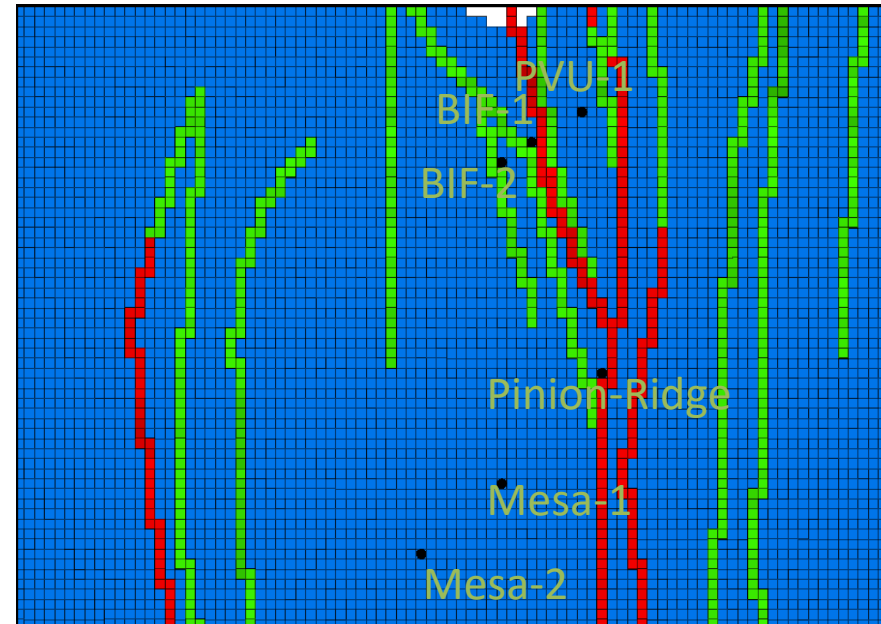
# MODEL PREDICTIONS

PVU-1, BIF-1, BIF-2, MESA-1, MESA-2, PINION RIDGE

# Site appraisal – criteria 1

Wellhead pressure below target -50 year results

Well	Wellhead pressure [MPa]	Below Target 34.5 MPa
PVU-1	34.9	
BIF-1	49.4	
BIF-2	36.4	
Mesa-1	30.3	yes
Mesa-2	28.8	yes
Pinion Ridge	45.1	

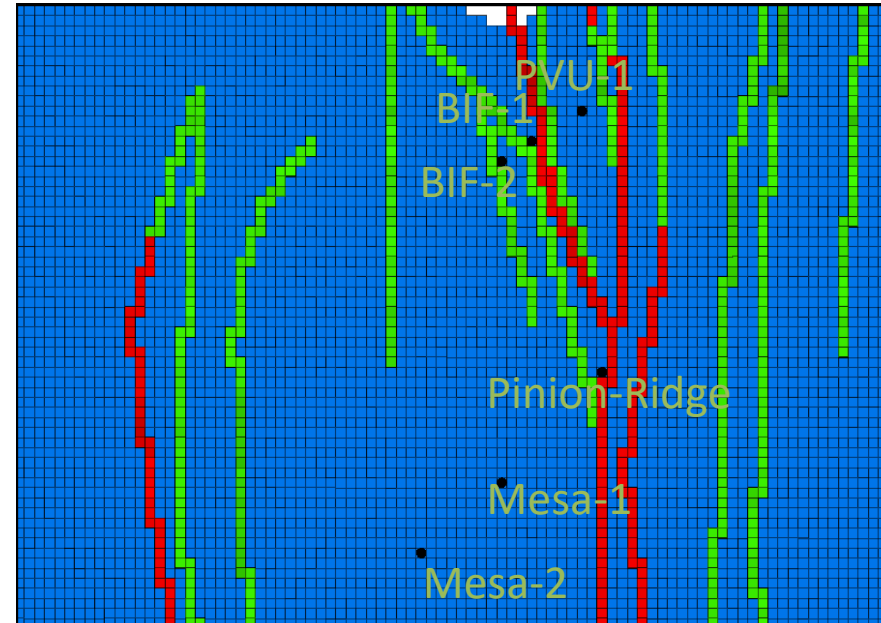


Note: Mesa-1 and Mesa-2 are shallowest injection sites (~3.7 km)

# Site appraisal – criteria 2

Surface heave -50 year results

	Maximum heave [cm]	
	Alpha = 1	Alpha < 1 (*)
PVU-1	7.89	4.94
BIF-1	5.31	3.39
BIF-2	5.64	3.60
Mesa-1	8.60	5.50
Mesa-2	6.58	4.21
Pinion Ridge	14.65	9.39



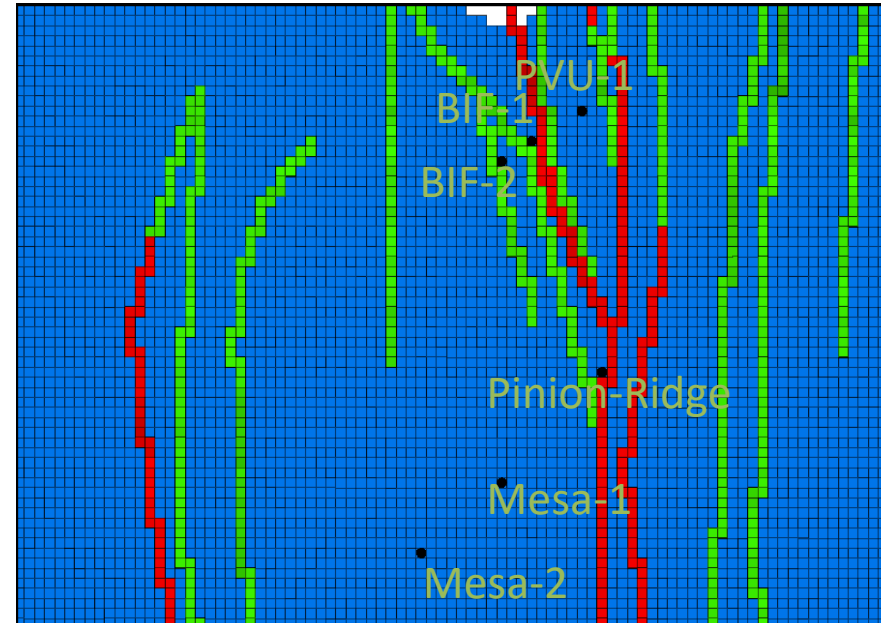
Lowest potential for surface heave: BIF-1 and BIF-2



# Site appraisal – criteria 3

Risk of induced seismicity in Leadville - 50 year results

	Minimum FoS - with respect to fluid pressure	
	Alpha = 1	Alpha < 1
PVU-1	0.845	0.774
BIF-1	0.866	0.780
BIF-2	0.946	0.869
Mesa-1	0.975	0.967
Mesa-2	0.910	0.832
Pinion Ridge	0.989	0.885



Lowest potential for slip: Pinion Ridge and Mesa-1



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# CONCLUSIONS

# Summary of model predictions

Well locations, in predicted order of increasing potential for:



A single site does not fill all criteria

PVU-1 (between impermeable faults) has worst potential for slip

(\*) measured by the minimum FoS Index in Leadville

(\*\*) measured by the maximum surface heave in the model



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**THANK YOU!**