6X^{online} Introduction Part II

March 2022

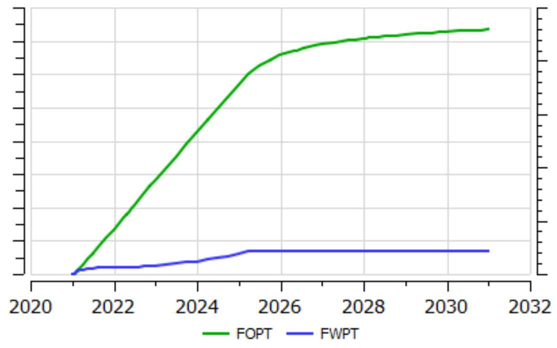
Welcome

Presenter

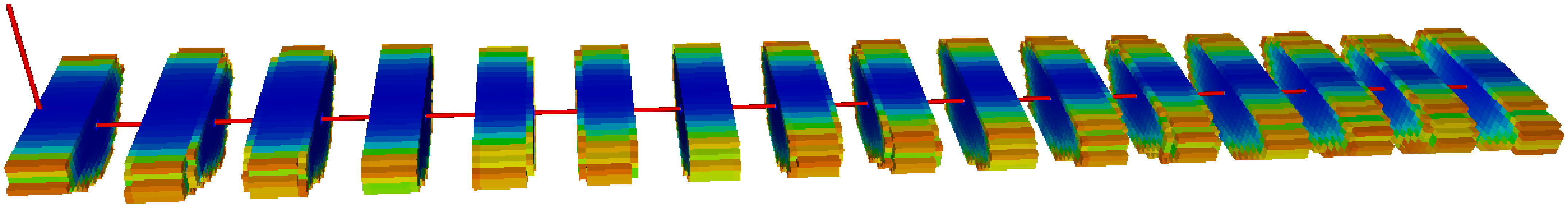
- Peter Forster
- RKS Technical Support, Houston

This presentation will be a combination of

- Slides & Online Demo (60 minutes)
- Closing Discussion (30 minutes)

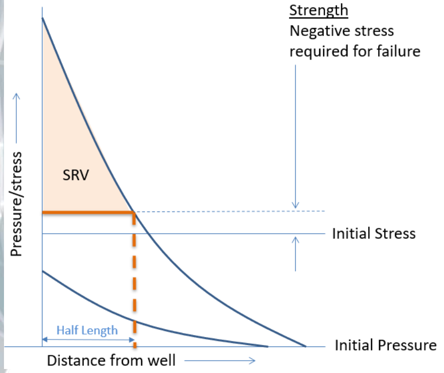


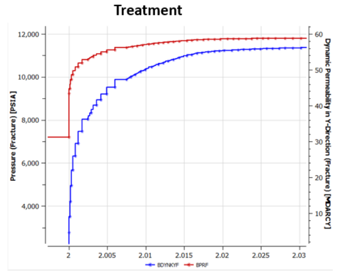
Please submit questions on the “chat” panel. We will monitor it and incorporate them into the closing discussion



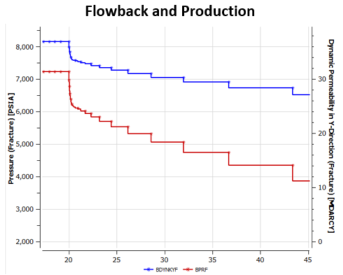
Introduction to 6X and 6X^{online}

- Previously (Feb 10th) we showed:
  - Single well – single stage
    - Changing the rock's response
      - allows **CALIBRATION**
  - Single well – multiple stages
    - Changing design, i.e. stage count
      - allows **EXPERIMENTATION**
- Today we will show:
  - Single well – 24 stages
    - Changing design, i.e. pump rate
      - allows **EXPERIMENTATION**
    - Iteratively changing the rock characteristics
      - To illustrate **CALIBRATION** to match history

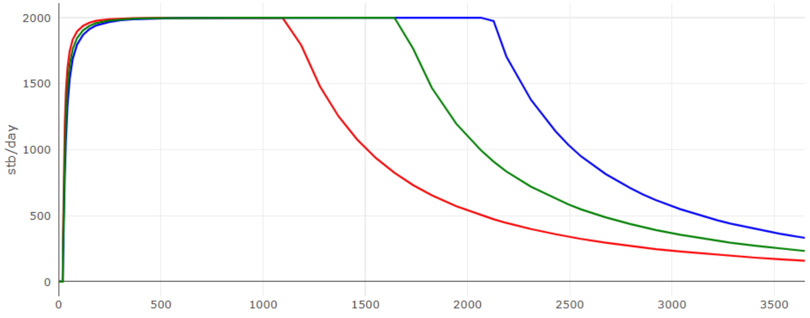




As fluid is pumped:
- Pressure increases until minimum stress is exceeded
  - Net stress becomes negative
  - Tensile failure adds permeability
  - Shear failure adds surface area due to rubblization

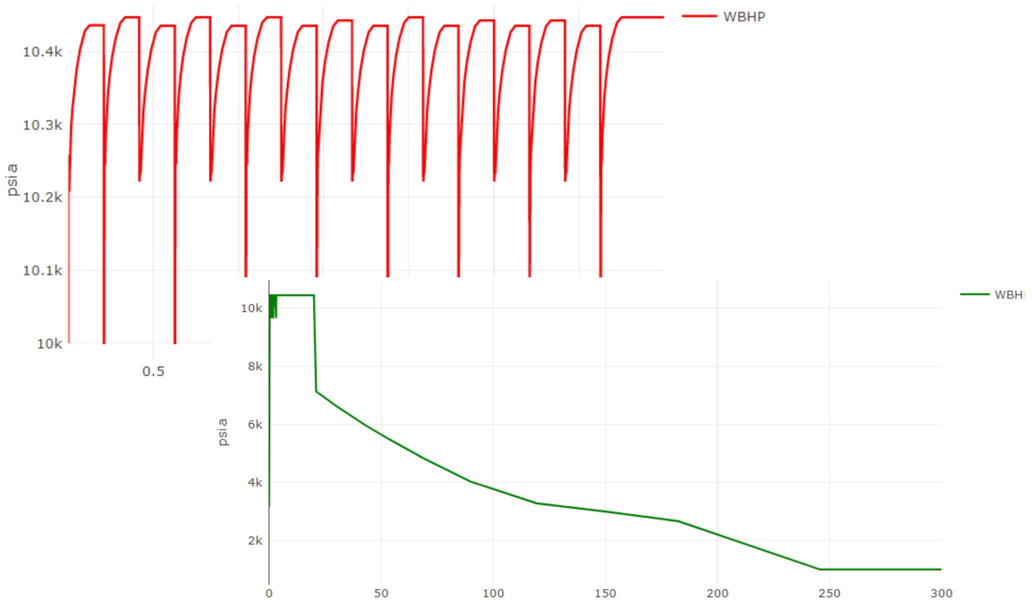


As flowback and production progresses:
- Pressure decreases
- Enhancement decays to a defined residual



Introduction – 6X Reservoir Simulator

- Integrates flow, frac design and geomechanics in ***<u>one</u>*** model
  - Multi-well, black-oil, compositional
- Requires a definition of the geology, fluids and stress state
- Models pumping schedule, flowback and production
- Focuses on decisions that influence production performance
- Workflows:
  - Well placement & spacing
    - Including interference & stress shadowing
  - Completion design
    - Including details of stages and clusters
  - Cyclic gas injection EOR
  - Re-frac

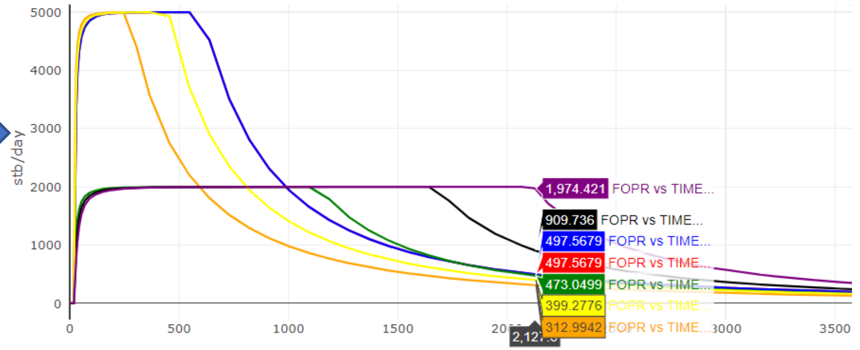


RidgewayKite

Introduction – 6X^{online}

- A **web** application to enable routine workflows
  - Supports limited functionality on layer cake models
  - Collates data
  - Runs 6X simulator
    - Locally or on an external server or on the cloud
  - Cases can be exported and customized to access advanced functionality

Note:
6X^{online} does not access all of the 6X functionality

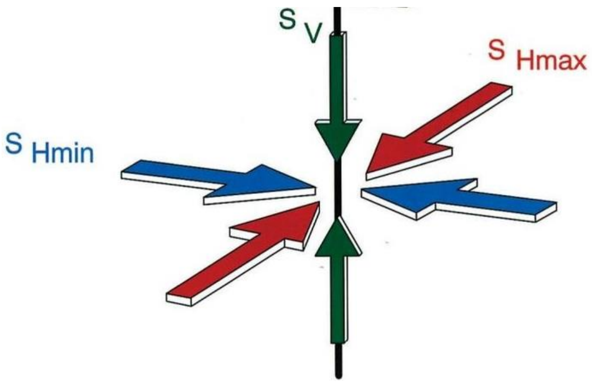


What do we mean "**Integrates flow, frac design and geomechanics**"?

6X Conceptual overview – Input initial state

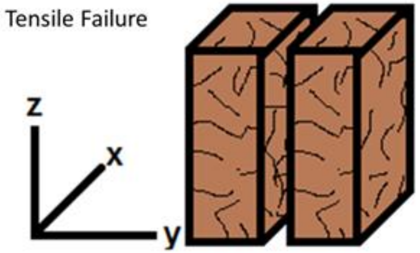
Stresses:

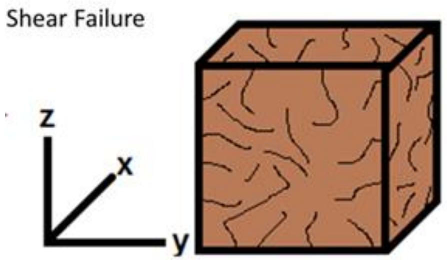
- Shmin, Shmax, Sv
- Strength
  - A measure of the extra force required to break the rock



Fracture enhancement parameters

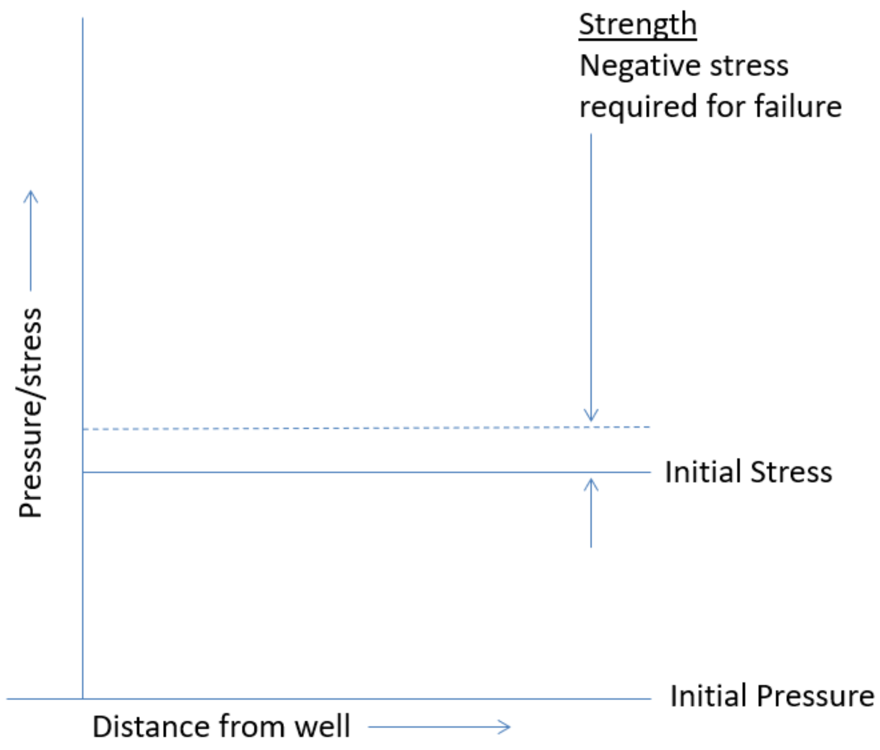
- Pore volume expansion
  - The expansion rate when the rock breaks and the fractures expand
- Tensile
  - The maximum amount of permeability to be added
- Shear
  - The maximum amount of matrix-fracture interface (surface area)
- Residual connectivity
  - The amount of permeability which will remain post-closure
    - For propped and unpropped volume





6X Conceptual overview

Model geomechanics of rock breakage



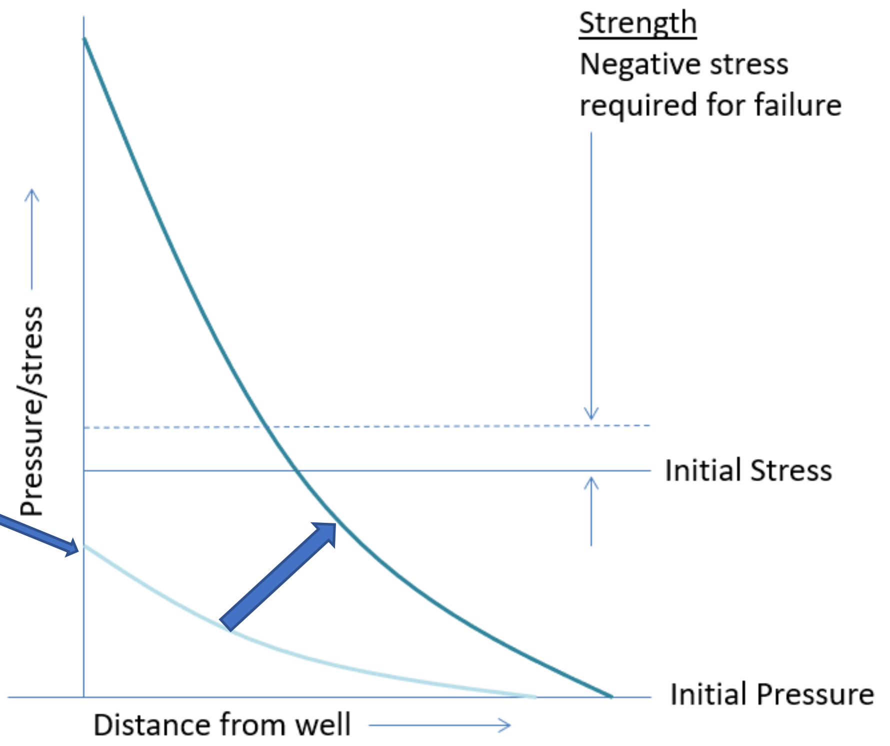
6X Conceptual overview

Model geomechanics of rock breakage

- As pressure increases due to pumping
  - Pressure exceeds the minimum stress and net stress becomes negative

As pumping initiates, the pressure

- Gets higher at the well
- Moves out into the reservoir

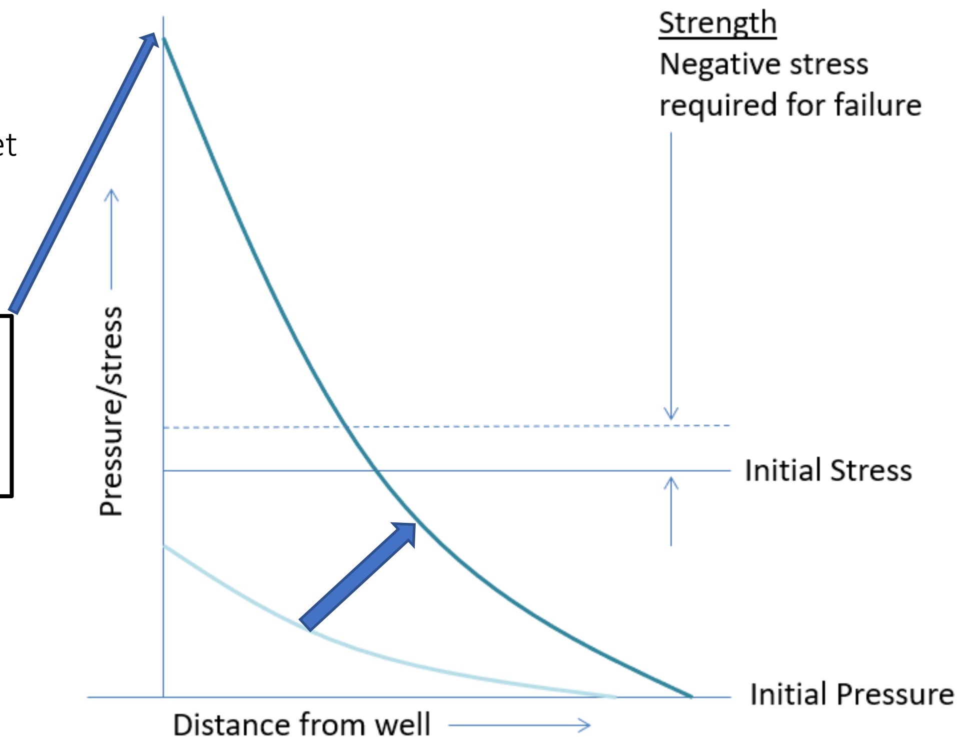


6X Conceptual overview

Model geomechanics of rock breakage

- As pressure increases due to pumping
  - Pressure exceeds the minimum stress and net stress becomes negative

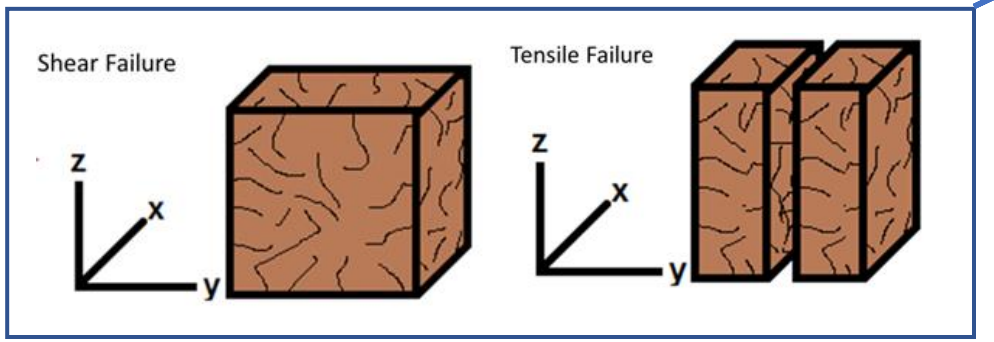
As pumping progresses the pressure
- Ultimately exceeds the initial stress
- Moves further out into the reservoir

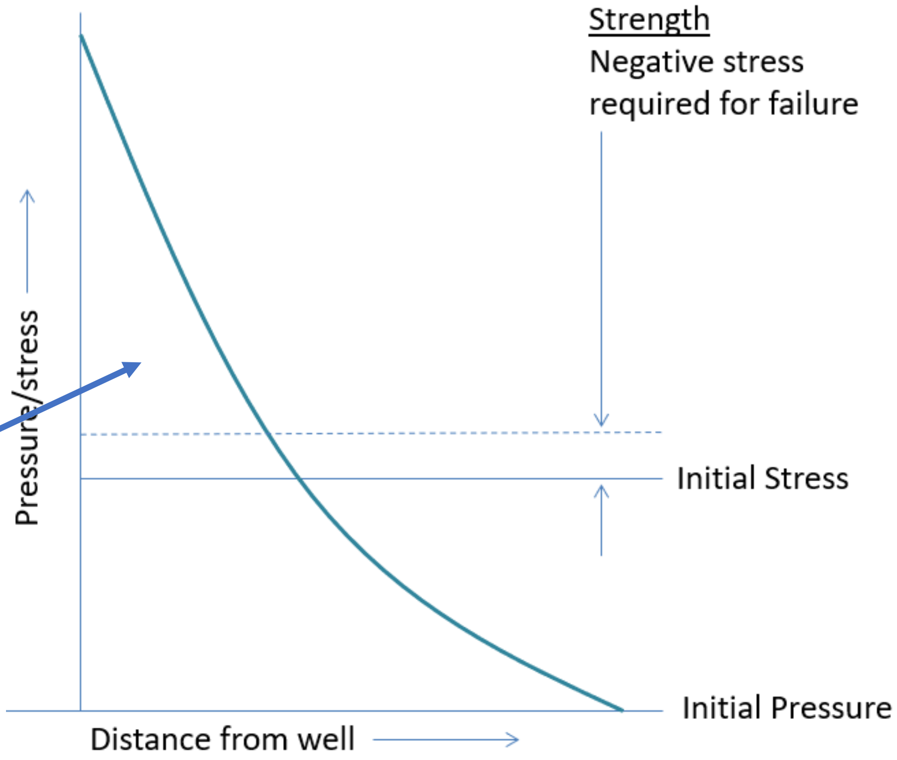


6X Conceptual overview

Model geomechanics of rock breakage

- As pressure increases due to pumping
  - Pressure exceeds the minimum stress and net stress becomes negative
- In the area of negative stress
  - Tensile failure adds permeability due to long cracks
  - Shear failure adds surface area due to 'rubblization'

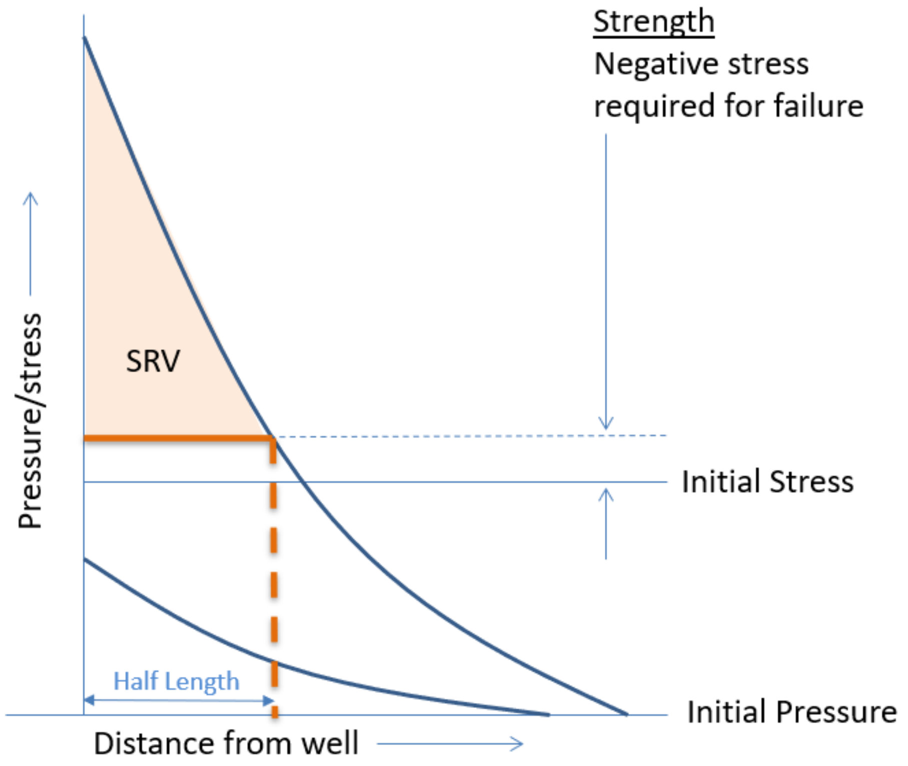




6X Conceptual overview

Model geomechanics of rock breakage

- As pressure increases due to pumping
  - Pressure exceeds the minimum stress and net stress becomes negative
- In the area of negative stress
  - Tensile failure adds permeability due to long cracks
  - Shear failure adds surface area due to ‘rubblization’
- The SRV size is determined by how far from the well the “negative stress zone” has reached



6X Conceptual overview

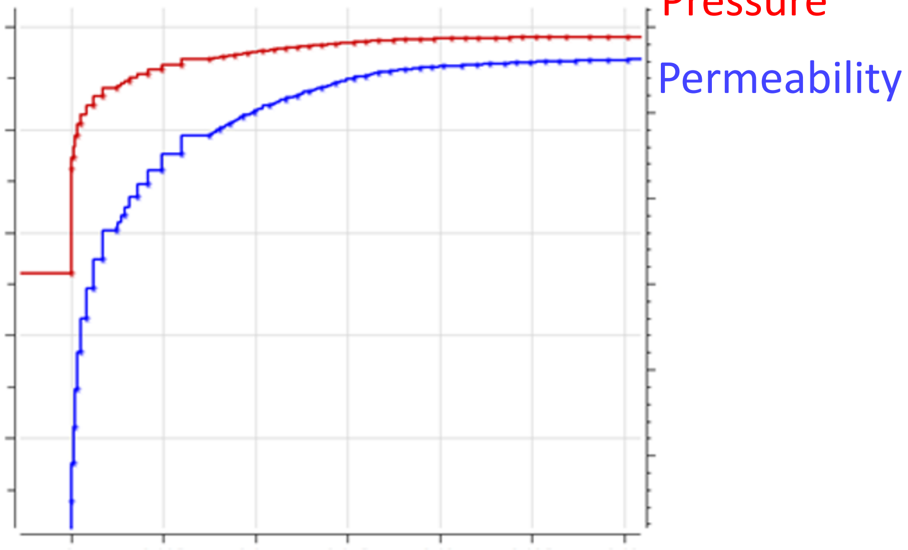
As pressure increases due to pumping

- Tensile failure adds permeability due to long cracks
- Shear failure adds surface area due to ‘rubblization’

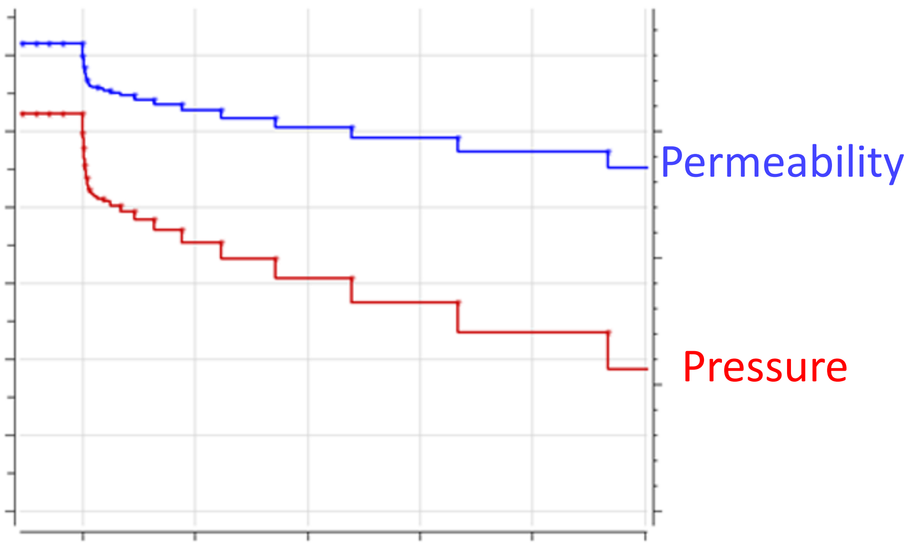
As pressure decreases due to flowback and production

- Net stress increases
- Permeability declines to a defined residual value

Treatment



Flowback and Production



Single well with multiple fracs – Examples

Example 3: Treatment Rate sensitivity

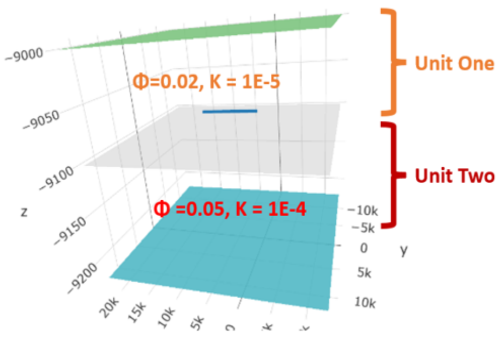
Example 4: History Match Well Performance

Example 3 – Injection Rate Sensitivity

- We will use a 24 stage design similar to previous examples
- The service company can pump at a range of rates. We will keep the overall design, but vary the rate and therefore the total job size.
- **Objective: Assess the impact of the injection rate on oil recovery**

The reservoir has a top depth of 9,000 ft and consists of TWO units:

- Unit One
  - Permeability = 1E-5 mDarcy, Porosity = 2%, Thickness = 100 ft
- Unit Two
  - Permeability = 1E-4 mDarcy, Porosity = 5%, Thickness = 120 ft



The units are in communication so have the same:

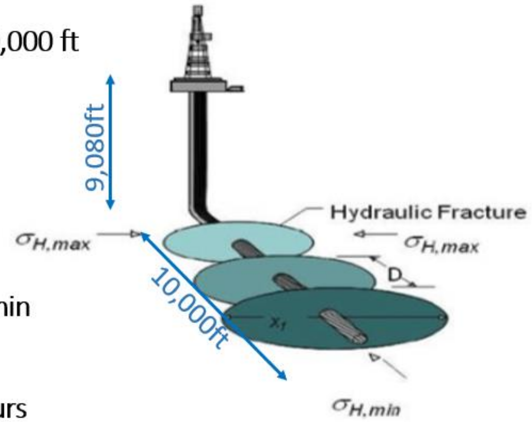
- Fluid
  - Light oil, with a bubble point of 3,500 psia
  - Gas Contact at 8,900 ft TVDSS (above unit One)
  - Water Contact at 12,000 ft TVDSS (below unit Two)
- Pressure
  - Initial pressure 7,200 psia
- Stresses:
  - SHmin 9,200 psia, SHmax 12,000 psia, SV 14,000 psia
- Fracture enhancement
  - Pore volume expansion 900 µSips, Tensile + 1000 mDarcy, Shear + 2 1/ft2, Residual connectivity stim 0%, prop 25%

The well has

- Depth 9,080 ft, Length 10,000 ft
- Stages 24

Each stage

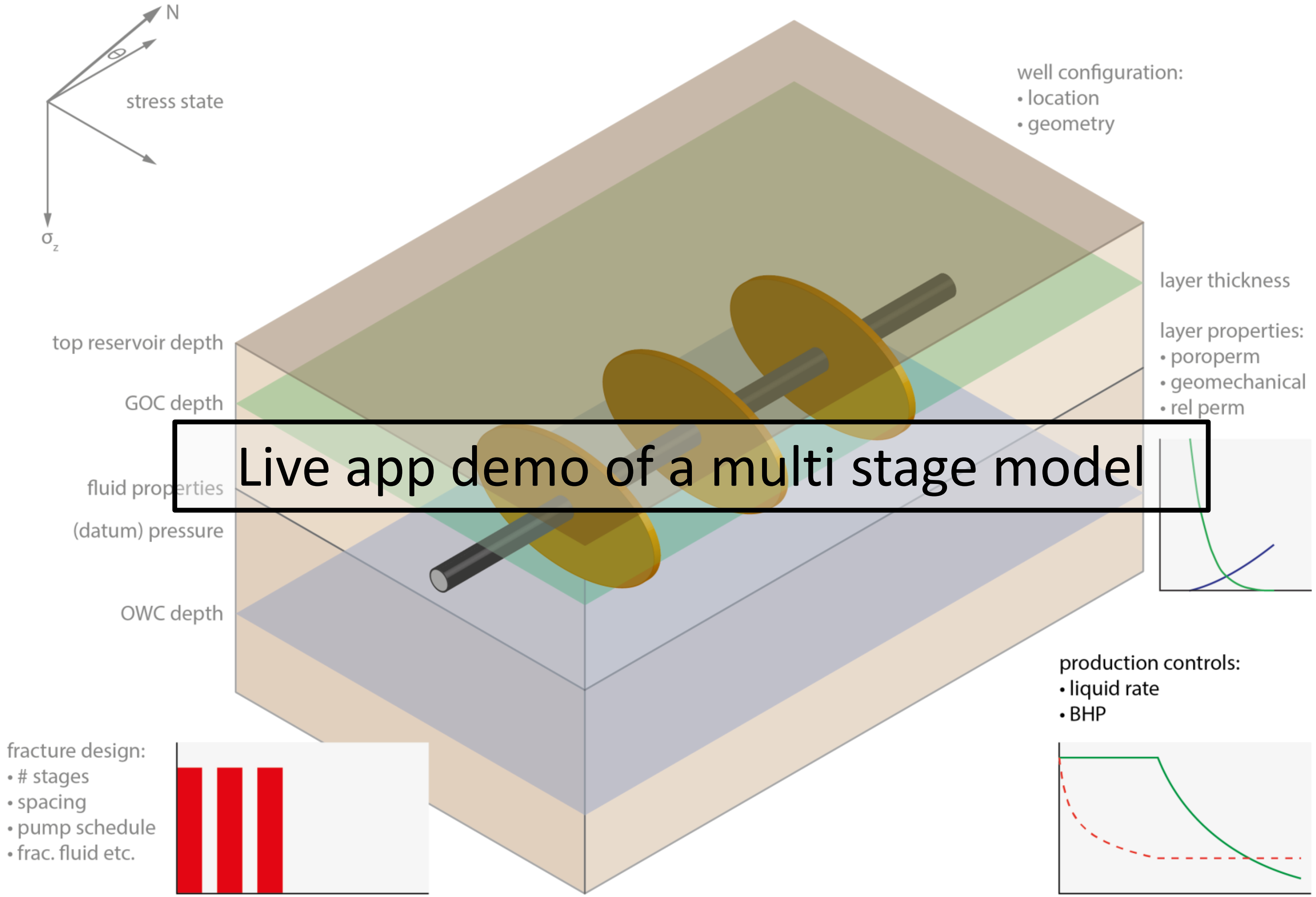
- Length 300 ft
- Spacing 120ft
- Rate 30, 40, 50 barrels / min
- Pumping time 3 hours
- Wireline operations 2 hours



Production

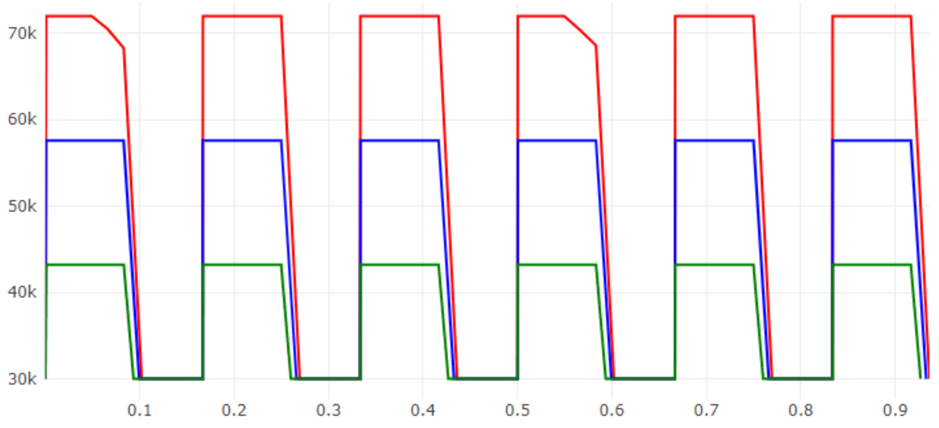
- 2,000 barrels / day of liquid, 4 years, Min BHP 1,000 psia

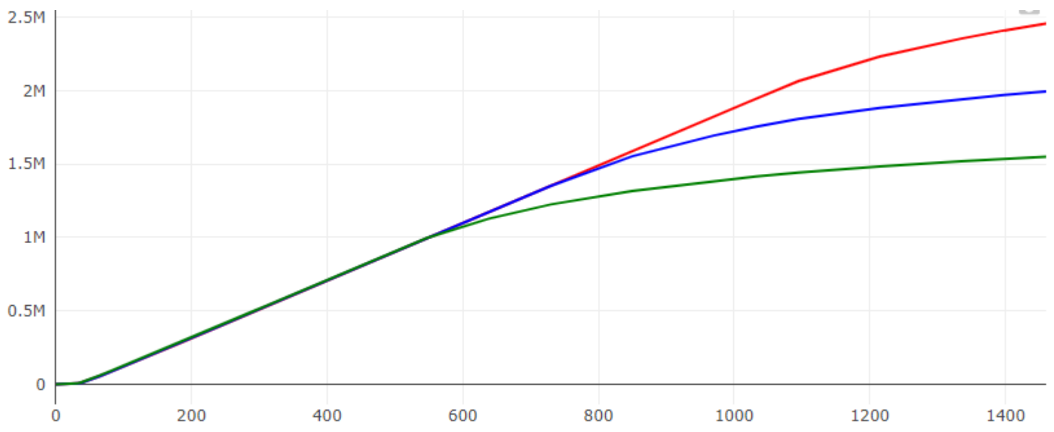
Live app demo of a multi stage model



Example 3 – Results Analysis and Conclusions

- Oil recovery increases with higher injection rate / job size
- Injection rate of 50 bpm cannot be sustained as the fractures are unable to take the fluid.
- Illustrates the importance of having a realistic, calibrated model
  - If the model showed it was possible to inject at very high rates, we would be misleading ourselves
  - Next, we will see how we can tune the rock properties to match observed rates and pressures





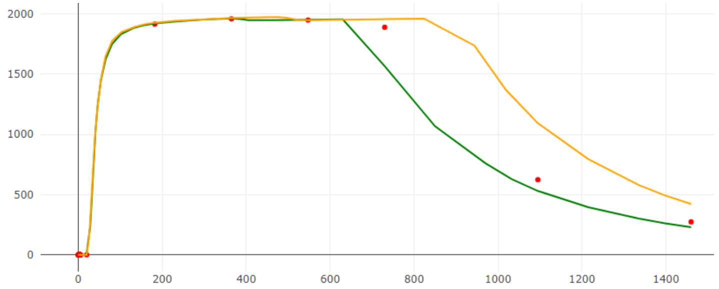
Single well with multiple fracs – Examples

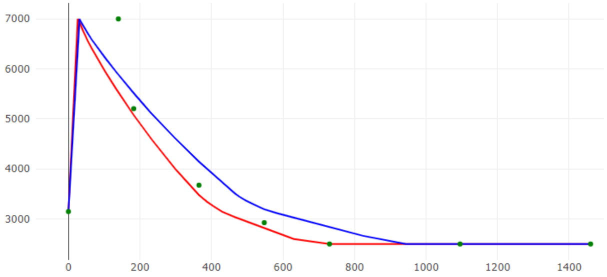
Example 3: Treatment Rate optimization

Example 4: History Match / Calibration

Example 4 – History Match Well Performance

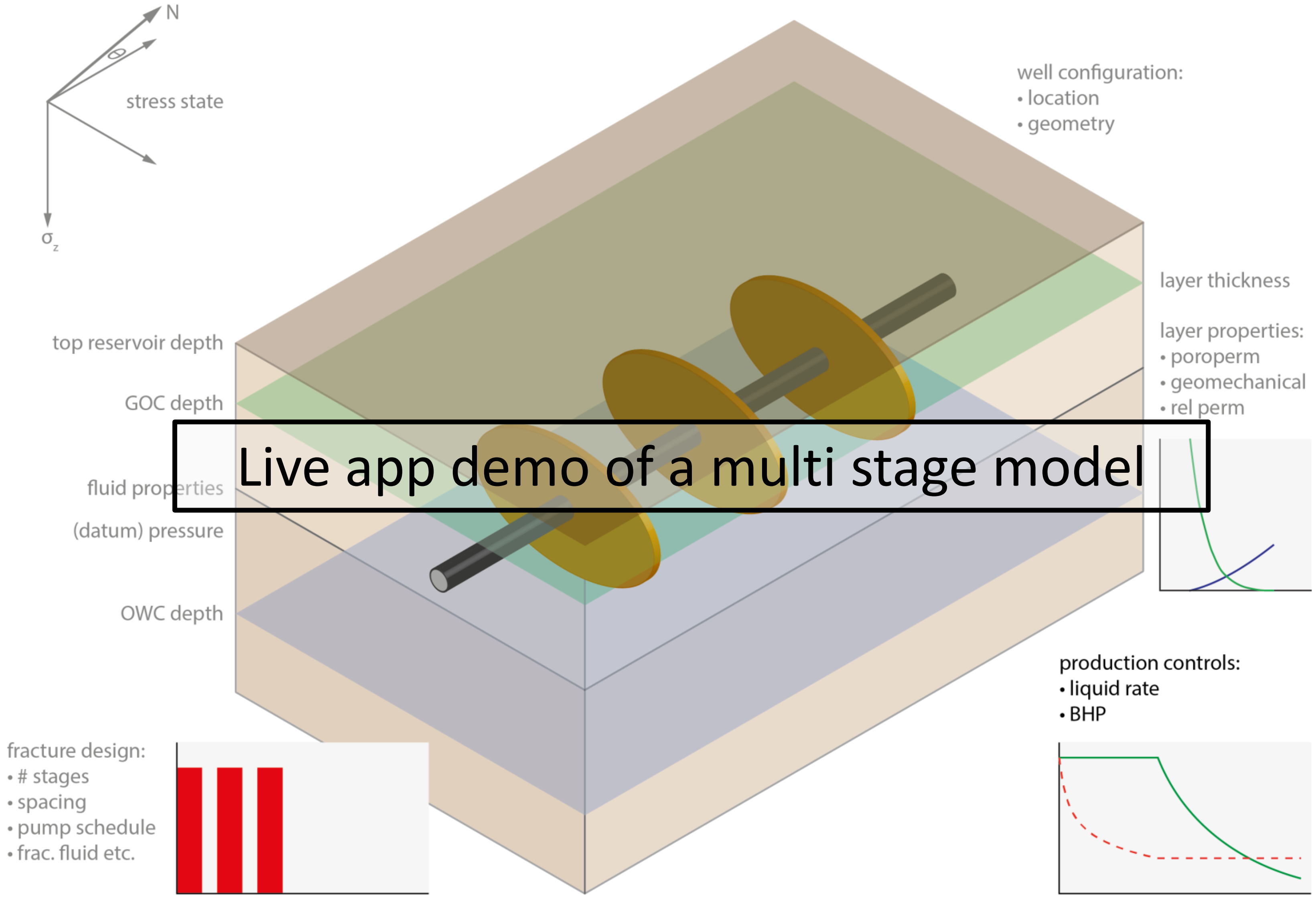
- The 24 stage stimulation program was started on day 0 at 45 BPM and then put on production.
- The well was produced over 3 years
  - Production plateau of 2000 STBD for 730 days
  - Initial flowing BHP 7,000 psi
  - BHP hits 2,500 psi limit at 730 days





- **Objective: Revise the geomechanical parameters to history match the model to observed well performance**

Live app demo of a multi stage model

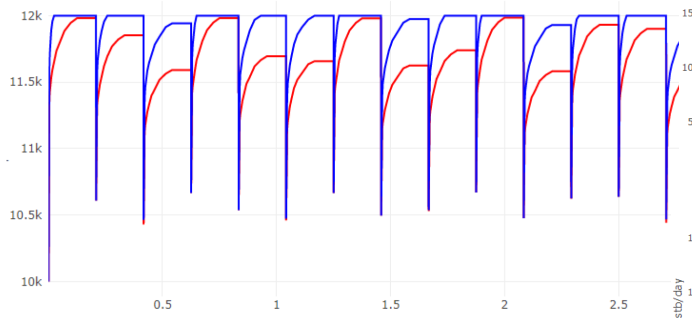


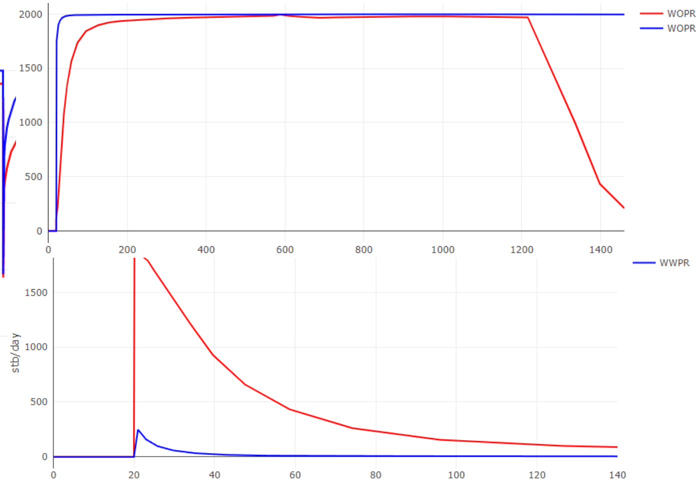
Example 4 – Results Analysis and Conclusions

“Geomech” can be calibrated to match observed performance

- Compressibility controls how rapidly the pore volume changes
  - Higher values allow the fracture space to expand in response to pumping – rock is “spongy”, fluid does not travel far
  - Lower values constrain the fracture space – rock is stiff, fluid passes along the fracture

strength	0	compressibility	500
perm addition (tensile)	500	residual-k (stim)	0
rubble generation (shear)	0.5	residual-k (prop)	25

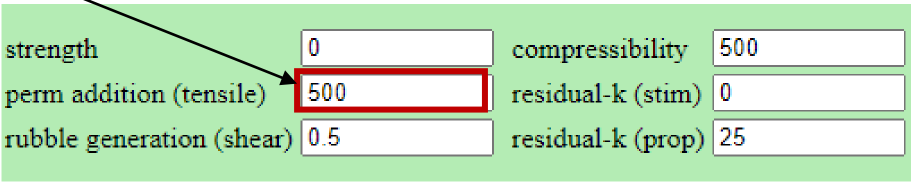


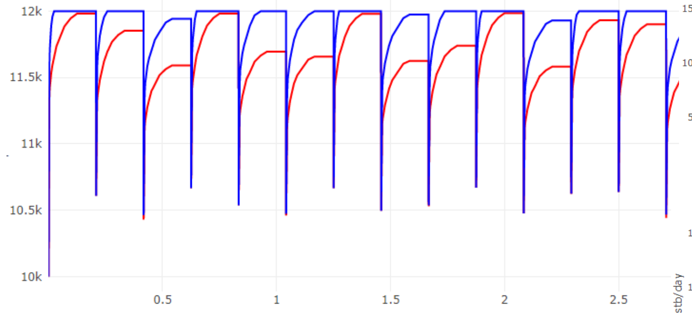


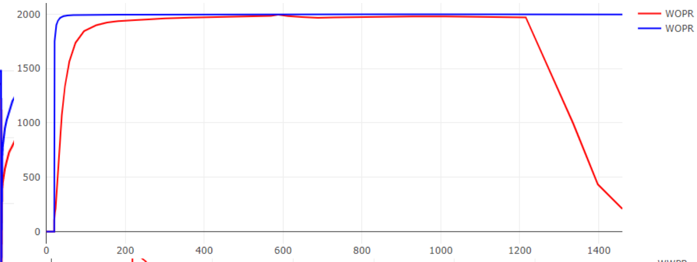
Example 4 – Results Analysis and Conclusions

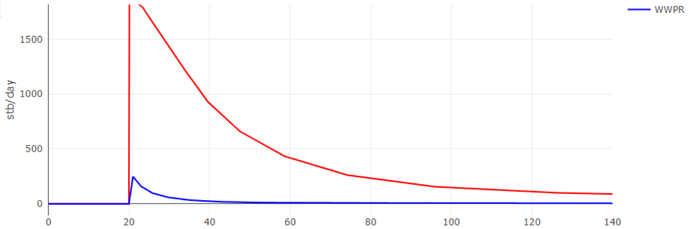
"Geomech" can be calibrated to match observed performance

- Compressibility controls how rapidly the pore volume changes
- Tensile controls the conductivity of the fractures
    - Higher values tend to keep the fluid in the fractures
    - Lower values may push fluid to the matrix
- BUT… "High" and "Low" are relative to the effects of …





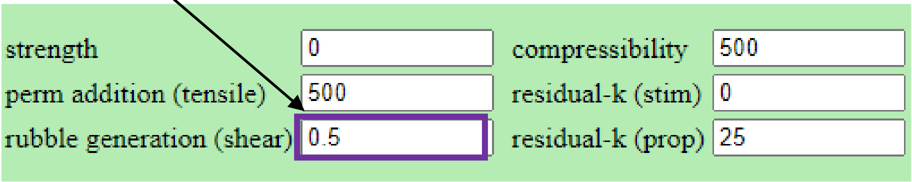


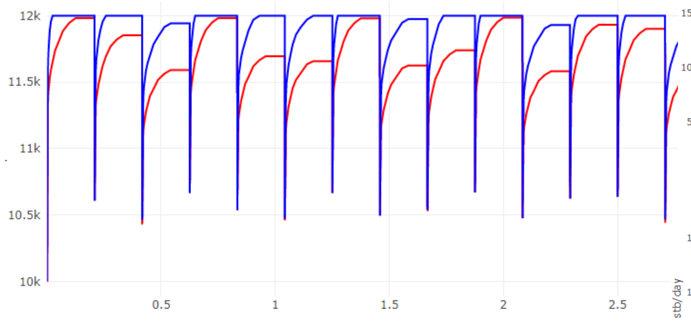


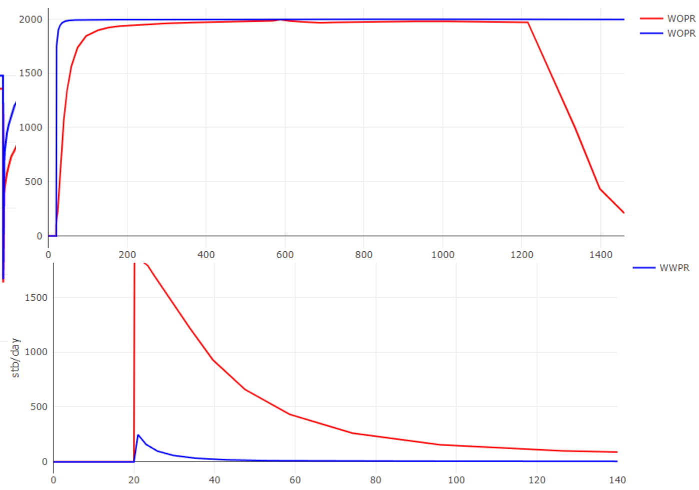
Example 4 – Results Analysis and Conclusions

"Geomech" can be calibrated to match observed performance

- Compressibility controls how rapidly the pore volume changes
- Tensile controls the conductivity of the fractures
- Rubble generation controls the flow between fracture and matrix:
    - Higher values enable
        - Frac fluid leak off during pumping (F -> M)
        - More oil production (M -> F)
    - Lower values enable
        - Frac fluid that stays in the fractures







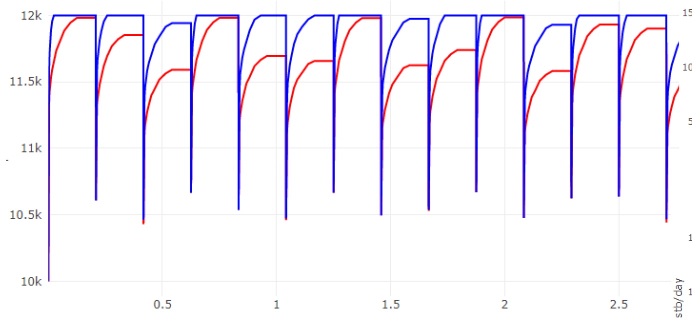
Example 4 – Results Analysis and Conclusions

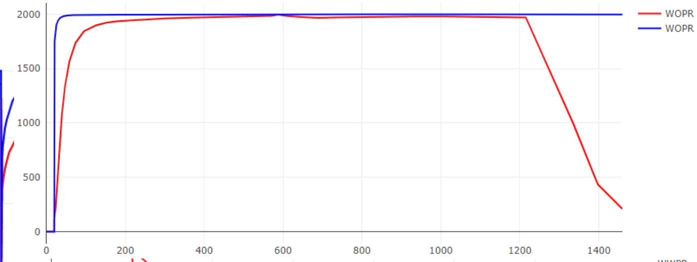
"Geomech" can be calibrated to match observed performance

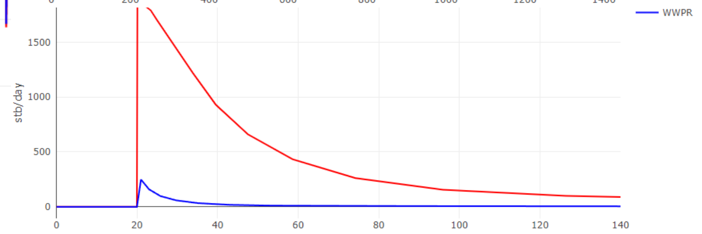
- Compressibility controls how rapidly the pore volume changes
- Tensile controls the conductivity of the fractures
- Rubble generation controls the flow between fracture and matrix:
  - Frac fluid leak off during pumping (F -> M)
  - Oil production (M -> F)
- Non-uniqueness of solution requires engineering judgement to constrain parameters

strength	0	compressibility	500
perm addition (tensile)	500	residual-k (stim)	0
rubble generation (shear)	0.5	residual-k (prop)	25

A calibrated model allows the performance implications of operational decisions to be evaluated with confidence







Summary – Introduction to 6X and 6X^{online}

- We have shown:
  - Single well – 24 stages
    - Changing design, i.e. pump rate
      - allows **EXPERIMENTATION**
    - Iteratively changing the rock characteristics
      - To illustrate **CALIBRATION** to history
- 6Xonline Access
  - Web address http://5.154.189.2:55555/
  - Or the **6Xonline button** on our web page
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  - Peter Forster
    - pforster@ridgewaykitesoftware.com
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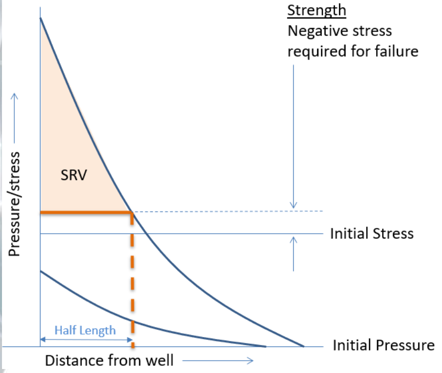
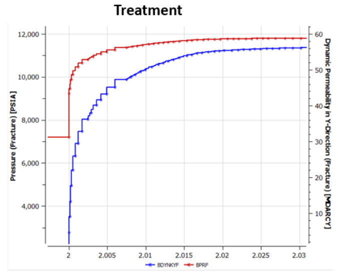
    - tmiller@ridgewaykitesoftware.com
  - Also: www.ridgewaykite.com





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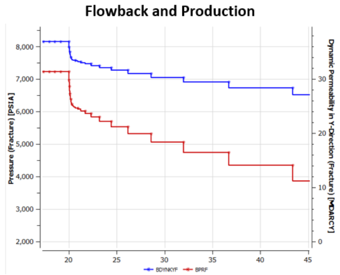

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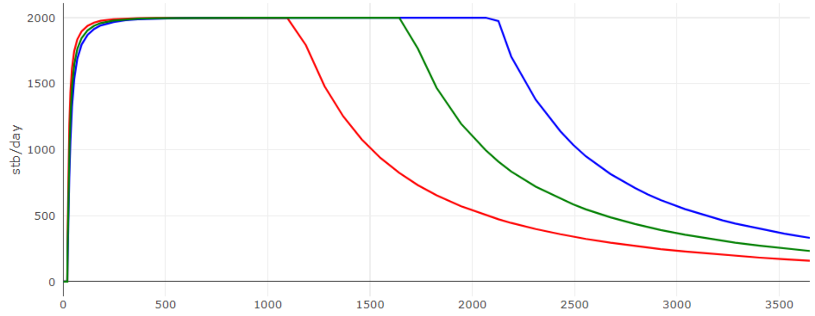
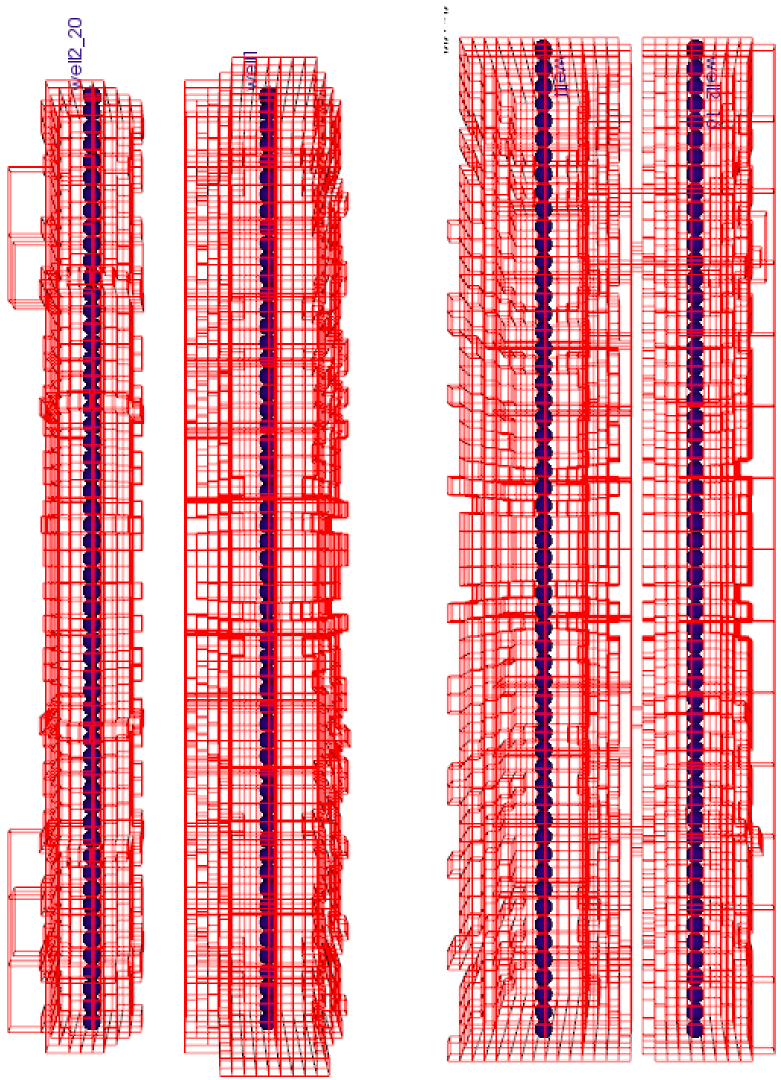


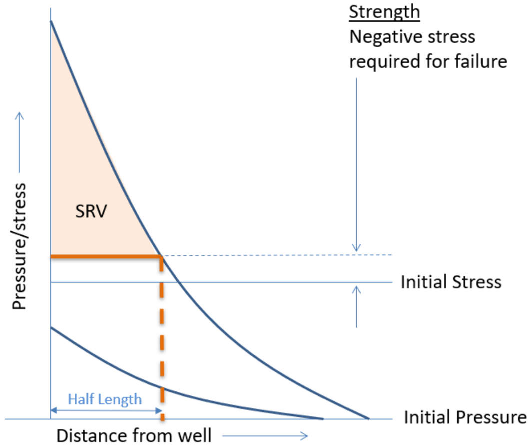
Next Presentation

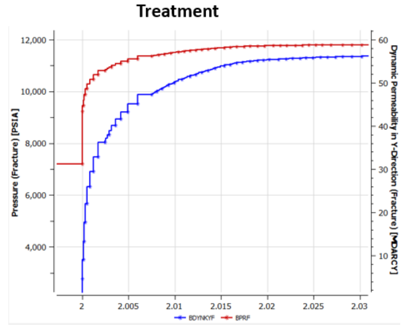
- Scheduled for April
- Examples will include
  - Multi well
    - well spacing based on parent / child interaction



Questions?

- From the Chat panel
- Live...





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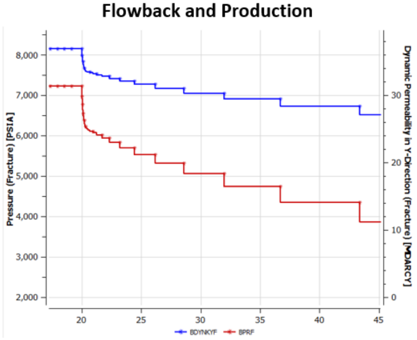

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- Pressure decreases
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- We will be back with the next presentation in April
- We will discuss modelling Parent / Child interactions