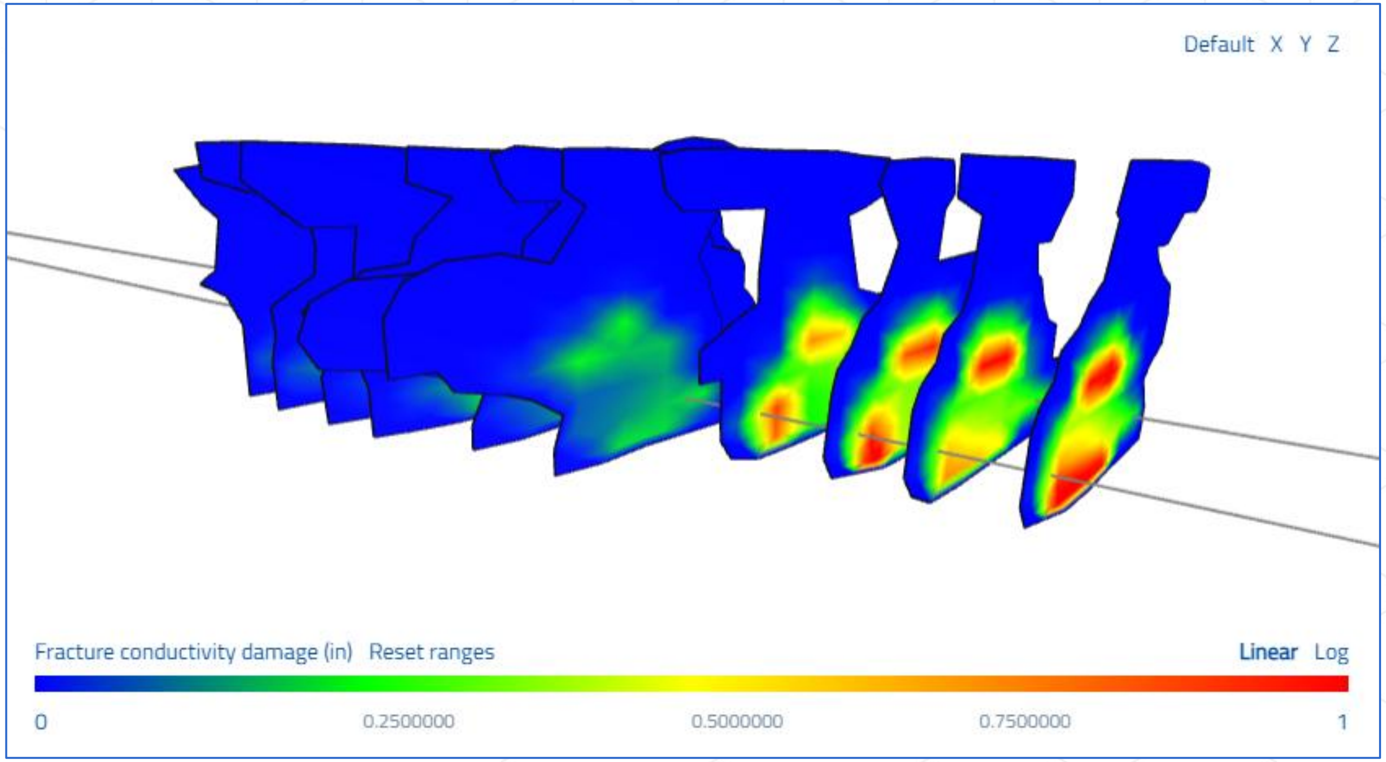


Damage Mechanisms

Means of modifying well productivity after frac hits

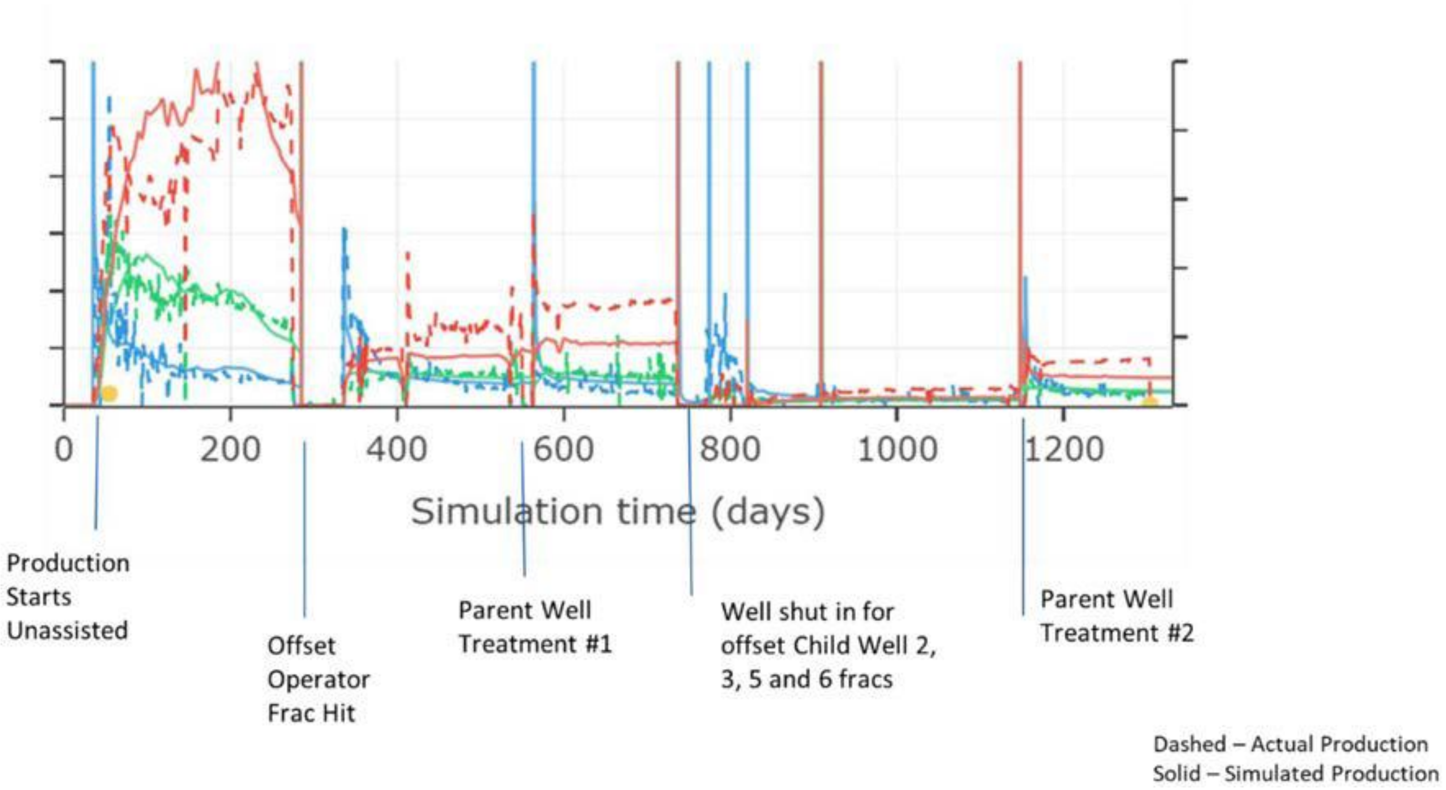
Damage Mechanisms

- **Fracture Damage Reactions** – Damage occurs within the fracture.
- **Matrix Damage –** Matrix damage is meant to mimic the effects of the capillary effects that might occur when leaking off water into depleted rocks. The leaked off water essentially ‘blocks’ the flow.
    - **Water Block Damage** – Damage blocks only the flow of hydrocarbons.
    - **Skin Damage** – Damage blocks the flow of both hydrocarbons and water.
- **Water Banking*** – Temporary damage that increases the water flow as a function of the amount of water leaked off. Typically used when the water cut increases post frac hit and then returns to normal after a short period of time.
- **Time Dependent Proppant Conductivity Loss** – The loss of proppant conductivity in addition to the specified proppant conductivity curves. Often, the proppant conductivity curves will not degrade over time enough to match predicted EURs. Allowing the proppant conductivity to degrade further will help lower the total EUR with only minor changes to early time production.

***Water banking is covered in another presentation.**

Damage Mechanisms - Fracture Conductivity

- Fracture conductivity damage occurs when a specific water solute ‘reacts’ with the fluid in the fracture and decreases the fracture conductivity. The user will specify the reaction rate, the potency and the damage type (conductivity or rel perm) to tune the reaction to real world results. Additionally, the damage in the fracture may be reversed using a different water solute in an injection treatment.



SPE-209152– Modeling of Parent Child Well Interactions, Ratcliff et al., 2022. Co-authored with Devon, modeled primary production, frac-hit-induced production losses, and damage remediation in a single continuous model.

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Damage Mechanisms - Fracture Conductivity

Water Solutes

FRACTURE PROPPANT PACK DAMAGE REACTIONS

	Primary water solute	(Optional) second water solute	Reaction rate constant [1/s]	Potency constant for the reaction	Damage type	Damage proportional to oil saturation	Reaction occurs only in the fracture	Damage proportional to time dependent conductivity degradation
1	FR	[BLANK]	0.000028	5000000	Conductivity	☐	☑	☑

Specify the water solutes that create the damage.

The reaction rate constant is the time it takes for the damaging water solute to be 'used up'. Note that the units are in 1/sec.

The potency dictates the severity of the damage. A negative potency will reverse previous damage.

Determines if the damage is either to the fracture conductivity or to the rel perm curves.

If 'damage proportional to oil saturation' is checked, then hydrocarbon must be in the fractures for damage to occur. Often, hydrocarbons are swept out by the frac water and not very much damage occurs.

If 'reaction occurs only in the fracture' is not checked, then the reaction is allowed to occur in the wellbore. While no damage occurs when reactions take place in the wellbore, the water solute is spent and may not cause damage in the fracture.

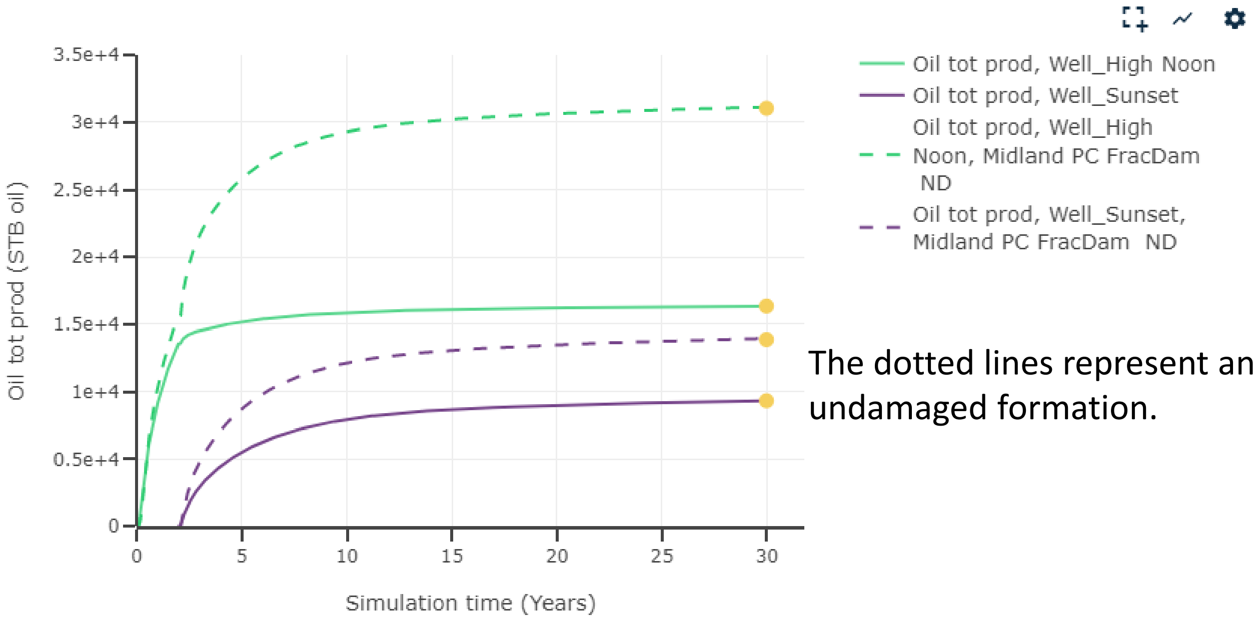
If 'damage proportional to time dependent conductivity degradation' is checked, then 'time dependent proppant conductivity loss' must also be applied (in the Proppants panel).

☑ Damage proportional to both oil and gas saturation

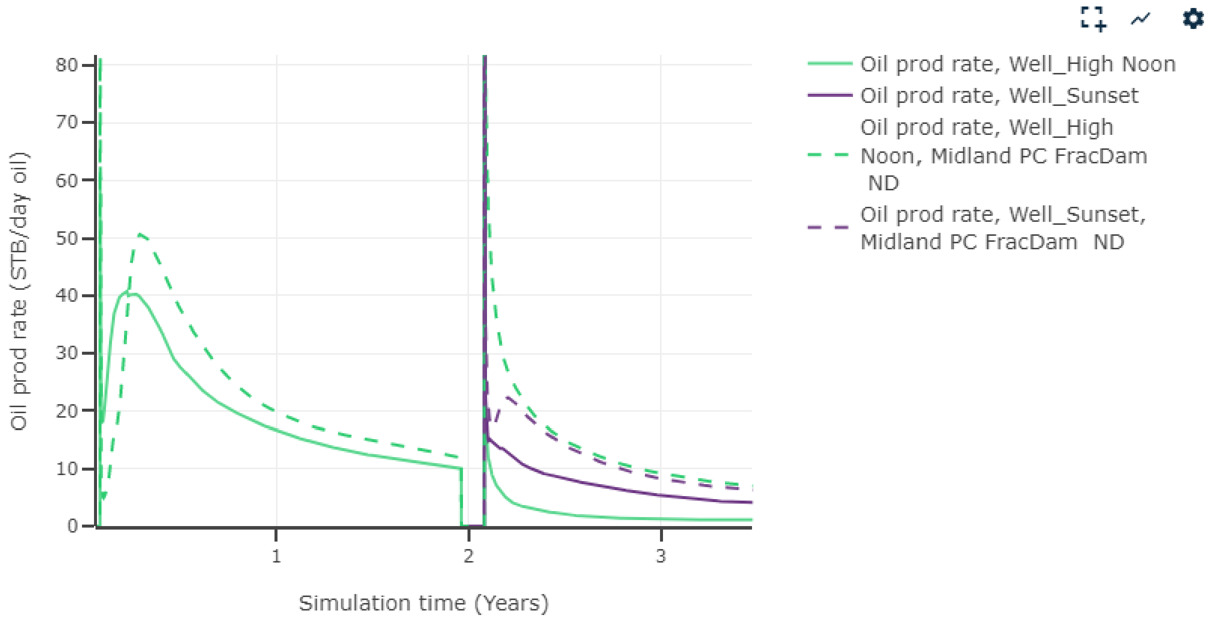
If damage proportional to oil saturation is checked, then damage can also occur when there is gas saturation.

Damage Mechanisms - Fracture Conductivity

Assessing the Damage

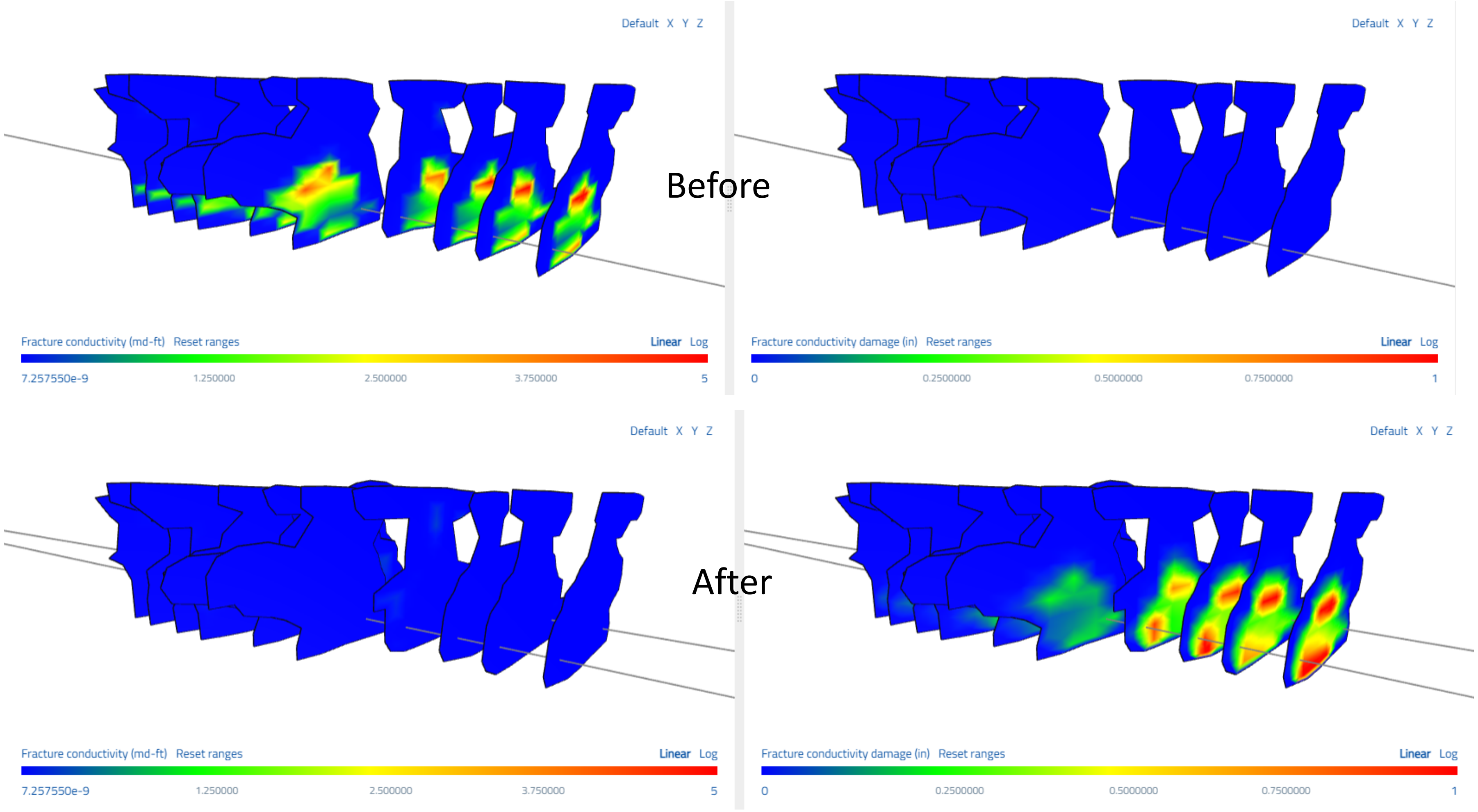


The dotted lines represent an undamaged formation.



The most identifiable result of damage is production losses. Depending on several factors, such as how connected the wells are, the damage may occur to both the child and the parent wells, as we see above.

Damage Mechanisms - Fracture Conductivity
Assessing the Damage



Before the child well frac'd, the fracture had high conductivity and no damage.

Afterwards, the fracture has very low conductivity and a lot of visible damage, thereby reducing the production.

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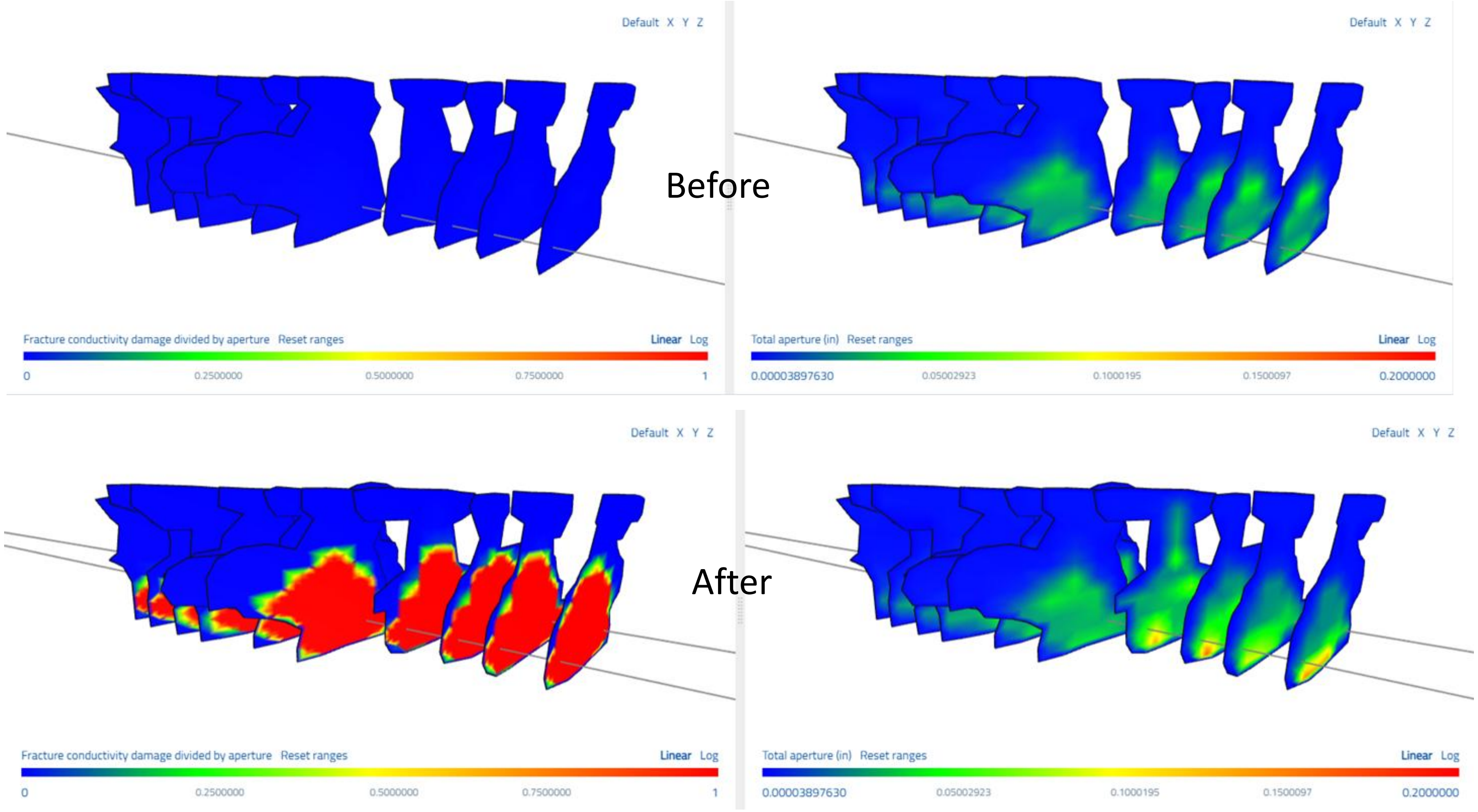
Damage Mechanisms - Fracture Conductivity

Assessing the Damage



To better understand the extent of the damage you can plot both the ‘total aperture’ and the ‘fracture conductivity divided by aperture’.

Both parameters are output by width, so if you divide the fracture conductivity by the aperture and the value is 1 or greater, then the damage to that part of the fracture has effectively reduced the aperture to zero.

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Damage Mechanisms – Fracture Skin Damage, Water Block

Water Solutes

Water block pressure reduction threshold
0.15

Specifies the amount of depletion as a function of pore pressure necessary for water block to occur. In this instance, an initial value of 6000 psi would require 900 psi of depletion before water block occurred.

Water block permeability multiplier
0.01

The maximum amount of permeability reduction to hydrocarbon (for water block) that can occur.

Water block maximum zone thickness [ft]

Limits the water block zone thickness to limit the total amount of water block that can occur.

Water block initial pressure factor
1

In the equation for water block formation, the 'initial pressure' is multiplied by this factor. Factors greater than 1.0 allow water block to form even if the formation is at initial pressure.

WATER BLOCK REDUCTION REACTIONS

	Water solute name	Reference composition	Unit for input	
1	Treatment Fluid	0.001	Mass fraction	

New Row Resize Table

Water block can also be reversed by specifying and pumping a different water solute (chemical treatment). The reference composition is related to the water solute composition in the fluid.

Damage Mechanisms – Fracture Skin Damage, Water Block

WATER SOLUTES

	Name	Type	Molar mass	Viscosity multiplier per 0.001 mass fraction	Power law exponent - n	St zero
1	FR	Modified Power Law	1000000	6232.08505706949	0.6	
2	Treatment Fluid	Inert Solute	1000000			

STEP 1

FLUID MIXTURES

Treatment

Name: Treatment

VISCOSITY SUMMARY

	Viscosity at room temperature and 170 s^-1 [cp]	Viscosity at reservoir temperature and 170 s^-1 [cp]
1	1	0.343742716711583

INJECTION FLUID MIXTURE COMPOSITION

	Water solute	Unit for input	Input quantity
1	FR	Mass fraction	0
2	Treatment Fluid	Mass fraction	0.001

STEP 2

$m_w s$

WATER BLOCK REDUCTION REACTIONS

STEP 3

	Water solute name	Reference composition	Unit for input
1	Treatment Fluid	0.001	Mass fraction

New Row Resize Table

$m_{ws,wb,ref}$

$$\Delta d_{wb} = 0.5 V_L \frac{m_{ws}}{m_{ws,wb,ref}}$$

Water block can be reversed by specifying and pumping a different water solute. The reference composition, $m_{ws,wb,ref}$ is related to the water solute composition the fluid $m_w s$. Therefore, a smaller value of the reference composition will result in more water block that is removed.

The user must first specify a water solute and use this to create a new fluid mixture to be pumped with the input quantity of the water solute that is to be used a treatment. Then the water block reduction reaction can be specified.

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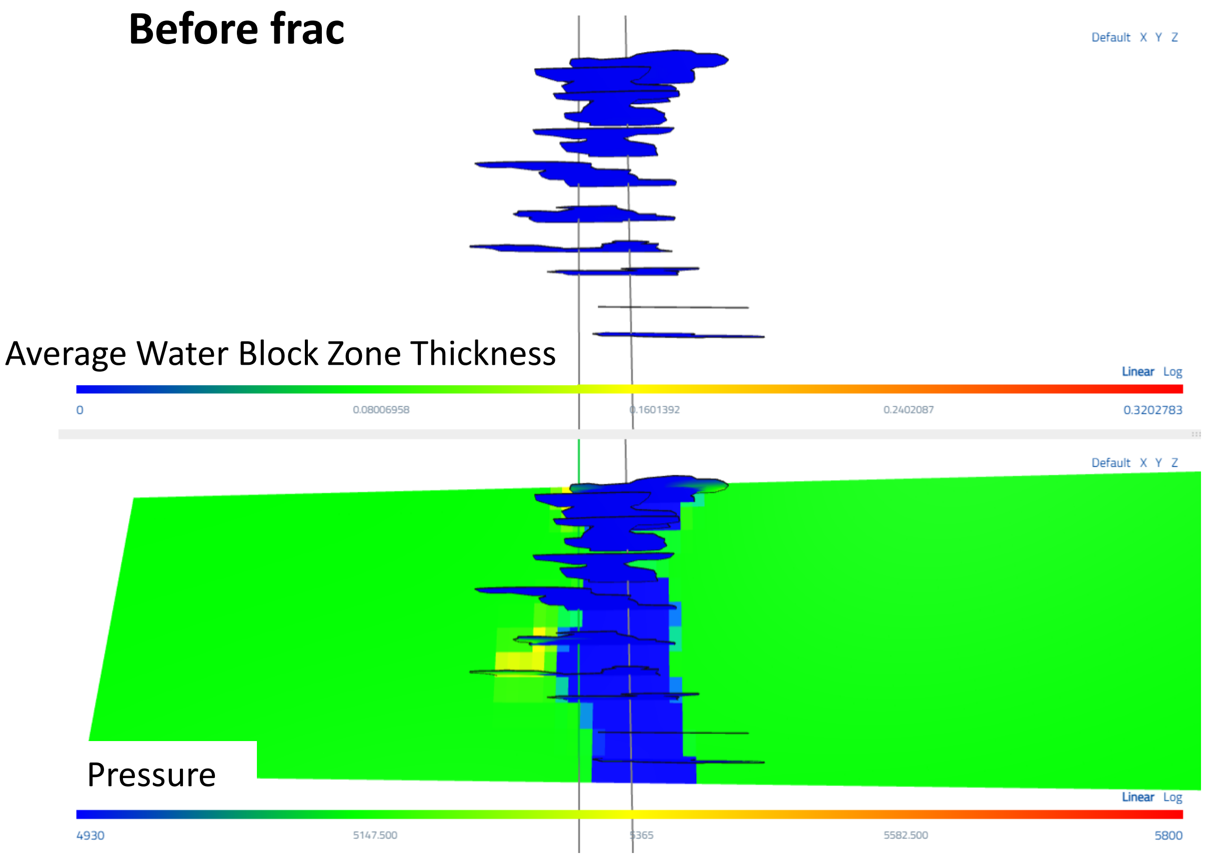
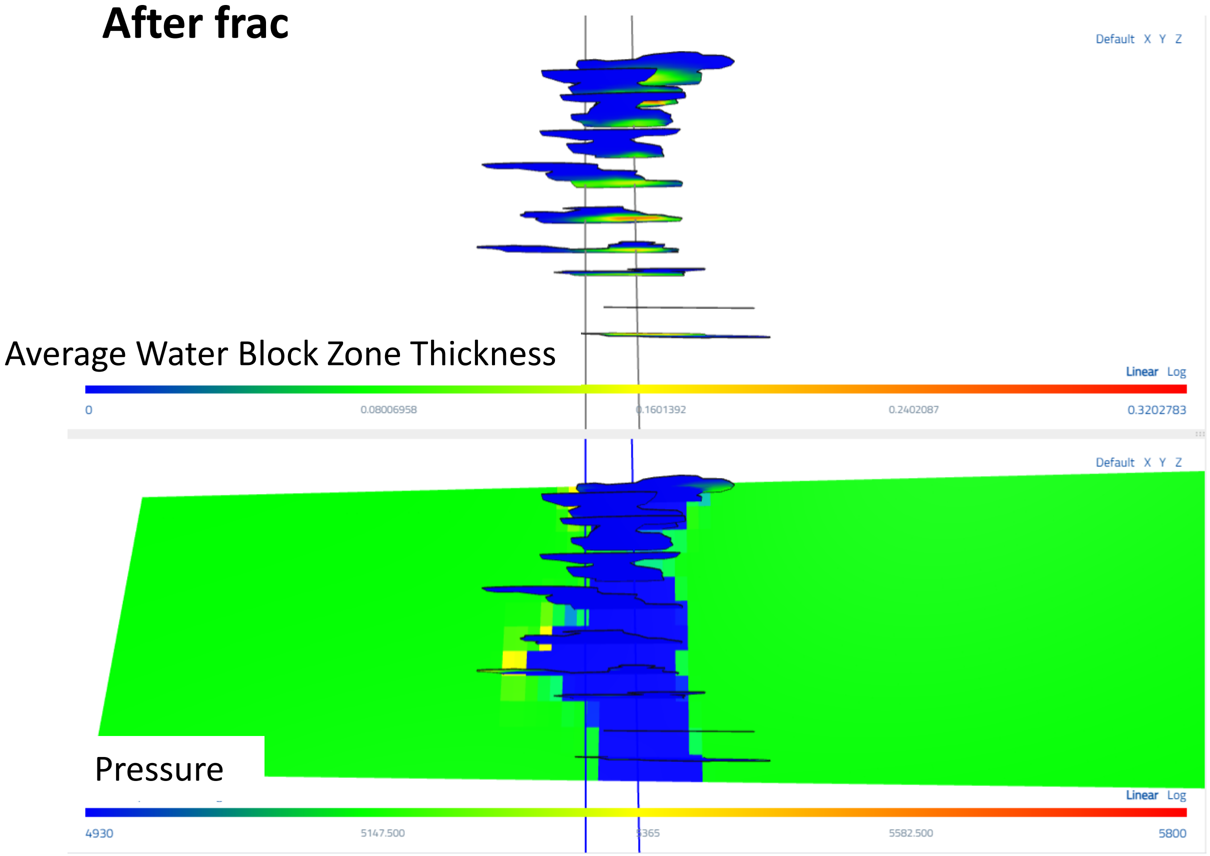
Water Block in the UI





Depletion extent shown in the UI with scales enhanced to show where water block will occur. Note how the average water block zone thickness mimics the depleted area.

Time Dependent Proppant Conductivity Loss

By default, proppant pack conductivity is function of effective normal stress (with an option to make changes irreversible), proppant concentration, formation properties (such as embedment), and ‘conductivity damage’ related to frac hits and chemical damage mechanisms.

There is also a capability to degrade proppant pack conductivity over time. This is motivated by: (1) observations from laboratory experiments suggesting time-dependent conductivity (Duenckel et al., 2017; Pearson et al., 2020), and (2) experience with history matching suggesting that time-dependent conductivity loss may help with matching late-time EUR observations and RTA curvature.

There is also the option to add water solutes that create ‘Reactions that undo time-dependent proppant pack conductivity loss’. This represents the effect of acidization and other chemical remediation treatments applied to the proppant pack.

Time Dependent Proppant Conductivity Loss

Proppants

TIME-DEPENDENT PROPPANT CONDUCTIVITY LOSS

	Proppant Name	Rate constant [days^-1]	Damage type	Rate scaling with effective normal stress (optional) [psi]	Minimum conductivity multiplier (optional)
1	40/70 Mesh	0.0002	2		
2	100 Mesh	0.0002	2		

Rate constant, $k_{D,td,j}$ in the equations outlined on the next page. We have found that 0.0002 is a good starting point for most simulations to match long term EURs.

Specify damage option 1 or 2. In almost all situations, option 2 is preferred . This is due to option 1 causing abnormal behavior on RTA plots.

Scales the rate constant with effective stress using the following equation. The user specifies $\sigma'_{n,td,ref,j}$ in the table above.

$$\left(1 + \frac{\sigma'_n}{\sigma'_{n,td,ref,j}}\right)^2$$

Minimum conductivity multiplier allowed. So, if 0.001 is specified, then the conductivity will not decrease more than 1000x.

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Time Dependent Proppant Conductivity Loss

Option 1:

$$\frac{d(D_{td,j}/m_j)}{dt} = \frac{k_{D,td,j}}{ln(10)} 10^{\frac{-D_{td,j}}{m_j}\frac{1}{k_{D,td,j}}}$$

Option 2:

$$\frac{d(D_{td,j}/m_j)}{dt} = k_{D,td,j}(1 - 36(\frac{(\frac{D_{td,j}}{m_j})^2}{2} - \frac{(\frac{D_{td,j}}{m_j})^3}{3})^2)$$

For either option, the user specifies $k_{D,td,j}$ for each type of proppant. This determines how quickly conductivity loss evolves over time. Larger numbers speed up the process and vice versa.

Option 1:

$$D_{td,fac,j} = 1 - \frac{D_{td,j}}{m_j}$$

Option 2:

$$D_{td,fac,j} = (1 - \frac{D_{td,j}}{m_j})^3$$

For each proppant, a time dependent conductivity damage variable is calculated. M_j is the amount of proppant mass per surface area of that specific proppant.

$$D_{td,fac} = \Sigma(\frac{D_{td,fac,j}C_{pr,j}}{C_{pr}})$$

$D_{td,fac}$ is the overall weighted average of all the different proppants. This factor is applied to the fracture conductivity. For instance, if it equals 99%, then the proppant pack conductivity is reduced by 99%.

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Time Dependent Proppant Conductivity Loss

Water Solutes

REACTIONS THAT UNDO TIME-DEPENDENT PROPPANT PACK CONDUCTIVITY LOSS

	Reactant	Rate constant [ft/s]	Damage constant [ft^4/s]
1			

Specify which water solute will serve as the reactant.

The rate constant (k_B) governing consumption of the reactant.

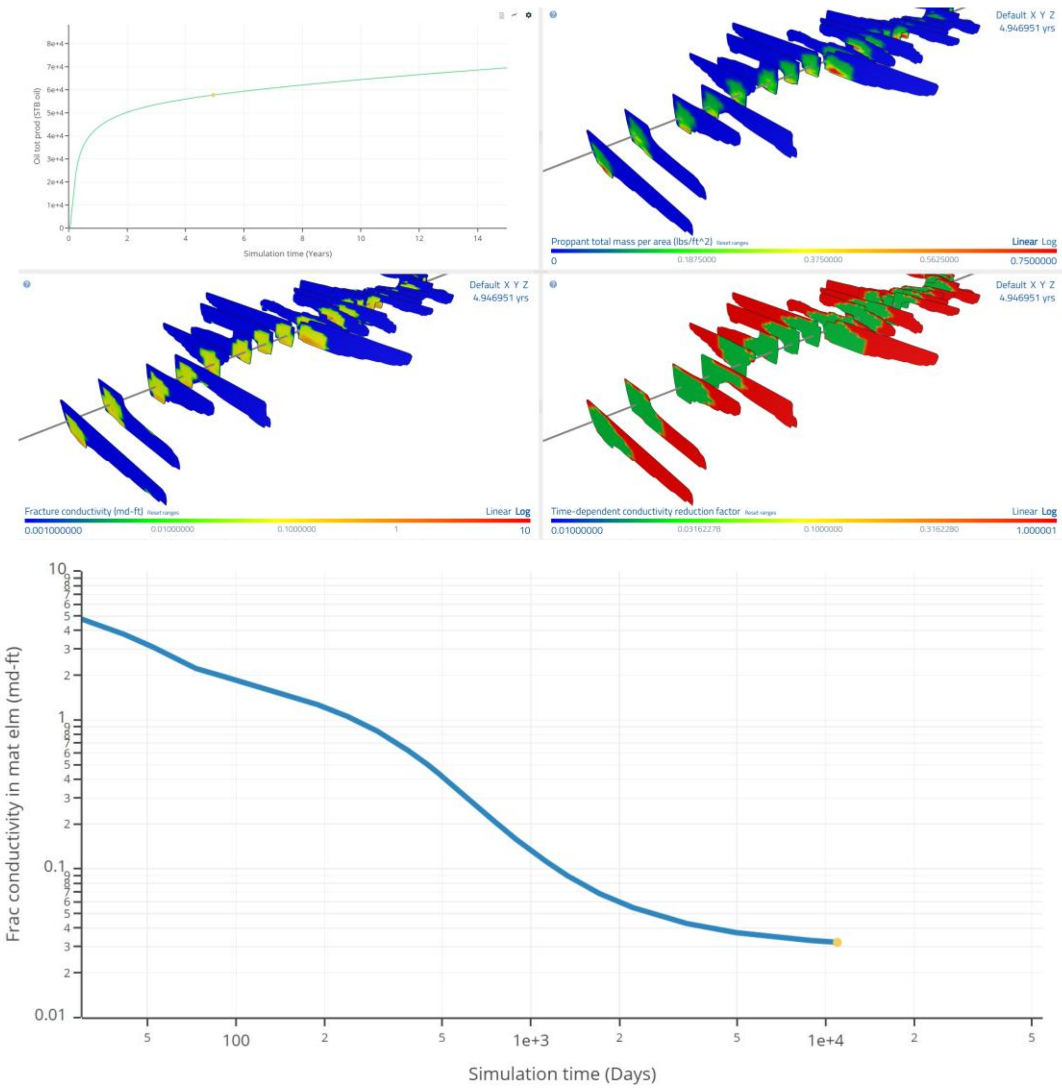
The damage rate constant (k) dictates how quickly time-dependent damage is undone by the reactant consumption.

$$\frac{d[B]}{dt} = -\frac{k_B f_s [B] D_{td,j} A}{\rho_p V}$$

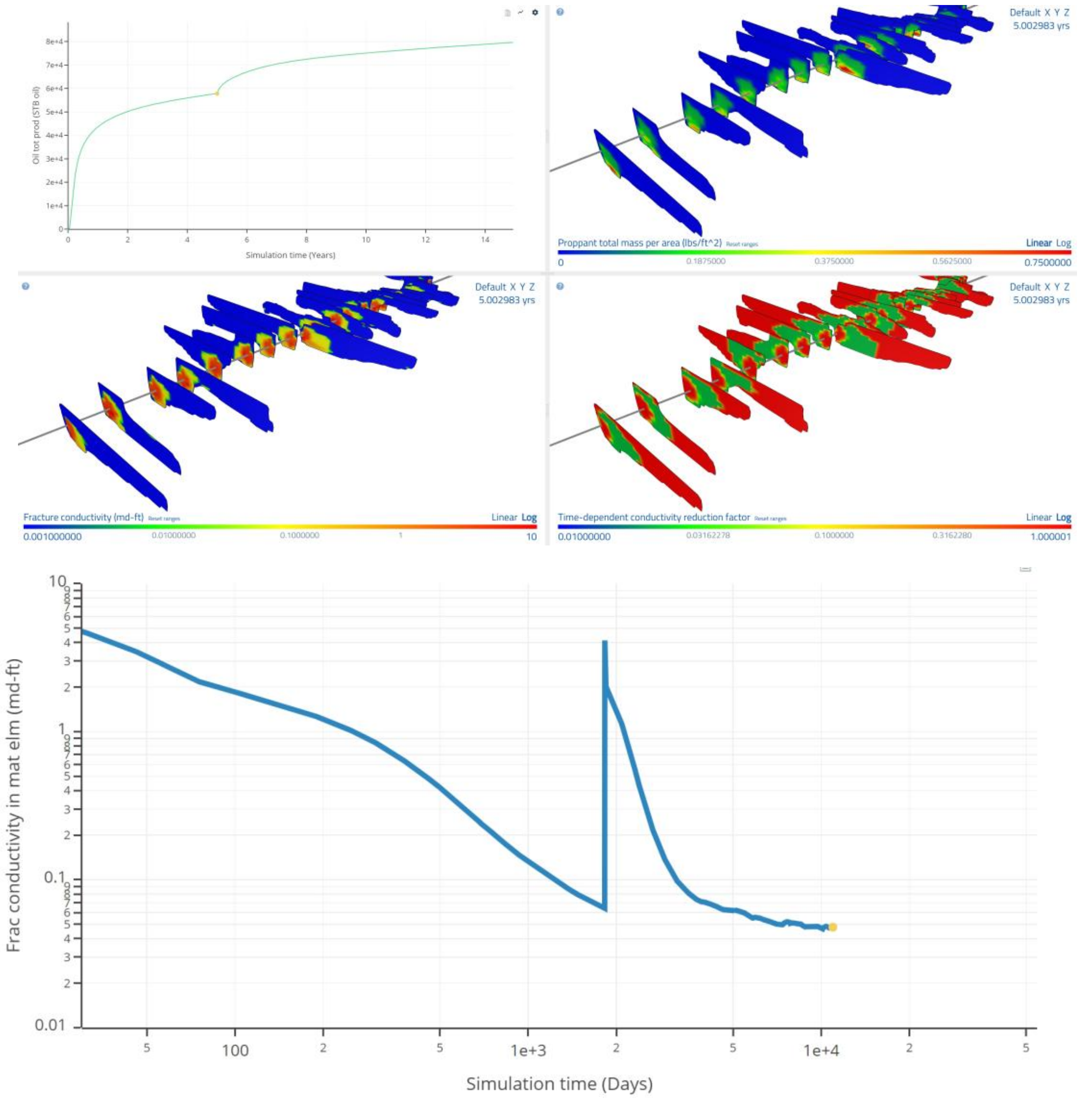
$$\frac{d(D_{td,j})}{dt} = -\frac{k f_s [B] D_{td,j}}{\rho_p V}$$

Reactions that Undo Time Dependent Proppant Conductivity Loss

Results without remediation



Results with remediation



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Thank You!

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