WP2 Unlocking marginal reservoirs

General Assembly
September 30th, 2025

Objectives and aims

- Define advanced well design workflow to select the best well configuration
  - Achieve positive business case (increase flow rate at limited additional costs)
  - Achieve acceptable risk
- Consider broader range of well concepts during concept select stage
- Include diversified case studies in terms of geographical spreading and development status
  - 4 case studies for the Slochteren Formation that face similar challenges
- Apply field development optimization workflow developed in GEOTHERMICA-RESULT
- Improve understanding of the impact of different drilling and completion solutions for various reservoir conditions
- Disseminate lessons learned to the Dutch geothermal sector

WP2 structure

WP 2.1 – Data collection and review

WP 2.2 – Modelling well concept scenarios and business case for selected cases

WP 2.3 – Research on drilling mud options

WP 2.4 – Reporting and white paper

		2024			2025				2026				2027				2028			
WP	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Deliverable
2,1																				Dynamic simulation models for case studies
2,2																				Optimization modelling results for each case study and drilling risk assessment matrix
2,3																				report on drilling mud research
2,4																				Summary Report and white paper

Major focus Minor focus Go no go Deliverable

Geo4all innovatieprogramma

Mede mogelijk gemaakt door: TKI NIEUW GAS Topsector Energie

4 case studies

Koekoekspolder (Greenhouse GeoPower supported by IF Technology)

- **Field in operation**: existing triplet
- Available updated model using production data

- Optimization of well locations and trajectories for new doublet
- Maximize business case i.e., Net Present Value (NPV)
- Assess drilling risks i.e., Directional Difficulty Index (DDI)

Regio Amsterdam (HVC jointly with Vattenfall, Gemeente Amsterdam)

- **Green field:** first doublet being planned
- Model with uncertain scenarios built by HVC

- Optimization of well locations and trajectories for new doublet
- Maximize business case i.e., Net Present Value (NPV)
- Assess drilling risks i.e., Directional Difficulty Index (DDI)

Luttelgeest (Aardwarmte Combinatie Luttelgeest supported by IF Technology)

- Alternative scenarios have been modelled by TNO:
  - "Do nothing": continue with triplet as currently operated
  - "Workover": fishbone completions, hydraulic stimulation and sidetrack
  - "New injector": replace problematic well by planned new injector

Regio Almere (HVC jointly with Vattenfall, Gemeente Almere)

- Truly green field development: little data available
- New area to be built: many houses, large heat demand expected

- Different approach required
- Several spatial planning questions:
  - How much space to reserve for geothermal site
  - A single or multiple land plots, and where?
  - Surface drilling locations, number of wells, well trajectories, play-opener doublet, all yet to be selected

- HVC to build scenarios of the reservoir model
- Optimization work to be started in Q4-2025

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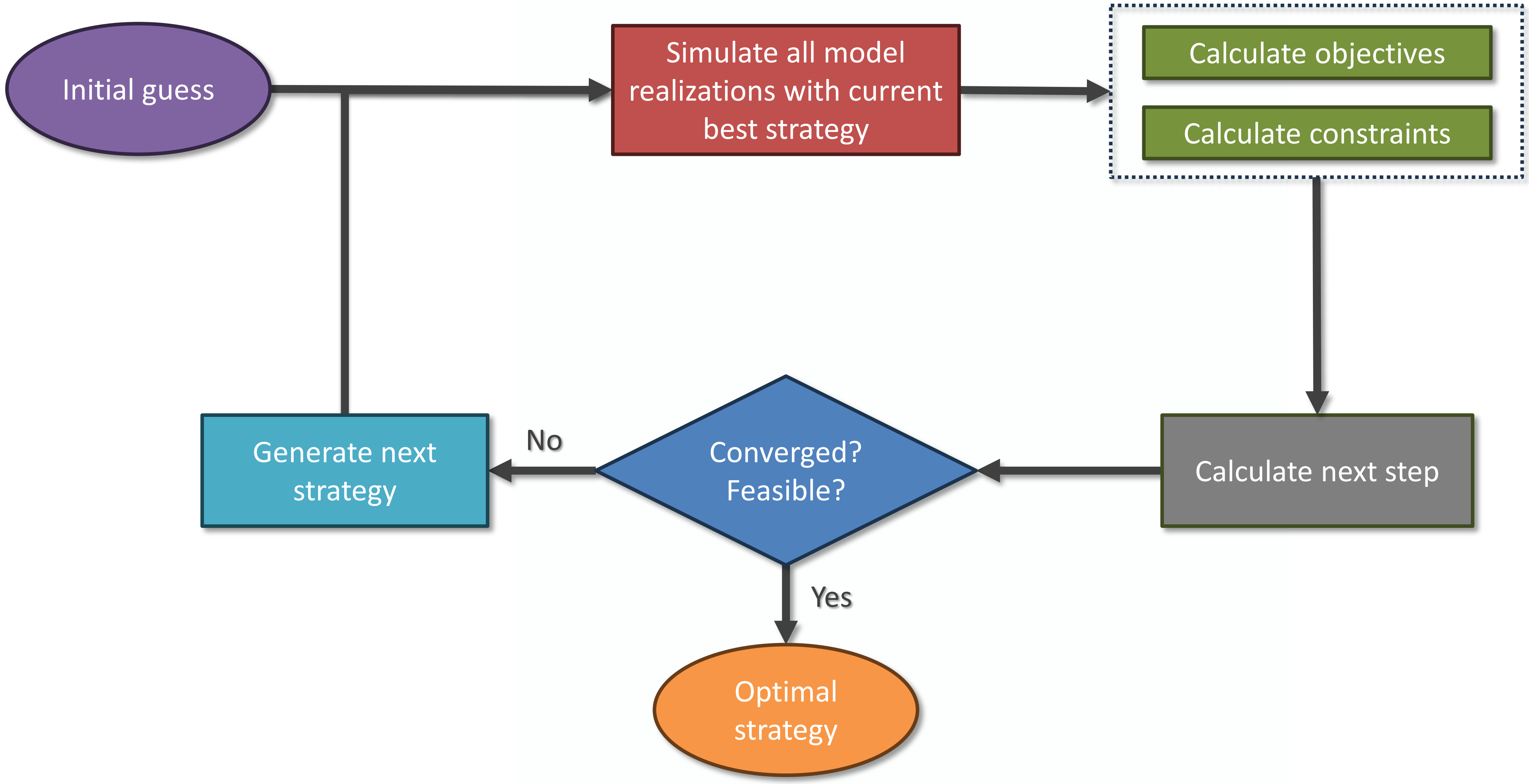
Optimization workflow in EVEREST

- Everest is an open-source decision support platform
- Developed jointly by TNO and Equinor
- Seeking robust solution in presence of uncertainties
- Uncertainties are captured using an ensemble of model realizations
- Employs model-based optimization methodology
- It is focused to be flexible and computationally efficient
- The practical applicability to real-life optimization challenges
- After years of research and development it has been released as open-source
- https://everest.tools



Economic and drilling risk assessment

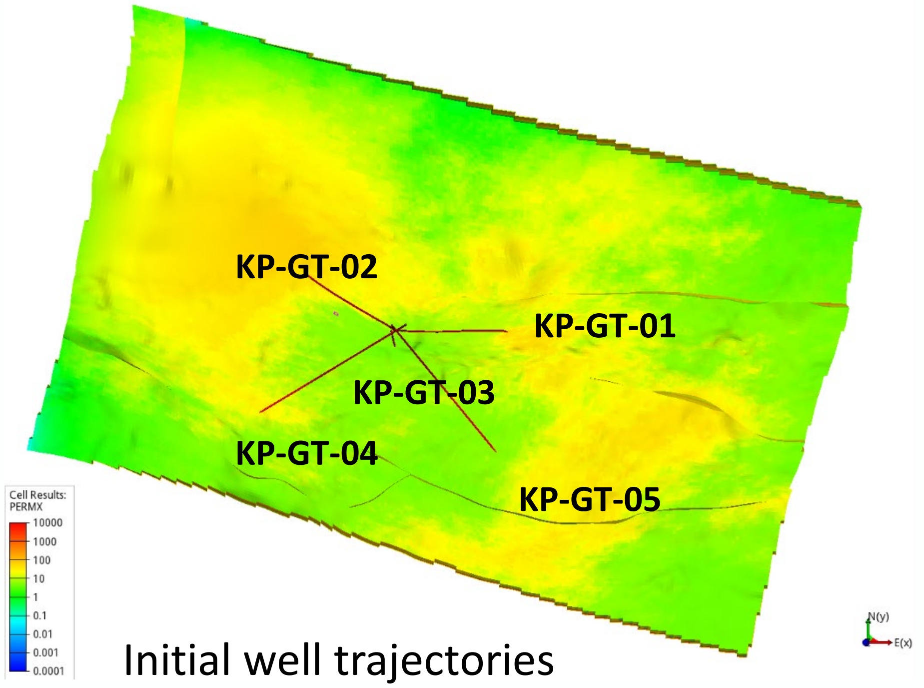
- **NPV Calculation includes:**
  - Initial Investment (**CAPEX**). Including **well cost.**
  - Ongoing Operational Expenses (**OPEX**)
    Expected Revenue: Projected income from the project.
  - **Discount Rate**: Rate at which future cash flows are discounted.
  - **Tax Rate**: Rate at which taxes are applied to the project's income.
  - **Inflation Rate**: Rate at which the purchasing power of money decreases over time.
  - **Project Life**: Expected duration of the project.
  - **Subsidy**: Financial assistance or grants provided by the government or other entities.
  - **Electricity Price**: Price of electricity used in the project.
  - **Heat Price**: Price of heat used in the project.
  - **Loan**: Debt financing obtained for the project.
  - **Equity**: Owner's investment in the project.

- **Refined drilling constraints and indicators:**
  - Imposed well shape constraints:
    - Maximum allowed dogleg severity
    - Maximum allowed well length
    - Maximum allowed inclination
    - Maximum allowed build rate
    - Maximum allowed turn rate
    - Maximum allowed step-out / TVD ratio
  - Evaluation of the relative difficulty of drilling a directional well
    - Directional Difficulty Index (DDI)
    - DDI combines wellbore geometry parameters:
      - True vertical depth
      - Along-hole displacement
      - Measured depth
      - Tortuosity
  - Fault stress indicator: Shear Capacity Utilization (SCU)
    - Considers pressure and temperature in the aquifer.

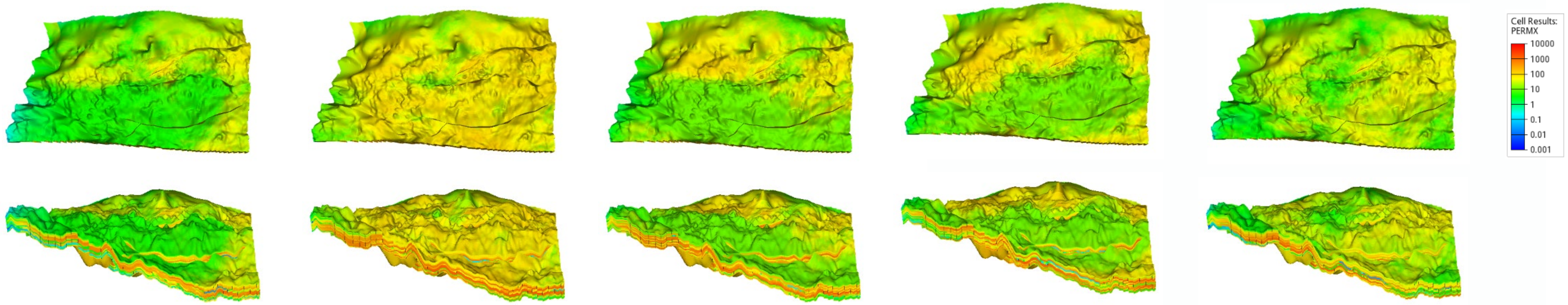
Koekoekspolder case

Koekoekspolder case: simulation model

- Information from seismic data (HIPE project)
- Local structure with faults
- Model has been history matched with production data by updating global and local permeability multipliers
- Geological realizations randomly generated with permeability and porosity ranges from upscaled well logs
- Also updated fault transmissivity multipliers to match pressure in wells



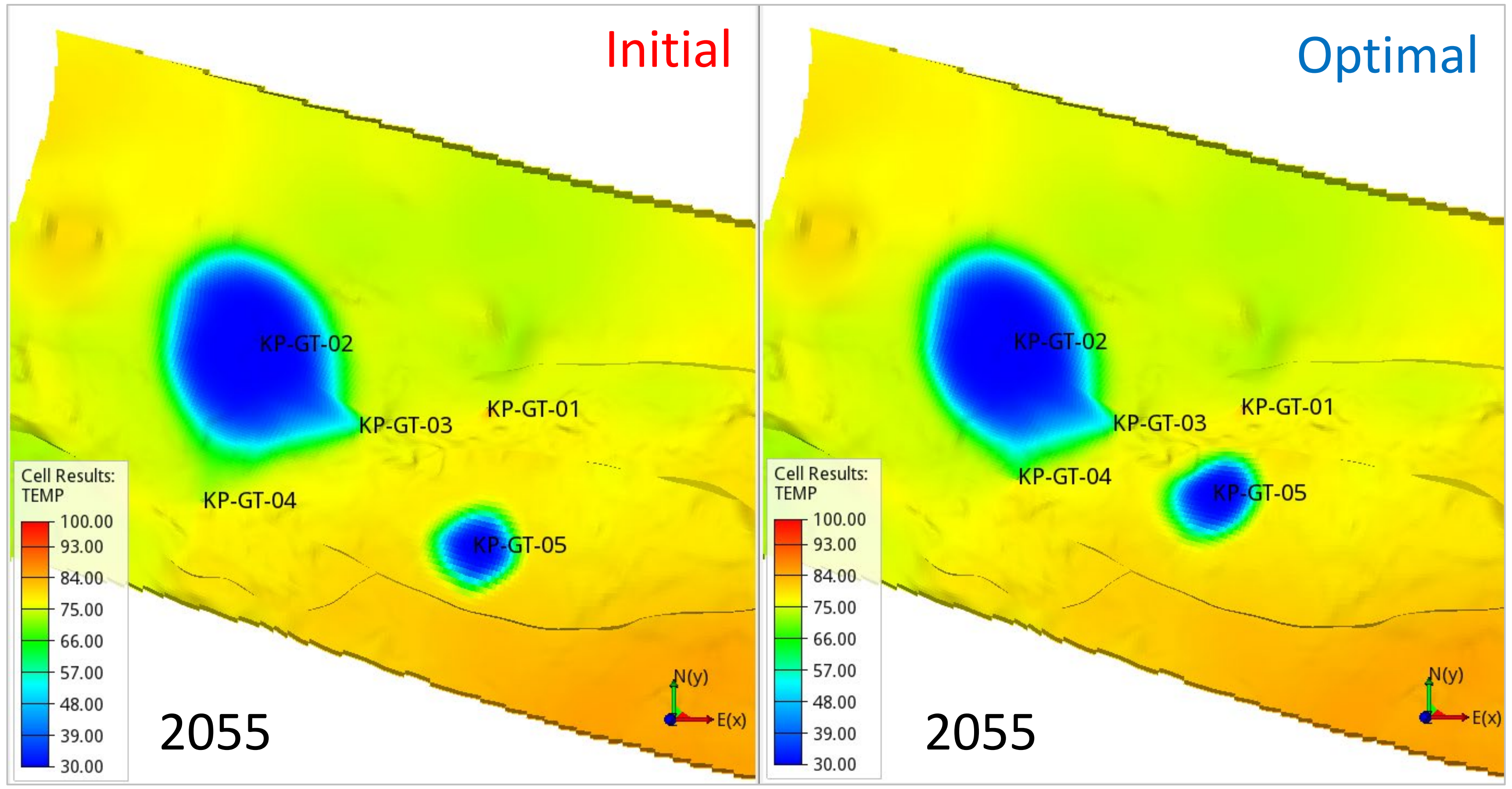
Initial well trajectories

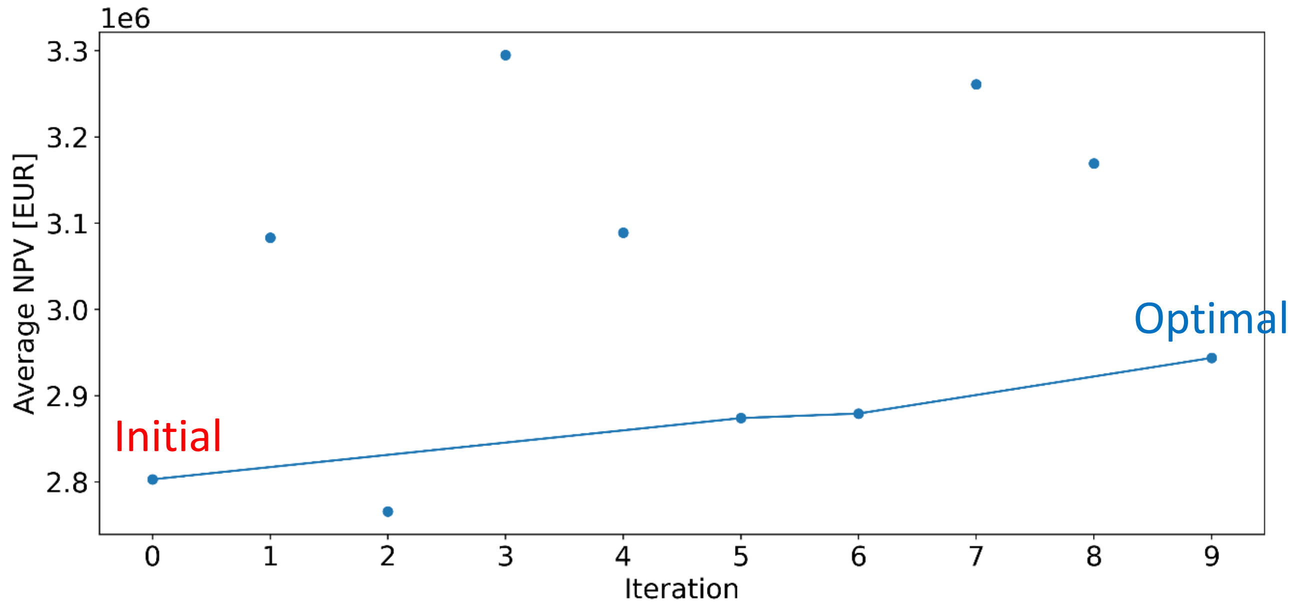


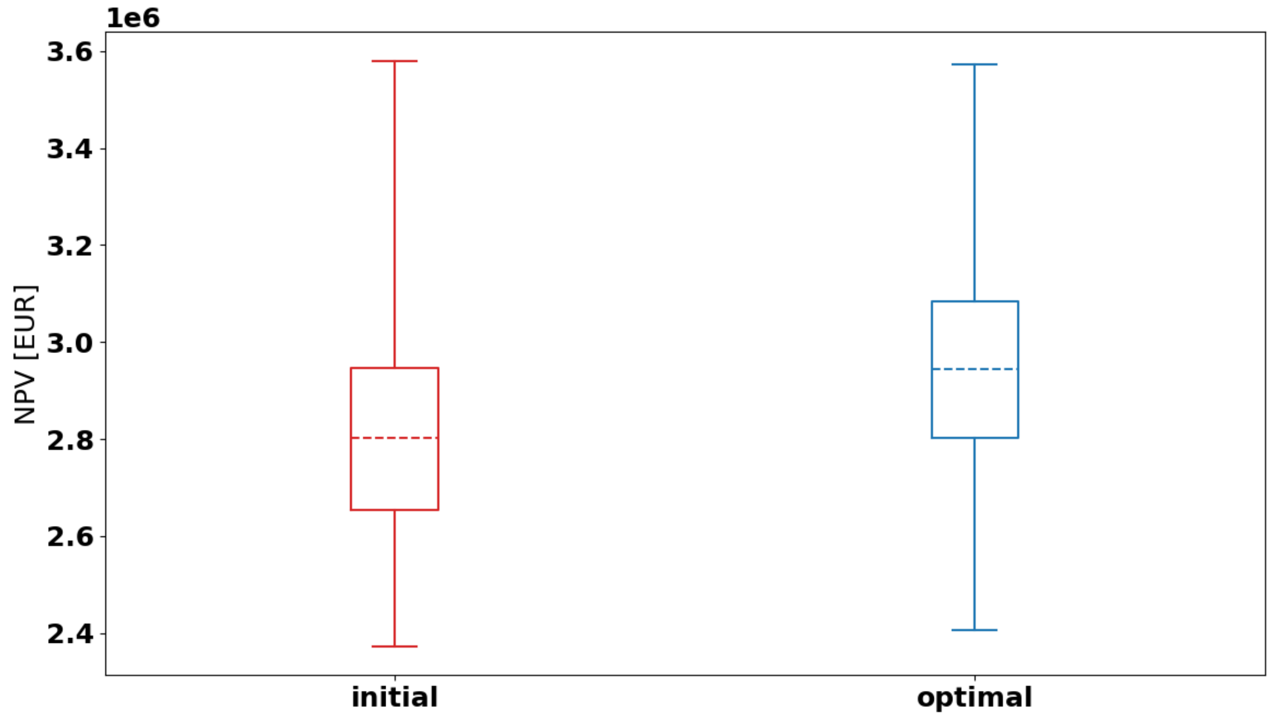
100 geological realizations

Koekoekspolder case: NPV

- Improvement in NPV values of about 0.15 million EUR after 9 iterations.
- All shape and fault stress constraints are satisfied in optimal scenario
- Similar uncertainty range for initial and optimal solutions, however improved worst case scenario.

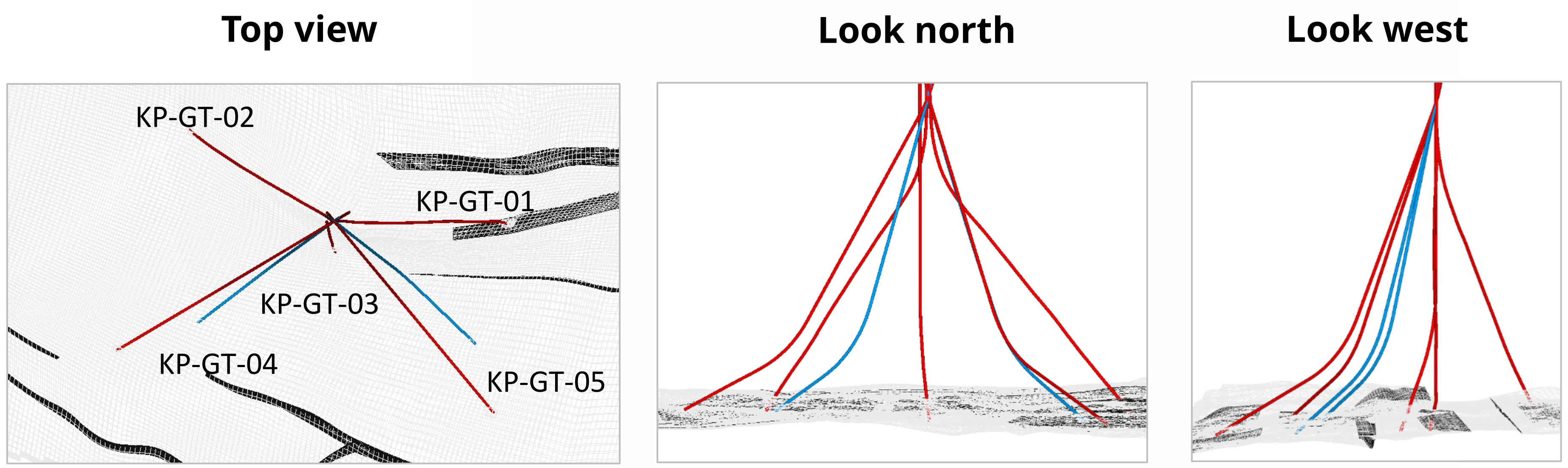


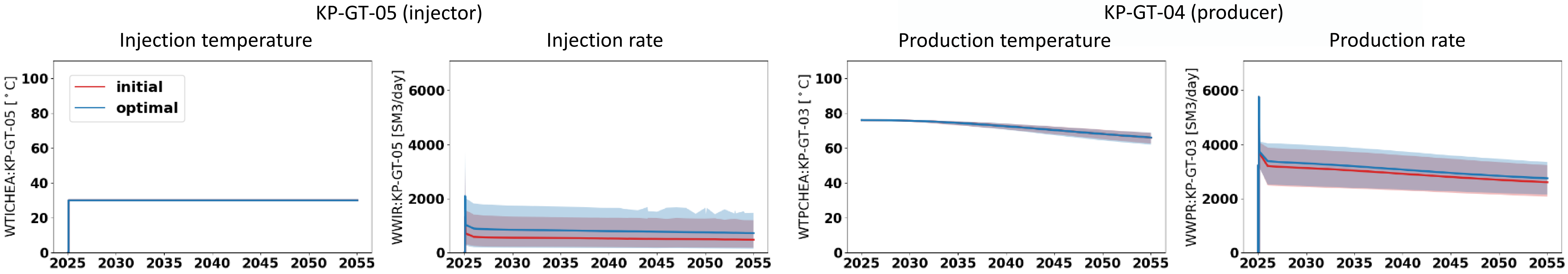




Koekoekspolder case: well locations and trajectories

- Trajectories of KP-GT-02 and KP-GT-03 are fixed while wells KP-GT-04 and KP-GT-05 are optimized.
- Both wells moved towards central drilling location.
- In optimal scenario KP-GT-04 produces at higher rate while KP-GT-03's production is slightly lower.
- The overall increase in well rate balances out a slight earlier cold-water breakthrough in KP-GT-04.





innovatieprogramma
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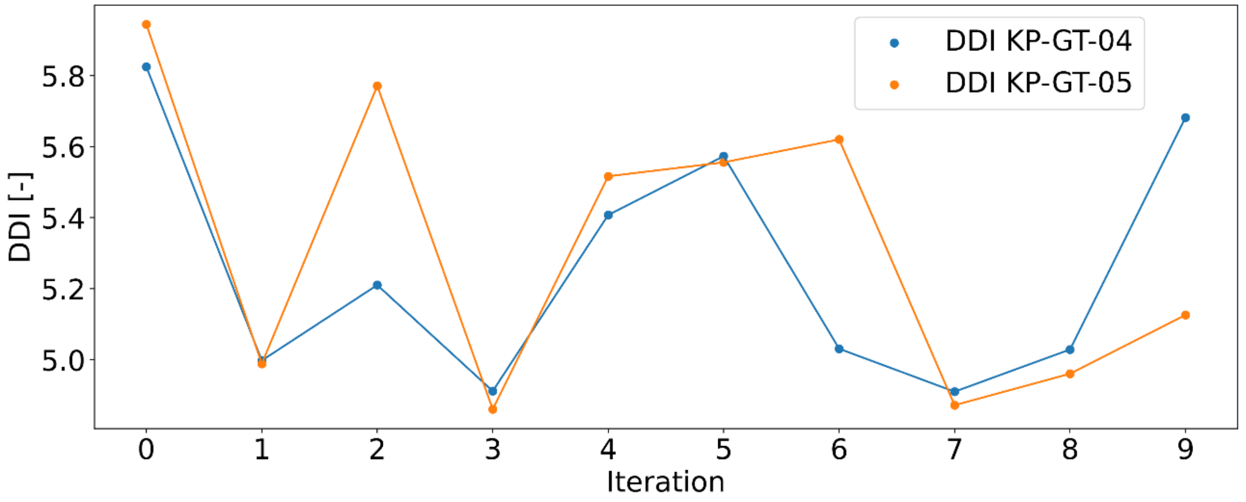
Koekoekspolder case: key constraints

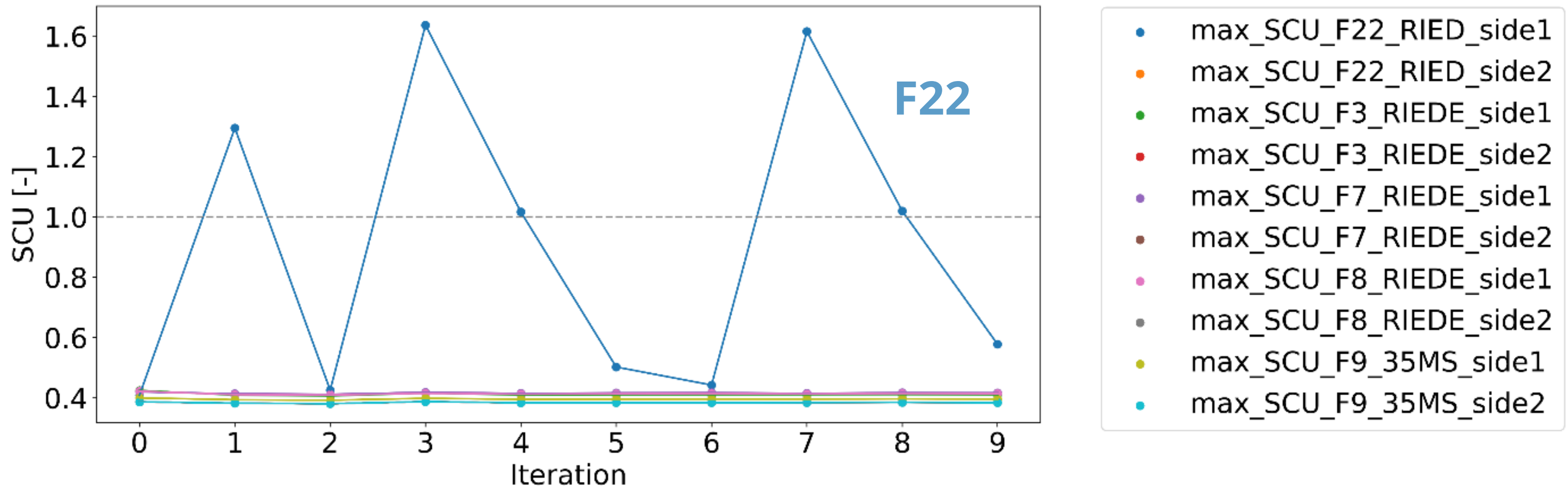
Drilling difficulty (DDI) reduced and < 6
therefore more simple well profiles

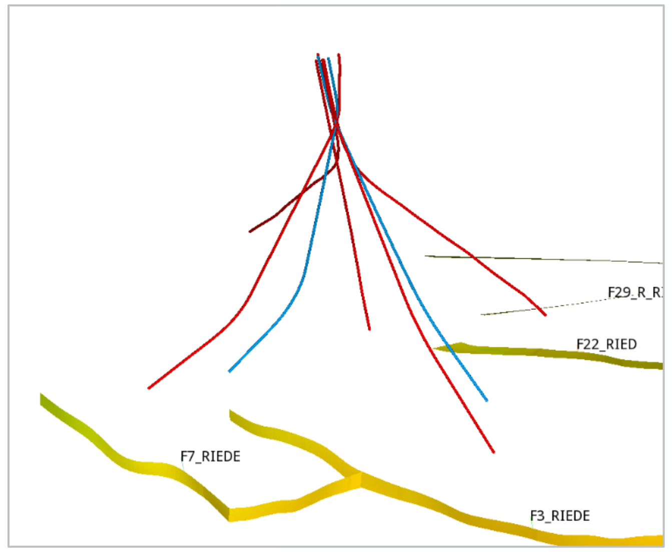


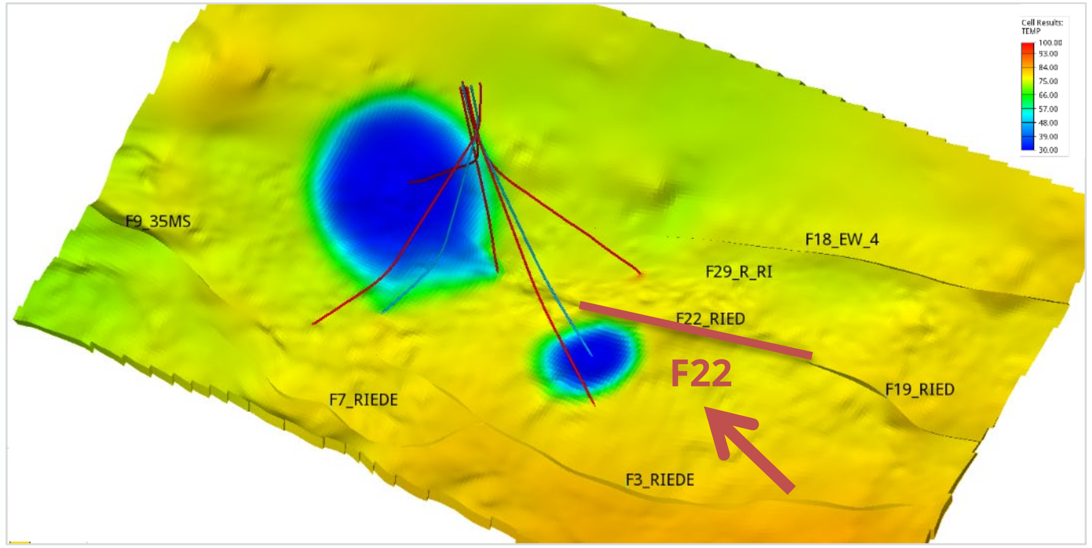
Difficulty	Well Type	Proposed Modifier
Less than 6	Relatively short wells. Simple profiles with low tortuosity	minus 10%
6.0 to 6.4	Either shorter wells with high tortuosity or longer wells with lower tortuosity	0
6.4 to 6.8	Longer wells with relatively tortuous well paths	plus 5%
Greater than 6.8	Long tortuous well profiles with a high degree of difficulty	plus 10%

Alistair W. Oag 2000, SPE 59196

Optimal solution guided to satisfy **stress change indicator** (SCU) below 1 at fault **F22**.







Geo4all
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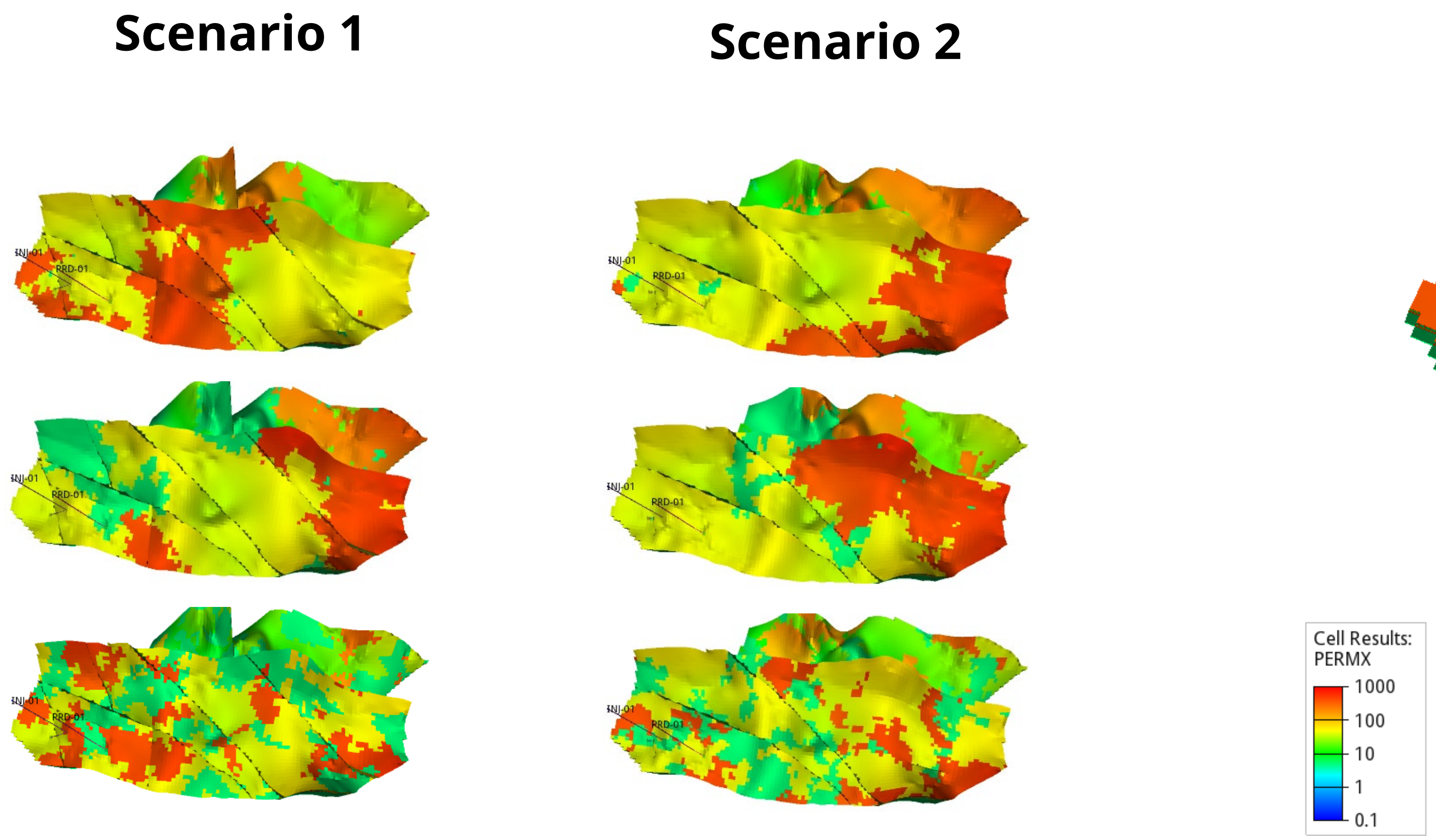
Amsterdam case

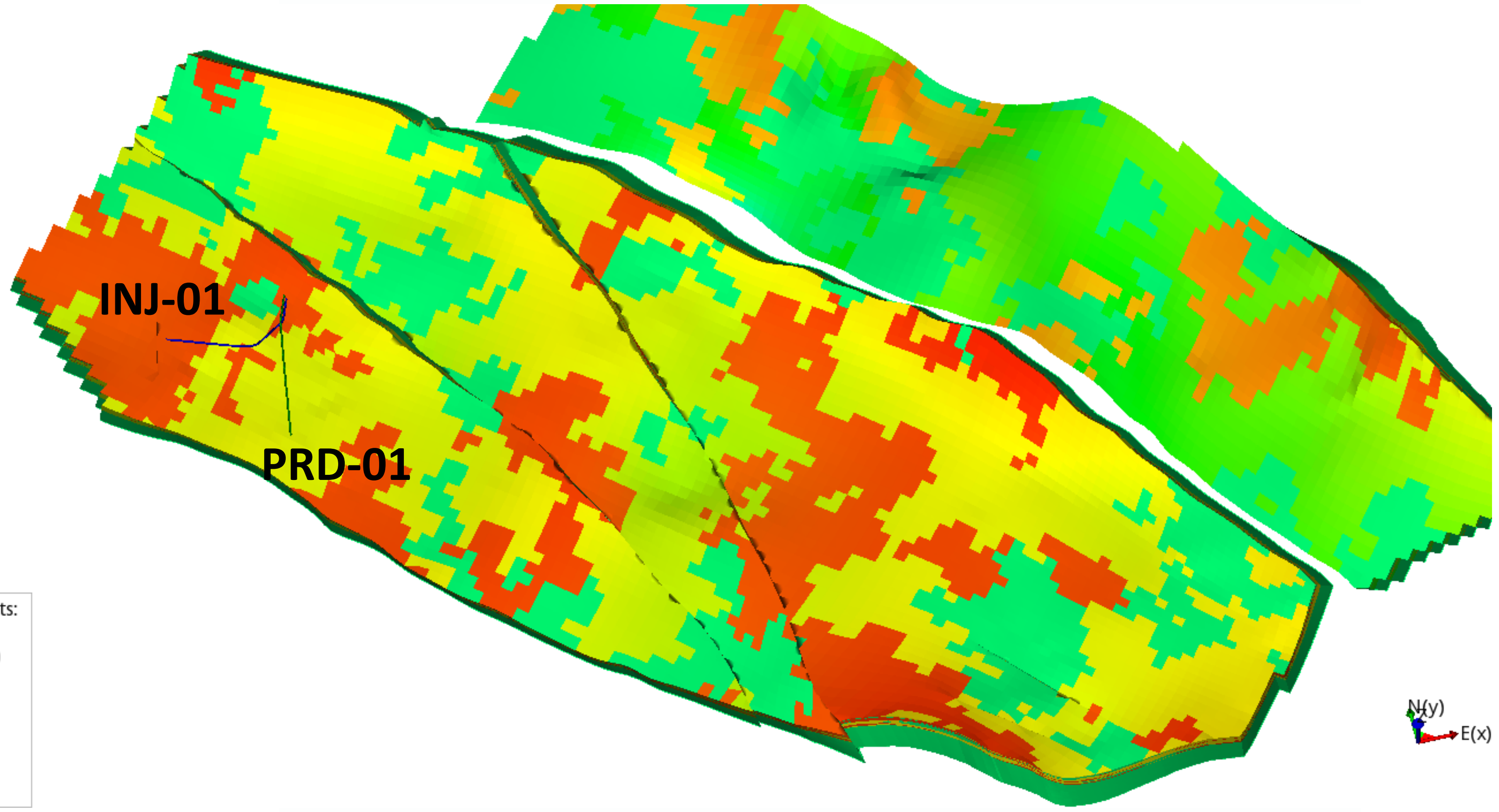
Amsterdam case: geological uncertainty

- Structural Modelling
  - Limited 2D seismic line density prevented reliable fault interpretation.
  - Expected fault density (based on analogue fields with 3D seismic) possibly higher.
  - Anticipating improved insights from upcoming 3D data, two structural scenarios:
    - Scenario 1: Conservative fault interpolation
    - Scenario 2: Hypothetical faults – increased effect of compartmentalisation

- Property Modelling
  - Petrophysical analysis ongoing, led by developer
  - Facies continuity uncertain; conceptual modelling out of scope
  - Used CNB porosity–depth–permeability trends
  - Facies modelling 3 types: dune base, slip face, sand flat, based on core interpretation
  - Dune base continuity varied (low–med–high) in three sets of realizations



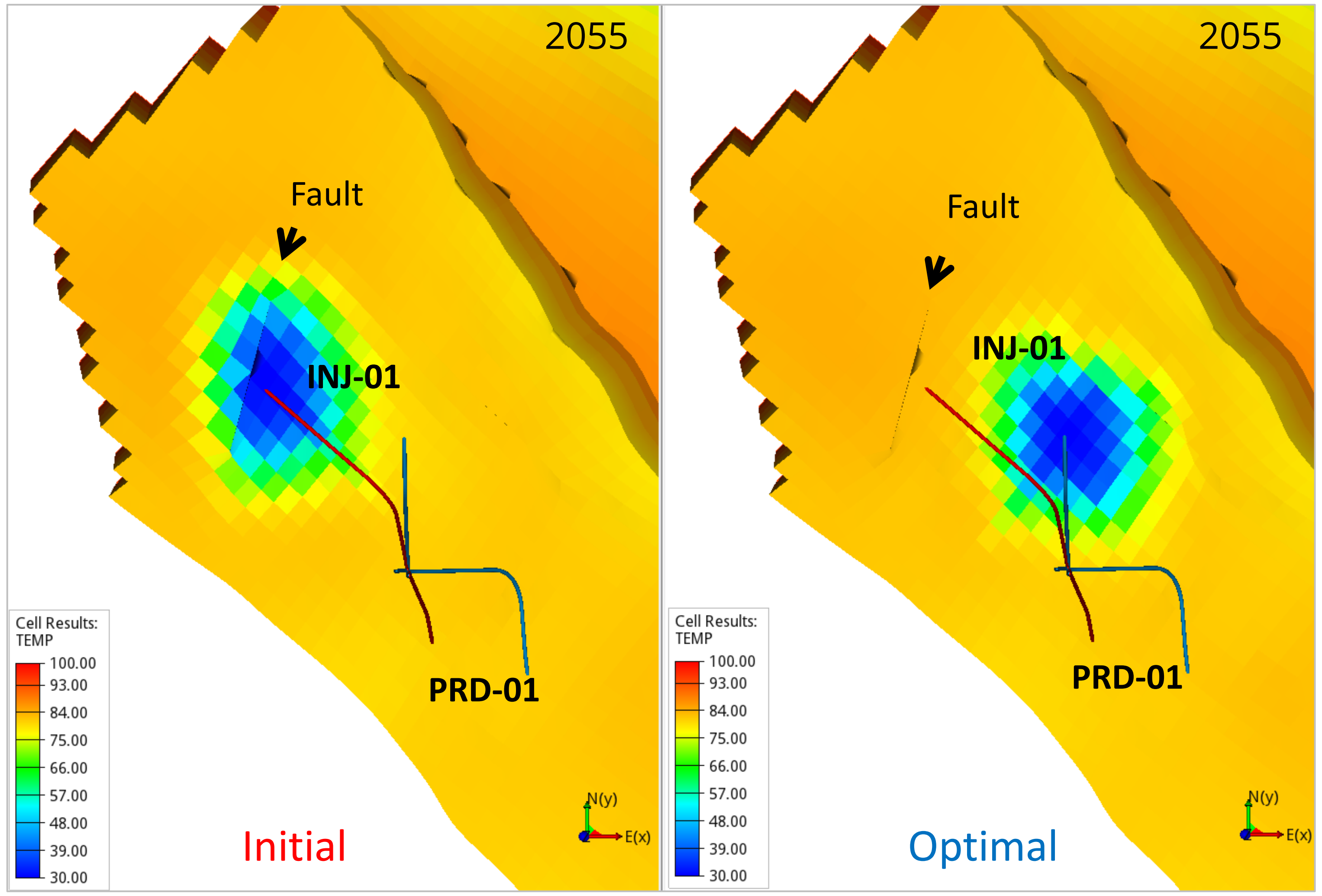
Total of 90 realizations

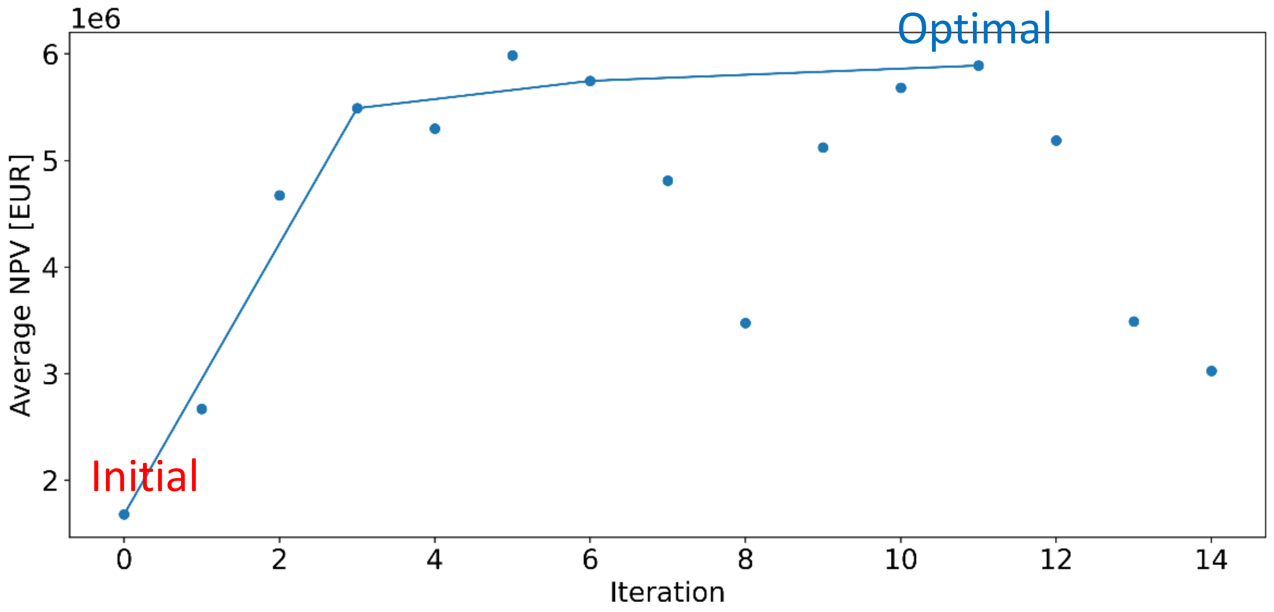


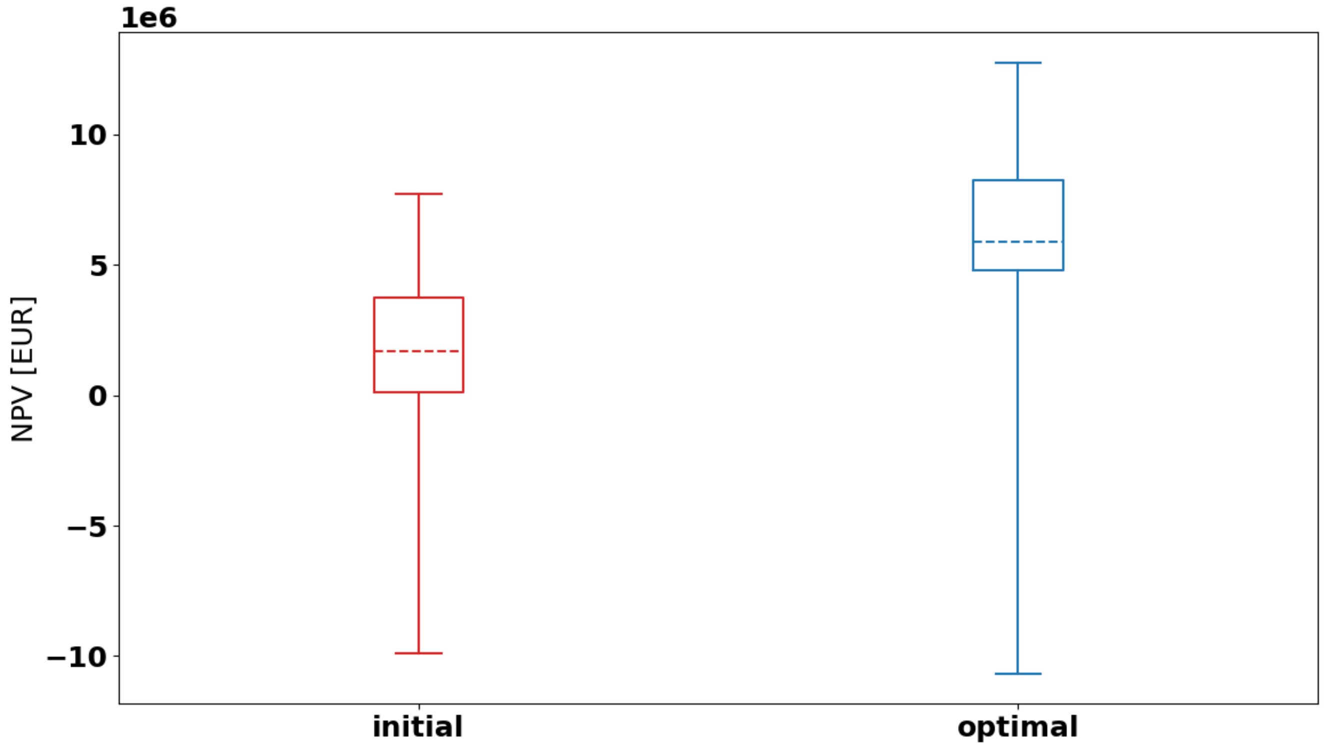
Initial trajectories for a doublet

Amsterdam case: NPV

- Significant improvement average NPV over several iterations (about 4 million EUR).
- Majority of models improved (see read and blue boxes representing values in between 25th and 75th quantiles).
- Unlike in KKP case, here the worse case scenario was not improved (it wasn't asked of optimization).



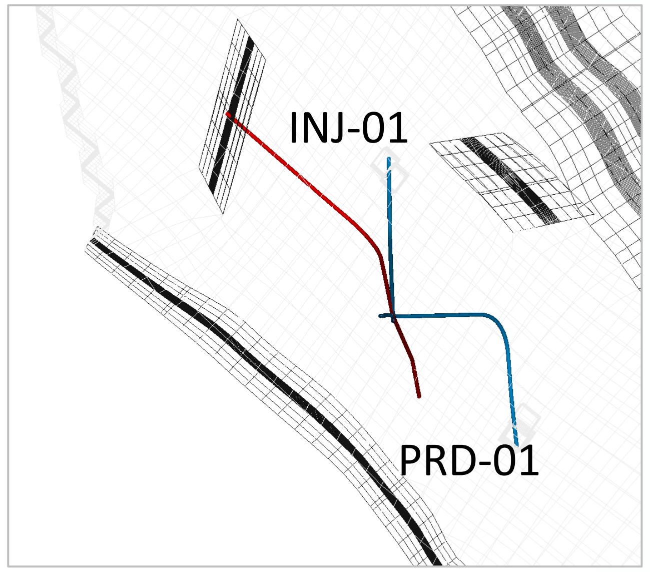




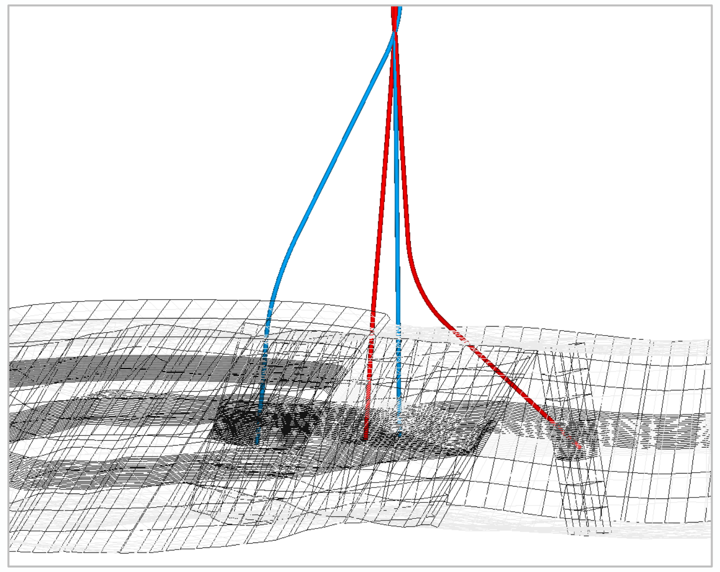
Amsterdam case: well location and trajectories

- Injector moved away from the fault. Producer placed further from injector, likely to prevent earlier cold-water breakthrough but also to increase production rate.
- Despite shorter injector the optimal well trajectories can produce at a higher rate.
- There is no cold-water breakthrough in the producer – optimal well distance.

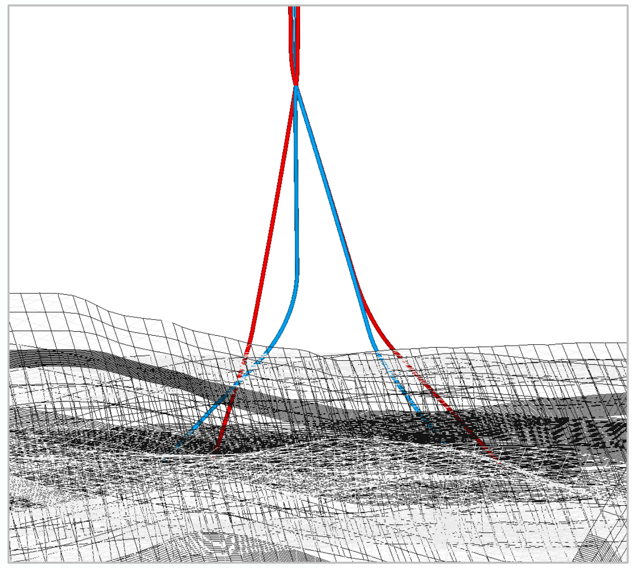
Top view



Look south

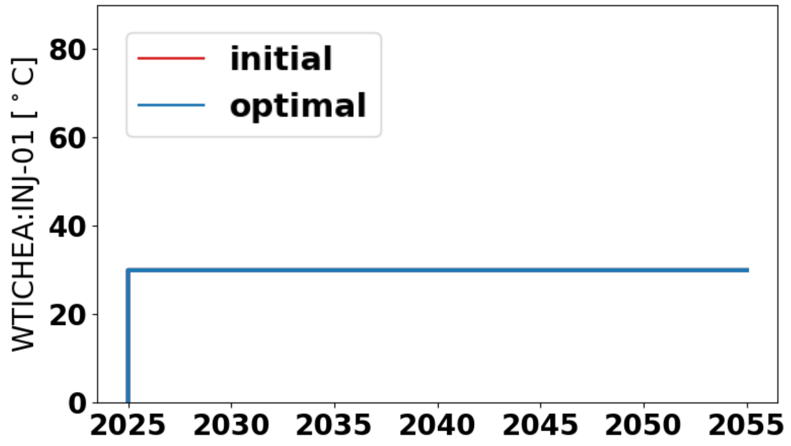


Look west

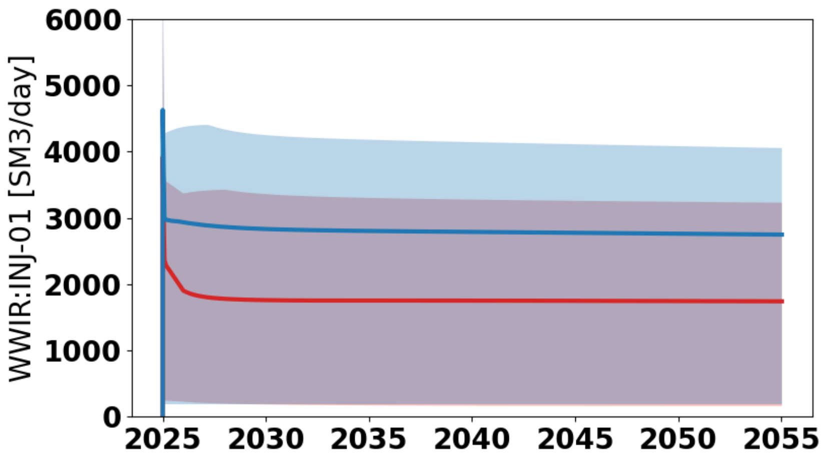


INJ-01

Injection temperature

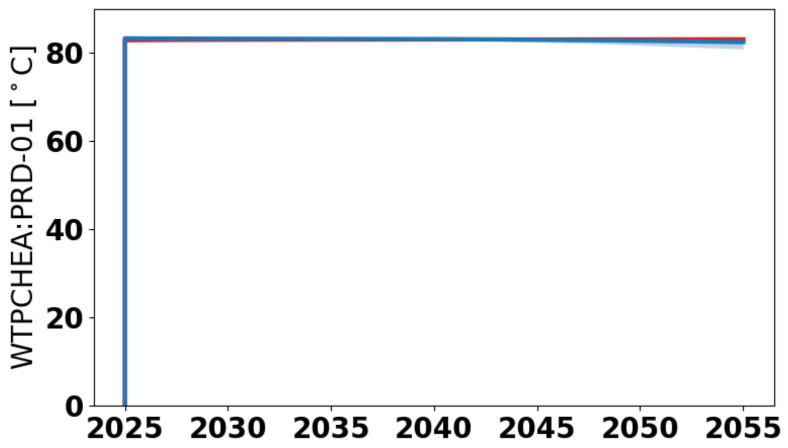


Injection rate

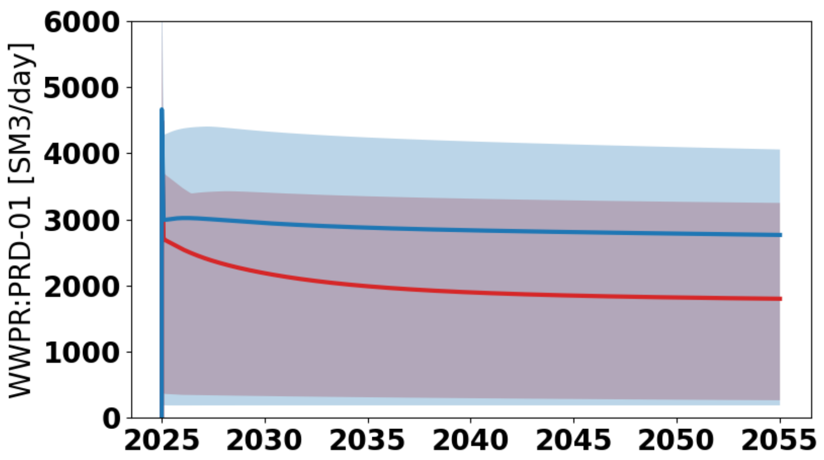


PRD-01

Production temperature



Production rate



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Amsterdam case: key constraints

Drilling difficulty (DDI) reduced and < 6 therefore
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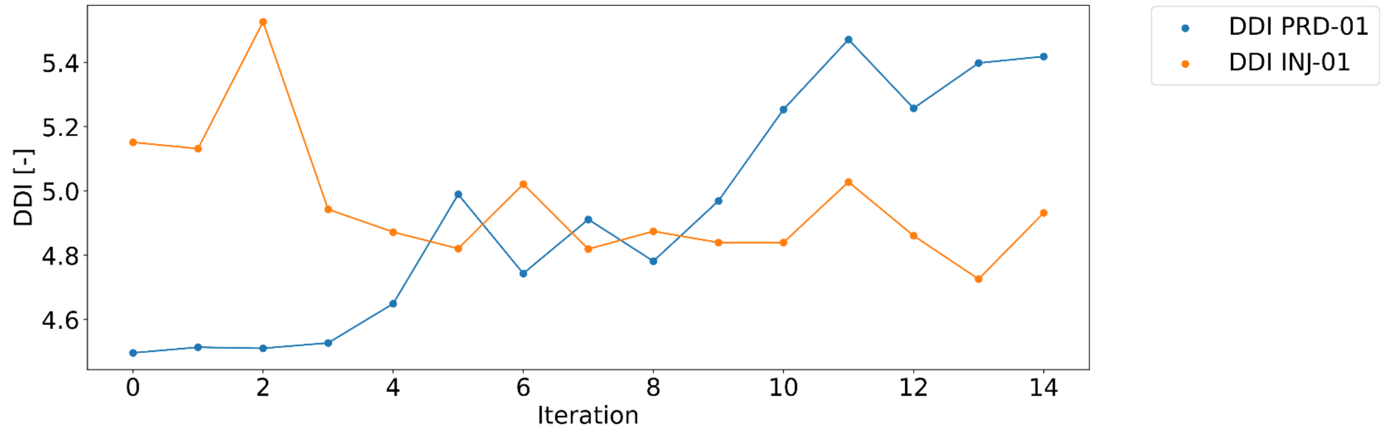
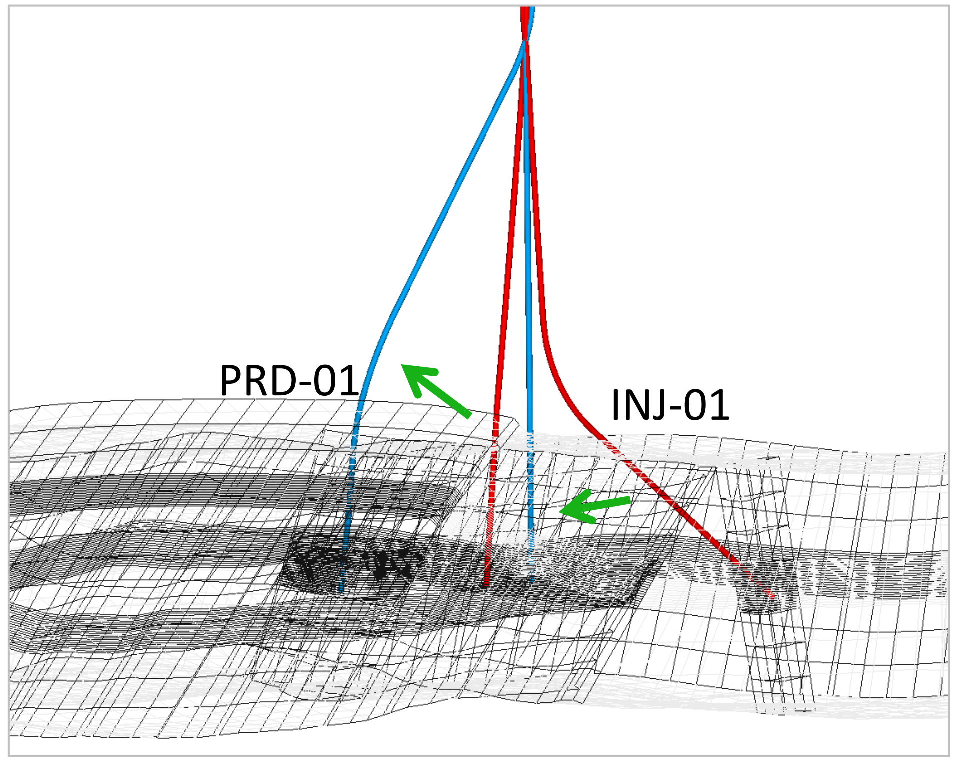
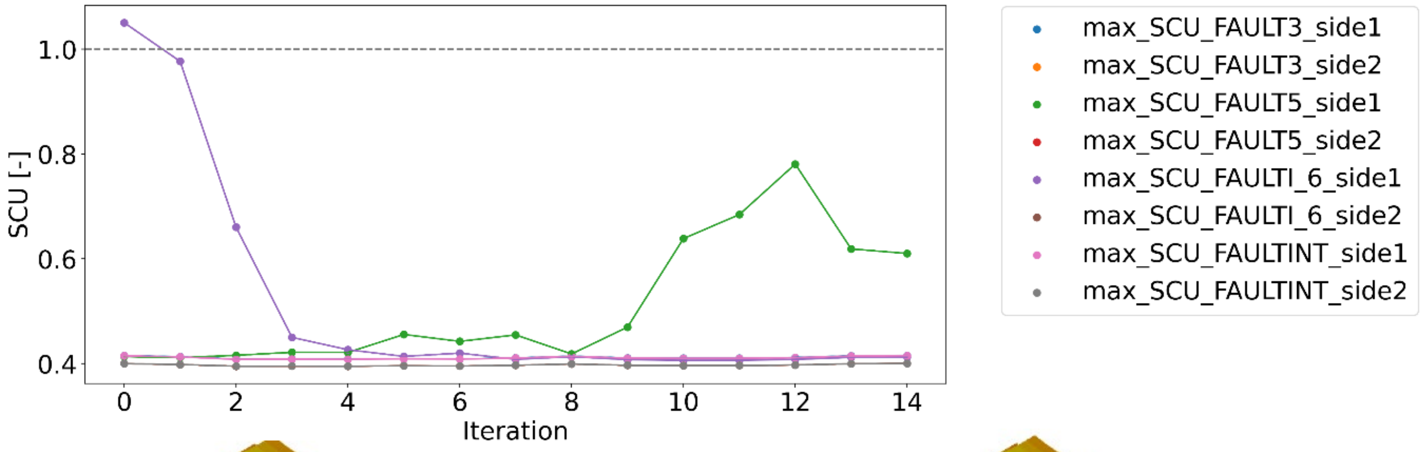
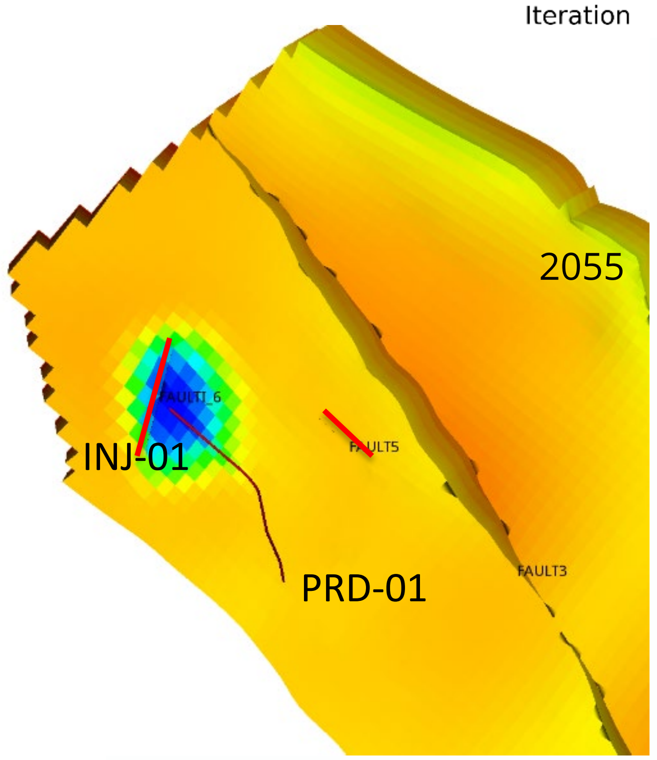


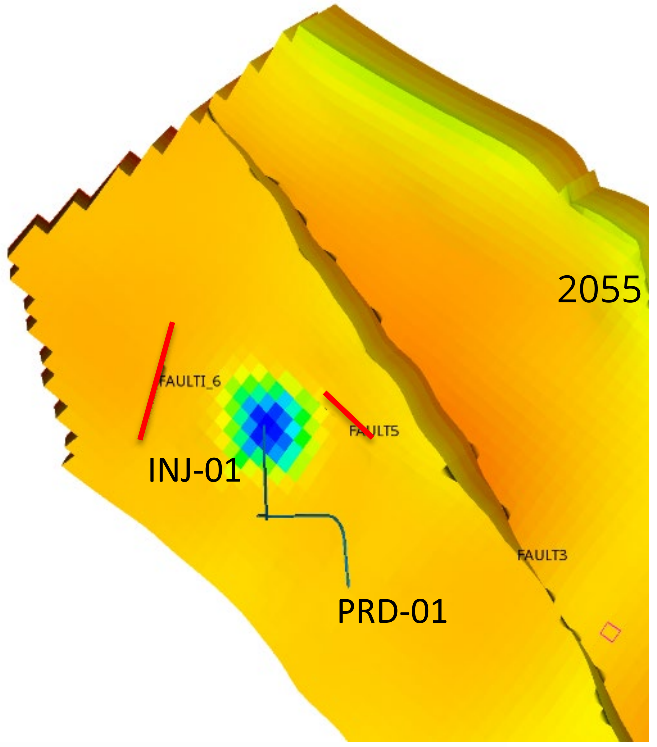


Stress change constraints violated for initial well trajectories at fault FAULTI_6.
No stress change constraint violated for optimal well trajectories.





Initial



Optimal

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Luttelgeest ACL case

WP2 Luttelgeest ACL case
Considered alternatives

- **Context:**
  - Luttelgeest geothermal activities involve two sites: ACL and Hoogweg
  - ACL (focus of this work) has 3 existing wells: one producer (LTG-GT-04) and two injectors (LTG-GT-05 and LTG-GT-06)
    - LTG-GT-06 has been a difficult well, thinner formation, low injectivity in practice
    - ACL is seeking help to improve the performance of that well
    - Drilling a new injector is also an alternative considered

- **5 scenarios modelled and compared by TNO:**
  - **Case 1**: as provided current situation (without new injector)
  - **Case 2**: fishbones in LTG-GT-06
  - **Case 3**: hydraulic fractures in LTG-GT-06
  - **Case 4**: sidetrack in LTG-GT-06
  - **Case 5**: replacing LTG-GT-06 by new injector

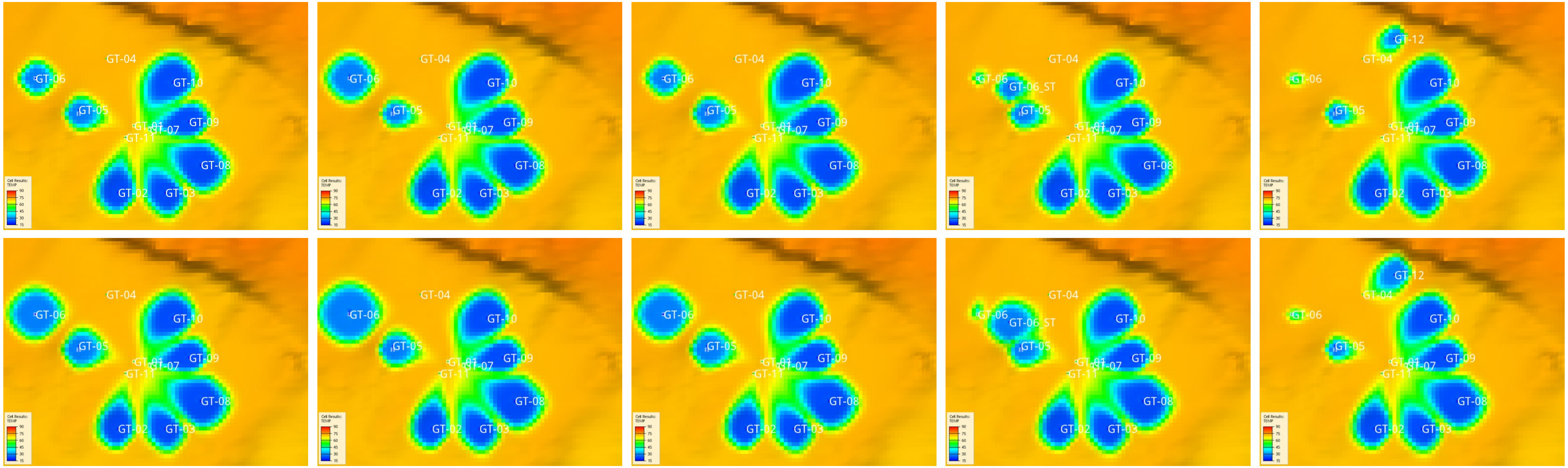
- All 5 cases have been considered **with** and **without** skin factors
  - Estimated and reported by IF Technology
- Note: **no pressure data was made available**, and that limits what can be quantified
  - Typical bottom-hole pressure (BHP) limits have been assumed

WP2 Luttelgeest ACL case: temperature

Case 1: as provided current situation (without LTG-GT-12) | **Case 2**: fishbones in LTG-GT-06 | **Case 3**: hydraulic fractures in LTG-GT-06 | **Case 4**: sidetrack in LTG-GT-06 | **Case 5**: replacing LTG-GT-06 by new injector LTG-GT-12

Without skin factors

With skin factors



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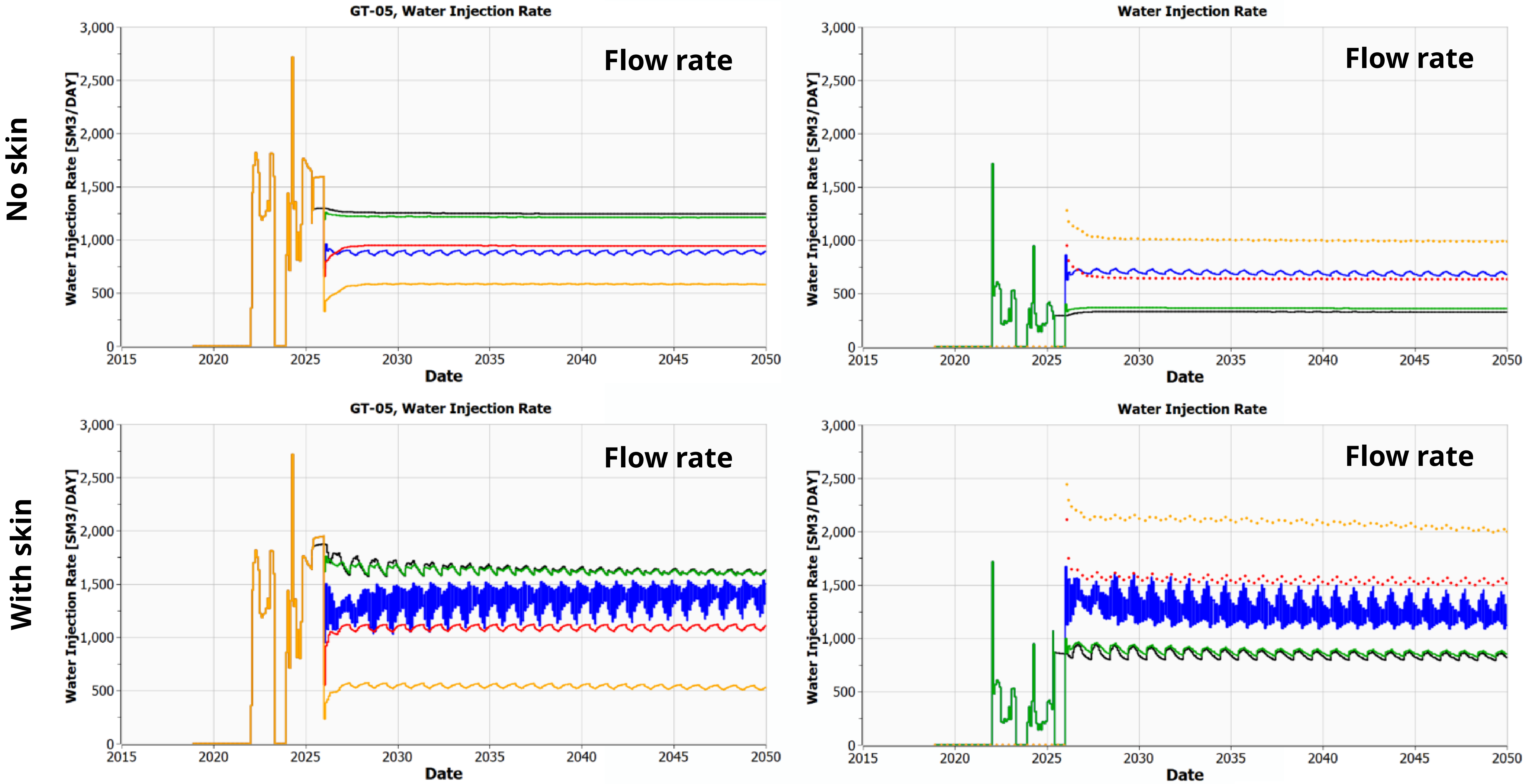
WP2 Luttelgeest ACL case

- Estimated skin factor reported by IF Technology has a significant impact on productivity potential of LTG-GT-04
- When no skin factor is considered, variations of LTG-GT-06:
  - Show little impact in heat production of LTG-GT-04
  - Affect injection flow rate of LTG-GT-05
- When skin factors are considered, variations of LTG-GT-06:
  - Impact both flow rates and temperature profile of LTG-GT-04
  - Affect even more injection flow rate of LTG-GT-05

LTG-GT-05 (injector) **LTG-GT-06** (injector)



ACL_1 ACL_2 ACL_3 ACL_4 ACL_5

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WP2 Luttelgeest ACL case
Initial conclusions

- Observations:
  - IF Technology report indicates target flow rates per well for forecast period
    - Currently prescribed flow rate controls in reservoir simulator without information about existing pressure limits
    - Therefore, choice was made by using the group control logic based on full re-injection of produced volumes

- More analysis still possible for this case, for now:
  - First conclusions point to: **Case 5 (new injector)** > **Case 4 (sidetrack)** > **Case 2 (fishbones)** are better than **Case 1 (current situation)**
  - **Case 3 (hydraulic fractures)** does not seem to improve much the situation
  - However, economic calculations are needed to determine if observed improvements (Cases 5 > 4 > 2) are worth additional costs

Thank you

WP2 Team:

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- WellPerform: Akram Miriyev, Niels Frinks
- HVC: Charlotte de Wijkerslooth, Cees Willems
- Gem. Amsterdam: Esmée Waardenburg
- Gem. Almere: Sabrine Strijbos
- Vattenfall: Ivo Vos
- Aardwarmte Combinatie Luttelgeest (ACL): Gerard Fuite
- IF-Technology: Nick Buik
- Greenhousegeopower (Aardwarmtecluster): Radboud Vorage
- EBN: Felix Bexkens, Nora Heijnen
- Canopus Drilling Solutions: Pieter van Nieuwkoop (Jeanet Schouten)

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