Geothermal Resource Group
TAPPING THE EARTH'S ENERGY

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Date: 1/6/2023

To: Lightning Dock Geothermal

From: Richard Holt

**Re: Numerical Model Adjustments and Scenario L - Final**

## Summary

Geothermal Resource Group (GRG) updated the existing numerical model with information from deep well 17B-7, which required the inclusion of a new fault and a higher background temperature gradient in the model. Scenario L was run which considers deepening well 17-7 to 8000 feet and producing it, while continuing to produce 45-7, and discontinuing use of 45A-7. Scenario L, run at 5500 gpm of production showed an immediate increase in plant inlet temperature that sustained for 20 years.

## Model Update

This briefly outlines adjustments to the Lightning Dock Geothermal (LDG) numerical model that incorporates new data and conceptual elements obtained from the drilling of 17B-7. The updated model was then used to forecast production temperature using the configuration of Scenario L.

New well 17B-7 is a deep well (more than 12,000 feet deep) drilled below existing well 17-7 (which is approximately 6200 feet deep). Well 17-7 has low permeability and low temperature. During the drilling of 17B-7, at a depth of approximately 8000 feet, well 17B-7 encountered total loss of circulation (indicating high permeability) with an estimated temperature of 315°F(157°C). In an initial modeling attempt, well 17-7 was deepened in the existing model and production was simulated. The location in the model contained both low temperature and low permeability and was unable to support production. Thus, the numerical model needed to be updated for both distribution of permeability and temperature.

Cyrq provided an updated conceptual model which is shown in Figure 1 (a cross-section approximately from 17-pad to 45-pad). In Cyrq's updated conceptual model a new deep fault is positioned below 17-7 with temperature of approximately 315 °C (157°C) at a depth of 8000 feet. Figure 2 shows the numerical model's permeability and temperature on a similar cross-section as Figure 1. The old model needed updating because, as shown in Figure 2, well 17-7 (when deepened to 8000 feet) would reach low permeability and only encounter relatively low temperature (model ver5-L90). The following adjustments were made to the existing model (the updated model is shown in Figure 3):

- New data (from well 17B-7) indicated that the "background" temperature gradient away from the central field area is higher than was in the previous model. The bottom of the previous version model (at -1700 mRSL, depth 3000m) was a "hot plate" at 120°C, which is a constant temperature boundary. After several iterations, it was found that increasing this bottom boundary to 165°C, results in a temperature of 157°C at a depth approximately 8000 feet, which provides a reasonable match to preliminary temperatures data from 17B-7.

- New data (from well 17B-7) indicated that the well intersected a high permeability fault at a depth of approximately 8000 feet. This fault segment was incorporated into the existing model as rigorously as possible without completely rebuilding the model. At the start of the update, it was unknown whether these two changes (higher temperature on bottom and a new fault) would negatively affect the model's natural state and history match calibrations. The temperature and permeability updates did not significantly affect the natural state and production history matches. Therefore, the modeling could proceed to forecasts.

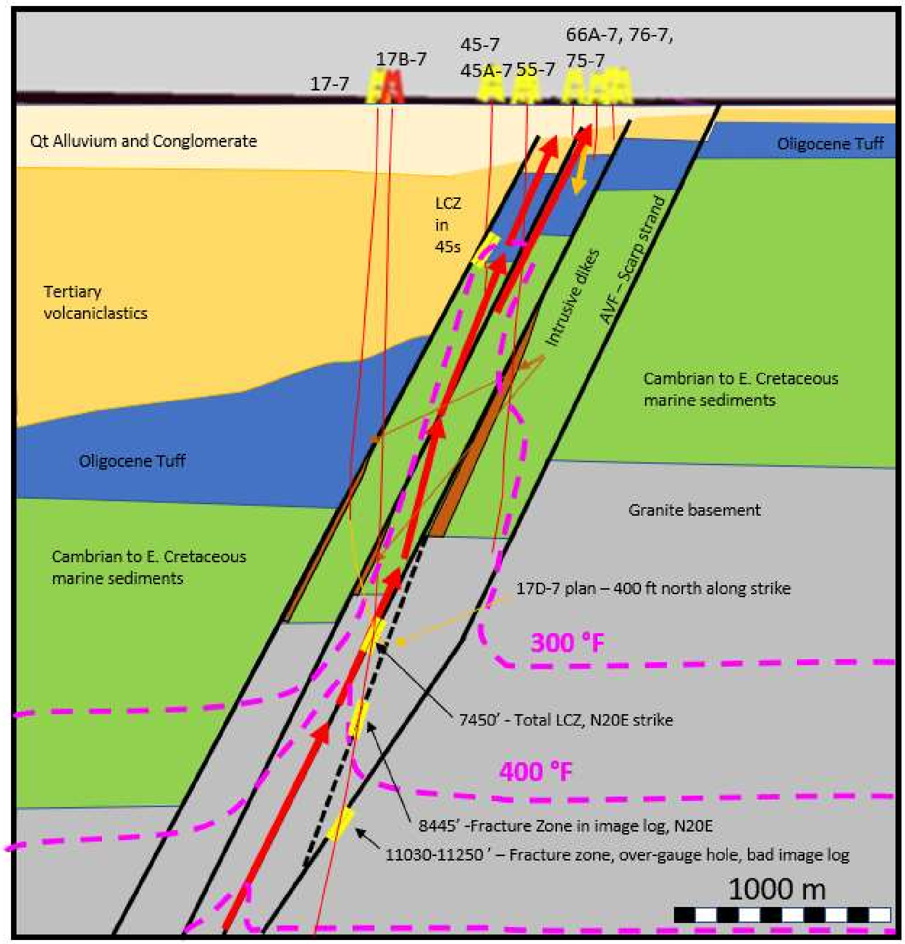


Figure 1: New updated conceptual model by Cyrq Energy

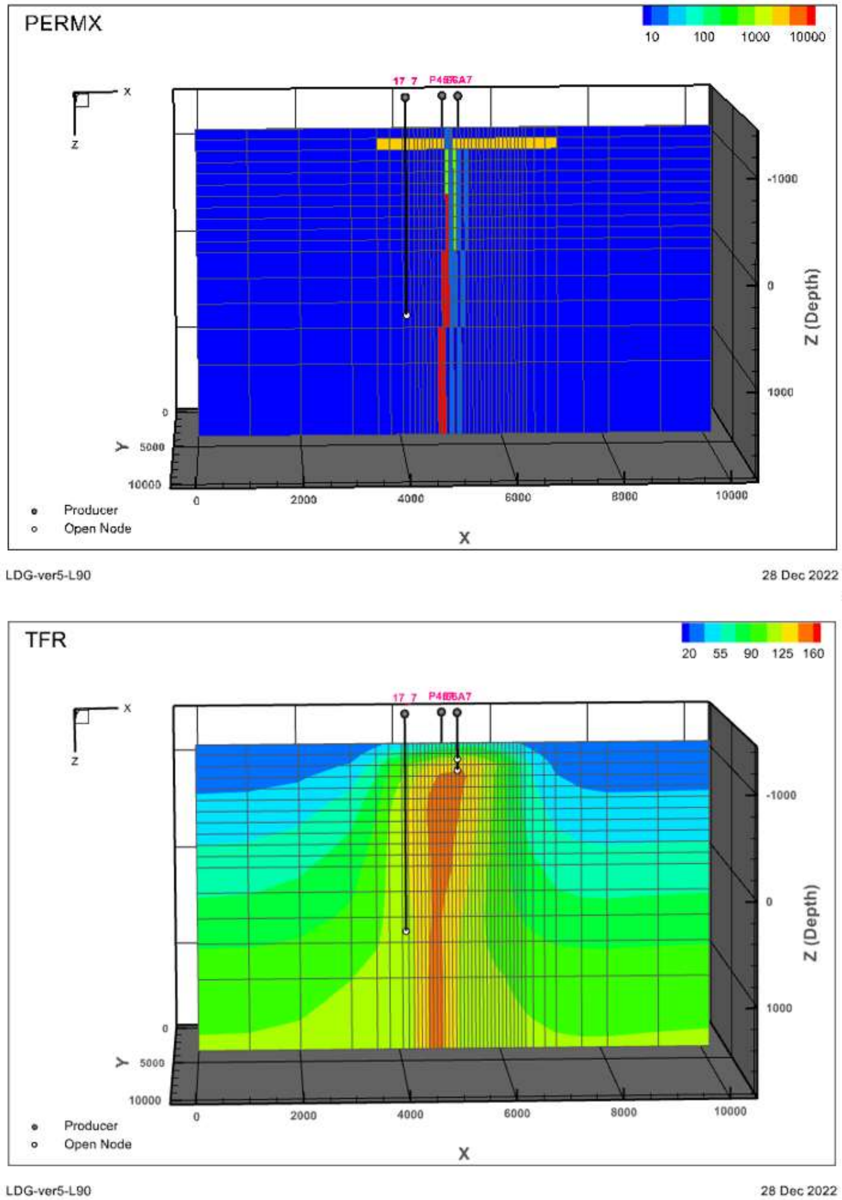


Figure 2: Old model before updating, showing 17-7 reaching low permeability and low temperature (model ver5-L90)

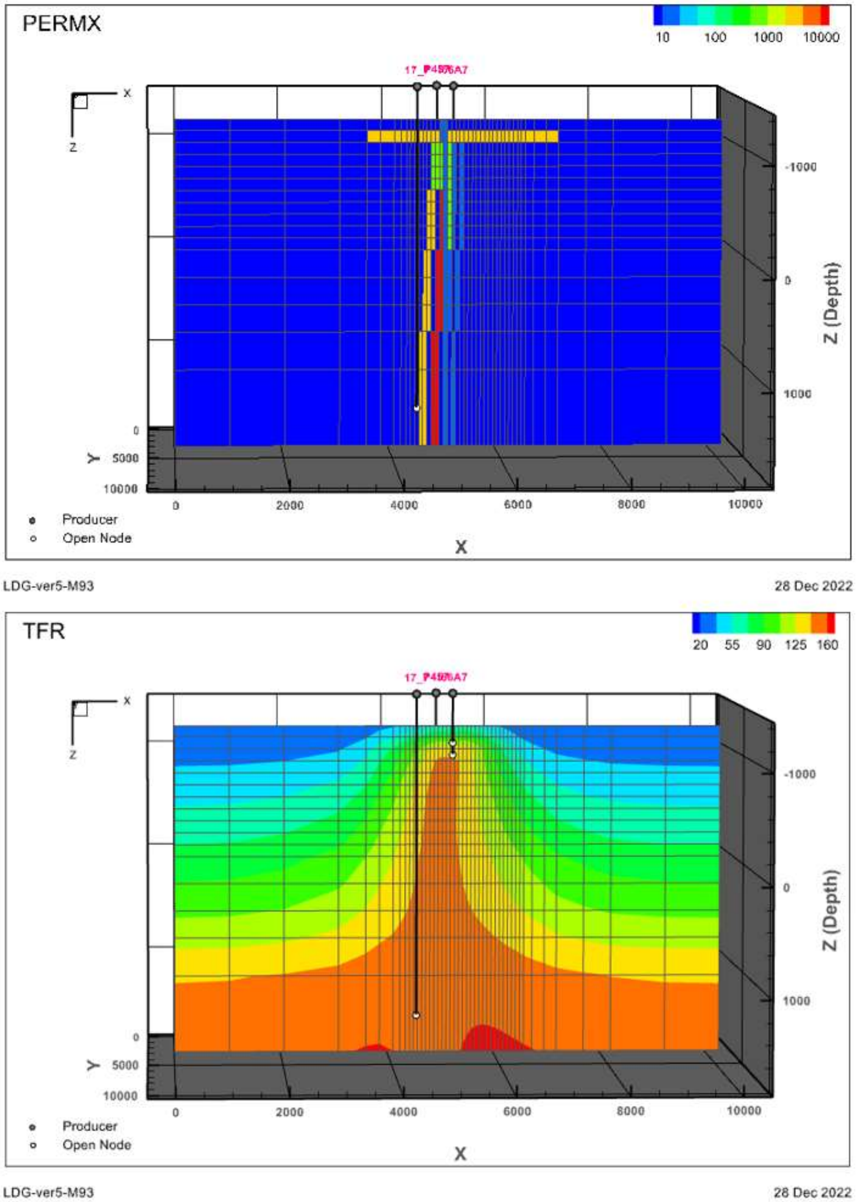


Figure 3: Updated model showing a deepened 17-7 well reaching high permeability in a new fault (orange material) and high temperature of 157°C (model ver5-M93)

## Forecast Scenario L

The updated numerical model was used to make forecast Scenario L. This scenario supposes 5500 gpm total production including a deepened 17-7 well, in the following configuration:

- Scenario L Production: Deepen 17-7 to 8000 feet and produce at 3000 gpm with a starting temperature of 315°F(157°C), which is consistent with the findings of 17B-7. Produce well 45-7 at 2500 gpm and shut-in and P&A well 45A-7.

- Scenario L Injection: Spread injection among existing injection wells without a booster pump with the following allocation: 53-7(365 gpm), 13-7(590 gpm), 75-7(1600 gpm), 76-7(365 gpm), 66A-7(1600 gpm), and 32-18(700 gpm)

For comparison purposes, Scenario L above is compared to a Base Case scenario at 5050 gpm production that supposes no drilling, using 45-7 and 45A-7 for production, and employing a booster pump to utilize the existing injection wells including deep injection.

- Base Case Production: No drilling, use existing wells. Produce 45-7 and 45A-7 each at 2525 gpm for a total of 5050 gpm.
- Base Case Injection: No drilling, use existing wells with booster pump to direct injection deep (into 17-7 and 32-18) as much as possible with the following allocation: 53-7(498 gpm), 13-7(493 gpm), 75-7(1494 gpm), 76-7(283 gpm), 66A-7(925 gpm), 17A-7(15 gpm), 17-7(797 gpm), and 32-18(299 gpm).

Figures 4 and 5 show the simulated forecasts for production flow rates and production temperature, respectively.

## Discussion of 45-7

There is an acceleration of 45-7's cooling in Scenario L. First it should be noted that the base case is the booster pump base case with deep injection into 17-7. In the model, this has a positive effect, with less predicted cooling. If the shallow injection, no booster pump base case scenario was used as the base case, the difference wouldn't be as pronounced. Besides the choice of base case, there are likely other reasons for 45-7 accelerated cooling in Scenario L.

Scenario L supposed production of 2500 gpm from 45-7 (relatively shallow) and 3000 gpm from a hypothetical deepened 17-7. In Scenario L, nearly all the injection (except for injection to 32-18) goes into the shallow injection wells, causing a large excess of shallow injection compared to shallow production. Previous scenarios have shown that with 45-7 and 45A-7 online producing 5000 gpm, removing 1000 gpm of shallow injection results in less forecasted cooling. Though the scenario has not been run, by logical extension it could be expected that excess shallow injection (compared to shallow production) could cause increased cooling. Further, as has been experienced in other geothermal fields, the cold water that *would have gone* to 45A-7 will be produced by the well remaining online. This is likely especially true at LDG due to enhanced vertical permeability put into the model to account for "induced downflow" near or around the 55-7 area that has dominated cooling forecasts for shallow production of 45-7 and 45A-7.

There is a possibility, however, of upside to producing only 45-7, while shutting 45A-7, that is not included in the model. Consider that the "induced downflow" occurred only *after* 45A-7 came online, it is possible, but unfortunately not predictable, that returning to producing 45-7, without 45A-7, will ameliorate, or perhaps cease the induced downflow.

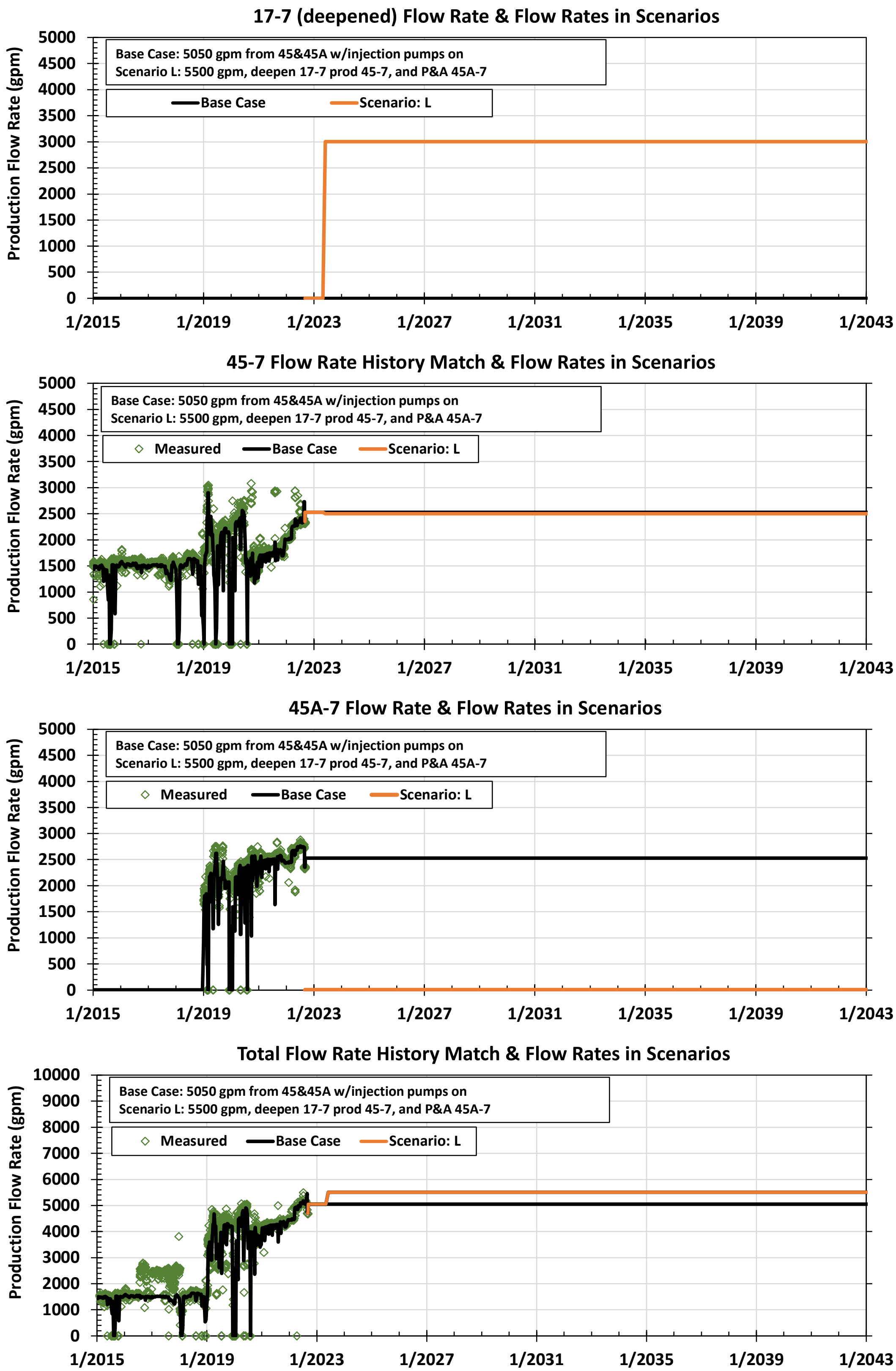


Figure 4: Simulation forecasts production flow rates Base Case and Scenario L

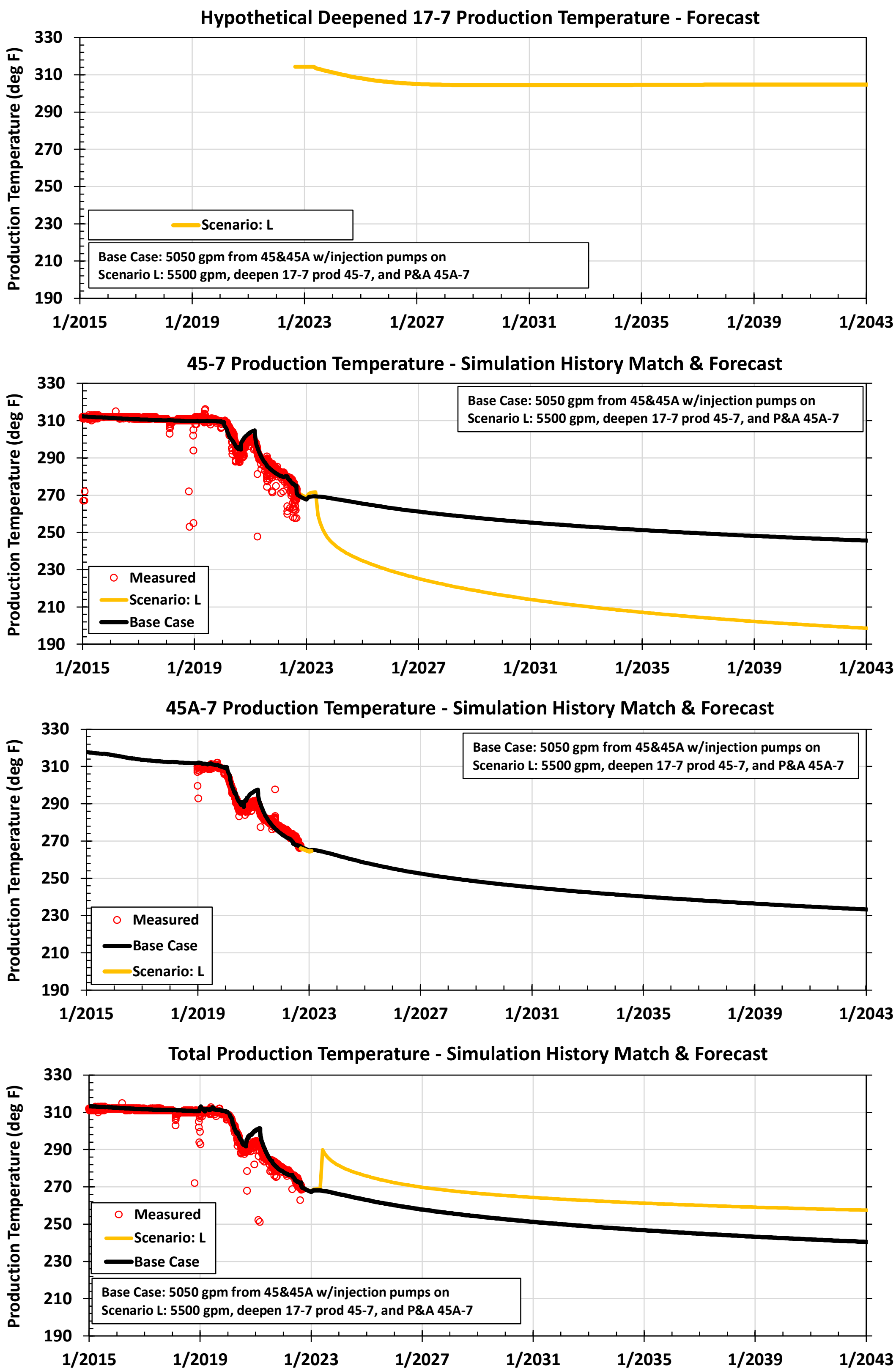


Figure 5: Simulation forecasts production temperatures Base Case and Scenario L