

# Wellbore Simulation to Model Calcite Deposition on the Ngatamariki Geothermal Field, NZ

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## ABSTRACT

Calcite scaling in geothermal production wells is a major cause of decline in many geothermal fields worldwide. Reservoir fluid, saturated with respect to calcite, flows up the wellbore and begins to flash to two-phase. During flashing, dissolved CO<sub>2</sub> migrates into the vapour phase, and calcite in the liquid phase becomes oversaturated. This mechanism has been observed in the Ngatamariki reservoir in New Zealand, and has resulted in production decline in several wells. Anti-scalant injection, mechanical cleaning, and chemical cleaning have all been used to manage wellbore calcite scaling at Ngatamariki.

Previous modelling work on calcite deposition has focused on the geochemical mechanism behind the formation of scale in a wellbore or reservoir formation. Based on this work, wellbore simulation has been used at Ngatamariki to predict the location and extent of deposition in wells to assist clean-out operations, forecast fuel capacity, and manage production wells effectively. This paper aims to summarise the observations at Ngatamariki and describe the methods in which wellbore simulation has helped field operation.

## 1. INTRODUCTION

### 1.1 The Ngatamariki Geothermal Field

The Ngatamariki geothermal field is located in the Taupo Volcanic Zone (TVZ), in the centre of the North Island of New Zealand, shown in Figure 1. An 83 MWe binary power station was commissioned in 2013, with a resource consent to take up to 60,000 t/d of geothermal fluid. The power station is supplied by up to four production wells in the centre of the field (NM5, NM7, NM12, and NM13), and nominally 100% of produced fluid is injected into up to four injection wells (NM6, NM8, NM9, and NM10) to manage pressure drawdown. The reservoir is in a compressed liquid state, with production temperatures of 280-290°C and dilute chloride waters with with gas content less than 0.3wt%, of which ~95% is CO<sub>2</sub>.

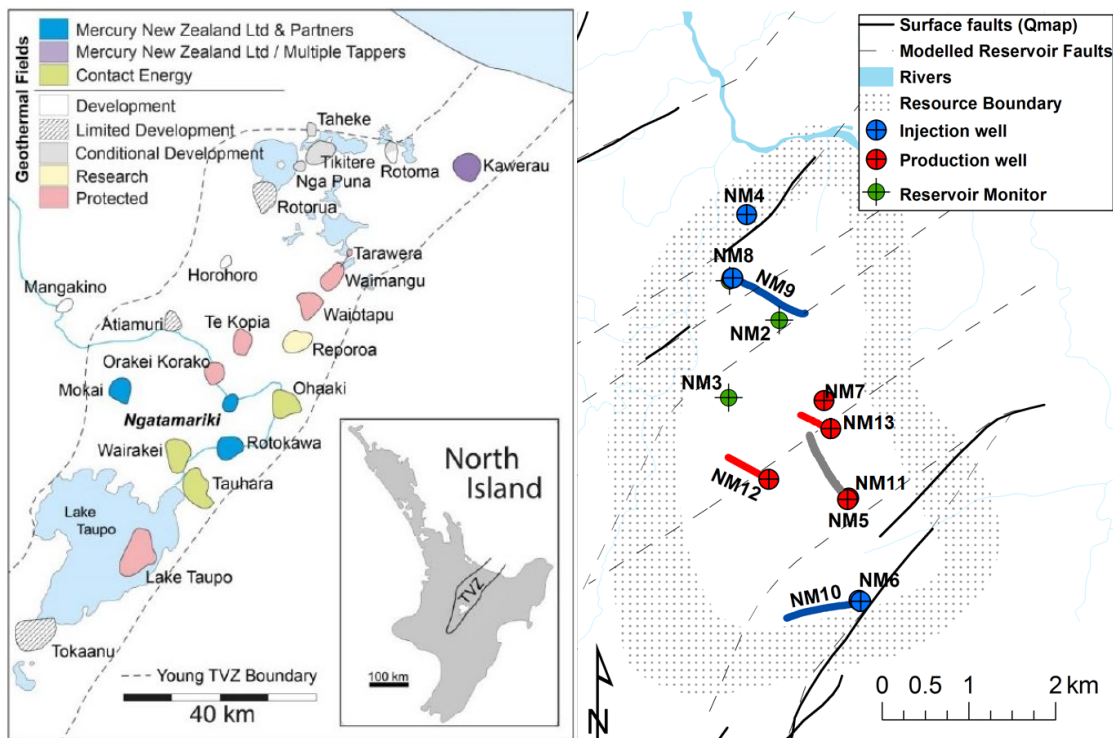
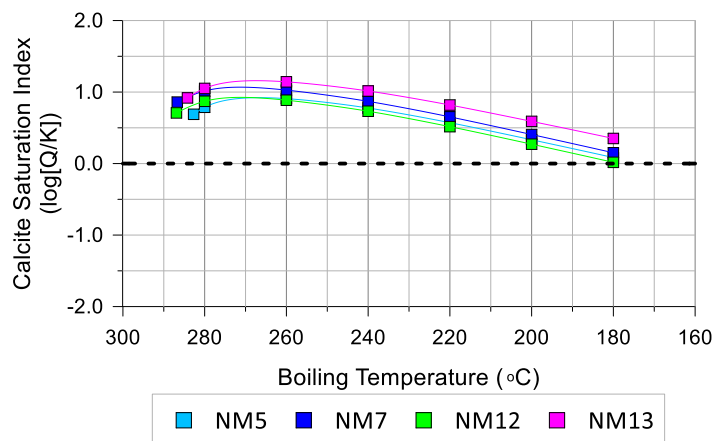


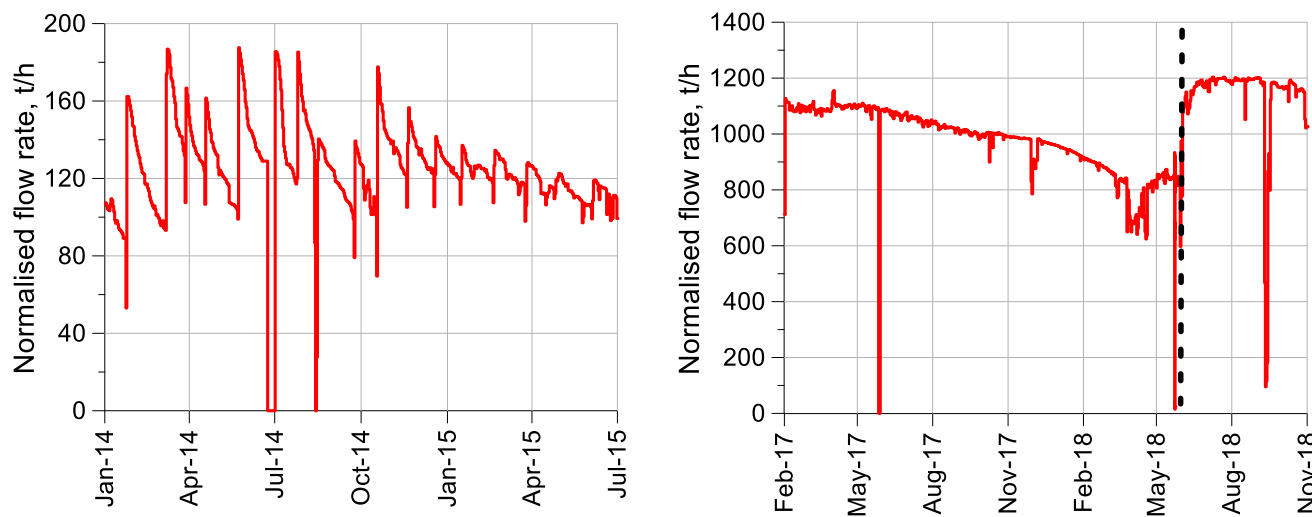
Figure 1. Left: Map of identified geothermal fields in the Taupo Volcanic Zone. Ngatamariki is shown in bold (Bibby, et al., 1995). Right: Layout of Ngatamariki geothermal field (Quinao, et al., 2017).

One of the major challenges faced at Ngatamariki has been production decline due to scaling, predominantly within the wellbore. Of the five production wells used since plant startup, four have had past decline due to scaling. A scale sample recovered from one well was analysed using XRD and found to be pure calcite. All the wells at Ngatamariki show production fluid that is oversaturated with calcite. Figure 2 shows the calcite saturation index (CSI) calculated from chemical samples for Ngatamariki’s active production wells in 2018. A positive CSI indicates potential to deposit calcite, however does not always result in deposition (Quinao, et al., 2017).



**Figure 2: Calcite Saturation Index (CSI) in Ngatamariki production wells.**

Both mechanical and chemical methods have been used to manage this calcite scale at Ngatamariki, securing fuel supply to the station in the long term. Broaching is a mechanical method used to clear wells. Machined tools with teeth and cutting edges are run on wireline and forced through blockages by jarring the toolstring (Wilson, et al., 2015). Figure 3 (left) shows how regular broaching recovered production and extended the life of one production well. Another mechanical method that has been used successfully is milling on coil tubing. The recovery of production capacity shown in Figure 3 (right) was due to a coil tubing intervention completed in a single day. Both methods are cost effective and have the advantage that they can be done with the well still flowing, which ensures cuttings are carried up and out of the well rather than into feedzones, eliminates the risk of casing damage caused by quenching wells, and avoids the need and cost of restarting wells afterwards.



**Figure 3. Left: The effect of regular broaching on production well performance. Each spike in flowrate follows 1-2 days of broaching. Right: The effect of mechanical workover via coil tubing on production well performance is shown with the black dashed line. Both flowrates are normalised to regular operating pressure**

Acidising is the only tested method that can clear scale formed in feedzones. A mixture of acid and inhibitor (to protect casing) can be injected either at the wellhead through bullheading, or at targeted locations with coil tubing. Anti-scalant has also been used at Ngatamariki to prevent scale from forming. A dilute mixture at a depth below the flash point is injected through tubing installed in the well. This can sometimes place restrictions on well operating limits as the flash point must be maintained sufficiently above the setting depth of anti-scalant tubing.

## 1.2 Calcite Deposition

The planning and execution of any job to manage calcite scale requires an understanding of how and where calcite scale deposits. Hot liquid produced from a reservoir will be in equilibrium with surrounding rock, generally controlled by the equilibrium reaction Eq(1):



As compressed liquid flows into and up a wellbore, pressure decreases until the saturation pressure of the liquid is reached, and vapour begins to form. This depth is known as the flash point or boiling point. The saturation pressure can depend heavily on the concentrations of various gases and salt in the reservoir fluid. When vapour is formed,  $\text{CO}_2$  concentration in the liquid phase drops rapidly through gas migration into the vapour phase, shifting the equilibrium reaction to produce more  $\text{CO}_2$ , thereby depositing  $\text{CaCO}_3$ , calcite.

Solving this chemical equilibrium with the distance above flash point predicted the shape of scale developed in a geothermal wellbore shown below in Figure 4 (left). Calcite thickness abruptly steps from 0 to the maximum at the flash point, with deposition thickness decreasing with elevation at a decreasing rate. Calibration of this model with factors for mixing length, initial concentration of calcite, and the 'delayed degassing' of liquid, produced closer matches to observed scale profiles, shown in Figure 4 (right) (Michels, 1992).

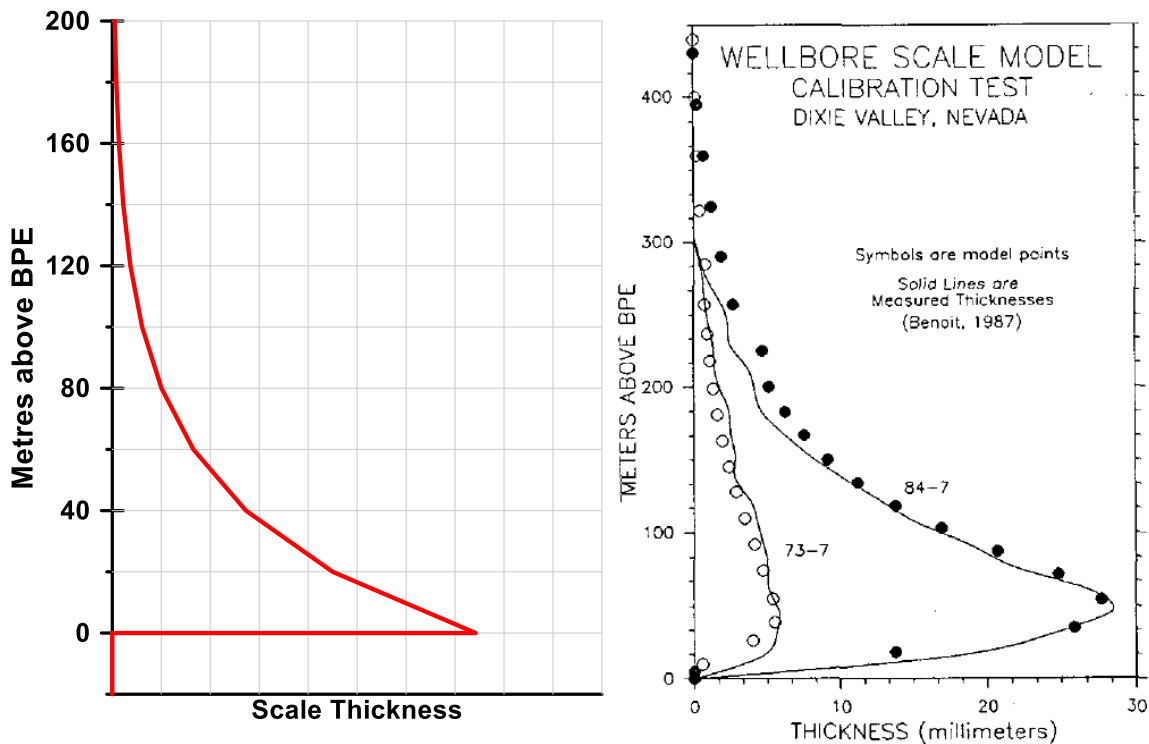


Figure 4. Left: Simple calcite scale profile from chemical equilibrium model. BPE = boiling point elevation. Right: Wellbore scaling model calibrated to observed caliper results in two wells (Michels, 1992).

### 1.3 Wellbore Simulation

Wellbore simulation can be used to model the physical behaviour of a geothermal well. A bottom-up simulation begins at the lowest feedzone with a starting pressure. The flowrate and temperature are dependent on the given feedzone parameters. With this information, all thermodynamic properties can be calculated, as well as an expression for the change in pressure and enthalpy with elevation. Various numerical methods can then be used to iteratively calculate the conditions at the next step up the wellbore. At Mercury an in-house wellbore simulator named Paiwera is used for the simulation of both production and injection wells (Franz, 2015).

Based on known parameters such as casing sizes, feedzone productivities, reservoir pressures and temperatures, a good match to a flowing PTS survey and the observed output of a well can be made. A well calibrated simulation can be used to predict how the output of a well will be affected by changing reservoir or wellbore conditions. It can also be matched to the decline of a well to understand the possible changes to have caused this decline. A powerful method is the comparison of the output curves of wellhead pressure against flowrate. Reservoir pressure or enthalpy decline change the shape of these curves in different ways to wellbore diameter reduction (due to scaling) or feedzone productivity loss, shown in Figure 5. The most telling sign of decline due to a wellbore obstruction is a large change in output at higher flowrates/lower discharge pressures, with minimal change in the maximum discharge pressure. At lower flowrates, the effects of a wellbore restriction are smaller due to the lower velocity.

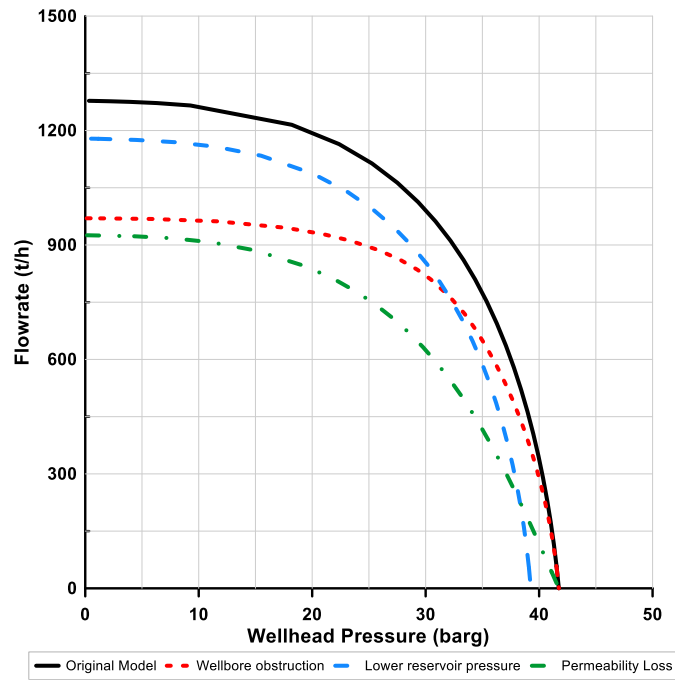


Figure 5: Deliverability curve for an example well showing impact of different decline mechanisms

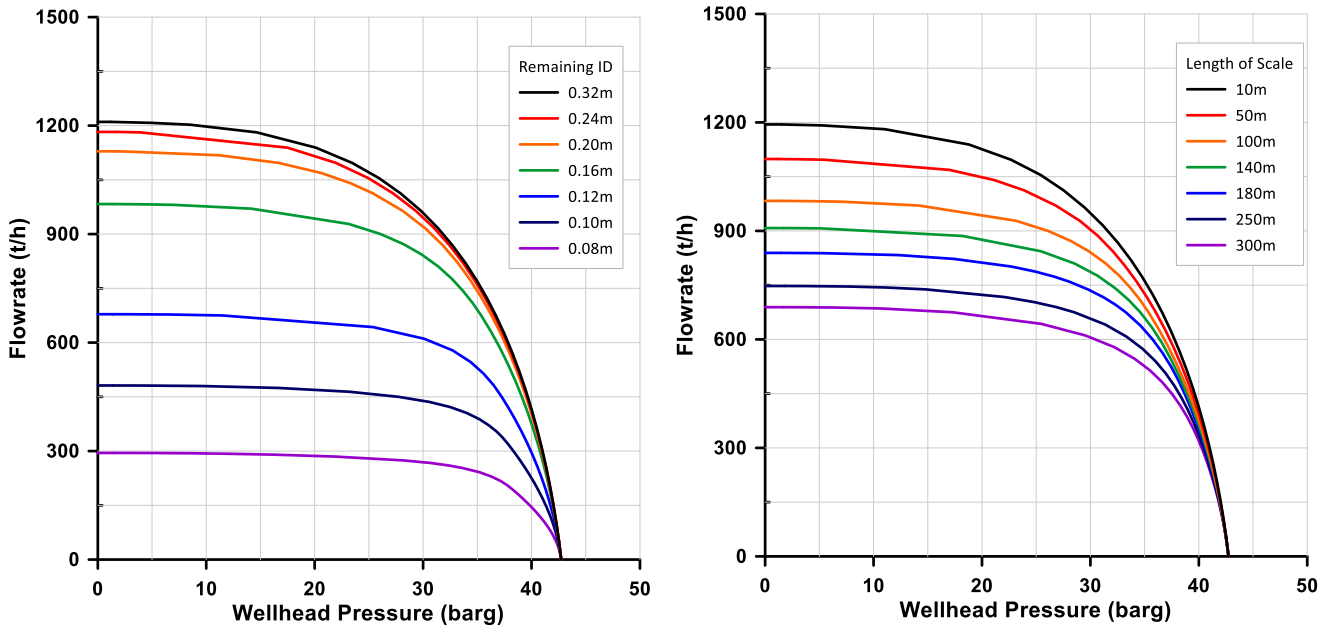
## 2. WELLBORE SIMULATION FOR CALCITE SCALING AT NGATAMARIKI

### 2.1 Simple Approach

A simple approach to modelling calcite scale in geothermal wellbores was used to justify interventions and predict the scale that would be encountered in these interventions. This could be done with minimal downhole work and proved robust enough for program planning. Two examples are described in this section, but this method has been used in other wells.

NM12 began operation in late 2014 with a capacity of 1050t/h of two phase fluid at its minimum operating wellhead pressure. NM12 began to decline at a slow rate in early 2017, accelerating over time. Enthalpy, permeability, and pressure changes were eliminated, leaving only wellbore changes as cause of the decline.

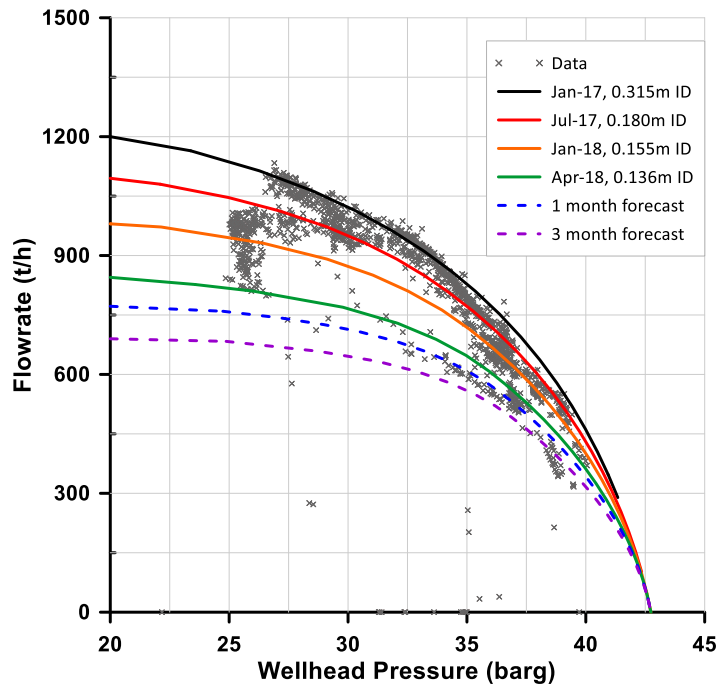
Based on a model matched to NM12 before scaling had occurred, the flash point at its most frequent operating condition (around 25 barg) was found. A section of scale was then added into this model by reducing the internal diameter, starting at the flash point and extending upwards. Two key parameters, the length and the thickness of scale, were changed to achieve a match to the flowrate and wellhead pressure decline showed by NM12. The variation of NM12 deliverability with changing scale length and scale thickness is shown in Figure 6 left and right. Different combinations of length and diameter could be used to match NM12 performance, but a 100m length of scale was chosen as a reasonable estimate from previous experiences. Wellbore simulation showed that a significant amount of scale can be built up before changes in flowrate can be noticed. In the case of NM12, even with the internal diameter being reduced from 0.315m to 0.2m (a 60% reduction in flow area) for a 100m section, there was less than 50t/h change in flowrate at the operating wellhead pressure of 25 barg. Once the restriction became noticeable, further decreases in diameter had increasingly larger effects on flowrate.



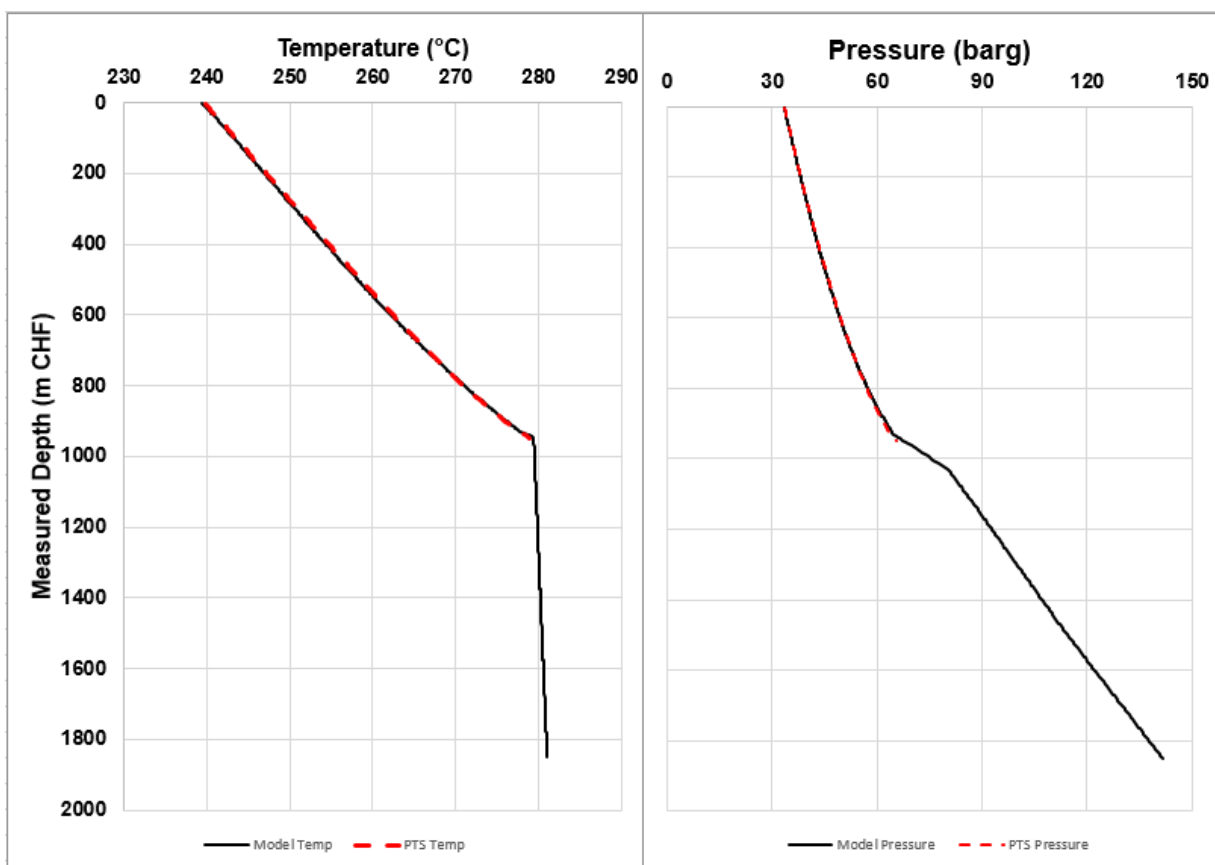
**Figure 6. Left: Simulated change in performance of NM12 with different scale thicknesses for 100m. Right: Simulated change in performance with different lengths of 0.16m internal diameter in the wellbore**

The decline of NM12 from January 2017 was matched by increasing the thickness of scale sections until the simulated output matched the performance, shown in Figure 7. A PTS run in NM12 in early 2018 could not pass 950mD, approximately 80m above the simulated flashpoint. The pressure and temperature measured to this depth matched closely to those predicted in the wellbore model, in Figure 8.

Based on the volume of the scale required to match NM12 decline rate, a scaling rate of 0.005m<sup>3</sup>/day at the current flowrate was estimated to forecast the performance of NM12 shown in Figure 7. Based on these forecasts NM12 decline would continue to accelerate, threatening Ngatamariki power station’s power output.



**Figure 7: Matching performance of NM12 with increasing scale thickness and forecasting based on scaling rate**



**Figure 8: PTS match to NM12 wellbore model in early 2018. Left: Temperature match, Right: Pressure match**

This was also applied to NM13. NM13 began operating in March 2018 with a similar capacity to NM12, however showed rapid decline nearly immediately, accelerating similarly to NM12. Again, wellbore restriction was identified as the most likely cause of decline by the deliverability curve shape and enthalpy and pressure monitoring.

The decline was thought to be too rapid to be due to scaling alone based on experience with other wells on the field, including NM12. NM13 also had casing damage occur during start up, and so the most likely cause of this decline was a combination of the casing damage providing an existing restriction, and scale forming at the same depth, further reducing the flow area. Wellbore modelling showed that, with various sizes of initial obstruction, the decline rate seen by NM13 could be explained by a similar deposition rate of calcite to NM12. This was proven in a repair job, where the casing damage was seen covered in calcite scale, restricting the well diameter to less than a few inches. Both NM12 and NM13 performance recovered to original levels after clearing wellbore obstructions.

## 2.2 Applications of Modelling

Wellbore modelling has proved to be a useful tool to approach the issue of well decline at Ngatamariki. In many situations, it can significantly build upon the findings of PTS surveys and eliminate the need for further downhole investigation. A simple approach can quickly provide answers to many of the key questions involved, including the most likely cause of production well decline and providing an estimate on the future decline if no operating changes are made.

In both NM12 and NM13, this justified intervention work to clear the wellbore by showing that the original performance would be fully recovered by clearing wellbore blockages. It was especially helpful in the case of NM13, proving for a new unsurveyed well that there were no major changes in permeability, pressure, or enthalpy.

During planning of these interventions, providing an estimate of the extent of scale that would be found helped greatly to anticipate the time and tools required, which translated directly to cost. Wellbore simulation was also used to predict the effect of different success criteria of cleaning. For example, the effect on well performance is very similar if only a 0.26m opening is achieved instead of the full 0.315m ID. This again can aid in selection of tools and drive down costs – clearing out larger diameters than required takes more time.

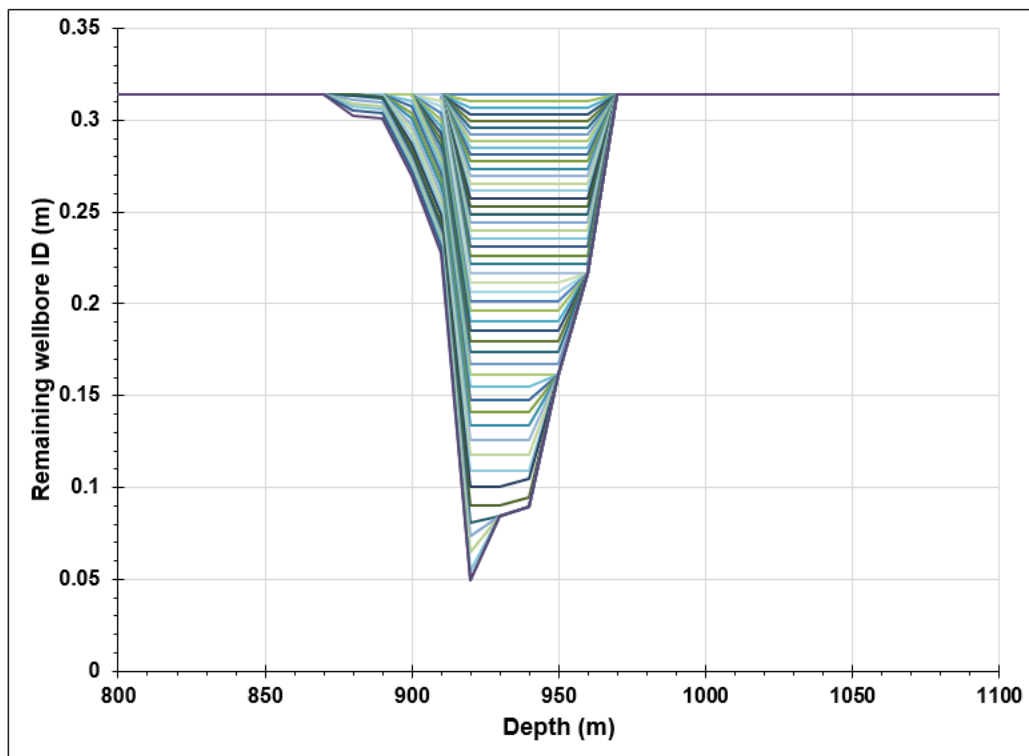
This modelling can also help operation of wells in normal condition. An understanding of the flash point of the well at different flowrates is required to either set anti-scalant tubing or operate the well so that scaling can be managed. For example, throttling a well moves the flash point upwards, depositing scale higher up the wellbore. This spreads the volume of scale deposited over a larger length which has less impact on well output than a large diameter restriction over a small length.

### 2.3 Simulating Deposition Over Time

There were significant assumptions made in the modelling of scale in the previous section. The key simplifying assumption was that wellbore scale could be modelled as a 'block', ignoring the shape expected from chemical modelling and experience with surveys in other scaling wells. To attempt to recreate that shape, rather than using a chemical modelling approach, the change in the flash point of the well over time due to increasing deposition was investigated. The chemical equilibrium solution assumed that the flash point of the well does not change over time, which is uncommon for an operating well.

An iterative approach of layering on sections of scale was used. A basic wellbore model was solved at a given wellhead pressure, and then a layer of scale was added extending upwards from the flash point by reducing the wellbore diameter. This was repeated, solving the model again to represent another time step, finding the new flash point, and adding more scale.

Two different approaches were made to determine how much to reduce the wellbore diameter. The first was to reduce the diameter by a set amount. The second approach was to take the flowrate from the model run and use it to calculate a volume of scale to deposit based on Ngatamariki's calcite oversaturation. An 'excess calcite' concentration of 1.3mg/kg was used based on the CSI of Ngatamariki production wells and multiplied by the flowrate in kg/s. This was then multiplied by the time to simulate in each step (in this case, 5 days) and divided by the density of calcite to obtain a volume. The volume was spread evenly across a 50m length above the flash point. This produced the scale profiles shown in Figure 9, where one line is drawn for every four simulations. The first approach produced similar results.



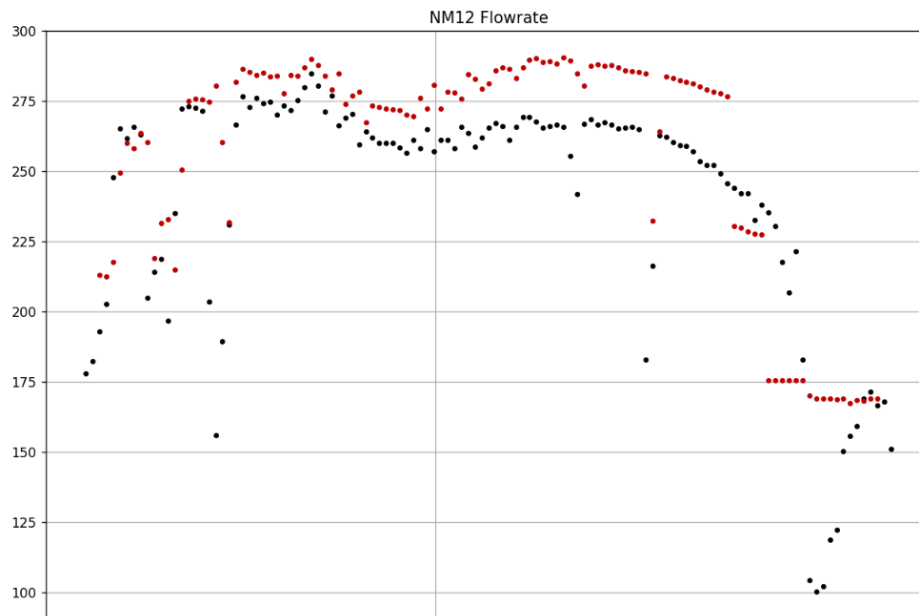
**Figure 9: Remaining wellbore diameter with depth from simulations**

Modelling a moving flashpoint generates a similar scale profile to that observed in many scaling wells, building to a maximum restriction and then dropping in an exponential manner.

The next step was to vary the amount deposited per time step to attempt to match the performance of scaling wells. This was attempted in NM12 and NM13. The average wellhead pressure over 5 day periods was used to simulate NM12, aiming to match the flowrate observed by depositing scale in the wellbore. The parameters to be changed were the time per iteration, the excess calcite concentration, and the distance over which the volume was deposited. Future studies across more fields could provide estimates of these parameters based on the thermodynamic and chemical conditions in the reservoir.

Unfortunately, attempting to match flowrate over time proved difficult. Very little impact would be seen until a critical point, at which flowrate would suddenly step down, compared to the smooth decline expected. An example is shown in Figure 10, where 50m sections of scale, 5 day time steps, and 0.8 mg/kg calcite oversaturation were used. A variety of combinations could not produce an accurate match to the performance of NM12.

It is likely that the step sizes used in simulations are too large – reducing the time step used, but also the step size of depth used by the wellbore simulator should be investigated to improve the match. This more refined wellbore simulation would reduce the step changes in output. Additionally, this approach has assumed deposition rate across a wellbore is linearly proportional to the flowrate of a well and is spread evenly across a set length. These assumptions simplify the problem, but inclusion of results from a solution to the calcite equilibrium to provide a length and shape of deposition could generate more accurate approximations of deposition rates.



**Figure 10: NM12 observed (black) and simulated (red) flowrates**

### 3. CONCLUSION

Wellbore simulation has significant value in geothermal field operation, and can be used to help the management of calcite scale in conjunction with downhole surveys. At Ngatamariki, wellbore simulation has been applied successfully to understand individual well performance changes in all production wells, not just the two examples presented in this paper. With simplifying assumptions, accurate wellbore simulations can forecast downhole conditions and explain production well performance, helping with the timing and planning of works to manage calcite scale. This has reduced the cost of interventions and the impact of well decline on station production.

An iterative approach of layering scale over time shows promising signs, being able to closely replicate the expected shape of calcite depositions, but needs refinement in future work. Extending the study to include more wells showing signs of scaling and using interpreted diameters from PTS or caliper surveys would be beneficial to improve the match and understand what prompts calcite formation. Additional factors such as the change in calcite saturation with elevation above the flash point should be investigated to obtain a better match to production data. If a chemical approach can provide inputs to the wellbore simulation it could be used to predict wellbore scaling from the beginning. This could accurately predict the shape of calcite deposits in production wells operating at various conditions, which could be used to optimise well operation to minimise the effect of scaling, delaying interventions.

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