ADAPTING SURFACE FACILITIES TO CHANGES IN ROTOKAWA RESERVOIR IN THE FIRST 5 YEARS OF NGA AWA PURUA

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ABSTRACT

The Rotokawa geothermal field has performed well during the five years since the commissioning of Nga Awa Purua Power Station, which brought about a five-fold increase in electrical output from the field. A process of careful monitoring supported by predictive modelling and evaluation of enhancement opportunities has been required to ensure this success. Pressure drawdown and chemistry trends in the reservoir have meant that changes to the production/injection strategy have been directed at improving the response of the field. The production to both power plants has experienced declining enthalpy pointing to a need for adaptive changes to maintain efficient operation over the plant lifetime. Nga Awa Purua has a centralised triple-flash steam separation arrangement and as a result its maximum output is sensitive to off-design fluid delivery conditions. The longer-standing second power plant, Rotokawa, also has a high-pressure fuelling requirement using an interconnected gathering system with aging wells. This paper summarises the experience and the optimisation, control and flexibility measures incorporated into plant and steam field operation.

1. INTRODUCTION

The total net output of the Rotokawa geothermal field increased by 138 MW after Nga Awa Purua was commissioned in 2010, adding to the existing 34MW produced by the Rotokawa station.

With the addition of the Nga Awa Purua triple flash plant, a series of challenges, as outlined in the following paragraphs, were introduced with the steam field and operation of the plant during its first 5 years. The Rotokawa steam field has a wide range of well outputs and enthalpies. The existence of strong compartmentalisation inside the reservoir results in low certainty of well output for future wells and changeable decline rates of existing wells. Variability of well behaviour has meant a fluctuation in two phase flow supplied to the station. Due to the power plant control mode, this has caused unstable steam flows into the turbine, resulting in fluctuating reduced output as the plant conforms to its limits.

Due to a reduction in field enthalpy, fluid take from the reservoir required to maintain output at both stations has increased, requiring a strategy to optimise the fuel and enthalpy requirements of both stations. Optimising steam field flexibility has been a key tool in supplying the two stations with the right fluid and enthalpy combination to maximise their productivity.

On the injection side, an injection strategy which aims to spread brine injection more widely in the reservoir, has called for increased flexibility in the surface pipeline system for both stations and caused the reinstatement of an existing well previously out of service.

Due to the different technology used for both stations their fuel requirements differ. A steam field optimisation aims to supply both stations with the optimum combination of wells whilst avoiding bottlenecks, minimising new construction costs and reducing the strain on particular parts of the reservoir to manage pressure drawdown. Flexibility to continue to operate the power plants fully fuelled when wells in the steam field are out of service for testing or maintenance is also an important consideration.

Reduction in enthalpy in the reservoir and its effects on plant operation has emerged as the main driver to optimise the supply of fuel to both stations and is described in detail in this paper.

2. OPTIMUM ENTHALPY RANGE FOR ROTOKAWA AND NGA AWA PURUA

2.1 Rotokawa and Nga Awa Purua Operating Characteristic

Nga Awa Purua is a triple flash plant while Rotokawa is a combined cycle plant with two bottoming Organic Rankine Cycle Ormat Energy Conversion (OEC) units and two separate OEC units powered both by steam and brine. As a result the fuel requirements and sensitivity to enthalpy vary significantly between both stations.

Figure 1 below illustrates the feasible operating range of Nga Awa Purua with varying station enthalpy. The plot shows that in particular a drop in enthalpy from the design enthalpy of 1560kJ/kg will incur a drop in output. Sensitivity to enthalpy is caused by the steam flow limitations inside the station. This includes both turbine and separator steam flow limits. The turbine flow limit maintains acceptable loading on the internals of the turbine based on the manufacturers rating. Reducing enthalpy will result in higher brine flows through the low pressure separators. The low pressure separators may experience reduced efficiency or wear with increased brine flow and ultimately this may limit the ability of the steam separation system to maintain optimum steam flows to the turbine.

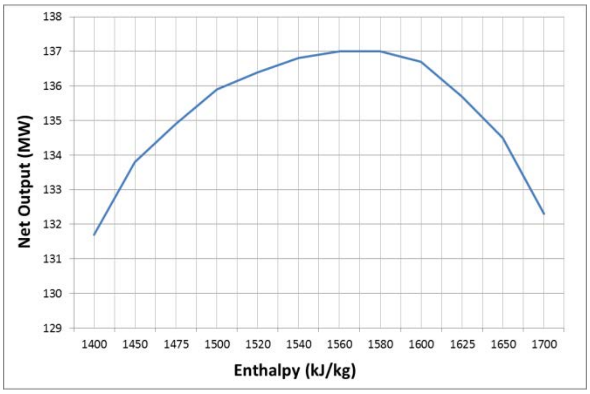

Figure 1. Sensitivity of Enthalpy Range to Nga Awa Purua Power Plants Power Output.

Figure 2 below illustrates the projected operating range of the Rotokawa power station with a wide range of applicable enthalpies. Two phase supply into the station is controlled to maintain sufficient steam pressure to the steam turbine. The power output of the steam turbine, two bottoming units and steam OEC unit does not vary with reducing enthalpy as the steam flow is maintained by increasing two phase flow. The total station output however is dependent on the brine flow to the OEC units. With reducing enthalpy the brine flow into the station increases providing more heat input into the unit. Eventually the brine flows into the station will increase above the flow capacity of the units and brine will be bypassed around the unit. At this point the maximum output of the unit is reached corresponding to the maximum output of the station.

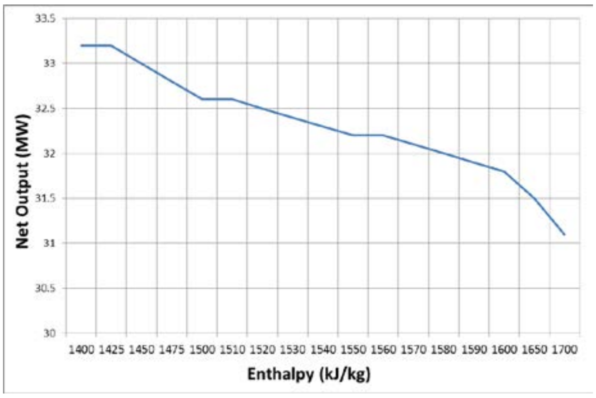

Figure 2. Sensitivity of Rotokawa Power Station Power Output to Enthalpy.

Consequently, based on the two very different station operating characteristics, a drop or increase in enthalpy impacts the two stations differently. The enthalpy of the wells is varied and it is key to the optimisation strategy to connect the right mix of wells to each station.

3. PLANT MODIFICATIONS DUE TO A REDUCTION IN ENTHALPY

The field enthalpy has reduced steadily since start-up of Nga Awa Purua and is predicted to continue to do so for the immediate operating future of the plant (Hernandez *et al*, 2015). As a result, a series of modifications have been investigated, but not yet implemented, to optimise the station.

Reducing enthalpy causes less than optimal High Pressure (HP), Intermediate Pressure (IP) and Low Pressure (LP) flows into the turbine. With lower enthalpies, the portion of high energy (HP) steam reduces. Some of this loss may be compensated for with steam separator pressure adjustments, however this is only effective for a short range of enthalpy and the field enthalpy at the current well configuration may drop below this range.

Major modification to the station are not justifiable at this stage so options which are being evaluated are as follows:

- Modifying aspects of the operating philosophy – by increasing the throughput of the station, output may be maintained albeit at a lower overall station efficiency. This would result in redirecting fluid via bypass lines and will return the unused energy back into the reservoir, however it will add strain to the injection facilities and capacities.
- Utilisation of low pressure steam or steam condensate for alternative purposes - This will rebalance the steam flows in the separation system to improve output.
- A binary unit may be implemented that utilises the additional brine into the station resulting from the low enthalpy improving efficient utilisation of the fuel.

For the Rotokawa Power Plant a lowering enthalpy means additional brine flow and while output is increased, the full utilisation of all the energy in that brine is not achievable with the current plant. In terms of plant modification, this offers the opportunity to upgrade and expand the brine processing facility for more output. This would require new or upgraded OEC units. Alternatively, if additional production to maintain steam flow to the turbine is not available then alterations to the turbine and separation pressure may be considered.

4.0 STEAM FIELD OPTIMISATION

The Rotokawa steam field consists of 20 active wells. The first wells of the field are related to production for the Rotokawa station, which has been operating since 1998. The subsequent wells were drilled to provide and dispose of fluid for the Nga Awa Purua station. Since the commissioning of Nga Awa Purua three additional make up wells have been drilled specifically for this station. Figure 3 below illustrates the steam field layout, showing the location of the two power stations relative to the Nga Awa Purua Production Pads.

To avoid process limitations and ensure efficient operation of both stations it is important to ensure flexibility to deliver targeted enthalpy fluid to both stations. This ensures no output restrictions due to off-design fuel supply. The current enthalpy of the Rotokawa wells ranges between 1340-1870kJ/kg. The optimum enthalpy balance for both stations would be as follows:

- Target 1560-1580kJ/kg for Nga Awa Purua as this results in the best balance of steam flows into the turbine and the highest conversion efficiency for this output.
- As explained in section 2.1 and shown in Figure 2 Rotokawa output is not as affected as Nga Awa Purua at lower enthalpies. However, the output from the existing brine units tails off significantly at higher enthalpies.

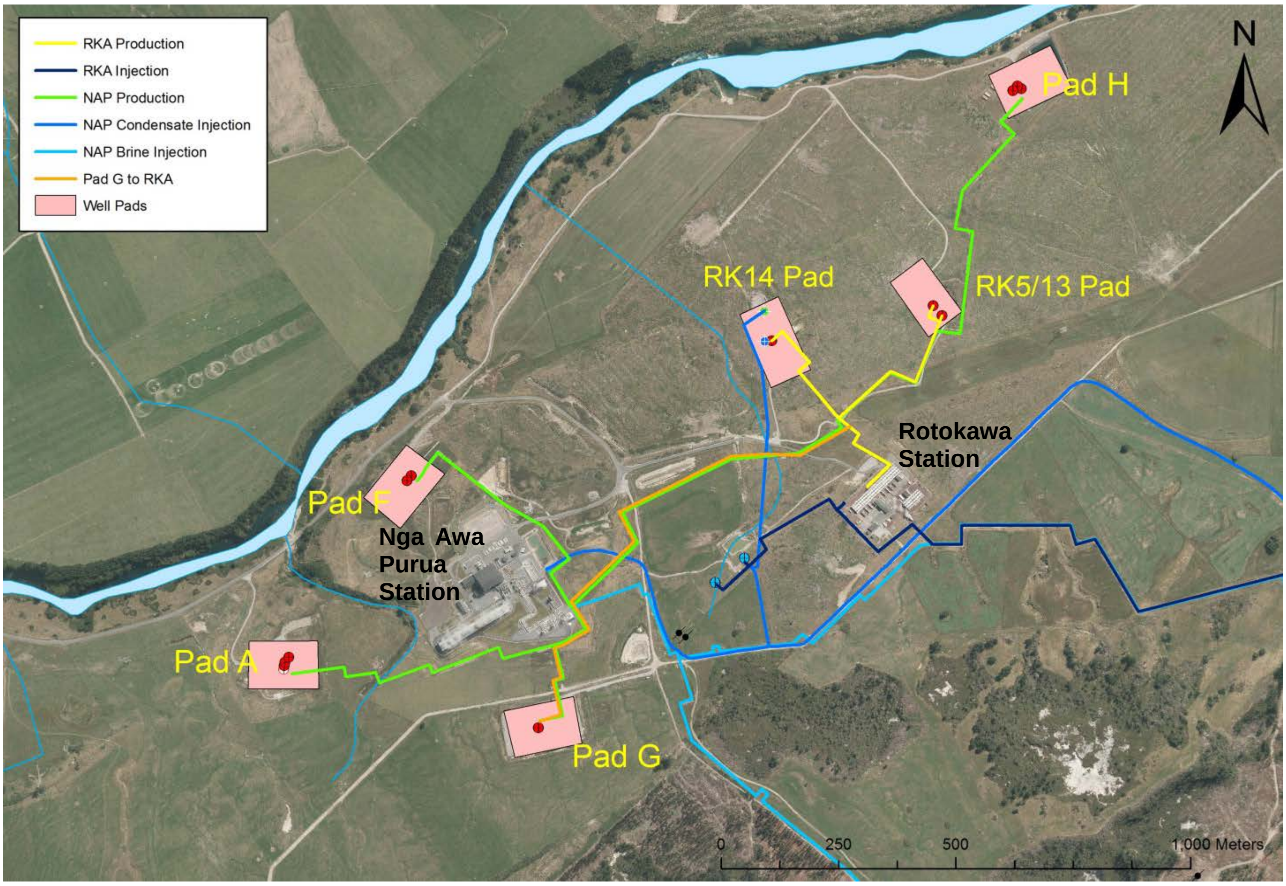

Figure 3. Layout of Rotokawa Steam field, showing both Nga Awa Purua and Rotokawa Power Stations as well as their Production wells.

Due to decreasing enthalpy experienced at the reservoir so far, with the current well locations and configuration, the focus is to ensure the target enthalpy is delivered to Nga Awa Purua. Two options may be utilised to optimise the enthalpy split between the two stations:

- Improving flexibility across the steam field by allowing wells to be divertible to either station. A well can then be replaced by one or a combination of wells to maintain the overall energy balance. The Rotokawa steam field has sufficient diversity to achieve this, however complete flexibility would incur a large infrastructure cost, so only limited pipeline modifications may be justified.
- Development of a facility to enable sharing of fluid between the two stations at a variable steam fraction. This would allow splitting the required fluid to supply each station at a desired enthalpy split. This would be achieved by first splitting the brine and steam and then supplying both stations with the required mix.

4.1 Improving Production Steam Field Flexibility

A steam field model that couples a steam field pipeline hydraulic model with the station characteristic and well output curves was used to evaluate the appropriate well connections. This provided a valuable tool to quantify the spare field capacity for each station, pressure drop limitations in the system resulting in debottlenecking opportunities and evaluating make up well locations to optimise well capacity and delivery. Based on the spare capacity of the wells connected to each station it was found that Nga Awa Purua had significantly more spare capacity available than Rotokawa. With the combination of wells connected to Rotokawa it would have suffered a significant loss in output with the loss of any of these wells. Based on this analysis the wells required to provide Rotokawa with sufficient spare capacity was determined and was used to evaluate the appropriate connection.

Nga Awa Purua currently has four production pads connected to it as shown in Figure 3 above. Pad H is already connected to Rotokawa via a direct pipeline connection between the cross country line from Pad H to Nga Awa Purua named the ‘interconnect’. Due to the style of the pipeline take off, it mainly allows steam to pass from the Nga Awa Purua system to the Rotokawa system and vice versa. Generally the requirement is for the interconnect to supply fluid from Nga Awa Purua to Rotokawa, however due to the natural difference in pressure between the two stations the flow is from Rotokawa to Nga Awa Purua. As a result HP separator pressures at Nga Awa Purua have to be raised to allow the reverse flow direction. This increase in HP pressure results in less HP steam flowing into the turbine accentuating the already lower flow due to low enthalpies from the field.

Consequently, it is not desirable to use the interconnect solely as a means of providing sufficient capacity to Rotokawa and an alternative means was sought after with an additional pipeline connection.

Evaluation of each Nga Awa Purua production pad and its wells relative to their capacity, enthalpy and pressure drawdown in the area determined that Pad G is the most appropriate pad to connect to the Rotokawa station with a new pipeline connection. The two wells originally located on Pad G during the optimisation study were RK32 and RK33.

The three wells that originally supplied the Rotokawa station, RK14, RK5 and RK13 are shown in Figure 3 above by the yellow supply line. The total capacity of the two wells located on Pad G matched the capacity required for Rotokawa should the largest of its suppliers fail and each Pad G well had sufficient capacity to replace one of the two smaller Rotokawa wells.

The enthalpy of RK32 on Pad G was relatively low such that it was compatible with lifting the average enthalpy for Nga Awa Purua closer to its optimum. It also provided additional brine flow to boost Rotokawa's brine OEC unit slightly. Further, the future production well, RK34, was due to be drilled on this pad, adding further potential well flexibility and capacity for Rotokawa. Consequently, Pad G proved to be the ideal pad to connect to Rotokawa, given the goal to optimise the field.

4.1.1 Pad G to Rotokawa Station Pipeline Connection

The connection from Pad G to the Rotokawa station is illustrated in Figure 3 above by the orange pipeline connection. Once the steam field optimisation project identified this as the optimal solution, the construction project for this pipeline was initiated in 2013.

Figure 4 shows a schematic of the new pipeline connection between Nga Awa Purua and Rotokawa. An additional header was added to the original one to allow diverting fluid between Rotokawa and Nga Awa Purua. All three wells including the now added RK34 have the capability to flow to either station, however cannot flow to both at the same time. This arrangement brought about a series of challenges to accommodate a variety of operating scenarios and the two different operating conditions of the two stations.

One of the key design requirements of this line was to maximise its flexibility. Future considerations included connecting wells from other pads to provide additional supply potential to Rotokawa. This meant providing the capability to flow a range of wells and therefore a range of flows. Thus, this required optimising the size of the line to promote a range of flows within the boundaries of an acceptable slugging risk. Due to the topography of the line surging caused by uphill slopes was likely, especially amplified by low steam velocities at lower flow rates. Initially as most of the supply to Rotokawa was still expected to be provided by the three original Rotokawa wells, the flow through the connection from Pad G was expected to be low and was expected to increase later with the natural decline of the Rotokawa wells.

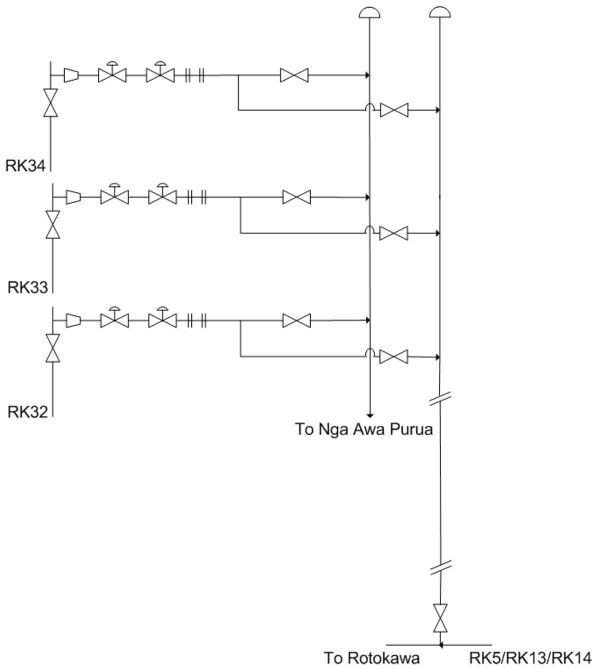

Figure 4. Pad G Connection Pipeline Schematic.

Evaluating the slugging risk at various flow rates and pipe sizes provided a tool to determine the optimum balance between pipeline size and allowable steam flows at low flow rates to reduce the risk of slugging. In addition, during the design of the line significant changes in topography were avoided by some targeted earthworks to further reduce the risk of slugging in these sections of the line.

Nga Awa Purua and Rotokawa are operated with two different control systems. Originally all instruments and valves at Pad G communicated with the Nga Awa Purua controller. However, to enable communication between the Rotokawa controller and the Pad G valves and instruments, remote control commanding was enabled from the Rotokawa controller. A control switching regime was enforced that prevents accidental simultaneous connection from one well to both plants. Switching one well from one plant to another is controlled by an electro-mechanical interlocking system. This serves the purpose of both preventing accidental well connections and providing a single switching point around which other software functions operate. Further instrumentation challenges were around flow measurement from the two phase orifice plate and communicating this flow to the appropriate station control system depending on the direction of the flow.

The Nga Awa Purua steam field piping is rated to a higher design pressure than the Rotokawa steam field piping. Pressure protection was added, located just upstream of the Rotokawa tie in, to protect the lower rated Rotokawa line. Evaluation of the pipe line hydraulic profile indicated that when all wells at Pad G are utilised at their full capacities, several bar of back pressure may be generated at the pad. Consequently, to protect the new line at the pad G end, the line was rated to the higher Nga Awa Purua pressure rating.

The steam pressure at the inlet interface for each station is different, where the Rotokawa station operates approximately 2 bar higher steam pressure than Nga Awa Purua. This opens up issues where flow may occur from

Rotokawa to Nga Awa Pura in a situation where an isolation error occurred on Pad G. Consequently, additional isolation safeguards were installed to reduce the risk of this. Castell Keys were installed on all Pad G wells, which require the isolation of one line to be fully closed before another may be opened.

Overall this was a successful project where Rotokawa is now connected to three additional wells on Pad G. The additional well since drilled on the pad, has provided additional spare capacity for the station and additional potential to optimise the fluid spread across the field. The additional brine supplied to Rotokawa has provided an uplift of approximately 2% in net output of the station.

4.2 Improving Injection Steam Field Flexibility

The Rotokawa injection field consists of four deep injectors and three shallow injectors. Figure 5 below illustrates the injection steam field set up of the Rotokawa steam field. The deep injectors located on Pad E and Pad D are primarily used for injection. RK20 is used solely for the Rotokawa station injection. Previously RK24 and RK23 were used for Nga Awa Purua brine injection, while RK22 was shut in and the station's condensate was injected into the shallow wells RK9 and RK12. Due to an injection strategy that drove to spread brine injection as much as possible, RK22 was re-instated for brine injection. Consequently, this freed up RK23 for condensate injection.

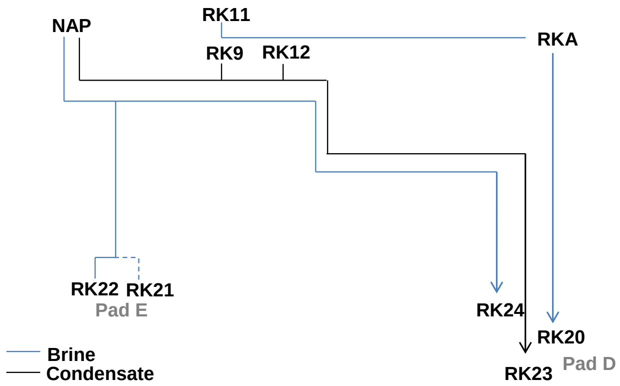

Figure 5. Schematic of Rotokawa injection steam field.

The re-instatement of the pipeline from the main Nga Awa Purua injection line to Pad E included cleaning the pipe line from deposited silica. A flow test carried out to test the adjacent RK21used the line to flow brine to a suitable injection well infield. This resulted in cooled brine inside the line depositing silica onto the pipe line walls. To mitigate the risk of blocking RK22 with the collected pipe line debris a cleaning process was carried out.

Initially three low points were selected and these parts of the pipe line were cleaned using an In-Pipeline Vehicle (IPV) system. However, not all sections of the line could be reached and residual debris remained that posed risk to the well. As a result, a dual parallel strainer system was set up to protect the well, where one strainer is used at a time and switched over once a large pressure drop across the strainer was noted. This allowed cleaning the strainer without having to shut down the well. A flushing process at the proposed operating flow rate was carried out to remove the debris inside the line. The flushed pipe line fluid was cooled in a cooling channel on Pad E before being collected in the Pad E pond. The fluid was then pumped via an HDPE line to the pad D pond, where it was left to soak. This process ensured the pipe line was fit to be reused to inject brine into RK22 without blocking the well with debris.

5.0 FUTURE CONSIDERATIONS

To optimise the enthalpy and fluid supply across the field in the future, further options will have to be considered. Additional flexibility to produce wells will assist with enthalpy management efforts by allowing more targeted production. However, beyond some reasonable available steps, this is a costly and risky option requiring new wells in newly approved areas. So a focus on optimising the surface facilities between the two stations to achieve the same ends will always be pursued in preference.

Lower enthalpies will result in higher brine flows through both stations. Rotokawa is more equipped to handle the additional brine, to a point, without downsides for plant output. Although it will currently not be able to make more output with higher inflows, it is more suited to be able to pass and inject the fluid with only minor modifications. Thus, it may be appropriate to facilitate flowing higher portions of brine to Rotokawa. Plant modifications, around the brine units especially, may be carried out at Rotokawa to improve the utilisation of higher brine flows and optimising output in these scenarios. Diverting higher brine flows to Rotokawa may be achieved through various options such as implementing a more field-based separation system for the Rotokawa station connected to some of the NAP wells. This would enable separating the two phase fluid and diverting the appropriate steam and brine flows to each station.

Another means of achieving this, without adding another separation system would be to improve the 'interconnect' connection mentioned earlier. Modifying this facility to allow better control over the steam fraction would allow better control and the potential to utilise the additional brine more effectively. This option would only be feasible when considering flow from the Rotokawa system to Nga Awa Purua due to the difference in station pressure between the two.

Further, a series of plant modifications, especially at Nga Awa Purua, may be implemented to accommodate lower enthalpies and thus adapt the plant to the natural energy balance in the reservoir. The initial response to lower enthalpies will entail higher throughput to maintain sufficient steam flows. The reservoir will initially be able to support this as proven through modelling and the consenting process, however the increase in take from the reservoir will require careful management of the additional strain placed on the different areas of the field to avoid localised pressure drawdown. Finally, to continue sustainable extraction while maintaining output and efficiency it may become viable in the future to carry out more major plant modifications.

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