Tiwi Geothermal Field: Reservoir Management After 40 Years of Commercial Operation

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ABSTRACT

The Tiwi Geothermal Field in Albay, Philippines is operated by Philippine Geothermal Production Company Inc. (PGPC). It began commercial operations in 1979 (Menzies et al, 2010a), initially with shallow production well drilling concentrated in the Naglagbong sector in the eastern part of the current production area. After a steep drop in productivity of the first wells due to the impact of entry of meteoric recharge into the reservoir, three other geographic sectors were developed for production starting in the late 1980s. These were the Kapipihan sector in the center and south, Matalibong sector in the northwest, and the Bariis sector in the southwest. Up until the mid-1990s, steam availability was maintained through drilling of new production wells across these new production sectors to support the 330 MW installed capacity of the power plants.

Through the years, multiple challenges were managed through various technical and operational initiatives and from these experiences, improvements in the understanding of the reservoir contributed to the development of the current reservoir management strategy in order to increase and maintain steam supply.

To recover steam production, drilling deep into the postulated upflow zones in the Bariis and South Kapipihan sectors aims to harness the deep liquid production zones, while casing deep isolates the well from the intrusion of acidic fluids found near the top of the liquid-dominated reservoir in some sectors. For existing wells, executing timely and appropriate well work options improves steam availability. On brine disposal, hot brine systems have proven much more reliable compared with cold brine systems and by utilizing idle wells, injection capacity shortfalls have been averted. At the same time, managing injection loads at different injection sectors should ensure adequate mass recharge with minimal thermal breakthrough, resulting to continued steam generation for years to come.

1. INTRODUCTION

The Tiwi Geothermal Field is operated by the Philippine Geothermal Production, Inc. (PGPC), a Filipino Corporation and wholly-owned subsidiary of Allfirst Equity Holdings, Inc. It is located in the northeastern flank of Mt. Malinao, in the municipality of Tiwi, Province of Albay, about 450 km southeast of Manila, seen in *Figure 1*. The production area is divided into four geographic sectors; the Naglagbong sector to the east, where the initial production was concentrated in the early 1980's, the Matalibong sector to the west, where superheated steam was exploited in the 1990's, the Kapipihan sector to the south, where liquid dominated wells have provided consistent production and the Bariis sector to the west-southwest where the highest reservoir temperature was measured (Sugiaman et al, 2004).

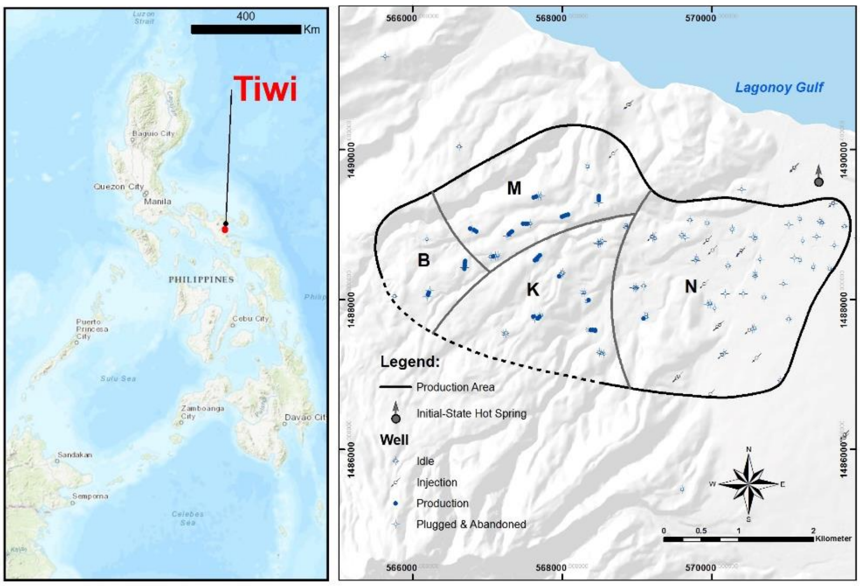

Figure 1: Location of the Tiwi Geothermal Field
(N = Naglagbong, K = Kapipihan, B = Bariis, M = Matalibong)

The Tiwi Geothermal field is described as a liquid-dominated, fracture controlled hydrothermal system covering an area of ~ 15 square km (Sunio et al, 2004). From the conceptual model, there are two postulated major upflow zones located in Bariis and South Kapipihan, with a minor upflow zone in South Naglagbong, as seen in *Figure 2*. The outflow zones are located in North Matalibong and the main one in North Naglagbong is influenced by prominent inferred and mapped fault structures.

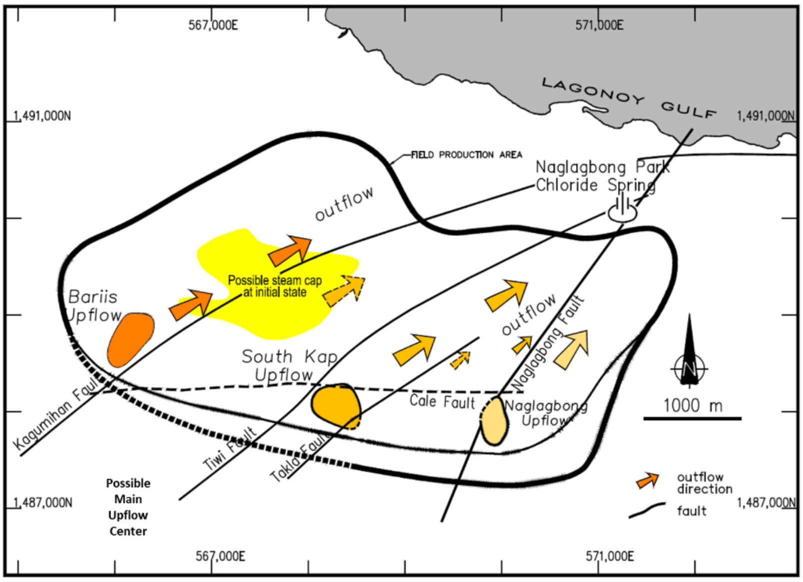

Figure 2: Initial State Model

The development history of the Tiwi field has previously been presented in Gambill et al, 1993, Sugiaman et al, 2004, Sunio et al, 2004, Menzies et al, 2010a. This paper focuses on the resource management that occurred in the past 10 years to complete the 40 years commercial operation of the field.

2. CURRENT RESOURCE STATUS

In 2009, the steam availability was calculated to be 430 kg/s (~190 MW) from 37 production wells (Menzies et al, 2010a). The steam supply has declined by about 5% annually to around 260 kg/s (~115 MW) coming from 31 production wells and 11 "huff-and-puff" wells. Huff-and-puff wells are unstable wells which have challenges in sustaining production and may cease flow or produce at low rates when surface pressure increases. The following sections discuss the various reservoir processes that have occurred and impacted the steam production over the past 10 years.

2.1 Pressure Drawdown / Liquid Level Rise

The Matalibong superheated steam zone evolved as mass extraction resulted in pressure drawdown (*Figure 3*), extensive boiling and eventual steam dry-out in the 1990's to the 2000's. Eight production wells (Kap-12, Kap-14, Mat-04, Mat-06, Mat-09, Mat-10, Mat-22, and Mat-23) produced superheated steam in 2008 (Menzies et al, 2010b) seen in *Figure 4a*, and of these eight wells, only 3 wells have remained steam-dominated (Mat-04, Mat-06 and Mat-22) while four became two-phase producers and one has ceased flow (Mat-09), seen in *Figure 4b*, as of December 2018.

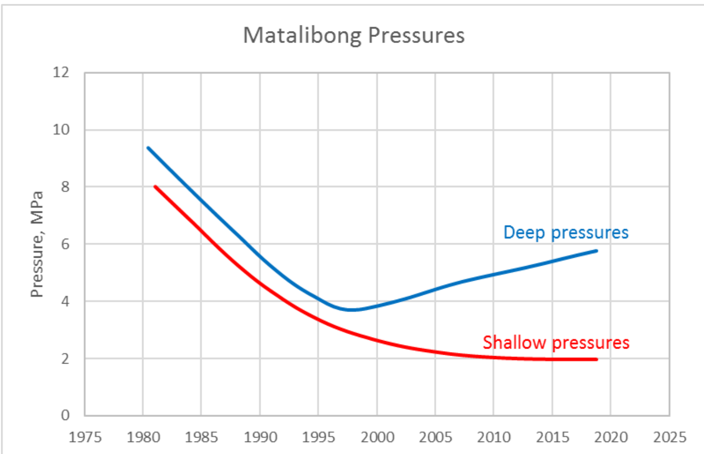

Figure 3. Matalibong shallow and deep pressure trends

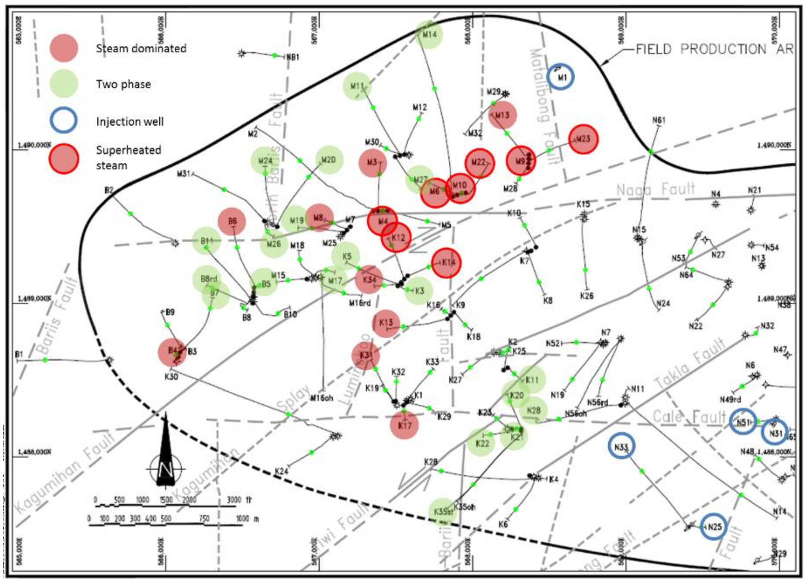

Figure 4a. Tiwi Well Locations and Production Characteristics, December 2008

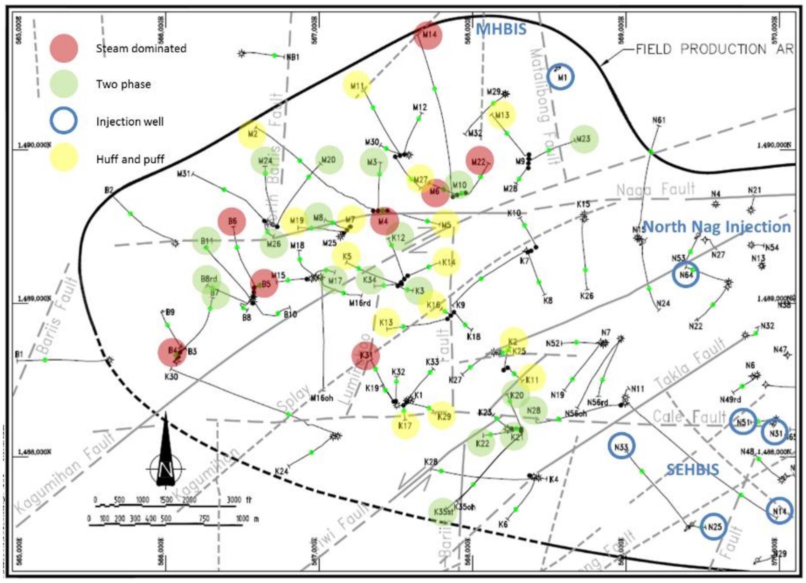

Figure 4b. Tiwi Well Locations and Production Characteristics, December 2018

The change in production characteristic was due to the rising steam water interface (Calibugan et al, 2015). The increasing water level, from 700 mbsl in 2008 to 565 mbsl in 2018, seen in *Figure 5*, effectively flooded the shallow steam zones in majority of the Matalibong wells (Aquino et al, 2019). From the 165 kg/s steam production in 2009 (Menzies et al, 2010b), this sector currently provides 90 kg/s, which is still 34 % of the total field wide production. As the water level continues to rise, in 2019, the enthalpy of Mat-22 has recently decreased from 2800 kJ/kg to 1400 kJ/kg, while its steam production is still significant (9-10 MW) there is a high chance that it will eventually decline. An added effect of the liquid level rise is the additional brine that needs to be disposed of.

It is postulated that the increase in liquid level was brought about by the recharge of peripheral waters and from the injection returns coming from the Matalibong Hot brine Injection System (MHBIS) going into injection wells Mat-21 and Mat-33. This theory is backed by reservoir tracer test results conducted in 2008, wherein tracers injected in these wells were recovered from Matalibong production wells e.g. Mat-20, Mat-14, etc., in less than 60 days, and by downhole pressure data from observation wells (Calibugan et al, 2015).

It was recommended to decrease the injection along the MHBIS by diverting 100 kg/s out of the 300 kg/s hot brine injection from Matalibong to the South Eastern Hot Brine Injection System (SEHBIS) in order to stem the rising liquid level (Calibugan et al, 2015). The activity was implemented from 2013 to 2015 but only showed ambiguous results (possible increase in reservoir temperature in Mat-05RD and Mat-07RD, seen in *Figure 6*) and did not change the rate of liquid level rise. Further evaluation is necessary to determine the cause of the liquid level rise to mitigate its aforementioned effects. Plans were made to prolong the hot brine diversion and further minimize injection to Mat-21 and Mat-33, however, with the continued increasing brine production, there is sometimes a need to fully utilize the MHBIS.

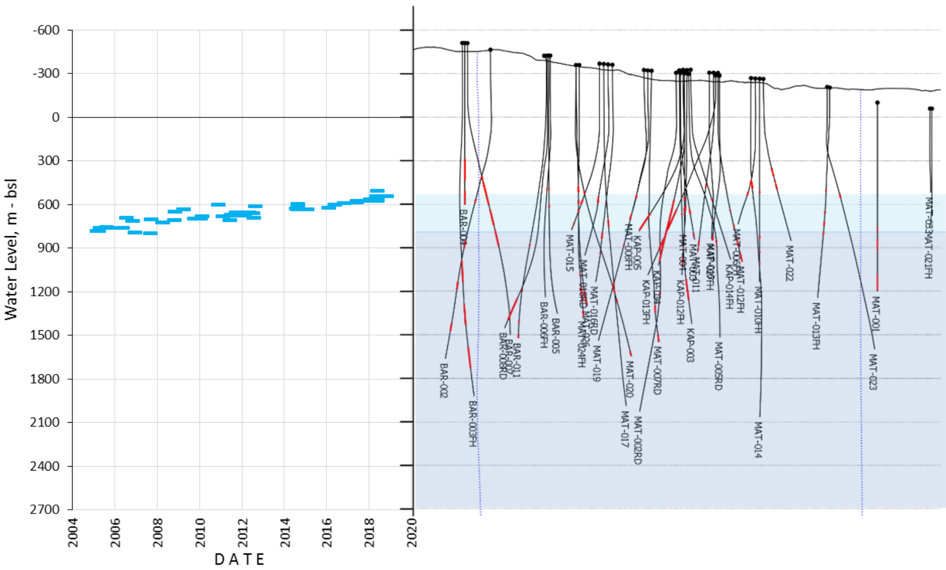

Figure 5. Matalibong Steam/Water Interface Depth

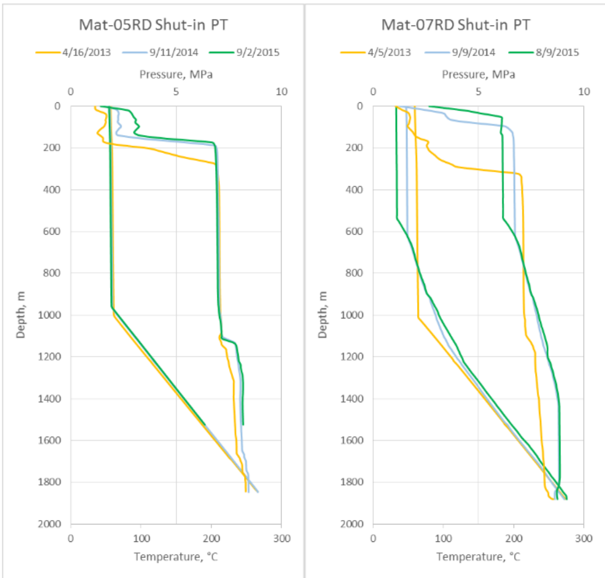

Figure 6. Pressure and Temperature Profile. Pre and Post Diversion of Matalibong Brine in 2013 and 2015, respectively

2.2 Wellbore Scaling

At the southwest of Matalibong lies the Bariis sector. The reservoir pressure in this sector of the field continues to be stable as seen in *Figure 7* and is believed to be one of the sources of recharge for Matalibong. Around 74 kg/s of steam or approximately 28% of the total field wide steam production of Tiwi comes from the Bariis sector.

One major process affecting production from this sector is wellbore scaling. Scale samples collected from Bar-08RD proved the presence of calcite. A scale drill out was conducted in Bar-08RD in May 2019 which cleared the obstruction, and the well recovered its original 12 MWe of production. Other wells, including Bar-11 and Mat-26 had successful scale drill-outs in 2016. In recent years, PGPC is also seeing some success with wireline broaching (Wilson et al, 2015) as a lower cost alternative to rig-based wellbore scale drill-out.

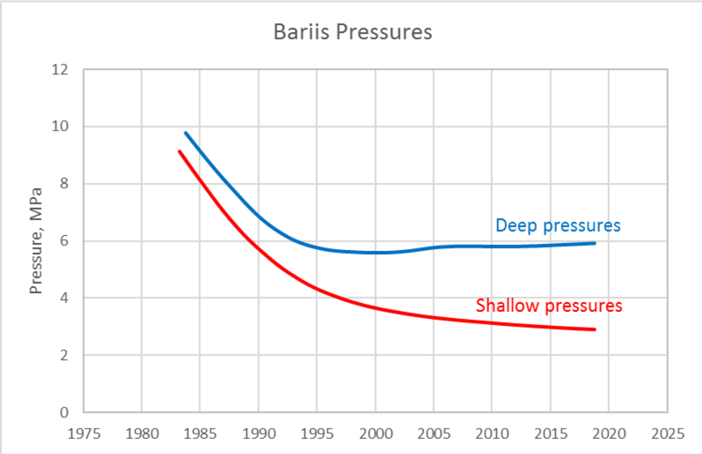

Figure 7. Bariis shallow and deep pressure trends

2.3 Acid Fluids

Production of corrosive fluids is also an issue in Bariis. Various theories have been forwarded on the source of acid (Crisostomo et al, 2015), but what has been clearly defined is that acid-sulfate fluids are apparently situated across a narrow zone between 670 mbsl to 1040 mbsl, seen in *Figure 8*. A previous effort to neutralize the acid sulfate fluids using downhole injection of dilute sodium hydroxide (NaOH) were successful only for a short time (Gardner et al, 2001).

The implemented strategy to address acid production is to case-off this section to prevent inflow of acid fluids, and this has been successfully implemented in three wells. However, one well (Bar-11) which was drilled in 2008 with a deep cemented casing to isolate said section, recently experienced inflow of acid which ate through the cemented liner at around 790 mbsl. This caused the well's pH to drop, leading to it being shut for the most part of 2018. A scale drill out and relining was done in April 2019 to re-isolate the acid zone and recover the well's production. Post-workover results showed the well generating 6 MW of neutral pH fluids. Overall, PGPC is very satisfied with this method of suppressing acid production, despite this case of acid breakthrough after the first 10 years of production. The success has justified plans to drill one more new production well in Bariis in 2019, and possibly more in the future.

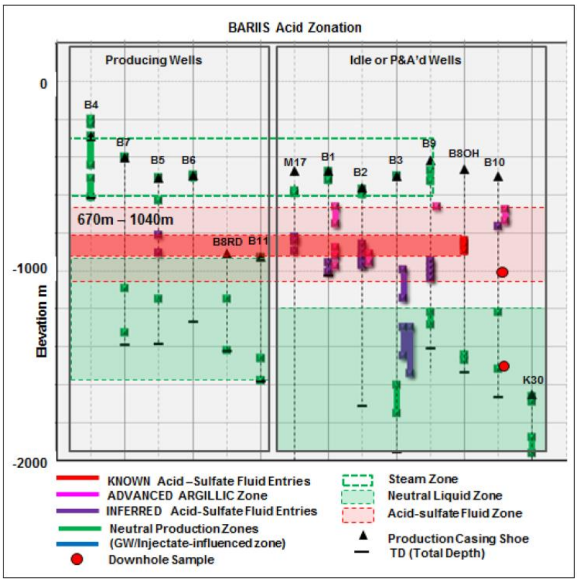

Figure 8. Schematic Diagram Showing the Vertical Distribution of the Acid Sulfate Zone in Bariis

2.4 Injection Returns

Around 37% of the current field wide steam production comes from the Kapipihan sector. Kap-35, drilled in 2008, has been a constant producer (9-10 MW) together with Kap-21, Kap-22, and Nag-28. Although chemical breakthroughs coming from the Southeast Edgefield Hot Brine Injection System (SEHBIS) have been noted in these wells (Mejorada, et al, 2016), thermal decline based on geothermometers, seen in *Figure 9*, has not been that significant, while mass support is very evident based on pressure trends, as seen in *Figure 10*, and a large deep-seated volume of heat exchange is suggested by microearthquake data, as seen in *Figure 11*. As a prudent reservoir practice, some hot brine injection was shifted from SEHBIS to the Northern Naglagbong, utilizing previously idle wells Nag-64, Nag-59 and Nag-50 as injectors starting in 2015 to achieve a surplus of injection capacity, diversify the distribution of injection, and allow thermal recovery of presumably cooled fractures paths.

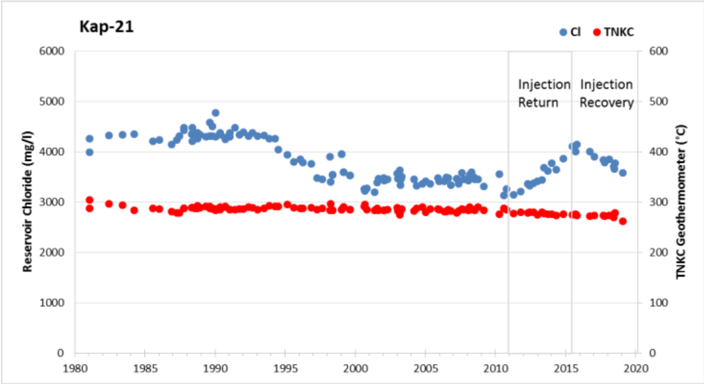

Figure 9. Kap-21 Reservoir Chloride and Na, K, Ca Geothermometer with Time

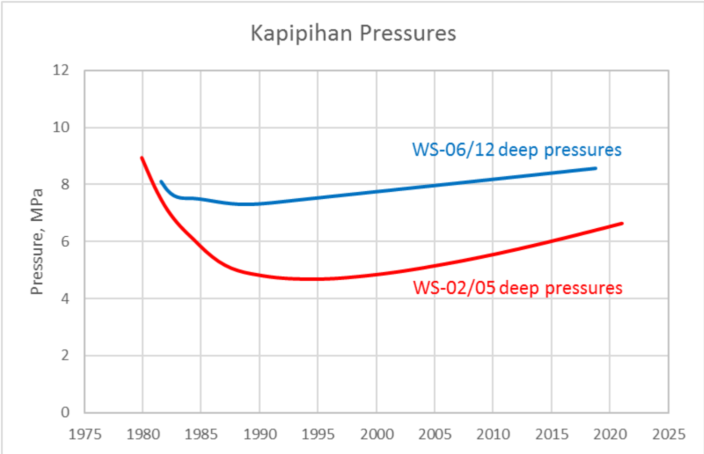

Figure 10. South Kapipihan deep pressure trends

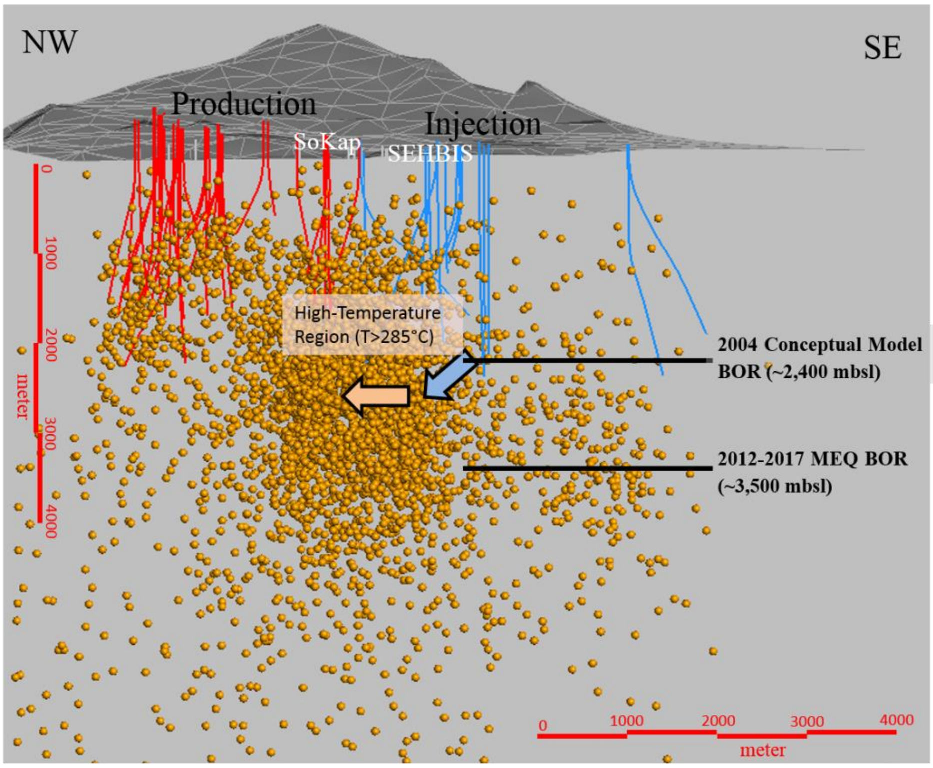

Figure 11. Recorded micro-earthquakes from 2012 to 2017. The arrows show the movement of fluids from SEHBIS towards the high temperature zone extending deep below the prolific South Kapipihan production zone

2.4 Cool Water Inflow

During the 1980's and 1990's influx of cool waters wiped out production in about half of the field, including virtually all of the Naglagbong wells (Gambill and Beraquit, 1993). With the stabilization of the pressure drawdown, seen in *Figure 10*, it was observed that the rate of encroachment of the Naglagbong cool water inflow via fault structures has decreased. Previous studies showed that when the Naglagbong meteoric recharge reaches the wells as shown by the increasing sulfate levels with no increase in acidity, it begins to decline in production and normally ceases flow after 3 years (Buenviaje, 1996). Kap-11 sulfate levels started to increase in 2011, as seen in *Figure* 12, and the well became a huff-and-puff well by the end of 2016. Currently, cool water inflow is starting to affect Kap-20.

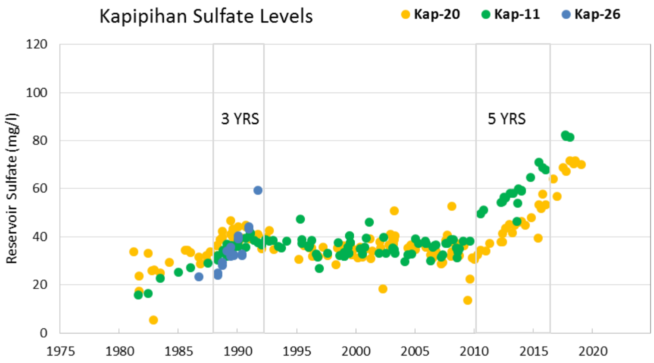

Figure 12. Cool water inflow as characterized by increasing sulfate levels in Kap-26, Kap-11 and Kap-20

3. RESERVOIR MANAGEMENT STRATEGY

With the myriad of challenges still affecting the Tiwi geothermal field, the following strategies are being implemented:

- Stabilization or mitigation of the rising liquid level has been targeted to address the shrinking Matalibong steam cap. Previous attempts to reduce the Matalibong injection rate might not have been enough to make a difference in the water level. Relocation of the Matalibong injection sink could be a possible solution but would require significant investment in the existing surface facilities. If the water level decreases, production recovery from affected wells is expected.
- Scale drill out using a work-over rig has been effective in recovering production from wells affected by scaling. Wireline broaching as an alternative has been moderately successful at a much lower cost, and will continue to be implemented to maintain production of the newly worked over wells. Other options, such as utilizing scale inhibition systems, are being looked into to prolong well production.
- Isolation of the shallow acid zone has been proven to be effective in keeping acid zones from producing and in maintaining and expanding production from the Bariis sector. The acid zones can be cemented behind casing.
- Varying the injection rates at different injection sectors, along with having buffer injection capacity, is a viable strategy to minimize thermal breakthrough. This allows mass and pressure support without thermal decline on the production wells, as seen in the prolific Kapipihan production area.
- Mitigation of the cool water inflows is still being studied by the resource management team. One possible strategy is to maximize injection in North Naglagbong to create an injection curtain in order to deter recharge of cooler waters.

4. FUTURE PLANS

After the last drilling campaign in 2008, wherein Kap-35 and Bar-11 were drilled, additional wells are planned to be drilled in the latter half of 2019. These additional wells will target the postulated upflow regions in both the Bariis and South Kapipihan sectors, and will incorporate the deep casing strategy as needed to isolate shallow acid or cool inflow zones. Furthermore, the new wells aim to tap the deep reservoir pressures, targeting zones defined by a massive cloud of microearthquakes, seen in *Figure 11*, which are believed to be triggered by thermal contraction when cooler fluids injected in SEHBIS causes the rocks in the reservoir to contract and slip as the fluid migrates back to the production area (Marcuap and Villamer, 2019). This suggest that there is still permeability and heat exchange down to ~ 3500 mbsl.

5. CONCLUSION

After 40 years of commercial production, continued monitoring and a dedicated resource management team that looks at both short- and long-term solutions have been effective in overcoming the challenges in Tiwi geothermal operations.

As of the first half of 2019 there are 31 stable production wells and 11 "huff-and-puff" wells that are contributing 115 MW of equivalent power generation. By the time this paper is presented, new wells will have been drilled in the field, and additional information from these wells may potentially open up opportunities of drilling additional production wells in the future to further augment current production.

5. ACKNOWLDEGEMENTS

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