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Te Mihi Steamfield Production Development Design

Kim Harwood[1], Kevin Koorey[2] and Chris Mann[3]

[1]Contact Energy, Taupo, New Zealand [2]MB Century, Taupo, New Zealand [3]MTL, Auckland, New Zealand

[1]kim.harwood@contactenergy, [2]KKoorey@mbcentury.com, [3]ChrisM@mtlnz.co.nz

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ABSTRACT

The Wairakei Steamfield now supplies three power stations with the commissioning of Te Mihi Station in 2013. In 2008 to 2013 period the development was focused in the Te Mihi plant area to maximise energy generation from increased reservoir take. The Te Mihi zone of the steamfield has been in production since 1983, principally supplying the Wairakei Station. In 2006 the supply to Poihipi Station was added and finally in 2013, Te Mihi Station. Through this period the existing stations remained in service while the new steamfield plant was integrated into a brownfields site. Reinjection capacity was significantly increased and new zones were commissioned.

Design challenges included the need to be compact to permit future production well drilling, topography, three different station inlet steam conditions, redundancy and buffer required in the reinjection system, flexibility to swing steam production amongst the stations, high steam quality, dynamic stability and maintaining production to existing stations during construction.

1. INTRODUCTION

The Te Mihi steamfield is located within the greater Wairakei geothermal reservoir 6 km northwest of the original Wairakei Power Station (Figure 1). It is the main up flow zone of a moderate temperature (270 deg C) reservoir producing from a mix of 38 two-phase, and 7 dry steam production wells. This Te Mihi steamfield was first drilled in 1958 and was not utilised until 1983. It then went through 30 years of development growth and configuration evolution that culminated in 2013 with the current configuration for the commissioning of the Te Mihi Station. The Te Mihi steamfield now supplies the three stations of Wairakei, Poihipi and Te Mihi with three different steam conditions, reinjects to three locations and represents 73% of the generation supply (figure 2). The final growth and evolution has been driven by the development proposal to reduce the Wairakei Station output and anticipate its retirement in 2026, build and locate the Te Mihi Station (160 MWe) (Hudson et al., 2012) close to the reservoir up flow zone and increase the total Wairakei reservoir take to 245,000 tonnes per day. This has resulted in an overall 110 MWe generation gain.

The earlier configuration evolutions were driven by making up for decline in first production zones of the Wairakei reservoir and the consequential supply shortfall against stations capabilities. The later evolutions were driven by the opportunity to maximise generation from greater Wairakei reservoir take.

This paper describes the plant, discusses the innovation, the complex features and design approaches used. In detail it will focus on the final evolution.

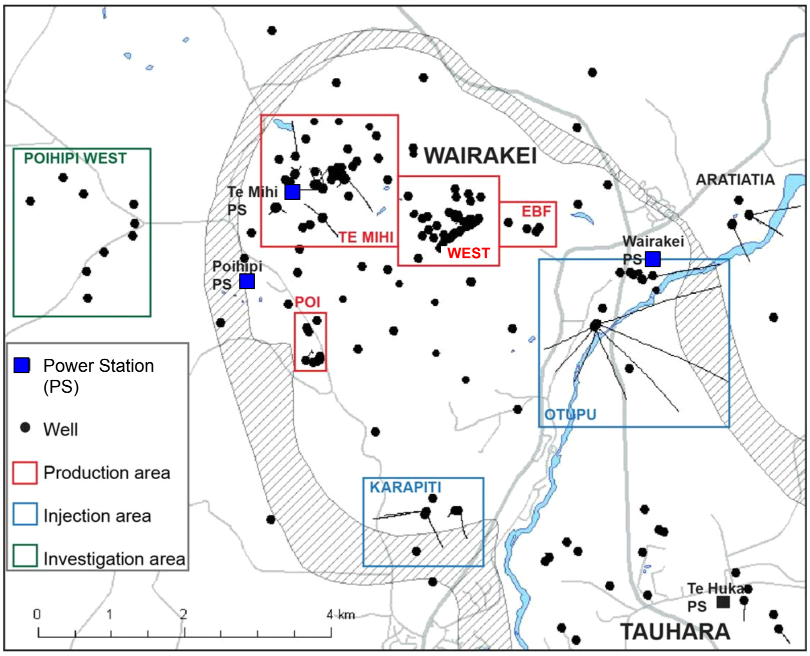

Figure 1: Wairakei production and reinjection areas and power stations

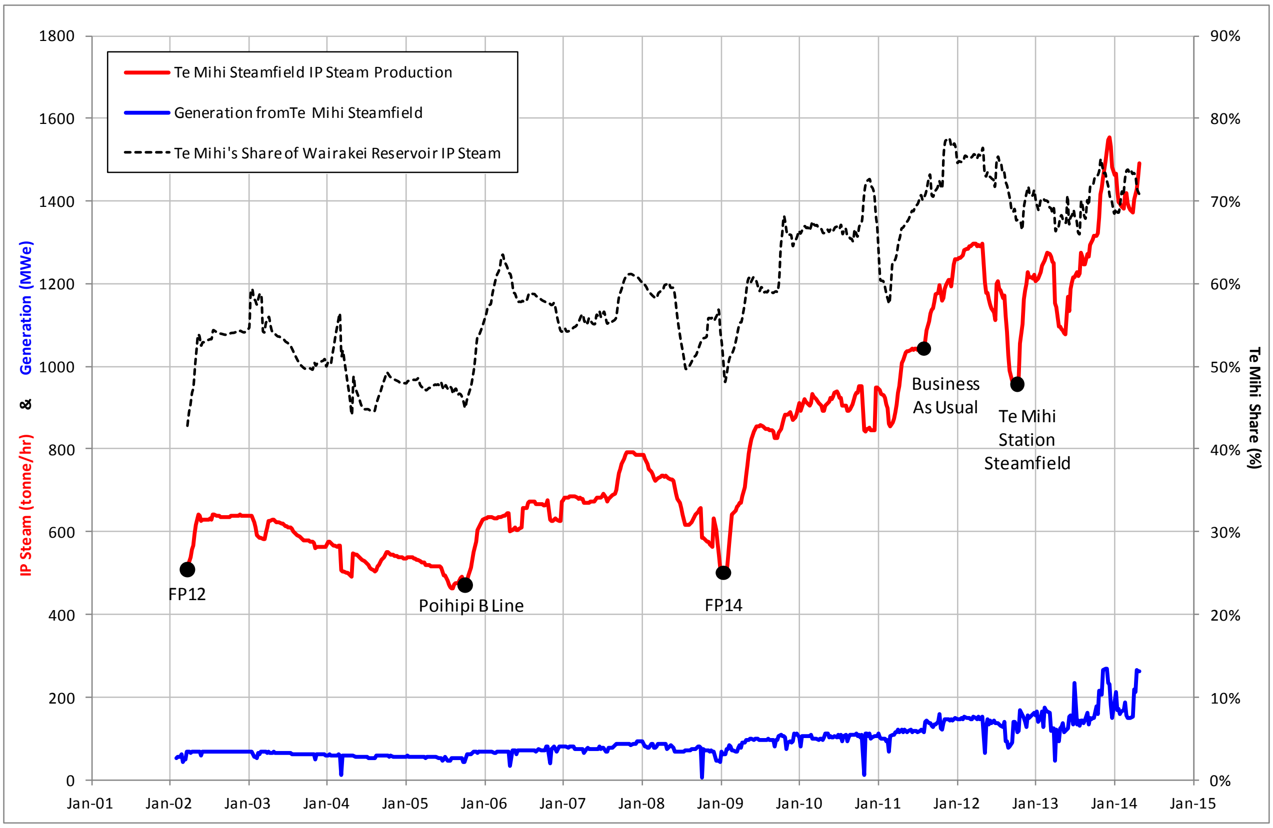

Figure 2: Te Mihi Steamfield Production History (2001 to 2014)

2. OWNER'S REQUIREMENT

The owner's requirement, especially in the final years focused on operational flexibility and the accompanying complexity of design and operation. Challenging factors to accommodate were the:

- differing demands of three stations
- dual redundant and dual modes of reinjection capacity
- commissioning Te Mihi Station while maintaining base load steam to the other stations
- raising the capacity of existing plant to accommodate project deferrals
- up scaling of equipment sizes
- competition for land with Te Mihi Station and well pads
- contractually fixed Te Mihi turbine inlet conditions and terminal points
- scalability for a third Te Mihi unit
- flexible swing of steam between three stations.

The owner's critical success factors were weighted towards:

- steam quality
- operational flexibility
- safe plant operation
- practical design for construction.

A collaborative approach with its consultants was preferred by the owner as it had informed client knowledge and wished to blend in 55 years of legacy experience on the Wairakei Field. Design courage was expected in increasing the scale of plant equipment and configuration innovation.

Through the last 7 years of history while the development case for Te Mihi Station was developed and delivered, the steam supply was modified and increased to meet the demand at Poihipi and Wairakei. The evolving design during this time was very much focused on the ultimate configuration while remaining economic through the entire history.

3. PROCESS DESIGN

The final design team had worked on this steamfield for some years, and there was a high degree of knowledge of the existing plant performance and confidence in the performance of the proposed wells. The design team had previously collaborated on this site in the design of the B-Line supplying steam to Poihipi Power Station, the steam mains into Wairakei Power Station, and the Aratiatia Reinjection System.

For the final evolutions the process design team had the task of providing intermediate pressure IP (4.6 bar.g) steam and separated water to the Te Mihi Station terminal point, and receiving back the low pressure (LP) (0.35 bar.g) separated water and cooling tower blowdown for reinjection. The input information was the existing steamfield system and new wells proposed to be drilled in a drilling programme. The well information was presented to the designers, with appropriate allowances for the uncertainty in drilled outturn and future decline in well performance. The station interface conditions were contractually defined by Te Mihi Station Engineer-Procure-Construct contract.

Developing a double flash system to supply the proposed Te Mihi Station around an existing multi pressure system, providing flexibility to allow Wairakei and Poihipi Station generation to be optimised, and providing flexibility in steamfield operation to maximise revenue during new plant commissioning and planned outages, was a challenge. Added to those was the undulating topography, allowance for a future 3rd unit at Te Mihi and an interim step that required part of the steamfield to be constructed and commissioned.

The first deliverables of the process design were the mass and energy balance, Process Flow Diagram (figure 3), and preliminary site layout. These documents were widely circulated and presented to project stakeholders outside the project design team. This conveyed the scale of the proposed project, and the relationship with existing plant. The design team undertook a significant exercise with the owner's site team to raise their level of understanding of the project scope, and to utilise their professional knowledge of the Wairakei system, and steamfield operation and maintenance to positively influence the design. This exercise included design reviews, hazard and operability study, and maintainability workshops. For example the review specifically targeted improving the health and safety and maintenance practices for the Karapiti Reinjection Pump Station. Learning from existing pumps stations the owner's team reviewed their maintenance practices to refined pump station design to ultimately reduce cost and increase staff safety.

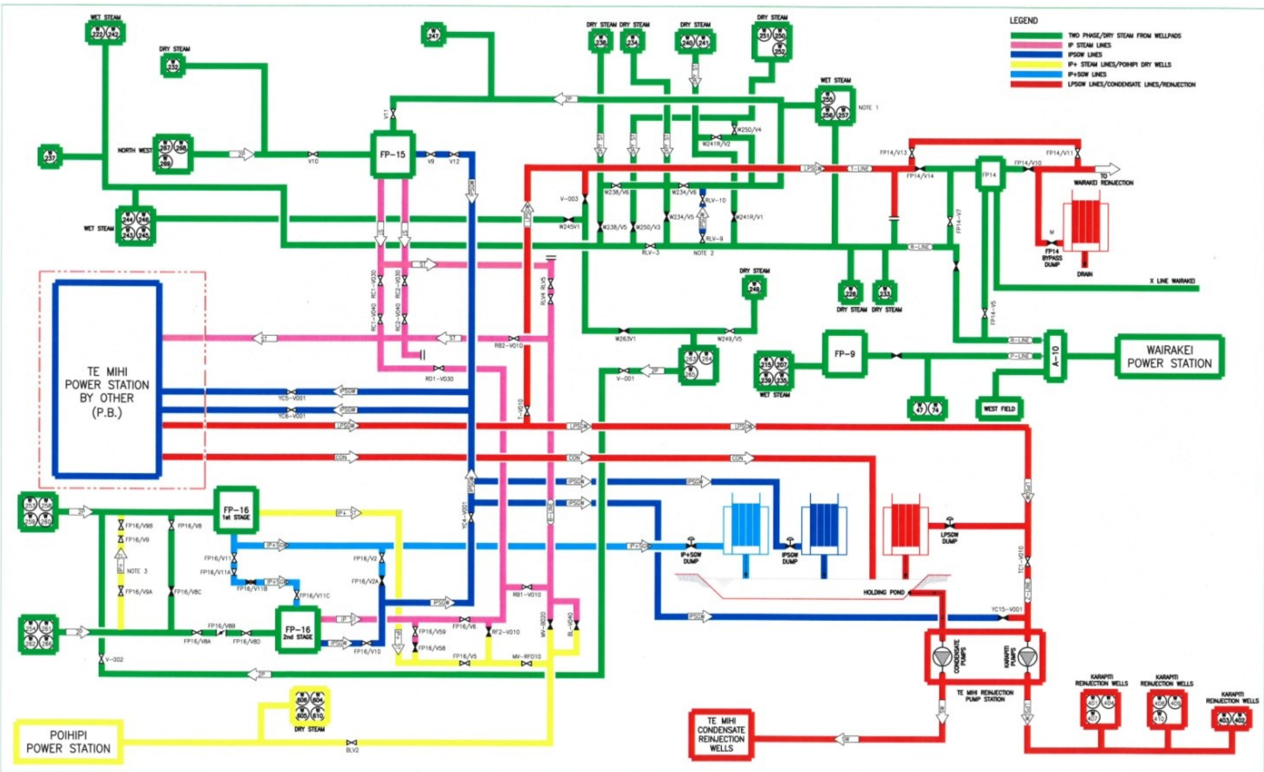

Figure 3: Te Mihi Steamfield Piping Flow Diagram

4. FLEXIBILITY FOR FUTURE

One of the key issues in the greenfields design of a geothermal steamfield is understanding the likely future operating scenarios. Through the reservoir life the down hole conditions change, stations are upgraded, built, and de-commissioned, new wells are drilled and added to the steamfield, and fluid chemistry changes.

With mature Te Mihi operating data, the design team took the opportunity to introduce more operating flexibility at extra capital cost because there was certainty it could be fully unitised. There were some known possible future changes: A third unit at Te Mihi has been allowed for in the station design, operating dry steam wells will deplete meaning the future supply would be all from two-phase wells, future production well development will be in the southern area close to FP16 and the reservoir enthalpy will likely decline at predictable rates. The team considered a range of scenarios for the future design flows through the steamfield, and chose design flow conditions that provided a balance between likely future capacity increase and capital cost of the project.

5. COMPLEXITY

Due to the Global Financial Crisis, the Te Mihi Station development was deferred in 2009 (Hudson et al., 2012). The steamfield production requirements were revised based on current steam supply and well decline rates, and further production was required to maintain steam supply to Wairakei and Poihipi until the Te Mihi Station was recommenced. A new project "Business as Usual" was started. It provided an increase in the interim steam supply, by constructing sections of the proposed complete Te Mihi steamfield system. This interim step provided another challenge, to maintain the integrity of the overall steamfield system design, minimise outages for pipeline cut-ins, provide a secure, robust, reliable design permitting the final evolution to be constructed around for Te Mihi Station. It all required innovative design and collaboration between the owner and designers to aggressively contest the emerging plans.

The piping flow diagram (figure 3) is complex because of the need for a double flash system to supply Te Mihi built around an existing multi pressure system, for flexibility to allow Wairakei and Poihipi stations generation to be optimised, and to maximise generation during new plant commissioning and construction outages. An important communication tool within the wider team was the use of schematics, charts, timelines and logic diagrams to distil the complexity into the important objectives that the future plant operator could support the design direction. For example how the future reinjection strategy would be delivered with the designs of the separated water dump system to holding pond, pump station to Karapiti reinjection wells, gravity pipeline to Wairakei reinjection wells and land corridors for 3rd Te Mihi Unit pipelines.

6. PLANT DESCRIPTION

6.1 Flashplants 9 and 10

The first Te Mihi production wells connected to Wairakei were medium depth two phase wells. These wells (known as the 200 Series) were drilled in the early 1960s in the east side of the Te Mihi area. Some are still in use today. In 1983 three were connected to a new flashplant, FP9. These wells were the first at Wairakei to use long two phase production lines, including uphill sections. The IP steam from FP9 was piped 2 km east to feed into the original IP steam main node (A10). The separated geothermal water from FP9 is piped down slope 1.5 km to LP flashplant FP10. FP10 separated water was discharged into the steamfield drains flowing to the Waikato River. The LP steam joined the LP line to Wairakei Station. The stable flow of IP separated water is maintained by holding a water level in the long pipeline between FP9 and FP10. Like most of the original Wairakei field, a simple manual system for flow control was used. The water level/flow in the leg between FP9 and FP10 was manually set and elevation difference used to provide passive self-regulating flow control. FP9 and FP10 provided 15 MWe of steam for Wairakei. This was the forerunner design of the water leg between FP15 and FP16 and the Te Mihi station (see below).

6.2. Dry Steam Wells and R line

Wells drilled further west into the Te Mihi zone found a shallow high pressure dry steam cap. These wells didn't require separation plants. A nominal pipe size (DN) 1050 pipeline was built in 1989 to take this dry IP steam 3 km to A10. The designers had foresight to design this line for two phase duty, which was put to use later in the Te Mihi development (see below). The R Line peaked at 65 MWe IP steam for Wairakei and had a problematic issue with high velocity superheat transport of well dust.

6.3. Poihipi and B Line

In 1999 the owner purchased the Poihipi Station situated 2 km southwest from Te Mihi. The Poihipi dry steam wells were declining and Te Mihi had the capacity so the 2 km DN1050 steam line (B Line) was built in 2006 to Poihipi and shared the dry steam wells connected to the top of R Line. It is capable of the maximum steam demand of Poihipi (55 MWe).

While Wairakei Station has lower turbine inlet pressure than Poihipi, the distance (7 km) and pressure drop (5 bar) between Te Mihi and Wairakei meant R Line steam pressure was too high for Poihipi. The best solution was to install a pressure regulating valve at the end connection of B Line to preserve the Poihipi well production and not heavily throttle the Poihipi unit governor valves. This regulating valve is still used but now to control the flash stage pressure at Flashplant 16 (FP16) (see below).

6.4. Flashplant 12

To utilise existing and new wells drilled below the Te Mihi steam cap a new flashplant, FP12 was built in 2001. It was connected to R line and separated water discharged to drain. It added 25MWe of capability for generation at Poihipi and Wairakei. Redundant IP separator and water vessels from the Ohaaki Station (1988) were modified for use and a second Ohaaki separator was added later. With the final design evolution of Te Mihi, FP12 has been decommissioned and is the only redundant Te Mihi plant. The vessels have been reused again for the well WK123 & 124 connections in the Wairakei Westfield.

6.5. T Line and Flashplant 14

By 2008 FP12 was at capacity limit, the high pressure drop down the R Line was causing pressure at the Te Mihi end of the line to run close to the pipeline design pressure (9 bar.g). To increase the flow from Te Mihi to Wairakei a new flashplant, FP14 and a parallel DN1050, T Line was built. These two lines combined were used to carry two phase flow 3 km to FP14 located in the centre Wairakei steamfield at A10.

The production entering R and T Lines became a mixture of steam from dry wells and FP12, two-phase from new wells and the separated water from FP12. Running the two lines in parallel had operational issues. The split of phases was not even and one line had a higher proportion of water. Even with the lines running fully down slope there was slugging and surging. Crossovers between the lines were fitted to mitigate but didn't completely solve the surging.

The decision to use both R and T Line to supply two phase fluid to FP14 initially posed a problem for the dry steam supply to Poihipi. The solution was not to over analyse and complicate. It was simply to connect the two phase wells and the water from FP12 to R Line down slope from the B Line connection. Therefore gravity prevented water flow into the B Line. R Line then became a steam main at one end and a two phase line at the other.

At the time T Line was designed, planning for the Te Mihi Station was under way. With foresight T Line was designed for both two phase and later post new station reinjection duty. This required two design cases for pressure, temperature and contents.

Additionally a large earth cut was required at the start of the line to ensure the line gradient was below the site level of the new station to eliminate boiling and the need to pump the reinjection flow to Otupu.

FP14 has two large IP separation vessels. These are the largest steam cyclone separator design in New Zealand with DN1200 inlet, 3.7m body diameter, 16.5m tall and 64 tonne weight. They incorporate a water tank in the bottom section with internal water duct and gas vent and a conical debris trap in the base. The capacity of FP14 is 850t/h of IP steam or 85 MWe, which with foresight was large and partially compensated for the deferral of Te Mihi Station in 2009.

When FP14 was built the owner was increasing reinjection at Wairakei and FP14 was connected to one of the original (1959) DN750 HP steam lines (L Line) converted to reinjection duty. This conversion required design to current piping codes, consideration of seismic loads, increased anchorage for the heavier contents and elimination of the existing vertical expansion loops and bellows with piping offsets and elbows.

6.6. Te Mihi Station Steamfield

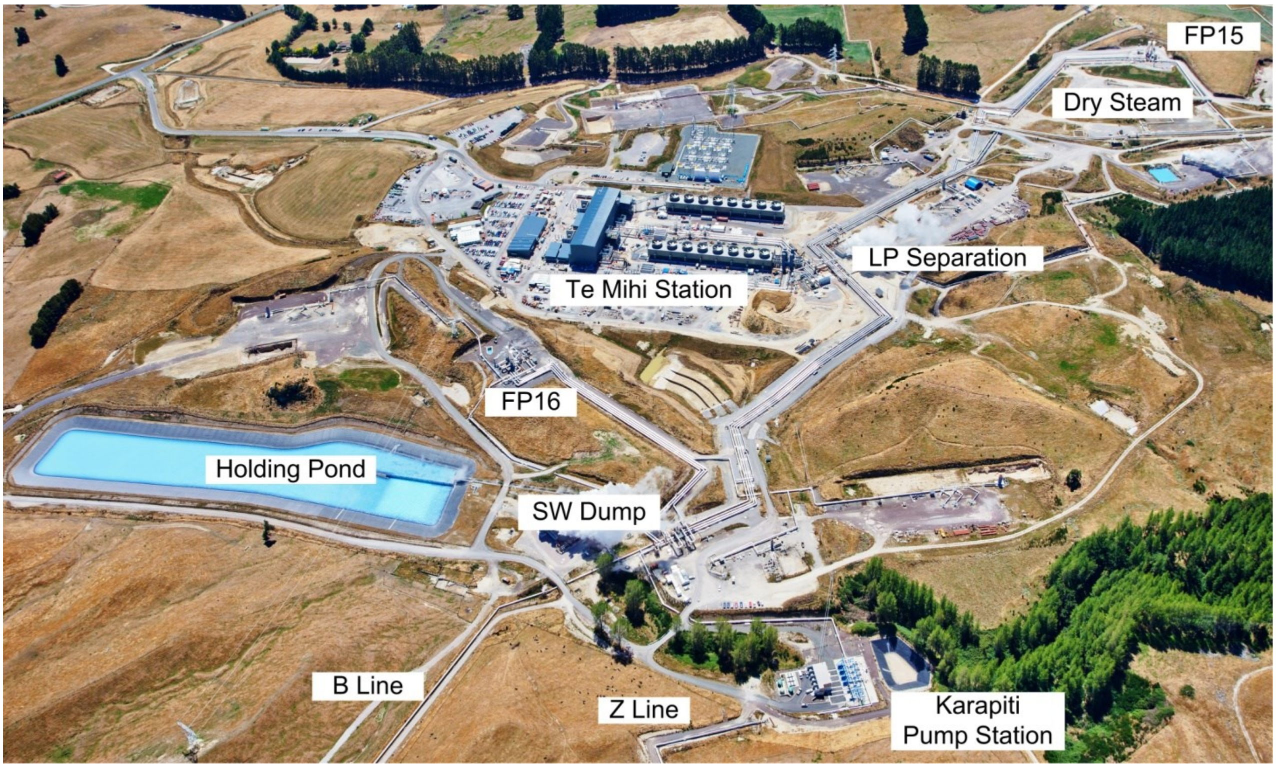

Figure 4: Te Mihi Steamfield Layout

In 2010 a substantial increase in production from central Te Mihi area was planned. This would supply Wairakei, Poihipi and the new Te Mihi Station. The steamfield plant would initially supply the three stations with 1,700 t/hr of IP steam (73 % of total reservoir capability) and 3,900 t/hr LP separated water for 250 MWe generation.

The steamfield now consists of 7 production well pads and 2 flashplants, FP15 and FP16. Five DN1050 IP steam mains, including B Line, supply Te Mihi Station. A common IP separated water pipeline runs between the FP 15, 16 and station (Koorey et al., 2015). Within the Te Mihi Station boundary the IP separated water is flashed to LP steam. LP separated water and cooling tower blowdown (4,200 t/hr) is returned for reinjection.

Te Mihi and Poihipi are more efficient users of steam and therefore the older Wairakei station has lowest priority for the total consented reservoir take of 245,000 tonnes/day. Because of the higher steam pressure needed for Wairakei (refer above) a common pressure was not possible without significant generation penalty. The steam systems were physically divided but to provide outage flexibility and optimisation of production, 7 swing wells can be switched between FP15/16 and FP14 using dual well pad manifolds.

The production wells were spread out north and south of the proposed Te Mihi Power Station site. With multiple choices of flashplant location and configuration, the design settled on a split separator plant setup, with FP15 to the north and FP16 to the south. The deciding factors were higher steam flows in the North to be utilised in the early years, and in later years higher flows into FP16 as the wells were drilled. The separators were located on higher ground with sufficient distance for steam pipeline purity improvement, and lower well connection costs.

Between FP15 and the Karapiti Pump Station runs a pipeline spine corridor passing adjacent to the station. The production wells feed into the top and bottom flashplant nodes. The common steam vent is situated at station delivery point for responsive pressure control. The corridor layout minimises interference with well drilling plans and has lower construction costs.

FP15 and FP16 both have two separators the same size as FP14. Each plant is rated at approximately 110 MWe. FP15 in its layout design has provision for a third separator for the possible third unit in the station. Both flashplants were located on ridges to the north and south of the Te Mihi Station. This allows IPSGW to flow under gravity and steam pressure, to the LP separator inlet flash valves and vessels at the station. The trade off disadvantage is that most of the production wells flow uphill in DN750 & 1050 pipelines that require special procedures to start-up but once at operating flows don't unduly surge.

Figure 5: Flashplant 15 and 16

6.6.1 Steam System

The Te Mihi Station IP steam pressure (4.6 bar.g) is optimised for the long term commercial management of the reservoir and is lower than the Poihipi Station pressure. The steam supply to Poihipi needs to be 1 bar higher than the Te Mihi Steam to avoid an 8 MWe penalty. To supply Poihipi with higher pressure steam FP16 has been built to run as double flash. Two phase fluid enters the first separator which produces IP+ (5.1 bar.g) steam and this is piped to Poihipi in B Line. The separated IP+ water then enters the second vessel and flashes IP steam and IP water. FP16 can also run the two separators in parallel to produce greater IP steam for Te Mihi when required. And Poihipi can also be supplied from the Te Mihi IP steam mains when FP16 is out of service.

The Te Mihi dry steam wells are still in use but all are now connected to FP15. The mixing of the dry steam with two phase fluid cleans the dust from dry steam wells to manage steam chemistry quality. The higher H_2S content steam is removed from Wairakei to better manage its river discharge consent.

Steam pressure control is delivered by the station common and unit IP (3 *100 %) rock pit vents. Production flow trimming is delivered by well group hand remote control valves or swing wells (see below). Steamfield and station overpressure protection is delivered with rupture discs on two phase pipelines upstream of the flashplants. Importantly the availability of a common vent permitted the steamfield to be commissioned ahead of the station to manage time and contractual risk.

With the commissioning of Te Mihi Station, T Line is designated for LP reinjection duty. During Te Mihi outages it can be quickly swapped back to FP14 for production with specific lockout procedures to intermittently raise Wairake's output until the old station is fully retired. This innovative mixed use of large pipelines is not common in the geothermal industry.

6.6.2. Reinjection

LP separated water and cooling tower blowdown from Te Mihi station is all reinjected. Two pipelines either run east through the Wairakei steamfield to the Otupu area (T Line), or run in a high pressure (30 bar.g) DN750 pipeline that runs 6km southeast to the Karapiti area (Z Line). These two lines provide 40 % operating redundancy and reservoir management flexibility. Flow is high at 3,900 t/hr and will grow in the medium term to 4,500 t/hr. The reinjection plant has longer term design provision for a 3rd Te Mihi unit

For abnormal events such as a Te Mihi Station unit trip, the system will adjust the reinjection flow rate to maintain control over the system, escalate if required with spilling to holding pond and allow a quick return to service of the unit. In the event a reinjection pump trips, or some other total event, the holding pond is sized to buffer 20 hours of IP separated and cooling tower blowdown. This will mitigate the risk of forced outages of the three stations supplied. Sulphuric acid dosing at the Te Mihi station is used to control pH and therefore mitigate silica scaling in long pipelines, reinjection wells and reservoir formations. In the event of pH control equipment failure the station LP steam pressure can be temporarily raised to 2.00 bar.g to lower the amorphous silica saturation index (Hudson et la., 2012).

6.6.3. Karapiti Pump Station

The Karapiti reinjection pump station is located 750m from the Te Mihi station and in a valley below the station level. The decision why and where to build the pump station was made by comparing the capital and running costs of a pump station against cost of drilling more wells, the central location to possible future flashplants and the demanding net positive suction head (NPSH) requirements for high speed and hot water pumps. It was estimated that 5 more wells would have been required without a pump station. There is also a high ridge between the station and the Karapiti reinjection wells and without pumps a large cut or tunnel would have been required for gravity reinjection.

The pump station power consumption is large in the geothermal industry. Four separated water pumps, two pond pumps and the auxiliaries are rated at 6 MWe. The design and equipment selection combined the skills and experience of the owner and design consultants. Key features are:

- Selection of API 610 pumps for improved reliability and security
- Stainless steel used for all wetted parts to mitigate possible acid pH dosing corrosion
- Pump evaluation criteria heavily weighted on pump performance rather than capital cost
- Design for maintenance and operation, with significant involvement of Wairakei's staff in design workshops
- Redundancy with 4 by 33% duty separated water pumps and 2 by 100% duty pond pumps
- H_2S gas risk managed with an open pump station design with no pits or low areas
- ABB variable speed drive (VSD) motor technology selected for efficient performance and interface with the distributed control system

This very large pump station has some innovative features, with a closed loop mechanical seal system, and water cooled VSDs. The seal water system recirculates cool clean water to the pump seals, maximising the seal life and pump availability.

The reinjection pumps are controlled via the VSDs to maintain a setpoint in the LPSW vessel at the Te Mihi Station. The control system has the lead pump's speed as the primary control output, with the follower pumps being controlled to match the pump torque input. This use of the torque function in the VSDs balances the pump power as they wear and build-up silica scale.

The project programme and the reinjection drilling programme resulted in pump selection and order prior to the drilling of the reinjection wells. The duty was selected based on somewhat predictable injectivity and the risk mitigation of variable speed, multiple pumps and reserve wells. The pumps had a range of duties including a short 2 year period reinjecting IP separated water while the Te Mihi Station was under construction. The designer was able to optimise the pumping/piping system to provide a solution that allowed one set of pumps to provide both the short term IP reinjection duty (moderate NPSH), and the longer term LP duty (low NPSH). This avoided the need to purchase additional pumps for the interim operating conditions.

The Karapiti pump station and Z line can operate while Te Mihi station is out of service to permit the steamfield to continue to supply Poihipi with IP Steam. Importantly this was also used to commission and operate the steamfield well before the Te Mihi station was completed.

Figure 6: Karapiti Reinjection Pump Station

<u>6.6.4. Holding Pond & Reinjection</u>

A large 72,700m3 holding pond is located 400m south of the Te Mihi station. The pond is 400m by 70m and propylene lined. The pond buffers reinjection flows and the size decision was based upon the cases of pump station trip, consequences like interrupted generation, probabilities and cooling time. The final decision on balance of capital cost and generation was to buffer 95% of events. Normal use of the pond will be start-ups and shutdowns and high separator level protection events. Up scaled atmospheric dumping silencers (< 5 m diameter barrels) release the energy to atmosphere from hydraulically actuated fail open valves. Should the entire reinjection and station trip coincidentally, the flow to the pond is 12,800 t/h for a short period.

Once the water has been stored in the pond it has become oxygenated, cooler, aged and cannot be mixed in any practical flow back into the Karapiti side due to pipeline scaling risk. Cooling tower blowdown further complicates with its low pH and sulphides being corrosive to low carbon steel pipelines. Because of these factors a separate system known as Poihipi Condensate is constructed of 316 stainless, fibre reinforced plastics and High-density Polyethylene (HDPE) materials. The fibre and HDPE has a temperature limit of 40 deg C. for long term life so the pond emptying control strategy considers level and pump intake temperature. It has a variable emptying capacity up to 1,250 t/hr. The 3 condensate wells are located 3 km west in the Poihipi area and a single late addition well in Karapiti, 6 km to the south.

Station cooling tower blowdown has priority and is added to the pond outlet screens ahead of and to moderate the bulk pond temperature. The pond is long and divided by a baffle wall because of terrain and the intent to increase the journey time from inlet to outlet. The opposite end to the outlet is purposely sunken to store a mass of cold water to moderate the initial temperature rise of high inflow situations.

Figure 7: IP+, IP & LP Separated Water Dump Equipment

6.6.5. Control, Electrical & Process Safety

Over the last 30 years manning levels have dropped, automation has increased, and technology costs have come down. This has driven the owner to change from manually reading gauge faces, to Lister Abbey remote telemetry SCADA, to fully integrated distributed control systems (DSC) and programmable logic controllers (PLC). In parallel the 11 kV power distribution capacities were increased to 9 MVA to cope with reinjection pumping load and greater automation, made dual redundant to increase availability and protect against forced outages.

The owner is finishing renewing all its geothermal control and monitoring equipment with a fully integrated ABB 800xA network and PLCs. The owner strongly emphasises that a new station and steamfield joining an existing group of 5 station and 3 steamfield (25,000 instrument tags) must have common DCS software and hardware to enable important process control strategies, simplify commissioning, after hours operation with low manning levels from one central control centre, distributed HMI for steamfield operators, reduce maintenance cost and simplify process data analysis. The HMI with abnormal situation management and aggressive alarm management strategy are used to speed the operator response time. The Te Mihi system communicates on 24 km of blown fibre high speed Ethernet TCP/IP network with dual redundancy fibre. Remote sites join via digital telemetry.

The total reservoir take and discharge flow rates are monitored in real time on the DCS to maximised generation from the fixed daily take. This locally developed software tool permits operation very close (0.5 %) to the ceiling of the limits and also allows optimum recovery from forced and planned outages. It draws data from 200 instrument tags from the wider Wairakei region to visually portray on the HMI the predicted daily usage. This would not have been possible without a fully integrated DCS and alone has benefits of millions of dollars pa and justifies the complexity demanded.

Optimising the reinjection pumping power system led to the selection of four 1200 kW variable speed drives for the main pumps, operating at 690 V AC with water convertor cooling. 415 V units didn't have the capacity and 11 kV was prohibitive due to expensive switchgear and greater building space need. Another optimisation was the design of control strategy chosen that mixed elements of cascade flow, level and temperature control.

High IP & LP separator vessel level was identified as a major accident hazard. To prevent this required safety instrument systems operating at Safety Integrity Level 2 which was implemented on a monitored fibre link with a fixed logic solver, redundant level detection, redundant mechanical valves, with all failing to a safe plant state. The site topography required a secure 2 km link between the water level protection valve station and Flashplant 15.

7. COMMISSIONING

The final design evolution has now been successfully commissioned although delayed by late Te Mihi Station commissioning. This delay was mitigated by the choice of a larger capacity FP14 that was able to maintain full Wairakei Station generation

IP separated water system transients identified early in design have been proven to be small in operation, somewhat due to the system having significantly more capacity for growth than commissioned at.

An unexpected and late reservoir engineering decision to limit the Karapiti wellhead pressures was managed by an additional well, throttling the flow at the wellheads using tandem orifices plates to manage cavitation noise and the variable speed characteristic of pumps. Notwithstanding that the pump characteristic selection work has proven correct and with additional margin capacity for the actual reinjection flows in first year.

No significant changes were made to system process control strategies during commissioning; however the challenge of integrating steamfield and station controls had to be carefully managed around conflicting intents. Successful commissioning was due to many factors absent from other development projects known to the authors. These were: the owner's staff that collaborated on the design also actively managed the commissioning, the process designer wrote the commissioning procedures, the planning was methodical and detailed, there was careful control of the activities between the steamfield and station teams, and plant limits were explored. And ad-hoc and casual approaches to commissioning were not acceptable to the owners' plant safety culture.

8. CONCLUSIONS

The owner’s complex design requirements were met with innovation. The size of plant equipment was scaled up from the conventional to mitigate the complexity and handle the high process flows. Through its history of the development the capital cost savings have been considerable because of foresight and careful plant blending. If the plant had been built conventionally the estimated impact on generation revenue from loss of flexibility and capability would have been between $ 40 to 60 M over the plants lifetime.

Achievement of this conclusion given the challenges can be attributed to close collaboration within a skilled and experienced design team with the owner, the owner had courage to accept managed design risks and there had been stage development.

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REFERENCES

R, Hudson K, G, Morris B, Pummer P, Teamen.:. Te Mihi Geothermal Power Project -- from Inception to Execution Proceedings, New Zealand Geothermal Workshop, Auckland, New Zealand (2012)

K, Koorey K, Harwood N, Lawgun.:. Modelling of the Separated Geothermal Water Flow between Te Mihi Flash Plants Proceedings, World Geothermal Congress 2015, Melbourne, Australia (2015)