

## Kawerau Industrial Direct Heat Use: Recent Developments

Andy Bloomer

50 Hinekura Avenue, Taupo, New Zealand

Andy@GeoEng.co.nz

**Keywords:** Kawerau direct heat

### ABSTRACT

Ngati Tuwharetoa Geothermal Assets Limited (NTGAL) supplies about 340-t/h of raw geothermal steam and 15-t/h of clean steam to the adjacent pulp, paper and timber mills from the Kawerau steamfield. Mighty River Power (MRP) operates the steamfield on behalf of NTGAL. MRP also operates its own 100 MW geothermal power station that was commissioned in 2008; this plant is known as KGL (Kawerau Geothermal Limited).

Geothermal process steam has been supplied to the mills since 1957. The steam is used in the pulp and paper process, for timber drying and for co-generation. Some of the steam is used in heat exchangers to generate clean process steam. An innovative technique developed by Norske Skog Tasman (NST) uses stripped geothermal condensate as feedwater for the heat exchangers.

The industrial direct use at Kawerau accounts for about 56% of all New Zealand's direct geothermal heat use and is the largest industrial direct use in the world. The steamfield is, however, increasingly being used for electricity production.

Recently there has been renewed interest in the use of geothermal steam for industrial processes and NTGAL is working with existing and new users to provide geothermal energy in different forms.

In 2010 NTGAL constructed a purpose-designed, high reliability, heat plant to supply clean steam to SCA's tissue mill. It also uses the NST condensate stripping process to generate feedwater; the process has been further refined.

NTGAL constructed pipelines to supply separated geothermal water (SGW) and steam to a new binary power plant commissioned by NST in December 2012. The SGW used is a by-product of the steam supply and some was previously discharged to the Tarawera River without the heat being extracted.

For the first 50 years of its operation the Kawerau steamfield supplying the mills was contained within an area of around one square kilometre. To increase the steam supply, and because production is moving to the south, in 2013 a new separation plant was commissioned south of the mills. The plant has a capacity of 200 t/h of steam and is fed by a well drilled in 1980 but not used in the interim. Two new reinjection wells have also been drilled out to the northwest. A total of 7 km of pipelines have been constructed to connect the new wells and separation plant, greatly increasing the extent of the working steamfield.

### 1. INTRODUCTION

The Kawerau geothermal field is located at the northern end of the New Zealand's Taupo Volcanic Zone, in the Bay of Plenty. It has been supplying geothermal steam to the adjacent pulp, paper and sawmills since 1957. Most of the energy is used for timber processing, however up to half the steam has been used in a back-pressure steam turbine to generate electricity, with the discharged steam then being used in other mill processes. (White 2009).

Over time mill processes have changed, but also plant has been constructed to make use of energy in the separated water: binary plants, TG1 (2.4 MW(e)) and TG2 (3.5 MW(e)), were constructed in 1989 and 1993. In 2008 MRP commissioned the 100 MW(e) Kawerau Geothermal Limited (KGL) geothermal power plant using steam turbines and drawing from separate production wells. About the same time the 8 MW(e) Geothermal Developments Limited (GDL) binary power plant was commissioned, again using a different set of production and reinjection wells. This paper does not detail those power plants and their steamfield systems.

In 2012 NST constructed the 23 MW(e) TOPP1 binary power plant. This plant uses steam and separated water from the NTGAL steamfield. The cooled, combined separated water and steam condensate is returned to NTGAL for disposal.

NTGA is a member of a Steamfield Management Committee – other members are MRP and NST. New geothermal developments undertaken by these parties are approved within the Steamfield Management Committee. The steamfield operations and reservoir performance are reported to a peer review panel annually.

The NTGAL steamfield currently has six operational production wells (KA19, KA27, KA30, KA35, KA37 and KA47). There are also agreements with MRP to take fluid from MRP's well KA45 and from the KGL two-phase main near the KGL power station.

The two-phase production fluids are separated in five separation plants. Traditionally the steam was sent to the mills and the water was discharged to the Tarawera River, but since 1991 increasing amounts of separated water have been reinjected. There are currently five reinjection wells: KA38, KA39, KA40, KA49 and KA53. The first three are shallow infield wells (drilled to 300 to 380 m and cased to 140 to 160 m) generally taking separated water at about 180°C. KA49 and KA53 are deeper (drilled to about 2,500 m and cased to 1,400 to 1,450 m). These two wells take cooler water, which may be dosed with acid to reduce the risk of silica polymerisation and scaling. However, under typical operating conditions the gas in the steam reduces the pH of the combined, cooled discharge fluid so that scaling does not occur.

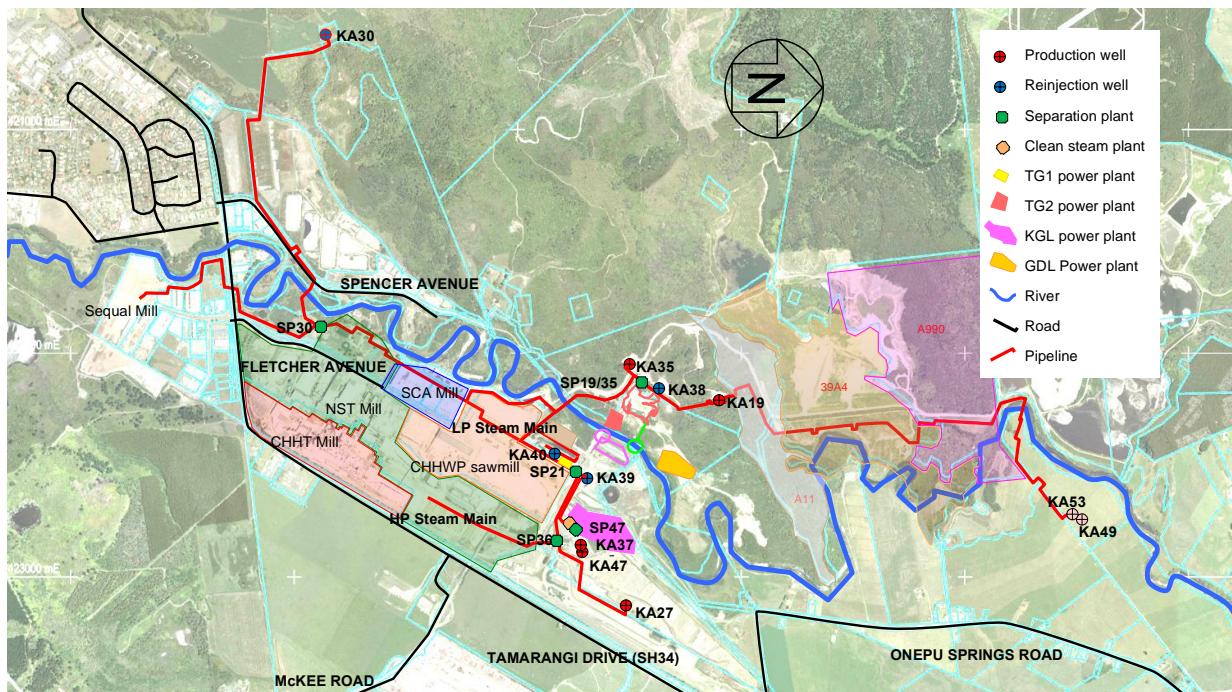


Figure 1 layout: Kawerau NTGAL steamfield

## 2. HISTORICAL STEAM PRODUCTION

Development of the Kawerau geothermal field began in the 1950s in parallel with development at Wairakei. Well output testing began in 1954, with mass flows from testing about seven wells peaking at 5 Mt in 1957, the year that steam was first supplied to the mills. Steam consumed within the mills is shown in the following figure (rather than total steam produced, which included significant test flows in the early years).

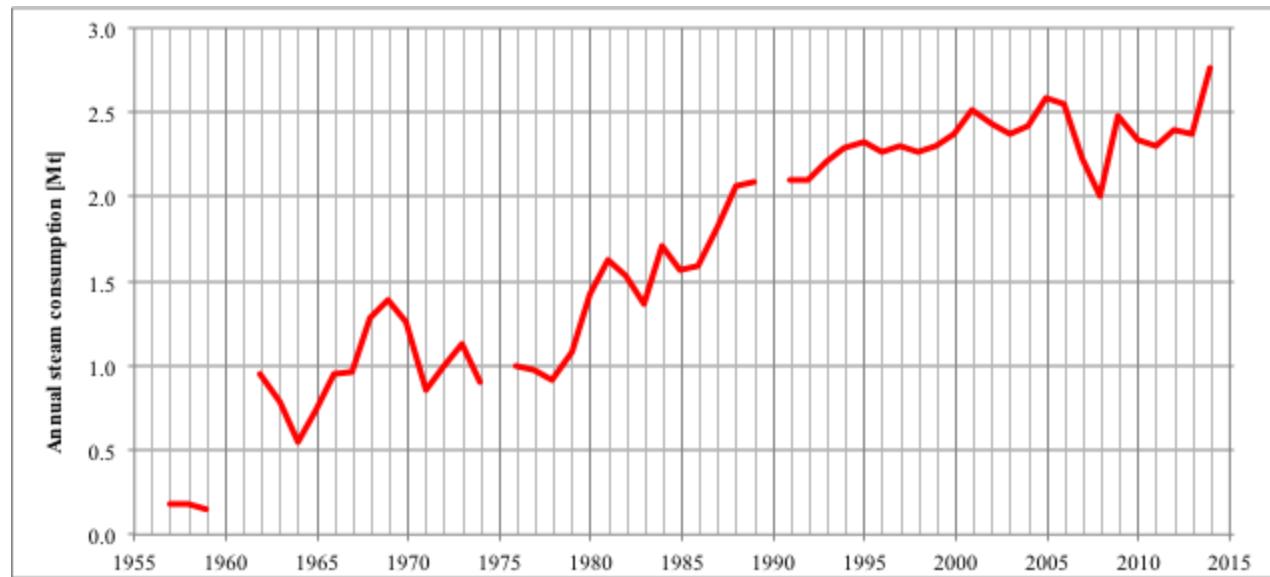


Figure 2: Annual steam consumption 1957 to the present

Figure 2 does not include supply of clean steam or of water for power production in binary plants. The clean steam is about 100,000 t per year and the water totals about 8 Mt per year. Small quantities of two-phase fluids are also supplied to GDL and KGL.

Steam was originally provided at two pressures: the low pressure (LP) steam was at 7 bar g. (100 psi) and the high pressure steam (HP) was at 14 bar g. (200 psi). The majority of the steam is provided through the LP system at 7 bar g.

The HP system, which now typically runs at about 10 bar g., is primarily used in timber drying kilns owned and operated by Carter Holt Harvey Wood Products (CHHWP).

### 3. “CLEAN” STEAM

Geothermal steam contains gases; at Kawerau these are typically about 1.5 to 2% of the steam flow (it has dropped over time from about 3%). The major gas is carbon dioxide, which is about 96% of the geothermal gases. Hydrogen sulphide makes up about 2.5% of the gas. “Clean” steam is steam that has had the geothermal gases stripped out. This process was developed by NST within the mill, where some of the geothermal steam is used to generate clean steam in heat exchangers. Two heat exchangers were installed in the late 1950s. Two further heat exchangers were installed in 1974 and a fifth in 1984. (Hotson, 2007). These heat exchangers were plagued by fouling caused by sometimes poor-quality feedwater. To overcome this, NST developed a process to treat the geothermal steam condensed on the primary side so that it could be used as feedwater on the secondary side. (Joss, Hotson, 1990). The geothermal steam condensate is first flashed then further processed in stripping towers to remove all the carbon dioxide and hydrogen sulphide. The ammonia, being highly soluble, can be retained in the condensate by controlling the amount of stripping steam used. This has the highly desirable consequence of raising the pH, so providing natural corrosion inhibition and reducing or removing the need for treatment chemicals.

### 4. NEW DEVELOPMENTS

Five new developments have been carried out in the last six years to provide energy to new customers and to provide for changes in production and reinjection.

#### 4.1 Clean steam for SCA’s tissue mill

SCA manufactures tissue at its mill in Kawerau. The energy source was primarily natural gas, but in 2010 NTGAL commissioned a plant to supply up to 26 t/h of clean or gas-free steam to SCA, replacing the steam from gas-fired boilers. (Moore 2011). Apart from the heat exchange process to generate clean steam, the plant was also innovative for NTGAL in that it ran at significantly higher pressures than were typical. To generate the 16 bar g. clean steam geothermal steam was separated at 22 bar g. However, this suited the main supply well, KA47, which was running in a throttled condition to prevent boiling in the formation. This boiling had led to calcite deposition. The two-phase fluid is taken from upstream of the throttling valve to be separated in a new separation plant, SP47, constructed specifically for the clean steam process. The separated water at 22 bar g., is flashed and injected into the adjacent two-phase main, which feeds the LP separation plant SP21, so extracting more steam from the fluid.

The separation plant and heat exchangers are duplicated so that one half of the plant can be taken out of service for inspection or repair, without disrupting supply to SCA. SCA usually operates 363 days a year, 24 hours a day. One half of the plant can separate up to 35 t/h of geothermal steam at an operating pressure of 22 bar g.

The separation plant has also been designed so that one separator can be used to provide 75 t/h of HP steam to back up or supplement the existing single HP separation plant, SP36.

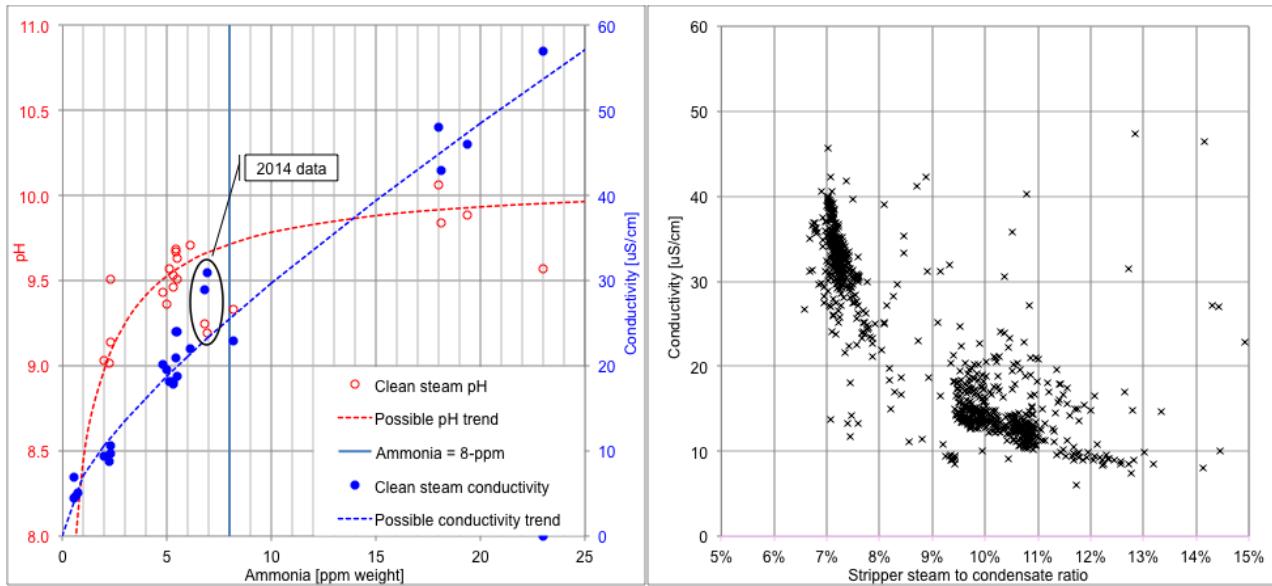


**Figure 3: Clean steam plant**

The photograph shows the twin separators with separate water vessels on the right, feeding the twin paired heat exchangers and adjacent preheaters (the preheaters, being relatively small, are behind and obscured by the heat exchangers). The twin stripping columns and vents from the flash vessels are behind the heat exchangers. The feedwater storage tank and control room are to the left, the elevated feedwater tank is visible behind the stripping towers, and the flash vessels are obscured behind the heat exchangers.

The clean steam plant uses the NST process, where the condensed geothermal steam is first flashed to atmospheric pressure then further stripped in twin stripping towers, which were duplicated for reliability as with most of the rest of the plant. Although the process followed the NST system, because of the higher operating pressure and slightly different stripping process, the process was modelled by GNS (Lind, Carey 2009). The modelling showed that the proposed system would work and was likely to generate a slight excess of condensate under most operating conditions. The chemistry was also modelled. (Mroczeck, 2009). During commissioning, trials were undertaken to determine the optimum levels of ammonia for pH control. It was found that there was a

good correlation between residual ammonia, pH and conductivity (Figure 4). Conductivity was then used as a proxy for pH to determine and to adjust the stripping rates.



**Figure 4: Relation between conductivity, pH, ammonia and stripping steam**

#### 4.2 Steam and water connections for NST's binary plant

NST commissioned a 23 MW(e) binary power plant, TOPP1, in December 2012. This power plant uses 115 t/h of steam and 600 t/h of separated water, both of which are supplied to the power plant by NTGAL. Supply of these fluids required modification to three of the existing separation plants and also construction of the new separation plant, SP30, as described below. (McPherson, 2013). The water from all four separation plants is combined. The separation plants all operate at slightly different pressures set by the pressure drop in the steam line between each plant and the NST supply point. Consequently the pressure in the water supply manifold is set a little below the lowest pressure of the four separation plants. This results in some minor flashing in the separated water, so to ensure that only liquid water is supplied to the binary plant preheaters, a separator was incorporated into the water supply manifold immediately before the plant.

The cooled combined condensed steam and separated water is returned to NTGAL for disposal. Part of the returned fluid is reinjected into well KA49 or KA53 (refer below), with the remainder being discharged via a cooling channel into the Tarawera River. The proportion discharged to the river is approximately the same as the amount that was originally discharged directly, but which has now had the temperature reduced from being diverted through TOPP1. The discharges to the Tarawera River need to comply with resource consent limits on mass flow, temperature and chemical content. To reduce the temperature of SGW discharged to the Tarawera River from the east bank a serpentine channel about 1,000 m long was constructed in 1989. This replaced the direct channel, which was about 60 m long. This had the effect of reducing the heat load by about 12 MW and reducing the hydrogen sulphide discharge by about 90%. (Wigley 1993).

Chemical modelling had shown that this fluid, which was at 85°C, was likely to result in silica polymerization and consequently scaling in pipelines and wells. To reduce the risk of such scaling an acid dosing plant was incorporated into the reinjection system to control the pH in the range of 4.5 to 5.0 pH units. The plant was modelled on the plant installed at the KGL power plant, although the conditions of the fluid being treated were significantly different. Whereas the KGL fluid is at moderate temperature and saturated, the TOPP1 fluid is sub-cooled. This makes dosing more tolerant to changes in process. A series of trials were carried out during commissioning to confirm the chemical modelling and the silica polymerization. These tests showed that the condensed steam naturally lowered the combined fluid pH and under normal operating conditions polymerization did not occur for four hours or more. This meant that the fluid had adequate time to travel through the reinjection pipeline and down the wells into the formation with very low risk of deposition.

#### 4.3 Separation plant SP30 and connections to KA30 and KA45

For the first 50 years of production the NTGAL steamfield drew fluids from a relatively small area of the field located to the north of the mills. However, continuing enthalpy and production declines from the late 2000s indicated that production should move to the south of the mills. An investigation programme carried out in the 1970s and early 1980s had included wells to the southwest, south and southeast of the mills (KA30, KA34, KA26 and KA29). KA30, in particular, drilled in 1980 was a large producer, producing over 100 t/h of separated steam during a short discharge test. However because of the distance to NTGAs main production system, KA30 was not connected at the time of drilling.

When additional steam was required for TOPP1 and to make up for production declines, NTGAL determined to construct a new separation plant closer to the proposed new centre of production. Consequently SP30, a separation plant with a capacity to produce 200 t/h of steam, was completed in January 2013. The separation plant uses a conventional single cyclone type separator, 2.400 m diameter and about 15 m tall, with a spiral inlet and an integral water drum. A calcite antiscalant system is used in KA30. The

chemical is mixed in a plant at SP30 and pumped from there to the well. The same system will also be used for future production wells feeding SP30

Well KA30 located about 1.5 km W of the mill was the first well connected to SP30 via a 1.75 km DN600 two-phase pipeline. The pipeline crosses the Tarawera River with a long cable-stayed span.



**Figure 5: KA30 two-phase pipeline spanning the Tarawera River**

KA30 has proved to be an excellent producer, producing well over 100 t/h of steam separated at 7 bar g., despite having sat unused for over 30 years.

A two-phase pipeline has also been constructed from MRP's well KA45. This will be used to make up steam during periods of shortfall in the NTGAL system. The well can supply up to 400 t/h of two-phase fluid.

The steam from SP30 is piped through a DN600 pipeline to the LP steam main just upstream of the NST terminal point in the NST car park, a distance of about 380 m. A pressure control valve has been installed here so that SP30 can be run at slightly higher pressure, if this is required to drive the separated water to TOPP1. The separation plant design pressure is 12 bar g.

The separated water is piped in a DN400 pipeline about 1,200 m to TOPP1. There is a bypass at TOPP1 so that a limited amount of separated water from SP30 may be bypassed to the cooling channel, however generally all SP30 water is directed to TOPP1 and consequently SP30 has the top priority for water supply as the other separation plants have alternative water disposal paths. Design and construction of this pipeline was particularly complex owing to the very narrow corridor through the industrial area, which was already congested with geothermal pipelines and other services.

SP30 has an adjacent discharge pond to take SGW during start up and at times of plant upset. The pond is unlined and the water dissipates by soakage and evaporation.

#### 4.4 New reinjection wells KA49 and KA53 and 4 km connecting pipeline

When the steamfield was first developed in the 1950s, all well test discharges, all separated water and all spent condensate was discharged to the Tarawera River. Over time these discharges have reduced; for example steam condensate is used in mill processes. Reinjection of about 200 t/h of the separated water commenced in 1991 to a shallow infield well, KAM1. This was done partly to maintain pressures in the shallow geothermal aquifer. The initial well declined in injectivity, owing to injection of cooler separated water causing silica scaling in the formation. Three subsequent shallow reinjection wells were drilled and the mass of water reinjected increased.

In 2012 – 2013 NTGAL drilled two outfield deep wells, KA49 and KA53. These were drilled to increase the total amount of fluid injected and to move towards deep injection. The shallow injection will be continued to maintain the shallow pressures. The initial use of wells KA49 and KA53 is to accept cooled fluid from TOPP1.

A DN500 reinjection main, about 3.6 km long, was constructed from TOPP1 to the KA49-KA53 well pad. Pumps are not used for injection of fluids but provision has been made for adding pumps in future, to increase the reinjection main capacity or if different pressure fluid streams are to be combined.

Although the route is relatively straight, it involved crossing over a ridge about 50 m higher than TOPP1 and a crossing of the Tarawera River. The ridge crossing means that the TOPP1 discharge pressure must be above about 5.5 bar g. to drive the fluid without flashing. However, the fluid does de-gas with the drop in pressure so an automatic gas vent is installed at the high point. Without this vent, vapour locks form, greatly restricting the reinjection flow.

The Tarawera River was crossed by piggybacking on an existing pipeline bridge; that bridge carries the NST-CHH sewer to the water treatment plant. A separate small stream was crossed and although the pipeline could span the stream, it was incorporated within a pedestrian bridge for aesthetic reasons.



**Figure 6: Reinjection pipeline concealed within pedestrian bridge structure**

#### **4.5 Sequal steam supply for timber drying**

NTGAL has recently contracted to supply steam to Sequal Lumber for use in timber drying kilns. Up to 30 t/h of raw geothermal steam will be supplied from SP30 at 7 bar g. The condensate will be returned to NTGAL for disposal. At the time of writing (May 2014) the supply pipelines are being tendered and details of the kilns have not been confirmed. It is likely that the kilns will be constructed in stages over two or three years, with the first likely to be commissioned in late 2014.

The steam pipeline will be DN300 about 1.4 km long. The condensate return pipeline, following the same route will be DN80. The condensate will be injected into the separated water line running from SP30 to TOPP1, but if the separated water flow is too low, the condensate will be discharged into the SP30 pond and pumped from there for disposal into the east cooling channel or west lagoon.

### **5. ELECTRICITY PRODUCTION**

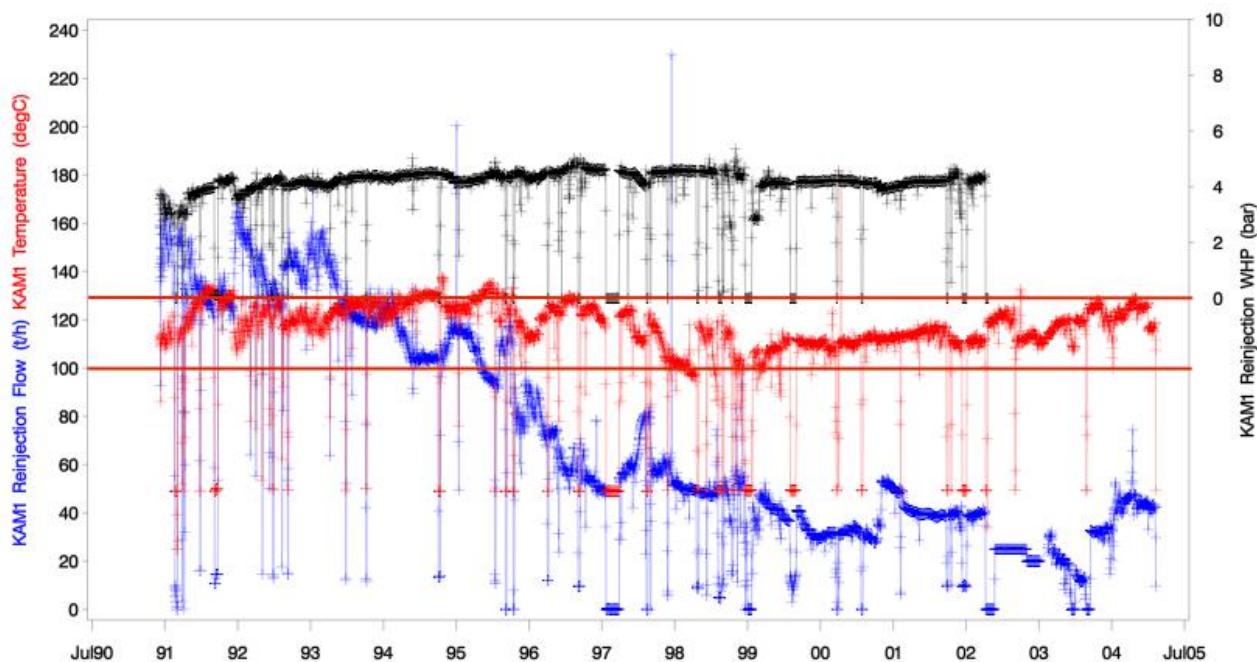
Although the original primary use for geothermal steam from the Kawerau field was for process heat within the pulp and paper mills, for a long period some was used in a back-pressure steam turbine to generate electricity for mill use. In this case the exhaust steam was further used in mill processes; in a liquor pre-evaporator, water heater and condensate stripper. (Hotson 2000), but would also be dumped to atmosphere if necessary. More recently electricity production has taken an increasingly significant part in the use of the geothermal energy. Otherwise unused separated geothermal water has been used to generate electricity in two small binary power plants. The construction of the 100 MW(e) steam turbine KGL power station in 2008 (Horie 2010, Foong 2010) was a significant change in both energy use and production rate in the Kawerau field. The 8 MW(e) Geothermal Developments (GDL) binary power plant was commissioned at about the same time, using two-phase fluids from a single production well, KA24. KGL and GDL power stations have their own consents to supply their own energy however, NTGA does have an arrangement to provide top up two-phase supply as required.

#### **5.1 Mill turbo-alternator**

The mill currently has a single 8 MW(e) backpressure steam turbine using geothermal steam. The turbine was installed in 2004, replacing a turbine installed in 1966. This turbine was used to balance steam flows as steam flows fluctuated within the mill to meet the demands of the paper machines. The mill has two other steam turbines, using process steam generated from hog fuel, black liquor or oil. (Hotson, 2000).

#### **5.2 Binary power plants TG1 and TG2**

Two relatively small Ormat binary plants have been constructed to use the energy from otherwise waste separated water. The first of these, the 2.4 MW(e) TG1 was commissioned in 1989 and uses water from the adjacent separation plant, SP21. It uses up to about 280 t/h of water at about 180°C and was designed to discharge the water at 130°C, which was determined to be a sufficiently high temperature to minimise the risk of silica scaling in downstream piping and reinjection wells. However, the plant typically takes the water down to a lower temperature. Initially the cooled water was discharged into a shallow reinjection well, KAM1, but over about ten years the injectivity reduced from 180 t/h to less than 50 t/h. The well was decommissioned and now the TG1 discharge water is discharged to a cooling channel and so to the Tarawera River.



**Figure 7: Reinjection well KAM1 flow and reinjectate temperature**

The second plant, the 3.5MW(e) TG2, was commissioned in 1993 and takes water from SP35. The cooled water, typically at less than 100°C is discharged to the adjacent west lagoon. The water from the lagoon flows into or around bathing pools before flowing into the Tarawera River. The area used to include the large chloride spring Umapokapoka, but the spring declined and stopped flowing in the early part of the twentieth century, probably as a result of lowered groundwater levels caused by down cutting of the Tarawera River.

### 5.3 Kawerau Geothermal Limited's 100 MW steam turbine

MRP commissioned its 100 MW(e) KGL power plant in 2008. The plant uses a double pressure steam turbine and forced draft wet cooling tower. The plant draws from production wells that are separate from the NTGAL wells, which supply the mills. However, there is a cross connection from the NTGAL steam supply system, so that KGL may take two-phase fluids from NTGAL when required.

### 5.4 GDL 8 MW binary power plant

GDL commissioned an 8 MW(e) Ormat binary power plant in 2008. The plant uses two-phase fluid from a single production well, KA24, which was drilled to a depth of 1,280 m in 1976. Cooled fluid is reinjected into one of two shallow wells, GDL1 or GDL2, located to the north and drilled to a depth of 300 m. NTGAL can supply this plant with additional two-phase fluid via a connection from the KA19 two-phase line.

### 5.5 NST 23 MW binary power plant

The fourth Ormat binary power plant at Kawerau is NST's 23 MW(e) plant, TOPP1, commissioned in December 2012. The plant produces about 21 MW(e) net. The fluid supply system is described above. The plant uses two isopentane turbines driving a common generator. The system is further described in McPherson, 2013.

## 6. NON-INDUSTRIAL USES

Other direct heat, but non-industrial, uses of geothermal energy at Kawerau includes bathing and glasshouse heating.

### 6.1 Bathing

Local people have used the geothermal water for bathing for generations. Formerly the outflow from a large natural spring, Umapokapoka was used. This is located near the middle of what is now the industrial development of the Kawerau geothermal field. As described above, this spring declined and the source of hot geothermal water is now the separation plants SP19 and SP35 that discharge surplus separated hot water into the lagoon area, along with the discharge from TG2 that is typically between 90 and 100°C.

The Kawerau District Council operates a heated pool complex in the middle of the Kawerau township. The pools were originally constructed in 1955. In 2008 a large spa pool was constructed; it is heated by geothermal steam passing through a heat exchanger.

### 6.2 Greenhouses

Two greenhouses using geothermal energy have been operated in the past. The first was constructed in 1982, the second in 1994. They used relatively modest amounts of steam. (Dunstall, 1998). Both have since been closed.

Further large-scale geothermally heated greenhouses for Kawerau are being investigated.

## CONCLUSION

The Kawerau geothermal field has been providing steam for industrial process for almost sixty years. In the last six years two new users of steam for industrial process have been connected. Increasingly, however, the energy is used for electricity production, with KGL's 100 MW steam turbine, GDL's 8 MW binary plant and NST's 23 MW binary plant having been commissioned in the last seven years. Two developments against this trend are the conversion of SCA's gas fired boilers to geothermal steam and Sequal's new timber drying kilns, again using geothermal steam.

The new customers and construction of TOPP1 has resulted in a step change in the supply of steam to NST and other users. In parallel with supplying new customers, other significant developments in the NTGAL steamfield are connection of KA30 to provide energy from south-west of the field's developed main system, construction of a new 200 t/h separation plant to use fluids from southern wells and drilling and connecting two new deep reinjection wells, several km to the north of the old steamfield. This has greatly increased the area of the developed NTGAL steamfield.

Although the three major plant owners on the field operate essentially separate operations, reservoir management is integrated and cross-connections between the production systems have been incorporated.

## REFERENCES

Bloomer A.: Kawerau Geothermal Development: A Case Study, *GHC Bulletin*, September 1998.

Carter, A. C. and Hotson, G. W.: Industrial Use of Geothermal Energy at the Tasman Pulp & Paper Co., Ltd.'s Mill, Kawerau, New Zealand, *Geothermics*, Vol. 21, No. 5/6, October/December 1992.

Dunstall, M., Foster, B.: Geothermal greenhouses at Kawerau. *Geo-Heat Center Quarterly Bulletin* 19 (3), 21-23, 1998.

Foong, K. C., Valavil, J., Rock, M.: Design and Construction of the Kawerau Steam Field, *Proceedings World Geothermal Congress*, April 2010.

Horie, T., Muto, T., Gray, T.: technical Features of the Kawerau Geothermal Power Station, New Zealand, *Proceedings World Geothermal Congress*, April 2010.

Hotson, J. Review and History of the Operation of the Geothermal Heat Exchangers at the Kawerau Mill Site, unpublished report for NTGAL, August 2007.

Hotson, G. W. and Everett, G.: Energy Model for an Industrial Plant Using geothermal Steam in New Zealand, *Proceedings World Geothermal Congress*, June 2000.

Joss, S., Hotson, J.: Boiler Feed Quality Water from Geothermal Steam, APPITA (1990).

Lind, L., Carey, B., Process Analysis for the NTGA clean steam supply to SCA. GNS Science Letter Report No: 2009/162LR for NTGAL, 2009.

McPherson, G., Koorey K.: Kawerau TOPP1 Geothermal Fluid Supply, *Transactions NZ Geothermal Workshop*, November 2013.

Mroczeck, E.: NTGA steam supply: condensate stripper chemistry. GNS Science Letter Report No: 2009/78LR for NTGAL, 2009.

Moore, G: Ngati Tuwharetoa Geothermal Assets Clean Steam Supply to SCA Hygiene Australasia's Kawerau Tissue Mill, *Transactions NZ Geothermal Workshop*, November 2011.

White, B.: An Updated Assessment of Geothermal Direct Heat Use in New Zealand, New Zealand Geothermal Association, June 2009.

Wigley, D. M., Stevens, L.: Developments in Kawerau Geothermal Field, *Proceedings NZ Geothermal Workshop*, November 1993.