ASSESSMENT OF PRESENT TAKE AND UTILISATION OF THE TOKAANU THERMAL BATH-HOUSE

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SUMMARY – The Tokaanu geothermal bath-house is located in an active part of the Tokaanu-Hipaua-Waihi thermal system. It is of high cultural importance and a viable commercial asset. The bath house utilises natural thermal spring water and bore water from a shallow well. Recent studies have indicated that the loss of pressure in the shallow reservoir due to the abstraction of water near the bath-house is partly responsible for the recent decline of the natural features in the Tokaanu reserve. This work focuses on the assessment of the current level of utilisation of the geothermal fluid and provides recommendations for a more efficient use of the available energy. This can minimise the abstraction of bore fluid to help the pressure recovery of the shallow reservoir while maintaining the operation of the bath-house.

1. INTRODUCTION

The Tokaanu geothermal bath-house is located in an active part of the Tokaanu-Hipaua-Waihi thermal system. It has a high cultural importance. The bath-house has been operating for the past 70 yeas. It is a commercially viable asset as a popular destination for about 130,000 visitors every year.

The Tokaanu thermal bath-house consists of 13 private pools (10 m^3 each) and two open- air public pools (a large 135.0 m^3 pool and a 13.0 m^3 toddler's pool). The private pools use geothermal mineral water while the public pools use heated fresh water (chlorine treated) from the Tupatomatua stream. A shallow (49 m deep) geothermal well (B8-N also referred to as BH-8 new) with a 4" (~100 mm) casing (Figure 1) produces a two-phase (steam and water) fluid. This fluid, referred to in this report as "type 1" fluid, is discharged naturally from springs and pools along a narrow 250 m long zone between Taumatapuhipuhi geyser and Te Ngutu pool in the Tokaanu Thermal Reserve. It has a chemical composition with a uniquely high level of dissolved minerals that distinguishes it from type 2 water in Paurini Pool and type 3 water (diluted type 2 water) discharged in the Tokaanu wetlands and Waihi foreshore (Hochstein et al. 2008). B8-N provides the heat to the public pools through two separate heat exchanger systems. The type 1 two-phase fluid condensates are then used to heat 5 private pools. Geothermal water (type 2) from the Paurini Pool is utilised to heat the other 8 private pools. Gravity driven (no pump) water flows inside a 150 mm diameter (6") PVC pipe about 240 m long (Figure2 & Figure 3).

Hochstein et al. (2008) pointed out that the loss of pressure in the shallow reservoir due to the abstraction of type 1 water near the bath-house (since 1966) is partly responsible for the recent decline of the natural features in the Reserve.

Figure 1. Well B8-N produces two phase (type-1) fluid (i.e. steam and liquid) to heat the public pools and 5 private pools.

The focus of this work is to assess the current level of utilisation of the geothermal fluid and provide recommendations for a more efficient use of the available energy. The aim is to show how the utilisation of type 1 water could be reduced to help the pressure recovery of the shallow reservoir while maintaining the operation of the bath-house.

This work is part of a project undertaken by the Department of Conservation (DoC) aimed at investigating the feasibility of restoring rare thermal features at Tokaanu that have been declining over the past 100 years.

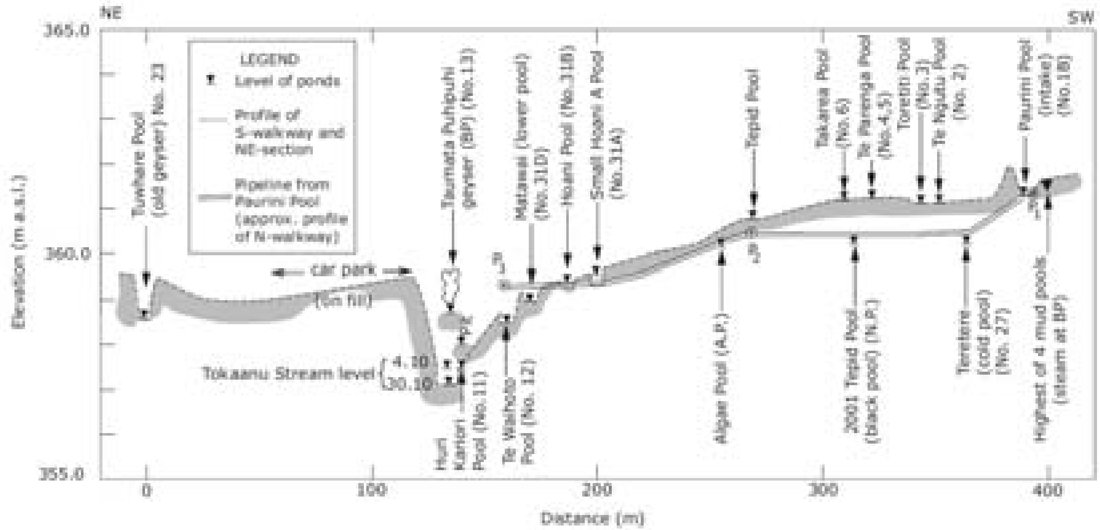

Figure 2. Section of Tokaanu Thermal Park showing elevation (level) of pools and waterways (From Hochstein, 2008)

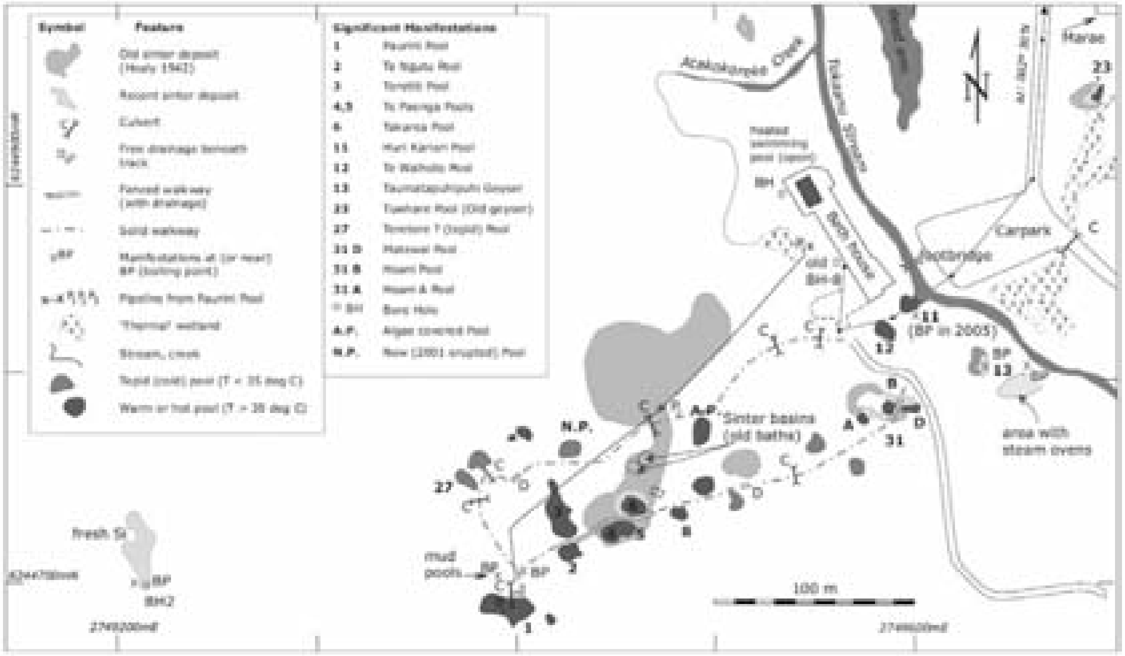

Figure 3. Map (1:2000 scale) of thermal manifestations of Tokaanu Thermal Park (From Hochstein, 2008)

2. HEAT LOSS FROM THE PUBLIC POOLS (HEAT LOAD)

Most of the thermal calculations listed below are based on winter conditions when heat load is at its maximum. The calculations are also made on the basis of 100 % all year round operation of both public and private pools at maximum operation temperatures. It does not take into consideration the reduced take when some of the private pools are closed during periods of low demand. (The calculations given in this report are based on available data and are intended to give good estimates only.)

The exposed surface of the open pools accounts for the main heat loss from the two public pools (main pool and toddler pool). Calculating the maximum heat loss is equivalent to the amount of heat needed to keep the pool temperature constant during operation.

The heat balance equation can be written as:

$$\sum Q_{in} = \sum Q_{out} \tag{1}$$

where:

$\sum Q_{in}$ is the sum of the heat gain components:

$$\sum Q_{in} = Q_{ir} + Q_{add} \tag{2}$$

Q_{ir} Heat gained by solar radiation (month of June) is about 80 W/m^2 for Rotorua taken from the data of the NZ Meteorological service (1983) (Hochstein and Prebble 2006).

Q_{add} Heat added (heat load) to keep the pool temperature constant.

$\sum Q_{out}$ is the sum of heat lost components:

$$\sum Q_{out} = Q_e + Q_{br} + Q_r + Q_{cond} \quad (3)$$

Q_e Heat lost by evaporation, comprising losses through conduction, free convection and forced convection (due to wind) at the water surface. Q_e is about 1.2 kW/m^2 for pool temperature of 40 $^\circ C$ and surface area calibrated for the Tokaanu area using meteorological parameters in winter conditions (Hochstein and Prebble 2006).

Q_{br} Heat lost by back radiation is about 0.2 kW/m^2 for pool temperature of 40 $^\circ C$ and surface area calibrated for the Tokaanu area in winter conditions (Hochstein and Prebble 2006).

Q_r Heat lost due to rain. Rain is sporadic, represents a small input and will be ignored. Q_r =0 (Hochstein and Prebble 2006).

Q_{cond} Heat lost through the pools walls by thermal conduction to the ground.

$$Q_{cond} = \frac{kA}{d}\Delta T \quad (4)$$

From above the heat added (required) is:

$$Q_{add} = Q_e + Q_{br} + Q_r + Q_{cond} - Q_{ir} \quad (5)$$

2.1 Main Pool

This measures 7 m × 17 m (open surface area 119 m^2), and has a total volume of 135 m^3 with the total area of the side walls and base about 179 m^2.

Q_e = 142.0 kW
Q_{br} = 23.7 kW
Q_{ir} = 9.5 kW
Q_{cond} = 12.2 kW

Using equation (5) Q_{add} = 168.4 kW.

2.2 Small Pool

This measures 4 m × 6 m (open surface area 24 m^2), with total volume 13 m^3 and side walls and base area 35 m^2.
Q_e = 28.8 kW
Q_{br} = 4.8 kW
Q_{ir} = 1.9 kW
Q_{cond} = 2.4 kW

Using equation (5) Q_{add} = 34.1 kW

2.3 Balancing tank

There are also heat losses from the covered balancing tank which is used for holding, heating and adding makeup water to the public pools. This tank has an open surface area 12.3 m^2, total volume 12 m^3 and side walls and base area 27 m^2.

Q_e = 14.4 kW
Q_{br} = 0.0 kW
Q_{ir} = 0.0 kW
Q_{cond} = 1.8 kW

Using equation (5) Q_{add} = 16.2 kW

2.4 Pipe lines

The heat loss through the pipe lines between the public pools and the pump house is estimated to be 3.0 kW (due to the short distance of the pipe and since some part of the pipe is buried underground).

2.5 Maximum heat load

Adding all the losses estimated above (2.1-2.4), the maximum heat load required to keep the public pools at around 40-39 $^\circ C$ during winter time is about:

$$Q_{add} = 221.7 \text{ kW}$$

The heat load can drop by 50 % during summer time.

2.6 Maximum pool loss in winter

The approximate pool losses (main pool) in 8 hours shutdown during a cold winter night can be assessed. If the back radiation component in 2.1 is neglected, the specific loss is (168.4 – 9.5) kJ/s.
Over 8 hours the total loss would be: $q_{lost} = 158.9 \times (60 \times 60 \times 8)$ kJ = 4.57×10^6 kJ.

The total energy stored in the pool is:

$$q = V \rho h \tag{6}$$

The unit for q is [kJ], the unit of water volume V is [m^3], that of water density ρ is [kg/ m^3], and the unit of enthalpy h of a liquid is [kJ/kg] with h depending on the water temperature T (h and ρ are listed in standard steam tables, see Zarrouk and Watson, 2008).

For a pool temperature $T_1 = 40\ ^\circ C$ at shutdown, the stored total energy q_1 is:

$$q_1 = 135 \text{x} 992.2 \text{x} 167.5 = 22.44 \times 10^6 \text{ kJ.}$$

The total energy q_2 after 8 hours of cooling at night is:

$$q_2 = q_1 - q_{lost} = 17.87 \times 10^6 \text{ kJ.}$$

Neglecting a minor change in water density, the change in enthalpy h is proportional to the change in total energy. Hence $h_2 = (q_2/q_1)\ h_1$ = 133 kJ/kg, yielding a water temperature T_2 of 32 $^\circ C$ after 8 hours of cooling.

(The morning temperature T_2 would be higher during summer time.)

The heat losses from the private pools do not have to be considered since the water leaving these pools is not used again (open system); these pools are emptied during the night.

3. PRIVATE POOLS WATER USE (LOAD)

Each private pool is about 10.0 m^3 in volume (private communications with Mr. Bob Hayes, Tokaanu bath-house manager) and the total filled volume for all 13 private pools is 130 m^3. For 16 hours (from 6:30 am to 10:30 pm) operation of the bath house with water turn-over every 4 hours ((Marshall and Eagles 2007), the total daily mineral water needed is about 520 m^3 or 8.95 kg/sec (at 42 $^\circ C$) during the 16 hour operation or an average of 6 kg/sec per day (24 hours).

At present this water is a mixture of cold water and type 2 water from the Paurini Pool, plus a mixture of cold water and steam condensates from bore-hole B8-N. The use of these two sources of water and heat offers the advantage of flexibility in the operation of the private pools (Bob Hayes, personal communication). Any modification to this would need to provide similar advantages in terms of availability of hot water.

Paurini Pool:
The current thermal water production from the Paurini pool is about 6.6 l/s (6.5 kg/sec at 60 $^\circ C$) measured at the bath–house over 16 hours of daily operation (Marshall and Eagles 2007). During the night, when the main valve at the bath-house (Figure 4) is shut, the water is spilled (through an opening in the pipe) over the old sinter flat near point P2 (Figure 2 and Figure 3). Therefore, it is estimated that water flow rate from the Paurini pool is continuous at 6.5 kg/sec for 24 hours a day and the actual daily production from the Paurini pool is about 570 m^3/day of water at 60 $^\circ C$.

Thus the total daily (over 24 hours) water production from the Paurini Pool (570 m^3) is more than the total daily (over 16 hours) volume of water required for heating the private pools (520 m^3). Having a storage tank at the bath house collecting the nightly flow would allow a steady water supply to the private pools and reduce the take.
It is important to obtain accurate measurements of the total daily water production from the Paurini Pool including the water loss over the old sinter flat during the night.

Figure 4. The PVC pipeline and 150 mm isolation valve for the Paurini pool water near the bath-house.

3.1 Current use of Paurini water

Type 2 water from the Paurini Pool is currently being used at the bath-house to heat 8 private pools through mixing with fresh cold water from the Tupatomatua stream (Figure 5).

Figure 5. Type 2 water (from the Paurini pool) mixing tank with leakage indicated by arrows.

Eight private pools require 5.51 kg/sec of mineral water at $42^{\circ}C$ (10 m^3 per pool and four hours turn over). It can be assumed that the Tupatomatua stream temperature in winter is $10^{\circ}C$ (measured summer temperature at the bath-house house was 20-21 $^{\circ}C$).

From energy and mass balance at the mixing tank for winter conditions:

$$\dot{m}_{Paurini} + \dot{m}_{Tupato} = \dot{m}_{private} \tag{7}$$

$$\dot{m}_{Paurini}.h_{Paurini} + \dot{m}_{Tupato}.h_{Tupato} = \dot{m}_{private}.h_{private} \tag{8}$$

where:

$$\dot{m}_{private} = \frac{8 \times 10}{4 \times 3600} \times 991.41 = 5.51 \ kg/\sec$$

$$h_{Paurini} = 251.2 \ kJ/kg$$

$$h_{Tupato} = 42.0 \ kJ/kg$$

$$h_{private} = 175.9 \ kJ/kg$$

From equations 7 and 8 above, the mass proportion of water needed $\dot{m}_{Paurini} = 3.51$ kg/sec of Paurini water and $\dot{m}_{Tupato} = 2$ kg/sec of cold fresh Tupatomatua stream water.

Based on a 6.5 kg/sec water flow rate from the Paurini pool, about 46 % heat and mass are not utilised at the bath-house during the (16 hours) day and 100 % during the night (8 hours). A small amount of this mass is lost through leakage in the mixing tank (Figure 5).

It is possible that the current water turn-over rate at the private pools is less than 4 hours, since there are no actual flow measurement data available. Direct measurement of water flow rates through the pools would be required to be more accurate and would improve calculations for energy conservation.

Improving the thermal utilisation of Paurini water

A plate type heat exchanger system could be used to reduce the temperature of the Paurini water from $60^\circ C$ to $45^\circ C$ while heating the public pool water to up to 40-42$^\circ C$. At these temperatures there would be no silica deposition from Paurini water inside such a heat exchanger (see section 5 below).

The thermal energy available is:

$$Q = \dot{m}(\Delta h) \qquad (9)$$

where:

$\dot{m} = 6.5 \ kg/\sec$

$\Delta h = (251.2 - 188.4)$

The drop in temperature from $60^\circ C$ to $45^\circ C$ in the proposed heat exchanger would release about 400 kW of thermal energy (equation 9) [assuming 100% thermal efficiency]. This is significantly larger than the 222 kW heat load, calculated in section 2.5 above, required for heating the public pools. Therefore such a heat exchanger would provide enough energy to heat the public pools, while retaining enough mass and energy (at $45^\circ C$) for the normal operation of the private pools. The cold water take from the Tupatomatua stream would also be minimised as external cooling would not be so necessary, and the amount of waste water discharged would be reduced.

Heat losses from the Paurini pipeline

The 150 mm pipe line which is about 240 m long brings the water from the Paurini pool to the bath-house at about 1 $^\circ C$ (measured) temperature drop (from 62 to 61 $^\circ C$) in dry summer time (no rain). Based on the energy loss equation (9) above; the heat lost from the pipe in summer would be about 26 kW given the 6.5 kg/sec of water flow rate and 1 $^\circ C$ temperature drop.

The heat lost in winter time would be higher (about 3 to 4 times) due to the increased temperature difference between the pipe line internal temperature and the external air temperature, as well as due to rain falling on the pipe. Long term measurements of the Paurini water temperature (at the bath house) are needed to better quantify the available energy, including such pipeline losses.

4. UTILISATION OF THE BORE (FLUID)

Well output:

The bore B8-N (Figure 1) has been in production since 1988. No output test has been done on the well to assess its thermal potential.
However the following observations can be made. Based on Marshall and Eagles (2007), the bore produces about 1.63 l/s or 1.56 kg/s of two-phase fluid with an average enthalpy of 580 kJ/kg estimated from the old/abandoned bore B2 output test (Bowman and Gould, 1987).

$$Q = \dot{m} \times h \tag{10}$$

Based on the above, the total thermal output of the well is about 905 kW. However, the actual output is highly uncertain since the enthalpy of the well has not been measured. It is very likely that the thermal output of the well is more than 1 MW due to the incorrect method for measuring the mass flow rate given in Marshall and Eagles (2007).

For accurate and reliable estimation of the heat and mass production from two-phase wells, it is recommended that an output test be carried out every two years or so (common practice). A wellhead pressure gauge can then be used to indicate the flow rate using the latest output test curves. *Measuring the flow rate of the condensates is not an accurate method as there should be a correction for steam loss*

Fluid use:

The water from the bore is used to heat the water for the public pools through two separate heat exchangers. The first is a pipe loop (about 42 m long) submerged in the balance tank and the second is a 2 m long, in-line, single pass shell and tube heat exchanger (booster). A small portion of the two-phase fluid is also used in the steamer near the well bore. The two-phase bore fluid is released at atmospheric pressure to the condensates tank. The steam condensates are collected in the steam condensate tank and gravity fed to an open air mixing tank which supplies 45 $^{\circ}C$ mineral water to 5 private pools.

Steam Condensate tank:

Significant amounts of heat and mass are lost at times from the bore fluid (type 1) at the condensates tank through evaporation (flashing), convection and spillage (Figure 6). The silica deposition on the outer surface of the tank is an indication of significant overflowing with time.

From mass and energy balance equations (7 and 8) above at the bath-house condensate mixing tank (Figure 7), the amount of fresh water needed to cool the condensates is calculated to be about 1.88 kg/sec. Therefore the total water used to cool the geothermal waters from both the Paurini pool (2 kg/sec, section 3.1) and the steam condensates (1.88 kg/sec) is about 3.88 kg/sec or 223.6 m^3/day, plus the makeup water needed for the public pools during "winter time". More water will be necessary during summer to cool the geothermal waters because the temperature of the Tupatomatua stream water will not be as cold then.

Figure 6. The condensate tank showing silica scaling, steam loss and over flowing of type 1 water.

Figure 7. Steam condensates and fresh water mixing tank which provides mineral water to 5 private pools. Water leak can be observed.

Improving the thermal utilisation of the bore

A down-hole heat exchanger (DHE) could be used to extract energy from the bore fluid. Such a DHE could be used to provide the energy to heat the public pools or boost the temperature of the pools during cold winters especially at start-up time, without the need to produce type 1 fluid. A well completed with a DHE will have a U-shaped tube carrying the fresh water into the well and out without mixing between the two fluids. This would allow the extraction of heat without the production of the type-1 fluid. The design, selection and final completion of a suitable DHE is outside the scope of this work.

Heat losses from the steam condensates pipe-line

Heat loss calculations using the equations below for exposed (un-insulated) steam condensate pipelines (a total of about 122 m long, measured) during full operation in winter time can be calculated, based on:

$$Q = C\Delta T \tag{11}$$

where:

C is the Thermal Conductance:

$$C = \frac{2\pi L}{\frac{1}{h_i r_i} + \frac{\ln(r_o/r_i)}{k} + \frac{1}{h_o r_o}} \tag{12}$$

For turbulent flow:

$$\text{Nu} = 0.023\ \text{Re}^{0.8}\ \text{Pr}^{0.4} \tag{13}$$

where:
Nu is Nusselt number.
Re is Reynolds Number
Pr is Prandtl Number

Given a temperature difference of about 90 $^\circ C$, the lost heat is about: Q = 70 kW.

5. SCALING AND CORROSION

The stainless steel condensate tanks have been replaced over time due to fatigue failure and corrosion. Fatigue damage is caused by continuous shaking from release of pressurised bore fluid and stress corrosion cracking is caused by the high chloride content of the deep (bore) water. (Old used condensate tanks can be seen on site, Figure 8). Silica deposits are visible on the tank surfaces deposited from overflow of the steam condensates (Figure 6). The flashing in the condensate tank also releases the non-condensable gases (mainly CO_2 and H_2S) from the bore water. The hydrogen sulphate (H_2S) contributes to the rapid corrosion in the steel pipes (Figure 8).

Figure 8. Current and former steam condensate tanks behind the bath-house. Also shown are the steel feeder pipe lines and the locations of corrosion due to the noncondensable gases (mainly H_2S) in the bore water.

Type 2 water from the Paurini pool carries less silica than the type 1 water from the B8-N well. The discharge of the Paurini pool water from the pipe-line near point P2 at night over several years did not produce any sinter (silica) deposits (Hochstein, 2008). Neither is there much visible silica deposition at the water mixing tank (Figure 5). Silica is under-saturated in Paurini water until temperatures fall below 40 $^{\circ}C$ (Hochstein 2008). Therefore it is anticipated that there would not be significant silica deposition inside the proposed heat exchanger extracting energy from Paurini water.

6. CONCLUSIONS

There can be gradual improvements to the current pool heating and water reticulation system. The aim of reducing the impact on the shallow reservoir by reducing type 1 water production, while maintaining the current level of operation is feasible. This would continue and be consistent with the previous significant and ongoing improvements in operating efficiency and resource utilisation carried out over recent years.

The current estimated maximum winter time heat and mass load for the Tokaanu bath-house (16 hour/day operation) is:

(a) 221.7 kW for the public pools.
(b) 6.0 kg/sec per day of mineral water at 42-45 $^{\circ}C$ for the private pools.

The current level of utilisation (6:30 am to 10:30 pm) of the Paurini pool water is limited to about 54 % for heating 8 private pools. The remaining mass and energy are not utilised (i.e. are "wasted") because during the night all the fluid is spelled over the old sinter flat near point P2 (Figure 2 and Figure 3).

It is apparent that the Paurini pool can provide all the water (6.5 kg/sec) for operating the private pools and about 400 kW of heat for the full operation of the public pools (cascaded use of energy).

A down-hole (DHE) heat exchanger in the bore could be used to heat the public pools or boost their temperature during cold winter start-up time, and provide additional energy for heating the private pools, without the need to produce (i.e. use or draw off type 1 fluid.)

If the Paurini pool water were used for heating all the 13 private pools through mixing with cold water, the total mass flow rate needed would be 5.7 kg/sec of Paurini water for the 16 hours of operation, or 334 m^3/day of 60 °C water, which is less than the current reported take of 377 m^3/day of 60 °C water (Marshall and Eagles 2007). It is also less than the actual daily take of 570 m^3/day discussed in section 3.

7. RECOMMENDATIONS

The following specific recommendations are made.

Pool covers

Evaporation is the major cause of heat loss from swimming pools. The water that evaporates carries heat away, leaving colder water behind. By covering the pool, we can reduce this heat loss by up –to 50 % depending on the material of the insulation cover used and duration of use. A retractable outdoor insulating swimming pool blanket (thermal pool blanket) could be used during the night to reduce heat losses from the public pools. This could be a centre core of closed cell foam, sandwiched between 2 layers of polyethylene woven fabric. Foam covers could also be used for the toddler (small) pool. The pool blanket is not expensive, is available locally in NZ, easy to use, and will significantly reduce heat loss from the public pools during the night, hence reducing the early morning start-up heat load. It will also reduce water evaporation losses, chemicals (chlorine) use and can help to keep the pool water clean.

Overnight storage tank

A geothermal fluid storage tank at the bath-house reception point would prevent leakage and overflowing and provide a source of extra fluid during morning start up and cold winter days. A similar storage tank system can be seen at the Te Aroha geothermal spring and thermal pool system.

Insulation

Heat loss from the main pipelines is up to about 96 kW. This is about 40% of the energy needed to heat the public pools so it is very significant. Insulated pipes could be used to reduce heat losses and so reduce the heat load and mass needed.

Reduce fluid extraction/re-allocated fluid flows

To reduce water abstraction from the deep geothermal fluid and potentially assist recovery of the natural thermal features at Tokaanu, two possible systems are proposed:

1. Use two separate systems, one for the private pools and another one for the public pools. In this scheme the private pools would continue to use Paurini pool water with mixing cold water, while using a down-hole heat exchanger (DHE) system for heating the public pools. A proper design of the DHE in the Tokaanu conditions would insure sufficient heat for the full operation of the public pools.

2. Use one system which takes the Paurini pool water through a plate-type heat exchanger and drops the temperature from 60 °C to 45 °C, while heating public pool water. A DHE could be used as a booster to the heat load for the public pool system.

For both options above, improved efficiency measures (insulation, stopping leaks and overflowing) could be taken to reduce heat and mass waste. The initial investment in setting up any of the systems above would have significant long term benefits due to halting the production of deep bore water and reducing the ongoing maintenance costs due to corrosion and scaling caused by the use of the deep (type 1) fluid.

The proposed system would provide operational flexibility to allow the bath manager to increase or decrease the heat intake depending on the seasonal and operational conditions.

Monitoring

A reliable data acquisition system and periodic measurements of water flow rate and temperature at the private and public pools should be used for both the geothermal and the fresh water cycle. It is necessary to have a record of heat and mass take and to develop a good understanding of the actual demand with seasonal variation. A similar monitoring system is used for the Rotorua hospital geothermal heating system. Loss (spillage) from the Paurini pool pipeline over the old sinter flat should also be measured.

8. ACKNOWLEDGMENT

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