Ohaaki consenting, modelling and resource assessment review: the best place to look for lessons on sustainable geothermal operation and monitoring

Campen, van B[1,*], Archer R[1]

[1] The Geothermal Institute/Energy Centre, University of Auckland Business School

b.vancampen@auckland.ac.nz

Keywords: Geothermal Resource Assessment, Ohaaki, Regulation, Flexibility

ABSTRACT

This article aims to derive lessons on sustainable geothermal operation and monitoring by reviewing the Ohaaki geothermal field along 3 dimensions:

- Ohaaki exploration, construction and consenting;

- Modelling and resource assessment;

- Operations and monitoring.

Resource assessments are categorized according to UNFC-2009 Framework, which prescribes inclusion of Economic, Feasibility and Geological criteria/dimensions.

1. INTRODUCTION

Ohaaki/Broadlands is one of the oldest geothermal fields to be exploited in New Zealand (and the world). It has a long, interesting history of government supported exploration since the 1960s, but was only commissioned in 1989, by which time 49 wells had been drilled.

Over its almost 30 years of well-documented operations, it has gone through 3 consent/resource proofing processes, and various adjustments of its resource assessment, due to combinations of geological, regulatory and market circumstances. Combining regulatory, historic, resource assessment and operational aspects in a review, should provide ample lessons for the sustainable exploitation of TVZ and other geothermal resources.

2. OVERVIEW OF OHAAKI EXPLORATION, CONSENTING AND OPERATION

2.1 Pre-commissioning exploration & decision-making (1937-1989)

The first scientific report of the Ohaaki area was made by Grange in **1937** as part of his description of the geology of the area to the north from Taupo (mentioned/cited in Carey&Grant, 1998). After the Second World War, the New Zealand government saw the strategic value of the centrally located TVZ geothermal resources and started an exploration programme, initially focused at Wairakei.

By **1964**, after the new Wairakei-geothermal stage-II hot-water-flash-plant had been commissioned, it became apparent that Wairakei couldn't be expanded, and the Department of Scientific Investigation and Research (DSIR) and the Ministry of Works and Development (MWD) were allocated a budget to start investigating other geothermal fields for a second station, including Broadlands/Oha(a)ki. The first well was drilled in 1965 (Martin, 1998). By **1968** MWD decided Ohaaki was the most promising field (estimated at 90 MWe, Martin (1998). By 1970, 18 *producing* wells had been drilled and the potential of the field was assessed at 120 MWe (MWD, 1977)

As a matter of fact, the potential of the Ohaaki geothermal resource was viewed quite differently by the 3 main governmental players, and at different time intervals:

- The New Zealand Electricity Department (NZED), responsible for planning and running the major New Zealand power plants and transmission network, was quite skeptical. Especially after the initial problems with Wairakei, they saw the potential of Ohaaki as risky and relatively small, especially compared to the large hydro stations they were planning to meet fast-rising demand;

- The Ministry of Works and Development (MWD) had been far more sanguine on the potential of the field on the back of an aggressive drilling campaign (23 wells drilled) and extensive well-testing programme (many wells were flow-tested for several years);

- The Department of Scientific and Industrial Research (DSIR) put out different estimates with a wide range of the field potential, as knowledge of the field and modelling expertise developed.

By the end of the 1960s/early 1970s (including the finding of Maui gas field in 1969), interest in geothermal power generation in general, and Ohaaki in particular, faded. In June 1971, the geothermal investigations were stopped by an interdepartmental committee and the wells were closed. At that time MWD estimated Ohaaki had a 'proven' resource of 100 MWe, with another 80 MWe additional potential.

Only after the oil shocks of the 1970s and growing general awareness of the limits to the world's resources (including the influential 1972-report by the Club of Rome' The Limits to Growth'), did the political drive to develop New Zealand's indigenous geothermal resources resurface. The geothermal investigation and drilling programme was re-started in July 1973.

The two subsequent drought years of 1973 and 1974 reinforced the need to diversify the New Zealand power generation matrix away from its high hydro domination. In 1974 the New Zealand Electricity Power Planning Committee recommended Ohaaki to be built at 150 MWe and producing by 1981 (first 50 MWe; another 100 Mwe a year later). By 1976, a total of 33 wells had been drilled and investigation drilling was considered complete at this time (Carey, 2013).

The 1977 Environmental Impact Report and subsequent 1978 Audit (CfE, 1978) stressed that more hot geothermal waste water going into the Waikato River would aggravate the existing heating and chemical pollution problems, largely created by Wairakei, the creating of many hydro dams and plans to use the Waikato River for cooling the large, new Huntly Power Station. The final *water rights* granted by the Waikato Valley Authority under the Water and Soils Conservation Act in 1978 (WR959 for 103,200 tpd – estimated to produce 116 MWe gross, 108 MWe-net) prohibited waste water discharge into the Waikato River, making re-injection necessary. This had been done in the USA and Japan, but not with such large volumes or conditions (Martin, 1998), which complicated the design.

Apart from technical issues, negotiation over land use with the Maori owners (Ngati Tahu) proved difficult and the commissioning date was postponed. In 1978 a 2-stage development with an initial capacity of 80 MW was proposed 'because of doubts about the yield of the field.' (Martin, 1998; original source probably NZED).

In October 1982, the Cabinet Works Committee gave approval to start work on Ohaaki and major contracts for a 116 MWe-plant were put into place in the month after, with an expected completion date by the end of 1988.

In 1988/89 Ohaaki was officially commissioned (on budget and on-schedule) as a 116 MWe-gross (106/8 MWe-net) generation station, consisting of: two 11 MWe HighPressure Turbines (left-over from Wairakei and intended to temporarily use the high pressure surplus steam in the first years of operation) and two 47 MWe Intermediate Pressure turbines.

2.2 1990s: Privatization and 1998 re-consent

Ohaaki ran at near/full capacity from 1990 to 1993/4 (see discussion operations), but then started losing steam potential. This was largely due to the predicted pressure drops, and the paucity[1] of new well drilling in the light of overcapacity and the start of the privatization process as New Zealand shifted to a liberal electricity market model (NZEM).

After the introduction of the Resource Management Act (RMA, 1991) and the privatization of Contact in 1996, Ohaaki was one of the first geothermal power stations to need a renewal in 1998 of its (then called) resource consent under the new RMA.

As electricity market prices were low, and Ohaaki had actually never used more than 47,000 tpd (annual average) of geothermal fluid, Contact only asked for a resource consent of 60,000 tpd, aimed at around 80 MWe[2] production (source: Contact consent application, 1998). As the RMA is based on the principles of 'sustainable management', the evidence presented by Contact discusses the sustainability of Ohaaki system under the proposed resource take, but mostly in generic terms. Brief reference is made (but no results or details given) to reservoir simulation modelling done at the University of Auckland in 1997 using 2 scenarios.

In the end Ohaaki received a new consent in 1998 under the RMA (WRC-100977, operative in 1999) for 14 years @ 60,000 tpd – aimed at generating 80 MWe. The RMA-consent has many more reporting requirements, but mainly targeted towards annual fluid production and 'effects', rather than re-assessment of resource/reserve in terms of (long-term) power production.

In 2002/3 the Waikato Regional Council brought out its Regional Policy Statement formalizing WRC's approach to geothermal sustainability through classification of 'development' (incl Wairakei, Ohaaki) and 'protected' resources. This was in part based on the WRC-SKM-2002 geothermal resource study for the whole Waikato region. This study estimates Ohaaki at 130 MWe (P50-prospective resource for 30 years, based on probabilistic stored heat assessment).

2.3 2000s and 2010s: re-consent and continued operation

After initial price drops at the end of the 1990s and early 2000s (including plant closures in NZEM), NZEM power prices started to rise again through the 2000s, due to the 2001 and 2003 droughts and the looming end of the giant Maui gas field. A new drilling campaign was started in 2005-2007/9 and Ohaaki production increased from less than 40 MWe in the early 2000s (less than 30,000 tpd average) to 66 MWe average in 2008/9 (41,000 tpd in 2008/9, another drought year).

As the newly targeted deep West Bank geothermal resources provided high enthalpy fluids, but limited permeabilityproduction has gradually fallen back, since 2009 to around 40 MWe. As electricity demand growth stalled after 2008/9 and the end of the existing consent was looming, no new wells were drilled until the new consent was secured.

In 2013 Ohaaki requested and received a new consent for 30 years at 40,000 tpd (aimed at generating 40-50 MWe - check consent reports); the project description explicitly mentions the option of converting one of the HP/IP-turbines into a low-pressure turbine, provided scaling and other operational issues can be resolved (and the economics make sense).

The consent also mentions the supply of steam to timber drying & other 'cascade' uses (as part of the overall 40,000 tpd consent): upto 4,000 tpd.

3. MODELLING HISTORY: MODELS, SCENARIOS, RESOURCE ESTIMATES & WELLS DRILLED

Modelling started in the 1970s by DSIR based on well productivity (decline) analysis and lumped parameter models (e.g. Grant-1973, 1975, 1976, 1978). 35 wells were drilled between 1965 and 1979 and extensively flow tested to support these analyses. This led to many different resource assessments, varying from 30-150 MWe. 100-110 MWe was the most frequent range quoted. A large cautionary note was made that well testing had shown a significant productivity drop (14% p.a.). It was expected upto 3 new wells p.a. would need to be drilled to run a 100 MWe+ plant and make up for lost productivity.

At the end of the 1970s/early 1980s the first numerical reservoir models were built and tested (e.g. O'Sullivan 1978, 1983, 1985, 1986). Starting with 1 block, these models became gradually more sophisticated (growing to 145 blocks 3D models from 1987) and showing reasonably good

[1] 1 well was drilled in 1989, and 1 in 1993; 3 new wells were drilled in 1995 (i.e. 5 over a 6-year period; considerably less than the 3 pa as planned to make up for the 14% estimated well decline).

[2] Note that – contrary to geothermal regulation in most countries - both the WSCA and RMA are water-, not energy-based regulations, and therefore the main 'consenting variables' are tonnes (per day, tpd) of fluid taken (and re-injected). The proposals accompanying the consent application do mention the intended/planned (MWe)-production, but these are not part of the final consent.

matches to (natural state) temperature, pressure, enthalpy and CO2-data (O'Sullivan et.al., 2015). These early models were run with simple operational scenarios, but were not seen as sufficiently developed for plant sizing and decision-making. Rather they were run as exercises to investigate and support previous analyses as discussed above. 15 additional wells were run between 1980 and 1989.

In the 1990s the numerical models were further developed, grew more complex (upto 2,048 blocks) and started to show moderate matches to (natural state) temperature, pressure, enthalpy and CO2-data (O'Sullivan et.al., 2015). These models started being used for operational decision-making. However, due to the liberalization of the electricity market and low power prices, only few (6) wells were drilled between 1990 and 1999/2000, and the average power output of Ohaaki dropped steadily from full capacity (106 MWe net) in 1991 to below 40 MWe in 2000.

For the 1998 re-consent, several long-term scenarios were run with the newest numerical models (O'Sullivan, 1997; 2,048 blocks) and two were briefly mentioned in the consent-application:

Scenario-1: No additional well drilling is undertaken and the energy output from the field declines.

Scenario-2: Deeper wells are added to maintain the steam output from the field at about 175 kg / second. (= 80 MWe)

The second option of deeper wells being added to make up for production decline fitted Contact's proposed consent and was seen as 'a robust scenario.' (Contact/Carey, 1998 Re-Consent application).

The 1997-UoA/Uniservices report (Newson & O'Sullivan, 1997, section 4) gives some more details:

- Both scenarios are modelled from 1997-2035 (38 years);

- Scenario-1 assumes only the existing wells are into production until 2035;

- Scenario-2 assumes 6 new make-up wells are drilled when the total steam flow drops below 175 kg/s (ca 15,000 tpd);

In scenario-1 the total mass flow decreases from 523 kg/s to 465 kg/s in 2009, and then increases again to 526 kg/s (ca 46,000 tpd) as the enthalpy decreases and the steam fraction of the production fluid decreases.

In scenario-2 the total mass flow increases from 523 kg/s in 1996 to 592 kg/s in 2013 (ca 51,000 tpd).

The second scenario modelled was the one to support Contact's consent application for 60,000 tpd, which was demonstrated to be robust over a 49-year period (1997-2035) to support 80 MWe generation. The consent was given for 14 years (1989-2013).

In the 2000s and 2010s the models were further refined (upto 43,102 blocks) and many different scenarios were run (upto 8 scenarios at a time). In 2004-2006 a new 'generation' of models was built (upto 7074 blocks) and run to investigate the operational options for Ohaaki to 'wind down' or invest in new wells and generation capacity. Upto 56 new make-up wells were. These scenarios were used to inform Contact's well drilling programme, and between 2002 and 2009 (especially in 2007) 15 new wells were drilled, in an electricity market with significant droughts (2001 and 2003) and rising power prices. Average production rose from around 37 MWe in 2000, to 66 MWe in 2008.

The production of these new wells started tapering off from 2010, but due to stagnating power demand/prices, and the looming end date of the existing consent, no new wells were drilled. In 2012/13 a detailed modelling report was presented as part of the re-consenting process, including 6 scenarios, in which the preferred (and consented) scenario of 40,000 tpd (2012-2048/2060 respectively in scenario 1B and 1F) was demonstrated to be sustainable for 48 years (i.e. considerably longer than the consenting period of upto 35 years) to sustain around 40-50 MWe, with a potential upto 55-60 MWe if one of the surplus turbines was converted and run as a low-pressure turbine to be connected down-stream and use additional energy from the existing fluid (conditional on managing operational/scaling issues). The modelling assumed 16 make-up wells to be drilled over that period to maintain steam supply. A scenario 1C of 45,000 tpd was modelled, but shown to be unable to sustain the required mass flow rate within the specified number of make-up wells. Scenario 1A with a lesser take of 35,000 tpd would only need 9 make-up wells over the modelled period (Contact/O'Sullivan, 2013 Re-Consent application). Contact was given the consent for 40,000 tpd (max daily fluid take) for 35 years. Modelling predicts that while mass take can be maintained, enthalpy will decline and that steam flow will level off at about 10,500 tpd from 2035.

However, in the period 2013-2017 the electricity market continued to face stagnating demand, oversupply and suppressed prices. The predictions were a new well would need to be drilled every 3 years to maintain production at 40-45 MWe (Source: Contact-AR-2015). Two new wells were drilled in 2013. Production has stayed around 40 MWe (<30,000 tpd).

4. OVERVIEW OF OHAAKI OPERATIONS AND MONITORING

From the various data sources (EA/EMI half-hourly generation data, Contact Annual Reports, Ohaaki Annual Reports to WRC), it seems Ohaaki did produce at full ca. 106 MWe-net capacity from 1990/91-1993/94. After that MWe-production started to taper off gradually until the 2000s, when it seems to have stabilized at around 40 MWe; it surged back to 60-66 MWe in 2008/9, but then fell back to an average of around 40 MWe pa until 2016/17.

Annual Reports to WRC normally state annual fluid take (and re-injection), which can be calculated into average fluid take (tpd), but the Ohaaki-consent is based on a maximum daily take. Only since 2013 does the maximum take seem to be listed systematically in the report: 37,548 tpd in 2015 (for around 50 MWe generation), while the average for that year is 27,553 tpd (i.e the maximum is 36% higher than the average take; similar as for 2014).

In general production (see fig 2 based on half-hourly data) has been very variable, with – on the top of the long-term declining trend - many short-term variations and power outages, so steam production is expected to have varied significantly as well (no other data available, though). These variations seem to have been more related to plant/equipment maintenance and operational issues, than intentional variation to market circumstances.

Fig 1: Ohaaki annual fluid take and generation

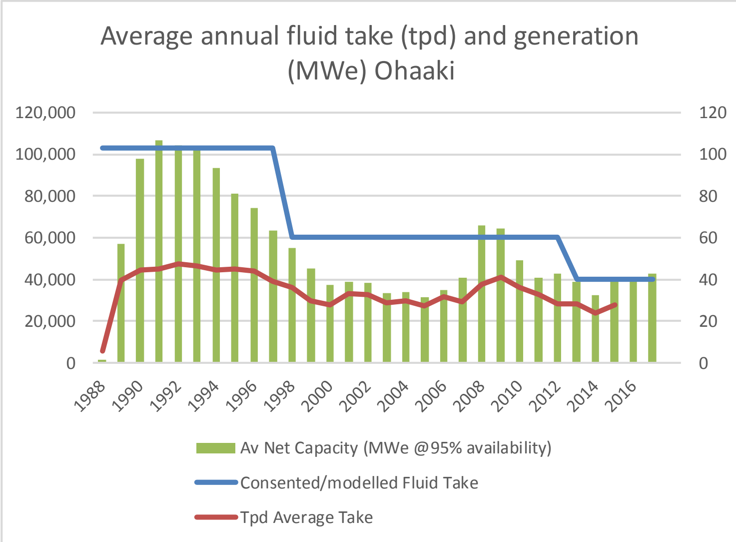
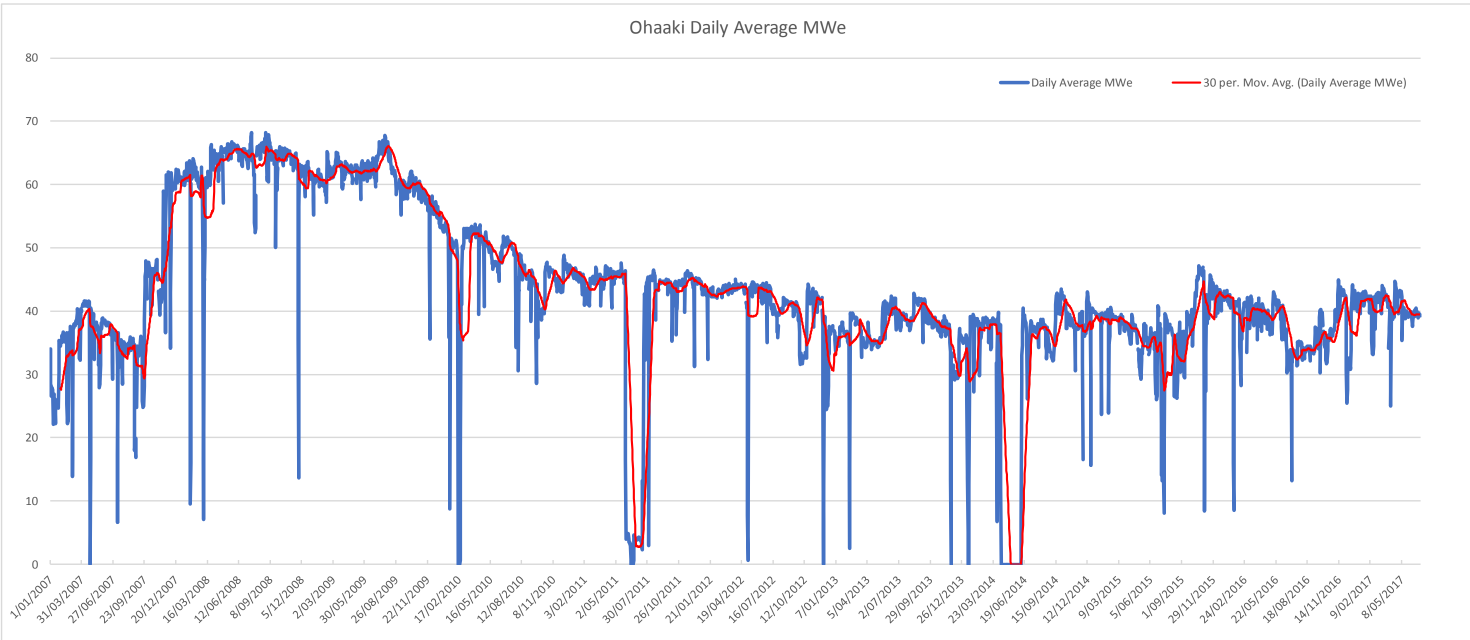
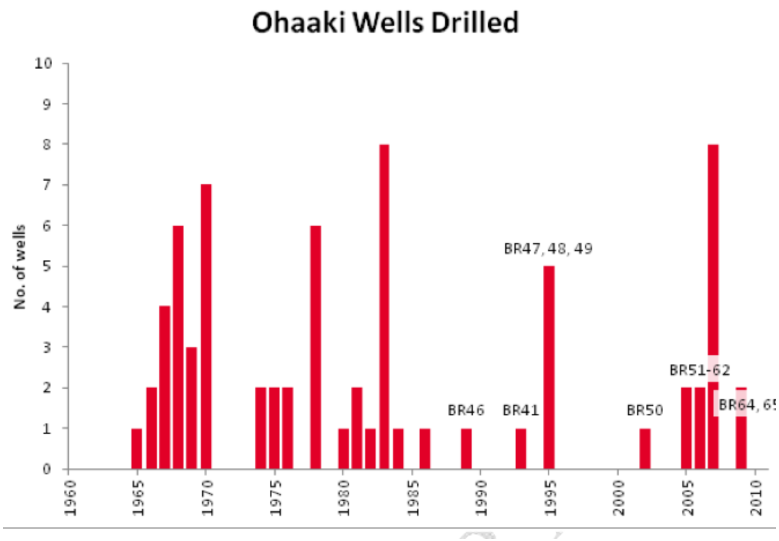


Fig 2: Ohaaki Daily (and 30-day/monthly) average MWe production 2007-2017 (source: EA/EMI half-hourly data series)



Of the 3 new wells pa originally predicted/planned to compensate for Ohaaki's predicted 14 % p.a. well decline, far fewer were drilled over the years, as illustrated in Figure 3).

Fig 3: Ohaaki Wells drilled 1964-2010 (Source: Ohaaki SMP, 2013)



5. CONCLUSION

Ohaaki has a long, and diverse history of exploration, modelling, resource assessment and operation. It is one of the best, publicly documented systems in the world: at 3 occasions 'official' resource assessments and environmental consent reports were submitted to the authorities (1977, 1998 and 2013). On top of that its annual reports to the regulator are among the most detailed and transparent there are publicly available in New Zealand (and possibly globally).

When the power station was built in the 1980s sufficient data was available to support this with lumped parameter models and well productivity/decline analysis. The 116 – 150 MWe (for 30-50 years) originally assessed/planned was based on an assumption of 14% well decline pa, and 3 new make-up wells pa to keep up steam supply (with 116 MWe instead of 150 MWe installed, there was assumed to be a few years of 'spare supply' with no drilling). This proved reasonably correct, but that over the operational period far fewer wells were drilled.

Unlike monitoring and reporting in the petroleum sector intermediate, annual reporting hasn't included 'official' (re)-assessments of Ohaaki's resource, but operational data over the years has shown a gradual decline of production/viable resource. However, as discussed in the previous sections, the reduction in Ohaaki production (and resource assessment) would seem to be as much due to market circumstances and regulatory settings as to field issues.

In 2005-2009 a new drilling campaign was executed, due to a general rising price trend, which increased production back to 65 MWe in 2008/9. This 'happened' to coincide with an additionally high price peak due to the 2008-drought.

After 2010 power production started to taper off again. The present 'proven' reserve for Ohaaki (at present market conditions) is 40-45 MWe for another 30 years[3]. Another 20-25 MWe of 'contingent resources' (contingent on scaling and operational issues being resolved, as well as market conditions/prices improving) might be available. For additional production at the higher end of this estimate, a new/variation of the resource consent might be necessary, as – though Ohaaki generally produces well below its 40,000 tpd consent limit on average – its maximum take in recent years has been considerably above its average and close to the maximum consented amount (e.g. 37,548 tpd max in 2015 for 27,553 tpd annual average).

A related discussion is whether Ohaaki geothermal production could be made more variable. Contrary to recent discussions in Hawaii and California (e.g. Edmunds, 2014; Urbank, 2016; Linvill, 2013), the short term, ancillary service flexibility, which is targeted with some geothermal plants in the USA, in New Zealand such flexibility would be more valuable to support seasonal/dry winter peaks, particularly now the amount of thermal plants in New Zealand has been heavily reduced. Such future flexibility in production might create additional value for geothermal power plants producing more when prices are high, hence increasing their Weighted Average Price. Ohaaki would be one of the best examples/pilots, due to its existing excess generation capacity.

As seen from power and fluid production over the years, this variability shouldn't be a principled problem, but Ohaaki's consent is likely to need approval for a variation. As plants like Ngatamariki already have such variability (75000 tpd max within a 65000 tpd annual average take), there shouldn't be any principled, legal objections there either.

REFERENCES

Bauer et al; *Environmental Impact Report for the Broadlands Geothermal Power Plant*. (1977)

Commission for the Environment (CfE); *Broadlands Geothermal Power Development – Environmental Impact Audit*. (1978)

Carey, B; *Witness statement in 2013 Ohaaki-reconsent application*. (2013)

Carey, B Grant, M; *Witness statement in 1998 Ohaaki-reconsent under RMA (1991).* (1998)

Edmunds, T.A.; *Integrated Stochastic Weather and Production Simulation Modelling*. Conference Paper · IEEE Innovative Smart Grid Technologies - Washington, DC. (2014)

Edmunds, T.A. and Sotorrio. P; *Ancillary Service Revenue Potential for Geothermal Generators in California*. In

[3] Contact 2013-17 Annual Reports to shareholders list Ohaaki as 50 MWe, up from 40 MWe in 2013. EMI-2015 lists Ohaaki Nett Operating Capacity as 70 MWe, Installed Capacity as 116 MWe.

Proceedings, Fortieth Workshop on Geothermal Reservoir Engineering. (2015)

Edmunds, T.A. and Sotorrio. P; *Ancillary Service Revenue Potential for Geothermal Generators in California*. FY15 Final Report. (2015b)

Edmunds, T.A., Sotorrio. P and Buscheck, T.A.; *Flexible Geothermal Power: An Economic Assessment*. FY14 Final Report. (2014)

Grant, M.A.; *Broadlands – a Gas-Dominated Geothermal Field*. In: Geothermics, Vol.6. pp.9-29. (1977)

Kortright, N.; *Ohaaki Geothermal Power Station – Renewing Resource Consents Comparison with Greenfield Development*. In: Proceedings of World Geothermal Congress. (2015)

Lawless, J. et.al.; *Sustainability of TVZ Geothermal Systems: the regulatory perspective*. In: Geothermics TVZ Special Issue. (2016)

Linvill, C., Candelaria J. and Elder C.; *The Value of Geothermal Energy Generation Attributes: Aspen Report to Ormat Technologies*. Aspen Environmental Group. (2013)

Martin J.E. (ed)*; People, Politics and Power Stations – Electric Power generation in New Zealand 1880-1996*. 2nd edition. (1998*)*

Matek, B.; *Geothermal Energy Association Issue Brief: Firm and Flexible Power Services Available from Geothermal Facilities*. US-GEA-publication. (2015)

Ministry of Energy (Oil and Gas Division); *A Review of the Role of Geothermal Resources in New Zealand*. (1982)

MWD; *Broadlands Geothermal Investigation Reports*. Ministry of Works and Development. (1977)

Newson J and O'Sullivan M.; *University of Auckland Uniservices Broadlands Modelling Report*. (1997)

O'Sullivan M. et.al.; *Computer Modelling Retrospective on Wairakei & Ohaaki*. In Proceedings World Geothermal Congress. (2015)

SKM/WRC; *Resource capacity Estimates for High-Temperature Geothermal Systems in the Waikato Region*. Report for Waikato Regional Council. (2002)

Urbank K. and Jorgensen A.; *Investigating Flexible Generation at The Geysers*; in GRC Bulletin. (2016);

Annual Report Series and datasets:

Annual Reports Contact to WRC and SMP (2003-2015)

Contact Annual Reports to Shareholders (1996-2016)

Contact/WRC, 1998 Resource Consent documentation

Contact/WRC 2013 Resource Consent documentation

EMI/EA half-hourly generation data (1999-July 2017) https://www.emi.ea.govt.nz/Datasets/Wholesale/Generation/Generation_MD

Min Works, NZED, DSIR Annual Reports (1964-1984)

Annex 1: Timeline and Decisions regarding Broadlands Ohaaki

Year	What?	Resource Assessment (UNFC-2009 framework)
1964	Decision to look beyond Wairakei	
1965	Drilling started at Ohaaki. Results created little enthusiasm with NZED due to small size	<200 MWe (E3F3G4 – exploration projects)
1968	Ministry of Works decided Ohaaki ‘most promising’ geothermal prospect, but NZED even less enthusiastic	90 MWe (*? yrs; E2F2G2)
1970	Prospect of Maui gas, so Ohaaki relegated to back-up plan	
1971	Drilling ceased and wells closed. Min Works regarded with 25 wells that it ‘proved’ 100 MWe (gross/net) and 180 MWe (gross) would eventually be feasible	100 (E2F2G2)-180 (E3F2G3) MWe (*? yrs)
1972	Labour Manifesto puts emphasis on indigenous energy resources against a background of growing Environmental concerns. Promised further development of geothermal resources => NZED accepted that Ohaaki had to be taken seriously	
1973	Min of Works drilling programme reinstated and authorised for 2 years drilling.	
1973-4	2 drought years and oil crisis make Ohaaki more attractive to NZED as a baseload plant that could be built “quickly” (quotation marks BvC)	
1974	NZED Power Plan included 50 MWe @Ohaaki in 1981 + 100 MWe additional in 1982	50 + 100 MWe (*? Yrs: E2F2G2)
1977-78	Environmental Impact Report + Audit for 150 MWe plant (DSIR, Min Works, NZED). Consented for 103,200 tpd for 20 years	150 MWe (* 20 yrs: E2F2G2)
1977	Commissioning date for Ohaaki is put back due to complex design work and negotiations with Maori land owners	
1978	A 2-stage development Is proposed with 80 MWe initially due to doubts about the yield of the field	80 MWe- ? (*20 yrs – E2F2G2)
1976-1980/82	Negotiations with Maori land-owners. Come to agreement	
1986	The announcement that several Government Departments (incl NZED) will become state-owned enterprises, legally distinct from the Crown, creates problems with Maori land-owners.	
1982-1988/89	Work contracting and start of construction with planned commissioning date 1988	116 MWe-gross 106/8 MWe-net (*10 yrs: E1F1G1)
Feb 1989	Start generation	
July 1989	Full commissioning. Generates (near) full capacity 1990-1993/4, then steam supply tapers off.	2*47 MWe IP + 2*11 MWe HP
1998	Reconsent @60,000 tpd referred to 2 scenarios in reservoir modelling report. Didn’t run more than 41,047 tpd average for 65 MWe (2009 after drilling 3 new wells)	80 MWe (gross? * 14 yrs: E1F1G1)
1998-2000/2003	Ohaaki run as two HP and one IP turbine	
2002	SKM-WRC resource assessment (probabilistic stored heat calculations)	130 MWe (gross?, 30 yrs: E3F3G4 exploration projects)
2005-2007/9	New well drilling campaign focusing on deep West Bank resources	
2007-2011	Ohaaki run with two IP and one HP turbine	
2011-present	Ohaaki run with one IP and one HP turbine	
2013	Re-consent @40,000 tpd supported by reservoir modelling and 6 scenarios. 2013-2017: never ran more than 28.090 tpd (average; max 37,548 tpd) for 43 MWe average.	40-60 MWe (net * 35 years – E1F1G1)
2017	Investigation into consenting options for more flexibility to run Ohaaki 40,000 tpd on average , but with some flexibility (10-25%?) to use more at some times, less at others. This could presumably bring average generation back to 50-60 MWe average	40 MWe (E1F1G1); additional 20 MWe (E2F2G2)

Annex 2: Ohaaki-Broadlands Overview

Period	1950s-60s	1970s	1980s	1990s	2000s	2010s
Regulation & Market	- pre-WSCA; - Wairakei presumed to reach limits; - ECNZ builds large hydro stations. - 1969 Maui gas find.	- WSCA (1967) - 1970 Oil Crisis - 1973&1974 droughts	- Drive to diversify from hydro generation - Construction of gas-fired plants - Preparations for electricity privatization	- RMA (1991) - Electricity Market Privatization - Contact acquired Ohaaki in 1996 - Low electricity prices	- 2001&2003&2008 droughts - End of Maui - Fast rise of electricity prices over 2000s - 1st wave private geothermal development	- 2nd wave private geothermal development; - 2009/10-2016: stagnation in electricty demand; - Closures of thermal plants
Exploration/Drilling/Construction	- 1937 & 1960-1971: surface geoscientific surveys; - 1964-1971: 23 wells generally 1100-1400mtrs (1@2400); - 1971: Geothermal investigations stopped	- 1973: restart Ohaaki exploration - 1974: Electric Power Plannning Committee recommends 150 MWe Ohaaki plant - 1974-1988: 20 wells 1100-1400mtrs	1988/89: Ohaaki commissioning 108 Mwe (net; 116 MWe gross); 30%+ steam surplus; 14% expected decline => redrill in ca 5 yrs; 3 wells p.a. planned	1995: 5 wells 2300-3000 mtrs	- 2005-2009: 14 wells 2200-3000 mtrs; - 2007-2011: Field-wide MT-surveys	- 2013: 2 wells 2800-3000 mtrs? - 2016: ? wells?
Consent		1978: crown water rights (WR959&WR-960) 103,200 tpd for 20 yrs; full reinjection (116 MWe gross)	- Ohaaki lost 10 years of its consent-time: 10 years left after 1989	- 1998/99: re-consent under RMA: 60,000 tpd take (80 Mwe) for 14 years; - 54,000 tpd re-inject; - also max 80 (TJ p.day - gross/net? Take)	- WRC Regional Policy Statement: Development Systems (like Ohaaki) with 'controlled depletion' vs. Protected Systems	2013-re-consent: 40,000 tpd take for 35 years (40-70 MWe)
Models & Resource Assessments		1970s: first lumped parameter models & well prodction/decline analysis 1974: MWD-report: 150 MWe (addition of all well-potentials?); 1977-MWD: expected 14% pa annual run-down (production decline analysis) & 3 new wells p.a	- 1983-: first simple numerical reservoir models of Ohaaki - Supporting/confirming existing resource assessments	1997/98 Updated UoA reservoir model used to support consent application: 60,000 tpd, 80 MWe	SKM (2002): 130MWe (stored heat; median, 30 yrs) 2004&2009: Reservoir Modelling Updates (source Contact-AnnualReport-to-WRC-2003: Tough2; 6455 blocks) Support 2005-2009 drilling campaign	- 2011-2012/3: Newest model (22,816 blocks) runs for Ohaaki re-consent; Contact-2013-report-to-WRC: 2013) - 2013: Reservoir simulations (6 scenarios + stored heat calculations) support consent application (40,000 tpd)
Actual production			Ran at full 108MWe capacity 1989-1993, but never used more than 47,300 tpd annual average (1992)	In 1990 declining well production, scaling & low market prices led to gradual production decline; 1996 'formally' derated by 10 Mwe	2001: derated by 38 Mwe; 2005: derated by 16 Mwe; 2007: rerated by 10 Mwe 40-65 MWe production	- 40-45 MWe average