Struggles Between Commercial Use and Conservation: Examples from New Zealand

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The large-scale use of a geothermal resource anywhere is likely to be a matter involving the government of the country. In a legal history of geothermal resource issues in New Zealand, Boast [1995] refers to them as "legal battles" fought out before courts and tribunals. The weapons are scientific and engineering ideas, presented by expert witnesses. For many years now, obtaining consents (permits and licences are generally called resource consents in New Zealand) has been a public process which is adversarial, that is, those for and against the proposal present evidence to a committee or court in support of their views. The developer normally presents all the scientific background to show that the resource is understood sufficiently to allow the effects to be predicted. There are often three separate groups: those in favour, those against on commercial grounds and those against on environmental conservation grounds. The expert witness, although paid by one particular group, has a professional duty to the court—they are not advocates, as are the lawyers, but experts whose opinion the court expects to be unbiased towards their client.

Historically in New Zealand, geothermal conservation has been poorly represented in the resource consent process. This might be due solely to the long time that geothermal resources have been used there, starting before concerns about the environment came into international prominence. In any event, it led to some public hearings with interesting issues in the context of this book. The aim of this chapter is to review New Zealand geothermal legislation and to give examples of particular scientific and engineering issues from developments at Rotorua, Wairakei and Ngawha.

14.1 Background to New Zealand Legislation Governing Geothermal Resource Use

The land area of New Zealand is similar to that of Japan or the UK, but it has a population of only 4.5 million. There is no evidence of any habitation before about 1200 AD; the nearest large land mass is Australia, 2,000 km away, and it is a similar distance from Polynesian islands. It was eventually settled by

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a Polynesian people, the Maori. King [2003] explains that as the land mass of the Pacific Ocean consists of very small scattered islands, Polynesians of necessity developed the ability to make long voyages. New Zealand was settled last in the Pacific, being a long way south, and he ventures the opinion that on arriving there, Maori found resources in plenty for the size of their population and abandoned long-distance voyaging. Having thus had no contact with the more populated parts of the world or competition for resources, Maori had an un-unified tribal society without written language or metal technology by the time of arrival of the British explorer Cook in 1769. European immigration proceeded only slowly in the nineteenth century, and New Zealand was governed on British principles as a Dominion, the same status as Australia, but from the outset, according to King [2003], with an approach more sympathetic to the welfare of the indigenous people than in Australia. The Treaty of Waitangi was drawn up by the first British-appointed Governor and accepted in 1843 by Maori tribal chiefs and the British. It has a bearing on geothermal resource use. New Zealand has a Governor General who is the representative of the British monarch. In 1975, the Waitangi Tribunal was set up to address Maori grievances that the principles of the Treaty had been ignored in some dealings.

Maori had traditionally lived near springs and made use of them for cooking, bathing and medicinal purposes and for the preparation of flax for weaving. They dug bathing pools, e.g. at Ngawha, and seem to have channelled spring water over short distances, e.g. at Rotorua and the more populated centres of the Taupo Volcanic Zone. Significantly for modern considerations, geothermal surface activity assumed importance in terms of their spiritual beliefs. Otherwise, the use that early European immigrants made of geothermal springs was very similar to that of Maori. The geothermal surface activity and features such as the Pink and White Terraces, similar to those existing at Pamukkale, Turkey, attracted European tourists. The association of geothermal heat with power did not come until very much later.

New Zealand was never a developer of new power generation methods but was quick to adopt available technologies, including hydroelectric generation for which it has a high potential. A hydroelectric station at Bullendale was built as early as 1886 (Martin [1998]) because of gold mining activity, and large hydroelectric dams and schemes were under construction by the 1920s. Although the first electricity-generating plants were installed and owned by private companies, government played the major role until privatisation in 1987. As the population and level of commercial activity grew so did the demand for electricity and hence the need for a structured approach to supply, and the New Zealand Electricity Department was established in 1959.

Electricity supply was restricted by WW2, as plant was unavailable for purchase overseas. Because of the long planning and construction period for new hydro-stations in particular, electricity continued to be in short supply into the early 1950s. The generation of geothermal electricity in Italy mentioned in Chap. 1 had not gone unnoticed and the idea of using the central North Island geothermal resources for the same purpose was proposed in 1924; however, good hydro-generation opportunities still existed at that time. Scientific interest led to the drilling of wells in the Taupo Volcanic Zone at Rotorua, Taupo and Tokaanu in the 1930s, and the discharges were used for heating and bathing. The shortage of electricity caused the government to set up a Geothermal Advisory Committee in 1949, and further issues led to the immediate choice of Wairakei for development. A survey of the entire Taupo Volcanic Zone resources was not made until the 1970s.

14.2 Acts of Parliament Relating to Geothermal Energy

Boast [1995] presented a history of geothermal legislation from a legal point of view, as mentioned above, but this section is directed to aspects relevant to geothermal engineering.

14.2.1 The Geothermal Steam Act 1952

The purpose of the Act was to enable the generation of electricity from geothermal energy to be controlled by the government; it provided for the private generation of electricity by means of a licence in the form of a contract between the government and the licensee. That it came at the very beginning of geothermal electricity development is evident from its wording—it displays an attempt to cover every eventuality without knowing what was possible. Thus, steam is defined as “steam, water, water vapour, and every kind of gas, and every mixture of all or any of them, that has been heated by the natural heat of the earth”, and “bore” is defined as “any well, hole or pipe which is bored, drilled, or sunk in the ground for the purpose of investigating, prospecting, obtaining, or producing geothermal steam, or which taps or is likely to tap geothermal steam: and includes any hole in the ground which taps geothermal steam”. Geothermal steam (using the definition of the Act) was already being used for non-electric commercial purposes and had been since 1881, when the government deliberately encouraged it with the Thermal Springs Districts Act of that year, aiming to promote tourism. The 1952 Act dealt with this existing use in a non-technical manner by defining a “Geothermal Steam Area” without mention of any physical attributes. Any area of land that was, or was believed to be, a source of geothermal steam under the definition of the Act could be declared a Geothermal Steam Area by Proclamation of the Governor General, after which the use of geothermal steam and bores there required a licence from the Minister, revocable at his sole discretion and with conditions of use specified by him. Existing users were to be allowed to continue without consent but only if the Minister agreed, “having regard to the public interest”.

14.2.2 The Geothermal Energy Act 1953

The Geothermal Steam Act was repealed after 1 year and replaced by the Geothermal Energy Act 1953, a 16-page document in place of the previous 6, representing more extensive and well-defined government control. This Act remained in force until the introduction of the Resource Management Act 1991. The primary purpose of the new Act was the same—to retain for government the sole rights to geothermal energy and control of its use. The clumsy definition of geothermal steam in the 1952 Steam Act was replaced by a definition of geothermal energy, which, perhaps only by chance, seems scientifically accurate enough to capture for the government all matter that comes out of the bore, including matter emerging from natural vents. It thus appears to cover precious metals and thermophilic bacteria which were not considered at the time (although this is the opinion of an engineer and not a lawyer). Drilling for geothermal energy and using it requires a licence from the Minister, the Minister of Works in this Act, with a few exceptions. In 1953 geothermal drilling practices were still being developed, and a Code of Practice for Geothermal Drilling did not appear as a NZ Standard until 1991. The Minister had the power to require an unsafe well to be sealed—the present Code of Practice defines a sealed well as having been "abandoned" and sets out the engineering requirements.

The wording of the Act provided for the introduction of fees for the geothermal energy used, defined in a set of regulations which could be changed from time to time. The Act gives the Minister the power to revoke a consent in response to non-compliance with any conditions attached to it, or if operations constitute a threat of danger to the public. Geothermal energy use was in its infancy in 1953, and it was to be several decades before Codes of Practice such as the NZ drilling code already mentioned and codes by the American Standards for Testing and Materials became available for use by NZ authorities.

The Act has been amended several times, the first in 1957 apparently because the 1953 Act provided continuation for those already using geothermal energy at the time it came into force, but excluded those who had a well, had been using it earlier but were not actually using it at that time. Later amendments came in response to events at Rotorua, which are to be explained.

14.2.3 Environmental Protection Versus Development

The government organised a survey of the nation's geological assets, including geothermal energy, which resulted in a report by the New Zealand Geological Survey—NZGS [1974]. It includes a section entitled "Assessment of geothermal energy resources". Guidance on environmental values appears to have been generated only informally, from within the geoscientific community. The protection of geothermal surface features from the effects of development became of concern in the late 1970s as a result of Rotorua and Wairakei experiences. Houghton et al. [1980] eventually produced a report which placed the geothermal resources of the TVZ in a ranking according to their state of development and priority for preservation, and the Resource Management Act was eventually to require regional planning incorporating environmental values.

In 1978 the Ministry of Works and Development applied under the Water and Soil Conservation Act, which at that time controlled the use of "natural water", to drill a well at Rerewhakaaitu in the TVZ. A suitable site was available at a privately owned timber processing yard, and the application included taking 2,500 tonnes per day for up to 5 years. The area lies on the edge of the Kaingaroa forest, a major source of timber for domestic and export markets, and it had been decided that sawmilling and timber treatment should be based around the perimeter of the forest to reduce transportation costs and effects. If the well would produce it was intended that the Minister of Energy would supply the discharge under the Geothermal Energy Act 1953 to the owner of the site, to tanalise logs by delivering the well discharge directly to a pressure vessel containing the logs and the necessary chemicals. Practically, the project went ahead, the well was drilled and turned out to be a producer, and timber treatment began. The site was about 3 km away from the Waimangu Valley, a geothermal tourist attraction untouched by development and with many spectacular surface features. In the meantime R. Keam, a co-author of the Houghton et al.'s paper [1980] started a complex appeals process—it was complex by being taken to increasingly higher courts. As a result of the first appeal, the consent to drill the well and take the fluid was cancelled on the grounds that the project was a random exploration at one point in a large field and that the benefit which might follow was not sufficient to justify the possible detriment to the Waimangu surface discharge. The Geothermal Energy Act defined geothermal energy as including water heated to over 70 °C, while the Water and Soil Conservation Act simply addressed natural water, and there was uncertainty about which was appropriate for the issuing of geothermal resource consents. The matter was finalised by the Court of Appeal [1982]. A licence under the Geothermal Energy Act was required by a developer as well as a consent to take water under the Water and Soil Conservation Act. The well at Rerewhakaaitu was abandoned, and protection of the resource was given priority; however, later events at Rotorua would again illustrate lack of coordination between various government departments and local government on the question of environmental protection versus development.

14.2.4 The Resource Management Act 1991

The Resource Management Act 1991 (RMA) regards geothermal resources as water resources; it relates to the use of land, air and water and specifies the principles under which they are to be managed and their use allocated. The need for sustainable use is emphasised. Responsibility is delegated to regional government, which issues and administers all consents to use geothermal resources. Under the Act each regional government is required to prepare a regional plan which identifies the particular resources in its area and how they are to be managed; it is a definition of regional policy. There have been various amendments to the Act, a significant one being an acknowledgement that although administered regionally, the allocation of resources can be made in consideration of the national interest. This means that an application for a geothermal power station project in the TVZ can be assessed considering the benefits to the nation as a whole. For those whose role in the process of seeking consents is to provide expert witness, Schedule 4 lists matters that should be considered in an assessment of effects on the environment.

14.3 Rotorua

The conflict between the use of the resource by means of wells and the conservation of its natural features is the single most important issue in presenting any history of geothermal use in Rotorua. The conflict was raised as early as 1938 but did not become a matter of public debate until the 1970s, reaching a climax in the 1980s. The same conflict eventually arose in respect to other NZ geothermal resources, but nowhere else were there such a large number of established small users as at Rotorua. There were in excess of 350 bores (wells) taking a total of more than 25,000 tpd of discharge to supply individual households, hotels, motels, two hospitals, a Maori Institute and a Government Research Institute. Use of the heat was not very efficient and the discharged water was returned as ground soakage rather than injection.

The early history of geothermal use at Rotorua is set out by the former NZGS Rotorua District geologist J.F. Healey [1980]. He records that by the 1880s famous European spas with considerably fewer natural resources had become very popular tourist attractions. The Thermal Springs Districts Act (1881) was introduced and the Minister of Lands announced that land in Rotorua would be the first offered for public selection "in order to lose no time in rendering available the wonderful curative properties of the mineral springs in the vicinity of Lake Rotorua".

The Act preamble states that it would be advantageous to the colony and beneficial to the Maori owners of land with geothermal springs for the land to be opened up to colonisation and made available for settlement, and it sets out the powers given to the Governor to achieve this end, which included the purchase of land from Maori by the government, or assisting Maori to sell or lease land to settlers. Maori rights were sometimes overridden, the reason for the establishment of the Waitangi Tribunal in 1975 to correct injustices. The three-page Act contains nothing to restrict the way that the springs might be used and is devoid of any scientific wording. Encouraged by the Italian efforts, the NZ Department of Agriculture suggested drilling for hot water and steam in 1933, and the DSIR Geological Survey opinion was that this could be successful throughout the Taupo Volcanic Zone. Two wells 23 m and 59 m deep were drilled in Rotorua, which prompted the Ministries of Health, Industries and Commerce and Tourism and Publicity into debate about whether production from wells would reduce the output of the springs that supplied the sanatorium (hospital). Thus, the concern that was to become nationwide by the 1980s had been placed on record by 1938. Healey records that the DSIR had provided a quantitative response that since about 2,700 tonnes per day was being pumped from the springs without any signs of "overdrawal", considerably more could be extracted without depleting the resources, an assertion that is unlikely to have been supported by any evidence that would be acceptable today.

Electricity shortages gave rise in 1948 to the formation of a Rotorua Borough Council committee charged with the responsibility of developing the use of geothermal heating in the town. The committee produced a draft scheme for hot water reticulation, and the Council drafted legislation under which it could drill wells and construct reticulation schemes and also raise money for these activities through rates. Healey states that a delay in presenting the draft legislation to the government was incurred by the Council's Tourist Department, on the grounds that it should, but did not, contain provisions for protection of the springs. He records that in 1945 the Tourist and Health Resorts Control Act had been modified by the addition of clauses giving the Governor General the ability to declare any geothermal spring area a "thermal water area" in which no geothermal wells could be drilled without the written permission of the Minister, granted after consultation with the Minister in charge of the DSIR. Apparently the modification to the Act was never used. Developments at Wairakei precipitated the Geothermal Energy Act, 1953, through which control over geothermal drilling and production throughout New Zealand was exercised. This Act enabled the Minister to delegate some powers, and for Rotorua they were eventually delegated to the District Council under legislation called "The Rotorua City Empowering Act, 1967". The resource was not well managed; the Empowering Act gave the Council the power to issue licences to drill wells but none were issued despite many bores being drilled in the period up to the late 1970s. When the matter of protection of the important surface features finally came before the courts, there was criticism that the Council had missed an opportunity to collect revenues from licences which could have been spent on resource investigations. The community was divided into conservationists and "bore" users. With the benefit of hindsight, if the groups ever existed, neither should be blamed. Successive governments had passed legislation and funded research programmes aimed at encouraging the extraction and use of geothermal energy, but without providing guidance on conservation. Deeper and larger output wells than the usual for Rotorua had been drilled to supply the Forest Research Institute, a government establishment for research into timber production, which was a large export industry. The primary tourist feature was a geyser, Pohutu, which by the late 1970s was becoming less regular in its performance; it was the main one of a small group. The extraction from bores was blamed. The geyser had ceased discharging earlier in the century, before wells had been drilled and before scientific instrumentation and understanding was available to interpret events, but it had restarted again without any intervention. Local government scientists appear not to have had the ear of the authorities; when attention was at last gained in the late 1970s, action was delayed because the historical measurements of surface activity and resource use were considered inadequate. Public concern for the geysers produced a government reaction, and a lengthy new scientific programme was undertaken after the inevitable political debate about who should pay. By 1986 evidence of annual variations in the daily take had been correlated with changes in resource pressure in the producing formations, these being measured as water level changes in several monitor wells, one of them fairly close to the Pohutu geyser. It was decided to impose restrictions on well discharge within a radius of 1.5 km of Pohutu, originally only for summer use, with exceptions permitted if there was no alternative source of energy, but eventually total closure was required of all wells within the 1.5 km zone. Punitive energy licence charges were imposed which made geothermal heating uneconomic.

The Rotorua Geothermal Users Association, a group of domestic well owners, challenged the Minister's authority to introduce these changes by a High Court action. In preparation for these proceedings, the association engaged the consulting firm of KRTA to examine the evidence on which the Minister was acting and asked whether bores needed to be closed. The report concluded that the Rotorua draw-off was certainly too large and that some wells must be closed; however, several weaknesses in the evidence presented by government scientists were identified. The first was that the pressure in the producing formations was measured as a change in water level of certain wells which would stand open without discharging—the monitor wells already mentioned. Using a well as a manometer relies on the temperature and hence fluid density distribution being constant; no checks on this had been carried out. The second was that the casing of an old well within the 1.5 km radius had recently failed, resulting in the formation of a crater and a continuous blow-out discharge. This was catalogued by government scientists as a spring not a well, and its influence on formation pressure was ignored—in fact, the influence of wells on formation pressure was never discussed in any of the published government investigations. An examination of the monitor well water level variations at and shortly after the blowout, and application of the Theis solution suggested that the blowout had contributed to the reduction in the well's water level. Thirdly, no scientific reason for adopting a 1.5 km radius of closure was given. The High Court challenge by the association was on the grounds of arbitrariness of the 1.5 km radius closure zone and that the Minister had exceeded his authority. The law gave the Minister authority to close wells (bores) that were "in the opinion of the Minister, affecting detrimentally other specified bores…or a specified tourist attraction". Courts are skilled at identifying critical issues, but need the guidance of expert witnesses; no expert witness was called by the Users Association. The written judgement (RGUA [1987]) indicates the level of understanding that the court was left with when it states:

> *I can imagine that something can be made of the efficiency of certain bores within the 1.5 km area which gives rise to different considerations as to likely impact.*

and in discussing the complaint that the 1.5 km radius was arbitrary:

> *…Proximity* (to Pohutu) *is the most relevant factor, and once that is established in my view questions of arbitrariness disappear.*

How the court was persuaded that proximity to Pohutu had been established as the most relevant factor in assessing the effect of well discharge is unknown, as the court proceedings are retained as confidential. The effect of the production from a number of wells on formation pressure at a particular location is a standard well testing issue, resolved by superposition of the Theis solution for each well at its discharge rate. This had been addressed in the KRTA report, which had concluded that certain large output wells 2 km away from the geysers, some owned by government organisations, could be producing a bigger pressure reduction at Pohutu than many of the private wells within 1.5 km. It was this aspect that provoked an appeal by the association against the proposal to apply the 1.5 km radius closure zone; many of its members were concerned about environmental impact. From a purely geothermal engineering point of view, a more equitable solution could have been designed to fulfil the need to protect the resource and was proposed by KRTA; however, the appeal was declined and all wells within a 1.5 km radius were closed.

The reduction in the total production from the resource produced a recovery of water level (resource pressure) over 2–3 years. The discharge frequency of Pohutu and the adjacent geysers, which had never been absolutely regular, increased to the point of discharging almost continuously. Areas of hot ground in Rotorua which had cooled off as a result of excessive production and been built on, now became hot again, causing hydrothermal eruptions, ground collapses and some property damage. Surface springs in many areas increased their discharge rate and new ones appeared. The well closures were hailed as a success, a victory for environmental protection over commercialism. The situation had been rescued, but clumsily, and a financial loss, and hence a loss of opportunity, had been unnecessarily incurred by individuals and taxpayers. The sad history of resource use at Rotorua from the 1960s to 1986 might justifiably be seen as the result of a failure by scientists and geothermal engineers to recognise impending problems, design solutions and exercise their influence on local government.

14.4 Wairakei

14.4.1 The Original Development 1956–2001

The origins of the Wairakei resource development are explained by Bolton [2009], who played a significant engineering part in it. It began as a combined project between the British and New Zealand Governments, the former wanting a cheap source of heat and power for the production of heavy water for its nuclear programme and the latter simply wanting more electricity. Not long after the turbines for the combined generation and processing plant had been ordered, the British need for heavy water decreased and the New Zealand Government continued with the development alone. This partly accounts for the many small turbo-generators which make up the power station, which operates on a double flash system but has three different turbine inlet pressures. Of the six 11.2 MWe capacity turbines, two are operated as back-pressure turbo-alternator sets and the others as condensing sets. In addition there are three pass-in condensing sets of 30 MWe capacity each, one 4 MWe back-pressure set and an Ormat binary plant. The steam-powered units were commissioned between 1958 and 1963 and the 14 MWe Ormat ORC plant in 2005 (Thain and Carey [2009]).

By the 1990s 140,000 tonnes per day of geothermal fluid was being produced from the wells. Up to that period, none of the produced fluid had been returned to the resource with the result that the nature of the surface activity was irreversibly changed. The main area of boiling water discharge had been Geyser Valley, a tourist attraction said to have tens of geysers and many more named springs;

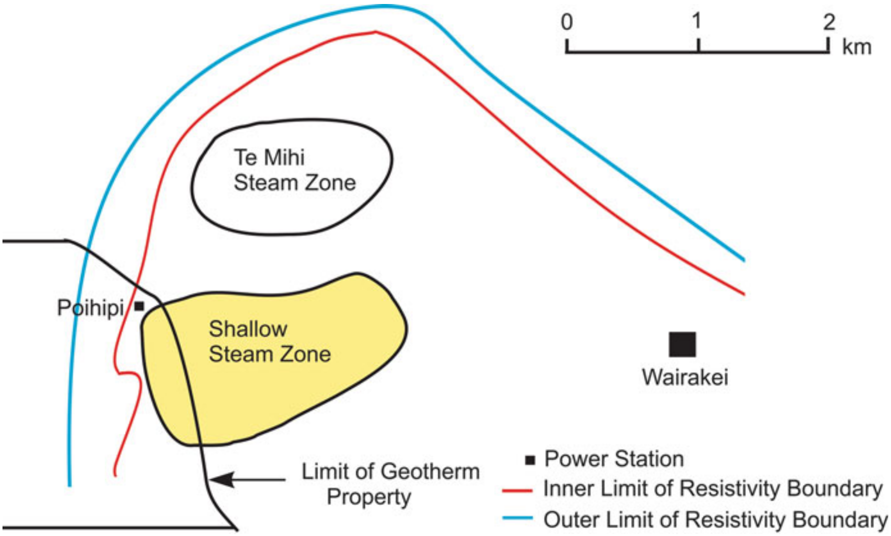


Fig. 14.1 Sketch map showing the Wairakei resource, two steam zones and the Wairakei and Poihipi power stations. The uncertainty in the resistivity boundary is indicated, as is the extent of the Geotherm property

Glover [1998] gives a detailed account, stating that neutral chloride water from the deep reservoir ceased to flow as a result of large-scale production. The surface activity changed from boiling springs and steam-heated features to acidic springs, and steaming ground increased in area and heat output. Various modifications were made to the scheme for flashing separated water, to improve efficiency. The high-pressure steam supply began to run down and in 1982 the high-pressure sets were removed for use elsewhere, reducing the installed capacity to 157.2 MWe. The resource and its operations represented a continuous research and development project for earth scientists in particular, and reservoir simulation at the University of Auckland was being developed, while it was being used to make predictions.

14.4.2 The Poihipi Development 1988–1997

In 1987 the electricity industry in NZ underwent a major change. The government-owned electricity department became a state-owned enterprise called the Electricity Corporation of New Zealand (ECNZ), and electricity generation by commercial companies was permitted. Many of the nationally owned regional electricity distribution authorities became private companies, and some had funds to invest. Mr. Alistair McLachlan, a local businessman and entrepreneur, had a small farm on land situated on the edge of the Wairakei resource. The resistivity boundary bisected his land and it was estimated that about 1 km^2 lay over the shallow steam zone (the largest of the two steam zones shown in Fig. 14.1) which had been extended by the extraction of water at Wairakei; a shallow well used for greenhouse heating produced steam consistent with it accessing the shallow steam zone, and Mr. McLachlan had consent to take 1,800 tpd of steam. In 1988, he applied for resource consents for his company Geotherm Energy Ltd to extract up to 44,000 tonnes per day (tpd) and inject up to 40,000 tpd, with smaller amounts of freshwater to be taken for cooling and disposed of by injection along with steam condensate, outside the resistivity boundary. There were four objections, from the Government Tourist and Conservation authorities on the grounds that surface activity had tourist and conservation values which would be diminished, from the local Maori Tribal Trust on cultural and loss-of-opportunity grounds and from ECNZ on commercial grounds that it would affect its production.

Consent was given by the regional authorities for the production of 10,000 tpd, of which not more than 3,000 tpd was to come from the shallow steam zone because this was an existing source of production for ECNZ and was the source of steaming ground activity of tourist and conservation value.

This consent was appealed by ECNZ, which meant that the application was referred to the Planning Tribunal (which has since become the Environment Court). Decisions of the Environment Court can only be appealed on grounds of law, and not on scientific or engineering matters. ECNZ had concern about the injection of the separated water, which had to be injected into the resource and not into freshwater formations surrounding it. The locality is heavily faulted and there was considerable debate about where the cool injected water would flow to; it would reduce Wairakei output if it flowed back to Wairakei production areas. The Tribunal's decision was that Geotherm's injection area must lie adjacent to the resistivity boundary and just within it, and its production wells must lie between that and ECNZ's part of the resource area and be cased to below the bottom of the steam zone. If injected fluid was to move in the direction of ECNZ's production, then it would affect Geotherm's production first. The production was allowed to remain at 10,000 tpd, with 3,000 tpd to come from the steam zone. No well was permitted to cross the vertically projected boundaries of Geotherm's property, a standard clause in New Zealand consents.

Geotherm proceeded with drilling wells into the steam zone, which turned out to be good producers. It had the option of purchasing from the Geysers field (California) a reconditioned steam turbine power station with a full-load demand which could be met by the 4,800 tpd of steam permitted from the shallow steam zone (the original 1,800 tpd plus the 3,000 tpd permitted by the Planning Tribunal). The payback period for the investment was less than 10 years, an attractive proposition, but subject to the risk that the steam zone pressure would decline beneath the Geotherm property before the investment was paid back. The only significant reservoir simulations carried out were for ECNZ, and they suggested that the steam zone pressure would decrease drastically in only a few years. Acting for Geotherm, the consulting firm of KRTA was limited to estimating the flow to Geotherm's production wells based on the thickness (about 125 m) and permeability of the steam zone, assuming that the source of steam was within ECNZ's part of the field. The indications were positive for Geotherm but there was uncertainty about the calculations as too little was known about the source. In the meantime, Mercury Energy, the Auckland area electricity distributor, formed a partnership with Geotherm and the 55 MWe (gross) Poihipi power station was built, a single turbine with a separate (tubular) condenser. The decision to install this plant cannot have been based on the consents that were available to Geotherm, as only the steam zone production was proven, and no doubt wider commercial considerations were involved. Its base load steam demand at full output is 10,700 tpd or just over twice the 4,800 tpd that was permitted, and its output when operated by Mercury Geotherm was varied during the day. ECNZ, which owned all major NZ geothermal and hydroelectric stations, was subsequently broken into smaller units and sold, and Wairakei and Poihipi are currently owned by Contact Energy.

Very little information on which to base a resource simulation was available for the Geotherm part of the resource where no well had been drilled into the steam zone previously. There was uncertainty about where the edge of the steam zone was, and eventually there was direct evidence of an edge in the form of high ncg (CO_2) concentrations, which is understandable if the steam zone is expanding into cooler ground so that the steam condenses leaving the gas. More recently Zarrouk et al. [2007] made use of the variable load operation of the station to examine the type of permeability model which best fits the well measurements. They show that the station was operated at an output of 29 MWe with a very regular step change to 8 MWe for about 5 h every day, with a minor but also very regular 7 MWe pulse superimposed. By modelling the response of the production wells and a monitor well to the pulsed discharge, they concluded that the steam zone is supplied by a fracture network which provides significant vertical flow. The shallow steam zone pressure has not declined to the extent initially predicted, no doubt because of this previously unknown enhanced permeability.

14.4.3 The First Proposed Tauhara Development

The resistivity boundary of the Wairakei resource is not a closed circle around Wairakei, but narrows then opens out again to surround what is known as the Tauhara resource—the two are connected by a relatively narrow neck in a single resistivity boundary. The town of Taupo sits partly over the neck and partly over what was understood at the time to be the Tauhara resource, which was explored by drilling while Wairakei was being drilled, and the wells mainly left unused thus acting as monitor wells. The effects of Wairakei production were seen as a fall in deep reservoir pressure which was interpreted as a fall in water level in the upper levels. The geology of the area can be imagined as a sandwich of permeable and impermeable layers, so that drainage of the lower layer by a flow towards Wairakei led to drainage of the layer in the sandwich immediately above, and then on to the next. Shallow wells had been drilled in Taupo for domestic hot water supply, and separate water levels at various layers of the sandwich were detected; Brockbank et al. [2011] show three layers and the pressure measurements from a large number of wells of varying depth, so that some are

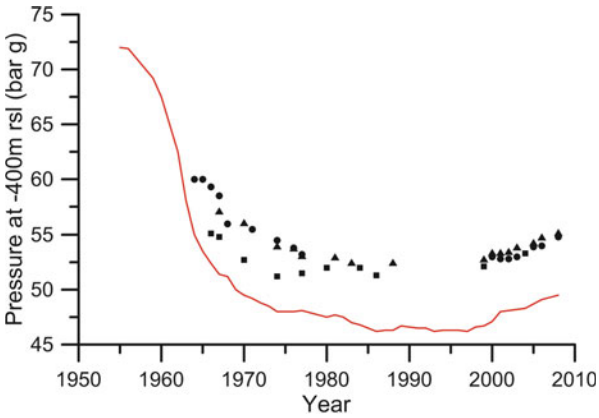


Fig. 14.2 Pressures at production depth in Wairakei (*full line*) and Tauhara (*individual points*) from evidence presented by Bixley to the Tauhara II Board of Inquiry hearing [2010] (*reproduced by permission of Contact Energy*)

in liquid and others in the steam-filled zone above the liquid level. Areas of steaming ground had existed since before the development of Wairakei, but in the 1970s the heat output began to rise; it peaked and later returned to normal and became referred to as a heat pulse. All of this was consistent with the drawdown of the Tauhara part of the resource by Wairakei, and in evidence Bixley produced data from which Fig. 14.2 has been plotted. The continuous line shows the way the mean pressure at production depths fell from the start of production to a minimum in the late 1990s when injection began; it has risen since then. The points are measurements at Tauhara wells—the pressure is higher but follows the same pattern, demonstrating a flow from Tauhara to Wairakei.

The Poihipi development had been prompted by the commercialisation of electricity generation; it began as one man's idea but soon after large organisations became involved and perhaps began to position themselves for the anticipated breakup and sale of ECNZ by the government. The Tauhara area had been regarded as a "poor relation" of Wairakei, but three applications to build power stations using it now appeared. Contact Energy applied for a 50 MWe steam plant combined with a 20 MWe ORC plant, and a Maori group together with a local electricity generator/ retailer for a 60 MWe station. A further proposal by the Taupo District Council, which already owned a small hydro-station, combined with Mercury Energy for a 100 MWe was lodged but later withdrawn. After some time all applicants except Contact Energy withdrew, and the outcome was the granting to Contact by the Environment Court [2000] of the rights to take and inject 20,000 tpd for a nominally 15 MWe power station. The court's decision is important here because it addressed the issue of the very slow rate at which some environmental impacts appeared compared to the length of time for which consents were issued. The Resource Management Act by then in force provided a maximum term of 35 years. The debate arose because of subsidence, which was ongoing in the area after almost 50 years of Wairakei production, and was still poorly understood. The Act required the potential effects of a proposed development to be balanced against the potential benefits, community wide. If subsidence from the first consented use of Wairakei was still appearing at the surface, with what should the effects of a new proposal for increased use be compared? Consents are written to require the setting aside of a sum of money from which to compensate the general public from any damage suffered. Were the new holders of the Wairakei consents and owners of the power development to pay for damage only just appearing but resulting from Wairakei operations carried out when it was owned and operated by the NZ Government? Was it possible to analyse the subsidence with sufficient accuracy to associate any future subsidence with particular resource use?

The Tauhara hearing decision (Environment Court [2000]) set out the principles by stating that:

> *We hold that consideration is to be given to the effects on the environment as it actually exists now, including the effects of past abstraction of geothermal fluid from the system, whether by Contact or anyone else. In considering the effects in the future of allowing the proposed abstraction, we hold that we have to consider the environment as it is likely to be from time to time taking into account further effects of past abstraction, and effects of further abstraction authorized by existing consents held by Contact or others, . . .*

This part of the decision acknowledged the difficulty in identifying the cause of any particular environmental effect and established the guiding principle.

14.4.4 The Renewed Wairakei Consents and the Te Mihi Power Station

The original Wairakei consents expired in 2001 and Contact sought to renew them. Disposal of separated water to the Waikato River, which was allowed under the original consents, was no longer acceptable—considerable evidence and debate ensued, but Contact submitted proposals to phase the practice out over a 10-year period, injecting the water both inside and outside the resistivity boundary of the resource. “Outfield injection” as the court preferred rather than reinjection raised the issue of contamination of freshwater aquifers, and infield injection became an issue associated with subsidence and the existing environment principle established by the Tauhara decision.

Wairakei subsidence had been quoted for many years as being amongst the greatest in the world—it is, but only in a few areas. Figure 14.3 is a surface plot of subsidence measurements at about 2001 but with the subsidence inverted, so the hollows show up as peaks. A sinuous heavy line leaving the top of the figure represents the Waikato River and the Wairakei power station is on its banks adjacent to the greatest subsidence. The same line, after it bifurcates towards the bottom of the figure, marks the shoreline of Lake Taupo. The dots mark survey points. Generally, the subsidence over the whole area within the resistivity boundary is very small and there is only one place where it is on a world record scale of more than 9 m, not far from the Eastern borefield and near the power station. It is also significant on the outskirts of Taupo (by a loop in the river in the figure). This location is in the area referred to as the neck of the resistivity boundary.

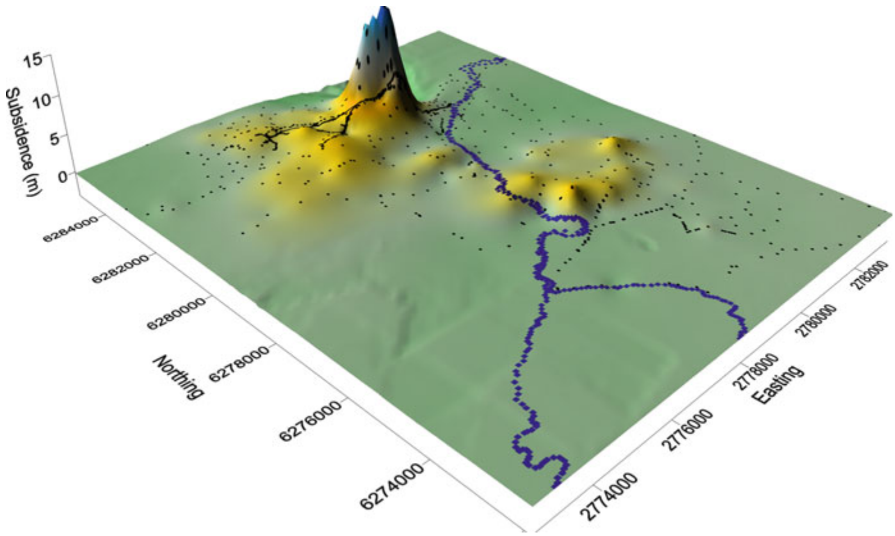


Fig. 14.3 Subsidence distribution over the Wairakei resource, inverted so that maximum subsidence (minimum elevation) appears as a peak (*Data originally provided by T. Hunt, figure created and presented as evidence to the Environment Court by A. Watson*)

At the time of the renewal hearings, attention was drawn to a new subsidence bowl in the built-up part of Taupo known as Crown Road. House damage had been experienced, but it was not clear that it was due to subsidence rather than poor building, and to confuse the matter further, it appeared that some of the houses had been built on gulleys filled with waste from sawmills, which did not offer a firm foundation. The bowl was increasing in depth and extent, however, although it is too small to appear in the figure.

Subsidence had been regularly monitored for many years and a grid of survey points had been established by the original Department of Scientific and Industrial Research (DSIR) and its modern form the Institute of Geological and Nuclear Science (GNS). Allis (see Allis and Zhan [2000]) had developed a method of predicting subsidence using a one-dimensional model. The subsidence was considered to be due to the presence of one or more formations with a very weak matrix which compacted when the fluid pressure decreased as a result of production. The pressure had decreased rather uniformly over the whole Wairakei part of the resource, however, which led to the conclusion that the weak formations were localised and of very small area. It was suggested by the author in evidence that cold downflow from shallow formations could have drained into formations occupied by steam zones, condensing them and reducing the fluid pressure to produce almost a vacuum. The heat capacity of a cold downflow in a well is very large, and if it entered a steam zone, the water flow rate through the permeable medium may not be fast enough to relieve the vacuum (the saturated vapour pressure of CO_2) and the formation would collapse. The Eastern borefield had many wells with broken casings, and the greatest subsidence was in that general locality. Hunt [1970] had demonstrated that changes in saturation of formations in response to production from the Wairakei resource could be detected by gravity measurements; the presence of steam reduced the material density and hence its gravitational attraction and vice versa if a large body of cold water filled the formation. At about the same time as the hearings were in progress, Hunt et al. [2003] independently associated measured gravity changes at Tauhara with a known downflow in a well. In any event, at Wairakei the area of maximum subsidence is very localised, suggesting the presence of either a very localised and particularly weak geological formation or precisely the right conditions for a very particular and as yet unconfirmed physical process to take place (in the same way as hydrothermal eruptions require a rare set of circumstances). The more recent publication by Allis and Bromley [2009] offers no firm conclusions on the mechanism.

The area of maximum subsidence coincided with an unpopulated, localised and very steep sided gulley, where changes in elevation and slope only became evident as a result of secondary effects—a stream backed up and formed a pond, a concrete canal carrying separated water from the field to the river changed slope and the wires between telegraph poles became tight.

For the hearings, and in opposition to the renewal of the consents, Taupo District Council (TDC) commissioned the preparation of expert witness statements which included predictions using a two-dimensional subsidence model based on a soil mechanics programme, described by White et al. [2005]. The choice of a two-dimensional model appears to accept an unnecessary restriction since numerical software was used. Geologists frequently draw two-dimensional cross sections, which convey accurate information if the material is solid. Many fluid mechanics problems were studied in two dimensions, but the solutions were compared with two-dimensional flows. If two-dimensional equations are written to represent a cross section through a three-dimensional flow field, the gradients in the third dimension are effectively being set to zero. Some of the formations are clearly uniform in thickness and could have a two-dimensional flow pattern, but there was interest in areas where the geometry appeared to be more three-dimensional. However, the main difference between these subsidence studies and those of GNS—Allis and Zhan [2000], for example—was that the TDC evidence was based on the idea that the compaction occurred in a deep formation, the upper layer of the main producing formation for Wairakei, and the GNS evidence that it occurred in shallow formations. It was clear to all that the result of the compaction was a changing pressure distribution throughout the resource which produced vertical movement that moved slowly upwards, eventually depressing the ground surface. The court's interest was in proposals as to what to do to reduce the impact of subsidence, in the light of the earlier Tauhara decision which recognised the ongoing problem. TDC's proposal was to inject beneath Taupo township, to bring the pressure distribution back to what it might have been before Wairakei production began in the 1950s; however, the court adopted the approach offered by Environment Waikato, the regional government responsible for resource management. This proposal was to inject into the neck of the resistivity boundary with the aim of maintaining the pressure distribution in that area as it then was. The pressure distribution beneath Taupo could then be regarded as the existing environment—it was a distribution due to the expiring consents. Provision was made in the renewed Wairakei consents for Contact to provide a bond to be drawn on in the event of damage to property by subsidence due to Wairakei operations. Within the hearing there was considerable detailed scientific and engineering discussion between the parties about the combination of deviated injection wells and new pipeline routes required to deliver the fluid to the area and how the resource pressure should be defined and measured. The court's decision was to renew the consents under a set of conditions described by Daysh and Chrisp [2009].

Shortly after the renewal of consents, Contact announced its intention to build a new power station on the Wairakei resource, to be called the Te Mihi power station and to phase out at least part of the original Wairakei plant. The Resource Management Act was constructed on the idea that consents to use natural resources would be granted by regional authorities, but provision was made for an application directly to central government if it was in the national interest, and in this case the application was heard by a Board of Inquiry selected by the central government and chaired by an Environment Court judge. Both the Te Mihi power station and an application for a new development at Tauhara called Tauhara II were considered by such Boards.

14.4.5 The Tauhara II Proposal

The Tauhara II proposal, for which Contact has received consent, is of interest here as an example of planning for a new resource. The proposal is illustrated by Fig. 14.4, based on a map in the evidence of Bixley for Contact Energy (the complete figure is contained in the written Board of Inquiry Decision [2010]). The resistivity boundary of the combined Wairakei and Tauhara resource, with its waist or neck, is shown in the figure.

It had been conjectured for decades that Wairakei and Tauhara had separate deep upflows of hot water, because although the effect of Wairakei production had spread measurably into Tauhara wells, some surface activity had remained unaffected. The decision records that further drilling has revealed possibly two separate upflows. The resistivity boundary comes close to the Rotokawa resource, consistent with the rather densely packed but apparently individual resources in the TVZ as shown in Fig. 2.8. Te Mihi, Wairakei, Poihipi and the two stations at Rotokawa all lie within 10 km of the proposed new station, which is to be a double flash system with a direct-contact condenser and a total generating capacity of 240 MWe.

Production and injection areas are shown on the figure; injection outside the resistivity boundary is permitted. The targetted injection area between the production area and Taupo to maintain the pressure constant beneath the urban area is indicated only approximately. The numerical reservoir model for Wairakei–Tauhara has been extended to cover the new development area and includes the data from

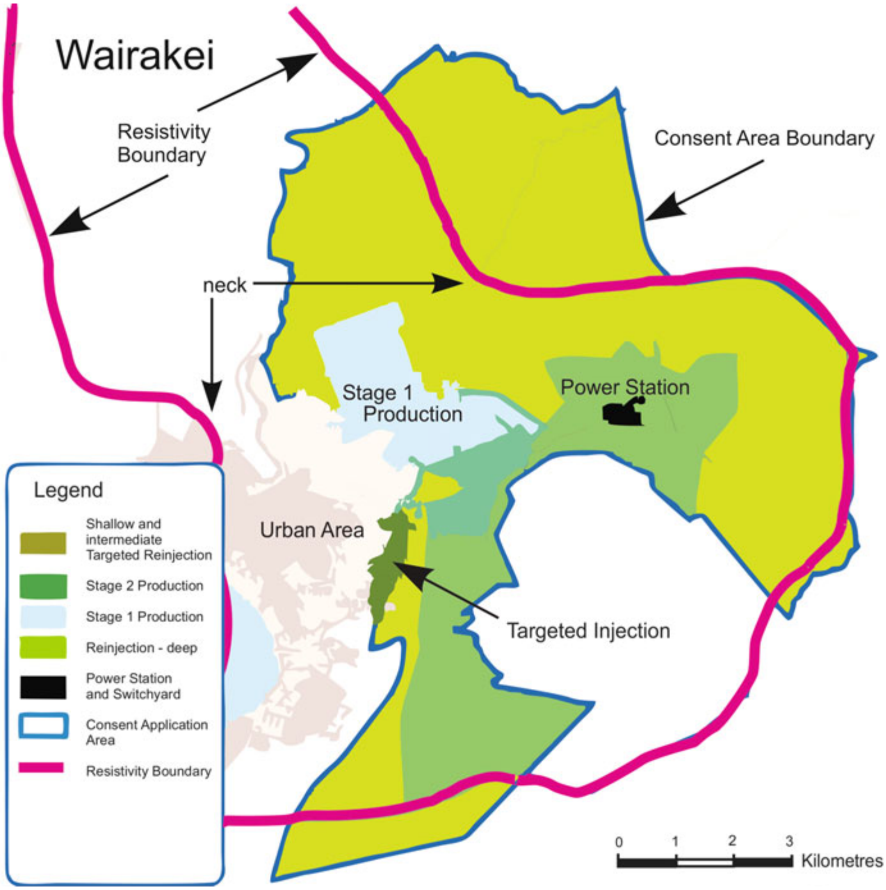


Fig. 14.4 Map of proposed Tauhara II development based on Board of Inquiry report and final decision [2010] Tauhara II geothermal development project, Appendix 8. The neck in the resistivity boundary previously mentioned is shown. (*reproduced by permission of Contact Energy Ltd*)

some new wells drilled. The model assumes that the heat is supplied by thermal conduction through the greywacke basement; from a heat transfer perspective, it is noteworthy that this has been found to be sufficient to provide for the high-temperature resource found, without the addition of a convective supply (upflow).

14.5 Ngawha

Ngawha is an example of a resource developed with a great deal of care for the surface activity and with a successful outcome so far as electricity generation is concerned. If the entire expenditure on its exploration and development was taken into account, its economic success would be questionable, but this is because the wells were drilled by the government and left as an idle investment for 15 years or more. There can be little doubt that the existing operation is economically successful. Ngawha lies several hundred kilometres north of the TVZ and is apparently an isolated, anomalous resource that would have been regarded as a risky exploration project. Nevertheless, it has a maximum measured well temperature of 320 °C, but 220 °C is a more representative average resource temperature.

The tectonic history of northern New Zealand is the subject of active debate (see Schellart [2012] who provides an examination of possible subduction modes viewed in a manner similar to that of Sect. 2.2.2). The geology of the resource is very simple from an engineering perspective; a layer of marine sediments approximately 600 m thick lies over greywacke to below the drilled depth of 2,300 m. The sediments are allochthonous, that is, they were deposited somewhere else and the entire block was moved into its current position by forces resulting from tectonic processes. The greywacke is heavily fractured but appear mainly sealed by mineral deposition. The well measurements show permeability at the contact between the sediments and the greywacke and also at localised zones within the body of the greywacke which suggests that the permeability is provided by faults.

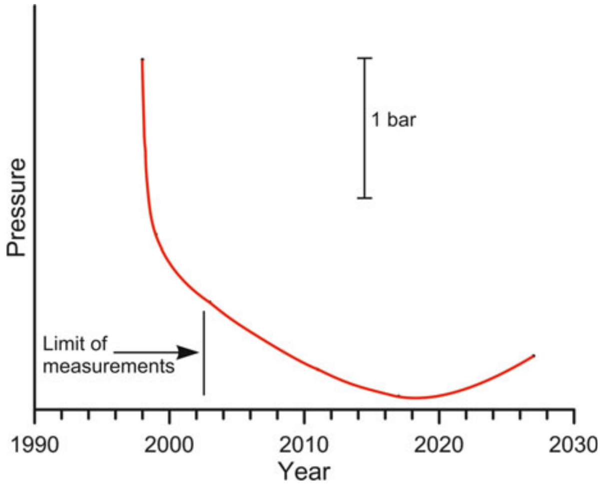
The area has relatively minor surface springs; they are not the vigorous localised discharges of the TVZ. The hot water was known to Maori and used for therapeutic bathing by digging shallow pits into the ground and allowing the hot water to fill them by seepage. The water carries minerals collected from the sediments and the baths are still in use today. The water also has a high mercury content; cinnabar (mercury ore) was mined at Ngawha in the early part of the twentieth century (Mongillo [1985]). To the geothermal engineer, perhaps the most significant features are the amount of CO_2 in solution in the liquid water resource fluid and the geometrical simplicity of the resource—which does not make reservoir simulation simple however. There are high concentrations of boron, and calcite scaling occurs in the wells. Although the resource fluid appears at the surface only at a very few places, CO_2 emerges over wider areas, although not sufficient to prevent vegetation. In particular a concentrated discharge of CO_2 is thought to be the cause of a lake having formed at one place over the resource where the gas flow rate has been enough to create a deep depression into which surface water has drained (Simmons et al. [2005]).

Mongillo [1985] collected all the scientific information on the resource, which was drilled by the New Zealand Ministry of Works and Development in approximately 1980. Although the population north of Auckland was low and industry sparse at that time, any increase in electrical load would have caused problems because generation was several hundred kilometres away and there were few acceptable transmission line routes through the Auckland isthmus. The development was deferred, the structural changes to the electricity industry already mentioned above took place, and a decision to obtain resource consents and build a power station finally resulted in an application in 1992 by Top Energy, the former local electricity distribution company. The wells were the property of the Ministry of Energy and had sat idle since being drilled in 1980–1982. The application was to take and inject up to 40,000 tpd, an amount for which there was no detailed scientific basis as the resource had not been discharged significantly. There was considerable concern by local Maori that the surface springs might disappear as they had at Wairakei, and a claim was made to the Waitangi Tribunal for Maori ownership of the entire resource. This was rejected but it was recommended that the springs be preserved, and this became a consent condition when the Northland Regional Council (NRC), the regional government, eventually gave consents, which it did for 10,000 tpd for a period of 10 years. The first year was to be used for the collection of baseline environmental data, since the area includes wetland with conservation value as well as the springs.

The geothermal water content of the spring water was identifiable by the chloride concentration, and spring protection was provided in the consents by a condition stating that if the mean chloride concentration in the spring water fell outside its normal variation, then the power station must cease to use the resource. The chloride concentration in the springs had a fairly large random variation presumably due to the long passage through the 600 m thick sediments to the surface and then mixing with rainwater near the surface. Nevertheless, this condition posed a risk for the developer, which was added to by the term of consent being only 9 years, a very short time to pay off a loan. The wells were purchased however and an Ormat ORC plant of 10 MWe capacity was commissioned in 1998, with production and injection at opposite sides of the resource. Two production wells and two injection wells were used, and the water was injected at 90 °C.

After 5 years of operation, Top Energy advised NRC that it wished to renew the consents when they expired and to increase production to 25,000 tpd and station capacity to 25 MWe. The porosity of greywacke is only a few % so the volume of water in the resource is small, and downhole pressures had begun to decrease almost from the start of production. One of the original wells, Ng13, was situated close to the springs and was reserved to monitor resource pressure; its wellhead pressure remained high due to the gas content. By 2004 measurement from all wells showed a consistent trend of falling resource pressure, a fall of about 0.3 bars per annum. Chloride concentration in the springs showed the same random variation as before production, with no certain evidence of any decline in their output. Nevertheless, the company took a conservative view, and in the new application, it suggested injecting extra freshwater at a rate sufficient to keep the wellhead pressure of NG13 steady; up to 1,600 tpd was estimated—this was a novel idea for a resource of this type. A 4,000 block TOUGH2 reservoir simulation model was developed by the University of Auckland (Prof O'Sullivan) and improved as time passed. At the time of the application (2004) extra water injection had not been tested, so in case it did not work as planned, reliance had to be placed on the model predictions, which were based on field data collected without the extra injection. The prediction was that the reservoir pressure would continue to fall until 2017 after

Fig. 14.5 Sketch of Ngawha resource pressure variation predictions made in 2003, showing the extent of the measurements at the time; measurements and predictions were coincident up to the marked "limit of measurements"



which it would rise slowly. The predicted and measured pressure variation is sketched in Fig. 14.5.

The concentration of CO_2 in the reservoir fluid was changing as production fluid was degassed, injected, reheated and recirculated back throughout the resource, and this effect was included in the model. The level of confidence in the prediction was said to be high until 2008, with lower confidence after this—the resource did not have a long history of use with which to refine the model. Figure 14.5 suggested that an important balancing of effects occurred in 2018 to produce a minimum in pressure, after which it would increase slowly. This was encouraging in terms of protection of the springs, but the minimum appeared long after the 2008 high confidence limit. NRC therefore declined the application to increase production but gave consents for the existing 10,000 tpd for a further 15 years, including the injection of up to 10 % more water than discharged. Top Energy appealed but eventually an unusual course of action was taken, with NRC support. Using provisions of the RMA, the Environment Court granted consent for a 6-month delay in the Appeal, with approval to carry out water injection trials, the results of which would be presented to the court at the Appeal hearing. The trial consisted of injecting nominally 1,000 tpd of extra water into the resource via an unused well about 500 m from the monitor well while measuring the pressure increase at the monitor well. The daily rate of injection could not be kept constant but the variations were recorded and used as input to the simulation model; the output was a graph of pressure increase to compare with the measurements. The monitor well pressure responded measurably about 10 h after the start of injection. The model predictions showed a much more rapid rate of pressure rise than was measured, but agreement after the initial rise was good. For the same hearing, a simple numerical model of the springs was produced which suggested that if the reservoir pressure was maintained to within ±1 bar, the variations in supply of reservoir water to the springs would result in a chloride concentration variation within the range of the natural variations on record. The court granted the renewal and increase in production to 25,000 tpd and approved an increase in installed capacity to 25 MWe. The 25-page decision provides detail (Environment Court [2006]). The amount of extra water to be injected was increased to 3,000 tpd to provide some margin above the 1,600 tpd which was anticipated to be sufficient.

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