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Possible Conflict Between the Interests of Tourism and Geothermal Power Development

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ABSTRACT

The discharges of holes drilled for geothermal prospecting or development may cause, through the lowering of the water table, the decay of local hot-spring activity. So far, the losses in New Zealand have been Geyser Valley, a major tourist attraction at Wairakei, two minor areas there, minor hot springs of Kawerau and Broadlands, with a fortunate escape for Waiotapu, a major attraction. There have also been losses through hydroelectric developments, especially at Orakeikorako, a major tourist attraction, where 75% of the hot springs have been flooded.

If one defines a "hot spring region" as a locality where hot spring areas of varied attractions can be conveniently visited from one center, then there are only five such regions in the world. Yellowstone National Park is preeminent in the number and size of its geyser basins, but the Rotorua-Taupo region, although poor in geysers, has the advantages of accessibility at all seasons, association with active volcanism, and a greater variety of scenery. Any further losses of hot springs in the region, now with four major tourist attractions, would be serious.

The underground reservoirs of hot water may last under exploitation for only 100 years, perhaps till nuclear fusion energy makes them unnecessary. Hence the fact that losses have been compensated by tourist interest in the bore field, and the power development, loses its significance, especially as later power developments will not have the same interest. Tourism, even if modified in ways not yet envisaged, can be expected to last as long as the natural springs, perhaps for thousands of years. Serious clashes between tourist interests and power developments seem to need further consideration only in New Zealand.

INTRODUCTION

The geysers, boiling pools, and the beautiful, deep clear pools on sinter aprons and terraces are a special attraction to tourists, who also find the associated boiling mud pools, bubbling mud pots, and steam vents interesting. In New Zealand the hot springs of the Rotorua-Taupo Thermal Region (also called the Central Volcanic Region) of the North Island, were an attraction to tourists long before the famed pink and white terraces were destroyed in the 1886 eruption. The hot water is supplied from underground aquifer reservoirs of hot chloride water. It is also known here that discharges of hot water even from prospecting drilling, long before there is any appreciable effect on the stores of hot water, can lower the water table locally, so that geysers cease to play, and hot springs cease to flow. Hot-spring regions with these attractions are not common, so that the possible serious diminution in the attractions of this region through geothermal power developments must be of interest to all nations.

Prospecting investigations have found numerous localities with springs of hot water, boiling pools, geysers, and fumaroles. However, for the purpose of this paper a "hot spring region" is defined as a region where many hot-spring localities occur, which are attractive in variety and accessible to tourists from one center. By this definition there are only five hot spring regions in the world: Yellowstone National Park, USA; Iceland; Kamchatka; north Chile; and Rotorua-Taupo region, New Zealand. A case could be made for the inclusion of some other regions, such as Japan, Indonesia, and the Philippines.

The most notable omission is probably Japan. Waring (1965) lists 248 localities in Japan. Information is also given by Uzumada (1965). The reasons for not including Japan are: (1) the hot spring localities are distributed throughout the whole length of Japan, with no one outstanding region, and the few geysers occur as far apart as Nororibetsu (Hokkaido) and Aso National Park in the very south; (2) most of the hot springs are not spectacular, but are simply discharges of hot water, providing the hot baths so much enjoyed by the Japanese; and (3) there is so much else to attract tourists in Japan, such as the large number of active volcanoes and calderas. Reasons (1) and (3) also apply to Indonesia and the Philippine Republic.

WORLD HOT-SPRING REGIONS

Yellowstone National Park

This region is the best described. The main description is by Allen and Day (1935). The hot-spring localities occur in an area about 100 by 50 km, not much different from the size of the New Zealand region. The region is 80% forest-covered, and is more than 1800 m in elevation. The region is unsurpassed for the number and size of the geyser basins and the height, beauty, and variety of geyser columns. The Upper Geyser Basin is unsurpassed anywhere. In a sinter-covered basin 3 by 1.5 km there are 42 geysers. The Lower Basin, of 40 km^2 area, has 42 geysers. In addition there are another 5 geyser basins and a further 36 geysers. There are also 35 geysers in Norris Basin, the largest of 10 mixed chloride-sulfate localities. Two localities of bicarbonate waters are depositing travertine, much in the form of beautiful terraces. Another eight localities are classed as sulfate springs with mud pools and a few fumaroles. The scenery includes coniferous forests in the west and open grasslands, snow-covered mountains, and intermontane valleys in the east. There are also waterfalls, Yellowstone Lake, Yellowstone River canyon; and the wild life of bears, bison, and wapitis.

Iceland

A well-illustrated description of Iceland's hot springs is given by Barth (1950). According to Waring (1965) there are 508 hot-spring localities, more than in any other country. The springs seem to be mainly hot or boiling pools. There are few geysers, although the original 'Geysir' is in Iceland.

The scenery and climate have been described by Thorsteensson (1946) and Rockwell (1974). The near absence of trees is very marked. East of the capital, Reykjavik, green valleys provide grazing but pass upwards into the desolate basalt plains, cliffs and gorges. The way north is past green hills like the Scottish Highlands. The influence of the Gulf Stream gives Iceland a much milder climate than would be expected from its nearness to the Arctic Circle. Nevertheless the winters are bleak enough to deter the tourist. The summers are not very hot and can be wet, but provide a beautiful atmosphere and views.

Many of the 60 000 tourists yearly visiting Iceland are not satisfied with the hot springs near the capital and will travel east to the Great Geyser, which is now inactive, although nearby Stokkur shoots up every 50 or more minutes. Further east there is the Hvervallir, between great icecaps, with deep blue pools on silica hillocks. South of the icecap is Hofsjökull with enormous stretches of hot springs on a dark and lonely highland desert.

Northwards is the town of Akuyreyri, and 100 km east of it is Lake Myvatyn with countless craters, fumaroles, and many solfataras. This bare land has the beauty of the colors of the decomposed volcanic rock, the yellow of sulfur and the golden green of the ubiquitous moss.

The discharges of numerous wells are used mainly in Reykjavik to supply hot water for domestic heating and greenhouses, and at Myvatyn Lake, for drying diatomaceous earth. Iceland is thus saved the cost of large imports of fuel oil. About 3 MW of electric power is generated for the town of Akuyeyri. There is abundant potential hydroelectric power available for the small population of 200 000. With the large number of hot-spring localities to supply hot water, more efficiently used for heat than power, there is no danger of any clash between the interests of tourism and geothermal energy.

Kamchatka

The last two of the four overseas regions in the list of hot spring regions must be regarded as potential, not actual, attractions to tourists. Information on Kamchatka hot springs is given by Piip (1937). Waring (1965) states that there are 61 groups of springs. Further information is available from Varen et al. (1970).

There is a hot-spring region in central Kamchatka, and a large one northeast of Petropavlosk, another to the west of this chief town and port, and one on the southern tip of the peninsula. Geysers are rare but Ustinova (1955) describes the Valley of Geysers, discovered in 1941. The geysers are in eight basins along 5 km of the Gesernaya River, 200 km northeast of Petropavlosk. More recent information is in a book of color photographs of Kamchatka with text in Russian and English by Gippenreiter (1969). Notes on the geography have been obtained from Gregory (1968). Kamchatka is a peninsula about 1000 km long and 300 km at the widest; thus it is similar in size to New Zealand. Distances between hot spring regions are much greater, and it seems that each of the four southern regions is comparable with the Rotorua-Taupo region. Kamchatka has an average latitude of 55°N. Though it is farther from the Arctic Circle than Iceland, Kamchatka has more of an extreme climate because of a cold Arctic current. The winters are very cold, but the summers are warm, not so hot as Siberia to the west, and can be wet and cloudy. To the east of the main range with only extinct volcanoes rising to 3600 m, there are between 17 and 22 active volcanoes with beautiful cone-shaped peaks. On the east side, which is of potential tourist interest, wooded tundra extends to the southern tip, but from somewhat south of Petropavlosk, extending north, there is larch and birch.

At present, tourist access to Kamchatka, either of foreigners or Soviet citizens, may be difficult, for it is a strategic area used for missile testing.

There are apparently no roads to the geysers; travel is on horseback. The increase in the standard of living in the Soviet Union will ultimately encourage visits by Soviet citizens. Probably they will want to see the first geothermal power station in the USSR (5000 kW) at Pauzhetsk. A motor road connects the station to the fishing town of Ozarny, which it supplies with power. Travel to Petropavlosk is by plane.

North Chile

It was only through J. Healy, of the N.Z. Geological Survey (unpublished reports to the N.Z. Department of Scientific and Industrial Research, 1964–72), who carried out investigations for the United Nations project, that I recognized north Chile as one of the hot-spring regions. The springs of El Tatio have been described by Zeil (1969), but information on the other areas comes from Healy. Some information came from Waring (1965). The geography of Chile is described in the Encyclopaedia Britannica (1974).

W. Zeil (1969) divides the El Tatio geothermal field into three zones, averaging 0.5 km in length and separated by 1 km and 0.5 km. In the three zones there are a total of 72 fumaroles, 40 geysers (rather small ones), and 62 hot springs. This impressive total makes the field the largest known geothermal field in the South American cordilleras.

About 350 km north, there are boiling pools and geysers at Puchildiza, warm springs at Kinisa and, 5 km downstream, hot springs at Lupe. About 55 km north of Puchildiza, there is another area of boiling springs and geysers at Polloquere, also called Surire, on a very large "salar" (salt-encrusted falt) close to the Bolivian border. Healy finds this the most beautiful geothermal area in Chile: "It is surrounded at intervals by groups of volcanoes and with the white salar deposits and blue sky reflected in the parts containing water, together with the wide expanse of flats on the western side . . . the sight is most impressive."

One needs only to add a reference to the Atacama Desert, between the coastal strip and the altiplano with its salars, and the views further south of the snow-covered cordilleras of southern Bolivia.

Investigations at El Tatio for the U.N. have reached the stage of planning a power development. This will no doubt lead to the elimination of some hot springs, but on the other hand should attract South American tourists to visit the first geothermal bore field and power station in the continent. The small population (480 000 in the two northern provinces) makes it unlikely that there will be any conflict between tourism and geothermal development, unless very large amounts of steam are required for desalination.

Rotorua-Taupo

According to Report 38 D by the N.Z. Geological Survey Staff (1974), there are 24 geothermal fields in this region. Allowing for fields with several areas, and areas missed, there are 36 significant hot spring localities. Only 6 areas can be classed as major tourist attractions: Whakarewarewa, Hell's Gate (Tikitere), Waimangu, Orakeikorako, Waiotapu, and Wairakei. The 3 last are either eliminated or threatened as major attractions by energy developments, and will be described later.

Whakarewarewa is the hot-spring area most likely to be visited by tourists. Grange (1937) describes Whakarewarewa, and lists eight geysers. The most recent description is by Lloyd (1965). There is a complex interconnected geyser system on a large sinter mound. Pohutu is the reliable geyser erupting to a height of 18 m, but two others can erupt with it, and Te Horu (The Caldron) boils furiously. In the Reserve there are examples of most types of hot-spring activity, clear boiling pools, mud pots, acid pools, and steam vents. There are also four other thermal areas in Rotorua City with minor and varied small hot springs and pools.

The geyser activity seems to have been greater in Grange's time (1936), but Lloyd says that it has increased since 1940. The geyser activity may be threatened by the exploitation of hot water for domestic purposes by more than 300 shallow wells in Rotorua City (Nairn, 1974). Hot water rises under Whakarewarewa and spreads northwards towards the lake, Rotorua. Geysers are sensitive to quite small water-level changes.

Hell's Gate, about 16 km northeast of Rotorua, is the main area in a large geothermal field, Tikitere, described by Grange (1937), Espanola (1974), and Nairn (1974). It is a major tourist attraction in spite of being an acid area. Tikitere contains large bubbling acid-sulfate pools with names like Dante's Inferno, and Devil's Bath.

Waimangu Thermal Area is a major tourist attraction not for the small, clear, chloride springs, but for the craters formed by phreatic eruptions which accompanied the Tarawera eruption of 1886. The interesting ones are Inferno Crater and Echo Crater, the latter with a hot lake, Frying Pan Lake, which has an area of 4.9 ha. Frying Pan Flat was the site of the famous Waimangu Geyser, 1900–1904, which threw a jet as high as 450 m. The Waimangu area is described by Grange (1937), Lloyd and Keam (1965) and Nairn (1974). The Waimangu-Rotomahana geothermal field is unlikely to be exploited for geothermal power.

COMPARISONS WITH ROTORUA-TAUPO

Yellowstone National Park is an outstanding thermal region. In comparison, the New Zealand region is especially poor in geysers, and the spectacular and changing activity of geysers has a special attraction for tourists. Nevertheless, New Zealand can offer certain advantages. The main advantage that New Zealand offers is the climate. Owing to an elevation averaging 2500 m in Yellowstone National Park, snow stays well into the spring, and the usual tourist season is three months, although good fall weather may extend to October, and many visits are now made in winter.

New Zealand's hot springs are accessible at all seasons, although naturally the summer season is preferable. In this respect New Zealand has an advantage over all the other regions, for even in Chile tourists would tend to avoid the hot summer sun. Another advantage, in comparison with Yellowstone at least, is the close association with active volcanism. The association of the major tourist attraction, Waimangu, with the eruption of 1886, has already been mentioned. Visitors can extend their tour 140 km to the south to visit Tongariro National Park. They can see the hot crater lake on Mt. Ruapehu, active in 1945–46. There is a lava flow on Mt. Ngauruhoe from the eruption of 1954, and evidence of later explosive eruptions, the most recent in March 1974 and February 1975. There is also the constant plume of steam from the fumaroles of Ketetahi on Mt. Tongariro. Everywhere in the region there is evidence in road cuttings of the innumerable pumice showers that covered great areas in the past, and in great cliffs by roadsides, there is evidence of the even more devastating ignimbrite flows. Unfortunately, no effort is made to direct the attention of tourists to these interesting sights. The Rotorua-Taupo region may have the advantage over Yellowstone Park of a greater variety of scenery. The Park is largely covered with coniferous forest, except where bare ranges rise above the timber line. The hot spring areas of the Rotorua-Taupo region are not closely associated with the beautiful, almost subtropical native forest, much of which was destroyed by the pumice eruptions. Tourists still see it surrounding the so-called Hot Lakes on a line from Rotorua to Rotoma, with others on a line south to Rotomahana. Until early this century the hot-spring areas were largely in the midst of great stretches of low scrub, the "tiger country." This undulating country had a certain desolate beauty. The addition of cobalt-containing fertilizer has converted much of this pumice country into farmlands, and there are also the large plantations of the alien Monterey pine, *Pinus radiata*. Therein lies a disadvantage as compared with Yellowstone Park, which being an untouched National Park is an harmonious whole, whereas in the Rotorua-Taupo Region the effects of man on the environment are only too obvious.

EFFECTS OF GEOTHERMAL DEVELOPMENTS

Wairakei

The natural activity at Wairakei is described by Grange (1937). Grindley (1974) has summarized the resources of the field. Gregg (1958) has given the flows of the hot springs.

In the Wairakei Valley, the stream has cut so far down that some of the water of the hot chloride aquifer is able to reach the surface, mix with cold surface water, and lose much steam. About half of the outflow of hot water into the cold stream came from Champagne Cauldron, a pool about 18 m in diameter, under steep cliffs. It is the most active center and almost a geyser. About every 30 minutes superheated water boiled up vigorously, sometimes to 3 m, and then made a great cascade over a cream-colored sinter terrace, Tuhuatahia. At every eruption a great cloud of steam rose into the air. The largest geyser was the Great Wairakei Geyser, which according to Grange was sending up a column to 18 m every 10 hours, playing then for 10 minutes. Some time after 1937 it became quite inactive. On this west side, the Black Geyser played over buff-colored sinter that appeared black when wet. The track down on the east side passed several hot pools to reach the main group of five geysers in Geyser Valley. The last, Bridal Veil (called Red Coral Geyser by Grange) sent from an orifice 1 m in diameter a cascade of water every 2-1/2 hours rushing down a steep, pink sinter slope 15 m high.

Waiora Valley, about 1.8 km southwest of Geyser Valley, was not nearly so much of an attraction to tourists, but was visited by parties from Wairakei Hotel. As this valley is higher, the hot pools were of chloride water mixed with cold water and reheated by steam coming up off the water below. The features of Waiora Valley were interesting, if not spectacular. Large explosion craters at the top were drained by a warm stream leading past large beautiful green and red pools, Emerald Pool and Claret Cup, to Devil's Eyeglass, a small spouting spring on reddish sinter.

The largest fumarole in the region, Karapiti Blowhole, with a discharge of 16 000 kg/hr of steam at 114°C (Wilson, 1955) was 2.7 km southwest of the hotel about 120 m higher. The blowhole was an evening attraction for tourists from the Wairakei Hotel; a show was put on with bottles, burning sacks, and such being thrown into the vent. In the number and variety of the geysers and hot pools Geyser Valley was equal to the best-known thermal area, Whakarewarewa, and like the latter had minor areas nearby. However, the scenery was inferior, and Maori associations were lacking.

The surroundings of Wairakei were not particularly attractive. The vegetation was largely native scrub with much self-sown *Pinus radiata*, and exotic weeds such as broom and blackberry where the scrub had been burnt. The most beautiful feature was the clear green, swift-flowing Waikato River as it passed over rapids, especially the Aratiatia Rapids and the Huka Falls where a flow of 6000 to 17 000 l/sec falls 15 m.

Effects of production drilling. The early history of the Wairakei Geothermal Power Project is given by Grange (1955) and Grindley (1965). These authors do not explain why a major tourist attraction was chosen. Probably the urgency of obtaining a source of power alternative to a coal or oil required an area of high natural heat flow to be chosen. I remember that geophysicists drew attention to the Tikitere geothermal field. As this seems to be a vapor-dominated field, if sufficient steam had been obtained by shallow drilling in this field, the recognition of the importance of underground reservoirs of hot water might not have come from New Zealand investigations.

In the choice of Wairakei, unfortunate from the tourist aspect, chance played its part; for the engineers were impressed by a shallow well discharging steam and water, drilled to about 100 m in the lower Waiora Valley, to supply heat to the Wairakei Tourist Hotel. I was present at a meeting in 1949 of engineers and scientists, at which it was decided to drill a line of prospecting holes, passing about 650 m southwest of Geyser Valley. I cannot recollect that the meeting gave any consideration to the possibility of harmful effects on the geysers and hot pools.

At this time the theory of hot springs then prevailing was that of A. L. Day (Allen and Day, 1935). Just as the dry steam from the wells at Larderello was assumed to be magmatic, natural hot springs were supposed to owe their heat to magmatic steam. Indeed fumaroles, such as the large Karapiti Blowhole near Wairakei were taken as evidence of steam almost wholly magmatic.

The nine rather shallow and small-bore prospecting holes on D-line (down to 300 m) gave discharges which later knowledge showed to be diluted with near-surface water, and higher in steam than if supplied from the deep reservoir below. The opinion expressed by the committee of scientists considering the results in 1951, was that not much consideration need be given to this "piddling" stuff, but that it was necessary to penetrate the deep cap rock to draw on dry steam (magmatic?). It is not surprising therefore that possible effects on Geyser Valley were not considered, for presumably there would be a reservoir of dry steam large enough to give a continued supply of heat to geysers and hot springs.

There was a different outlook on the prospects of generating geothermal power when in 1955, Well 20, a hole of 20.5 cm diameter, was sunk to 611 m, and gave a discharge of 440 tonne/hr at 14 kg/cm^2. It gradually became evident that a large aquifer of hot water could be tapped at 400 to 750 m, and from this water, steam at more than 14 kg/cm^2 could be simply separated. Further drilling of production wells continued to assure enough steam to supply a power station of 200 MW, instead of the 20 MW approved on the basis of the prospecting holes.

As the geysers of Geyser Valley drew on the same aquifer, the lowering of artesian pressure by the numerous well discharges, especially considering that the Wairakei stream had cut down its valley about 45 m lower than the bore field, meant that the Geyser Valley was doomed. There were reports of diminishing activity from 1954 onward, until in 1972 the Valley was closed to visitors, and is now becoming overgrown and inaccessible. The loss of Geyser Valley has of course been replaced by the great attraction for tourists of the geothermal field with the columns of steam from the steam/water separators at each well, and the power station itself, the first in the world to generate power from underground hot water.

It is rather curious that the pools and springs in Waiora Valley are not much affected, except that Claret Cup has become a muddy pool (A. Slatter, personal commun., Chemistry Division, Wairakei). However as the area is close to the main bore field, access is closed, and the path in any case is blocked by fallen trees.

In spite of the fact that, as pointed out by Grindley (1974), the natural heat flow from the whole field has actually increased from 450 to 750 MW, according to Dawson and Dickenson (1970), Karapiti Blowhole has ceased to discharge. A new thermal area west of the old blowhole, marked by a large mud pool surrounded by high banks of red, decomposed ground, almost as impressive as pools on White Island, is hardly likely to attract tourists.

Events may have been different if the shallow prospecting drilling had first been carried out in the field to the southwest towards Karapiti Blowhole, which must have been supplied by a reservoir of steam above the deeper water. Here in this Te Mihi field the deep "200" series of investigation holes were drilled much later. The rogue bore No. 204, discharged from a crater about 10 times the steam output of an ordinary production well. This steam might not have been discovered if the hole had been cased earlier, and had been drilled to the depth planned. It would have been a more rational method of utilizing the field if power production had been first based on this near-surface steam, followed later by production from the deeper hot water. In this case the loss of Geyser Valley might have been postponed for a long time, and perhaps altogether avoided.

In an environmental study of the Wairakei Power Plant, Axtmann (1974) points out that the plant is now one of the prime tourist attractions with 100 000 visitors yearly, two-thirds of them from overseas. He considers that the Wairakei Plant's contribution to the national well-being far outweighs the loss of a few thermal springs in a land that has more than its fair share of such attractions. (My outline of the main geothermal tourist attractions cast some doubt on this last clause.) He waxes quite lyrical about the haunting sight of the eerie beauty of the bore field seen at dusk on a moist day when fleecy plumes arc skyward. These considerations apply only to Wairakei, for it can hardly be supposed that later geothermal power plants will attract additional tourists or even the same tourists. Later bore fields will not be so impressive, for water and steam may not be separated at each wellhead; instead, the combined discharge piped to the power station site to be separated there.

Onepu Hot Springs

The natural activity has been described by Studt (1958) and Mahon and Finlayson (1962), and the Kawerau geothermal field by Healy (1974). Onepu Hot Springs can never have been of much attraction to tourists. There are hot seepages to the Tarawera River, and a few hot pools on sinter flats. The small lake, Rotoitipaku, over a ridge in a scrub-covered valley, was more attractive, but not very accessible. Mahon and Finlayson (1962) sampled six springs at the south end of the lake.

The possibility of utilizing natural steam was the reason for siting the Tasman Pulp and Paper Mill on the east bank of the river opposite the springs. Eight productive drill holes supply 180 tonne/hr of process steam to the mill, and 10 MW of electric power can be generated. From the evidence of drill holes, the reservoir of hot water should be able to supply a 100-MW power plant. No one seems to have thought of the possibility of developing the hot springs area as a reserve and park for the people of the town of Kawerau, 2 km southwest of the mill, which has grown since 1956 to house the workers in the mill. This might also attract tourists, but if 100 MW is developed, the springs will be lost completely. Moreover the Tasman Company proposes to add insult to injury by using the beautiful valley over the ridge as a dumping ground for mill effluent.

Ohaki

Grange (1937) gives only a short paragraph to this area, 20 km northeast of Wairakei. The Broadlands Geothermal Field, about 3 by 2.5 km is described by Browne (1974). The main feature was a pool of clear, chloride water, bordered by a fretted, overhanging, white sinter. Its overflow (12 l/sec) had encrusted a wide area with sinter. It may have been the most beautiful single pool in the region. As it was an easy walk of 1 km from the Taupo-Rotorua main road, many tourists, mainly New Zealanders, must have visited it.

A full-scale drilling program was carried out here from 1966 to 1971, and after the fuel crisis, started again in 1974. One of the first holes drilled, BR 3, was sited close to Ohaki Pool, and with BR 2, gave good supplies of hot water, equivalent to a power potential of 13 MW. After about one year, Ohaki Pool was drained. There was only a deep hole in a mass of dirty-gray sinter, surrounded by a rough wooden fence.

THREATENED BY PROSPECTING

Waiotapu

Waiotapu is a popular tourist area about 23 km south-southeast of Rotorua, on the main Rotorua-Taupo Road. The field has been described by Grange (1937), and in more detail by Lloyd (1963). The geothermal resources are considered by Healy (1974).

The most picturesque of the great variety of the geothermal features is Champagne Pool, of clear water and about 60 m in diameter, encircled by a track from which one sees the brown, fretted sinter, the bubbling or superheated water. One can walk over the spectacular formation of brown and yellow sinter that forms a sloping terrace 100 by 80 m, wetted by the shallow overflow, building up little terraces. The path follows a warm stream past lakes in explosion craters, and boiling and colored pools down to Lake Ngakoro, about 500 by 150 m with a fine view over scrub and farm land to Mt. Tauhara. On entering the reserve, one climbs a mound of decomposed ground, with large sink holes, up to 18 m in diameter and 12 m deep, with small boiling pools, steam, and sulphur deposits. There are other springs outside the reserve, especially a much-visited group of boiling mud pots.

Seven prospecting drill holes, three of them to about 1000 m, recorded a temperature of 295°C. Further drilling was not warranted as the well discharges indicated low permeability and sealing by calcium carbonate. As Holes 6 and 7 were only 400 m and 500 m from Champagne Pool, it is fortunate that this major attraction was not ruined. Healy (1974) has recommended further reassessment of the field. I contributed to the scientific investigation of Waiotapu, but I cannot recall that any consideration was given to the risk of losing Waiotapu as a tourist attraction.

HYDROELECTRIC DEVELOPMENTS

Orakeikorako

A later and fuller description than that by Grange (1937) is given by Lloyd (1972). Lloyd began in 1958 to record the geothermal activity before the field was flooded by Lake Ohakuri, and also to detect the effect of the raised water on the system. A summary of this information, together with the unpromising data from four prospecting drill holes has been given recently by Lloyd (1974).

The Orakeikorako area was probably the best thermal area in the country from the tourist aspect for the numbers of geysers, hot pools, and sinter terraces, and for its scenic attraction in a gorge of the Waikato River, which had to be crossed on a current-propelled punt to reach the main hydrothermal area of 0.5 km^2.

The largest geysers were on the west bank, most of them on a large sinter apron of 10 000 m^2. The great geyser on the apron was Orakeikorako, throwing out jets to 63 m, of which Lloyd said "a more impressive geyser would be difficult to imagine." There were seven geysers in a distance of about 1.2 km; Porangi Geyser was the largest, frequently erupting geyser and spouted to 24 m.

On the east bank, the attractive features were the sinter aprons, ending in steep sinter-covered scarps up to 25 m high, beautiful when wet or algae covered. Above Golden Fleece Terrace was Artist's Palette, an almost level sinter area of 9710 m^2, with hot springs of widely varying activity.

Outside the tourist area, about 1.6 km south of the riverside terraces, were the Red Hill Springs, where all available space by the river was occupied by 214 springs, 17% of them geysers, and the sinter aprons framing them. Lloyd says that "the hot springs on the precipitous river gorge below Red Hill were perhaps the most spectacular in New Zealand."

The lake formed for hydroelectric power generation, Lake Ohakuri, filled up from 19 January to 2 February 1961. All the geysers on the west bank were covered, and the terraces on the east bank of the river, and the hot springs at Red Hill were also covered. About 75 of the features mapped by Lloyd have been lost. Tourists can still see some terraces and Artist's Palette as well as some small geysers.

The main attraction in the tourist area now is Ruatapu, or Alum Cave, where from an opening 9 m wide framed by two tree ferns, a 40-degree slope descends 39 m to a very clear, acid pool.

Tokaanu and Waihi

The hot springs at both Tokaanu and Waihi are described by Grange (1937) and the geothermal fields separately by Paterson (1974) and Hogan (1974). Mahon and Klyen (1968) sampled 80 springs for a chemical survey.

The hot springs of Tokaanu, mainly small boiling pools on sinter flats along a small strip on the Tokaanu stream, are not of great interest, except for a well-known geyser, Taumatapuhipuhi, mentioned by von Hochstetter (1864). Grange (1937) said it played every 6 minutes to only 3.5 m, but now is even less active.

On the hillside above the village of Waihi, about 2.6 km to the west, there is the Hipua thermal area of steaming cliffs, hot acid springs, and steam vents. The steam clouds rising from the hill cliffs are prominent features in moist weather, especially as one drives south on the main road from Taupo. The area is inaccessible and dangerous without paths, but if it were opened up, the rather unusual nature of the acid springs with reddish precipitates, hot black mud, in conjunction with the wonderful views over Lake Taupo, could help to make the whole Tokaanu-Waihi field attractive to tourists.

The Tokaanu Geothermal Field has suffered and also could benefit from hydroelectric development. When I assisted J. Healy (1942) in sampling Tokaanu Springs, I camped with him in the right of way marked in Mahon and Klyen's map as "parking area." Here I had a very good view of a pool described by Grange as boiling up to 1 m, and superheated, the spring numbered 25 by Mahon and Klyen. This was then the best geyser that I had seen. Regularly every half-hour, it sent up a column perhaps 2 m wide to a height of 13 m. This geyser was a victim of hydroelectric development, for shortly afterwards control gates were installed at the lake outlet at Taupo to maintain a higher level of the lake. This higher level stopped the playing of the geyser, and would also have stopped any other geyser activity from developing.

The possible benefit from hydroelectric development is that between the main road and Tokaanu there is nearly completed, a large power station of the last power development on the Waikato River, By complex engineering constructions of canals and tunnels, the station is supplied with water from the slopes of Mt. Ruapehu. An information center is provided to explain the scheme to the public. With the combined interest of the power scheme, the Tokaanu and Hipua thermal areas, and the historic associations of Tokaanu and the Maori village of Waihi, there could develop a major tourist attraction to replace lost attractions.

Spa Sights

The Spa Sights area, not far from the Spa Hotel, once a popular tourist hotel, 2.6 km southwest of Taupo, is described by Grange (1937) and is now considered part of the Tauhara Geothermal Field described by Grindley (1974).

On the flat about 20 m above the river, there was an acid area with much decomposed red ground, boiling mud pots, and one fumarole—Satan's Glory. Beside the Waikato River, there were a number of boiling chloride pools, two of them once geysers. Crow's Nest Geyser on a mound 2 m high and 1.5 m in diameter, was very well known to tourists. It played every 4 hours, sending 30 shots up to 18 m at 2-minute intervals. The surroundings were very beautiful in a river gorge at a sharp bend of the river with cliffs, steaming in places 20 m high on each side, with the clear green river rushing swiftly past.

The geyser ceased to play sometime after 1937. It was probably affected by the control gates installed at the Lake Taupo outlet to control the lake level. In about 1951, E. Lloyd and D. R. Gregg (unpublished work) induced eruptions of two or three of the geysers by dropping in packages of calcium carbide. The field is hydrologically connected to the Wairakei geothermal field, and as pressures in the Tauhara geothermal field are dropping, it is now unlikely that the geysers will play again.

PROSPECTING FOR SULFUR

Rotokaua

The Rotokaua Geothermal Field is on the east bank of the Waikato River about 9.5 km east of Wairakei. Grange (1937) has given a description of the natural activity. Browne (1974) has discussed the geothermal resources.

I sampled water and gases at this area in 1937 and was much impressed by the interest of the thermal features. The main natural feature is shallow Lake Rotokaua, some 1200 by 600 m. Other features are boiling springs on a striking sulfur- and sinter-covered bay of the lake; a large black boiling pool; a natural shaft of narrow diameter, perhaps 2 m, lined with beautiful yellow sulfur; and large sink holes, one with an easy descent to a perpetual gusher called Black Geyser. I could not understand at the time why this interesting area was so little known and visited. There were many springs to be sought out in the scrub-covered flat, and the beautiful views over Lake Rotokaua and a great extent of scrub land to Mt. Tauhara. The reason for the neglect was probably the difficult access, alleviated since 1960 by a bridge at the Aratiatia Dam.

Rotokaua was noteworthy for the large amount of surface sulfur. Even in 1937, the locality had been somewhat spoiled by desultory workings. Recently, a thorough investigation by prospecting holes to about 70 m has shown the unsuspected presence of a band of sulfur ore beneath overburden 20 to 50 m thick (McLachlan, 1971). Reserves are estimated as 5 to 6 million tonnes of sulfur in 30 million tonnes of ore. Steam from a geothermal prospecting drillhole, RK 1, supplies steam for a pilot plant to extract sulfur by the Frasch process.

If sulfur can be economically won at this field (doubtful at present), the value to New Zealand of the sulfur, required for superphosphate production, but now all imported, is so great that the loss of the area as a potential major tourist attraction will have to be accepted.

CONCLUSIONS

The four overseas hot spring regions, except perhaps north Chile, do not seem to be in any danger as tourist attractions from geothermal developments, but it is clear from Table 1 and the discussions that there are actual losses and serious threats to the Rotorua-Taupo region.

What is disturbing about these losses is that there seems to have been no serious consideration beforehand of the threat to each attraction and no public interest in the loss. Some years ago it was proposed to raise the level of Lake Manapouri in the South Island to develop the full potential hydroelectric power supplied by the lake. The power developed at Manapouri, about 400 MW, is used for the electrochemical production of aluminum. Because of the threat to the beautiful shoreline of the lake, there was a great public outcry, and the presentation of a widely signed petition had so much influence on the government that the plan

Table 1. Losses of hot springs in the Rotorua-Taupo thermal region.

Geothermal field	Hot-spring area	Attractions lost	Comment on attractions lost	General comment
		Losses through geothermal prospecting or power development		
Wairakei	Geyser Valley	Geysers	Major attraction	Hot spring features gradually lost 1955–1972, due to deep drilling and hot water discharge
	Waiora	Colorful pools	Not so well known or visited, now inaccessible	
	Karapiti blowhole	Largest fumarole in region	Much visited	Total steam discharge greater now in more than one new fumarole, but these not tourist attractions
Kawerau	Onepu Hot Springs	Small hot pools, attractive lake	Little known or visited	Only a minor loss
Broadlands	Ohaki	Ohaki Pool	The most beautiful hot pool in region	Lost through prospecting hole BR 3 discharging nearby
		Losses threatened by geothermal drilling		
Waiotapu	Waiotapu	Champagne Pool, sinter terrace, sink-holes	Major attraction	Threatened by close prospecting drillholes, luckily poor discharges
		Losses from hydroelectric development		
Orakeikorako	Orakeikorako	Numerous geysers, sinter terraces	Over 75% of hot springs lost	Lost through flooding by Lake Ohakuri
Tokaanu	Tokaanu	Large geyser	In 1941 played every half hour	Lost by raising level of Lake Taupo for hydroelectric river-flow control
Tauhara	Spa sights	Geysers	Crow's Nest Geyser much visited before Wairakei so popular	Probably affected by control gates on Lake Taupo outflow, in any case lost by effects of Wairakei drawoff
		Losses from prospecting for sulfur		
Rotokaua	Rotokaua	Boiling springs, sink holes, mud-pools	Not well known or visited, could have become major attraction	Not accessible and spoiled through sulfur prospecting, may be entirely lost by sulfur exploitation
		Losses from drilling for domestic hot water		
Rotorua City	Whakarewarewa	Large geysers, variety of features	Most visited, Pohutu Geyser best known in region	Shallow drilling in Rotorua City may have reduced the number of geysers (effect obscured by increase in rainfall), in any case a threat

was largely given up. It seems to me that in 100 to 200 years, there will be so much power available from nuclear fusion that such hydroelectric power will be unnecessary. In another 100 years the natural regeneration of the native bush cover could restore either the new lake coastline or the restored old coastline to full beauty. Moreover, during all the interval there would still be all the natural untouched beauty of the mountains around the lake.

The case is very different with geothermal power. If the heat stored in rock (about five times that in the hot water) is not utilized, the efficiency of power generation is very low, perhaps 1 to 2% of the heat available. At present, the life of a geothermal power development may not be more than 40 years, but if it is extended to 100 years or more by using the heat stored in the rock, it will approach the time when abundant energy will be available from nuclear fusion. Even if the reservoirs of very hot water are replaced by water heated by rock, it is most unlikely that the geysers will be restored, as their formation depends on a high temperature of the water. Even if hot springs flow, it may take hundreds of years to produce sinter aprons and terraces. The low temperatures will also make unlikely the occurrence of vapor-dominated systems to supply boiling muddy pools of sulfate water, and steam vents. My opinion is that there has been in past periods of the order of hundreds of thousands of years, natural depletion and regeneration of the hot water reservoirs. The intervals must be of the order of thousands of years, so that one cannot rely on the formation of new reservoirs in the near future.

Tourism has been known in the Western world for at least 2000 years, to judge by the guidebook of Pausanias to the Roman Empire. One cannot envisage from the present rapid expansion how it will develop in the next 100 or 1000 years. It may be only chance that determines whether a magma intrusion, which might cause regeneration of hot springs, produces instead pumice eruptions such as those that have devastated the central North Island in the past. The intervals between such eruptions seem to be about 1000 years, and such an eruption may be overdue to make futile these throughts about losses of hot spring areas. At any rate, one expects the hot spring areas, left in their natural state to interest tourists in numbers increasing to some stable maximum for a period of 100 to 1000 years. Hence these areas are probably of more value in their natural state than if used for a short period of power generation.

An attempt can be made to make a comparison in money terms between the values to New Zealand of geothermal power and tourism attracted by the hot spring region. A typical estimate of the power generated in a year by the Wairakei Power Plant is 1248×10^6 kWh for 1974-75 (personal commun., N.Z. Electricity Department). The cost of generation of geothermal power at Wairakei in 1974 was 0.47 N.Z. cent per kilowatt-hour (personal commun., Geothermal Engineer's Office, Ministry of Works and Development). Hence the value of the geothermal power generated at Wairakei in one year can be taken as N.Z. $6 million. The value of the tourism earnings for 1972-73 was $85 million, and they are increasing rapidly (N.Z. Official Year Book, 1974), for according to a ministerial statement, Reserve Bank travel receipts for 1974-75 were N.Z. $103.8 million. It is hard to estimate the proportion of the tourist trade attracted by the hot spring region. A rough guess is 10%. This is roughly confirmed by the fact that the region is one of six mainly visited by tourists, and also by the ratio 2:11 of Tourist Corporation Hotels in Rotorua and Taupo to the total number. The ratio of hotel and motel beds in Rotorua and Taupo to those in other resorts gives too high a value because Rotorua, being a city of 30 000 people, all the accommodations are not for tourists. The ratio to all the accommodation in New Zealand, just under 1:10 is a better value. Hence the value of the tourist trade is about $11 million. However all this would not be lost if the hot spring areas were lost; there would still be the attraction of the Hot Lakes, Maori culture in Rotorua, and trout fishing. On the other hand the value of the tourist trade is export earnings, and a better value for comparison with this would be the cost of the fuel oil imported for power generation, according to a ministerial statement in an appeal to save power, $18 million. This is the maximum value of savings in overseas funds that could possibly be made by additional geothermal stations. At present the savings from Wairakei generation are additional to tourist trade earnings, but further losses of hot springs might cause reductions in these earnings. At any rate, one can see that earnings from hot spring tourism and geothermal power are of much the same order, with the difference that tourism needs less overseas capital for development; and returns from it can be expected to last longer, but it demands more labor.

New Zealand has advantages in climate and scenery to make up for fewer hot springs and geysers. However there is a lack of imagination in efforts to make the hot spring areas more attractive to tourists. Much could be done in encouraging native vegetation around the areas. In too many areas, native scrub is invaded by self-sown exotic pines, or after burning it is invaded by weeds such as blackberry and broom. In view of the losses, care should be taken to preserve minor thermal areas, although it does not seem that many can be upgraded to replace losses. Imagination could be shown in extending tours by visitors to provide more variety. For example at Tikitere, there is a neglected area, Ruahine, 2.5 km northwest of Hell's Gate, where there are two boiling pools, one black, one dark brown, mentioned by von Hochstetter (1864). A. L. Day, in 1937, considered these the finest acid pools he had seen anywhere. Most of the minor areas are acid areas; there is not much to replace geysers, and boiling, clear, chloride pools, but acid pools and especially mud volcanoes and porridge pots are of more interest than warm chloride pools. Typical of neglected areas are Ngatamariki (Healy, 1974) inaccessible in commercial pine forests, and Mokai with two acid areas described by Grange (1937), but simply included in farmlands on the conversion of the scrub to pasture about 1955 by the Lands and Survey Department.

A source of much of the neglect of the thermal areas is that the hot spring areas were originally Maori lands. Since the last century, they have been sold or leased to private owners, some of whom have developed them with more or less capital and imagination for visits by tourists.

At the 1949 Pacific Science Congress, I put forward a motion in the geological session that the government be urged to constitute a National Park to take over all the thermal areas, and administer and develop them to the best tourist advantage, but this motion had no support from geologists. If this had been done, there would have been some authority to put forward a case for tourism in the face of ill-considered geothermal prospecting. It seems to me that in view of the increasing losses of hot spring attractions there is a strong case for such a Rotorua-Taupo National Park, comprising only the thermal areas, and such attractive surroundings as would add to the scenic interest of the springs.

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