Before the Hearings Committee

under: the Resource Management Act 1991

in the matter of: a submission by the Parahirahi C1 Trust in respect of applications by Ngawha Generation Limited for resource consents required for the continued operation of the Ngawha Geothermal Power Station and the Ngawha Expansion Project and a notice of requirement to the Far North District Council by Top Energy Limited

Statement of evidence of Tom Powell for the Parahirahi C1 Trust

Dated: 22 July 2015

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STATEMENT OF EVIDENCE OF THOMAS POWELL

QUALIFICATIONS AND EXPERIENCE

1 My full name is Thomas Solon Powell.

2 I have thirty-seven years' experience in the geoscience of geothermal energy exploration and development.

3 I hold a Masters of Art Degree in Geology, with Honours from the University of California, Santa Barbara.

4 I am currently a Research Associate with the University of Canterbury and have my own consulting business Powell Geoscience Limited.

5 Previously, I was Geoscience Manager – Geothermal at Mighty River Power for six years. I have also held roles as the Senior Geologist/Geochemist for Thermochem Inc., and Advising Geologist for Unocal Geothermal and Exploration Manager for Philippine Geothermal, Inc.

6 I have significant experience as a wellsite geologist, exploration geochemist, development geologist/geochemist, geosciences manager, technical consultant and trainer in the Western USA, Asia Latin America and New Zealand.

7 I am a member of the American Geophysical Union, Geothermal Resources Council and New Zealand Geothermal Association

8 A list of my publications is attached as **Appendix A**.

CODE OF CONDUCT

9 I have read the Code of Conduct for Expert Witnesses contained in the Environment Court Practice Note 2014, and I agree to comply with it. My qualifications as an expert are set out above. I confirm that the issues addressed in this brief of evidence are within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed.

SCOPE OF EVIDENCE

10 I have been engaged by the Parahirahi C1 Trust (*the Trust*) to provide technical geoscience advice in relation to Ngawha Generation Limited's applications for consents to continue to operate, and to expand, geothermal power stations at Ngawha (*the Project*). In addition to providing technical advice on the current consent applications, I also provided technical input into the Cultural

Impact Assessment (dated 19 September 2014) that was prepared for Top Energy.

11 I understand that the Trust is in ongoing discussions with Top Energy regarding the Project, and I have been involved in discussions on technical matters.

12 My evidence addresses the following geoscience related matters that are relevant to managing the effects of the Project on the Ngawha reservoir and the Ngawha hot springs:

12.1 Abstraction/injection rates and "load following";

12.2 Staging of the proposed expansion;

12.3 Maintenance of reservoir pressure;

12.4 Effects on the Ngawha hot Springs; and

12.5 Monitoring.

13 I also comment on the issue of cultural indicators.

SUMMARY

14 I have identified some issues relating to the proposed Project that I consider should be addressed in order to ensure that the Ngawha reservoir and Ngawha hot springs are sustainably managed. In my view, these matters are all capable of being addressed in conditions. The key issues are:

14.1 The specification of an annual abstraction rate would seem to allow for "load following" operation of the power plant, where production rate is changed to generate more at times of higher power market demand. This scenario is not in the best interests of sustainable and safe operation of the field and will complicate monitoring data. Consent conditions to specify either a maximum daily take or maximum installed generation capacity should be included to prevent load following operations.

14.2 I agree with staged development as a prudent approach to the expansion of geothermal generation at Ngawha. However, I believe the requested two year observation period between the expansion from 50 MW generation to 75 MW generation is too short. Resource expansions are often plagued by mechanical problems, which shorten and/or degrade early resource monitoring data and reservoir tests. The appearance of unexpected resource problems is also common, and these often take a period of years to detect, characterise and address.

14.3 Without a careful and robust monitoring period, the Ngawha resource risks over-development. Although the developer suffers commercial loss in cases of inadvertent over-development, over-development typically results in inefficient use and degraded potential of a shared resource. In the case at Ngawha, long-term sustainable operation of the field will forestall a decline in hot spring temperature and flow, which can be expected after field abandonment. I recommend a minimum five years observation period, incorporating two injection tracer tests to adequately characterise thermal depletion processes in the numerical model.

14.4 I believe the programme of reservoir pressure maintenance has been successful in maintaining hot spring flow and temperature, and that monitoring data has shown that the hot springs show a direct but delayed response to reservoir pressure. I offer relatively minor recommendations for changes to conditions bearing upon pressure measurement and monitor well replacement.

14.5 In order to maintain the Ngawha hot springs at near their natural state, any necessary and intentional adjustments to reservoir pressure made to maintain hot spring flow and temperature should be gradual and in the order of 0.25 bar. Should hot spring chemistry change beyond natural variability due to ongoing loss of gas from the reservoir fluids as a result of the Project, best endeavours should be made to restore gas to the reservoir by adjustments to the power plant cycle or reinjection of separated gas. The Reservoir Management Plan should include plans for operational and monitoring changes necessary to address a significant change in hot spring flow and/or temperature that is attributable to the Project.

14.6 Well monitoring needs to include an accurate method of measuring production enthalpy and a comprehensive programme for characterising the reservoir intervals and production characteristics of new production wells, both of which are necessary for numerical model calibration.

14.7 Characteristics such as the look, feel, smell and presence of bubbles in the Springs can be monitored by measuring pH, gas chemistry, gas flow, and suspended solids. Some of these characteristics are measured as part of the current monitoring programme. For the other characteristics, baseline measurements would be useful for determining whether any changes in the Springs are attributable to the Project or natural processes.

ABSTRACTION / INJECTION RATES AND "LOAD FOLLOWING"

15 I understand that annual maximum extraction and injection limits are proposed for the Project. In theory, this might allow the developer to produce the field at high rates when wholesale power prices are high, and produce at low rates when power prices are low. This type of production scheme is called "load following" and is practiced at a number of geothermal fields for a variety of reasons. In my experience, this type of production scheme can lead to field problems, such as accelerated well casing failures due to thermal cycling, which can lead to well blowouts. It also makes monitoring of reservoir pressure and performance more difficult.

16 I consider that, in the interest of monitoring and managing reservoir pressure for the maintenance of hot spring flow and temperature, and in the interest of safe and sustainable development of the resource, "load following" should not be used.

17 Preventing a "load following" operational scheme is a matter that is capable of being addressed in conditions. This could be done by specifying a maximum daily extraction rate, or by specifying a maximum generation capacity for the plant appropriate to the average daily production rate of the annual fluid take.

STAGING OF SECOND NEW 25MW POWER STATION

18 I consider the tripling of generation capacity proposed by Top Energy to be a 'big step' for the Ngawha resource. The operating history of the field suggests that the first 25MW stage is a reasonable next step. I do however believe that a carefully considered staged approach is necessary between the first 25MW extension and the second 25MW extension.

Need for staging

19 Staged development is the best approach to achieve sustainable development of geothermal resources. One of the major failings of the geothermal industry has been the tendency to install too much generation capacity, driven by economies of scale, which favour large initial developments.

20 The effects of over-development are often disastrous. It often results in more rapid resource depletion than would be experienced otherwise. It also results in inefficient use of the resource because, for much of its life, the power plant runs at a different production characteristic than it is designed for. Developers have the option of re-tooling the plant to run efficiently at degraded production

characteristics but this requires additional investment, which a project earning less than initially expected is unlikely to have.

21 An unsettling aspect of production of a geothermal resource at or above its sustainable capacity is the appearance of unexpected changes in resource characteristics. It is common for a resource to produce with relatively few problems at a low rate of production only to develop new, unanticipated problems at a high rate of production. The sorts of problems that might crop up at Ngawha include pressure compartmentalisation within the reservoir, mineral scale and loss of pressure support due to escape of reinjection water from the system.

22 Reservoir compartmentalisation and loss of injection water from the system would reduce reservoir pressure support, resulting in zones of pressure depletion within the reservoir. In cases of severe localised reservoir pressure depletion, fluid boiling in the reservoir can lead to the precipitation of mineral scale in production wellbores. The developer would then face the unsavoury choice of moving injection closer to production to maintain pressure support but which would also be expected to accelerate thermal degradation of production, or of somehow living with the problem.

23 The history of "surprises" observed when resource development approaches or exceeds its maximum sustainable production rate supports the wisdom of a staged development approach. A key aspect of this is an appropriate observation time between generation increases, so that "surprises" in resource characteristics can hopefully be observed before they become severe problems.

24 Numerical reservoir simulation models have become the gold standards in supporting high levels of resource development, but these models are non-unique. In other words, they can be constructed in a number of different ways, using different reservoir parameters and still match the production data used to calibrate them. As a consequence, the models are only as accurate as the breadth of calibration data allows them to be. Unfortunately, how the system responds to higher production and injection rate is rarely part of the calibration dataset. As a consequence, it has been rare in my experience that numerical models predict all aspects of resource response after relatively large jumps in installed capacity. There always seem to be surprises. The fact that resource numerical models typically live a life of constant refinement, punctuated by complete overhauls every few years, is testimony to these surprises.

25 In my view, the principal risk that the proposed generation increase presents to the Ngawha resource is accelerated thermal degradation. In other words, if the resource is smaller or contains less favourable characteristics than anticipated, it will cool off more

quickly than expected. The result of over-development in most other resources is rapid depletion of reservoir pressure, but this is not expected at Ngawha because reservoir pressure is maintained by full reinjection. As a result, if the Ngawha resource is smaller or less suited for a higher production rate than anticipated by the numerical model, injection returns will cool the resource faster than anticipated.

26 In the event of premature cooling of the Ngawha resource, the party suffering the most will be the developer. Plant and other infrastructure will have been bought and at some point left idle before they can be paid for. The resource typically also suffers because the resulting poor investment return of the Project prevents prudent and optimal management. New injection and production wells needed to manage resource cooling become difficult to justify from an economic perspective. While the developer suffers an economic loss, the community also suffers in the form of a loss in the potential of a shared resource.

27 If and when the Project is abandoned, cooling of the resource can be expected to result in decreased reservoir pressure and thus decreased hot spring flow. The heat stored in the cap rocks of the system will likely maintain the temperature of the plumbing system to the springs for decades or possibly even centuries after the system is abandoned, but the increased density of the waters in the deep reservoir, due to its lower temperature relative to preproduction, would be expected to result in lower pressure at the top reservoir than at preproduction. Numerical models of hot springs show that their flow and temperature are sensitive to reservoir pressure, so these would be expected to decrease following field abandonment. For this reason, I see decline in hot spring temperature and flow after field abandonment as an unavoidable consequence of the Project. Should the Ngawha resource be cooled more quickly than anticipated, field abandonment would come sooner and the ultimate decline in hot spring flow and temperature would come sooner, as well.

28 With it kept in mind that the hot springs have been suggested to have existed at something close to their present state for the last four centuries (CIA, p8), the prospect that they might be lost after the abandonment of the power Project is troubling. The long-term future of the hot springs lies in the long-term, sustainable development of the resource.

Providing for staging in conditions

29 Appropriate staging can be achieved through conditions. I do not, however, consider that the proposed two year production period is an appropriate observation time between the proposed step changes in generation. In my experience, these are large changes. The resource is potentially being asked to sustain an additional 50%

increase in generation after a 100% increase only two years prior. Such rapid increases in generation need to be carefully considered.

30 In my opinion, five years production is the minimum appropriate observation time between step changes in generation. The increased rate of extraction and injection to the reservoir and the deployment of new production and injection wells around the reservoir will have a dramatic effect on the fluid flow paths within the reservoir. In my experience, it takes at least six months for the flow paths around a new injection well to stabilise within a producing reservoir. This is the typical waiting period for new wells before implementing injection tracer tests to determine the speed and heat sweep efficiency of injection-to-production flow paths. Coupling this observation with multiple new production and injection wells, the flow paths may take a year or longer to stabilise.

31 Following the stabilisation of fluid flow paths, the capacity of the injection fluids to effectively sweep heat from the reservoir without prematurely cooling production wells is determined by injection tracer tests. A non-toxic, thermally stable and readily detectable chemical is injected with the reinjected reservoir water and its recovery in production fluids is monitored. This monitoring period usually lasts between six months and a year. The results are then analysed and as a final step the numerical model is adjusted to reproduce the results.

32 Under ideal circumstances, then, the response of the reservoir to increased extraction and injection might be characterised and modelled within a two year period. Things don't always go to plan, however. Sometimes injection wells fail before the test can be completed, upsetting established fluid flow paths and compromising the value of the results. Sometimes there is a failure in the injection tracer itself, due to degradation or adsorption on to reservoir rocks. Sometimes the entire tracer test is compromised by contamination of samples in the field or laboratory. Over the longer term, the capacity of injection wells may increase or decrease with time, due to stimulation of permeability or plugging due to injected solids, changing the injection capacity of the well and the stability of fluid flow paths in the reservoir. Sometimes short circuits between injection and production wells are detected, requiring a shift of injection and/or production over the following years to prevent undue cooling of production.

33 Taken together, it seems unrealistic to expect that injection-to-production fluid pathways might be adequately characterised after only two years of observation. Perhaps a good example of what might be expected after the first additional 25MW plant at Ngawha would be the experience at the Kawerau Field, after an approximate doubling of production in August 2008.

34 This experience is documented by a conference paper by Mighty River Power authors (Askari and others) presented earlier this year at the World Geothermal Congress in Melbourne. They describe two separate tracer tests on different sets of injection wells, one 14 months after start-up and a second 28 months after start up. The observation times of the tracer tests were more than a year each due to first arrivals at production wells typically taking 50-100 days and with average tracer travel times of greater than 200 days. Injection management was complicated by pressure interference between injection wells and solids plugging of wells. The overall conclusion of the work was that, despite the lack of an immediate threat of production cooling, the injection wells utilised at start up were not optimally located and over time injection would need to be shifted to other, untested parts of the field periphery. A similar conclusion from tracer tests following the initial 25 MW expansion at Ngawha would likely require a reconfiguration of production and injection prior to the second 25 MW expansion.

35 Within the recommended five year monitoring period between the second and third power plant additions at Ngawha, and in order to increase the accuracy of the numerical model in modelling thermal degradation, I recommend that there should be at least two reservoir tracer tests of all injectors and producers to determine injection fluid residence times and return path dispersion (i.e. heat sweep efficiency). The first test should be conducted after approximately one to two years of continuous operation and the second after approximately three-four years of operation. The second test is necessary to robustly characterise changes in the injection program, such as shifting of injection, following the results of the first test. I would also recommend that, if available, injection wells planned for the third expansion be tested in this second tracer test. Results from the second test should be complete before the end of the five year monitoring period, otherwise the five year monitoring period should be extended to include all results. These results should be incorporated into the reservoir numerical model and numerical model reports should show the match of modelled versus actual tracer returns for both tests.

MAINTENANCE OF RESERVOIR PRESSURE

36 I support the proposed approach for maintenance of reservoir pressure, including the requirement to keep reservoir pressure within a specified Allowable Pressure Range.

37 To date, Top Energy has maintained reservoir pressure at the lower end of the allowable pressure range but could easily increase reservoir pressure by increasing supplemental surface water injection. I believe the hot spring monitoring data show a delayed and subtle response to changes reservoir pressure, indicating that

spring flow and temperature can be managed by changes in reservoir pressure.

38 I consider that it would be appropriate for conditions relating to maintaining reservoir pressure to address the following matters:

38.1 In relation to the accuracy of monitoring bores/wells, I consider that the proposed accuracy level of less than ±0.4 bar is below the accuracy of modern pressure meters and less than is needed for the fine-tuning of reservoir pressure. Modern meters, pressure gauges and pressure transducers (with digital readout to data loggers) can easily achieve ±0.1 bar accuracy, and I accordingly consider that a ±0.1 bar accuracy should be required in conditions.

38.2 If a new monitoring bore/well is required, I believe that the pressure range in any new monitoring well needs to be equivalent, in reservoir terms, to that in the existing NG13 monitoring bore/well. That is, the conditions should require the pressure in a new monitoring bore/well be maintained within a similar pressure range corresponding to an equivalent baseline pressure to that for NG13.

EFFECTS ON THE NGAWHA HOT SPRINGS

39 In my view, the proposed Project has the potential to affect the Ngawha Hot Springs (*the Springs*), by lowering the temperature of the Springs and altering the chemistry of the Springs.

Incremental pressure changes

40 In order to avoid causing any dramatic changes in the Springs, I consider that, where reservoir pressure is intentionally changed (by supplemental injection) for the purpose of maintaining hot springs flow, any such pressure changes should be carried out in small increments, such as 0.25 bar increments. The delay in hot spring temperature response to reservoir pressure that I believe is evident in the monitoring data suggests that any necessary pressure changes should be gradual.

Maintenance of Spring chemistry

41 I consider that there is a risk that the Project will alter the chemistry of the Springs, particularly in relation to the potential loss of gas from the reservoir due to its release to the atmosphere in the power plant cycle. The effect of reservoir gas on hot spring chemistry, particularly that of the dominant reservoir gas, carbon dioxide, is to buffer the pH of the water. The pH or acidity of the water has a large impact on how the hot spring water feels, with high pH hot spring waters, such as at Te Aroha, Waikato, exhibiting a "slippery" feel and more acidic hot spring waters, such as at the Polynesia Pools at Rotorua exhibiting a more "raw" feel. A change in the

reservoir gas concentration, when transmitted to the surface springs has the potential to change hot spring pH and the feel of the hot spring water.

42 I consider that the loss of gases from the reservoir fluids and the 21 month return time of reservoir tracer to the Springs suggests that the Springs chemistry is already in the process of adjusting to lower levels of gases in the reservoir fluids. In my opinion, it is likely that the Spring chemistry may diverge from within historical variability in the next decade or so.

43 With this in mind, it would be appropriate for the conditions to require maintenance of Spring chemistry within the range of historical variation and, if a material change is observed, implementation of techniques to restore Spring chemistry. If Spring chemistry shows changes due to loss of gas from the reservoir, a feasible solution would be the reinjection of a greater proportion of noncondensible gas separated in the power plant cycle back into the reservoir. This reinjection of a greater portion of gas would be expected to help return the Spring chemistry to their original state. I am aware of other geothermal projects where noncondensible gas is injected back into the reservoir with spent geothermal brine. For example, the Puna Geothermal Project on the island of Hawaii, USA, uses a similar binary power plant technology to that at Ngawha and reinjects 100% of noncondensible gas as a solution to hydrogen sulphide emissions restrictions.

Reservoir management plan

44 In addition to including a description of the operational and monitoring measures to be taken in response to any increasing or decreasing reservoir pressure response trends, I consider that the Reservoir Management Plan should also describe operational and monitoring measures to be taken in response to any increasing or decreasing hot spring temperature and flow rate. Such a requirement would ensure that a plan is in place to return the hot springs to their natural state in the event that hot spring temperature and flow rates change to beyond historical variation.

MONITORING

45 I generally support the proposed monitoring regime for the Project. I do however consider that, for the sake of accurately calibrating the numerical model, monitoring should include:

45.1 Regular production well enthalpy monitoring to observe reservoir thermal degradation and assist in numerical model calibration. The existing technique of measuring production enthalpy at Ngawha uses a chemical geothermometer to determine reservoir temperature and thus production enthalpy. There are many cases where chemical geothermometers are known to be inaccurate, particularly in instances of injection water return. The enthalpy measurement technique should conform to the industry standard of separately measuring steam and water flow in two phase production pipelines;

45.2 Tests to identify the depth and productivity index of production feed zones, and to determine the enthalpy and production rate of the well under at least 3 different wellhead pressures.

CULTURAL INDICATORS

46 I understand that characteristics such as the look (e.g. colour), feel, smell and presence of bubbles in Springs are important to the Trust from a cultural perspective. I have already mentioned how pH plays a large part in determining the feel of water. Smell is, in large part, determined by the gas chemistry of gas bubbles. Hot spring pH and gas chemistry are both measured as part of the present monitoring program. The presence of bubbles might be measured by capturing bubbles from the Springs in an inverted funnel and measuring the flow of gas, either by fixed apparatus or by spot measurements. The look and colour of the water in the Springs might be measured by the concentration and chemical makeup of suspended solids. For those characteristics which are not measured by the present monitoring program, a set of baseline measurements would be valuable in tracking the source of any changes noted by human observation and in determining if the changes are attributed to the Project or to natural processes.

Tom Powell
22 July 2015

APPENDIX A – LIST OF PUBLICATIONS

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