

**BOARD OF INQUIRY  
TE MIHI GEOTHERMAL POWER STATION PROPOSAL**

In the Matter                      of the Resource Management Act 1991

And

In the matter                      of resource consent applications by Contact Energy Limited  
in respect of the Te Mihi Geothermal Power Station Proposal

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**REBUTTAL EVIDENCE OF MICHAEL JOHN O'SULLIVAN**

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## **Introduction.**

1. My name is Michael John O'Sullivan. I am a professor in the Department of Engineering Science at the University of Auckland. I refer the Board of Inquiry to the statement of my qualifications and experience in my evidence in chief. I reaffirm my commitment to comply with the code of conduct for expert witnesses in the Environment Court.
2. The purpose of this brief of evidence is to respond to the evidence of Dr Arnold Watson (for Waikato Regional Council) and Dr John Burnell (for Geotherm Group (In receivership) relating to the potential for reinjection pursuant to the consent sought by Contact Energy Limited ("Contact") to have adverse effects on production under the Geotherm Group consents.
3. Dr Watson in his paragraph 19 states:

*"ECNZ's evidence to the Court was that according to Prof O'Sullivan's modelling, production from the shallow steam zone would decline to an insignificant level in a few years, and that geological interpretations indicated a high risk that GEL's injected water would flow directly back to ECNZ's part of the reservoir via faults, and would decrease its production".*

4. This statement raises two issues:

- (i) Production from the shallow steam zone
- (ii) Injection in the deep liquid zone.

These are very different matters and therefore I will deal with them separately.

### **Shallow steam zone**

5. My model of the early 1990s predicted that the pressure in the shallow steam zone would decline. In the event, the production and injection strategy followed at Wairakei over the last 15 years is not identical to any of the scenarios I presented at the Waikato Regional Council hearing of consent applications by ECNZ (Contact's predecessor) in 1994 (I think this is the model to which Dr Watson refers). Probably the closest is Scenario BT(R70). As my exhibit MJO4 shows, the steam zone pressures I predicted back in 1993 match the actual pressure decline reasonably well. The steam zone in my 1993 model was not quite hot enough, so that the temperature then and therefore the pressure are both too low. After that the pressure declines, but at a rate less than indicated by the measured data for WK205. In my view, my 1993 reservoir model of the shallow steam zone was therefore a reasonable representation of field conditions.

6. However, as Dr Watson points out in his paragraph 20:

*“In the event, Prof O’Sullivan’s predictions did not turn out to be correct; the shallow steam zone is still producing today at the rate granted in GEL’s original consents.”*

7. The reason for the inaccuracy of my model in this respect is the way in which I represented the operation of the steam zone wells. I used a deliverability option in the form:

$$\text{Flow rate} = \text{Productivity Index} \times (\text{Reservoir pressure} - \text{Cut-off pressure})$$

Thus if the reservoir pressure drops below the specified cut-off pressure the well ceases production.

8. So back in 1993, I was too conservative with my choice of the cut-off pressure. The wells have kept on producing when the shallow steam zone pressures have dropped to low levels. Thus the problem with my 1993 model was not really with the representation of the underground reservoir, but rather with the way in which I represented future well behaviour. Thus I disagree with the following statement made by Dr Watson in his paragraph 21:

*“But modelling in that part of the field in general has been demonstrated to be unreliable ...”*

9. In fact, my 1993 model represented the shallow steam zone quite well and my current model is considerably better in this respect. The representation of the deep liquid zone under Geotherm by my 1993 model has not been proven to be either good or bad because the injection proposed back then has not occurred and there are no production wells in this area accessing deep liquid and thus no data are available.

### **Injection in the deep liquid zone**

10. The second matter Dr Watson raises is the risk of return of injected water to a production area. In his paragraph 20 he states:

*“Deep production was never achieved by GEL and hence the injection of separated water in the Poihipi and current Geotherm area has never been tested. In my opinion it remains almost as uncertain today as it was then where any water injected into that part of the field will migrate to and how quickly;”*.

11. For several reasons that I will now discuss, I do not agree with Dr Watson about the uncertainty of the fate of injected water - both back in 1994 and now in 2008.
12. The main determinant of the direction in which injected water flows is the underground pressure regime. Water flows from a high pressure zone to a low pressure zone. There is no uncertainty about this statement - it is a fundamental law of nature. It is essentially the same principle that determines that water flows downhill.
13. Another fact about which there is no uncertainty is that production at Wairakei over many years without injection has caused a large pressure drop near the production borefields. This was true in 1993 and is still true today. This means that any water injected infield at Wairakei will be attracted towards the existing pressure "sink" near the Western borefield and Te Mihi.
14. It would require a very large pressure drop at the Geotherm site to establish a rival pressure sink to attract injected water. The Geotherm consents have production in close proximity to its injection. This would suggest there is little likelihood of a significant pressure sink developing.
15. Geotherm may, however, be able to achieve separation between production and injection vertically by distance and low vertical permeability. Certainly, this was expressed to be the intention in the evidence presented in support of the applications in 2004, but this concept is dependent on locating permeability at depth to enable reinjection to occur. If such conditions are present (there is no clear evidence that they are), they would also mean that deep injection by Contact Energy (as planned) will not significantly affect Geotherm as it would also be vertically separated from Geotherm production, and much further away horizontally
16. The significance of the pressure regime is that it determines the flow directions. For the reasons discussed, I believe most injection is likely to flow towards the Contact steamfields where pressure drawdown is greatest. The flow speeds, however, depend on the detailed permeability structure, particularly the presence of high permeability faults. In this regard, I acknowledge some of the uncertainty expressed by Dr Watson.
17. For a reservoir modeller, faults are a problem because geologists seem able to identify many of them and it is often not clear which are important in

affecting the flow of water and steam. In the case of Wairakei the various reports we have had access to over the years have identified one set of major faults running NW-SE and another running SW-NE.

18. Some of the NW-SE faults have been identified as significant flow paths by tracer tests. These are the faults that run from the Wairakei borefields over towards Poihipi Road.
19. In our model, we do not represent the faults explicitly. In faulted and fractured zones, we assign large permeabilities and if there is a clear preferential direction, we assign a larger permeability in one direction. In most parts of the model, we have a lower vertical permeability than horizontal permeability. Thus we often use a different permeability in each of three directions, and therefore Dr Watson's statement about our flows not being directionally sensitive (paragraph 22) is not correct.
20. Because of the large pressure gradient from the Poihipi Road area to the Western Borefield existing in 1993 (and also now), in my 1994 evidence I stated that most of the injected water from the Poihipi project would flow towards the Western Borefield. Further, because of the presence of the large NW-SE faults (identified by geologists and tested with tracers) I also stated that these flows could be rapid. I believe there is little uncertainty about either of these statements.
21. The fact that I was too conservative in my choice of cut-off pressures for the wells in the shallow steam zone at Poihipi does not in my view affect the validity of my statements about the migration of injected water.

### **Injection in Areas 1&2**

22. In my evidence in chief for the current hearing, I discussed scenario TM2 which includes some infield injection in areas 1 & 2 near Karapiti. Given the issues raised by Dr Watson, I will now discuss in greater detail the effects of injection at these locations.
23. There are three issues of importance:
  - i. Will a pressure sink be created at the Geotherm location?
  - ii. What is the geological structure in the zone between Geotherm and Areas 1 & 2?
  - iii. Will injected water from Areas 1 & 2 adversely affect production by Geotherm?

### **Pressure sink**

24. The development of a significant pressure sink at Geotherm requires first that there is sufficient permeability and high enough temperatures there to sustain production. In my model the temperatures and the permeabilities are too low for the target production to be achieved. Admittedly my model is cooler than the measured temperatures for Well GGL1 (see Exhibit MJO5). However, the measured temperatures are in the 180-220degC range which is still marginal for successful production at Wairakei.
25. My model has low permeabilities in liquid zone in the Geotherm area. This is based on results from drilling deeper wells in the Poihipi Road area (e.g. 610). It was also found to be necessary in order to get our model to match the downhole temperatures in several wells in the southern area.
26. Dr Burnell's model must have high permeabilities in the Geotherm area as he predicts a successful operation of the project. His production enthalpy of 760KJ/kg corresponds to a temperature of ~180degC which is reasonable in terms of the measured values. In my model, I use a deliverability option that shuts down a well when the downhole temperature falls as low as 180degC as this is the experience of well behaviour at Wairakei. I used this option with the wells for the Geotherm project and which partly explains the poor performance of the Geotherm project in my model. Production could be maintained if pumping was introduced and possibly this is what Dr Burnell had in mind when he allowed low temperature wells to function in his model. However pumping introduces considerable extra cost and as it was not discussed in the Geotherm application I did not allow for it in my modelling.
27. I am unable to assess his model further because he does not show the match he has achieved to the downhole temperatures for GGL1 or the nearest neighbour wells. He does not discuss any permeability tests that were carried out on GGL1 and he does not provide the permeability structure he has used in the Geotherm area.
28. Even supposing that production and injection could be carried out by Geotherm, would it create a pressure sink? Locally there would be a pressure low near the Geotherm production wells and a pressure high near the Geotherm injection wells. But with a balanced production and injection strategy, as required by the Geotherm consents, there will be no nett loss of mass. Because the injected water is at a lower temperature, there will be a nett volume change and therefore a small pressure low will develop. Its

magnitude will depend on the difference in elevation of the production and injection by Geotherm. However as I pointed out above, if Geotherm production and injection are separated from one another vertically then Geotherm production will also be separated from Contact injection as in this case Geotherm injection and Contact injection would be at a similar elevation.

29. If there is only a small pressure difference and small flow between Area 1&2 and Geotherm, and in my opinion this is likely, then there may be little to be learned by carrying out the tracer test suggested by Dr Watson (para 26). A tracer test will only show up a preferential flow path if there is a pressure gradient driving water along it.

### **Permeability Structure**

30. Is there a high permeability flow path connecting Areas 1 &2 to the Geotherm area as Dr Watson and Dr Burnell suggest may be the case? I cannot say for certain that they are incorrect, but all the information from wells drilled in the general area and all the numerical experiments I have conducted with my model suggest that it is unlikely to be so.

### **Effect of injection in areas 1 & 2 on Geotherm production**

31. Because of these factors, I do not think that the Geotherm pressure sink will exert a large attraction on the cooler water injected deep in Areas 1 & 2 by Contact Energy, compared with the very large attraction of the pressure low at the Wairakei Borefields.
32. In my model, the pressure high created by injection at Areas 1 & 2 pushes a small amount of hot water towards Geotherm, thus enhancing production. Most of the flow is towards Wairakei. If there was a very high permeability fault or fracture running directly from Areas 1 & 2 to Geotherm some cooling could occur, but it would be minor compared with the effect of Geotherm's own injection.
33. I note that I do not agree with the statement made by Mr Matthews that:

*"In other words, Professor O'Sullivan predicts adverse effects on any Geotherm development".*

In fact my modelling showed some marginal benefits to Geotherm in some cases.

34. In his evidence Dr Burnell points out that injection by Contact (in my Scenario TM2 or his Scenario 2) helps to maintain pressures (shown in his Figure 26). I agree with this conclusion.
35. However, I disagree with his statement in paragraph 6.10, referring to his Figure 26, that: *“There it can be seen that pressures in the Geotherm property fall to around 26 bar. The reason for the pressure decline is that Contact extracts an extra 110,000 tonnes/day from the reservoir and only reinjects an extra 75,000 tonnes/day.”*

Dr Burnell does not explain the role that Geotherm production has in the pressure decline shown in Figure 26 and produces no modelling evidence to back his statement. For example he could have produced a fourth plot of Geotherm pressures for the case where there is no production or injection by Geotherm. I expect that such modelling studies would show that some of the initial steep pressure decline shown in Figure 25 is due to Geotherm production.

36. Similarly I disagree with his statements that the cooling of Geotherm production in his Scenarios 2 and 3 must come from the cool water injected by Contact Energy in Areas 1 and 2. The increased pressure under Geotherm for Scenarios 2 and 3 allows a larger production rate, as shown in Dr Burnell’s Figure 23. The question is where this extra cool flow comes from?
37. In this regard it is worth noting that Dr Burnell’s Figure 24 shows Geotherm production cooling even when there is no injection by Contact Energy in Areas 1 and 2. This not surprising as the Geotherm property is at the edge of the Wairakei geothermal system and production there is likely to attract some low enthalpy water from the west. It is also worth noting that for Dr Burnell’s Scenario 2 (his version of my Scenario TM2) the enthalpy is not much below that for Scenario 1. Thus, for Scenario 2, Dr Burnell’s results do not indicate a significant cooling effect and for the small effect that is shown it is not obvious whether it arises from extra cool water from the west or from Contact Energy’s injection.
38. Dr Burnell’s Scenario 3 does show some cooling of Geotherm production resulting from Contact Energy’s injection. However the scale of his Figure 24 may be misleading. The drop in enthalpy between Scenario 1 and Scenario 3 after 45 years of production is only about 20kJ/kg (equivalent to a temperature difference of only 4.5degC).

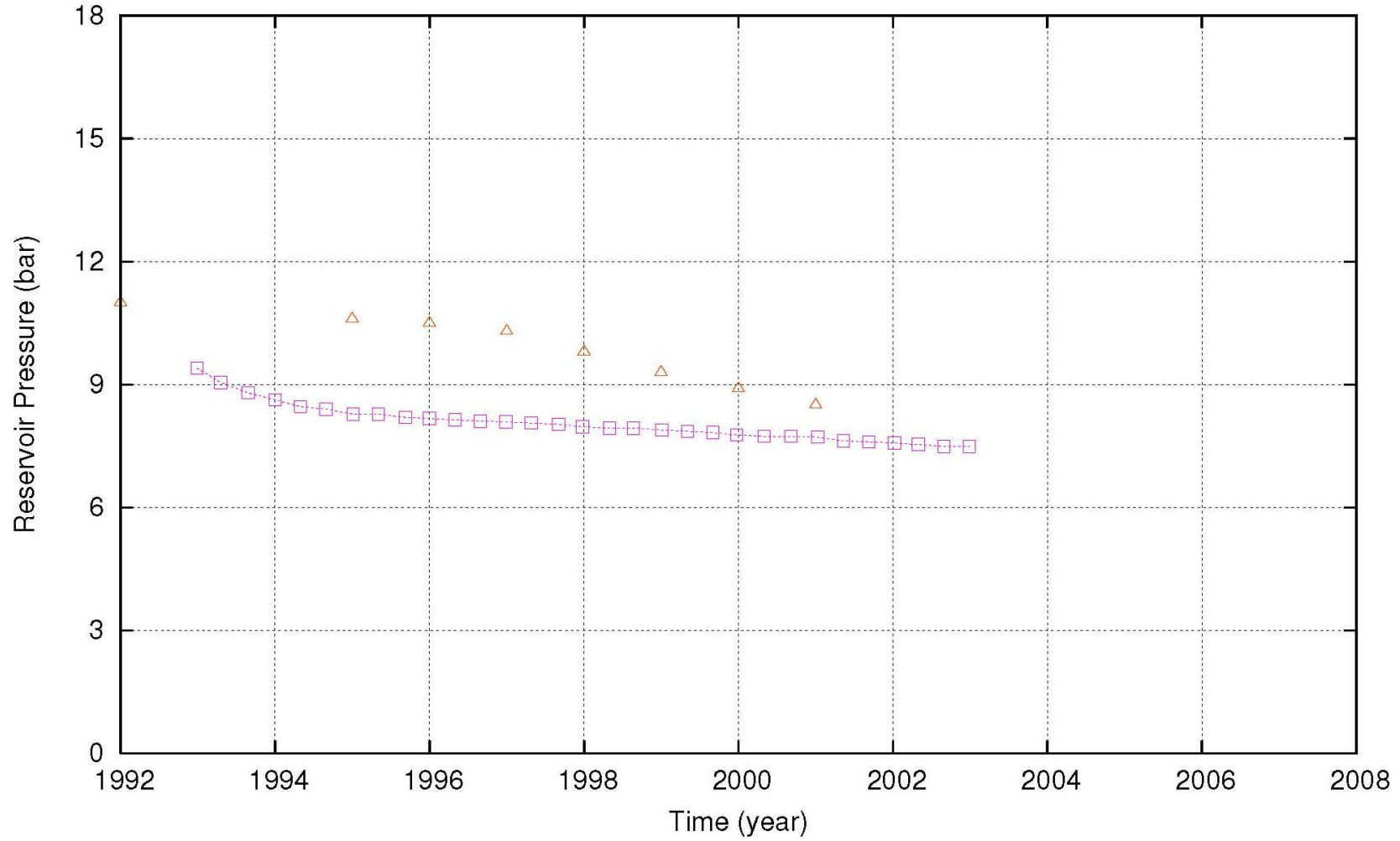
39. Thus in my opinion Dr Burnell is overstating the potential adverse effect of Contact Energy's injection in Areas 1 and 2 on Geotherm production. Therefore I do not agree that his modelling results support his recommendation for a 1.5km distance between Geotherm production and Contact Energy injection.
40. His recommendation for a larger separation between injection of colder condensate and production has no scientific basis. The travel speed of the thermal front (the hot/cold interface) between an injection site and a production site is independent of the injection temperature. All that changes is the temperature of the injected water when it breaks through at the production wells. In either case (separated water or condensate) the break through temperature is sufficiently low to cause production to cease. Thus there is no point to Dr Burnell's recommendation in his paragraph 6.21.
41. In summary I wish to emphasise some of the matters I have covered above:
- i. The interaction between an injection site and a production site depends on the pressure distribution, with water flowing from high pressure to low pressure.
  - ii. The speed at which the water flows depends on the permeability structure. It can flow preferentially along faults and fractures.
  - iii. My modelling has not shown either of these conditions to be of concern with regard to the interaction between Contact injection in Areas 1 and 2 and Geotherm production.
  - iv. My modelling and Dr Burnell's modelling do not show a problem of adverse effects on Geotherm production resulting from injection by Contact in Areas 1 and 2 (my Scenario TM2, his Scenario 2).
  - v. The pressure regime and the permeability structure I discussed in my 1994 evidence with regard to the interaction between ECNZ production and Geotherm injection are both very different to the current situation with regard to the interaction between Geotherm production and Contact energy injection.

- vi. Therefore I do not see the need to establish a larger buffer zone between Geotherm production and Contact injection than was in my Scenario TM2. Mr Carey has captured that position in the buffer area he has identified in his rebuttal evidence.

**MJ O'Sullivan**

EXHIBIT MJO 4

Wairakei 1225 Model  
Poihipi Steam Zone Pressure

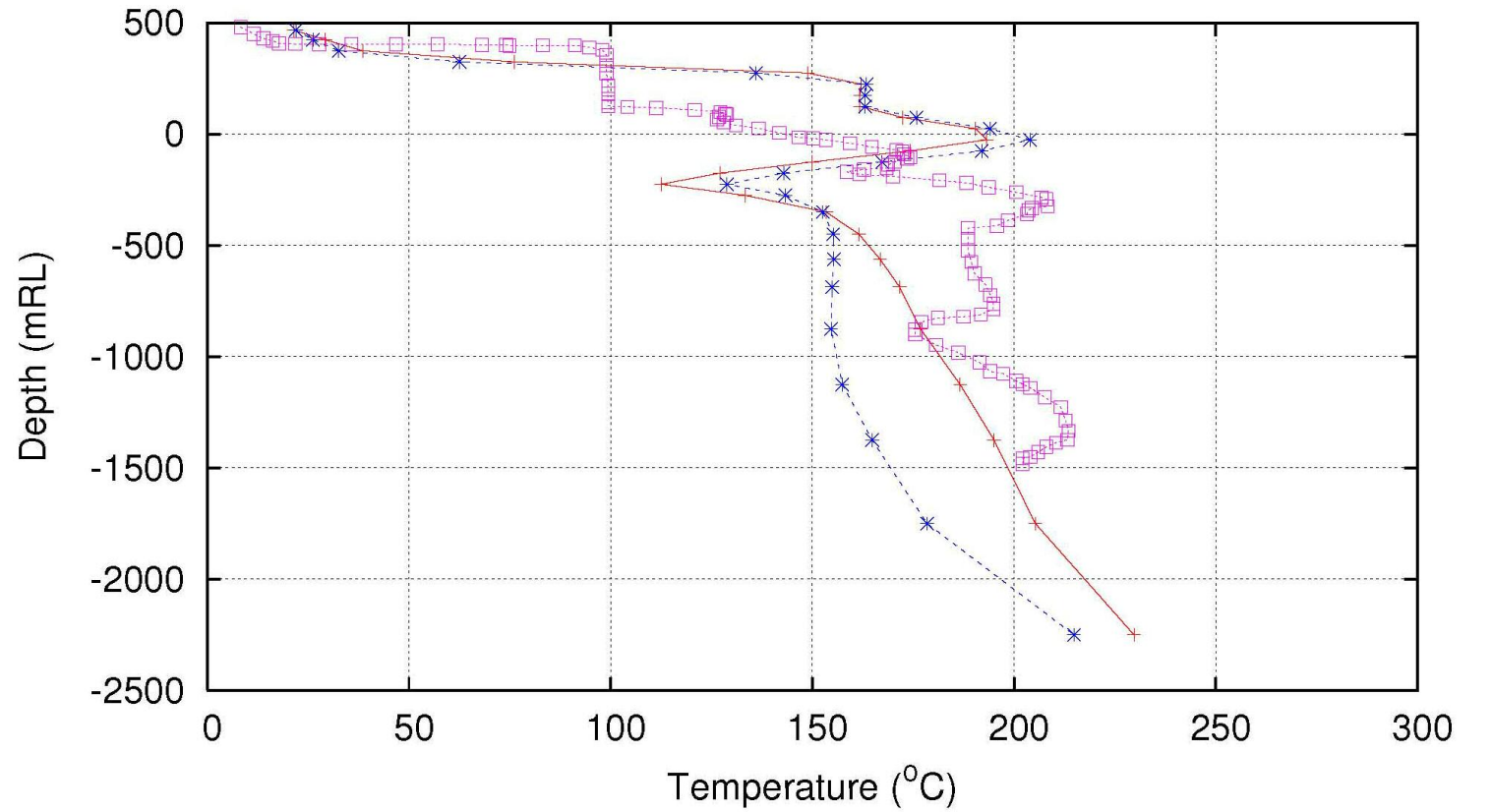


Model 1225 - CC 46 (170 mRL) ---□---

WK205 △

EXHIBIT MJO 5

Temperature at Column 733



2007 Model at 2006.00 —+—  
2006 Model at 2006.00 - - \* - -

GGL1 23AUG2006 ···□···

