IN THE MATTER OF	The Resource Management Act 1991
AND	
IN THE MATTER OF	Lake Rotorua Nutrient Management – **PROPOSED PLAN CHANGE 10** to the Bay of Plenty Regional Water and Land Plan

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STATEMENT OF EVIDENCE OF JAMES CHRISTOPHER RUTHERFORD ON BEHALF OF THE BAY OF PLENTY REGIONAL COUNCIL

Evidence topic: Catchment loads – ROTAN

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Qualifications and experience

1. My full name is **James Christopher RUTHERFORD**. I am an emeritus principal scientist employed part time by the National Institute of Water and Atmospheric Research (NIWA) as a catchment processes modeller, a position I have held for 43 years.

2. I have been involved in developing and applying computer models of water and nutrient movement through catchments, water quality and ecosystem health in rivers, lakes and estuaries. I have also helped design and conduct field and laboratory studies to support modelling.

3. I have the following qualifications: BE (hons) and PhD (Engineering Science) from the University of Auckland. I am currently a member of the New Zealand Freshwater Sciences Society and Hydrological Society, and was formerly a member of the Institution of Professional Engineers. I have been a member of the Water Quality Technical Advisory Group (WQ TAG) convened by the Bay of Plenty Regional Council (BoPRC) since its inception in the late 1980s.

4. I was involved with research on the Rotorua lakes and their catchments between 1977 and 2005 when I led projects that:

   (a) identified trends in Lake Rotorua water quality linked to waste water treatment plant discharges,

   (b) predicted the role of nutrient releases from the lake bed in delaying lake water quality recovery following discharge reductions, and

   (c) identified increasing trends in stream nitrogen concentrations.

   I helped Dr Noel Burns develop the lake Trophic Lake Index (TLI) used by BoPRC and other councils to monitor time trends in the water quality of Lake Rotorua and elsewhere.

5. I have presented evidence at three consent hearings for the Rotorua wastewater treatment plant, and for the Waitangi Tribunal hearings about the discharge of wastewater to the Kaituna River in the late 1980s. I have published 6 papers in scientific journals, presented >16 papers at conferences and written >20 reports on Lake Rotorua.

6. As a member of the WQ TAG, I helped set the nitrogen load target for Lake Rotorua; identify the need to control of both nitrogen and phosphorus loads, and set limits on nitrogen and phosphorus loads from wastewater.

7. I have read the Expert Witness Code of Conduct set out in the Environment Court's Practice Note 2014 and I agree to comply with it. I confirm that the issues addressed in this statement of evidence are within my area of expertise, except where I state I am relying on the specified evidence of another person. I have not omitted to consider material facts known to me that might alter or detract from my expressed opinion.

Scope of Evidence and Summary

8. My evidence concerns the effects that land use has on nitrogen losses within the catchment, and what proportion of those losses reaches the lake. Nitrogen is a plant nutrient that affects lake water quality as discussed by Professor Hamilton in his evidence.

9. My evidence addresses four questions:

   (a) Are the results of modelling work reported in 2011 still valid?

   (b) What proportion of the total nitrogen loss reaches the lake?

   (c) Will the nitrogen reductions in PC10 meet the lake load target?

   (d) How quickly will lake loads decrease after PC10 comes into force?

10. As part of my research at NIWA during the mid-1990s I instigated and led development of the computer model ROTAN (ROtorua and TAupo Nitrogen model). ROTAN uses OVERSEER® to estimate nitrogen losses from farmland, and then routes water and nitrogen through groundwater and streams to the lake, taking account of attenuation. ROTAN is calibrated to match monitored stream nitrogen concentrations using groundwater residence times[1] and aquifer boundaries[2]

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[1] Morgenstern, U.; Daughney, C.J.; Leonard, G.; Gordon, D.; Donath, F.M.; Reeves, R. (2015). Using groundwater age and hydrochemistry to understand sources and dynamics of nutrient contamination through the catchment into Lake Rotorua, New Zealand. *Hydrology & Earth Systems Science 19: 803-822.*

[2] White, P.A., Rutherford, J.C. (2009) Groundwater catchment boundaries of Lake Rotorua. *GNS Science report, 2009/75LR for Environment Bay of Plenty.*

published by GNS-Science. ROTAN was developed because none of the models available at the time was capable of incorporating OVERSEER® and modelling groundwater using the available information.

11. Between 2009 and 2011 BoPRC contracted NIWA to calibrate and test ROTAN in the Rotorua catchment (hereafter called the ROTAN-2011 study). OVERSEER version 5.4.2 was used in the ROTAN-2011 study, being the current version at that time. Results are contained in three NIWA reports on hydrology and historic farming[3], nitrogen calibration[4] and scenario modelling[5]. The ROTAN-2011 study informed the PC10 process by estimating the reductions in nitrogen loss required to meet the target lake load, together with the likely rate of recovery.

12. Since 2011 OVERSEER has been upgraded and version 5.4.2 is no longer supported. BoPRC is using OVERSEER version 6.2.0 in the PC10 process. I understand from Alastair MacCormick that OVERSEER version 6.2.0 calculates nitrogen losses from dairy and dry stock farms in the Rotorua catchment that are, on average, 88% higher than losses calculated using OVERSEER version 5.4.2.

13. In March 2016 BoPRC contracted NIWA to recalibrate ROTAN using OVERSEER version 6.2.0, together with revised groundwater boundaries and recent stream monitoring data.

14. Recalibration of the ROTAN-2011 model proved impossible within the time available because of a requirement for extensive reprogramming. This was necessitated following upgrades made by ESRI to the ArcGIS software in ROTAN, and by Microsoft to the Visual Basic and Microsoft Access components. Reprogramming of ROTAN is currently being undertaken by the University of Waikato to provide daily-weekly nitrogen loads for their lake water quality models, but that work is incomplete to-date.

15. NIWA was, therefore, commissioned to develop a simplified version (hereafter referred to as ROTAN-Annual) and calibrate it using: OVERSEER version 6.2.0

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[3] Rutherford, J.C.; Tait, A.; Palliser, C.C.; Wadhwa, S.; Rucinski, D. (2008). Water balance modelling in the Lake Rotorua catchment. *NIWA Client Report HAM2008-048*. Hamilton.

[4] Rutherford, J.C.; Palliser, C.C.; Wadhwa, S. (2009). Nitrogen exports from the Lake Rotorua catchment – calibration of the ROTAN model. *NIWA Client Report HAM2009-019.* Hamilton.

[5] Rutherford, J.C.; Palliser, C.C.; Wadhwa, S. (2011). Prediction of nitrogen loads to Lake Rotorua using the ROTAN model. *NIWA Client Report HAM2010-134.* Hamilton.

nitrogen losses; recent stream monitoring data; revised groundwater boundaries; and updated land use information. Results of that study are found in my report to BoPRC[6].

16. My evidence uses nitrogen loss estimates supplied to me by BoPRC. These estimates were made using OVERSEER version 6.2.0 by Alastair MacCormick, Natalie Meidema and Michelle Hosking from BoPRC. The methods used are contained in their report[7]. I contributed to that report by attending a meeting with farmers which reviewed historic land use maps, supplying data on historic stocking rates from my earlier report (Rutherford et al., 2008), and checking results.

17. My evidence uses groundwater boundaries estimated by GNS-Science and described in their report[8]. I undertook the water balances calculations that are appended to that GNS-Science report.

18. In summary the main conclusions from my report are:

    (a) Its annual time-step makes ROTAN-Annual consistent with OVERSEER and the target annual load for Lake Rotorua, and suitable to support the PC10 process.

    (b) In the model, water and nitrogen travel to the lake by three pathways: quickflow, slowflow and streamflow. Nitrogen removal along each pathway (termed attenuation) is quantified using three separate coefficients whose values were calibrated to match observed stream concentrations.

    (c) Model predictions were insensitive to quickflow attenuation because quickflow made only a small contribution to the total lake inflow. Slowflow and streamflow attenuation strongly influenced stream concentrations and lake load.

    (d) Several different combinations of quickflow, slowflow and streamflow attenuation coefficients gave a similar good match between observed and predicted concentrations. This does not pose a serious problem when

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[6] Rutherford, J.C., MacCormick, A. (2016). Predicting nitrogen inputs to Lake Rotorua using ROTAN-Annual. *NIWA Consultancy Report 2016102HN*. Project BOP16201. October 2016.

[7] MacCormick, A., Rutherford, J.C. (2016) Update of the ROTAN discharge coefficients into OVERSEER 6.2.0. *BoPRC Report.* December 2016*.*

[8] White, P.A.; Tschritter, C.; Lovett, A.; Cusi, M. (2014). Lake Rotorua catchment boundary relevant to Bay of Plenty Regional Council's water and land management policies, GNS Science Consultancy Report 2014/111. 99 p.

predicting lake loads. The model was run using combinations of coefficients (termed a Monte Carlo simulation) and the statistical distributions of predicted lake loads calculated.

(e) ROTAN-Annual predicted that the ‘most likely’ steady state load assuming current land use is 750 t y^{-1} with a 95% confidence interval of 670-840 t y^{-1}. The most likely load is not significantly different from the ROTAN-2011 estimate of 725 t y^{-1}. This confirms that the results of the 2011 study are still valid even though OVERSEER has changed, new groundwater boundaries have been defined and there are seven years more stream monitoring data.

(f) ROTAN-Annual predicted that on average 42% of total nitrogen losses were attenuated (viz., did not reach the lake). This compares favourably with published estimates of catchment-scale attenuation in other catchments both in New Zealand and overseas.

(g) For the loss reductions specified in PC10, the model predicts the steady-state lake load to be 425 t y^{-1} with a 95% confidence interval of 390-460 t y^{-1}. This is 5% higher than the target lake load of 405 t y^{-1} but, given the uncertainty, the difference may not be statistically significant. These lake loads exclude rainfall on the lake of 30 t y^{-1}.

(h) The statistical distributions of the measurements used to calibrate ROTAN-Annual and the model coefficients are unknown and there is no way they can be determined from the available information. Therefore, the 95% confidence interval of 390-460 t y^{-1} for the steady state lake load under PC10 is only approximate.

(i) Nevertheless, there is only a low probability (circa 2.5%) the lake load will be less than, and a high probability (circa 97.5%) it will be greater than, 390 t y^{-1}. There is only a low probability (c. 2.5%) the steady state lake load will be greater than, but a high probability (c. 97.5%) it will be less than, 460 t y^{-1}.

(j) Without knowing the statistical distribution of the measurements and model coefficients it is not possible to estimate precisely the probability that the steady state lake load will be any particular value, such as the steady state target load of 405 t y^{-1}.

(k) If it is assumed that the distribution of predicted lake loads is uniform with upper and lower bounds of 390 and 460 t y^{-1} then there is a 21% probability the steady state lake load will be less than, and a 79% probability it will be greater than, the target of 405 t y^{-1}.

(l) If it is assumed that the distribution is normal with upper and lower 95% limits of 390 and 460 t y^{-1} then there is a 13% probability the steady state lake load will be less than, and an 87% probability it will be greater than, the target of 405 t y^{-1}.

(m) Of more interest is the possibility that the steady state lake load will be greater or less than the target by an amount that will have a detectable effect on lake water quality. I do not know what the implications are of exceeding or not attaining the target lake load.

(n) I assumed that provided the steady state lake load is within 10% of the target then lake water quality will meet the expectations of PC10. If so then the steady state lake load will need to lie between 365 and 446 t y^{-1}.

(o) I then assumed that the steady state lake load is either normally or uniformly distributed (as in Clauses (k) and (l) above).

(p) Making these assumptions, I estimated that the probability that lake load reductions:

   (i) will be <u>more</u> than required is negligibly small, and

   (ii) will be <u>less</u> than required is 12-20%.

(q) In my opinion:

   (i) There is a negligible risk the nitrogen control measures in PC10 will be <u>more</u> than required to meet the lake target.

   (ii) There is a risk (c. 12-20%) that nitrogen control measures will be <u>less</u> than required to meet the lake target.

   (iii) The nitrogen control measures in PC10 will result in a significant reduction in current lake load which (on the basis of Professor Hamilton's evidence) will help improve lake water quality.

(r) ROTAN-Annual predicts that nitrogen reductions specified by BoPRC will reduce lake loads to within 25% of the target (405 t y^{-1}) within 25 years although steady-state may not be reached until after 2100.

19. Since the date of that report no new information has come to my attention that might alter my conclusions.

Background materials and reports referenced

20. In addition to the papers and reports referenced above, during the course of preparing this evidence I have had regard to the following documents and materials:

(a) the Council section 42A report

(b) evidence of Professor Hamilton and Andrew Bruere.

Basis of my opinion

21. Its annual time-step makes ROTAN-Annual consistent with OVERSEER which reports nutrient loss at an annual time step. Its annual time-step also makes ROTAN-Annual consistent with the target load for Lake Rotorua. ROTAN-Annual is contained within one software platform (Microsoft Excel) runs quickly, and lends itself to calibration and sensitivity analysis. These features mean ROTAN-Annual is suitable for supporting the PC10 process. In contrast the original ROTAN-2011 model requires three software platforms (ArcGIS, Microsoft Access and Visual Basic) making calibration and sensitivity analysis difficult and time consuming. ROTAN-Annual complements the daily-weekly time-step ROTAN-2011 model which the University of Waikato uses to support its lake water quality modelling. .

22. Nitrogen is lost from pasture, forest and urban land driven by rainfall. Drainage carries soluble nitrogen into groundwater which may take years-decades to reach the lake (termed slowflow). Surface runoff carries soluble and insoluble nitrogen into drains and streams within hours-days (termed quickflow), although surface runoff is infrequent at Rotorua. Streams collect quickflow and slowflow and transport it to the lake (streamflow).

23. Not all nitrogen lost from the catchment reaches the lake because of removal along the delivery pathways (e.g., plant uptake and denitrification). The word attenuation is used to mean the difference between the nitrogen load at the point where it is generated and where it enters the lake.

24. In ROTAN-Annual separate attenuation coefficients are defined for each of the three pathways. During calibration, constraints were placed on the three attenuation coefficients based on published attenuation coefficients and/or calculations using published data.

25. Predicted annual flows matched observations within 95% confidence limits. Accurately predicting flow is important because OVERSEER predicts nitrogen losses as a flux (units kg y^{-1}) and in ROTAN-Annual stream fluxes need to be divided by flow to get concentrations for comparison with observed stream concentrations. A satisfactory water balance increases confidence that groundwater catchments have been defined appropriately.

26. The model was calibrated using standard methods to identify combinations of the three attenuation coefficients that gave a good match between observed and predicted stream total nitrogen concentrations at ten monitoring locations over a 30 year period.

27. Model predictions were insensitive to quickflow attenuation because most Rotorua soils are permeable and surface runoff (quickflow) makes only a small contribution to the total lake inflow. The slowflow and streamflow attenuation coefficients strongly influenced stream concentrations and were found to be inversely correlated (viz., if the slowflow coefficient was high, the streamflow coefficient was low). This behaviour was expected. Despite being negatively correlated, the steady-state lake load was negatively correlated with both the slowflow and streamflow attenuation coefficients (viz., if the slowflow and streamflow coefficients were high, the lake load was low).

28. During calibration spatially uniform attenuation coefficients did not produce a satisfactory match between observed and predicted TN concentrations at all monitoring sites. The two possible reasons are that there are errors in the input or monitoring data, and/or that there are ‘true’ spatial differences in attenuation. Allowing attenuation coefficients to vary spatially did not significantly reduce uncertainty in predicted lake loads and resulted in differences between catchments that had no scientific basis.

29. Different combinations of quickflow, slowflow and streamflow attenuation coefficients gave a similar match between observed and predicted concentrations. This occurred because the three coefficients were calibrated using only stream nitrogen concentrations, albeit measured in ten different streams.

30. There are insufficient data available to estimate attenuation coefficients independently of the model. Were there more information about groundwater nitrogen concentration, water age and land use history within the groundwater catchment, then the slowflow attenuation coefficient could be estimated independently from the model. This was attempted using the sparse data available and reduced uncertainty in the slowflow attenuation slightly.

31. Because several different combinations of attenuation coefficients were identified during calibration, a Monte Carlo simulation was used to predict the statistical distribution of lake loads. One thousand combinations of coefficients were selected randomly with the reasonable expectation that, although the predicted lake loads may be variable, they will be unbiased. The statistical distributions of predicted lake loads were then calculated.

32. It should be noted, however, that the current modelling provides no guidance on whether it is best to target quickflow (e.g., riparian buffer strips), slowflow (e.g., groundwater denitrification) or streamflow (e.g., aquatic plant growth) in order to reduce lake loads.

33. Following calibration, ROTAN-Annual predicted that the ‘most likely’ steady state load assuming current land use is 750-760 t y^{-1} (excluding rainfall on the lake) with a 95% confidence interval of 670-840 t y^{-1}. The ROTAN-2011 study estimated 725 t y^{-1} which is not statistically significantly different from the ROTAN-Annual estimate.

34. Catchment-scale attenuation (viz., the sum of all nitrogen losses from land and point sources minus the load entering lake) was estimated to average 42% with a 95% confidence interval of 32%-50%. This compares favourably with published estimates of catchment-scale attenuation in other catchments both in New Zealand and overseas. The ROTAN-2011 study found that attenuation was negligibly small in nine of the ten major catchments. This was noted at the time to be a surprising finding. ROTAN-Annual used higher nitrogen losses (predicted by OVERSEER v 6.2.0) than the 2011 study (OVERSEER v 5.4.2) and observed stream concentrations could only be matched assuming 32%-50% attenuation.

35. Incorporating the loss reductions specified in PC10 by BoPRC, ROTAN-Annual predicted the ‘most likely’ steady-state lake load to be 420-440 t y^{-1} with a 95% confidence interval of 390-460 t y^{-1}. The target lake load is 405 t y^{-1} (viz., 435 t y^{-1} including rainfall on the lake of 30 t y^{-1}). The difference (15-35 t y^{-1}) suggests that the

loss reductions specified by BoPRC, while significantly reducing lake loads, may not reach the target of 405 t y^{-1}.

36. Since upper bound uncertainty may be as high as 10%, the ‘most likely’ lake load may not be significantly different from the target. On the other hand, the target reductions were set based on ROTAN-2011 modelling which used OVERSEER version 5.4.2. While engineering and gorse control measures targets were not based on OVERSEER modelling, the percentage reductions achieved through these measures is lower in this ROTAN-Annual study (15%) than in the ROTAN-2011 study (25%).

37. Calibration and recovery rate are affected by groundwater travel times. ROTAN-2011 and ROTAN-Annual were both calibrated to match the mean residence times (MRTs) measured in each of the major springs and streams. However, ROTAN-2011 models a small number of large aquifers, whereas ROTAN-Annual models a large number of small aquifers. ROTAN-Annual predicts a slower recovery rate than ROTAN-2011. The rapid recovery predicted by ROTAN-2011 was unexpected and raised questions about whether large aquifers can realistically be assumed to be fully-mixed, even though their MRTs matched published values.

38. ROTAN-Annual model assumes that groundwater travel times vary linearly with distance from where drainage occurs to where groundwater re-emerges – an assumption that is untested. However, predictions were found to be insensitive to groundwater travel time and two published estimates of MRTs gave very similar steady-state lake loads.

39. ROTAN-Annual predicts that nitrogen reductions specified by BoPRC are likely to reduce lake loads to within 25% of the target within 25 years although steady-state may not be reached until after 2100.

Reports/Update

40. I am not aware of reports that criticise my evidence or supporting reports. My reports have been peer reviewed within NIWA, GNS-Science and/or BoPRC. Any issues raised were addressed prior to final publication.

41. A copy of the ROTAN-Annual report is attached to my evidence as Appendix 1.

Conclusion

42. In my opinion:

    (a) The nitrogen loss reductions specified in PC10 are likely to achieve a steady-state lake load of 420 t y^{-1} which is close to (5% higher than) the target of 405 t y^{-1} (disregarding rainfall on the lake of 30 t y^{-1}).

    (b) The 95% confidence interval of the steady-state lake load is 390-460 t y^{-1}. This means there is only a 2.5% probability it will be less than 390 t y^{-1} and a 97.5% probability it will be more than 390 t y^{-1}. Conversely there is a 97.5% probability it will be less than 460 t y^{-1} and only a 2.5% probability it will be more than 460 t y^{-1}.

    (c) Within this confidence interval, it is not possible to estimate precisely the probabilities of different steady-state lake loads.

    (d) Nevertheless, it is assumed that:

        (i) the objectives of PC10 will be met provided the steady state lake load is within 10% of the target, and

        (ii) the distributions of lake load are either normal or uniform,

    (e) Then the probability the lake load reductions will be

        (i) more than required is negligibly small

        (ii) will be less than required is 12-20%

    (f) Lake loads are likely to reduce nitrogen loads on Lake Rotorua to within 25% of the target load within circa 25 years although the full benefits will not occur before 2100.

    (g) The main reason is that aquifers have mean residence times that vary between 15.5 years (Ngongotaha) and 145 years (Waingaehe). Aquifers with short residence times are likely to approach steady state within the term of PC10 but those with long residence times will take a long time to reach steady state.

(h) The estimate of 42% for catchment-scale attenuation estimated using OVERSEER version 6 within the ROTAN-Annual model is consistent with published values, and more realistic than previous estimates made during the 2011 study which used OVERSEER version 5.

(i) Engineering and gorse control targets have not been adjusted following adoption by BoPRC of OVERSEER version 6.2.0. This may have contributed to the predicted steady-state lake load under PC10 being 420 t y^{-1} which is slightly higher than the target of 405 t y^{-1}. However, given the high uncertainty in model predictions this difference may not be statistically significant.

Appendices

Rutherford, J.C., MacCormick, A. (2016). Predicting nitrogen inputs to Lake Rotorua using ROTAN-Annual. *NIWA Consultancy Report 2016102HN*. Project BOP16201. October 2016.

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