In the matter of:	Clauses 6 and 8 of Schedule 1 – Resource Management Act 1991 – Submissions on publicly notified plan change and variation – Proposed Plan Change 1 and Variation 1 to Waikato Regional Plan – Waikato and Waipa River Catchments
And:	**Wairakei Pastoral Ltd** Submitter
And:	**Waikato Regional Council** Local Authority

Statement of evidence of Richard George Cresswell

Block 1 Hearing Topics

Dated: 15 February 2019

STATEMENT OF EVIDENCE OF RICHARD GEORGE CRESSWELL

SUMMARY AND CONCLUSIONS

Summary

1 The CSG Technical Reports referenced in the Section 32 Evaluation Report for PC1 describe a significant body of research and modelling used to define the PC1 approach. I have reviewed the reports that relate to nutrient generation and transport listed in **Appendix 2**: Healthy Rivers Plan Technical Reports, appended to my evidence.

2 There are, however, several primary assumptions and constraints within the PC1 approach to nutrient management (prescribed by these reports) that result in simplification of the nutrient management options across the region. Specifically:

2.1 First, a spatial approach was recognised as a pre-requisite for equitable assessment but was "set aside due to information gaps" identified during the CSG investigations. Spatial variability should, and can, be considered during the process of developing PC1 and be reflected in the operative document.

2.2 Second, the freshwater objectives in PC1 make the implausible assumption that farms have control to reduce all pollutants at the farm gate and do not consider up-stream inputs. Whole-of-catchment loads (as resource limits) need to be included in any assessment of down-stream nutrient load.

2.3 Third, the freshwater objectives assume common transport processes for all contaminants across all catchments, despite reports identifying distinctly different pathways and timings for each of the designated key indicators (e.g. the role of nitrate attenuation is acknowledged, but was not incorporated into options).

2.4 Fourth, key indicator levels (TN, TP, NO_3, NH_4, E. coli and Clarity) are used in PC1 as proxies for river health, with the implicit assumption that a reduction in these will improve river condition. Causal and spatial variability in relative importance to sub-catchment processes should be included in any assessment of catchment health – and reflected in the Table 3.11-1 freshwater objective attributes in PC1.

3 The approach to nutrient management proposed in PC1 employs largely deterministic, steady-state, empirical models. That is, models that rely on averaging long-term datasets and provide

outputs generated through look-up tables designed to assimilate management practices and interpolate existing data sets to provide localised results. This relies on adequate and accurate data to populate the data files and causal relationships to generate output files. Fundamentally this is only accurate within the known bounds of current data restrictions and cannot be extrapolated beyond the limitations of current datasets.

4 To overcome the limitations of a deterministic model, a process-driven modelling platform can be adopted, integrating groundwater and surface water models such that the simplifications noted above can be identified and addressed to provide a customised approach that explores the same scenarios and achieves resilient results for Table 3.11-1 and PC1.

5 An approach to resolve the limitations of the PC1 approach would be development of an integrated farm management-nutrient transport-surface water and groundwater numerical model, or decision support tool, that can be used to provide spatial and temporal predictions (i.e. that is not constrained to current or past conditions) of the potential impacts from changes in land use and farm management practices and hence will aid in supporting the general objectives of PC1.

Conclusions

6 The use of steady-state, deterministic models restricts a property or enterprise's ability to predict the impacts of future changes to farming practice or to respond to changing climatic conditions or the impacts from up-stream sources of nutrients to down-stream discharges.

7 The ability to predict future impacts of changing land use and farm practice will improve the chances of successful uptake of, and compliance with, PC1 objectives/provisions.

8 A mechanistic, stochastic and dynamic model for nutrient transport under varying land management scenarios is required that integrates property, enterprise and sub-catchment processes to provide end-of-catchment discharge loads (limits and targets) and values for the freshwater objectives which reflect the values for the river in the Vision and Strategy.

9 The Ruahuwai Decision Support Tool (RDST developed by WPL incorporates multiple sub-models to simulate biophysical processes in agricultural systems and model nutrient (and other freshwater objectives) pathways under different land uses.

10 The RDST allows targeted mitigations both spatially (by sub-catchment) and temporally (through daily assessment) to explore

and test the outcomes and objectives of PC1 in a more consistent and robust way at property, enterprise, and sub-catchment scales.

EVIDENCE

Block 1 Hearing Topics

1 My name is **Richard George Cresswell**. I have the qualifications and experience recorded in my curriculum vitae **attached** to this statement of evidence as **Appendix 1**. Key aspects of my recent expert experience relevant to these Hearings include:

1.1 Expert witness for nutrient transport across the Selwyn-Waihora district.

1.2 I was engaged by Bay of Plenty Regional Council to undertake a review and evaluation of the use of nutrient transport models for use in a catchment calculator to help inform regional decisions for water quality and explore scenario options for sustainable land use in the Bay of Plenty region.

1.3 I provided expert witness for the water quality assessment of proposed urban development in the Northern Beaches area of Sydney, Australia for a major land developer.

1.4 Expert witness on hydrogeochemistry and hydrogeology for a major coal seam gas company operating in northern New South Wales, Australia and technical review and advice for coal seam gas companies across New South Wales and Queensland.

1.5 I led the Northern Australia Sustainable Yields Project that provided the first pan-Northern Australia assessment of all water resources, including predictions of impacts under multiple climate change scenarios.

1.6 I am engaged by the New South Wales Natural Resources Commission to provide technical review and advice on Water Sharing Plans and their relevant groundwater sources.

2 I have been engaged to prepare this evidence in support of the submissions and further submissions made by Wairakei Pastoral Ltd (**WPL**) on the Proposed Waikato Regional Plan Change 1 (**PC1**) and Variation 1 to Proposed Waikato Regional Plan Change 1 – Waikato and Waipa River Catchments (**Var1**).

3 Relevant to my qualifications and experience, my evidence focuses on the use of numerical models to assess current and future potential impacts of different land uses on nutrient transport and delivery to surface and groundwater systems.

4 Specifically, this evidence focusses on the science that underpins the provisions that will be considered under Topic B3 in Block 1 of these Hearings, and includes some preliminary comments on the use of OVERSEER® alone (as opposed to the use of other decision support tools including APSIM) to calculate the Nitrogen Reference Point (**NRP**).

5 I have also provided a reviewer role for groundwater elements of the Ruahuwai Decision Support Tool (**RDST**), including assessment of the Collaborative Stakeholder Group (**CSG**) technical work undertaken for the PC1 process.

6 I will address both APSIM and OVERSEER®, and the RDST in more detail in my later evidence for Topics C1 and C8 in Blocks 2 and 3 of these Hearings.

7 My evidence has been prepared in accordance with the Code of Conduct for expert witnesses as set out in Section 7 of the Environment Court of New Zealand Practice Note 2014.

LIMITATIONS OF PC1

8 The Section 32 Evaluation Report (**Section 32 Report**) provides the background justification for actions to achieve PC1. Of relevance to this evidence, Part C introduces the Technical Information that supports PC1. This evidence provides an evaluation of this technical information as it relates to nutrient transport and the functional objectives of PC1.

9 I review what I consider to be the primary assumptions and constraints of the prescribed PC1 approach to nutrient management that result in inappropriate simplification of the nutrient management options across the region.

10 Firstly, a spatial approach was considered during the process of developing PC1 but “set aside due to information gaps”. This is largely a function of the inability of deterministic models to extrapolate beyond known data limits, either temporally or spatially.

11 The use of spatially-explicit models such as the RDST can, however, bridge this information gap and provide spatial prioritisation that can alleviate this constraint.

12 In the Section 32 Report discussion on scenario modelling, the Waikato-Waipa catchments were split into 74 sub-catchments and at this scale reduction of discharges of nutrients, pathogens and sediments was required universally and barely managed to constrain key indicators to acceptable levels. At this scale, the RDST constitutes 10 of the sub-catchments in PC1. The WPL experts (including myself) can demonstrate that the spatial

variability seen by more fine grained modelling in the RDST sub-catchments across the model domain provides the scale required to identify critical source areas.

13 Secondly, the freshwater objectives in PC1 make the implicit assumption that properties and enterprises have the ability to control or reduce all pollutants at the farm gate.

14 This does not account for upstream inputs, or background inputs to the system. Thus, Upper Waikato background levels (in the absence of any land use change) of nitrogen (**N**) and phosphorus (**P**) already account for 40% and 55%, respectively, of the in-stream N and P (e.g. Vant, 2014). This is acknowledged in the Section 32 Report (p 65), but this contribution is effectively ignored in the analysis and determination of limits to streams.

15 Therefore, there needs to be explicit accounting for non-farm inputs and in-stream processes (e.g. in-stream attenuation, Alexander, et al., 2002) in the modelling processes and the setting of freshwater objectives in Table 3.11-1.

16 PC1 recognises that modelling and monitoring of P, E coli and erosion (sediment) are complex, difficult and poorly constrained (especially at the farm management unit (**FMU**) scale), so the focus is on modelling N, which can be better constrained and the modelling results better appreciated, with other indicators requiring greater use of expert opinion, with due recognition of the background inputs in the modelling process, even if these inputs are not included in policy.

17 Thirdly, the PC1 freshwater objectives assume common transport processes for all pollutants across all sub-catchments (e.g. the role of attenuation is acknowledged but is not incorporated into options).

18 This assumption ignores two critical aspects of nutrient transport processes, namely:

i. Attenuation rates, transport processes and lags are linked, but not dependent. For example, attenuation rates for nitrate denitrification are more dependent on how much (or how little) oxygen is present in the waters (the redox state), than travel times (though longer travel times increase the likelihood that reducing conditions will occur), which are dependent on physical hydraulic properties and water-rock interactions, whilst lags are dependent on the impedance of the system. Only in a system that is physically homogeneous, with equal rates of water transport in all directions and at all locations (i.e. isotropic) are they causally inter-related. In natural environments, uniform causal links are fortuitous and coincidental.

ii. The transport processes for N and P are partly similar and partly different. Thus, both may be transported in solution in surface and groundwaters, though P is also preferentially transported attached to fine-grained particles suspended in overland flows.

19 Spatial variations in attenuation across different catchments and between different indicators need to be considered in any modelling and policy decisions to account for variability in soil types, groundwater flow, structural breaks, seasonal and inter-annual variability and topography, amongst other bio-physical considerations (Clague, et al., 2019).

20 There has been concern raised over future spikes in nutrients reaching waterways (the “Load to come”) (e.g. Morgenstern, et al., 2015). My opinion is that this concern is overstated.

21 Indeed, the same data was re-analyzed more recently (Stewart, et al., 2016) with the conclusion that the mean residence time (**MRT**) for groundwaters may actually be much greater than modelled due to mixing of multiple sources of water from different depths in an aquifer.

22 I have analysed the age data for Upper Waikato groundwater and note that a distinction in MRT is observed between shallow and deep groundwaters, giving support for the view that shallow flow paths dominate the water sampled at the stream baseflow sites.

23 Further, analysis of isotopic data suggest that MRT calculated by Wilson and Shokri (2015) overestimated the time taken for young groundwaters to reach waterways, whilst underestimating the time taken for older groundwaters.

24 This analysis suggests that nitrogen transport to the surface waters occurs primarily via shallow, relatively fast groundwaters. Therefore, any nitrate pulse associated with previous landuse changes over the past 40 years is likely to have already moved through the system.

25 Deeper waters take longer paths over longer periods of time which may favour greater attenuation of nitrate prior to discharge downstream towards the Lower Waikato reaches.

26 This matter is further explored in the evidence of Mr Williamson.

27 If excess levels of nutrients are found to reside in (or leach from) soils along flowpaths to waterways, these need to be placed in the

context of the ability of the flowpath to attenuate that spike rather than the mere presence or otherwise of that spike.

28 By undertaking sub-catchment modelling based on sound bio-physical processes tailored to individual indicators and calibrated and validated against observed data, high confidence will be achieved in predictive capabilities of models and the capability to model different mitigation scenarios in a spatial and temporal sense.

29 Lastly, key attribute levels (i.e. total nitrogen (**TN**), total phosphorus (**TP**), nitrate (**NO_3**), ammonium (**NH_4**), E. coli, clarity) are used in PC1 as FWO for river health, with the implicit assumption that a reduction in these will improve river condition.

30 It is recognised that, in a general sense, reduction in overland erosion and gully erosion will reduce TP, total suspended solids (**TSS**) and visibility (clarity), while restriction of stock from waterways will improve river health in all indicators.

31 Resource managers and regulators must also consider the actual causal relationships between the freshwater objectives as well as the spatial distribution, between responses of different indicators, and any limitations on generalities in treatment or mitigation scenarios.

32 Ultimately, prediction of future impacts requires quantitative consideration of direct and indirect causes of contaminant inputs and the processes for each to accumulate in the environment and in-stream. Hence, impacts can only be treated with a common practice if a causal relationship is confirmed (e.g. we can appreciate that use of fertiliser increases both TN and TP).

33 Modelling specific farming practices must therefore be accommodated within a broader, sub-catchment-scale appreciation and incorporation of bio-physical processes that treat pollutants separately and independently, recognising any defined dependency links.

34 To achieve this, monitoring results are key to defining mitigation actions and constraining models, whilst in-stream levels will provide ultimate calibration for all models and validation of on-ground actions.

AN ALTERNATIVE METHODOLOGY FOR NUTRIENT TRANSPORT

35 By adopting a process-driven modelling platform, integrated with groundwater and surface water models, the simplifications outlined above can be identified and addressed to provide a customised

approach that achieves the same environmental outcomes as the PC1 approach.

36 My evidence briefly describes a methodology, that addresses the primary limitations and constraints in nutrient generation and modelling outlined above, using the APSIM modelling framework to complement the use of OVERSEER® as a N reference determinant and uses results and implications for the 10 sub-catchments in the RDST area as examples.

37 APSIM (Holzworth, et al., 2014) provides a tool to generate spatially and temporally explicit NRP and provides a tool for evaluation of farm management practices that can predict the consequences of mitigation strategies on N leaching, implicitly including multiple pathways and dependencies within farming systems.

38 APSIM simulates biophysical processes in agricultural systems at a daily time-step and models N pathways under different land uses. APSIM generates N leaching values that can be integrated across sub-catchments, providing sub-catchment-scale outputs from farm and enterprise-scale modelling that can be input to the RDST.

39 Results from APSIM can be directly compared to those from OVERSEER®, with the advantage of providing a timeseries for incorporation into a predictive, catchment model to guide mitigation responses to target exceedances.

40 WPL has developed a catchment model (the RDST) that integrates property, enterprise and sub-catchment processes to provide end-of-catchment discharge loads (limits and targets) and the setting of freshwater objectives as outlined in Table 3.11-1.

41 As noted, I will address APSIM and the RDST in more detail in my later evidence for Topics C1 in Block 2.

CONCLUSIONS

42 A process-based, dynamic farm systems' model should be employed to support land management decisions. This model should have enough temporal and spatial resolution to target critical properties and enterprises and provide predictive capability to evaluate mitigation and climate scenarios.

43 Nitrate leaching rates need to be generated as daily time series for individual land uses to generate inputs to surface and groundwater models that combine to provide a catchment approach to nitrate transport that can be calibrated against observed nitrate levels at

stream gauges. This should also calibrate against the steady-state, deterministic model in a general sense.

44 The ability to predict future impacts of changing land use and farm practice will improve the chances of successful uptake and compliance with PC1 objectives/provisions. Thus, a mechanistic, stochastic and dynamic model for nutrient transport under varying land management scenarios is required that integrates property, enterprise and sub-catchment processes to provide end-of-catchment discharge loads (limits and targets) and the setting of freshwater objectives in Table 3.11-1.

45 As a complement to the steady-state, empirical, deterministic OVERSEER® model, ASPIM is a process-driven model that provides improved temporal resolution and spatial integration relevant to PC1 and a tool that can be used to predict future impacts to nutrient transport under changed farming management. That is, APSIM provides a mechanistic, stochastic and dynamic model for nutrient transport under varying land management scenarios.

46 APSIM can be used as a pre-experimental tool to explore the potential response from different conditions imposed on a farm and hence constrain experimental parameters and allow the exploration of varying management strategies, such as fertiliser application rates, stocking rates and seasonal changes and hence can be applied to development of effective mitigation and management strategies.

47 The RDST developed by WPL incorporates APSIM to simulate biophysical processes in agricultural systems and model N pathways under different land uses. This generates N leaching values that can be integrated across sub-catchments, using site-specific daily inputs, providing integrated, catchment-scale outputs from property and enterprise-scale modelling that can be input to the RDST at a daily time-step.

48 The RDST allows targeted mitigations both spatially (by sub-catchment) and temporally (through daily assessment) to achieve the outcomes and objectives of PC1 in a more consistent and sophisticated way at property, enterprise, and sub-catchment scales.

Dr Richard Cresswell
Principal Hydrogeologist and Water Discipline Lead
15 February 2019

REFERENCES

Alexander, RB, Elliot, AH, Shankar, Ude and McBride, GB, 2002. Estimating the sources and transport of nutrients in the Waikato River Basin, New Zealand. Water Resources Research **38**(12) 1286-1299

Clague, JC, Stenger, R and Morgenstern, U, 2019. The influence of unsaturated zone drainage status on denitrification and redox succession in shallow groundwater. Sci. Total Env., 660, 1232-1244

Holzworth, DP, Huth, NI, deVoil, PG, Zurcher, EJ, Herrmann, NI, McLean, G, Chenu, K, et al., 2014. "APSIM - Evolution towards a New Generation of Agricultural Systems Simulation." Environmental Modelling & Software **62**: 327–50.

Morgenstern, U, Daughney, CJ, Leonard, G, Gordon, D, Donath, FM and Reeves, R, 2015. Using groundwater age and hydrochemistry to understand sources ad dynamics of nutrient contamination through the catchment into Lake Rotorua, New Zealand. Hydrol. Earth Syst. Sci., **19**, 803-822.

PCE, 2018. *Overseer and regulatory oversight: Models, uncertainty and cleaning up our waterways*. Parliamentary Commissioner for the Environment. Wellington. ISBN: 978-0-947517-12-0

Stewart, MK, Morgenstern, U, Gusyev, MA and Maloszewski, P, 2016. Aggregation effects on tritium-based mean transit times and young water fractions in spatially heterogeneous catchments and groundwater systems, and implications for past and future applications of tritium. Hydrology and Earth System Sciences, Discuss., doi: 10.5194

Vant, 2014. Sources of nitrogen and phosphorus in the Waikato and Waipa Rivers, 2003-2012. *Waikato Regional Council Technical Report* **2014/56** *Document#* ***3210294***

APPENDIX 1: RICHARD CRESSWELL CURRICULUM VITAE

Dr Richard Cresswell

Principal Hydrogeologist

Responsibilities
Principal Hydrogeologist; Water Discipline Lead
Justice of the Peace (Queensland)
Fellow of the Peter Cullen Trust

Qualifications
1993: PhD (Geology), University of Toronto
1987: MSc (Geology), University of Toronto
1984: BSc (Hons. Geology), University of Sheffield

Current Affiliations
American Geophysical Union
Australian Institute of Mining and Metallurgy
Australian Water Association
Geochemical Society
International Association of Hydrogeologists

Fields of Special Competence
Richard has over 30 years of research experience in geochemistry, particularly the use of radioisotopes, including applications in archaeology, meteoritics, geomorphology, biomedicine and, for the last 15 years, in hydrogeology and hydrogeochemistry. He has authored over 40 scientific journal articles and numerous reports and book chapters. His fields of special competence include:

- Water resource management (availability, yield, reliability and management)
- Groundwater – surface water interactions
- Novel (geochemical, isotopic and geophysical) techniques in water resource assessment
- Groundwater Impact Assessments for the resources, energy and infrastructure industries
- Groundwater-dependent ecosystems
- Expert Advice to the Coal Seam Gas industry and regulators
- Technical report writing

Selection of Experience

***Eco Logical Australia** (a Tetra Tech Company)*
2015 - current
Principal Hydrogeologist : Water Discipline Lead
Significant projects include:

- Technical Lead: Farm and Catchment Nutrient Modelling for New Zealand Dairy Deelopment (Funding: Wairakei Pastoral Ltd (NZ); $400k+)(2015-)
- Technical Direction: Design and Construction of Deep Water Monitoring Bores, Hunter Coalfields (Funding: NSW Department of Industry; $160k+)(2018-)
- Independent review and advice: NSW Water Sharing Plans: GAB Water Sources; Coffs Harbour Unregulated and Alluvial Water Sources; Central Coast Unregulated Water Sources (Funding: Natural Resources Commission; $30k+)(2018-)
- Technical Lead: Water and geochemistry advice for the Narrabri Gas Project (Funding: Santos Energy NSW; $300k+)(2015-)
- Project Technical Lead: Groundwater-dependent ecosystem (GDE) Monitoring and Management Plans (Funding: Santos Energy NSW, Shenhua Watermark Coal)(2015-)
- Independent Groundwater Audit & Review: various coal and CSG operations across the Sydney, Gunnedah and Surat Basin Coalfields (Funding: Rio Tinto Coal Australia, Glencore Coal, Whitehaven Coal, Origin Energy, Santos GLNG)(2015-)
- Project Director and Technical Lead: Water quality & trigger assessments (Funding: Mount Isa Mines; $200k)(2016-2017)

- Project Director and Technical Lead: Carrapateena Mine Development Water Studies (Funding: OZ Minerals P/L; >$500k)(2015-)
- Project Director and Technical Lead: Peak Gold Mine Development Water Studies (Funding: NewGold P/L; $200k)(2015-)
- Water lead: Due diligence investigations for major NT infrastructure proposal (Funding: *confidential*)

Jacobs Engineering
2013 - 2015
Principal Hydrogeologist; Practice Leader: CSG related Groundwater *(since 2012)*
Significant projects included:

- Member: Federal Minister's Expert Panel for Major Coal Seam Gas Projects (Funding: SEWPAC)(2011-2015)
- Groundwater geochemist: GEMCO – Angurugu River manganese runoff study (Funding: GEMCO; $50k)
- Technical Lead: EPBC Act Springs Conceptualisation Geochemistry Assessment (Funding: Queensland Office of Groundwater Impact Assessment (OGIA); $200k)(2014-2015)
- Technical Lead: Tiedman Field Trials: Soil Survey and Assessment of Produced Water Irrigation Trials (Funding: AGL; $200k)(2014-2015)
- Technical Lead: Hydrogeochemistry of PEL238 (Funding: Santos Energy NSW; $300k)(2013-2014)
- Project Leader: Groundwater Impact Assessment for Mount Owen Continued Operations (Funding: Glencore; $300k)(2013-2014)
- Geochemistry Lead: Quantifying water and nitrate transport across the Selwyn-Waihora Floodplain, New Zealand ((Funding: Central Plains Water; $150k)(2014)

Sinclair Knight Merz (SKM merged with Jacobs in December 2013)
2011 - 2013
Senior Hydrogeologist; Practice Leader: CSG related Groundwater *(since 2012)*
Significant projects included:

- Technical Project Lead: NSW Coastal GDE and Groundwater Quality Project (Funding: NSW Office of Water, Office of Environment and Heritage and National Water Commission)(2011-2012)
- Member: Federal Minister's Expert Panel for Major Coal Seam Gas Projects (Funding: SEWPAC)(2011-2015)
- Practice Leader and Geochemical Modeller: Deep brine injection trials (Funding: Santos GLNG; $75k)(2013-2014)
- Hydrogeology Lead: Tender Design for a major metropolitan tunnel project (Funding: Transurban; $120k)(2013)
- Project Leader: Impacts of Coal Seam Gas on Aquifers in NSW (Funding: NSW Office of Water; $30k)(2012)
- Discipline lead: Woolgoolga to Ballina Pacific Highway Upgrade - Groundwater Working Paper (Funding: RMS; $80k)(2011-2012)
- Project Manager: Bowdens Silver Mine Groundwater Impact Assessment (Funding: Kingsgate P/L; $700k)(2011-2014)
- Project Leader: Xstrata Coal NSW, Groundwater impact assessment for Liddell Coal Operations (Funding: Xstrata Coal NSW; $700k)(2011-2013)
- Project Leader: Wilpinjong Coal Mine Rapid Groundwater Assessment (Funding: Peabody Energy Australia; $105k) (2011-2012)
- Team Leader: Great Artesian Basin Water Resource Assessment – Hydrodynamics Team (Funding: CSIRO; $300k) (2011-2012)
- Expert Panel for Major Coal Seam Gas Projects (Funding: DSEWPaC)(2011-2014)

CSIRO Land and Water
2007 - 2011
Principal Research Scientist; Stream Leader: Water for a Healthy Country Research Flagship

- Member: Federal Minister's Expert Panel for Major Coal Seam Gas Projects (Funding: SEWPAC)(2011-2015)
- Project Leader: Great Artesian Basin Water Resource Assessment (Funding: DEWHA/National Water Commission; $5M) (2010-11)
- Pure Recycled Water for the Lockyer Valley, South-east Queensland (Funding: SEQ Urban Water Security Research Alliance; $2M) (2008-10)

- Stream Leader: Water in Northern Australia. Responsible for project delivery for 9 research projects across northern Australia (11 full-time equivalents; >$3M) (2007-11)
- Project Leader: Northern Australia Sustainable Yields (Funding: National Water Commission; $6M) (2008-09)
- Project Scientist, Murray-Darling Basin Sustainable Yields (Funding: National Water Commission; $7M)(2007-08)
- Stream Leader: Groundwater Characteristics and Management (2008-10). Responsible for project delivery across 22 projects (20 full time equivalents; >$8M)

CSIRO Land and Water
2004 - 2007
Senior Research Scientist

- Project Leader, Salinity Dynamics, Co-operative Research Centre for Landscapes, Environments and Mineral Exploration Program 4 (Funding: CRC LEME).
- Project Leader, Angas-Bremer Prescribed Wells Area – Integrated System Model Project (Funding: DAFF Community Stream Sampling and Salinity Mapping in the Murray-Darling Basin Project).
- Project Leader, Pioneer Valley – Seawater Intrusion Assessment (Funding: Queensland Department of Natural Resources and Water).

Integrated Water Sciences, Bureau of Rural Sciences, Department of Agriculture Fisheries and Forestry
2002 - 2004
Senior Scientist; Project Leader; Program Manager

- South Australia Salinity Mapping and Management Support Project (SASMMSP): Commonwealth Sub-projects Manager (Funding: National Action Plan for Salinity and Water Quality- NAPSWQ).
- Landscape evolution and regolith materials of the Angas-Bremer Plains, South Australia (Funding: National Action Plan for Salinity and Water Quality- NAPSWQ).
- Relationship between regolith landforms, landscape processes, groundwater quality and dryland salinity – Jamestown, South Australia (Funding: National Action Plan for Salinity and Water Quality – NAPSWQ).
- Targeting salinity at the farm scale: empowering landholders through practical interpretation of airborne geophysics (Funding: Grains R & D Corp.)
- Climatic influence on the expression of dryland salinity (Funding: BRS, Grains R & D Corp.)
- Groundwater evolution in the Bland catchment of NSW (Funding: ARC, through SPIRT Grant to University of Melbourne).
- Origins and evolution of salt in the regolith (Funding: various though BRS).

Bureau of Rural Sciences, Agriculture Fisheries and Forestry Australia
2000 - 2002
Research Scientist; Project Leader

- South Australia Salinity Mapping and Management Support Program, Commonwealth sub-Project Manager (Funding: NAPSWQ)
- Watertable change in the cropping area of the South West slopes, NSW (Funding: Grains R & D Corp.)
- Catchment Characteristics Case Study: Kyeamba Creek, NSW (Funding: Murray-Darling Basin Authority)
- Deputy Program Leader, Program 3, Co-operative Research Centre for Landscapes, Environments and Mineral Exploration (Funding: BRS).

Department of Nuclear Physics, Australian National University
1995 - 2000
Research Fellow (Funding: Quaternary Research Centre, Australian National University) Applications of cosmogenic radionuclides in hydrogeology, landform processes and archaeology

1993 - 1995
Postdoctoral Fellow (Supervisor: Dr. L.K. Fifield, Australian National University) Accelerator mass spectrometry sample preparation, analysis, interpretation and research

IsoTrace Laboratory, University of Torronto

1991 - 1993

Sample preparator – processing of CO_2 gas samples for ^{14}C analysis by accelerator mass spectrometry

1987 - 1993

Research Assistant (to Dr. R.P Beukens) Radiocarbon analyst's assistant

Department of Geology, University of Torronto

1984 – 1993

Research Assistant (to Professor J.C. Rucklidge) Research on accelerator mass spectrometry

1984 - 1990

Teaching Assistant

Courses: Mineralogy (2nd and 3rd years); Crystallography (2nd and 3rd years); Optics (2nd year); Phase Diagrams (2nd year); Igneous petrology (2nd year); Planetary geology (1st year); Introductory geology (1st year); Field camps (1st and 3rd years).

Awards and Scholarships

2010	CSIRO Division of Sustainable Ecosystems Award for Excellence (Northern Australia Land and Water Taskforce Science Report - co-lead author)
2009	CSIRO Division of Land and Water Cash Reward: Northern Australia Sustainable Yields Project Leader
2008	CSIRO Chairman's Medal: Murray-Darling Basin Sustainable Yields Project Team
2008	CSIRO Division of Land and Water Valued Contribution Award: Murray Darling Basin Sustainable Yields Project
2004	Best Presentation Award: ASEG Salinity Symposium, Sydney, Aug. 2004
2001	Executive Director's Award, Bureau of Rural Sciences
2001	Alison Furbank Award for Scientific Communication, Bureau of Rural Sciences
2001	Australia Day Award, Agriculture, Fisheries & Forestry - Australia
1990-1991	H.V. Ellesworth Graduate Fellowship in Mineralogy
1987-1991	University of Toronto Open Doctoral Fellowships (4 consecutive awards)
1987-1988	H.V. Ellesworth Graduate Fellowship in Mineralogy
1987-1990	University of Toronto International Student Differential Fee Waiver Scholarships (3 consecutive awards)
1985-1987	University of Toronto Open Master's Fellowships (2 consecutive awards)

Theses

PhD: ^{14}C Terrestrial Ages and Weathering Activities of Meteorites using CO and CO_2 Fractions from Step-wise Temperature Extractions

Synopsis: radiocarbon determinations of different carbon species from meteorites and their usage as age discriminants, cosmic-ray flux indicators and meteorite histories, with particular references to the meteorites of Antarctica.

MSc: Radio-carbon Dating of Iron Using Accelerator Mass Spectrometry

Synopsis: extraction, purification and measurement of radiocarbon in small (gram-size) iron artefacts, to obtain dates of manufacture and an insight into the material's metallurgical history.

BSc: The Geology of the Wrekin

Synopsis: 1:10,000 scale mapping of the 25 km^2 region centred on a Precambrian inlier of volcanoes surrounded by early Paleaozoic transgressional sediments; overlain by Quaternary peri-glacial deposits.

Peer-reviewed Scientific Papers, Books and Chapters

Greene, R., Timms, W., Rengasamy, P., Arshad, M. and Cresswell, R. (2016)
Soil and aquifer salinization: Toward an integrated approach for salinity management of groundwater. Chapter 15 *in* Jakeman, A., Barreteau, O., Hunt, R., Rinaudo, J.-D. and Ross, A. (Eds.) Integrated Groundwater Management. Springer, x + 953pp. ISBN: 978-3-319-23575-2

Herron, A., Cresswell, R., Barnett, B., Puech, V. and Cetin, L. (2015)
Integrated surface – ground water interaction approaches that can account for water quantity and quality transport.
36th Hydrology and Water Resources Symposium. Engineers Australia, Hobart 2015

Cetin, L.T, Conland, N., Jordan, P.W., Cresswell, R., Herron, A. and Sands, M. (2014)
An Integrated Catchment Modelling Approach for Exploring Water Allocation and Nutrient Limit Setting Policies.
American Society of Agricultural and Biological Engineers. 21st Century Watershed Technology Conference and Workshop. Hamilton, New Zealand.

Van Opstal, J.D., Huibers, F.P. and Cresswell, R.G. (2012)
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APPENDIX 2: HEALTHY RIVERS PLAN TECHNICAL REPORTS

1 Several reports were commissioned by the Technical Leaders Group (**TLG**) for the Healthy Rivers Project (**HRWO**) and referenced in the Section 32 Evaluation Report. These reports aimed to enhance the understanding of the linkages between land use practices and observed responses and included several with direct relevance to nutrient generation and transport. These are listed in **Table 1**.

Table 1 Summary of relevant PC1 reports concerning nutrient generation and transport.

No.	Report Tile	Author(s)	Date	Organisation
1.2	Groundwater resource characterisation in the Waikato River catchment for Healthy Rivers Project	White, P., Tschritterm C., Rawlinson, C., Moreau, M., Dewes, K. and Edbrooke, S.	2015	Geological & Nuclear Sciences
1.3	Estimation of lag time of water and nitrate flow through the Vadose Zone: Waikato and Waipa River Catchments.	Wilson, S. and Shokri, A.	2015	Lincoln Agritech
1.4	Review of historical land use and nitrogen leaching: Waikato and Waipa River catchments	Hudson, N., Elliott, S., Robinson, B. and Wadhwa, S.	2015	Waikato Regional Council
1.5a	Short term field investigations of groundwater resources in Waipa River Catchment – January to April 2015	Rawlinson, Z., Riedi, M.A., Schaller, K., Bekele, M.	2016	Geological & Nuclear Sciences
1.5b	Groundwater field investigations over the 2014-15 summer in support of the Healthy Rivers Project.	Hadfield, J.	2015	Waikato Regional Council
1.6	Prediction of Subsurface Redox Status for Waikato Healthy Rivers – Plan for Change: Waiora He Rautaki Whakapaipai Project	Close, M.	2015	Institute of Environmental Science and Research, Ltd (ESR)

No.	Report Tile	Author(s)	Date	Organisation
1.7	Summary of ground water information for consideration by the Collaborative Stakeholder Group	Petch, T.	2015	Technical Leaders Group for the Healthy Rivers Wai Ora Project

2 I have reviewed the documents shown in **Table 1**, with a specific focus on assessing these reports' contributions to understanding nutrient generation and transport processes and linkages to nutrient considerations in the Section 32 Report. My condensed review findings for each report are discussed in the following sections.

Report 1.2. Groundwater Resource Characterisation in the Waikato River Catchment for Healthy Rivers Project (White, *et. el.*, 2015).

3 Critical to nutrient processes, Appendix 1 describes the general groundwater conditions with relation to nitrate levels for all sub-catchments of the Upper Waikato. Whilst not temporally constrained, it is likely that this information can be useful in populating steady-state nutrient transport models such as CLUES.

4 The Section 32 Report uses this information as support for increasing N levels at surface water sites due to on-going groundwater discharge via baseflow.

5 The generalised data requires scrutiny to assess efficacy for the summaries provided. A general lack of data is highlighted in the discussion, forestalling realistic incorporation into nutrient models.

Report 1.3. Estimation of lag time of water and nitrate flow through the Vadose Zone: Waikato and Waipa River Catchments (Wilson and Shokri, 2015).

6 The deeper groundwaters in the Upper Waikato (compared to shallow groundwaters in the Lower Waikato) result in relatively long modelled lag times (>40 years) for nutrients to travel from the surface to groundwaters.

7 N is treated as conservative (i.e. assuming that it does not attenuate), however, tritium dating suggests transport times 10-100 times faster than the modelled times implying considerable uncertainty in the modelling results.

8 I have analysed forty-three (43) tritium analyses (17 groundwaters and 26 surface waters) collected over the period 2004-2015 and

used isotopic modelling to determine MRT and uncertainty for waters feeding these sites. In general, I find:

8.1 The surface water sites record short (less than 40 years) MRT, which are similar to estimated MRT for the shallow groundwaters.

8.2 Deep groundwaters exhibit variable calculated MRT but include very old water that do not appear to contribute to surface water discharges.

8.3 Estimated flow paths for the shallow groundwater feedng the surface water sites range from one to six kilometres.

8.4 Deeper groundwaters exhibit longer MRT, with potential flow paths greater than 10 km.

9 My analysis suggests that nitrogen transport to the surface waters occurs primarily via shallow, relatively fast-moving groundwaters. Therefore, any nitrate introduced to the system associated with land use change over that time is likely to have already moved through the system.

10 Deeper groundwaters take longer paths over longer periods of time, which will favour greater attenuation of nitrate prior to discharge downstream and beyond the limits of the RDST.

11 Spatial variability is highlighted, but not explored and the role of attenuation requires further investigation.

12 This report is addressed in more depth in the evidence of Mr Williamson.

Report 1.4. Review of historical land use and nitrogen leaching: Waikato and Waipa River catchments (Hudson *et. al.*, 2015)

13 Spatial variability in nitrogen loss is described across the 74 sub-catchments (including the 21 of the Upper Waikato) and illustrates that land use change mitigation must be targeted and is not necessary in some sub-catchments.

14 Temporal trends are available for some sub-catchments that could be used for calibration of dynamic models. Temporal changes in land use are also described. Dairy and sheep and beef are identified as the primary land uses responsible for excess N leaching. Some important land uses were not considered (e.g. dairy support) or not fully included (e.g. irrigated crops).

15 Attenuation of nitrate was not considered, however, and only results from OVERSEER® were included. An increase in N loss was therefore observed in all Upper Waikato sub-catchments.

16 The Section 32 Report acknowledged the limitations of the OVERSEER® modelling identified in this report, including that, "a nitrogen-related farm practice using one version of the model cannot be compared with a later version of the model." (p. 150), but still defaults to it as the primary model for nutrient transport at the farm/property scale. Expert opinion was used to compare estimates of N leaching and significant discrepancy was found with the OVERSEER® results.

17 The limitations of OVERSEER® are highlighted in the Parliamentary Commissioner for the Environment's recent review of "*Overseer and regulatory oversight: Models, uncertainty and cleaning up our waterways*" (PCE, 2018, p. 47).

18 I will address the limitations of OVERSEER® in more detail in my later evidence for Topics C1 and C8 in Blocks 2 and 3 of these Hearings.

Report 1.5a. Short term field investigations of groundwater resources in Waipa River Catchment – January to April 2015 (Rawlinson, *et. al.*, 2015) and
Report 1.5b. Groundwater field investigations over the 2014-15 summer in support of the Healthy Rivers Project (Hadfield, 2015).

19 Data presented in these reports indicated:

19.1 Highly variable nitrate levels were observed across a small dataset of bores.

19.2 Strong seasonality could be seen in groundwater and surface water, including in tritium data.

19.3 Shallow wells have young waters (<70 years) suggesting little, or no, old water in these wells. This implies fast flow dominates transport of nutrients.

20 Most bores exhibited at least some level of low redox conditions, hence indicating a high propensity for denitrification.

21 The limited dataset does not consider geothermal inputs, with only summer sampling undertaken.

22 The age dating incorrectly assumes differences in ages would reflect differences in response to land use, with an indication of depth to age relationships for individual catchments and for specific

rock types, though it is not possible to assign actual cause and effect relationships.

23 Data in this report is used in the Section 32 Report to support the potential lag effect and future pulse of nutrients to waterways. Further seasonal information should be gathered if this is to be supported.

24 The data suggests the P pulse is seen earlier and separately to the N pulse: i.e. different processes influence different nutrients.

Report 1.6. Prediction of Subsurface Redox Status for Waikato Healthy Rivers – Plan for Change: Waiora He Rautaki Whakapaipai Project (Close, M., 2015).

25 This report noted that most shallow aquifers exhibited reducing conditions, thereby promoting shallow denitrification. The choice of "shallow" (and "medium" and "deep"), however, was somewhat subjective and groundwater flow and discharge processes were assumed to be simple.

26 The spatial distribution of redox conditions is useful for incorporation into groundwater models that incorporate the facility to attenuate nutrient signals (e.g. MODFLOW/MT3D/MODPATH). The generated denitrification rates support the use of attenuation across the Upper Waikato sub-catchments.

27 The relative proportions of reducing to oxidising conditions were used to estimate catchment attenuation rates. These can be compared to modelled rates. The discriminant analysis used to generate the relative redox condition, however, utilises many parameters that are not directly related to groundwater (e.g. geological factors) and this reduces the confidence in the methodology.

28 The Section 32 Report defers the use of this information to a future phase of planning (beyond 2026) as it could not be included in the current modelling framework.

29 I note that the discriminatory analysis used to assign redox status was largely poorly constrained by actual field data and causal relationships are not apparent. A finer scale of modelling is required to facilitate the level of sub-catchment variability.

Report 1.7. Summary of ground water information for consideration by the Collaborative Stakeholder Group (Petch, T., 2015).

30 This report summarises the six groundwater reports discussed above. It is important for the Commissioners to note that wording relating to groundwater in the Section 32 Report appears to have been copied directly from Petch (2015).

31 Petch (2015) explains in the introduction of his report that "All this work was targeted to provide a general understanding of regional ground water resources and particularly ground water age and nitrogen attenuation processes in the sub-catchments."

32 The report highlights the highly variable and sparse observation data that supports the use of distributed modelling supported by targeted field studies and local field calibration. Significant extrapolation is required using geology as a linking factor.

33 For the Upper Waikato, high nitrate levels are observed, but also the high potential for denitrification (attenuation), especially in comparison to the Mid and Lower Waikato. Other redox indicators are considered to support modelling of denitrification. The high concentrations of nitrate observed in groundwater of the Upper Waikato are associated with land use change, though no consideration is given for natural sources or point sources across the sub-catchments.

34 Groundwater geochemistry suggests no discernible trends over the past 40 years, despite land use changes, though the report asks whether the pulse is perhaps yet to come (the "lag" effect), or has it been attenuated? The report incorrectly states that model predictions compare to tritium dating results, which they do not.

35 The modelling relies on an early version of OVERSEER® for comparison to land use production. The current version would produce higher concentrations of nitrate suggesting the attenuation suggested in the report is conservative (i.e. under-estimates the actual amount).

36 My concern with a conclusion that the N pulse may still be travelling through the system is that, from the provided age information, there should be locations where we should have already seen the pulse. This is not evident. There should be evidence of the pulse in parameters other than nitrogen, however, that should be looked for. But that was not done in this report.