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 JONATHAN WILLIAMSON

Block 1 Hearing Topics

Dated: 15 February 2019

WILLIAMSON WATER & LAND ADVISORY
Unit 5A, 11F Factory Road
Waimauku, Auckland
Phone: 021 65 4422
Email: jon.williamson@wwa.kiwi
Web. www.wwa.kiwi

WILLIAMSON
WATER & LAND ADVISORY
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SUMMARY AND CONCLUSIONS

Nitrogen Load To Come

1 My evidence demonstrates that a fundamental premise of the provisions in PC1, specifically the concept of groundwater N "load to come", is conceptually flawed - because it is inconsistent with scientific principles of redox chemistry, and lacks scientific observation data and robust modelling support.

2 In summary, as the residence time of groundwater (age) increases, its chemical composition progressively changes, with oxygen depletion through redox reactions occurring. Redox reactions follow an ecological succession with nitrate reduction (typically, resulting in environmentally benign dinitrogen gas) being the most energetically favoured in the succession following removal of dissolved oxygen in groundwater (**Figure 1**).

3 The steady increase in nutrients over recent decades measured within surface waters in some areas where changes to higher intensity land use have occurred is a result of surface water runoff and the discharge of young groundwater. There is no evidence of old groundwater discharges having high nitrate loads, and the explanation that the effects of past land use changes have not yet materialised in the receiving environment (due to groundwater lag) is unlikely to arise (in terms of probability) from a catchment management perspective and is not supported by fundamental principles of groundwater science (as discussed above).

4 Nitrate is readily removed under reducing conditions (typical of old groundwater), therefore the focus of PC1 for achieving its objectives and outcomes with respect to improving water quality in the region should be on young groundwater typically directly connected to surface waters and surface runoff events (quick flow events). Both flow processes have limited opportunity for constituent removal or restoration without management interventions or mitigations.

5 In my opinion, the potential nitrate "load to come" concept due to the decadal or longer lag effect is unlikely in a New Zealand context where our catchments are small (on an international scale) and regularly dissected by dendritic drainages. This is because, in the case of:

5.1 ***Long groundwater flow paths*** *(decades or longer)* - nitrate will be attenuated through denitrification;[1] and

5.2 ***Short groundwater flow paths*** - the nitrate load is oxic and stable and will be discharged relatively quickly and therefore any increases in concentration will be observed in the surface water flow record within months to years of the land use change (not multi-decades or longer).

6 My alternative conceptual model developed from the information above, which is supported in overseas experience (Seitzinger *et. al.*, 2006; Blicher-Mathiesen *et. al.*, 2014) and emerging NZ new data (Stenger *et. al.*, 2014) is presented in **Figure 6.**

7 PC1 adopts a blanketed policy approach with regard to managing water quality effects across the landscape. PC1 as notified currently ignores the dynamic nature of the

[1] This is demonstrated in the Upper Waikato, where nitrate-nitrogen concentrations in groundwater are not increasing over time as stated in White *et. al.* (2015) (Table 4.2).

landscape's assimilative capacity (**Figure 7**) i.e. the discharge footprints of land parcels vary not only on the basis of land use but also across differing sub-catchment physical characteristics, including the sub-surface. Spatial variability across sub-catchments is therefore a matter that should be considered when deciding resource consent applications.

8 Consequently, in my opinion, PC1 will not have the desired effect with respect to nitrate water quality improvements without amendment to change the focus from managing the "load to come" to managing constituent load attached to quicker flow processes such as surface runoff and source areas of young groundwater discharges. In other words, the short-term (2016-2026) is more critical in terms of ensuring that freshwater quality is maintained or improved to meet freshwater objectives.

9 Adopting a more dynamic landscape-based approach, cognisant of the differing assimilative capacity of the landscape, will provide greater flexibility for landowners to manage their activities within the constraints of agreed freshwater objectives. It therefore follows that both environmental sustainability and economic utility of the land can be optimised.

10 The consequences of adopting a more dynamic landscape-based set of provisions are that:

10.1 Short-term improvements (2016-2026) in freshwater quality will have a greater likelihood of success; and

10.2 The longer-term (80-year) improvements component of PC1, while important from the perspective of the Vision and Strategy would (as a result) become less important from a water quality perspective.

Springs

11 WPL made a submission opposing references to "springs" as the term is not defined, which creates uncertainty, and sought that the term be either deleted or PC1 amended to include an appropriate hydrological definition of springs.

12 To remedy this gap in the PC1 provisions, I recommend that the following hydrological definition of springs for the purpose of PC1 should be included in the Glossary of Terms:

> **Springs**: means a water body derived from an underground source that flows year-round at a minimum flow rate of 5 L/s.

13 The definition embodies the seasonal characteristics (perennial), significance of the water body with the quantum of flow specified, and also is specific regarding its derivation from an underground source.

Subdivision of Sub-catchment 66

14 WPL requested that Sub-catchment 66 be sub-divided into Sub-catchments 66A (Tahorakuri) and 66B (Ohakuri), as proposed Sub-catchment 66A (Tahorakuri) relates to a section of the river that is functioning as a river, rather than a riverine lake as is the case in Sub-catchment 66B (Ohakuri).

15 Dr Neale discusses the technical rationale for this subdivision in his evidence.

16 From my perspective as a hydrologist, I can confirm that the proposed sub-catchment boundaries (66A and 66B) conform with fundamental catchment delineation principles with the boundary lines following topographic ridgelines or flow divides, as shown in **Figure 8**.

Conclusions

17 The groundwater N "load to come" concept, defined in the PC1 background documents as a load of N in groundwater derived from land surface recharge that will take many decades to discharge into the receiving environment, is contrary to the principles of groundwater redox chemistry.

18 Recent N concentration increases in surface waters are explained by "quicker flow processes" including surface runoff and young groundwater discharges, which are relatively short or medium-term responses, respectively.

19 The N "load to come" concept associated with old groundwater is fundamentally an oxymoron, because old groundwater (which is responsible for the groundwater lag) has been subjected to redox reactions involving the progressive depletion of dissolved oxygen following by nitrate conversion to benign nitrogen gas.

20 My review of key background reports, as detailed in **Appendix B** of my evidence, identifies a number of concerns and shortcomings, such that in my view, they do not provide a robust scientific basis supporting PC1 (as notified) for the "load to come" concept.

21 From a scientific perspective, I consider that the PC1 provisions should be amended so that:

21.1 Farm Environmental Plans can be designed to target mitigation of constituent generation (i.e. all four contaminants) via quicker flow process (surface runoff and young groundwater); while

21.2 The NRP or similar concepts of more severe land use controls, should only be applied on areas identified as high risk N source areas, as shown for example in **Figure 6** for the Ruahuwai area in the Upper Waikato.

22 A definition of "springs" is provided for the purpose of PC1 to meet WPL's concerns, as follows:

> **Springs**: means a water body derived from an underground source that flows year-round at a minimum flow rate of 5 L/s.

23 Sub-catchment 66 should be subdivided on the basis of ecological functionality (as described by Dr Neale) of the river reaches concerned. My evidence confirms that the proposed hydrological boundary is correct from a hydrological perspective.

EVIDENCE OF JONATHAN WILLIAMSON

Block 1 Hearing Topics

1 My name is **Jonathan (Jon) Williamson**. I have the qualifications and experience recorded in my curriculum vitae attached to this statement of evidence as **Appendix A**. Key aspects of my recent expert experience relevant to this Hearing include:

1.1 Kaituna & Rangitāiki Catchment Models. *Client:* Bay of Plenty Regional Council (**BOPRC**). *Project Description:* My consultancy was commissioned by the BOPRC in 2017 to develop a hydrological model to simulate the water quantity and quality of the rivers and streams that comprise the Kaituna and Rangitāiki Water Management Areas (**WMAs**) using the SOURCE catchment modelling framework. The specific purpose of the model was to aid in the decision-making process for setting of water allocation limits and water quality objectives, which are a requirement of the National Policy Statement for Freshwater Management (2104) - as amended in 2017 (**NPS-FM**). The work undertaken was a collaboration between my consultancy and BOPRC, with my consultancy undertaking the data analysis, APSIM (daily crop production and nutrient leaching model), flow and constituent model development, and scenarios assessments. The work is ongoing and while a draft report has been produced, this is not publicly available at the time of writing.

1.2 TANK (Tutaekuri, Ahuriri, Ngaruroro, and Karamu Rivers) SOURCE Catchment Model. *Client:* Hawkes Bay Regional Council (**HBRC**). *Project Description:* Development of a daily hydrological and water quality model within the SOURCE modelling framework to support review of the policy underpinning management of land and water resources encompassed within the greater Heretaunga and Ahuriri management zone ('TANK' Catchment). The project was a joint collaborative effort between HBRC and my consultancy. My consultancy was responsible for constructing, calibrating and conducting land use simulations of the SOURCE model using the SMWBM as the rainfall runoff model, and integration of a MODFLOW model of the Heretaunga plains developed by HBRC staff. I was technical lead and also developed the tools for disaggregating OVERSEER annual loads into daily loads.

1.3 Lower Ruamahanga Valley Groundwater. *Clients:* Ongaha Farms Limited, Wairarapa Water User Society Inc., Greater Wellington Regional Council. *Project Description:* An interesting project in that my consultancy started out working for an applicant and a submitter on the aquifer connectivity maps and aquifer categorisation rules in the Wellington Proposed Natural Resources Plan (**PNRP**). Through the development and presentation of accurate and robust evidence, my consultancy was subsequently commissioned (in mutual agreement of all parties) to undertake further groundwater modelling and participate in expert conferencing that resulted in significant revision of aquifer connectivity maps for the Lower Ruamahanga River Valley in the PNRP.

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 primarily on the key concept of "load to come" in groundwater nitrate discharge to the surface water receiving environment. I also address the definition of "springs" and the subdivision of Sub-catchment 66.

4 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.

Science Modelling that Underpins PC1

Introduction

5 The Section 32 Evaluation Report (**Section 32 Report**) explains (Part E.3.7, p179):

> There is sufficient information on which to base the proposed policies and methods. In particular, the technical work has been undertaken to do a comprehensive assessment of the monitoring data and information available on the rivers, lakes and wetlands in the catchment. This included additional field investigations to inform groundwater lag time considerations and faecal sources and providing forums to gather mātauranga Māori specifically to inform Plan Change 1.

6 From my review of the Healthy Rivers Wai Ora (**HRWO**) Project Groundwater Studies listed in **Appendix B**, whilst it is difficult to definitively understand how this technical work has been used in informing the provisions in PC1, it is clear that the groundwater nitrogen (**N**) "load to come" issue was a key concern to those involved in preparing PC1 and to WRC.

7 For example, the Section 42A Report discusses the "load to come" and states:

7.1 … the time it takes for nitrogen to move through the soil profile to groundwater, and then to surface water. This means that the effect of actions put in place to reduce nitrogen now may not be seen in the water for some time (the length of time lag varies across the catchment). It also means there is a nitrogen 'load to come' from historic land use that is yet to be seen in the water. (para 15)

7.2 Once in groundwater, nitrate is very difficult to remove, with lag-times up to 80 years before the contaminated groundwater re-enters a surface water body. (para 82)

7.3 Nitrogen in groundwater can take many decades to emerge into surface water, and as a result, it is likely nitrogen levels will continue to increase over time. (para 92)

7.4 For some sub-catchments there is also a 'load to come' in that recent losses to groundwater are only just starting to show in monitoring records. (para 143)

8 It would therefore appear that the primary concerns with regard to the "load to come" issue which supported the development of the PC1 policy package, were twofold:

8.1 The impacts of current and any subsequent land use change might not appear in the down gradient receptors for decades; and

8.2 The impacts of mitigation management actions being implemented might not be realised in water quality measurements for decades.

9 In particular, it appears that the two key documents relied upon to justify the PC1 provisions with regard to the "load to come" effect were:

9.1 Wilson, S. and Shokri, A., 2015. Estimation of lag time of water and nitrate flow through the vadose zone: Waikato and Waipa River Catchments. Report 1058-9-R1. Consultancy report by Lincoln Agritech Ltd prepared for Healthy Rivers Wai Ora Project.

9.2 Close, M., 2015. Prediction of Subsurface Redox Status for Waikato Healthy Rivers - Plan for Change: Waiora He Rautaki Whakapaipai. Institute Of Environmental Science And Research Limited. Consultancy report prepared for Healthy Rivers Wai Ora Project.

10 However, as detailed in **Appendix B** of my evidence, both of these reports have a number of shortcomings, summarised as follows, such that they do not appear to provide a sound scientific basis for supporting the PC1 "load to come" concept:

10.1 Wilson and Shokri (2015):

(a) Focus almost solely on the vadose (unsaturated) zone - neglecting saturated zone groundwater travel times, which are typically 100-200 times greater in the Upper Waikato sub-catchments;

(b) Significantly underestimate the land surface recharge flux in the Upper Waikato sub-catchments;

(c) Overestimate the travel times in the vadose zone; and

(d) Consequently, over predict the age of young groundwater and under predict the age of old groundwaters.

10.2 Close (2015):

(a) The body of work employed a new methodology, which appeared to still be under development at the time of the report;

(b) The accuracy of the work was acknowledged by the author at a conference in 2018 to be severely affected by spatial bias (clustering); depth bias (predominantly shallow samples); sample selection bias (65-85% of samples from oxic water); and attribute bias (samples unevenly distributed among attribute categories);

(c) Consequently, the results particularly in the Upper Waikato sub-catchments did not compare accurately to observed data.

11 I accept that there will be short-term lagged loading effects from land use change, and by short term I consider that the majority of such effects (acknowledging spatial variability across the catchment) are likely to arise within 10 to 15 years. However, I do not accept (on the basis of the scientific information available within the catchment and globally), that longer-term lag effects (>20 years) are a justifiable assumption. The paragraphs in the following section explain the basis of my opinion.

Nitrogen in Groundwater

12 The Section 32 Report explains (Part C.2.2.1) that in developing a plan change that addresses N, phosphorus, E. coli and sediments (the "four contaminants") there is a need to understand the linkages between land use practices and observed responses of the four contaminants in the receiving surface waters.

13 N (unlike the other three contaminants) is primarily transported to surface waters via a sub-surface pathway – leaching from the soil to groundwater followed by transport and re-emergence into streams.

14 The Section 32 Report explains (Part C.2.2.1) that this transport pathway takes time (sometimes decades – "the lag effect") and can involve N removal by a microbial process known as denitrification (the N attenuation effect).

15 Seitzinger, *et. al.*, (2006) explains that one of the positive outcomes of denitrification is that it can reduce eutrophication of downstream ecosystems, while Anderson *et. al.*, (2015) describe denitrification as a valuable ecosystem service for protecting aquatic habitats from non-point source or diffuse contaminants.

16 Overseas field studies indicate that denitrification:

16.1 Efficiency in groundwater can range from 0% to 100%;

16.2 Is spatially heterogeneous (varies across catchments); and

16.3 Depends locally on aquifer hydrogeology and mineralogy (Seitzinger, *et. al.*, 2006).

17 Denitrification in groundwater is a redox (or complementary oxidation and reduction) process, and occurs via microbially-mediated processes under anoxic (low-oxygen) aquifer conditions. The process involves the reduction of highly reactive and mobile nitrate via the intermediary (or incomplete denitrification by-product) nitrous oxide (N_2O), to environmentally benign nitrogen gas (N_2).

18 During redox processes, microorganisms favour the most energetically efficient reaction. The order of reaction[2] is $O_2 > NO_3^- > Mn(IV) > Fe(III) > SO_4^{2-} > CO_2$ (McMahon and Chapelle, 2008). Once oxygen is depleted, nitrate (NO_3) is the next readily available electron receptor (**Figure 1**).

[2] Referred to as the ecological succession of terminal electron-accepting processes.

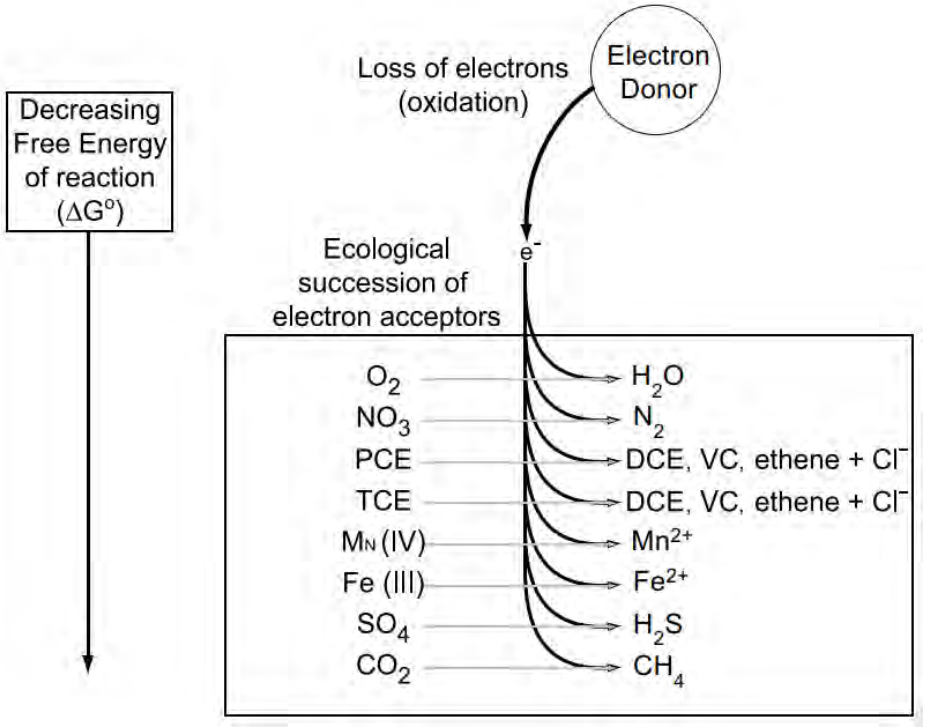

Figure 1. Ecological succession of electron-accepting processes and sequential production of final products (source: McMahon and Chapelle, 2008).[3]

19 It is often possible to determine the predominant redox process occurring in a groundwater system based on the concentration of redox-sensitive species like dissolved oxygen (**DO**), nitrate (**NO_3^-**), dissolved manganese (**Mn^{2+}**), dissolved iron (**Fe^{2+}**), sulphate (**SO_4^{2-}**), and sulphide (**S^{2-}**) (McMahon and Chapelle, 2008).

20 It is interesting to note that the Upper Waikato has proportionally the greatest number of wells with elevated iron and manganese (see table in para 99 p19 of the Section 42A Report). The implication of this from a redox chemistry perspective is that a higher proportion of wells (compared to the other sub-catchments listed) are in a more reduced state, where nitrate reduction would be well advanced or surpassed in the ecological succession.

21 Anoxic (reducing) conditions typically occur in older groundwater[4] or waterlogged soils, which can be found in:

21.1 ***Deep groundwater*** - where interaction with oxygenated recharge waters are insignificant to nil;

21.2 ***Shallow groundwater*** - within a low permeability aquitard; within a shallow aquifer underneath a low permeability spatially extensive confining layer e.g.

[3] PCE, tetrachloroethene; TCE, trichloroethene; DCE, dichloro-ethene; VC, vinyl chloride.

[4] The age of groundwater is defined as the time that has elapsed since the water first entered the aquifer. For example, some of the rain that falls on an area percolates (trickles) down through soil and rock until it reaches the water table. Once this water reaches the water table, it moves though the aquifer. The time it takes to travel to a given location, known as the groundwater age, can vary from days to thousands of years. http://www.waterencyclopedia.com/Ge-Hy/Groundwater-Age-of.html#ixzz5cjXQQzZ4

Lower Ruamahanga C3 aquifer; within soils with high organic content; within waterlogged soils; or where deep deoxygenated groundwater has re-emerged into shallow groundwater at the discharge zone of a catchment.

22 Generally, in a New Zealand context (as opposed to large continental countries), where the groundwater transport pathway is:

22.1 Short and/or fast (groundwater discharging to surface water quickly) - groundwater age is typically young (<15 years[5]) and the potential for denitrification is low to moderate; and

22.2 Long and/or slow (taking significant time) - groundwater age is old (say >20 years) and the potential for dentification is high.

23 **Figure 2** below shows idealised groundwater flow paths within a landscape, and indicates that in general groundwater flow paths within valley floors or sides (discharge areas) are typically much shorter in duration than under elevated topographical areas (recharge areas) that are distant from surface water sinks (rivers, streams, wetlands, lakes, etc).

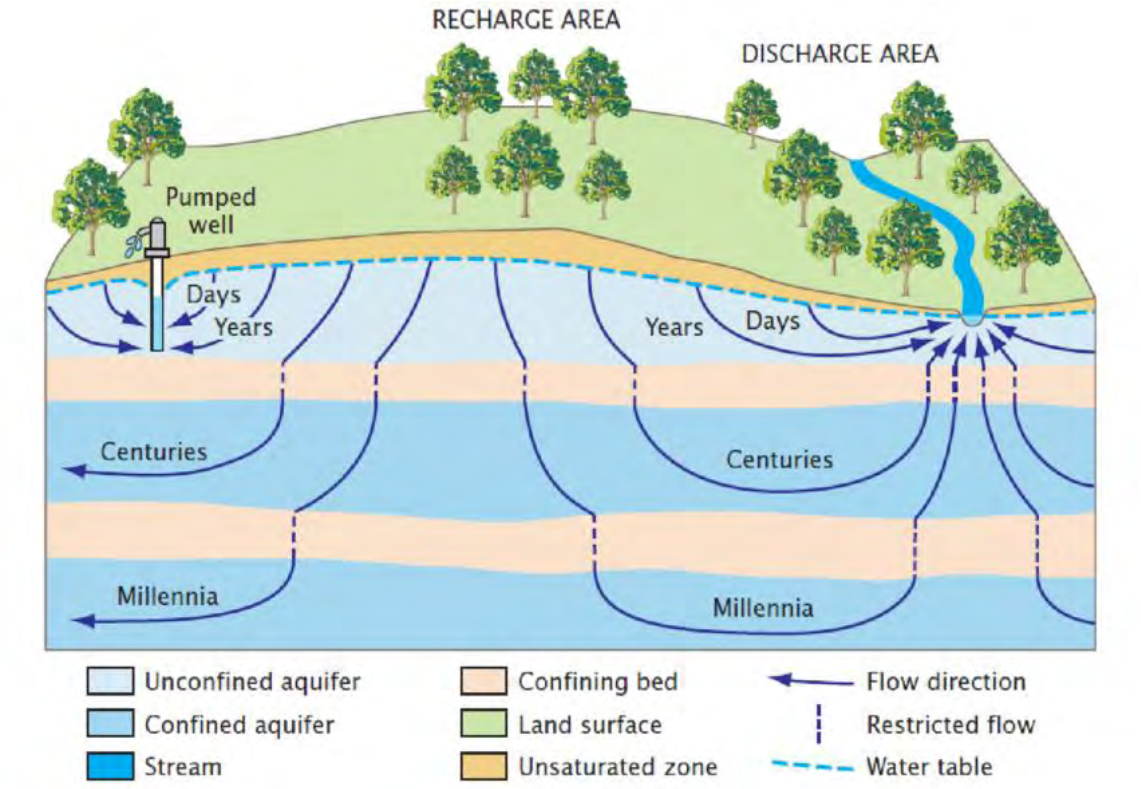

Figure 2. Idealised cross section showing groundwater flow paths and indication of timing from recharge to discharge areas (source: Focazio, *et. al.,* 2002).

[5] Categorisation of groundwater as "young" or "old" can be a subjective topic and it would seem views differ given the range in hydrogeological flow regimes under discussion.

24 While mixing of groundwater of differing ages (especially at shallow depth) confounds the analysis of land use impacts on groundwater and the receiving environment, in a general sense:

24.1 Shallow groundwater in high permeability aquifer will typically have higher concentration of nitrate than deeper groundwater (Freeze and Cherry, 1979; Burow, *et. al.*, 2010; Welch *et. al.*, 2011) because nitrate is stable and will not be removed (reduced) in oxic environments (Woodward, *et. al.*, 2016). However, exceptions to this are noted (Stenger *et. al.*, 2008), particularly where permeability is extremely low leading to water logging and/or where the carbon content is high in shallow soils; and

24.2 Old groundwater will typically have a low concentration of nitrates (Burow, *et. al.*, 2010), due to progressive depletion of dissolved oxygen leading to denitrification along the groundwater flow path.

25 The general trend of decreasing groundwater nitrate concentration with depth (Hallberg and Keeney, 1993) and/or groundwater age has been noted in studies worldwide (Burow, *et. al.*, 2010; Welch *et. al.*, 2011), as exemplified in **Figure 3** and **Figure 4** below. A similar trend of decreasing groundwater concentration with depth has also been noted in recent New Zealand publications for Ministry for the Environment (**MfE**) (Moreau *et. al.*, 2016).

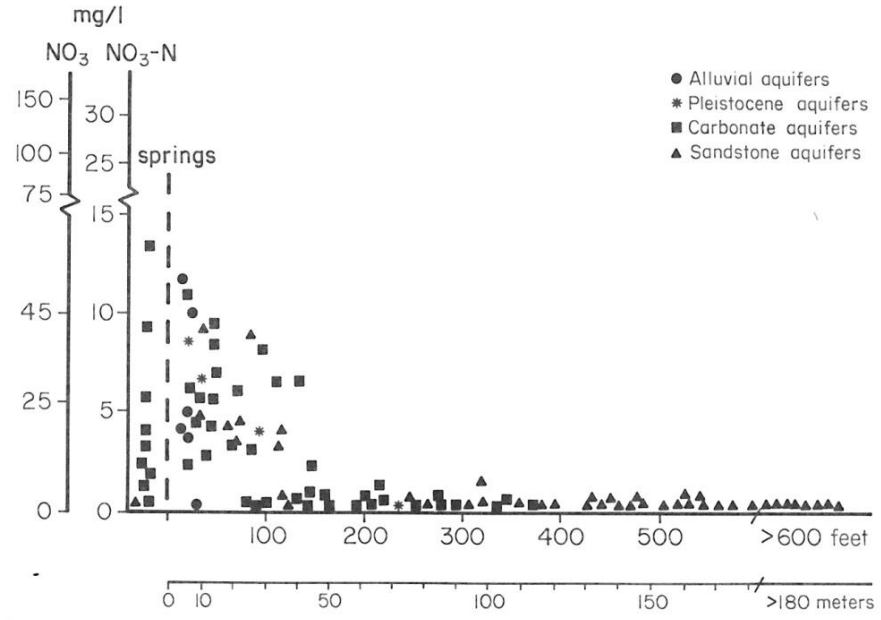

Figure 3. Nitrate concentrations in groundwater versus depth of groundwater tapped by well (source: Hallberg and Keeney, 1993).

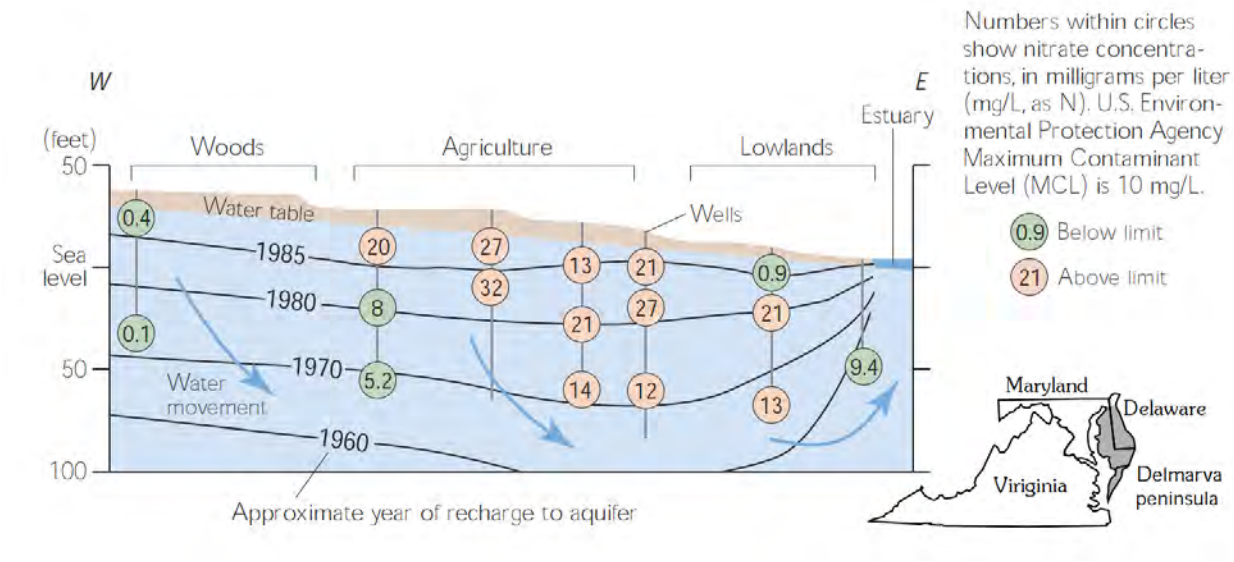

Figure 4. Diagram showing groundwater nitrate concentrations decreasing with depth and age from monitoring during 1989-1990 (source: U.S. Geological Survey Fact Sheet 134-99).

26 Published studies have demonstrated the major role subsurface processes can have in attenuating agricultural nitrate losses in groundwater dominated catchments where the necessary redox conditions occur (Korom, 1992; Hallberg and Keeney, 1993; Conan *et. al.*, 2003; Woodward, *et. al.*, 2013; Hadfield, 2015). For example, **Figure 5** below schematically depicts the influence of the reducing conditions beneath the redox boundary, where the nitrate plume leached from cultivated land has been denitrified in the deeper aquifer.

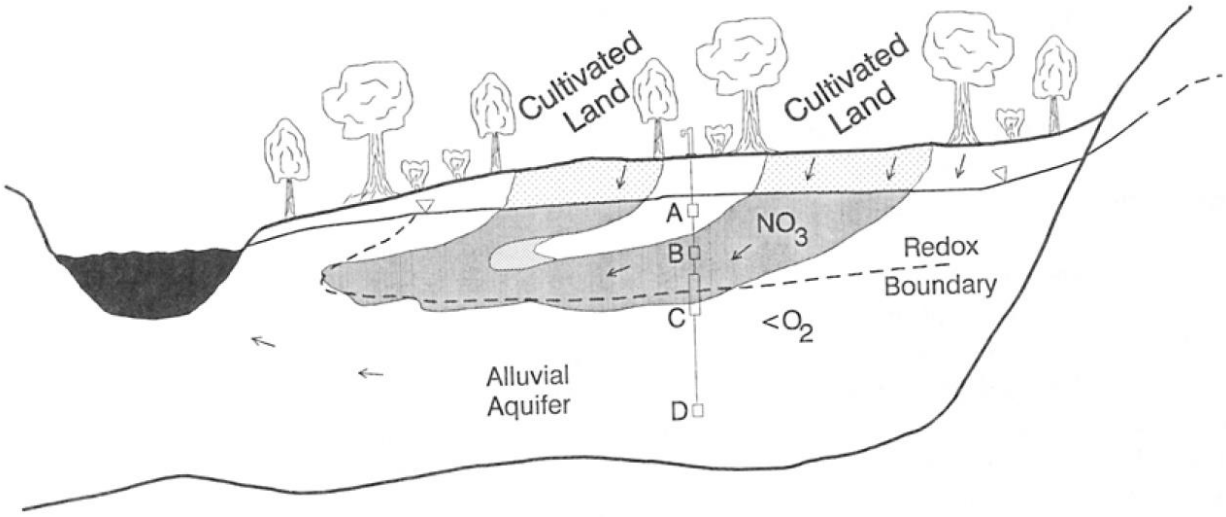

Figure 5. Schematic diagram showing nitrate plume derived from cultivated land in shallow groundwater above the redox boundary and low nitrate concentrations in deeper groundwater due to denitrification (source: Hallberg and Keeney, 1993).

27 In my opinion, the potential nitrate "load to come" concept due to the decadal or longer lag effect is unlikely in a New Zealand context where our catchments are small (on an

international scale) and regularly dissected by dendritic drainages. This is because, in the case of:

27.1 ***Long groundwater flow paths*** *(decades or longer)* - nitrate will be attenuated through denitrification[6]; and

27.2 ***Short groundwater flow paths*** - the nitrate load will be discharged relatively quickly and therefore any increases in concentration will be observed in the surface water flow record within months to years of the land use change (not multi-decades or longer).

28 The conceptual model developed from the information above, which is supported in overseas experience (Seitzinger *et. al.*, 2006; Blicher-Mathiesen *et. al.*, 2014) and emerging NZ new data (Stenger *et. al.*, 2014) is presented in **Figure 6.**

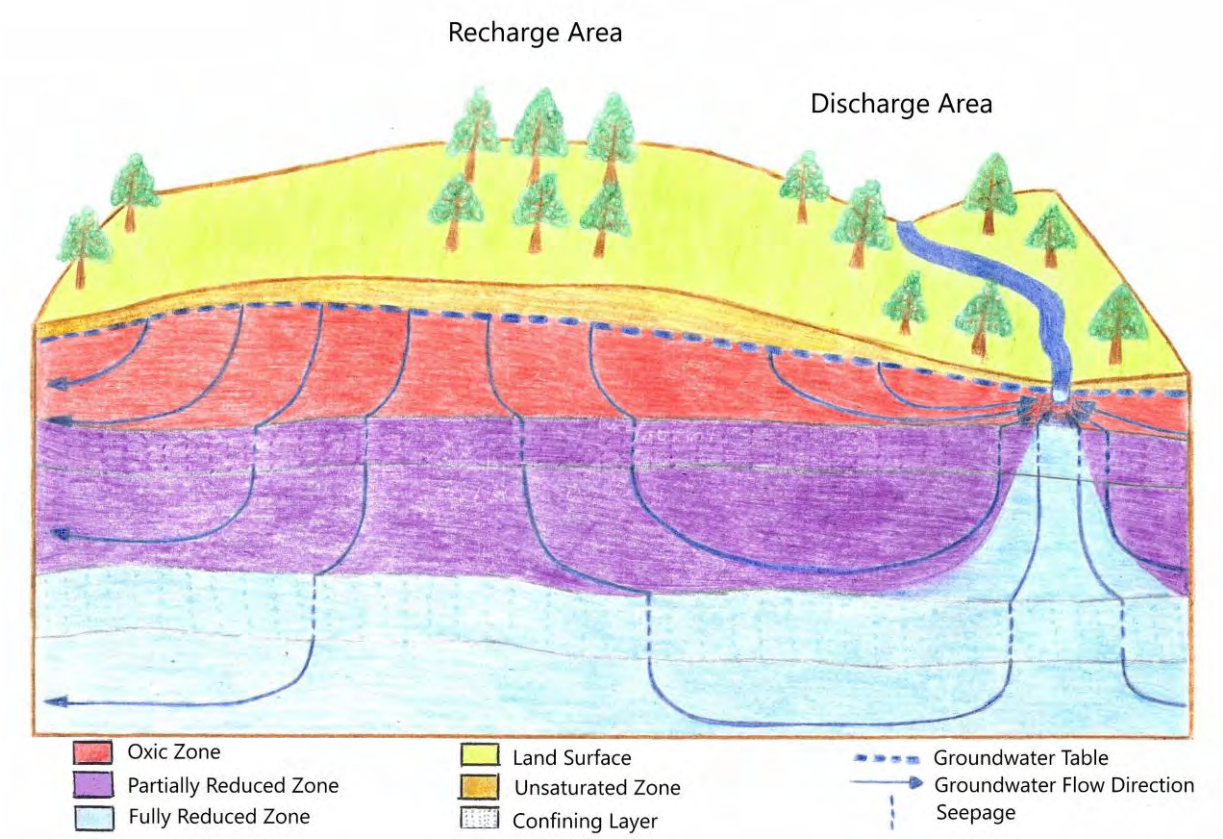

Figure 6. Idealised groundwater redox hydrogeological cross section, showing groundwater dentification through reduced zones.

[6] This is demonstrated in the Upper Waikato, where nitrate-nitrogen concentrations in groundwater are not increasing over time as stated in White *et. al.* (2015) (Table 4.2).

29 The implications of this conceptual model are that:

29.1 The “load to come” concept is inconsistent with scientific principles of redox chemistry; and

29.2 The hydrogeological functionality of the landscape varies; hence the same land use activity on different parts of the landscape will have a different impact on the receiving environment. For example, dairying on a lowland terrace in reasonably close proximity to a river will have a much greater impact on river water quality than the same land use either at greater distance from the river or at a higher elevation within the catchment. Therefore, management strategies can apply varying levels of stringency to reflect such spatial variability across sub-catchments; and

29.3 The “robbing Peter to pay Paul” concept referenced in para 149 of the Section 42A Report is not a valid analogy because additional N loss allowances in low N risk areas (areas where old groundwaters are sourced) will not result in additional N discharges to the receiving environment.

30 This conceptualisation has significant implications for river water quality vulnerability from land use in different parts of the landscape.

31 To exemplify this point, **Figure 7** below presents a map showing N source risk areas in the Ruahuwai area of the Upper Waikato. The analysis was undertaken by my consultancy team (under my supervision) using the groundwater modelling packages MODFLOW-2005[7] and MODPATH Version 6.0[8] calibrated to available stream flow and bore water level and quality data.

32 Analysis was undertaken of the relative groundwater nitrogen risk of a land parcel within the overall catchment, as measured at the receptor i.e. the discharge point of the flow pathway. The analysis was undertaken using forward particle tracking in MODPATH, through development of a risk index calculated progressively at each model cell along the flow pathway.

33 The risk index represents the time-weighted average decay rate of a groundwater flow path multiplied by the maximum age of the groundwater along that flow path. High decay rate rates (representative of anoxic conditions) and greater residence times (older groundwater) receive higher values, and vice versa. Hence, low risk is assigned to flow paths with higher values and vice versa.

34 In general, source areas of higher groundwater N risk are located in the riparian margins adjacent to streams, and the risk progressively reduces with i) distance from the stream, ii) increasing land surface elevation, and iii) in areas with lower permeability sub-soils (**Figure 7**).

[7] MODFLOW-2005 is a modular three-dimensional groundwater flow model developed by the United States Geological Survey (Harbaugh, 2005) designed to simulate steady and transient flow in irregularly shaped groundwater flow systems in which aquifer layers can be confined, unconfined, or a combination of confined and unconfined. MODFLOW is considered a worldwide industry standard groundwater modelling package.

[8] MODPATH is a particle tracking code developed by the United States Geological Survey that is used in conjunction with MODFLOW. Particles are tracked through time assuming they are transported by advection using the flow field computed by MODFLOW, either forward in time or backward in time (Pollock, 2012).

35 It should be noted that this analysis was focussed on the assimilative capacity of the groundwater flow component, but other studies have demonstrated there are also other mechanisms for attenuation of N e.g. in peaty soils, riparian areas, and within the stream itself. Alexander *et. al.*, (2002) in particular discuss a range of explanations for the low N discharge relative to the root zone N losses in the Upper Waikato.

36 The conclusion that I have drawn from this analysis is that the PC1 provisions should be modified to reflect the transmission pathways of both surface runoff and groundwater flow (young and old) and therefore have different level of stringency depending on the assimilative or attenuative capacity of the land. In other words, spatial variability needs to be reflected in policies and rules and be considered when deciding resource consent applications.

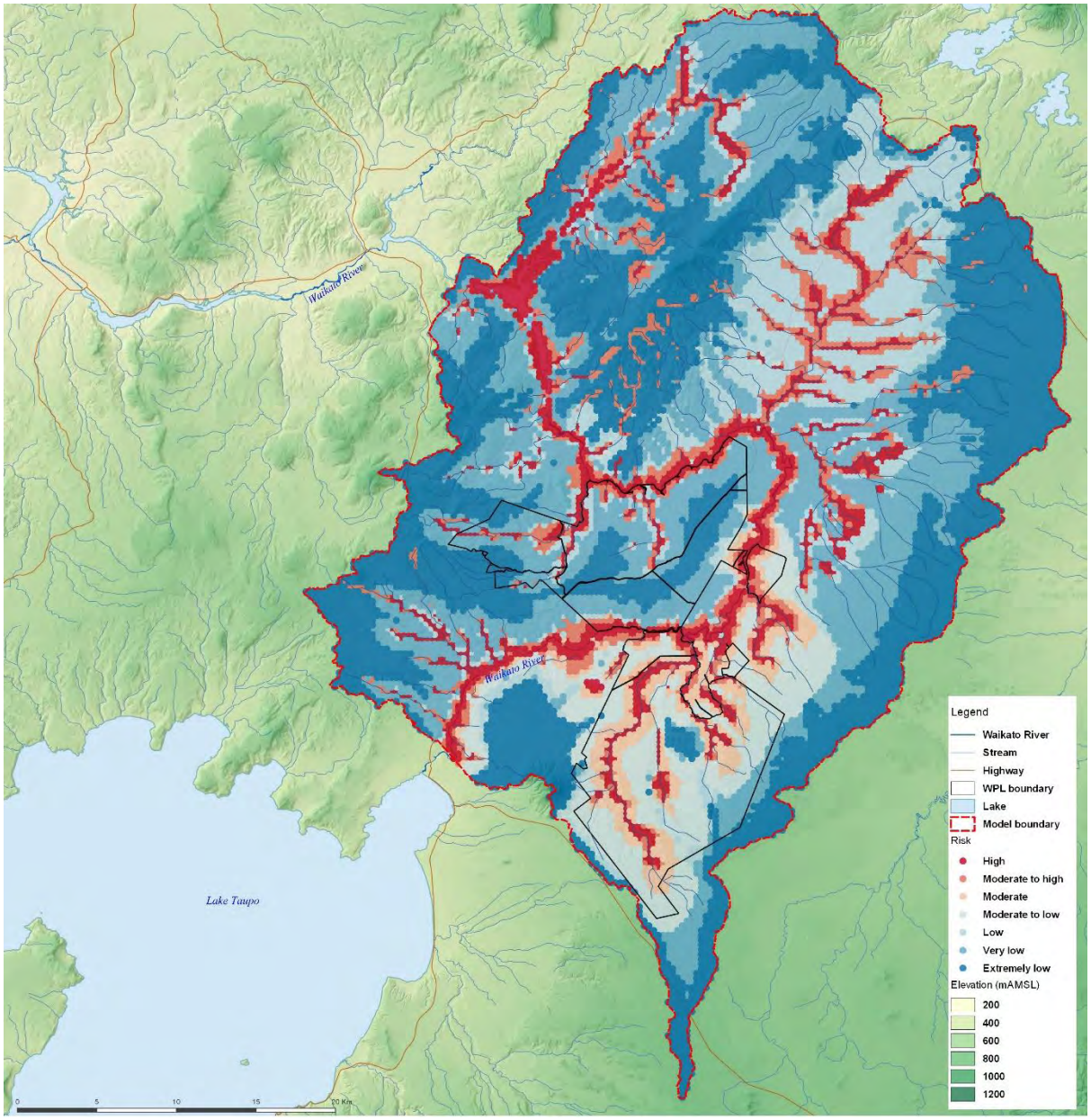

Figure 7. Ruahuwai nitrogen source area risk map.

Other Comments on the Section 42A Report

Definition of Springs

37 WPL made a submission opposing references to springs as the term is not defined, which creates uncertainty, and sought that the term be either deleted or PC1 amended to include an appropriate hydrological definition of springs.

38 The Section 42A Report explains (para 173):

> In relation to "springs", Officers note that the Oxford dictionary definition of spring is: *A place where water or oil wells up from an underground source, or the basin or flow formed in such a way.* This would appear to be consistent with common usage of the term, and hence, Officers do not consider a definition in PC1 is necessary.

39 However, this response does not account for the temporal variability and hydrological significance of springs. Springs can be perennial (flow year round) or ephemeral (flow intermittently - typically only when groundwater levels are highest), and the flow significance can vary within these temporal bands. For example, the spring may be only a seepage or minor spring, which typically occur at geological boundaries between units within a rock formation. Furthermore, perched and leaky water tables may give rise to springs at higher elevations than the local groundwater table in discrete localities. This is common in the Upper Waikato sub-catchments due to the interbedded nature of the airfall deposits from the Taupo eruption, with lower permeability tuff or ash layers typically providing the basal layer for perching.

40 To remedy this gap in the PC1 provisions I recommend that the following hydrological definition should be included in the Glossary of Terms:

> **Springs**: means a water body derived from an underground source that flows year-round at a minimum flow rate of 5 L/s.

41 The definition embodies the seasonal characteristics (perennial), significance of the water body with the quantum of flow specified, and also is specific regarding its derivation from an underground source.

Subdivision of Sub-catchment 66

42 WPL has also requested that Sub-catchment 66 into Sub-catchments 66A (Tahorakuri) and 66B (Ohakuri). As proposed Sub-catchment 66A (Tahorakuri) relates to a section of the river that is functioning as a river, rather than a riverine lake as is the case in Sub-catchment 66B (Ohakuri).

43 Dr Neale discusses the technical rationale for this subdivision in his evidence.

44 From my perspective as a hydrologist, I can confirm that the proposed sub-catchment boundaries (66A and 66B) conform with fundamental catchment delineation principles with the boundary lines following topographic ridgelines or flow divides, as shown in **Figure 8** below.

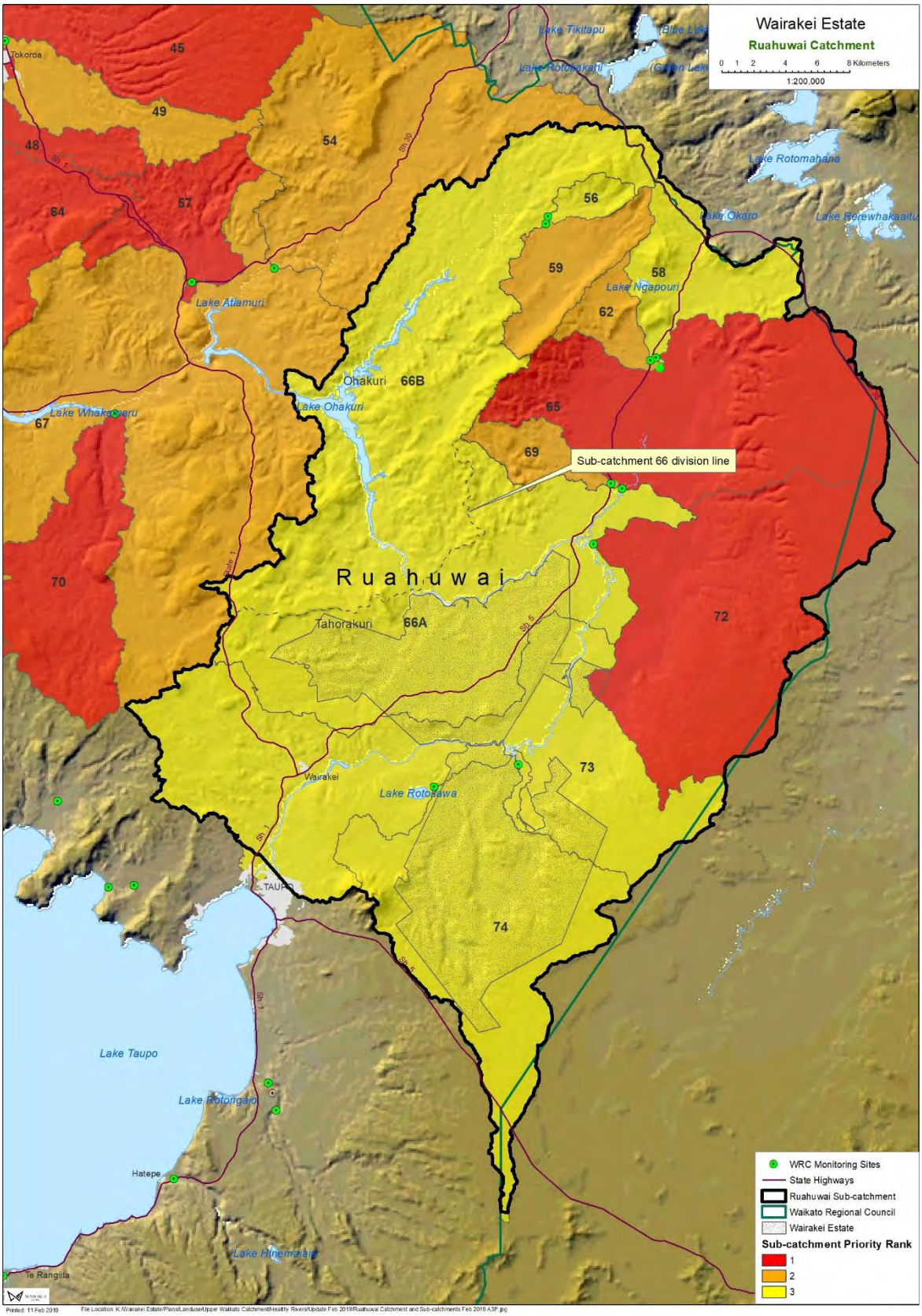

Figure 8. Subdivision of Sub-catchment 66.

CONCLUSIONS

45 The groundwater N "load to come" concept, defined in the PC1 background documents as a load of N in groundwater derived from land surface recharge that will take many decades to discharge into the receiving environment, is contrary to the principles of groundwater redox chemistry.

46 Recent N concentration increases in surface waters are explained by "quicker flow processes" including surface runoff and young groundwater discharges, which are relatively short or medium-term responses, respectively.

47 The "load to come" concept associated with old groundwater is fundamentally an oxymoron, because old groundwater (which is responsible for the groundwater lag) has been subjected to redox reactions involving the progressive depletion of dissolved oxygen following by nitrate conversion to benign nitrogen gas ($\mathbf{N_2}$).

48 My review of key background reports, as detailed in **Appendix B** of my evidence, identifies a number of concerns and shortcomings, such that in my view, they do not provide a robust scientific basis supporting PC1 (as notified) for the "load to come" concept.

49 From a scientific perspective, I consider that the PC1 provisions should be amended so that:

49.1 Farm Environmental Plans (Hearing Block 3) can be designed to target mitigation of constituent generation (i.e. all four contaminants) via quicker flow process (surface runoff and young groundwater); while

49.2 NRP or similar concepts of more severe land use controls (Hearing Block 2), should only be applied on areas identified as high risk N source areas, as shown for example in **Figure 6**.

Jonathan Williamson

Managing Director, Williamson Water & Land Advisory

15 February 2019

Appendix A. Jonathan Williamson Curriculum Vitae

Jon Williamson

HYDROGEOLOGY /
HYDROLOGY / IRRIGATION

CURRENT POSITION

Managing Director

QUALIFICATIONS

Bachelor of Science (Earth Science) – University of Waikato, NZ. 1993.

Master of Science and Technology (Hons 1), University of Waikato, NZ. 1995.

Certified Resource Management Act Commissioner (Decision Maker) - 2007 to June 2015.

PROFESSIONAL MEMBERSHIPS AND AFFILIATIONS

New Zealand Hydrological Society (Member of the Executive Committee 2007 to 2011)

Summary of competencies

- Business development
- Client relationship management
- Project directorship
- Technical directorship
- Business strategy

Hydrogeology

- Hydrogeological (groundwater) and catchment hydrology (surface water) processes.
- Groundwater flow modelling.
- Groundwater recharge.
- Contaminant transport modelling.
- Piezometer design and installation.

Hydrology

- Rainfall-runoff modelling.
- Constituent generation and discharge modelling.
- Catchment water balance and water management studies.
- Water management plan preparation.
- Water supply planning.
- Irrigation scheduling.
- Dam storage analysis.
- Design minimum flow analysis.

Water Engineering

- Owners Engineer on irrigation schemes developments.
- Design Manager - Pressure piping systems.
- Riverbank and infiltration gallery design.
- Production bore design, procurement and contract management.

General

- Preparation and presentation of expert witness evidence.
- Water related RMA consent applications.
- Environmental impact and sustainability assessment.
- Design and implementation field testing and sampling investigations.
- Instrumentation, compliance monitoring and data management.
- Simulation model and database software development.

Project experience

Williamson Water Advisory Limited, New Zealand

Jan 2015 to Present:

Managing Director

PROJECT | Ruataniwha Basin Recharge and Irrigation Scheduling Analysis

Client: Hawke's Bay Regional Council

Role: Jon was Technical Lead for a study that developed groundwater recharge and irrigation water use datasets for a groundwater model. The models developed using APSIM and SOURCE were calibrated to catchment water balances derived from river and stream flow and soil moisture observation data.

PROJECT | Peer Review of Discharge Consent Renewal for Silver Fern Farms Takapau

Client: Hawke's Bay Regional Council

Role: Jon undertook a technical review of the hydrogeology and irrigation scheduling reports supplied to support a wastewater discharge consent renewal.

PROJECT | Ahuriri Estuary Catchment Model

Client: Hawke's Bay Regional Council

Role: Jon was the Technical Lead for the development of a daily hydrological model using the SOURCE framework for assessment of nitrogen, phosphorus, E. coli and sediment discharges into the estuary.

PROJECT | Te Tua Storage and Stream Augmentation Analysis

Client: Hawke's Bay Regional Council

Role: Jon was the Technical Lead for the development of a daily hydrological model using the SOURCE framework for assessment of the capability of the proposed 5.0 Mm^3 Te Tua Dam to augment the Ngaruroro River under differing flow conditions.

PROJECT | Kaituna River and Rangitikei River Catchments SOURCE Catchment Models

Client: Bay of Plenty Regional Council

Role: Jon was the Technical Lead for the development of a daily hydrological and water quality model using the SOURCE modelling framework from eWater to support review of the policy underpinning management of land and water resources encompassed within the two catchments. Jon developed an extension to the Soil Moisture Water Balance Model (SMWBM) to account for vadose zone process and enable simulation of the lag in rainfall recharge and nitrogen leaching. The project was a joint collaborative effort between BOPRC and WWA staff.

PROJECT | Lower Ruamahanga Valley Groundwater

Client: Ongaha Farms Limited & Wairarapa Water User Society Inc & Greater Wellington Regional Council.

Role: Jon undertook a review of the hydrogeological information available for the Lower Ruamahanga Groundwater Management Zone and conducted an investigation into the degree of connectivity between the Q2-Q4 aquifer and the Ruamahanga River, and the Proposed Natural Resources Plan (pNRP) classification of the groundwater take. A three-dimensional geological model was developed to better understand the geological context of the valley. MODFLOW and MT3D models were developed to simulate the groundwater surface water interaction, and differences in water quality between the river and aquifer water. Deliverables included Environment Court Evidence for the Ongaha Farm consent appeal, and Evidence for a submission on the Proposed Regional Plan Change, which then lead to further modelling and joint witness statements.

PROJECT | TANK (Tutaekuri, Ahuriri, Ngaruroro, and Karamu Rivers) SOURCE Catchment Model

Client: Hawkes Bay Regional Council

Role: Jon was the Technical Lead for the development of a daily hydrological and water quality model within the SOURCE modelling framework to support review of the policy underpinning management of land and water resources encompassed within the greater Heretaunga and Ahuriri management zone ('TANK' Catchment). The project was a joint collaborative effort between HBRC and WWA staff.

PROJECT | Ruahuwai (Upper Waikato) Catchment Model

Client: Wairakei Pastoral Limited

Role: Jon was a senior member of team comprising WWA, HARC (Australia), EcoLogical (Australia) and Jacobs (Australia) to develop and calibrated a daily time step SOURCE model and a MODFLOW model of the catchment between Lake Taupo and Lake Ohakuri. Jon led the construction, calibration and prediction simulation of the MODFLOW model, and personally undertook calibration a number of sub-catchments with the SMWBM, in support of the SOURCE modelling.

PROJECT | Waverley Wind Farm Construction, Taranaki

Client: Trust Power Limited

Role: Technical Director. Development of a MODFLOW numerical groundwater flow model to assess the impact of shallow dewatering and pumping from a water supply bore on local streams from foundation construction of a 48-tower wind farm. Modelling was also used to optimise the groundwater abstraction rates, with objective function being to minimise flow while meeting the drawdown objectives with different construction techniques, such as sheet pile coffer dams and spear points wells.

PROJECT | Pueto Catchment Revised SOURCE Model for Lowflow Assessment

Client: Wairakei Pastoral Limited

Role: Jon was the Technical Lead for the development of a revised SOURCE catchment model for the Pueto Stream catchment to accurately simulate and analyse low flows at a new gauge site that was to become the compliance point for water abstractions within the catchment.

PROJECT | Motutangi-Waiharara Groundwater Modelling Sustainable Yield Assessment (Far North)

Client: Motutangi-Waiharara Water Users Group

Role: WWA were commissioned by the Motutangi- Waiharara Water User Group to undertake sustainable yield assessment through the development of a MODFLOW model on the section of the Aupouri Aquifer between South Houhora/Motutangi in the north and Waiharara in the south. The user group consists of sixteen irrigators who were seeking either increased or new allocations from the aquifer totalling 15,050 m^3/day.

PROJECT | Avocado Irrigation Bore Procurement – Motutangi (Far North)

Client: Murray Forlong

Role: Procurement and contract management (NZ3910: 2013) of exploratory drilling. Still in progress.

PROJECT | Avocado Irrigation Bore Procurement – Waiharara (Far North)

Client: Honeytree Farms Limited

Role: Procurement and contract management (NZ3910: 2013) of exploratory drilling and production bore drilling programmes for two 250 mm diameter 100 m deep bores. Bore was successfully drilled by DrillFore NZ Ltd and screened in a shellbed aquifer producing 70-80 L/s each.

PROJECT | Water Management Planning Services – Tapora (Kaipara Harbour)

Client: Harbour Edge Avocados Limited

Role: WWA were engaged to prepare resource consent applications, and undertake research into catchment water balances and water supply options for the future development of a 320 hectare avocado orchard within the regional planning context of the preferred aquifer (deeper shellbed aquifer) being fully allocated.

PROJECT | Tasman Plan Change 52 – Upper Motueka

Client: Horticulture New Zealand

Role: WWA were engaged to undertake a reliability assessment for the water users in the Upper Motueka of the proposed water allocation rule changes under Tasman District Council Plan Change 52 (PC52), which had potential to decrease baseflow and change the reliability of the Motueka River for irrigators in the upper reaches. The study used data from the three main gauges located in Upper Motueka (Wangapeka River at Walter's Peak, Baton River at Baton Flat, and Motueka River at Woodstock as assess flow statistics and reliability for different actual and future use scenarios.

PROJECT | Peer Review – Maunu-Maungatapere-Whatitiri Aquifer Report

Client: Northland Regional Council

Role: Jon undertook a peer review of a groundwater model developed to assess the sustainable yield of the Maunu-Maungatapere-Whatitiri Aquifer.

PROJECT | Cape Foulwind Dairy Farming Complex New Bore Water Supply

Client: Landcorp Farming Limited

Role: Landcorp sought a supplementary water supply at each of three dairy sheds at Cape Foulwind. Services undertaken included: hydrogeological review, production bore design, preparation of tender and NZS3910:2013 contract documents, tender review and contract award recommendation report.

PROJECT | Avocado Orchard Bore Procurement & Take Consent - Kaikohe

Client: Honeytree Farms Limited.

Role: Hydrogeological assessment to support a groundwater take consent application from a fractured basalt aquifer near Kaikohe. Procurement and contract management (NZ3910: 2013) of exploratory drilling and production bore drilling programmes. Bore successfully completed barefoot from 30-60 m by McMillians Drilling grout Ltd and produces 25 L/s.

PROJECT | Irrigation Take Hydrological Impact Assessment

Client: DI Cathcart Limited.

Role: Assessment of catchment yields and groundwater baseflow component to demonstrate zero net impact during summer on residual stream flows from an irrigation take out of a decommissioned mine pit near Huntly. Work required because of catchment at full allocation.

PROJECT | Water Bottling Plant Hydrogeological Assessment - Fiji

Client: Confidential.

Role: Supply sustainability peer review.

PROJECT | Te Raite Station Water Supply Due Diligence

Client: Landcorp Farming Limited

Role: Undertook a high-level review of the landuse and water supply options for a 1,800 ha dry stock farm as part of development planning for optimising the economic utility of the land. Consideration was given to more intensive pastoral operations and landuse change to horticulture in suitable area.

PROJECT | Central Interceptor Preliminary Design

Client: Jacobs NZ Limited / AECOM on behalf of Watercare Services Limited

Role: Technical lead and Practice Reviewer for hydrogeology as part of the ground investigations and preliminary design phase.

PROJECT | West Coast Farms Water Supply Assessment – Cape Foulwind and Burkes Creek.

Client: Landcorp Farming Limited

Role: A water supply and irrigation demand assessment for potential dairy conversions and irrigation developments at the Cape Foulwind and Burkes Creek farms. Specific requirements of the assignment were to investigate current and future stock water demands and infrastructure capacity, as well as irrigation demand, and potential new water supply options.

PROJECT | Bore Construction Review

Client: Kaipi Holdings Limited

Role: Hydrogeological review in relation to well design, drilling, construction standards, and construction contract in response to dissatisfaction with bore performance on a Tegal chicken and dairy farm operation in Taranaki.

PROJECT | Bore Construction Review

Client: Hernly Farms Limited

Role: Hydrogeological review in relation to well design, drilling, construction standards, and construction contract in response to dissatisfaction with service of drilling company on a Tegal chicken and dairy farm operation in Taranaki.

Sinclair Knight Merz Ltd (then Jacobs NZ Limited), New Zealand

August 2011 to Jan 2015:

Irrigation Development Manager and
Principal Hydrogeologist/Water Resource Engineer

PROJECT | Hydrogeological Assessment of Dune Lakes

Client: Northland Regional Council

Role: Jon was Technical Director for a study that assessed the importance of groundwater flows on dune lakes at Kai Iwi and Pouto Point, through the development of a catchment and lake water balance simulator connected to Jon's soil moisture water balance model (SMWBM).

PROJECT | Aupouri Aquifer Groundwater Model Update

Client: Northland Regional Council

Role: As consultant for the 2000 model developed, Jon was asked to work with the successful consultant on the 2014 model update and to undertake a formal peer review of the work undertaken.

PROJECT | Central Rail Loop (Contract 1 & 2) Early Works

Client: Fulton Hogan & John Holland Joint Venture

Role: Hydrogeological advisor on groundwater impacts and consenting requirements of a range of proposed underground station and tunnel construction methods.

PROJECT | Owner's Engineer: Wairakei Irrigation Stage 2 ($7M)

Client: Landcorp Farming Ltd

Role: Project & Design Manager. Development of a Concept Design, Tender Documents (RFT), interactive tender process, tender evaluations, contract award, contract administration, and construction supervision.

PROJECT | Project Raindrop (Confidential Multi-Purpose Water Storage & Use Scheme in North Canterbury).

Client: Integrated Water Rakahuri Limited

Role: Bib Manager for consortium comprising Jacobs, GHD and Jacobs Associates. Responsible for teaming arrangements and bid strategy. The project involved technical design elements for dam, canal, tunnel, mini-hydro power, irrigation distribution and irrigation demand.

PROJECT | Variation 1 of the Land and Water Plan (Environment Canterbury) for the Selwyn Waihora Catchment

Client: Central Plains Water Ltd (CPW)

Role: Validating a SOURCE water balance and balance model for the Selwyn-Waihora catchment.

PROJECT | Wairakei Estate Irrigation Engineering Options Study

Client: Landcorp Farming Ltd

Role: Design Manager. This project prioritised land for centre pivot irrigation, considered various intake and pipe reticulation options to utilise the available water take consents, and end with the development of a preferred concept design for the entire estate (3,500 ha).

PROJECT | Owner's Engineer: Wairakei Irrigation Stage 1 (Broadlands Farm) Irrigation Development ($2.5M)

Client: Landcorp Farming Ltd

Role: Project Director. Owner's Engineer & Hydrogeological Advisory Role on the D&C contract for the construction of an irrigation system. Tasks include preparation of tendering document, design review, contractor management and construction monitoring.

PROJECT | Hunter Downs Irrigation – Owners Engineer

Client: Hunter Downs Development Company Limited

Role: Irrigation scheme of 40,000 Ha, drawing water from the Waitaki River and irrigating the farmland north of the river to Otipua (immediately south of Timaru). The irrigation scheme will service between 200 and 300 landowners within a total command area of 60,000 hectares and has an estimated capital cost of approximately $400M.

PROJECT | Central Plains Water – Stage 1 Irrigation Distribution D&C Project

Client: McConnell Dowell Limited

Role: Bib Manager for SKM's Tender Design inputs into the McConnell Dowell bid.

PROJECT | Road of National Significance (RoNS) Pūhoi to Wellsford Pūhoi to Warkworth Section Planning Alliance

Client: New Zealand Transport Authority

Role: Lead Hydrogeologist providing investigation and assessment of hydrogeological impacts, and expert witness at Board of Enquiry. The project comprises an 18.5 km long 4-lane dual carriageway, with an estimated 8Mm^3 of earthwork cuts, each of which required hydrogeological investigation.

PROJECT | Mayfield-Hinds Irrigation Scheme Upgrade – Stage 1 and 2 Tender Design

Client: Fulton Hogan Limited

Role: Bid Manager and leadership of SKM's inputs, facilitated a risk workshop and participated in innovation workshops. The project involves the pressurising of the irrigation distribution system for 25,000 ha in South Canterbury.

PROJECT | Helensville Water Supply Groundwater Investigations

Client: Watercare Services Limited

Role: Jon provided technical leadership of a study than undertook desktop planning of drill hole locations, drilling investigations and hydraulic testing, water quality analysis and decision making on viability of new sources investigated.

PROJECT | Lower Piako Comprehensive Consent Monitoring

Client: Waikato Regional Council

Role: Project Director for a hydrogeological assessment of potential groundwater impacts on the Kopouatai peat dome from maintenance works (silt removal) in the Elstow, Northern, and Tee Canals. A conceptual hydrogeological model was developed to help inform the assessment of the efficacy of monitoring works. A recommended approach for a monitoring programme was presented to best accomplish the objective of identifying the impacts of maintenance works.

PROJECT | Ruataniwha Water Storage and Irrigation D&C Project

Client: McConnell Dowell Limited and Fletcher Construction Limited

Role: Bib Manager for SKM's inputs into McConnell Dowell & Fletcher Construction JV's bid. SKM was responsible for the distribution component of the bid.

PROJECT | Te Anau Basin Irrigation Pre-Feasibility Study

Client: Landcorp Farming Limited

Role: Project Director and Technical Lead for a study that investigated options for supplying water for irrigation in the Te Anau Basin. The study was undertaken under a MOU between Landcorp and Meridian Energy Limited, with a key objective being to maintain a net neutral or positive impact on hydro generation from the Manapouri Power Station.

PROJECT | Mangima and Mat-I 2/Mat-I 3 Hydroelectric Plants Feasibility Study

Client: Philnewriver Power Corporation (Philippines)

Role: Technical Direction and Peer Review on the hydrological yield components of the project.

PROJECT | Rajabasa Geothermal Development Project Water Supply Options

Client: PT. Supreme Energy

Role: Hydrological and hydrogeological review of Rajabasa (Indonesia) area to assess potential for a 60 L/s water supply. Work included development of a rainfall runoff model to assess catchment water balances.

PROJECT | Ohaaki Marae Geoscientific Peer Review of Subsidence and Hydrological & Hydraulic Assessment of Flooding

Client: Contact Energy Limited

Role: Technical Director and presented to the Marae Board and also at a Hui at the Marae on the study findings. Was later asked to develop evidence for a Maori Land Court case.

PROJECT | Whangamarino Wetland, Water Quality Influx Modelling Options

Client: Department of Conservation

Role: Technical Director for development of advice on modelling methodologies that could be used to estimate sediment and nutrient loads entering the wetland and to assess the effectiveness of potential mitigation options to improve water quality within the wetland.

PROJECT | Rajamandala Hydroelectric Power Plant - Technical Environmental Due Diligence

Client: Financiers: Japan Bank of International Cooperation and Mizuho for Sponsors: Kansai Electric Power and Indonesia Power

Role: Hydrology Technical Director and responsible for components of the Hydrological review.

PROJECT | Rantau Dedap Geothermal Project Water Supply Options

Client: PT. Supreme Energy

Role: Hydrogeological review of Rantau Dedap area to assess potential for an 80L/s groundwater supply and costs.

PROJECT | Southland Coal To Fertiliser Plant Water Supply and Discharge Pre-Feasibility Options Study

Client: Solid Energy NZ Ltd.

Role: Technical Director on a water supply and discharge study that determined the relative technical feasibility and cost-benefit of five identified options.

PROJECT | Onemana Town Water Supply Replacement Bore Procurement

Client: Thames Coromandel District Council

Role: Project and Technical Director for a programme of works to commission a new bore and decommission the bore being replaced. Work included development of a bore specification, undertaking of a tender process, preparation of a construction contract, appointment of a drilling contractor, and owners engineer on hydrogeological issues and contract issues during the construction process.

PROJECT | Lender's Technical Advisor for Ambuklao and Binga Hydropower Plants Refinancing

Client: Confidential

Role: Involvement in review of hydrology as lender's engineer for refinancing of the two power plants in the Philippines.

PROJECT | South Australia Energy Storage Options

Client: South Australian Government

Role: Peer review of the hydrological and geological aspects of a draft report entitled "Energy Storage Technologies, South Australia, Phase 1 & 2", which was prepared Sinclair Knight Merz and Worley Parsons.

PROJECT | Wairakei Geothermal Steamfield Groundwater Quality Review

Client: Contact Energy Ltd.

Role: Technical Director.

PROJECT | Coca-Cola Putaruru Source Vulnerability Assessment

Client: Coca-Cola Amatil (NZ) Ltd.

Role: Project and Technical Director for a study that involved review of the hydrogeology and artesian water supply risks at the Blue Spring, near Putaruru. The work was initiated as part of Coca-Cola's Global Watershed Management and Source Water Protection Program.

PROJECT | Coca-Cola Christchurch Operations Source Vulnerability Assessment

Client: Coca-Cola Amatil (NZ) Ltd.

Role: Project and Technical Director for a study that involved review of the hydrogeology and groundwater supply risks at the Woolston soft drink bottling plant, the Hornsby juice and powdered drink factory, and artesian water bore at Ouruhia. The work was initiated as part of Coca-Cola's Global Watershed Management and Source Water Protection Program.

PROJECT | Dam Storage versus Pumping Energy Costs Analysis

Client: North Otago Irrigation Limited

Role: Technical Director for a hydrological and economic modelling exercise to assess the optimal storage and pumping regime required to minimise pumping costs.

Sinclair Knight Merz Ltd, New Zealand

2010 to August 2011:

Section Manager – Water Resources Group

PROJECT | Peer Review of Rodney District Council Helensville Water Supply Scoping Report

Client: Auckland Council

Role: Jon provided technical direction on this review.

PROJECT | Ellerslie to Ascot Stormwater Upgrade

Client: Auckland Council

Role: Jon provided specialist hydrogeological advice on groundwater related impacts from the proposed 320m long, 1950 mm diameter micro-tunnel during resource consent condition negotiations with Council.

PROJECT | Groundwater-Surface Water Interaction Policy Review For Basalt Aquifers In Northland

Client: Northland Regional Council

Role: Project Director and Technical Reviewer for this study, which was undertaken in three parts: a) high level review of policy development and technical assessments undertaken both in New Zealand and internationally relating to surface water and groundwater interconnection, particularly in regards to applicability to basalt aquifer catchments; b) development of a conceptual groundwater model to independently evaluate key processes responsible for the interconnection between surface water and groundwater in basalt aquifers and enable the evaluation of the relative influence of management strategies/policies; and c) as case study of the Otakia surface water catchment, which is hydraulically linked to the Maunu-Maungatapere-Whatitiri aquifer, to inform decisions on surface water groundwater management.

PROJECT | Whitford Landfill Review of Surface Water & Groundwater Contaminant Trigger Levels for Consent Compliance

Client: Waste Management Ltd.

Role: Project Director.

PROJECT | Negotiation of Ancillary Agreement in Respect of Hydrogeological Matter Relating to Operation of the Ngatamariki Geothermal Power Station

Client: Wairakei Pastoral Ltd.

Role: Jon was WPL's technical expert and worked with WPL's corporate lawyers Harmos, Horton and Lusk to negotiate appropriate terms with Mighty River Power Limited.

PROJECT | Wentworth Valley Bore Refurbishment & Pipeline Connection Contract, Whangamata

Client: Thames Coromandel District Council

Role: Project Director for a project that included tendering of drilling services to clean out and put into services an existing production bore, installation of new monitoring piezometers, and a separate contract for construction of a

water pipeline and valves between the bore and reservoir at the water treatment plant, and RTU's and electrical controls.

PROJECT | Waterview Connection Tunnel and Great North Road Interchange. Tūhono Alliance

Client: Leighton Contractors and Fulton Hogan Limited

Role: Nine month secondment to alliance as Lead Hydrogeologist during the Statement of Interest and Abilities and Interim Project Alliance Agreement submission phases. The project involved turn out cost tender design for twin 2.8 km long 15 m diameter three land road tunnels. Alliance Partners included Leighton Contractors, Fulton Hogan Contractors, John Holland Tunnelling, SKM and AECOM.

PROJECT | Croydon Mine Aquifer Testing, Southland Lignite Mining PAG4

Client: Solid Energy NZ Limited

Role: Jon was Project Director and Technical Director for a commission to design and manage a programme of works that encompassed all the hydrogeological testing aspects associated with the proposed Croydon open cut lignite mine. This included drilling programme management (12 boreholes), logging of drill core, design and installation supervision of vibrating wire piezometers, preparation of installation manuals for vibrating wire piezometers, lugeon testing, design of a large diameter (200 mm) bore to 180 m deep for testing pumping, analysis and reporting.

PROJECT | Maungatapere Aquifer Sustainable Yield Study

Client: Northland Regional Council

Role: Jon was Project Director and Technical Director for the development of a groundwater model in FEFLOW to assess the impacts of pumping on some high aesthetic value springfed streams.

PROJECT | Tauhara II Geothermal Power Development

Client: Contact Energy Limited

Role: Preparation of evidence for EPA Board of Enquiry related to groundwater effects from the operation of the proposed geothermal power station.

PROJECT | Opoutama Wastewater Disposal AEE Peer Review

Client: Hawkes Bay Regional Council

Role: Technical director for a peer review undertaken by an intermediate hydrogeologist on behalf of the HBRC processing officer for a consent application to apply treated wastewater to land at a coastal Hawke's Bay settlement. The project involved technical review of hydrogeological components of the AEE, liaison with the applicant and their consultants, and provision of expert witness evidence at the resource consent hearing.

PROJECT | Wampu Hydroelectric Power Scheme - Technical and Environmental Due Diligence

Client: Korea Eximbank & SMBC

Role: Technical Director for the Hydrology review.

PROJECT | Proposed Central Canterbury Dairy Factory

Client: Fonterra Limited

Role: Water supply due diligence analysis and subsequent analysis (post sale and purchase agreement) to support changes in groundwater take consent conditions.

PROJECT | Lake Terrace Water Supply Pump Station Production Bores Review and New Bore Design

Client: Christchurch City Council

Role: Technical reviewer.

PROJECT | Reporoa Geothermal Power Development

Client: Genesis Energy Limited

Role: Technical lead on groundwater and surface water baseline monitoring reports and development of investigation work programme.

PROJECT | Ngatamariki Geothermal Power Development

Client: Wairakei Pastoral Limited

Role: Technical review of the applicant's AEE and preparation of various reports including an initial peer review and expert evidence for a Council hearing.

PROJECT | Tauhara II Geothermal Power Development

Client: Contact Energy Limited

Role: Technical lead on assessment of groundwater quality impacts from disposal of condensate and separated geothermal water. Included conceptual analysis, numerical modelling analysis, development of best practical options for managing land disposal, and reporting associated with the resource consent application.

PROJECT | Huntly Coal Seam Methane Project

Client: Solid Energy Limited

Role: Peer review of injection bore construction and testing. Specialist advice to the project team on numerical modelling to assess the groundwater impacts of deep well injection of dewatering brine from the coal measures. Peer review of the groundwater impact assessment report for a proposed pilot scheme and advice on RMA consenting strategy with respect to groundwater impacts.

PROJECT | Fonterra Kapuni Factory Water Supply

Client: Fonterra Limited

Role: Advice on technical and economic feasibility of a 500 m deep bore for factory water supply, along with assessment of alternatives and consultation with the existing incumbent water suppliers.

PROJECT | Pahiatua Bore Water Supply

Client: Tararua District Council

Role: Review of background reports on the bore construction and local hydrogeological setting. Provision of advice with respect to viability of the constructed bore to meet projected demands and water quality, and identification of other options.

Sinclair Knight Merz Ltd, New Zealand

May 2008 to 2010:

Client Manager – Water & Environment Business Unit

PROJECT | Feasibility Study of Managed Aquifer Recharge for Canterbury

Client: Environment Canterbury

Role: Preparation of a report outlining the concept of managed aquifer recharge and a conceptual scheme might operate on the Canterbury Plains.

PROJECT | Canterbury Meat Packers Groundwater Take Application

Client: Environment Canterbury

Role: Jon undertook a review of the geology and hydrogeological aspects of the application on behalf of Environment Canterbury and prepared a Section 42 Officers Report.

PROJECT | Kopuatai Peat Dome Drainage & Desktop Hydrological Study

Client: Department of Conservation

Role: A literature review and field survey to confirm history of drainage and current drainage configuration. The current knowledge of peat bog hydrology and a conceptual model of hydrological processes were developed. The current hydrological impacts on the wetland and the resulting vegetation distribution were assessed, along with the identification of preliminary management options from a hydrological perspective for maintenance of wetland habitat.

PROJECT | Huntly Power Station – Feasibility Study for Wastewater Disposal via Bore Injection

Client: Genesis Energy Ltd.

Role: A phase one desktop review was undertaken of publicly available hydrogeology data and geological records. Various options were identified and their relative merits compared, along with recommendations for the second stage.

PROJECT | Review of Barhill Chertsey Water Use Consents

Client: Environment Canterbury

Role: Undertook a review of the groundwater impacts associated with the proposed irrigation schemes, particularly focussing on the appropriateness of the groundwater model developed.

PROJECT | Review of Northland Coastal Aquifers

Client: Northland Regional Council

Role: Preliminary water balance assessments of numerous small coastal aquifers in Northland.

PROJECT | Peer Review of NZ Refinery SPH Spill

Client: Northland Regional Council

Role: Review of aquifer properties, likely plume dispersion and containment strategy.

PROJECT | Mataura Lignite Hydrogeological Studies

Client: Solid Energy NZ Ltd.

Role: Project director for a study that comprised hydrogeological and mine water management components. Key focuses included development of a groundwater model for groundwater impact assessment and seepage prediction, and GOLSIM model for mine water management.

PROJECT | East Taupo Arterial Catchment Hydrology & Stormwater Design

Client: Fulton Hogan Ltd.

Role: Jon's role in this design construct project of a new section of State Highway 1 bypassing Taupo involved technical review of the catchment hydrology simulations and implications for culvert design.

PROJECT | Coca-Cola Papua New Guinea Source Vulnerability Assessment

Client: PT Coca-Cola Indonesia Ltd.

Role: Project Director for SVA, which involved review of the hydrogeology and groundwater supply risks in the area of the bottling plant, as part of Coca-Cola's Global Source Water Protection Plan.

PROJECT | Coca-Cola Tahiti Source Vulnerability Assessment

Client: Coca-Cola South Pacific Pty Ltd.

Role: Project Director for SVA, which involved review of the hydrogeology and groundwater supply risks in the area of the bottling plant, as part of Coca-Cola's Global Source Water Protection Plan.

PROJECT | Valetta-Ashburton Groundwater Management Zone Hearing

Client: Environment Canterbury

Role: Jon undertook a review on behalf of Environment Canterbury and prepared a Section 42 Officers Report (expert evidence) of the Canterbury groundwater model used by 78 applicants for the assessment of the effects from their proposed groundwater takes (combined 3.6 m^3/s) for pastoral irrigation.

PROJECT | Upper Waikato Landuse Change Flood Hydrology Modelling Study

Client: Environment Waikato

Role: Jon had a lead scoping and technical review role on this project, which evaluated the flood hydrology impacts of land potential conversion from forest to pasture.

PROJECT | Lower Waikato Flood Protection Zone: Pump Station Service Level Review

Client: Environment Waikato

Role: Jon was Project Director for a technical assessment determining the hydraulic capacities of the pump stations throughout the Lower Waikato flood protection zone and to ascertain their ability to meet original design requirements. This assessment included the delineation of pump station catchments, a review of the pump station assets and capabilities, and the calculation of rainfall under a variety of rainfall criteria.

PROJECT | Governance of Water. A proposal by The Turnbull Group – July 2009

Client: N/a

Role: Jon was a member of the Turnbull Group, which was an independent, multi-sector body bringing together a group of people with substantial expertise and experience across a range of relevant disciplines and interests in water science, management and use. The group were committed to a solutions-based approach to improved water management and took a leadership role in the development of commonly agreed principles and structures through which competing interests in water resources could be reconciled.

PROJECT | Groundwater Technical Review: Consent Applications for the Construction and Operation of Tasman Mill North Valley Landfill, Kawerau

Client: Environment Bay of Plenty

Role: Preparation and presentation of Section 42A Officers' Report at Council Hearing

PROJECT | Wanganui Water Supply Groundwater Modelling

Client: Wanganui District Council

Role: Development of a finite element groundwater model for the assessment of sustainability and security of a municipal groundwater supply from a 100 to 700 m deep dipping shell rock aquifer.

PROJECT | Whangamarino Wetland Hydrology Study – Monitoring Plan

Client: Department of Conservation

Role: Investigation of the hydrological regime of Whangamarino Wetland in the Waikato region. The overall objective of the ongoing study is to understand the relationship between surface water inflows, wetland water levels, inundation extents and composition of wetland flora. The initial stage of the project involved revision of long term hydraulic modelling approaches and development of a monitoring plan for collection of meteorological and hydrological data.

PROJECT | Waipu Irrigation Ponds Hydrogeological Assessment

Client: Department of Conservation

Role: Site investigations and hydrogeological analyses to estimate potential groundwater inflow rates to irrigation ponds in Waipu, Northland. DOC required an understanding of potential mixing rates affecting planned fish eradication using chemical pesticides. A simplistic numerical modelling approach was used to understand groundwater dynamics at the site and provide estimates of potential groundwater inflow rates.

Sinclair Knight Merz Ltd, New Zealand

Feb 2006 to May 2008:

NZ Manager - Natural Resource Management Sector

PROJECT | Wetalla Pipeline EIS Groundwater Assessment

Client: SKM Internal

Role: Internal technical review of groundwater assessment report.

PROJECT | East-West Arterial Gateway EIS Groundwater Assessment

Client: SKM Internal

Role: Internal technical review of groundwater assessment report.

PROJECT | Pike River Underground Mine Hydrogeological Studies

Client: Pike River Coal Limited

Role: Jon was Project Director and personally responsible for the modelling components of this project. Work included a hydrogeological review of all the data collected for the mine resulting in an updated hydrogeological conceptualisation. A groundwater model was then developed and calibrated to measured field conditions and stream baseflows. The model was used to assess various construction issues including: prediction of seepage rates to a 4 m diameter ventilation shaft; assessment of the hydrogeological conditions on the footwall (wet) side of a semi-impermeable thrust fault; prediction of seepage to a 4 m tunnel as it penetrates the fault; and design of advance dewatering bore requirements.

PROJECT | Quarry Water Management Study

Client: McDonalds Lime Limited

Role: Technical Director for a modelling analysis of quarry water runoff and harvesting to meet the quarries water supply requirements. The GOLDSIM model was used to optimise the pond storage requirements given the various quarry water demands and losses.

PROJECT | Waikato River Flood Hydrology Technical Panel

Client: Environment Waikato

Role: Member of a five-person panel comprised of technical representatives from key stakeholders in the Waikato Catchment (Mighty River Power, Carter Holt Harvey, Wairakei Pastoral Ltd, Environment Waikato). The panel was charged with agreeing the science behind likely hydrological impacts from forest to pasture conversion on local stream, at the nine hydropower dams, and within the Lower Waikato.

PROJECT | Ahuriri Station Drainage Issues, Napier

Client: Landcorp Farming Limited

Role: Jon was Technical Director for a study that determined how much water flowed into the drainage system within the station during spring tide conditions from three outlet and calculated the difference to what was being pumped, which was due to groundwater up-welling within the station. This was aimed at determining whether the energy costs associated with pumping were reasonably proportioned amongst stakeholders. The study also provided an assessment of practicable engineering solutions for the removal of floating algae from the front inlet grill of the main drain pump-station. The algae required manual daily clearance during peak summer and an engineering solution was developed to facilitate removal of the algae in a more efficient, safe and cost-effective way.

PROJECT | Esk River Mini Hydropower Development

Client: Trustpower Ltd.

Role: Technical Director for a hydrological study assessing head pond storage options and power house flood levels for two 2 MW stations on separate tributaries. Study also involved scoping of hydrological monitoring and calibration of a stream flow model.

PROJECT | Takou Bay Station Irrigation Dam Analysis

Client: Landcorp Farming Limited

Role: Project Director for a study that assessed the costs and benefits of arable to irrigated dairy farming on a 400 ha dairy farm unit near Kerikeri. The study also evaluated the hydrology of Lake Monowai and the potential of the Kerikeri Irrigation Company supplying winter spills to a new dam on Landcorp's property. Goldsim modelling was undertake to integrate the operation of the Lake Monowai and the proposed dam and determine the optimal size of the new dam.

PROJECT | Traveston Crossing Dam Environmental Impact Statement

Client: Queensland Water Infrastructure

Role: Internal (semi-independent) reviewer for the groundwater impacts components of this project.

PROJECT | Waiheke Island Groundwater Modelling

Client: Auckland Regional Council

Role: Project Director for two separate MODFLOW modelling assignments (Waiheke West model and Oneroa/Onetangi model) that sought to assess sustainable yield, with bore drawdown and position of the saltwater interface key analysis criteria.

PROJECT | Diamond Aqua (Fiji) Mineral Water Bottling Plant

Client: Diamond Aqua Ltd.

Role: Analysis of likely hydrogeological conditions of the local aquifer, bore headworks and water treatment process to report on bore water security to meet US Health Officials requirements for bottled water imports.

PROJECT | Sweetwater Station Irrigation Concept Design and Cost Benefit Analysis

Client: Landcorp Farming Ltd.

Role: Concept design of an irrigation system for approximately 700 ha. Cost benefits analysis using engineering cost data and production data from Landcorp.

PROJECT | Aratiatia Station Irrigation Cost Benefit Analysis

Client: Landcorp Farming Ltd.

Role: Project Manager for a study that assessed the irrigation demand, water supply options, and centre pivot layout for pasture irrigation. A high level cost benefit analysis was then undertaken using input data from Landcorp.

PROJECT | Sweetwater Station Irrigation Groundwater Take Investigation and Consenting

Client: Landcorp Farming Ltd.

Role: Jon was Technical Director for a study programme that involved approximately 3 years of physical investigation (drilling and testing), modelling, analysis, reporting and Council Hearings work associated with a large water take application. Jon presented expert evidence at the Council Hearing.

PROJECT | Tairere Hills Dam Assessment & Water Management Plan for Kaikohe Water Supply

Client: Far North District Council

Role: Project Manager for a study that initially assessed suitable locations for a dam, potential dam storage volumes available, and pre-feasibility costs. A GoldSim model was prepared to optimise the dam storage requirements and operational management of the water supply system. This was used to inform the development of a draft Water Management Plan.

PROJECT | Kawakawa Riverbank Filtration Borefield

Client: Far North District Council

Role: Peer review of work undertaken by another consultant into an underperforming of newly established water supply borefield within a river floodplain.

PROJECT | Victoria Park Tunnel Specimen Design

Client: Transit NZ

Role: Technical Director for hydrogeological components of the specimen design development. Work included design of investigations, testing and monitoring requirements, determination of the site's hydrogeological conditions, development of a numerical model to assess engineering construction options for groundwater control and to determine impact/mitigation requirements.

PROJECT | Torbay Sewer Tunnel Upgrade

Client: North Shore City Council

Role: Development and simulation of a SEEP2D model to predict tunnel seepages and pressure head on the pipe pre and post construction upgrade.

PROJECT | Review of Water Allocation and Over-allocation Models

Client: Ministry for the Environment

Role: Project Director for project involving staff from Melbourne, Auckland and Christchurch, which provided a discussion documents of available water allocation policy options for Central Government to consider for different situations in New Zealand.

PROJECT | Hobson Wastewater Tunnel

Client: Watercare Services Limited

Role: Jon project managed the hydrogeological investigations, which included drilling and aquifer hydraulic testing, and Jon also undertook the development and simulation of a groundwater model to determine seepage rates to the 25x25 m access shaft in Orakei Domain, with different engineering options to mitigate seepage.

PROJECT | Jacks Bay Water Supply Review

Client: Tappenden Holdings Ltd.

Role: Project Director for review of existing groundwater supply for private estate at Jacks Bay. Work involved an integrated review of regional hydrogeological setting, borehole construction and performance, water treatment process and reticulation.

PROJECT | Waikato River Water Take Applications – Expert Evidence. April 2006.

Client: Wairakei Pastoral Limited

Role: Jon prepared and presented technical hydrological evidence for the applicant at the Environment Waikato Hearing for three large irrigation water take consent applications.

PROJECT | Tairua-Pauanui Water Supply Options Peer Review and Issues and Options Studies

Client: Thames Coromandel District Council

Role: Project Director for peer review of other consultants water supply options. The review resulted in identification of two water supply strategy options. The recommended strategy option was the development of a Water Management Plan approach. As part of the review work was undertaken to assess the potential of the various raw water source capacities identified within Controlled Activity guidelines and potentially available under a Discretionary Activity process. Work involved review of Tairua River catchment characteristics, development of a rainfall-runoff model and a dam flood routing model to determine dam storage requirements for three on- and offline dam options analysed. Other work included assessment of geological parameters for potential groundwater supplies from hard rock aquifers and alluvial aquifers using conventional and riverbank filtration technology.

PROJECT | King Orchards Irrigation Supply

Client: Far North Avocado Management Ltd.

Role: Project Director for planning the drilling and testing of irrigation bores for an avocado orchard. This involved the design of large diameter (250 mm) production bores and nested piezometer monitoring bores, preparation of a tender specification for the drilling works, and testing works to demonstrate negligible effect on aquifer sustainability and shallow dune wetland systems.

PROJECT | Awanui Artesian Aquifer

Client: Northland Regional Council

Role: Project Director for the development of a groundwater model for the Awanui Artesian aquifer. The objective of this work was to determine the likely effects of permanent closure of abandoned free flowing artesian bores on the surrounding environment. This will assist NRC decisions with regards to the sustainable management of groundwater resources in the area.

Sinclair Knight Merz Ltd, New Zealand

Jan 2003 to Feb 2006:

Water Resources Management Team Leader

PROJECT | Whitford Quarry Extension Hydrogeology Peer Review

Client: Auckland Regional Council

Role: Project Director for peer review of hydrogeological components of an application to deepen a hardrock quarry adjacent to a major municipal landfill.

PROJECT | Rawene Water Supply Options

Client: Far North District Council

Role: Project Director for a project that involved development of a rainfall-runoff model to assess design minimum flow requirements as part of a consent renewal process and options analysis for supplementary water supply. This was followed by a groundwater investigation drilling program.

PROJECT | Maungaturoto Water Supply

Client: Environmental Operation Ltd on behalf of Kaipara District Council

Role: Jon was Project Manager for a preliminary study that assessed the groundwater potential within the existing surface water supply catchments. The study then assessed the capability of an existing irrigation dam to augment the Maungaturoto water supply, including the Fonterra dairy factory.

PROJECT | Clearwater Orchard Irrigation Dam Design and AEE

Client: Clearwater Orchards Limited

Role: Project manager for 450 ML dam design and consenting project located in the Far North. Directly responsible for undertaking of hydrological yield modelling to determine optimal capacity of dam and residual flow requirements of contributing streams. Management of geotechnical investigations and dam design inputs, as well as the RMA planning and coordination of consultation. The resource consent was obtained without public notification.

PROJECT | Kaikohe Water Supply Groundwater Options

Client: Far North District Council

Role: Project Director for detailed assessment of groundwater aquifers in Kaikohe area. This review involved ranking of aquifer systems on the basis of multiple criteria assessment, and was used to develop an exploration drilling strategy.

PROJECT | Assessment of Effects of Decommissioned Underground Coal Mine on Water Quality in a Potable Supply Aquifer, Siersza, Southern Poland

Client: Central Mining Institute

Role: Jon was appointed foreign expert and spent 2 months in Katowice (Poland) initiating the 4-year EU funded project.

PROJECT | Tasman Solid Waste Landfill Hydrogeological Security Review

Client: Norske Skog Tasman

Role: Jon undertook a review of previous hydrogeological information and prepared a hydrogeological report on the landfill and identified any gaps in knowledge with respect to confirming the landfill's contaminant discharge hydrogeological security.

PROJECT | Otway Basin Drainage Scheme Hydrogeological Investigation

Client: Environment Waikato River and Catchment Service Group

Role: Jon was project manager for the project, which involved hydrogeological investigations and subsequent analysis to assess potential impacts on the Kopouatai peat dome from the proposed drainage scheme. A groundwater model was developed to assist development of engineering design options to mitigate any potential impacts.

PROJECT | Expert Witness June 2005

Client: Wairakei Pastoral Limited

Role: Jon was involved in the High Court proceedings in the matter relating to four references to the Proposed Waikato Regional Plan between Ecologic Foundation Inc. and Fish and Game Council against Environment Waikato Hearing. Jon prepared evidence for Wairakei Pastoral addressing the relief sought by Ecologic. The case was won by Wairakei Pastoral Limited and Carter Holt Harvey on jurisdiction issues.

PROJECT | Preliminary Site Appraisal of Mini-Hydro Power Schemes

Client: Vantage Group Ltd.

Role: Jon was project manager for a project that involved GIS mapping, and analysis of land surface gradients (particularly steep falls), catchment areas and flow characteristics for mini-hydro on Kiwi Forest Groups lands in Central North Island.

PROJECT | Whakatane Woodwaste Hydrogeological Investigations

Client: Environment Bay of Plenty

Role: Jon was Project Manager and Technical Director of an investigation into hydrogeological and groundwater quality characteristics of 40 decommissioned woodwaste landfills around Whakatane. The project investigated potential contaminant discharges from the sites including PCP's and dioxins.

PROJECT | National Farm Irrigation Study

Client: Landcorp Farming Ltd

Role: A high level irrigation demand analysis of every property in Landcorp's portfolio to inform the Landcorp Board on where irrigation should be considered.

PROJECT | National Farm Water Supply Study

Client: Landcorp Farming Limited

Role: Jon was project manager for a study that involved assessing the water supply arrangements for all of the farms with respect to regulatory, water security, water quality and future-proofing issues, identifying and ranking the risk for each operation, and prioritising improvements/changes. Landcorp have 60 farms in New Zealand's North Island and 40 farms in the South Island, ranging in size from approximately 1,000 ha to 180,000 ha. As Landcorp's business is heavily reliant on a secure supply of good quality water for stock and human consumption, shed washdown and to some extent irrigation, changes in central and regional government water management regulations has the potential to impact on Landcorp's business if constraints are imposed on future water abstraction.

PROJECT | Clearwater Avocado Development Water Supply Due Diligence Investigation

Client: Far North Avocado Management Ltd.

Role: Investigations were carried out to assess the water supply availability for irrigation of a proposed 300 ha avocado orchard. One deep bore to 180 m was drilled and when this was confirmed inadequate, focus was diverted to assessing the surface water supply and site potential for a dam. Hydrological modelling was carried out of the various streams and proposed dam and to assess the optimum dam size to meet the projected irrigation demand. Investigations were also initiated to determine underlying ground conditions and suitability for dam founding and construction material. Jon was project manager and technical director.

PROJECT | Northern Southland Groundwater Modelling Study

Client: Environment Southland

Role: Extending on the work completed for the Riversdale Aquifer, development of a transient MODFLOW model of the Riversdale, Longridge Waipounamu and Wendonside gravel aquifers. The model is currently being completed and will be implemented to defend water policy decisions that Environment Southland need to make with respect to pending groundwater abstraction consents and the impact on the Mataura River. Jon managed the project and modelling effort.

PROJECT | Sweetwater Orchards Groundwater Abstraction Consent Renewal

Client: Sweetwater Orchards

Role: Project Director for preparation of a groundwater take resource consent renewal.

PROJECT | Taupo Forest to Pasture Land Conversion Project

Client: Wairakei Pastoral Limited

Role: Jon is project manager for this multi-disciplinary project. Preparation of a consenting strategy associated with resource consent requirements for converting 25,000 ha of Pinus Radiata forest to dairy farms and possible irrigation of the farms. Following this, were commissioned to assess the regional economic impact and environmental impacts of the land conversion. Drilling program to facilitate aquifer hydraulic and water chemistry characterisation, and surface water quantity and quality benchmarking of the site under the existing forestry profile. Given the size of the

landholding, the study is effectively a regional groundwater study for the western Reporoa Basin and eastern Tauhara catchments.

PROJECT | Ihumatao Quarry Expansion Dewatering

Client: Auckland International Airport

Role: Commissioned to review groundwater and settlement predictions of the proposed quarry expansion adjoining Auckland International Airport's proposed northern runway. Jon conducted the groundwater modelling review and presented technical evidence at a Council Hearing between held jointly between Manukau City Council and ARC.

PROJECT | Waitaki Catchment Groundwater Investigation

Client: Ministry for the Environment

Role: Project Director for a comprehensive review of groundwater resources within the Waitaki catchment. Data was obtained from Environment Canterbury, their predecessor catchment board and Electricity Corporation of NZ archives. A component of the study identified the impact of seepage from canals on local groundwater resources of the Mackenzie basin.

PROJECT | Vailima Brewery Wastewater Disposal Study

Client: Samoa Breweries Limited

Role: Groundwater investigation to assess the fate of contaminants in the receiving environment from wastewater disposal pits installed at Vailima Brewery, Apia, Samoa.

PROJECT | Rangiputa Station Groundwater Consents and Drainage Issues

Client: Landcorp Farming Limited

Role: Jon project managed a study undertaken to secure retrospective consent for 3 bores with combined abstraction of 2,085 m^3/day. The project also involved preparation of advice with respect to the statutory framework and client's legal position in relation to flooding that had occurred on their land due to a downgradient neighbour blocking a major drain to the coast.

PROJECT | Henderson Bay Avocado Water Supply Due Diligence

Client: Far North Avocado Management Ltd

Role: Orchard irrigation water supply pre-purchase due diligence assessment.

PROJECT | Four Northland Aquifers Hydrogeological Assessments

Client: Northland Regional Council

Role: Preliminary hydrogeological investigations of groundwater resources at Coopers Beach/Cable Bay, Mangawhai, Glenbervie and Three Mile Bush. The studies were used to inform Regional Council of the groundwater flow regime, groundwater recharge and discharge dynamics, a preliminary sustainable yield estimate and to identify any information gaps and investigation and/or monitoring requirements. Jon's involvement in the project was as client champion and technical director.

PROJECT | Dargaville Water Supply Options Assessment

Client: Environmental Operation Ltd on behalf of Kaipara District Council

Role: Review of regional geology, and available groundwater bore details and consents to assess potential options and the feasibility of groundwater as a replacement potable water supply for Dargaville. The project progressed into an exploratory drilling programme targeting three aquifer types (coastal sands, inland sands and basalt).

PROJECT | Avocado Orchard Groundwater Supply Due Diligence Assessment

Client: Far North Avocado Management Ltd.

Role: Hydrogeological assessment to determine the technical and economic feasibility of groundwater supply for a proposed 150 ha avocado farm.

PROJECT | Mangere Tidal Storage Basin Wastewater Balancing Model

Client: Watercare Services Ltd.

Role: Jon was responsible for development of a dynamic computer simulation model that facilitated assessment of storage requirements and pumping regimes for operation of a Tidal Storage Basin system within the constraints of the discharge permit, which was governed tidal constraints in the harbour receiving environment.

PROJECT | Ruawai Town Supply Bores Hydrogeology and Bore Security Assessment

Client: Environmental Operation Ltd on behalf of Kaipara District Council

Role: Hydrogeological assessment of the Ruawai town water supply bores. The study was initiated during the options analysis process for improving the water quality of the water supply, which also included preparation of a resource consent renewal application. The primary objectives of the study were to: i) assess the security of the groundwater supply from surface influences in line with the NZDWS 2000 and ii) assess the impacts of pumping on other bores users. The study involved a downhole casing condition assessment using submersible camera, review of regional hydrogeology and water quality, groundwater modelling assessment of impacts and travel paths using MODFLOW and MODPATH, and formulation of recommendations for verifying the security of supply from surface contamination.

PROJECT | Kulwin Mineral Sands Mine Pit Dewatering Trial

Client: Professional Peer Review for SKM Risk Committee

Role: During the pre-tender phase of a multi-phase mineral sands mining project for Iluka Resources Limited a peer review panel (PRP) was established to audit the design of a mine dewatering trial pit. The objective of the PRP was to provide corporate assurance that any aspects of the project did not expose SKM to unacceptable levels of risk. Jon was chairperson of the PRP and responsible for reviewing technical aspects of the project, which revolved around the ability of a MODFLOW model developed to predict dewatering rates and provide fundamental design specifications for the dewatering borefield and water retention basin.

PROJECT | National Cost Benefit Analysis of Water Allocation in the Waitaki Catchment

Client: Ministry of Economic Development, New Zealand

Role: National cost benefit study of water allocation in the Waitaki Catchment in light of the government pending decision to introduce the Resource Management (Waitaki Catchment) Amendment Bill to Parliament in December 2003. The study was required to provide supporting information for the development of a water allocation framework and the aid the decision-making process for resource consent applications. Jon's involvement in the study involved researching the Environmental impacts of competing demands for water including Meridian Energy's Project Aqua hydroelectric scheme and a number of large community irrigation schemes. Jon also participated in two rounds of focussed workshops with irrigator, environmental, and recreation groups.

PROJECT | Ruawai Aquifer Management Zone Bore Survey and Preliminary Hydrogeological Study

Client: Northland Regional Council

Role: This study was commissioned to increase the level of hydrogeological understanding of the Ruawai aquifer and to assess primary issues of concern including: flowing artesian bores; effect of land uses on shallow groundwater (including dairying and horticulture); occurrence of poor water quality in some bores, especially elevated salinity, iron, and manganese; sustainability of groundwater abstraction (quantity available). The study involved a field survey of all the bores in the region, test pumping of four selected bores at strategic locations, water quality analysis, and hydrogeological analysis and reporting.

PROJECT | Wairua Falls Power Station

Client: North Power Ltd

Role: Assessment of the potential for upgrading the power station to meet the generation capacity of the exiting resource consent. Jon project managed the hydrology assessment components of the study. The study work included assessment of flow duration characteristics for winter and summer conditions in the Wairua River, and dry period correlation for ten known power crisis times between the Wairua River and other major hydro power rivers of New Zealand (Waikato and Clutha River systems). The likely generation capacity at the Wairua station was assessed for these times, when historical spot electricity prices were high.

PROJECT | Wastewater Treatment Plants Inflow and Water Balance Modelling Assessment

Client: Central Hawkes Bay District Council

Role: Jon was project manager for the assessment of inflow and storage capacities of the district's five wastewater treatment plants. The analysis was carried out using a dynamic simulation model developed by Jon.

PROJECT | Riversdale Aquifer Sustainable Yield Assessment

Client: Environment Southland

Role: Development and steady state calibration of a MODFLOW model for preliminary assessment of the aquifer dynamics and sustainable yield of the Riversdale gravel aquifer. Aquifer recharge is predominantly governed by water level in the Mataura River. Aquifer hydraulic conductivities are in the order of 100-500 m/day and a recent influx of large consent applications, some as much as 15,000 m^3/day, has raised concerns regarding the sustainability of the supply and effect on spring-fed stream and river flows.

PROJECT | Chelsea Sugar Refinery Environmental Audit & Groundwater Investigations

Client: New Zealand Sugar Company Limited

Role: Various projects were initiated following Section 92 requests for additional information on various discharge consents at the refinery and landfill. Jon's involvement included client champion and project manager for the multi-disciplinary site assessments including factory environmental audit, stormwater dye tracing and capacity assessment, groundwater contamination investigation, landfill capping material permeability assessment, landfill hydrogeology assessment, and geotechnical assessment of landfill slope stability.

PROJECT | Motions/Meola Closed Landfills Leachate Generation Mitigation Hydrogeological Study

Client: Auckland City Council – Utility Planning

Role: Project manager for a groundwater investigation to determine appropriate measures to mitigate landfill leachate generation. Work conducted includes review of existing information, development of a historical landfill deposition sequence plan, assessment of hydrogeological conditions from exiting information, identification and assessment of various options to either mitigate leachate generation or collect leachate discharge, and preparation of scope of works for a detailed field investigation and groundwater modelling assessment to confirm the suitability of the favoured options.

PROJECT | Kapiti Regional Rainfall Frequency Analysis

Client: Kapiti Coast District Council

Role: Technical manager for L-Moment method of regional rainfall frequency analysis and preparation of rainfall frequency isohyet maps generated using the kriging geostatistical method.

PROJECT | AB Lime Landfill Resource Consent Hearing

Client: Awarua Brown Lime Ltd.

Role: Preparation and presentation of Statement of Evidence at a Regional Council Hearing for the AB Lime proposed regional landfill. Evidence covered groundwater, surface water and ecological impacts and contingency measures.

PROJECT | Teidamu Springs Mineral Water Bottling Plant Proposal, Fiji

Client: Akhil Projects Limited

Role: Catchment hydrogeological and water quality assessment, consultation with Mineral Resources Department Fiji, and preparation of an Environmental Impact Statement to support a resource consent application to bottle mineral water from a natural spring emanating from fault brecciated basalt.

PROJECT | Russell Coastal Aquifer Sustainable Yield Groundwater Modelling Study

Client: Northland Regional Council

Role: Development of a MODFLOW model comprising 5,395 active cells in 3 layers representative of alluvium and the underlying clay and hardrock stratigraphy. The model was calibrated to seven years of groundwater level data from 6 boreholes. A soil moisture accounting model was used to precondition recharge for the groundwater model. Predictive simulations of the model assessed the position of the saltwater interface and aquifer management options.

Sinclair Knight Merz Ltd, New Zealand

May 2000 to Jan 2003:

Senior Hydrogeologist (Water Resource Specialist)

PROJECT | Assessment of Bore Performance and Sustainability of Proposed Abstraction Rates, Paparore, Far North

Client: Stanisich Orchards

Role: Analysis of bore drawdown data and assessment of sustainability and groundwater impact on neighbouring bores for a proposed abstraction of 500 m^3/day.

PROJECT | Kaitaia Golf Club Water Resource Consent Application

Client: Kaitaia Golf Club

Role: Project manager for the preparation of an AEE and resource consent application to the Northland Regional Council on behalf of the Kaitaia Golf Club. The project involved assessing the effects of abstracting 280 m^3/day of water from Lake Waimimiha, a coastal dune lake. A lake water balance model was developed, which comprised simulation of groundwater seepages and surface water runoff, and utilised historical daily rainfall and evaporation to assess the effects of irrigation pumping.

PROJECT | Assessment of Bore Performance and Sustainability of Proposed Abstraction, Houhora, Far North

Client: Terra Nova Orchards

Role: Provision of test pumping, analysis, and community consultation services to support a resource consent application for 300 m^3/day from a new irrigation bore. Assessment of time-drawdown and distance-drawdown to determine the aquifer hydraulic characteristics and the sustainability of the proposed pump rates.

PROJECT | Cosseys Dam Hydrological Flood Forecasting Model

Client: Watercare Services Ltd.

Role: Development and operation of an integrated catchment hydrology and dam flood forecasting model. The model runs automatically, obtaining input data from a MetService FTP site and real time data via GPRS link from the dam site, and is used to predict dam storage levels on a daily basis under five discharge regimes. Jon's involvement included development of the modelling software code and overall project management.

PROJECT | Peer Review of Silverfield Wastewater Storage Tank: Geotechnical and Groundwater Evaluation for Resource Consent Purposes

Client: North Shore City Council

Role: Peer review of the aquifer hydraulic testing and groundwater modelling aspects of the URS report. The work was undertaken to evaluate the likely groundwater and ground subsidence impacts from the proposed construction technique (piled soldier-and-waler support system) for a 10 m deep wastewater storage tank within an alluvial palaeochannel system.

PROJECT | Westcoast Farms Land Development Project

Client: Landcorp Ltd.

Role: Project Manager for the hydrology and hydrogeology aspects of a large AEE for New Zealand's largest farmer. Project involved landuse change and earthworks covering 5 farms with a combined land area of 4,500 hectares, Westcoast, South Island. Conversion of non-productive (swampy) farm lands into dairy farms with high stocking rates via "humping and hollowing" and "flipping" techniques. Investigations included assessments of change in hydrologic and hydrogeologic functionality of the land and impacts on catchment water balance, storm flows and water quality.

PROJECT | AB Lime Landfill Investigation

Client: Awarua Brown Lime Ltd.

Role: AEE for feasibility of developing a regional landfill within the decommissioned areas of an existing quarry. Project manager for hydrogeology, hydrology and leachate generation modelling aspects of the AEE.

Work conducted included:

- 350 m of HQ core drilling in the Winton Hill Limestone Formation and Chatton Mudstone Formation,

- packer testing and pump testing,
- installation of groundwater monitoring probes,
- hydrogeological analyses in including groundwater modelling,
- installation of surface water monitoring sites for flow and quality,
- development of a rainfall runoff model to access loss of runoff with landfill development,
- water balance assessment of leachate generation rates and site water management issues, including stormwater and leachate retention storage.
- production of three technical reports.

PROJECT | Mangere Asset Condition Risk Assessment Database

Client: Watercare Services Limited

Role: Development of a functional database for archival of asset data and condition risk assessment for the Mangere Wastewater Treatment Plant.

PROJECT | Waihi Dam Hydrology Study

Client: Eastland Power Ltd

Role: Project manager for hydrology assessment of issues associated with proposed modifications to the Waihi dam hydropower operational management. Involvement included calibration of a rainfall-runoff model, assessment of reservoir flood routing/water balances, prediction of power generation under differing operating scenarios and reporting.

PROJECT | Rangiora Wastewater Treatment Plant Hydrogeological Study

Client: Waimakariri District Council

Role: Project manager for a hydrogeological investigation of the groundwater conditions at the WTP site. Work included drilling and assessment of the feasibility and impacts of utilising the gravel alluvium for wastewater disposal.

PROJECT | Peer Review of Beverley Hills Borefield Groundwater Modelling Sustainable Yield Project, Whangamata

Client: Thames Coromandel District Council

Role: Peer review of Montgomery Watson groundwater modelling report that assessed the sustainability of groundwater pumping for the town supply bores at Whangamata, with regard for salt water intrusion and impacts on groundwater levels.

PROJECT | Deep Creek and Beach Haven Combined Stormwater/Sewer Tank Construction

Client: North Shore City Council

Role: Assessment of groundwater seepage to tank during construction and groundwater impacts using MODFLOW. Information used for the resource consent application and design of engineering solutions for construction dewatering.

PROJECT | Woodend and Waikuku Beach Wastewater Treatment Plants Status Report

Client: Waimakariri District Council

Role: Review of available data and formulation of preliminary status of the sites in relation to the environmental performance, on-going viability and additional data requirements for both sites. Involvement specifically concerned with effluent disposal to land.

PROJECT | North Shore Wastewater Treatment Plant Stage 4 Upgrade

Client: North Shore City Council

Role: Involvement in project comprised the following major tasks:

- Development, calibration and simulation of a dynamic flood routing model of the oxidation ponds for analysis of their water balance and discharge dynamics. The model was used to assess operating levels required to prevent overflows from 1 in 50-year event. Design events and time series data was simulated in the analyses.

- Stormwater modelling using XP-SWMM to assess oxidation pond cut-off channel modifications required to prevent overtopping into the ponds from a 1 in 50-year event. Also assessed modification to the dam wall of the largest contributing catchment to prevent spillway overflows from a 1 in 50-year event.
- Setup of geostatistical routines for calculation of oxidation pond sludge volumes that would require land disposal during the pond desludging operation.

PROJECT | Stage 2 Groundwater Contamination Investigation. New Plymouth

Client: MCK Metals Pacific Ltd.

Role: Onsite groundwater contamination investigation of a metal foundry (tap makers) site. Project involvement included design of aquifer hydraulic testing programme, analysis of aquifer monitoring and test data, estimation of potential contaminant migration and an overall project review role.

PROJECT | Whitford Landfill Piezometer Drilling Project

Client: Waste Disposal Services Ltd.

Role: Project management and design of drilling programme for replacement of monitoring piezometers.

PROJECT | Sweetwater Nurseries Bore Performance Analysis, Far North

Client: Hamilton Nurseries Ltd.

Role: Reassessment of pump test data and extrapolation of results to assess the potential drawdown effects on neighbouring properties. Preparation of technical report to be used as part of consent renewal application.

PROJECT | Whitford Landfill Advice to Peer Review Panel

Client: Auckland Regional Council & Waste Disposal Services Ltd.

Role: Review of monitoring and contingency plan for the protection of groundwater and surface water quality within a major Auckland landfill. Review of landfill hydrogeological security model and assessment of ongoing applicability for contaminant containment. Review and update of water quality trigger levels for both internal management (TL1) and regulatory body (TL2) purposes. Provision of geostatistical services relating to as-built landfill grade with respect to design.

PROJECT | Kaiapoi Wastewater Treatment Plant Short Term Consent Application

Client: Waimakariri District Council

Role: Development, calibration and simulation of a dynamic Windows based water balance model for the WTP that was used to determine the consent discharge requirements. The model included modules for simulating I/I flows to the plant based on antecedent conditions in the catchment, and modules for oxidation pond and wetland water balance. Built into the model was the flexibility to utilise time series output from a groundwater model for wetland infiltration losses.

PROJECT | Kaiapoi Wastewater Treatment Plant Hydrogeological Investigation

Client: Waimakariri District Council

Role: Hydrogeological study to assess the potential of enhancing ground soakage rates from a 34 hectares wetland used for disposal of treated effluent. Assessments of bacterial contaminant transport and optimisation of a pumping system to provide maximum utilisation of the filtration properties of the underlying stratigraphy from both a contamination and hydraulic perspective. Project involved drilling and test pumping of six boreholes to determine vertical pressure gradients and typical aquifer properties, and development of MODFLOW and MT3DMS models.

PROJECT | Three Kings Stormwater Soakage Hydrogeological Investigation

Client: Metrowater-Auckland City Council

Role: Project Manager/Principal Modeller. Investigation into the hydraulic capacity and feasibility of fractured basalt flows to accommodate stormwater from a landlocked catchment prone to flooding. Also investigated the aquifer impacts from soakage disposal using a MODFLOW model, and determined the optimal soakage borefield configuration, including bore numbers, depths and spacing. Field investigations included a GPR survey to delineate the basalt and tuff areas, air-percussion drilling of 11 boreholes, monitoring with Solinst Leveloggers, constant

discharge injection and test pumping. A three-dimensional geological model was developed using GMS to conceptualise the site and exported directly to the groundwater model.

PROJECT | Review of Nine Northland Aquifers Extents

Client: Northland Regional Council

Role: Mapping of nine vulnerable aquifer extents in terms of their logical geological and cadastral boundaries for groundwater management purposes and inclusion in Council's Regional Plan. Aquifers mapped included Aupouri, Bland Bay, Coopers Beach–Cable Bay, Mangawhai, Matarau, Maunu, Oakura, Ruawai, Taipa.

PROJECT | Groundwater Investigation and Modelling of the Former Phyllis Street Landfill

Client: Auckland City Council – Utility Planning

Role: Project Manager/Principal Modeller. Following embankment failure along a seepage face after a significant storm event, the council commissioned a hydrogeological investigation to increase their level of understanding of the geological and hydrogeological conditions of the site and to determine whether perched water tables or generally high regional groundwater levels were responsible. A GPR survey followed by a drilling and testpit excavation program was carried out. Results from this were used to conceptualise the site hydrogeology using the GMS stratigraphy modelling packages. A three-dimensional groundwater model (MODFLOW) was developed to predict historical groundwater levels.

PROJECT | Chamberlain Park Golf Course Groundwater and Baseflow Impact Modelling Study

Client: Auckland City Council

Role: Project Manager/Modeller. Two phased study aimed at assessing the efficiency of the irrigation management system and determining impacts on Meola Creek and Western Springs from increased groundwater abstraction at the golf course for irrigation. A dynamic soil moisture water balance model (SMWBM) was utilised for irrigation analysis. A MODFLOW groundwater flows model was developed including transient calibration to assess the groundwater and baseflows impacts from increased abstractions. The study also involved assessment of historical irrigation efficiencies using SMWBM and recorded irrigation usage data.

PROJECT | Lower Waitaki Alluvium Groundwater Investigation

Client: Otago Regional Council

Role: A regional bore survey to identify the location, ownership, purpose and specifications of bores, landuse practices at each property, and determine the suitability of each bore for subsequent water quality and quantity monitoring. Monitoring was subsequently conducted over a nine-month period for 20 bores and analysis of results determined the seasonal variation in water quality due to broadacre pasture irrigation and identified potentially contaminated areas. An assessment of aquifer flow rates and hydraulic characteristics was conducted in addition to an assessment of seasonal pressure fluctuations and aquifer water balance.

HydroGeo Solutions, Auckland

August 1998 to May 2000:

Hydrogeologist

PROJECT | Hikurangi Swamp Hydrological Instrumentation

Client: Whangarei District Council

Role: Supply and installation of six automated water pressure sensors and associated interface and power supply. Equipment will be used to measure flood levels on the levee banks adjacent to the river and monitor controlled flooding of swamp pockets

PROJECT | Groundwater Remediation, Auckland

Client: Skellerup Industries Ltd.

Role: Monitoring and sampling of groundwater bores and trade waste sewers for BTEX constituents. Maintenance and rehabilitation of nutrient injection bores blocked by biofouling.

PROJECT | Tomarata Sand Quarry Groundwater Consent Reporting, Northland

Client: Manukau Consultants Ltd.

Role: Analysis of groundwater monitoring, local rainfall and groundwater abstraction data since commencement of sand extraction in March 1997. Reporting of groundwater impacts.

PROJECT | Kawakawa Sewage Treatment Plant Hydrological Modelling, Northland

Client: Environment and Business Group Ltd.

Role: Provision of specialised hydrological expertise to aid in the resource consent application for the STP. A dynamic Windows based Sewage Treatment System Water Balance Model (STSWBM) was developed to assess and predict daily sewage inputs to the STP and optimise oxidation pond volume and pumping configurations to minimise non-compliant discharges.

PROJECT | Assessment of Bore Performance and Sustainability of Proposed Abstraction Rates, Paparore, Far North

Client: Private Orchards

Role: Provision of test pumping, analysis, and community consultation services to support a resource consent application for irrigation bore. Assessment of time-drawdown and distance-drawdown was performed to determine the aquifer hydraulic characteristics, groundwater impact on surrounding bores and sustainability.

PROJECT | Aupouri Aquifer Sustainable Yield Groundwater Modelling Study

Client: Northland Regional Council

Role: Project Manager/Modeller. Groundwater modelling study to enhance Council understanding of the regional aquifer system and provide guidance on management and allocation of the groundwater resource. Study comprised review of hydrogeological data and development, transient calibration (1987-1999) and sensitivity analysis of a two-layered regional MODFLOW model representing an area of 430 square kilometres. A soil moisture model was used for preconditioning groundwater recharge to the MODFLOW model.

PROJECT | Assessment of Water Management Performance and Strategies of three adjoining mines owned by Rio Tinto Coal NSW (Howick, Hunter Valley and proposed Carrington mine)

Role: Mines currently (1999) operated independently with study required to determine the feasibility of a combined water management system.

PROJECT | Cooks Beach Treated Effluent Irrigation Groundwater Modelling

Client: Tonkin & Taylor Ltd.

Role: Modeller. Conceptualisation and development of single layer MODFLOW model with three permeability zones to assess the groundwater impacts and likely contaminant transport rates from effluent irrigation. Utilisation of a soil moisture accounting model for preconditioning groundwater recharge inputs into the groundwater model. Transient calibration to an 85-day irrigation trial.

PROJECT | Pauanui-Tairua Sewage Treatment Upgrade Hydrological Assessment

Client: Environment and Business Group Ltd.

Role: Assessment of the relationship between sewage inflow volumes, disposal discharge volumes, oxidation pond levels and rainfall for the Pauanui Wastewater Treatment Plant.

PROJECT | Russell Sewage Treatment Plant. Northland

Client: Environment and Business Group Ltd.

Role: Analysis of stream flow data prior to and post commencement of a deep bore injection field for treated effluent. Determination of increase in baseflow to the adjacent stream as a result of this.

PROJECT | Lake Conjola - Additional Groundwater Modelling, South Coast, NSW

Client: NSW Dept. Public Works & Services

Role: Modeller. Reassessment of the capability of dunes sands to accommodate treated effluent exfiltration system. Trench system relocated and model reconfigured to include peak monthly and seasonal effluent loadings in transient simulations.

PROJECT | Groundwater & Contaminant Transport Modelling of Varsol Spill, Tannery Factory Site, Richmond, Victoria

Client: Victoria Environmental Protection Authority

Role: Assessment of the future impact on the Yarra River from numerous white spirit spills, incorporating the remedial effects of a cut-off and wall drainage system in the model.

PROJECT | Lake Conjola Sand Dune Exfiltration Study, South Coast NSW

Client: NSW Dept. Public Works & Services

Role: Hydrogeological assessment of the suitability of a back-beach dune system for disposal of treated effluent, and the impact on local water body receptors. A regional groundwater flow model using MODFLOW was developed to aid in the analysis.

PROJECT | Whites Creek Waste Management Facility, Maitland, NSW

Client: Theiss Environmental Services

Role: A regional groundwater model MODFLOW was developed to assess the impacts of mining from two nearby operations on groundwater elevations within the proposed landfill, which is to be situated within a decommissioned open cut void at the Bloomfield Colliery. Predictions were also made of the timing for ultimate groundwater recovery post-mining considering the altered rock hydraulic properties within the mined areas.

PROJECT | Residential Development & Sewerage Irrigation Scheme, Wyong, NSW

Client: Coffey Geosciences Pty Ltd.

Role: Development and steady state calibration of MODFLOW model. Numerical contaminant transport modelling via coupling of groundwater flow model to the mass transport model MT3D. Assessment of contaminant distributions after twenty years of irrigation for various application concentrations.

PROJECT | Gerringong and Gerroa Sewerage Treatment Plant Sand Dune Disposal Concept Design, NSW

Client: Baulderstone Hornibrook

Role: Development of a MODFLOW model to assess various site options and possible impacts on nearby receptors of sand dune disposal of secondary treated effluent.

PROJECT | Spoil Runoff and Soil Moisture Infiltration Study, Hunter Valley Mine, NSW

Client: Rio Tinto

Role: Construction of v-notch weirs on two spoils runoff catchment plots and installation of piezometers in adjacent areas. Correlation study of rainfall versus catchment runoff and monitoring of runoff salinities. Analysis of soil moisture infiltration front for discrete storm events. Soil moisture data collection from 16 sensors through the spoils profile. Comparison of soil water percolation on nearby undisturbed alluvial lands to rehabilitated spoils.

PPK Environment & Infrastructure, Sydney (formerly Rust PPK)

April 1995 to August 1998:

Hydrogeologist

PROJECT | Nebo Creek Alluvium Sustainable Yield Study, Nebo, Central Eastern Queensland

Client: Nebo Shire Council

Role: Development and calibration of a single layer MODFLOW model of the Nebo Creek alluvial aquifer consisting of 2,700 active cell and covering an area of approximately 50 square kilometres. Review of hydrological data and determination of aquifer recharge mechanisms. Calibration of an AWBM rainfall-runoff model to measured streamflow using the 100-year historical rainfall record for Nebo. The long-term synthetic streamflow record was utilised for determining the recharge component in the MODFLOW model. Modelling enabled predictive simulations for assessment of sustainable yields and appropriate resource management.

PROJECT | Yandicoogina Channel Iron Deposit, Pilbara, Western Australia

Client: Hamersley Iron

Role: Development of a MODFLOW model to predict future drawdown rates during advance dewatering and to assess various pumping configurations for optimising dewatering within a minimal timeframe. Transient calibration of the model to field measurements at eight observation bores.

PROJECT | Karuah Landfill and Sewerage Ponds, Karuah, NSW

Client: Port Stephens Council

Role: Hydrogeological and water quality investigation in and surrounding the existing solid waste landfill and sewage ponds, and subsequent development of rehabilitation management plans. Comprehensive field investigation involving test pits, drilling and hydraulic testing of numerous boreholes, piezometer installation, groundwater, pond water and soil sampling for water quality analyses.

PROJECT | Raymond Terrace Landfill, Raymond Terrace, NSW

Client: Port Stephens Council

Role: Hydrogeological and water quality investigation in and surrounding the existing operating solid waste landfill and adjoining wetland areas. Comprehensive field investigation involving drilling and hydraulic testing of numerous boreholes; piezometer installation; borehole and surface water sampling for heavy metals and relevant organic compound analyses. Subsequent development of surface water and rehabilitation management plans based on findings of field study.

PROJECT | King Park Decommissioned Landfill, Raymond Terrace, NSW

Client: Port Stephens Council

Role: Hydrogeological and water quality investigation in and surrounding the existing closed solid waste landfill (playing fields) and adjoining river. Comprehensive field investigation involving test pits, drilling and hydraulic testing of numerous boreholes; piezometer installation; borehole and river sampling for water quality analyses, and soil samples for heavy metals and relevant organic compound analyses. Subsequent development of rehabilitation and contamination dispersion mitigation plans based on findings of field study.

PROJECT | Mobil Service Stations, NSW

Client: Mobil Oil

Role: Aquifer tests to determine hydraulic properties of the site geology and preliminary contaminant transport assessments for numerous sites.

PROJECT | Esfahan Metro Light Rail Tunnel Feasibility Study, Iran

Client: Esfahan Regional Metro Company

Role: Development of a three dimensional plan and a vertical MODFLOW model to assess effects on alluvial groundwater regime from sheet piling during construction of light rail tunnel, dewatering requirements and the impacts of dewatering on world heritage buildings.

PROJECT | Anna Bay Wetlands Study, Port Stephens, NSW

Client: Hunter Water Corporation

Role: Hydrogeological investigation to determine degree of coupling between the wetland sediments and underlying sands. Involved vibro-coring, installation of piezometers, bail down tests, pump tests and permeameter tests.

PROJECT | Brown's Mountain Co-disposal Emplacement Area, Hunter Valley, NSW

Client: Kayuga Coal

Role: Exploratory drilling to delineate location and extent of reverse fault. Hydraulic testing conducted within the regolith and fresh rock along the fault zone to determine likely seepage rates and suitability for tailings beach (dam).

PROJECT | Glendell Colliery (Liddell Joint Venture), Hunter Valley, NSW

Client: Glendell Coal

Role: In-situ testing of interburden, coal and alluvium lithologies for bulk and discrete unit hydraulic conductivities using pneumatic straddle packer assemblages, test pumping and slug tests. Development of regional finite element

plan model (AQUIFEM-N) to evaluate groundwater impacts on both alluvial and hardrock aquifers from mining induced depressurisation. Estimation of pit seepage at various stages of mine development and design of dewatering strategy.

PROJECT | Glendell Coal, Hunter Valley, NSW

Client: Glendell Coal

Role: Reconfiguration of finite element groundwater model to formulate dewatering strategy and optimise production bore configuration and pumping rates.

PROJECT | Anna Bay Sand Aquifer Model, Port Stephens, NSW

Client: Hunter Water Corporation

Role: Development of a single layer finite element groundwater model (AQUIFEM-N) comprising 2165 elements defined by 1190 nodes and representing an area of 26.5 square kilometres. Transient calibration was conducted using historical groundwater data for 33 monitoring piezometers from 1979 to 1995. Predictive modelling enabled assessment of sustainable aquifer yields, suitability of one bore as aquifer status indicator and design and positioning of future production bores.

PROJECT | Anna Bay Sand Aquifer Model, Recalibration, Port Stephens, NSW

Client: Hunter Water Corporation

Role: Recalibration of existing model utilising improved base of aquifer information and rainfall-runoff-percolation model as pre-condition for determining recharge input to AQUIFEM-N model.

PROJECT | Hunter Valley Coal Mine Alluvial Lands Groundwater Study, Hunter Valley, NSW

Client: Coal & Allied

Role: Test pumping of alluvium to determine hydraulic conductivities and suitable locations for future dewatering bores installations.

PROJECT | Gold Project, Osborne Copper

Client: Placer Pacific Limited

Role: Development of regional computer numerical model (AQUIFEM-N) to assess potential groundwater resource and optimal borefield configuration. Verification and recalibration of model to new data.

PROJECT | South West Rocks Sewage Treatment Plant Balance Tank Augmentation Study, NSW

Client: NSW Dept. Public Works

Role: Design and development of a dynamic stormwater-runoff water balance model for assessing the required storage capacity of a proposed balance tank or alternative disposal methods given projected increase in daily loadings.

PROJECT | Comprehensive Mine Water Management Studies

Role: Numerous studies were conducted over three years, each essentially involving:

Assessment of peak discharge rates for mine catchments using the Rational Method for sizing of reticulation and storage facilities.

Assessment of the historical performance (frequency of overflows, frequency of make-up water requirements) of proposed and (in some cases) operational mine water management systems through time-series simulation of catchment runoff with a dynamic soil moisture accounting model.

Development of operational rules for the water management system in line with regulatory requirements for each area.

Various clients where mine hydrology assessments were conducted included:

- Drayton Coal Mine (Upper Hunter Valley, NSW),
- Howick Coal Mine (Upper Hunter Valley, NSW),
- Muswellbrook Open Cut Coal Mine (Upper Hunter Valley, NSW),
- Mt Pleasant Coal Mine (Upper Hunter Valley, NSW),

- Kayuga Open Cut Coal Mine (Upper Hunter Valley, NSW),
- Dartbrook Underground Mine (Upper Hunter Valley, NSW),
- South Lemington Coal Mine Extension (Hunter Valley, NSW),
- Bengalla Coal Mine (Upper Hunter Valley, NSW),
- Mt Owen Coal Mine (Hunter Valley, NSW),
- Warkworth Coal Mine (Hunter Valley, NSW),
- Hellyer Base Metal Mine (Tasmania), and
- Hunter Valley Coal Mine (Hunter Valley, NSW).

PROJECT | Hunter Valley Coal Mine Floodplain Dewatering Project, NSW

Client: Coal & Allied

Role: Monitoring and analysis of groundwater levels on a monthly basis for a period of two years. Assessment of aquifer properties for determining production and observation bore locations and specifications, and production of monthly-summary dewatering progress reports.

PROJECT | Pit Stability Investigation, Glendell Coal Mine, Hunter Valley, NSW

Client: Glendell Coal

Role: Drilling and drill core logging of all geotechnical aspects (lithology, joint spacing, hardness etc.).

PROJECT | Electroresistivity Survey Sussex Inlet, NSW

Client: NSW Department of Public Works and Services

Role: Investigation of depth to base of sand aquifer in the Sussex Inlet area.

PROJECT | Rhondda Colliery Fire Extinguishment, Lake Macquarie, NSW

Client: Coal & Allied

Role: Initiation of project to extinguish fires from old underground working. Development of thermal distribution mapping to assess extent of fires. Thermal infra-red air surveys conducted to determine fire migration.

PROJECT | Groundwater Quality Sampling, Hunter Valley Mine, NSW

Client: Coal & Allied

Role: Sampling and analysis of water from the Hunter River, adjacent alluvium and underlying coal measures. Characterisation of the water chemistry and determination of degree of mixing and occurrence of leakage through a 4 km long cut off wall.

PROJECT | Groundwater Monitoring, Glendell Coal Mine, Hunter Valley, NSW

Client: Glendell Coal

Role: Monitoring of groundwater levels within hardrock and alluvium piezometers with automated recorder. Quarterly analysis and reporting of groundwater chemistry and levels for two years.

Waikato University

March 1993 to February 1995:

Masters Research

PROJECT | Measurement and Modelling of Evaporation Processes, Wetland (Peat Bog), North Island, New Zealand.

Role: Evaporation measured using Bowen Ratio Energy Balance technique. Penman-Monteith Model used diagnostically to estimate bulk canopy resistances with various meteorological conditions and degrees of canopy wetness. Penman's open water potential evaporation equation evaluated as means of predicting evaporation rates from limited set of meteorological data. Water balance calculations performed utilising evaporation and other measurements.

Publications

- Williamson J.L. and Zhao, H., 2018. Water Quality Model Performance Evaluation Methods. Hydrological Society & Meteorological Society of NZ Joint Conference. 4 to 7 December 2018.
- Williamson J.L., 2017. Development Of Vadose Zone Functionality For Regional Scale Catchment Modelling In eWater Source. New Zealand Hydrological Society Conference. 28 November to 1 December 2017.
- Zhao, H., and Williamson, J.L., 2017. MODPATH Simulation and Post-Processing for Estimating Flow-Weighted Groundwater Age. New Zealand Hydrological Society Conference. 28 November to 1 December 2017.
- Diack, E.E. and Williamson J.L., 2017. Disaggregation Of Total Nitrogen Input Loads For Utilisation In Source Catchment Modelling. New Zealand Hydrological Society Conference. 28 November to 1 December 2017.
- Loft, J., and Williamson J.L., 2017. Scientific Discovery Through Utilisation Of The Source Catchment Model In The Bay Of Plenty. New Zealand Hydrological Society Conference. 28 November to 1 December 2017.
- Williamson, J.L. and Diack E.E., 2016. Parameterisation and Simulation of the SMWBM within the SOURCE Catchment Model. New Zealand Hydrological Society & Australian Hydrology and Water Resources Symposium. 28 November to 2 December 2016.
- Williamson, J.L., and Sheppard, M., 2010. Managed Aquifer Recharge: Sustainable Water Resource Management on the Canterbury Plains, NZWWA 2010 Annual Conference.
- Williamson, J.L. and Wesra, S., 2008. Climate Change Impacts on Groundwater Recharge in New Zealand. Proceedings of the New Zealand Hydrological Society & Meteorological Society of New Zealand Joint Conference. Shantytown, 17 – 20 November 2008.
- Williamson, J.L., James, D, Outram, P.M, and Hinson, B., 2008. Tairua Pauanui Water Supply Issues and Options Study. Proceedings of the 50th Annual Conference and Expo of the New Zealand Water and Wastes Association.
- Williamson, J.L. and Outram, P.M., 2007. Dynamic Computer Simulation Informing Water Management Plans For Municipal Supply Schemes. Proceedings of the 49th Annual Conference and Expo of the New Zealand Water and Wastes Association.
- Williamson, J.L., 2006. Balancing Environmental and Economic Outcomes for Agricultural Sustainability. Invited speaker at NZ Resource Management Law Association Annual Conference.
- Outram, P.M., and Williamson, J.L., 2006. Detailed Stream Assessment and Strategic Allocation for Water Supply Development. Proceedings of the New Zealand Hydrological Society 2006 Symposium, Christchurch.
- Williamson J. L., 2005. Assessment of mine flooding process on groundwater in aquifers surrounding the decommissioned Siersza Mine. Preliminary modelling report (Draft A, 20/7/05). Główny Instytut Górnictwa, Katowice, Poland.
- Williamson, J.L. and Hughes, B., 2004. The Northern Southland Groundwater Model - A Classic Model Setting but Modellers Nightmare. Proceedings of the New Zealand Hydrological Society 2004 Symposium, Queenstown 17-18 November 2004.
- Williamson, J.L., 2004. Demonstrating The Hydrogeological Security of a Site Situated In Karst for the New Southland Regional Landfill. 16th Annual Conference of the Waste Management Institute New Zealand Inc, Auckland 9-11 November 2004.
- Williamson, J.L., 2003. Cosseys Dam hydrological forecasting model. Proceedings of the New Zealand Hydrological Society 2003 Symposium, Taupo 18-21 November 2003.
- Williamson, J.L. and Jones, D.A., 2003. Coastal aquifer modelling at Russell. Proceedings of the New Zealand Hydrological Society 2003 Symposium, Taupo 18-21 November 2003.
- Williamson, J.L., 2002. Hydrological implications of hump and hollowing on the West Coast, South Island, New Zealand. Proceedings of the New Zealand Hydrological Society 2002 Symposium, Blenheim 3-6 December 2002.
- Williamson, J.L., 2002. Hydrogeological investigations for enhancing infiltration of treated effluent at the Kaiapoi WWTP, Canterbury, New Zealand. Proceedings of the New Zealand Hydrological Society 2002 Symposium, Blenheim 3-6 December 2002.
- Swabey, S and Williamson, J.L., 2002. Karst hydrogeology and landfills – A case study from Southland. Proceedings of the New Zealand Hydrological Society 2002 Symposium, Blenheim 3-6 December 2002.
- Williamson, J.L., 2002. An Integrated Catchment Management Approach to Flood Mitigation in Meola Catchment, Three Kings, Auckland. Accepted for the New Zealand Water and Wastes Association Annual Conference, Christchurch, NZ.

- Williamson, J.L., 2002. Model for simulating I/I flows and water balances of wastewater treatment plants. Accepted for the New Zealand Water and Wastes Association Annual Conference, Christchurch, NZ.
- Williamson, J.L., 2000. Regional analysis of the Aupouri aquifer for sustainable development, Northland, New Zealand. Abstracts of the Fresh Perspectives Conference (Joint Conference of NZ Hydrology, NZ Meteorological & NZ Limnological Societies).
- Mackie C, Williamson J.L. and Finnegan L., 1998. Computer based modelling of the Anna Bay Sand Beds for Sustainable Development. IAH International Groundwater Conference, Melbourne.
- Campbell D.I. and Williamson J.L., 1997. Evaporation from a raised peat bog. Journal of Hydrology, 193, pp 142-160.
- Williamson J.L., 1995. Evaporation, Energy and Water balance Studies from the Kopouatai Peat Dome, North Island, New Zealand. Unpublished MSc Thesis, University of Waikato.
- Williamson J.L. and Campbell D.I., 1994. Evaporation form the Kopouatai peat dome. NZ Hydrological Society, 1994 Symposium.

Awards

- 2004 John Winton (Environmental Business Unit) award for outstanding technical paper. “An Integrated Catchment Management Approach to Flood Mitigation in Meola Catchment, Three Kings, Auckland”.

Completed Courses

- eWater SOURCE. New SOURCE Functionality. Training course presented by eWater in Auckland, 6-7 December 2016.
- Customising eWater SOURCE. Introduction to customising Source through the development of plugins. Canberra, 8-10 March 2016.
- Jacobs eWater SOURCE Internal Training Workshop. Fundamental principles and development of SOUCRE models. Auckland, 13-14 November 2014.
- Sinclair Knight Merz Project Management 3. Introduction to Capital Project Delivery, 2012.
- Sinclair Knight Merz Future Leaders Program, 2011. Coach.
- Construction Contracts Administration Course. University of Auckland (Completed 2008)
- Sinclair Knight Merz Future Leaders Program, 2007 and 2010. Facilitator.
- FEFLOW Groundwater Modelling Course. Centre for Groundwater Studies. Brisbane, October 2007.
- SKM Managing People Course (2006)
- Making Good Decisions Commissioner Training Course - University of Auckland, NZ. April 2007.
- SKM Commercial Manager Training.
- SKM “Presentation of Technical Information”. May 2000.
- Model Calibration and Predictive Analysis using PEST. Presented by John Doherty (PEST Author). Palmerston North, November, 2001.
- Groundwater Recharge Workshop. 3rd–4th July 2000. Canterbury Regional Council & Institute of Geological & Nuclear Sciences.
- Advanced Visual Basic Programming – October to December 1998. Northern Sydney Institute of TAFE (Hornsby Campus).
- Advanced Visual Basic Database Programming – 4801CJ, April to June 1998. Northern Sydney Institute of TAFE (Hornsby Campus).
- Modelling Multi-Component Contaminant Transport, July 1997. ANSTO & University of Technology Sydney.
- Rust PPK inhouse training – “Internal QA/QC Auditors Course” March to September 1996.

Appendix B. Review Of HRWO Project Groundwater Studies

1 A number of reports were commissioned by the Technical Leaders Group (**TLG**) for the HRWO Project 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, as summarised in **Table 1**.

Table 1. Summary of available PC1 groundwater reports.

No.	Report Tile	Author(s)	Date	Organisation
1.2	Groundwater resource characterisation in the Waikato River catchment for Healthy Rivers Project	White, P., Tschritter, 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 Agritec
1.4	Review of historical land use and N 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	Rawlison, Z., Riedi, M., 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)
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 whether these reports contribute to achieving the objective of understanding the linkage between land use practices and observed water quality responses in receiving water bodies. My review findings for each report are discussed in the following section.

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

3 The report's coverage comprises:

3.1 Review of geological history, and geological units and their properties.

3.2 Development of conceptual three-dimensional geological models within the Waikato River catchments zones.

3.3 High-level summary of zone geology, basic water budget, groundwater piezometric level and water chemistry.

4 The document provides useful background reference material, but falls short of providing any understanding of how land use is specifically linked to responses in surface water discharges.

5 Land use is only mentioned twice in the main body of the report: i) in the recommendations (Section 6) and ii) in the summary (Section 7). Both sections say effectively the same thing - recommending the building of steady-state groundwater flow models to assess the water quality effects of land use options.

6 Given the fundamental principles regarding groundwater flow paths, and nitrate transport and attenuation in groundwater outlined above, I was surprised that the scope of the report did not include:

6.1 Hydrogeological cross sections showing groundwater flow paths;

6.2 Comprehensive assessment of nitrate, aquifer oxidation status indicators (iron and manganese) and groundwater age data in the context of the monitoring point location within the landscape and the groundwater flow path.

7 In my opinion, this report does not therefore assist in understanding how land use practices impact on water quality discharges in the receiving environment.

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).

8 The report's coverage comprises:

8.1 A focus on the estimation of vadose zone[9] lag times - that is, the time it takes sub-soil drainage waters to reach the groundwater table.

8.2 The estimations largely exclude saturated zone groundwater flow paths, although a thin mixing zone at the uppermost part of the unconfined aquifer has been included. Therefore, the calculations largely focus on the unsaturated zone shown in green in **Figure 9**.

[9] The vadose zone extends from the top of the ground surface to the water table, and is by definition shallow ("vadose" is Latin for "shallow") and unsaturated.

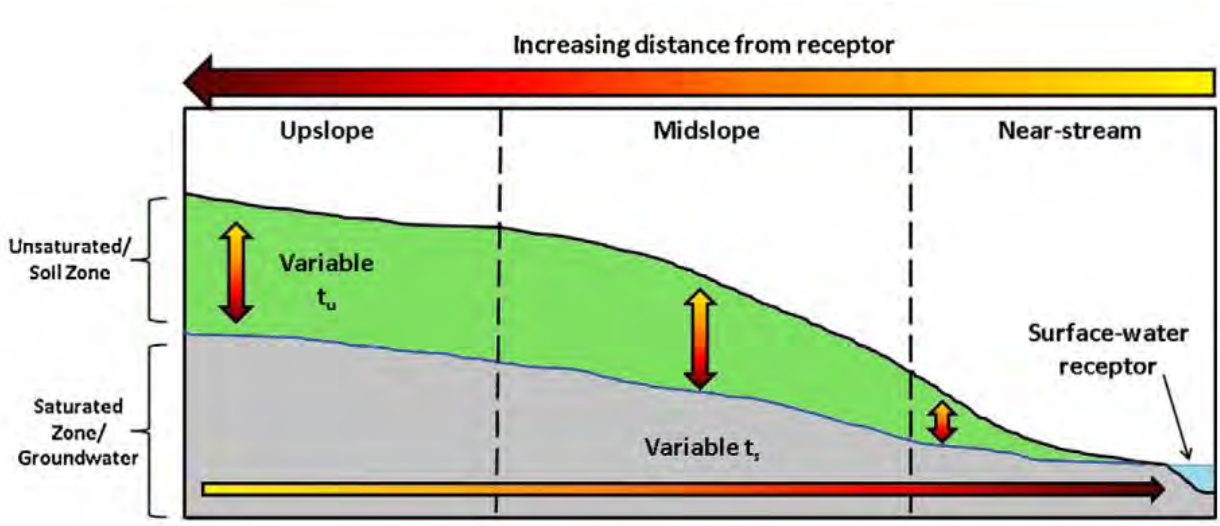

Figure 9. Total time lag (t_T) from source to receptor, including the unsaturated soil pathway (t_u) and the saturated groundwater pathway (ts). Arrows indicate the variable duration of t_u and t_s, depending on the depth of the soil profile and proximity to a receptor, respectively (source: Veroa, *et. al.*, 2016).

8.3 Input data derived from regional-scale databases and accordingly calculations contain a number of simplifying assumptions.

8.4 The calculation methodology comprises three main components:

(a) Land surface recharge (**LSR**)[10] calculated by a daily soil moisture balance tool;

(b) Vadose zone (underground water above the water table) travel time estimation, based on soil drainage volume, depth to the water table, and the average calculated vadose zone water content; and

(c) Nitrate mixing (or penetration) time for the upper dynamic portion of the saturated aquifer.

9 A fundamental flaw with the methodology implemented for the purposes of defining groundwater lag times is that it focuses largely on the vertical component of unsaturated flow from the sub-soil to the groundwater table (e.g. within the green zone above the water table in **Figure 9**), and neglects the sub-horizontal saturated groundwater flow component (i.e. from the water table to groundwater discharge zone).

10 The saturated groundwater flow component is typically a much longer flow path than the vertical unsaturated flow path, and therefore the travel time associated with the saturated groundwater flow path is typically greater (even when accounting for the fact that vertical hydraulic conductivity is typically an order of magnitude lower than the horizontal).

[10] Land surface recharge (LSR) is the amount of rainfall remaining for sub-soil drainage and hence percolation towards the groundwater table, after evaporative, surface runoff, and replenishment of soil moisture deficits has occurred.

11 To exemplify this point, Figure 9 of the report shows that the depth to groundwater (or thickness of the unsaturated zone) is less than 130 m for 90% of the area. In contrast, the median and average length of saturated groundwater flow paths in the sub-catchments covered by the Ruahuwai Decision Support Tool (**RDST**)[11] are approximately 2.13 km and 3.54 km, respectively and up to approximately 27 km. This is shown in **Figure 10,** which provides the distribution of groundwater flow path travel distances for each water table cell within the RDST groundwater model, of which there are 18,085 cells. This suggests that the distance of saturated flow paths are typically at least 16 times greater and up to 100 times greater than unsaturated flow paths.

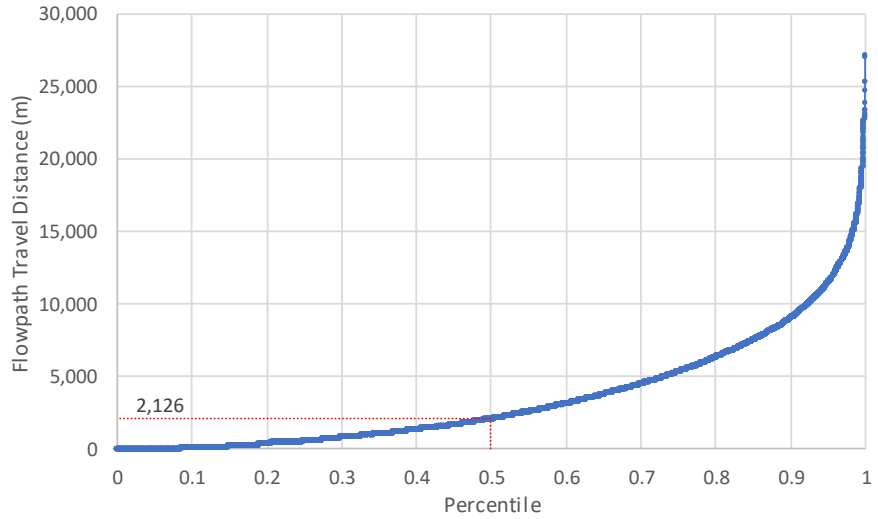

Figure 10. Groundwater flow path travel times in Ruahuwai Decision Support Tool.

12 The consequence of only considering the vadose zone travel time in the analysis is that the travel time for the vadose zone will be overestimated – that is, of longer duration than in practice.

13 The partitioning of rainfall into surface runoff and groundwater recharge was undertaken using a stormwater curve number approach, with no attempt to check the resulting catchment base flows against measured stream gauge data. Consequently, a key input to the model is assumed correct.

14 I have compared the simulated mean LSR to median base flows in a number of Upper Waikato streams to check this assumption. As summarised below, the model significantly underestimates LSR and therefore base flows. For example:

14.1 ***Otamakokore Stream*** – modelled 0.70 m^3/s versus measured 0.92 m^3/s (76%).

[11] The RDST is a complementary series of modelling tools developed for the contributing catchments to the Waikato River between the Lake Taupo Outlet Gate and the Ohakuri Tailrace. The models include an agricultural production simulator (APSIM), a surface water flow and constituent model (SOURCE) and a groundwater flow and constituent model (MODFLOW/MT3D/MODPATH) that collectively enable the environmental impact of differing land use and land management scenarios to be assessed.

14.2 ***Pueto Stream*** – modelled 2.1 m^3/s versus measured 5.01 m^3/s (44% of actual base flow flow).

14.3 ***Torepatutahi Stream*** – modelled 1.72 m^3/s versus measured 4.16 m^3/s (41%).

14.4 ***Waiotapu Stream @ Campbell*** – modelled 0.71 m^3/s versus measured 1.44 m^3/s (49%).

14.5 ***Waiotapu Stream @ Reporoa*** – modelled 2.08 m^3/s versus measured 3.28 m^3/s (63%).

15 On average, the modelled LSR is roughly half the measured stream base flow, which is a significant disparity.

16 With respect to the calculated travel times for the vadose zone (the key objective of the report), the calculated values varied markedly from measured groundwater mean residence times (**MRT**), as shown in **Figure 11**.

17 The model significantly over predicts the time water takes to percolate down through the vadose zone and therefore the age of shallow groundwater (young groundwater). For example, the root mean square error (**RMSE**) for groundwater less than 7 years old is 5.2 years, which is 35% greater than the average measured MRT.

18 The model under predicts the age of older groundwater greater than 35 years old, where the RMSE is 15.1 years, which is 34% of the average measured value.

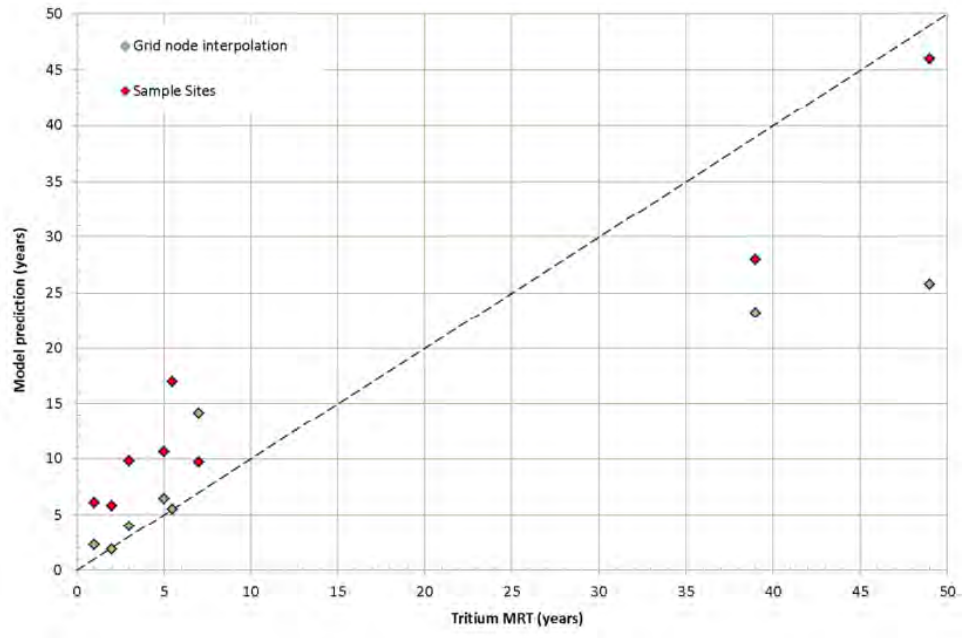

Figure 11. Comparison between predicted travel times and tritium mean residence time (source: Figure 17 from Wilson and Shokri, 2015).

19 Given the methodology employed, which focuses on the calculation of travel times in the vadose zone plus very shallow mixing, this under-prediction of older groundwater age is unsurprising, as older groundwater (>20 years) typically travel through the

saturated zone along lateral flow paths for significant periods of time, which is not considered by the model.

20 To reinforce this point, if we accept that surface waters in the highly porous Upper Waikato sub-catchments between Taupo and Reporoa are largely groundwater base flow dominated, it follows that water age in streams in this area (particularly during low flow periods) will be largely representative of the age of the groundwater discharging into the streams within that catchment[12].

21 Water age in the streams and groundwater within these Upper Waikato sub-catchments from tritium dating data supplied by WRC is plotted on **Figure 12** against data provided for the relevant sub-catchments (Kawaunui, Mangawara, Otamakokore, Pueto, Torepatutahi, Waiotapu, Whirinaki) in the Upper Waikato along with the data provided in Figure 17 of Wilson and Shokri (2015) (reproduced in **Figure 11** above).

22 **Figure 12** shows that measured groundwater and surface age (from tritium derived water mean residence times) range from 10-200 years. Simulated age is again over estimated for ages less than 25 years, but the key take out point is that for groundwater older than 25 years the simulated age is underestimated. To make up the difference between simulated and measured age requires the addition of between 15 to 120 years, which must equate to saturated sub-horizontal groundwater flow that is not considered by the methodology in the Wilson and Shokri (2015) report.

23 The under prediction of groundwater travel time or groundwater age for groundwaters greater than 25 years (common in the Upper Waikato in particular) indicates that saturated (sub-horizontal) lateral groundwater flow is i) significant/important, and ii) more likely a longer time component than vadose zone travel, particularly for older groundwaters.

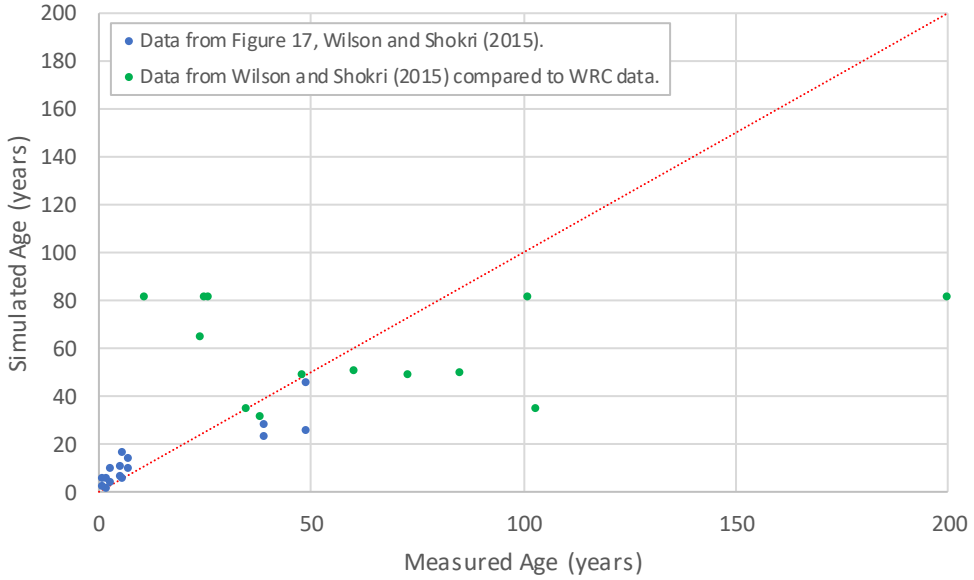

Figure 12. Comparison between predicted travel times and tritium derived mean residence times (data source: Figure 17 from Wilson and Shokri (2015), augmented with additional data from Waikato Regional Council).

[12] This was a key finding in Hadfield (2015a), where he found the age of groundwater discharging from springs was largely the same as the water in the streams.

24 In conclusion, it is my opinion the methodology presented by Wilson and Shokri (2015) is flawed because it (i) focuses solely on vadose zone travel and neglects saturated zone travel times; ii) underestimates the flux of recharge water; and iii) overestimates the travel times in the vadose zone.

25 The key conclusion I have drawn from the work is that saturated (sub-horizontal) lateral groundwater flow is significant/important, and more likely a longer time component than vadose zone travel.

26 Therefore, this contradicts the report's opening premise, which as stated in Section 1.1, was that "vertical flow through the unsaturated zone can account for a substantial fraction of the overall travel time from the root zone to a surface water body" (p. 6).

27 The implication of this is that denitrification, which is typically associated with older groundwater is more important than this report leads the reader to conclude. Therefore, the role of denitrification within different parts of the landscape with different underlying hydrogeological flow paths should play a significant role in policy planning and decision-making.

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

28 The report's coverage comprises:

28.1 Review and characterisation of historic land use types in the 74 HRWO sub-catchments.

28.2 Decade interval assessment of land use change in the sub-catchments from 1972 – 2012 was the intention. The 1972 land use data was derived by digitising combined hardcopy maps from 1958 and 1972, data for 1996, 2002 and 2008 was from an New Zealand-wide study by Motu Economic and Public Policy Research, with the 2012 land use data provided by WRC. No land use data was reportedly available for the intervening decades -1982, 1992 and 2002 (although Motu data was available for 2002), so instead a linear interpolation in ArcGIS was used to define the land use change during these three decades. The interpolation being to the nearest decade where data was available.

28.3 Review of historical N leaching yields for the pastoral land use types (sheep, beef, dairy) from New Zealand published literature where estimates were obtained from the OVERSEER® model (farm nutrient management and planning tool). Two studies were considered, one for the Rotorua catchment (Rutherford *et.al*., 2009) and a Waikato study (Judge and Ledgard, 2009). OVERSEER considers factors such as rainfall, soil types, fertiliser application rates as well as stocking rates. It was acknowledged that version 6 of the model over-represents N so only data derived from version 5 was utilised in the study (Dymond, *et. al.*, 2013). Historic leaching levels for 1972 were back calculated (hind cast) based on data from both the Rotorua and Waikato catchments. The study used published farm scale assessment to provide absolute and relative leaching loss estimates.

28.4 Review of published historic N leaching yields to provide values for other land use types (e.g. horticulture, forestry, native forest, urban). Intermittent land uses such as cropping was assigned to dairying and a uniform approach was taken to the other land uses.

29 Land use types were defined and categorised into 10 types within the catchment studied (dairy, sheep and beef - hill/high country, sheep and beef - intensive, forestry, maize, horticulture, native forest and scrub, other animal, urban, miscellaneous). Changes in the predominant land uses (pastoral, forestry and the balance combined) over the study period are illustrated in **Figure 13**. The four land use types shown in **Figure 13** reflect the main land uses within the catchment; pastoral is 61%, followed by forestry and native forest at 31% and the balance being amalgamated for display.

30 Overall, as indicated in **Figure 13**, the land use change over the study period was minor. Some sub-catchments did record a greater change in land use, such as the introduction in dairying in some sub-catchments (e.g. Waipawa, Puniu, Waipa) and a reduction in others (e.g. Horotiu and Kirikiriroa). As a proportion of the total catchment, dairying peaked in 1996 with intensive sheep and beef farming replacing dairying in some sub-catchments (e.g. Ohote and Lower Waikato). The authors also suggest the reduction may be a result of inaccurate assignment of dairying in the earlier decades.

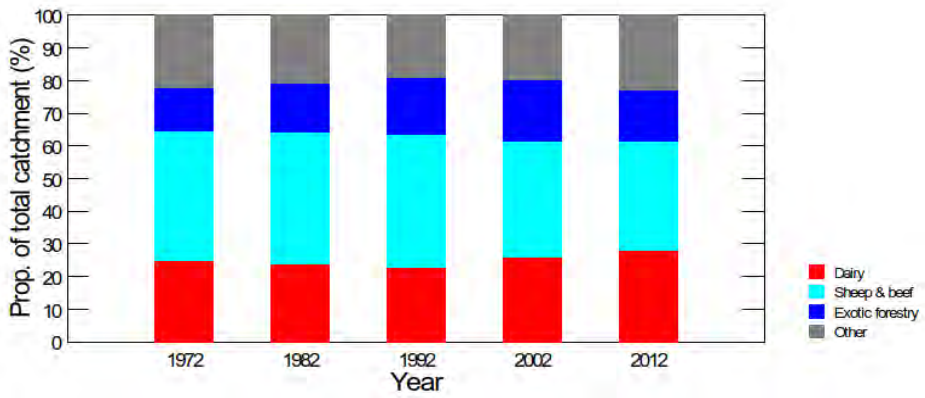

Figure 13. Proportion of different land uses within the Health Waters catchments from 1972 to 2012. (data source: Figure 3-2 from Hudson *et. al,* 2015).

31 N leaching yields for individual land uses, derived from numerical modelling and historic data have increased since 1972, the most pronounced increase was for dairy farming, with the most pronounced reduction being for sheep and beef-high/hill country. An increase in sheep and beef - intensive farming replaced the sheep and beef - high/hill country, and where a reduction in sheep and beef - intensive was noted, this was offset by an increase in dairy.

32 The following trends in N loss/leaching rates (noting that leaching does not necessarily translate to an environmental impact particularly in areas where groundwater flow paths are long) were reported:

32.1 On a catchment (Waikato River) wide basis, a 66% increase in N loss/leaching rates are predicted by OVERSEER since 1972. While dairy land area has increased marginally (5.4%) in the catchment since 1996 (usage was higher in 1972), dairy farm intensity has increased more markedly, hence the overall N leaching contribution is predicted to have increased by 20% since 1972

compared to 4% for the combined other land uses. The trend in N losses over the study period is shown in **Figure 14**.

32.2 Increases in N losses are most prevalent since 1992 in most sub-catchments, the most pronounced being the Waipa sub-catchment, and from 2002 in the Upper and Lower Waikato sub-catchments. The increases in N losses are attributed to both the intensification of dairying and the change in land use from non-dairying activities (e.g. sheep and beef-high/hill).

32.3 A decrease in the N yield for the Kirikiriroa sub-catchment is described as being the result of a reduction in discharge from a closed landfill within the catchment, although a reduction in N losses would be expected with an increase in urbanisation, and a corresponding decrease in dairying.

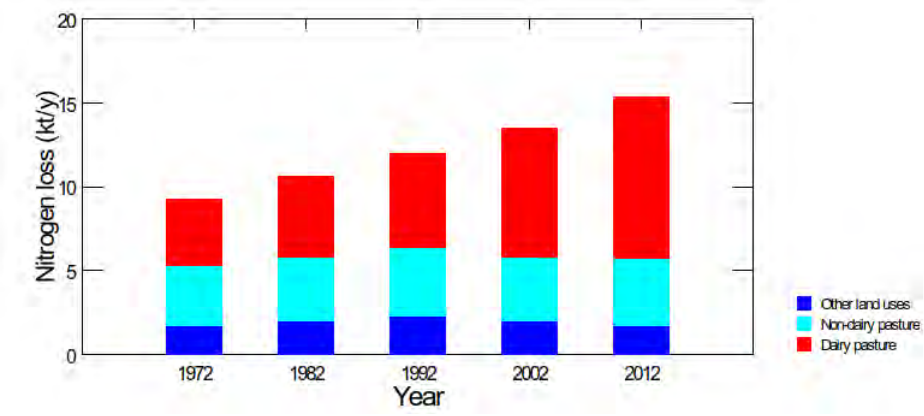

Figure 14. Trend in nitrogen losses within the entire Health Waters catchments from 1972 to 2012. (data source: Figure 4-1 from Hudson et. al., 2015).

33 As alluded to above, and acknowledged by Hudson, *et. al.* (2015) the study does not take into account attenuation of N in groundwater, lakes and streams. It is acknowledged in the document that calculated N levels would be reduced over time, but the authors consider the relative increases and trends in N leaching are independent of attenuation.

34 I would agree in part with this, but also point out that (as referred to above in my evidence) not every land parcel within the landscape has the same nitrate assimilative or attenuative capacity. That is, areas of young groundwater in close proximity to rivers will have very low attenuative capacity, whereas areas significant distances from drainage receptors will likely have long groundwater flow paths and therefore high nitrate attenuative capacity. It is therefore important to have regard to such spatial variability across sub-catchments.

Report 1.5a. Short term field investigations of groundwater resources in Waipa River Catchment – January to April 2015 (Rawlinson, *et. al.*, 2015)

35 This report is a data collection report that included groundwater level surveying, water sampling for chemistry and age dating, and limited hydraulic testing. The report focussed solely on the Waipa River catchment and was aimed to inform the

development of a Waipa River Catchment flow and N transport model due for completion in 2016/2017 (*as yet not publicly available*).

36 Because the scope of my evidence focuses on the Upper Waikato catchment, this report was not reviewed in detail.

Report 1.5b. Groundwater field investigations over the 2014-15 summer in support of the Healthy Rivers Project (Hadfield, 2015).

37 This report is a data collection report, with some albeit limited assessment of data results. The report objective was to collect data and provide to collaborating investigators (e.g. modellers such as White, et. al., 2015; Wilson and Shokri, 2015; and Close, 2015).

38 The type of information collected included: flow confirmation survey; low flow gauging; well information surveys; water chemistry sampling; groundwater level surveys; investigation of redox conditions in groundwater; radon surveys and water age dating.

39 Key findings from the report include:

39.1 Of the 116 wells sampled, the mean and median nitrate concentrations were approx. 1.56 ppm and 0.23 ppm, respectively[13], with 65% showing no nitrate contamination (< 1 ppm concentration).

39.2 Mean and median groundwater residence times estimated from the summer monitoring results were 114 and 95 years, respectively.

39.3 Groundwater age is expected to increase with depth in a recharging groundwater regime.

39.4 While there is no simple linear relationship between groundwater age and depth, old groundwater is typically low in nitrate, while young groundwater is variable in nitrate concentration depending on land use and attenuation.

40 From a reviewer's perspective the report is considered reasonably accurate, aside from the calculation errors (discussed above) overstating nitrate concentrations in groundwater.

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

41 The objective of the report was to predict subsurface redox status as a basis for assessing the likely amount of denitrification and informing policy decisions for each of the sub-catchments in the Waikato Region under the HRWO Plan Change project.

[13] The report actually stated mean and median nitrate concentrations of 2.5 ppm and 0.75 ppm, respectively. However, I checked these values using the data presented in Appendix IV and found that the calculated values included the non-numeric value "<0.05". I substituted this with 0.049 and obtained a mean and median of 1.56 ppm and 0.23 ppm, respectively.

42 Close (2015) explains that "reducing conditions are necessary for denitrification, thus the groundwater redox status can be used to identify subsurface zones where potentially significant nitrate reduction can occur". This is consistent with my summary in **paragraph 17** above.

43 The study used water mean chemistry concentration data in 554 bores as an indicator for reducing conditions, which occur when concentrations of oxygen (**O_2**) are low, nitrate (**NO_3**) is low and manganese (**Mn**) is high. The threshold for reducing used in this study were < 1.0 mg/L for O_2, < 0.5 mg/L for NO_3-N, and < 0.05 mg/L for Mn.

44 The calculated redox status at 67% of the 554 bores was then related to 10 mappable parameters within the fields of geology, topography and soil characteristics using linear discriminant analysis (**LDA**). The relationships developed were then tested on the remaining 33% of bores. The report does not elaborate on the accuracy of the testing or verification step. However, the relationships developed by the model were extended across the entire catchment to provide an indication of likely redox status.

45 While there is much to admire about the approach and it's potential, it is difficult to verify its accuracy without the availability of the input well chemistry data, and unfortunately the results in the area of my scope (between the Lake Taupo gates and Lake Ohakuri) do not seem to match what the ground conditions measured at the Wairakei Estate i.e. oxic conditions generally prevail down to the groundwater table and within a shallow mixing zone, followed by reducing (anoxic) conditions at greater depths within the saturated profile. This seems to be acknowledged by the author where he states (Close, 2015):

> This predicted result *(oxic conditions at depth)*, and the associated groundwater chemistry from the shallow and medium depth wells around Lake Taupo, contrasts with what is usually observed in groundwater systems, with reducing conditions usually being more likely in deeper flow paths with longer residence times (other things being equal). [underlining and italics added]

46 Furthermore, at the NZ Hydrological Society Annual Conference in December 2018, Mr Close presented a paper (Close *et. al.*, 2018) on follow-on research that indicated there were a number of issues with the accuracy of the earlier work due to:

46.1 Spatial bias (clustering);

46.2 Depth bias (predominantly shallow samples);

46.3 Sample selection bias (65-85% of samples from oxic water);

46.4 Attribute bias (samples unevenly distributed among attribute categories).

47 Close *et. al.*, 2018 proposed a new method that attempted to address the bias, and preliminary results suggested a marked improvement in the Waikato catchment, with the kappa statistic[14] improving from 0.22 to 0.87, where values close to 1 represent strong predictive ability and values close to 0 represent limited predictive ability.

[14] Kappa statistic gives model predictive ability taking random agreement and sample selection bias into account.

48 However, the results from Close *et. al.*, (2018) were clearly not available at the time when PC1 was being prepared, hence Close (2015) has been relied upon and this states:

> In the southern portion of the Healthy Rivers catchments influenced by the Taupo eruptions, slow nitrate leakage via longer, deeper flow pathways, will less likely encounter reducing conditions. Hence the likelihood for attenuation is lower and the time for contamination of deeper aquifers will be longer as will the time to remediate them. (p 7).

49 This conclusion is the complete opposite to the findings from my own work around the WPL Enterprise, and the conceptual model presented above (**Figure 6**) which is consistent with most of the literature.

50 The finding is also contradictory to the findings of White *et. al.*, (2015), which was prepared for the HRWO Plan Change Project. For example, White *et. al.*, (2015) stated:

> Commonly Mn (manganese) is greater than MAV (maximum acceptable value) and Fe (iron) is greater than guideline concentrations. Elevated concentrations of these elements indicate anoxic conditions in groundwater. Therefore, anoxic conditions are probably common in Upper Waikato groundwater.

51 Where Close (2015) and I agree is that the distribution of reducing zones has implications for the nitrate load to come and the time distribution of the load entering HRWO sub-catchments.

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

52 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).

53 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.”

54 Concerns relating to this report are embedded in the concerns of the previous reports described above and need not be repeated here.

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