Memo

File No:	2014 09 24
Date:	24 September 2014
To:	Chairman, Technical leaders Group
From:	Tony Petch, Tony Petch Consulting Limited
Subject:	**Report on Ground water workshop and draft work briefs for additional investigations of ground water age and denitrification potential.**

Background

The Healthy Rivers - Plan for Change: Waiora He Rautaki Whakapaipai project will establish targets and limits for nutrients (N & P), sediment and *E. coli* in water bodies across the Waikato and Waipa catchments.

One of the most critical components to enable realistic policy to restore and protect the Waikato and Waipa rivers is an understanding of whether the water quality in the rivers reflects the current intensity of land use in the catchments particularly for nitrogen. Preliminary work completed in the Upper Waikato catchment concludes that…

> *It is reasonable to expect that ground water's contribution to nitrogen to surface water quality at the monitoring sites will continue to increase…. and that the rate of increase and the time over which it occurs is poorly understood* (Aqua*linc*, 2013).

A recent economic analysis of the costs of meeting national water quality objectives for the Upper Waikato shows the main determinant of cost is the extent to which river water quality (especially nitrate nitrogen) is in equilibrium with catchment land use (Doole, 2014).

These two studies highlight the importance of understanding nitrate loads and transport times from the land, via ground water to streams, and the extent of attenuation processes within aquifers and riparian zones. The shape of the critical policy to equitably restore and protect the Waikato and Waipa Rivers demands a better understanding of these processes. This knowledge will also determine the extent new farm and land management practices are required to be adopted and requirements for improved treatment of point source discharges to the rivers. In turn, this will enable defensible estimates of remediation costs to meet the community's desired water quality targets in the rivers.

The technical leaders group approved a work brief on 21 August 2014 to identify the priority information and investigations needed to understand the temporal response of the ground water resources of the Waikato and Waipa catchments, especially the relationship between current land use intensity and observed ground water and surface water N (Appendix 1). Te Roopuu Hautuu endorsed the work brief at their meeting 3 September 2014.

The ground water workshop was held Friday 19th September at Waikato Regional Council. The work shop agenda and process is outlined in Appendix 2:

Workshop outcomes

Appendix 3: State of knowledge and current ground water projects.
Appendix 4: Knowledge gaps and risks.
Appendix 5: Proposed ground water work programmes (6 months; 1 year; 2 years) provided from the workshop.

Approach to obtaining additional ground water information
Two critical factors have determined the ground water experts' recommendation on how to answer the question of the N load to come. First; the relatively fragmented state of ground water knowledge in the Waikato catchment (detailed knowledge in some areas of the catchment and little in other areas); and second; the very short time to obtain the critical information required to improve the current understanding. With these factors in mind, the panel recommend a staged approach.

In the short term, further develop and refine the steady-state estimation tool used by NIWA for assessing the costs of meeting national water quality objectives for the Upper Waikato (Economic Joint Venture Initiative). This tool is already being extended over the rest of the Waikato catchment for phase 2 of the Joint Venture Initiative. The model will be supplemented, within six months, by a range of additional field and office-based studies that build our understanding of the ground water resources; their age, age distribution and assimilation (denitrification) potential and the N load to come

Further investigations, delivered in stages over the next two years, includes further refinement of the NIWA tool through inclusion of the temporal N loading information, and enhancement of existing, or development of new, more sophisticated ground water transport models. These models would be supported with a greater understanding of spatial and temporal loads and ground water flow processes and losses (denitrification). The value of the current ground water research and investigations are recognised and the proposed work programme for year 1 and year 2 builds on this existing knowledge.

The ground water experts' panel identified four interlinked work streams to better estimate of the load of N to come, together with the associated uncertainty;

- improvements to NIWA's surface water quality tool (refer 1 below)
- field work and hydrogeological desktop studies to support model and tool development (refer 2,3,4 below)
- more accurate estimates of N leaching from current and historical land use (refer 5 below)
- further development of mechanistic ground water models including more sophisticated approaches (longer term: year 1 and 2 and current MBIE or Waikato Regional Council investigations)

Recommended Investigations

A summary of the investigations recommended to be <u>completed</u> if possible by mid-February 2015 includes;

1. Develop and refine the NIWA (EJVI) surface water quality tool/model (that includes ground water processes) for the entire Waikato catchment by incorporating information from the work programmes outlined in 2) to 4) below to provide estimates of the steady-state N load to come with estimates of associated uncertainty.

2. Develop conceptual ground water models to inform assimilation capacities, at the sub-catchment scale, for the upper Waikato, Waipa river (nearly complete) and the middle and lower Waikato river catchments.
3. Updated geological models and the time of travel through the unsaturated zones over the study area.
4. Undertake an extensive field programme during the 2014 summer to provide additional required information on: hydrology (low flow gauging and associated stream and ground water head elevations), geological information from well logs in critical parts of the region; aquifer characteristics (pumping tests for T, S and k; regional piezometric levels to establish ground water flow paths; water chemistry (especially N); and ground water/surface water (springs) age and age distributions.
5. Estimate changes in land use intensity and N leaching rates for the Waikato and Waipa catchments decennially from 1940 to 2000 and quinquennially thereafter (noting that this work may not be available to inform the NIWA tool/model in the first instance).

The panel acknowledges the time to complete this work is extremely short and projects will need close coordination with continuous communication between those involved. The panel also acknowledges the importance of relevant long-term research being undertaken in the Waikato catchment and the important role this work plays in growing our understanding of ground water age, denitrification and loads of N to enter surface water and its quality equilibrates with present land use intensity.

Work briefs for recommended work

Appendix 6: Draft work briefs to provide the highest priority ground water information within the next 6 months.

Appendix 6 outlines draft work briefs to provide the highest priority ground water information within the next 6 months as input for more enhanced modelling of economic impact of the land use changes required to restore and protect the Waikato and Waipa rivers. The work briefs will be refined and negotiated between the Waikato Regional Council, other ground water experts involved in the project and the contracting agencies.

Other comment

The close dependencies between the recommended work programmes and the very short time available to complete the work suggest the need for careful project management and control. Waikato Regional Council should consider immediately engaging a suitable project manager to ensure the project concludes successfully.

Recommendations

1. TLG approve the proposed programme of investigations (Appendix 5) and development of a range of tools and models with various timeframes and complexities to estimate the N load to come and its associated uncertainty.

2. TLG recommend the proposed work programme (Appendix 5) and associated draft work briefs (Appendix 6) for approval by the Te Roopuu Hautuu.

3. Waikato Regional Council engages a suitable project manager to ensure the project concludes successfully.

Appendix 1: Work Brief: Ground water age and denitrification potential (Completed)

Work Brief

Identify the priority information and investigations needed to understand the ground water resources of the Waikato and Waipa catchments, especially the relationship between current land use intensity and observed ground water and surface water N concentrations and loads.

- The work would be led by a member of the TLG who would convene a panel of experts in Waikato's ground water systems and their hydro-geochemistry with the purpose of:

    1. Summarising the state of ground water knowledge in the Waikato and Waipa catchments in relation to the information requirements of the Healthy Rivers - Plan for Change: Waiora He Rautaki Whakapaipai project.
    2. Identifying high priority information gaps and the investigations required to improve understanding of ground water hydraulics, water chemistry, ground water age and ground and surface water interactions where they are not sufficiently known.
    3. Identifying methods for obtaining the priority information promptly including refining the models for ground water-surface water in the Upper Waikato and Waipa catchments.
    4. Identifying any information and investigations required to improve the understanding of N attenuation between soil, ground water and streams.
    5. Determine the patterns of land use change and intensification over the last 50 years.
    6. Identify likely costs and timeframes to complete the investigations and provide the information required.

- Provide a report to the TLG summarising the output from the experts' deliberations. Specifically,:
    - the state of ground water knowledge in the Waikato and Waipa catchments;
    - Priority investigations and information to be gained (including indicative costs and timeframes) to determine the relationship between current land use intensity and observed ground water and surface water N concentrations and loads in the rivers.

Process

- One day workshop of ground water experts in early September to undertake the brief.
- Write report covering the outcome of the workshop and the priority information and investigations and their indicative cost and timeframes.
- A further two days of input for preparation for workshop, clarification and review of recommendations in the report and any presentations that may be required.

Timing

Work brief completed	13 August
Work Brief approved by Te Roopu Hautu	TBC
Contracts let	5 September (TBC)
Meeting convened	18 September (TBC)
Report on proposed priority information and investigations required	3 October (TBC)

Appendix 1: cont…/

Proposed Expert Panel Members

Convenor – TLG member (Tony Petch)
John Hadfield (WRC) – Intimate knowledge of regional ground water systems and processes
Greg Barkle (Aqualinc) – Extensive knowledge of ground water systems and modelling. Undertaken modelling projects to support the Economic joint venture initiative.
Murray Close (ESR) – Extensive ground water experience nationally and leader of MBIE funded programme operating in the Reporoa area.
Roland Stenger (Lincoln Agritech) – Expertise in sub-surface continuum from soil to surface water including hydrology and geochemical transformation processes.
Paul White (GNS) – Extensive ground water experience nationally and in the Upper Waikato and Taupo areas especially.
Sandy Elliot (NIWA) – Expertise in catchment modelling with particular emphasis on surface water quality. Estimated N, P and E coli. concentrations and loads in surface water to support Economic joint venture initiative.

References

Aqua*linc*, 2013; Estimated Age in Surface water and Changes in Nitrogen Concentration in Ground water in the Upper Waikato Catchment., Aqua*linc* contract report H13001/2 for Ministry of Environment.

Doole G, 2014; Evaluation of policies for water quality improvement in the Upper Waikato catchment. MPI unpublished contract report for the Economic Joint Venture Initiative 2014. Copy held by Waikato Regional Council.

Appendix 2: Ground water workshop agenda and process (Completed)

Agenda	Process
08.30 - 0900 Coffee plus chat	Free format
0900 - 10.00 State of knowledge, current projects, gaps and risks associated with each gap ***Outcome***: a good understanding of what is known about ground water resources in the Waikato and Waipa catchments, what projects are underway, what the gaps are (especially in relation to nitrogen loads to come, ground water age, denitrification processes) and the risks of these gaps (e.g. lack of knowledge or poor policy).	Introduction and objectives, HS&E, Facilities: Tony (10 min) State of knowledge and current projects: In twos share and discuss your views on the state of knowledge as you see it. Identify current projects you are aware of that relate to the challenge. Identify principle themes that each wanted identified. Work on butcher's paper. (10 min) Report back to the group (10 min - 3 min each) Gaps and risks associated with each gaps: Identify critical gaps and their risks, In twos, share and discuss your views on the gaps and risks as you see it. Work on butchers paper (10 min) Report back to the group (10 min - 3 min each) Group discussion (10 min - 2min each)
10.00 - 10.30 Reflection and break	Photocopy each experts papers
10.30 - 12.00 Design work (investigations and research) required within: 6 months; 1 year; 2 years ***Outcome***: a draft list of investigations, modelling projects and research required to support policy development.	Design work (investigations and research) required within 6 months. Working as a group and on white board.(30 min) Design work (investigations and research) required within 1 year Working as a group and on white board.(30 min) Design work (investigations and research) required within 2 years Working as a group and on white board.(30 min)
12.00 - 12.30 Kai time	
12.30 - 14.00 Ranking and prioritising work (investigations and research) within the time periods required **Outcome:** ranked and prioritised work programmes required within: 6 months; 1 year, and 2 years.	Ranking and prioritising (investigations and research) required within 6 months. Working as a group and on white board.(30 min) Ranking and prioritising (investigations and research) required within 1 year Working as a group and on white board.(30 min) Ranking and prioritising (investigations and research) required within 2 years Working as a group and on white board.(30 min)

Appendix 2: cont…/

14.00 - 15.00 Identifying critical elements of high priority work required in work briefs **Outcome:** draft critical elements identified for priority work programmes (input to work brief requests).	Identifying critical elements of high priority work required in work briefs: In twos share identify and discuss your views on the critical elements of high priority work required in work briefs as you see it. Work on butcher's paper. (30 min) Report back to the group (20 min - 10 min each) Group discussion (10 min - 2min each)
15.00 - 15.30 Reflection and break	
15.30 - 16.00 Next steps. By whom and how. Reflections on the day.	Group discussion

Appendix 3: State of knowledge and current ground water projects

Upper Waikato	Waipa	Middle and Lower Waikato
Modelling		
Aqua*linc* – Upper Waikato (with Waipapa and Little Waipa) numerical models of ground water flows and flow paths and inferred estimation of ground water ages; Currently focused on calibrating nitrogen loadings and assimilation, requires further development. Also path-line estimation of water age and lags for MfE and EJVI NIWA – First order steady state estimation tool including assimilation but not lag of N, P and E coli. for MfE and EJVI ESR – Reporoa catchment GW model Lincoln Agritech model development on stream water conc. of N, P and flow relationship (ground water or runoff) GNS – Geological data over region Geological models and conceptual model in area. Ground water-surface water and ground water-geothermal interaction in area NIWA – Sparrow model ESR – Predictions of reducing zones (assimilation) in GW over whole of the Waikato region. GNS AEM modelling of Putaruru well-field and Blue Spring LAL Stream GEM modelling 2015 (Tahunaatara Stream)	GNS – review and beginning of conceptual model for WRC LAL Stream Generating Eigen Model (GEM) modelling 2015 (Puniu River catchment)	WRC – conceptual flow models for Hamilton Basin, Pukekohe and Pukekawa completed in late 1980s. GNS - Geological model, rainfall recharge Pukekohe LAL Stream GEM modelling 2015 (Mangatangi Stream catchment)
Water Budgets for recharge estimates		
General budgets – over whole area Specific budgets – Tokoroa/Kinleith Specific estimates of recharge completed for Aqualinc's GW model of UW region.		Specific budgets – Pukekohe, Pukekawa, Ohinewai, Waahi, Hamilton Basin

Appendix 3: cont…/

Ground water/surface water interactions (water quantity)		
General information – over whole area, generally good from MRP and Var 6 (GNS). Specific information - Tokoroa/Kinleith	General information – details in some limited areas but generally little known	General information – over whole area Specific information – Pukekohe, Pukekawa, Hamilton Basin. Source: WRC tech reports
Ground water chemistry		
General – moderate coverage usually with single or few repeat observations of chemical spp. Specific details in Tokoroa/Kinleith, Reporoa, Lichfield and Putaruru Note: Care is needed when interpreting ground water quality data, as it is depth and flow-path specific and may not represent the whole aquifer or how surface water quality is responding. Surface water base flows provide more integrated data than ground water monitoring data. But we need to know which ground water is feeding surface water as this can change with season and flow. Temporal data sets on ground water chemistry are not sufficient and critical information on screen depth is missing in ~ 30 per cent of the ground water data.	General – moderate coverage usually with single or few repeat observations of chemical spp. Hamilton Basin has some frequent observations Note: there are 800 wells across the region: 170 have 10 or more observations for N. 500 can be used for estimating redox potential. Some have good lithological descriptions and clearly identified screen depths.	General – moderate coverage usually with single or few repeat observations of chemical spp. Moderate spatial and temporal surveys in the Hamilton Basin, Pukekohe, Pukekawa, and Waiuku

Appendix 3: cont…/

Upper Waikato	Waipa	Middle and Lower Waikato
Ground water/surface water ages		
Note MRT does not implicitly describe the distribution of ages that make up this mean age and the distribution of waters is important when considering load to come. This also is impacted by where the N load is spatially located in a catchment related to stream recharge. 29 ground water MRT estimates available 2 existing surface water MRT available 12 more surface water ages due to be reported by GNS. Preliminary relationship between SiO_2 and MRT estimate used for EJVI study Note: about 150 ground water MRT estimates over the last three decades in the Waikato area are available.	~10 ground water ages in the Waipa catchment	Several ground water ages in Pukekohe, Pukekawa and Hamilton Basin

Appendix 3: cont…/

Upper Waikato	Waipa	Middle and Lower Waikato
Surface water quality monitoring sites		
5 surface water quality monitoring sites on tributaries catchments with flow information is available. 7 sites Waikato main stem all flow weighted 11 other water quality monitoring sites without flow information. LAL: combined analysis of surface water quality and flow data to improve understanding of land to water transfer pathways (Otamakokore, Tahunaatara, Waiotapu) Note: only 25 per cent of the surface water quality monitoring sites have associated flow monitoring and they are poorly distributed for analysing ground water-surface water interactions.	3 flow weighted surface water quality monitoring site on tributaries. 3 flow weighted surface water quality monitoring sites on the main stem of the Waipa LAL: combined analysis of surface water quality and flow data to improve understanding of land to water transfer pathways (Mangapu, Mangatutu, Puniu, Waipa @ Otorohanga and @ Pirongia)	3 flow weighted surface water quality monitoring sites with flow weighting on tributaries. 8 flow weighted monitoring sites on the Waikato main stem LAL: combined analysis of surface water quality and flow data to improve understanding of land to water transfer pathways (Mangatangi, Matuhuru, Whakapipi).
Piezometric surface/ground water flow		
General – few continuously monitored wells available sub regionally Specific – detailed piezometric surfaces available in Tokoroa/Kinleith Reporoa, Lichfield and Putaruru The Upper Waikato ground water model has been calibrated against 625 ground water level data points.	General – most wells are located in lowland areas Specific – detailed piezometric surfaces and ground water flow paths available for the Hamilton lowlands and some for the Waipa catchment	General – most wells are located in lowland areas Specific – detailed piezometric surfaces and ground water flow paths available for Pukekohe, Pukekawa, Waiuku and the Hamilton lowlands

Appendix 3: cont…/

Upper Waikato	Waipa	Middle and Lower Waikato
Hydrogeological properties		
General – few tests/interpretations of T, S, and k Specific – more detailed information for Tokoroa,/Kinleith Note: significant gaps in pumping tests, aquifer characteristics throughout the region.	General – Few sites with aquifer properties available Specific – T, S, k available for Hamilton lowlands Note: quality of lithological descriptions variable – few professional logs available	General – Few sites with aquifer properties available outside the areas below Specific – T, S, k available for Pukekohe, Pukekawa, Waiuku, Ohinewai, Huntly and Hamilton lowlands
Land use		
Note limited data on land use and change in land use intensity over time. Note: MPI has general data. Historical Agstats are available from NIWA (Chris Palliser) for the last 80 years (approx.) but on county basis and these boundaries have changed with time (non-trivial task). Agribase is available from the mid-1990s. Note: DairyNZ has general production statistics for the Waikato and more detailed information in the Upper Waikato. WRC has land use intensity data from 2002, 2008 and 2012 from the LCDBs and Agribase. Data available should be accessed to a farm scale.		

Appendix 4: Knowledge gaps and risks (whole of Waikato)

Denitrification We need more detail about the spatial variation of reducing zones (indicating denitrification potential). We know a lot about reducing zones at selected research sites but scaling up in 3 dimensions remains a challenge. We also don't know how much ground water passes through these zones. An integrated hydrological and bio-geochemical approach is essential. Rank: important! We need to understand where and when the denitrification processes (heterotrophic, autotrophic) occur in ground water/surface water flow paths. This requires characterisation of the ground water/surface water systems. Rank: important!! There is potential to use excess N_2 measurement for assessing denitrification occurrence. This would be more cost-effective where a good understanding of flow paths has already been established. Rank: important.
In-stream and riparian denitrification Need to consider these near and in-stream process processes in the analysis of total denitrification opportunities along flow paths, particularly when evaluating mitigation options. An estimate of overall denitrification is of greatest importance though. Rank: important
Ground water ageing and age distribution Further water ageing information is required to understand lag effects and the significance of current monitoring. An integrated approach is required for tritium-based surface water and ground water age dating to elucidate the lag times arising from different water reservoirs (and associated flow paths) contributing to surface water bodies. Sampling at 'summer base flows' is important (for ground water and surface water sampling), Surface water sampling should additionally be carried out at 'winter base flows'. Note that ground water dating per se is less cost-effective where it only provides point information valid for the location of a single well screen. Establishing ground water age profiles at sites where multiple depths can be sampled is more informative. Re-sampling of previously sampled sites is particularly desirable as that enables MRT distribution rather than just MRT to be estimated. Silica (SiO_2) should be included in any new samplings, including the WRC routine ground water and surface water monitoring programmes, This has potential as a less expensive age proxy. Water dating may be most useful where process-based modelling and denitrification investigations are also being carried out, as understanding of flow paths, lag times, and denitrification is required to defensibly link source and impact. Rank: important!!
Modelling Models to predict nitrogen impacts from land-use change on ground and particularly surface water are lacking for much of the study area. The modelling that has been undertaken has not yet achieved confident transport calibrations. Only mechanistic ground water models incorporate age distributions and flow pathways to predict ground water nitrogen and load to come on a temporal basis. A semi-mechanistic model such as Rotan could be used but a good understanding of the ground water and surface water system is required first. A conceptual ground water model is an important first step. Rank: important!!! The scale of the models need to link with the regional geomorphology and ground water and surface water quality monitoring sites.

Appendix 4: cont…/

Surface water/ground water interactions Need to have a good understanding of low flow and the proportion of base flow and quick flow to determine water budgets and potential ground water contributions to surface water flow. Base flow chemistry, water age and age distribution are important to determine ground water/surface water connectivity. This allows an understanding of flow pathways, short-circuiting, and summer/winter ground water contributions. This also allows an understanding of seasonal dynamics of the ground water/surface water connections. Supplemental information of base flow and ground water chemistry is required in specific areas and through time. Rank: important!!
Unsaturated flow There is insufficient understanding of unsaturated flow through the vadose zone. It is important to account for travel time and can add significant lag not accounted for directly in saturated ground water models. Vadose zone characteristics affect the subsurface lag time and potential for denitrification to occur. Rank: important!!
Hydrology An understanding of basic hydrology, water budgets, rainfall, evapotranspiration, low flows all contribute to the development of a conceptual model that is fundamental to understanding the opportunities and location of denitrification processes. Highly accurate evapotranspiration estimates (as usual) are currently lacking. Rank: important but we are more confident in this area than others.
Geothermal nitrogen sources Any analysis of nitrogen loads and denitrification needs a basic understanding of geothermal sources of nitrogen, where relevant. It is important in some parts of the upper Waikato (but as a secondary issue to understanding denitrification processes). Rank: Relatively important.
Land use One of the least known and critical factor determining the load of N to come and the opportunities for denitrification is change in land use, intensity and leaching over time. Specifically needed, given the likely distribution of ground water age in the upper Waikato, is an estimate of land use intensity and nitrogen leaching every decade from 1940 through to the year 2000 with estimates quinquennially thereafter to the present. Given its importance, information which currently exists but is withheld should be made available. Rank: important!!!

Appendix 5: Proposed ground water work programmes (6 months; 1 year; 2 years)

Note: The 6 month, 1 year or 2 year is the time that the output can be delivered but work needs to start on all of the work streams.

Tools and Models

Investigation One: A refined and extended version of the NIWA upper Waikato estimation tool is required to provide best estimate of the steady-state N load to come.

Note: This tool is being extended for the whole of the Waikato catchment below Huka Falls. It is also important to note that this simplified, steady-state approach does not include critical aspects lag or denitrification directly. These must be informed from other work and entered as a series of imposed scenarios.

1. Refinement in 6 months is to be achieved by:

    a) Improvements that the ground water experts can identify *(Revised NIWA work brief required - attached)*
    b) Where justified, developing conceptual models of ground water systems in tributary catchments to refine the estimates of N assimilation and transport in the NIWA model. These conceptual GW models incorporate specific information, at the tributary level, on water budgets, base flow, recharge, geological and subsurface formations, denitrification capacity, current land uses, Ground water and surface water age data and ground water and surface water chemistry data, and N leaching estimates. This will include hydrogeological information from the numerous Waikato Regional Council technical reports and from the foundation design reports for the Lower Waikato flood control scheme. The tributary catchments will be determined by surface water quality monitoring sites. In some cases River Environment Classes could be used. Conceptual models for the Upper Waikato and the Middle and Lower Waikato as well as the Waipa river will be available by January 2015. *(Revised GNS work brief required - attached)*

2. At end of year 1 by:
    a) Enhancing the NIWA tool to incorporate annual time step estimates;
    b) Incorporating land use change; surface water ages and age distributions and nitrogen loads; an allowances for unsaturated flow lags;
    c) Reviewing ground water capture boundaries if justified. *(Information will only become available via ground water models)*

3. At end of year 2 by:
    a) Improve assimilation estimates by incorporating information on the denitrification potential; and
    b) Incorporating other available research and information from enhanced regional monitoring and investigation programmes. *(Work brief required after completion of year 1 work programme).*

Appendix 5: cont…/

Tools and Models

Investigation two: Develop existing and appropriate new ground water models to provide estimates, including uncertainties, of the temporal N load to come.

1. In 6 months :

    a) Refine and develop geological models for the upper (nearly complete), middle and lower Waikato and Waipa (nearly complete) catchments. *(revised work brief required GNS - attached)*
    b) Estimate time of travel through unsaturated zones in all three catchments (*Work brief required Lincoln Agritech – incomplete attached*)

In Year 1 and 2 (needs more input on timing) by:

2. Further develop the existing upper Waikato ground water model to include information from item 1 above, the temporal N loadings, (item 3 below) to allow the predicted N export to be better calibrated against measured surface water N concentrations to estimate tributary assimilation coefficients. (*Work brief required Aqualinc*)

3. Develop appropriate steady state ground water flow and transient transport models capable of describing temporal estimated of N load to come including spatially variable denitrification potential in the Middle and Lower Waikato and Waipa catchments. *Note: JH has flagged that the exact nature of the model required does need some clarification based on need. (Work brief required)*

Denitrification

Continue work by ESR, LAL and Waikato Regional Council to assess denitrification potential and occurrence. This would include regional mapping of denitrification potential by ESR and work with LAL under the Ground Water Assimilation Capacity programme (MBIE funded). Shallow drilling to determine the depth of the redoxycline and sampling for excess N_2 gas at selected sites would assist with mapping and modelling. *(No work brief required)*

Appendix 5: cont…/

Estimate land use intensity and N leaching over time

Investigation Three: Estimate land use intensity and N leaching over time

Specifically needed over all catchments at the tributary level, given the older ground water ages identified in the upper Waikato, is an estimate of land use intensity and nitrogen leaching every decade from 1940 through to the year 2000 on as finer spatial scale as possible with estimates quinquennially thereafter to the present. *(Work brief required - attached)*

Summer field work programme (EW to complete)

Investigation Four: Field work programmes

In 6 months:

1) Complete a summer field work programme to provide additional information on:
    a) basic hydrology, including low flow gauging and stream head elevations associated with low flow conditions, aquifer pumping tests for T, S and k if available, surveyed ground water levels to create regional piezometric maps indicating ground water flow paths;
    b) water chemistry especially N, silica and excess N_2 gas and radon where justified;
    c) ground water and surface water age and age distribution for a range of flow conditions and ground water depths at a site;
    d) geological information from well logs in critical parts of the region. *(Work brief required - attached).*

2) Expand the regional ground water quality monitoring network in critical areas to monitor ground water N spp.

In year 1:

Continuing some of the summer field work described above in critical areas identified (including specifically catchments where land use and stream water quality appear inconsistent).

In year 2:

Continuing a modified summer work programme covering the items described above in critical areas in the region.

Appendix 5: cont…/

Additional work programmes and investigations

Note: At this stage the work outlined below is not sufficiently well defined and should be held until the investigations identified above have been completed.

Investigate ground water flow paths, residence times and denitrification potential within critical catchments
Investigate vadose zones and ground water residence times in critical catchments
Investigate the efficacy of examining ground water N_2 excess as a method of identifying denitrification potential (with other methods of estimating denitrification and ground water age distributions)
Investigate the viability of a 'recirculating well test' for assessing denitrification potential
Enhance the regional hydrological network by establishing 3 lysimeters (upper Waikato, middle/lower Waikato, and the Waipa catchment) to estimate ground water recharge and to calibrate recharge models.

Appendix 6: Draft work briefs to provide the highest priority ground water information within the next 6 months

Work brief covering Investigation One (Item 1a: Appendix 5)

Development and refinement of the NIWA catchment model

Model overview[1]

A simplified catchment model has been developed to predict the median concentrations of nitrate, TN, TP, E. Coli and phytoplankton chlorophyll (Chl) in the upper Waikato catchment (Taupo to Karapiro). This model is being extended to cover the entire Waikato catchment downstream of Huka Falls. The model predictions are made for existing water quality stations in the tributaries (nodes), and these nodes also define the sub-catchments of the system. The models for TN and TP are constructed such that key parameters relating source loadings to concentrations can be incorporated into an economic model. For E. Coli, the current CLUES model is used.

Changes in Chl are predicted from changes in nutrient concentrations, with the relation inferred from spatial correlations down the hydro network (across sites) rather than trends at a site over time. This assumption is conservative.

The TN model is a steady-state model. Since there are lags in catchment response, we cannot use the measurements directly to calibrate decay coefficients. Therefore we estimate the decay by providing three levels: a) maximum, based on current concentrations; b) minimum, based on a reasonable lower estimate of decay; and c) best estimate, based on Clues results and other existing information (e.g. Taupo work). We estimate decay in the hydro lakes from measured loads. The TP model is also steady state, with decay tuned to measurements.

A factor is used to convert from flow-weighted concentrations (derived from loads) to median concentrations. Measured factors are used for TN (with projection to other sites). For TP, the factors are tuned to give the correct measured concentration for TP – this ensures that TP concentrations increase in proportion to the load, with measured concentrations as a base level. For E. Coli, it is assumed that concentrations increase in proportion to loads, with the measured concentrations as base.

Model enhancements

The model will be enhanced by incorporating a range of new information derived from recommended field studies and from the ground water conceptual models.

Critical steps

a) Decide nodes and delineate sub-catchments to be modelled. This will likely follow previous work and be based on monitoring locations, but the sub-catchments may be reviewed taking into account hydrological information arising from this project.
b) Summarise available information for each sub-catchment (or suitable aggregations of sub-catchments) including information from the conceptual models (investigation 1 (1b) and investigation 2 (1a)), stream and groundwater dating, hydrological information (provided from other work-streams), water budgets, water chemistry, N load and concentration histories, and groundwater denitrification zones. This information will be integrated to inform selection of N attenuation factors and their uncertainties, at a descriptive level.

[1] *Note: this work brief is modified from that for the model completed recently by Niwa for the upper Waikato catchment*

c) Confirm point source locations and loads (N, P, E Coli) for Waipa river and middle WRC)
d) Optimise the catchment model to provide the best fit to measurements for P and E. coli, and incorporate information on nitrogen attenuation
e) Report model results, interpretations and implications, and provide key results to economic modellers

Timelines
End Feburary 2015

Performance measures
Timely provision of the report.

Milestones
Sub-catchment summaries prepared by end of March 2015.
Revised catchment model prepared by end of April 2015.
Draft report on catchment modelling prepared by May 2015, and finalised by June 2015.

Dependencies
Source nutrient loadings used in the economic model for the baseline case.
Point sources provided by WRC.
Timely completion of other investigations in the work programme.

Indicative cost
$50,000

Contracting Agency: NIWA
Staff contact: Sandy Elliott
E: sandy.elliott@niwa.co.nz

Work brief covering Investigation One (Item 1b: Appendix 5**) and Investigation Two (Item 1a:** Appendix 5**)**

Review of hydrogeological data and development (or refinement) of conceptual hydrogeological 'models' of the upper, middle and lower Waikato River and Waipa River catchments[2]

Project description

Conceptual hydrogeological models of the middle and lower Waikato and Waipa River catchments will be developed and information from advanced numerical modeling of the upper Waikato reviewed. These will assist to inform sustainable water management and policies developed to restore and protect the Waikato River as required by the Vision and Strategy for the Waikato River (Te Ture Whaimana o Te Awa o Waikato) and the National Policy Statement for freshwater management.

Initial work will review the existing hydrogeological information for the middle and lower Waikato and Waipa catchments. The project will identify remaining information gaps in the middle and lower Waikato and provide a recommended work plan to address them. The initial work will ensure that a hydrological dataset exists from which more detailed conceptual hydrogeological and numerical groundwater models can be created. in subsequent contract phases.

The conceptual models will include information on recharge distribution and rates, lithological units and aquifer delineation, hydraulic characteristics, piezometric head distribution, availability of water chemistry and age data and flow boundaries. It is anticipated the more detailed work will be completed for these sub-catchments following this project when more comprehensive data are available.

A preliminary piezometric surface will be created using available ground water level data, and levels of rivers and lakes using the highest resolution DEM that spans the entire upper Waikato and middle and lower Waikato river sub-catchments. LeapFrog Geothermal or other acceptable software may be used for 3D visualization.

Timelines[3]

Draft reporting will be provided by February 20. This will include:

- review of hydrogeological data following collation of all relevant monitoring datasets within the upper, middle and lower Waikato and Waipa River sub-catchments;
- identification of remaining information gaps in the available dataset;
- advice regarding further work to provide remaining critical data
- conceptual models for each of the sub-catchments with emphasis on SW quality contributing catchments
- 3D visualisation of conceptual models using acceptable software.

[2] *Note: this work brief is modified from that for the recently completed conceptual ground water model for the Waipa catchment. The work brief requires review from Paul White, GNS.*

[3] *These dates need refining and discussion with potential contractors*.

- Reporting will include a description of the process and models. Preparation of the final report will be completed within two months following comment by Council. This timeframe is reliant on timely provision of data from Council databases.

Performance measures
Timely provision of the draft reporting as described.

Milestones
Receipt of draft reports as described above by February 20, 2015 and final reporting within two months thereafter.

Indicative cost
$80,000

Contracting Agency: GNS-Science
Staff contact: Paul White
E: P.White@gns.cri.nz

Work brief covering Investigation Two (Item 1b: Appendix 5**)**

Estimate time of travel through unsaturated zones in the upper Waikato, Waipa and middle/lower Waikato River catchments

Background

The movement of infiltered water through the unsaturated zone to the ground water table is an important process for carrying soluble contaminants such as N to ground water and their ultimate discharge to rivers and streams. The time taken for water and excess nutrients from land use to reach ground water is an important part of the lag time between the impacts of land use impacting on ground and surface water quality. This information is critical in answering such questions as 'Has ground water nitrate concentrations reached equilibrium with the current land use and intensity?' and 'If limits to leaching rates are set, how long will it take to see improvement in [shallow] ground water quality?'

Project description

This project focusses on estimating the response time for additional nitrogen leaching from a change in land use intensity to be delivered through the unsaturated zone to the water table. The project should consider the factors involved in nitrate transport through the unsaturated zone such as; drainage through the soil profile, the depth to the water table, the water content of the unsaturated zone, the physical properties of the unsaturated zone and chemical attenuation process that may occur. The project should also include an estimate of the time taken to mix in the uppermost rainfall recharged portion of the aquifer.

It is acknowledged time lags associated with diffuse discharges comprise several other components: including the time for soil chemical properties to reach a new equilibrium following land use change and the time for the water resource to respond to the effect. These are not matters to be covered in this project

Method

- Estimate a daily soil moisture balance for representative soils and lithologies for the upper Waikato, Waipa and middle and lower Waikato River catchments using appropriate methods to characterise drainage through the soil and its regional variability (Irrigation should be included where known).
- Estimate the travel time through the unsaturated zone based on estimated soil drainage, depth to the water table and the estimated water content of the unsaturated zone.
- Estimate a mixing time for N (nitrate) in the upper parts of the aquifer through which shallow ground water flow occurs (aquifer dynamic zone).
- Validation of soil drainage estimates against known aquifer recharge estimates and validation of unsaturated zone travel times against available ground water age data.
- Preparation of draft report.
- Completion of final report.

Timelines
Contract let by 7 November 2014
Sources of input data identified and estimates of soil properties for representative soils and lithologies for the catchments complete by 30 January 2015
Model parameterisation complete by 27 February 2015
Model optimised and validated by 13 March 2015
Draft report complete by 3 April 2015
Final report complete by 1 May 2015

Performance measures
Representative sites and lithologies agreed by Waikato Regional Council hydrogeology staff
Model optimisation and validation agreed by Waikato Regional Council hydrogeology staff

Milestones
As per timelines above

Indicative cost
$40,000

Contracting Agency: Lincoln Agritech Ltd
Staff contact: Roland Stenger
E: roland.stenger@lincolnagritech.co.nz

Work brief covering Investigation Three (Appendix 5**)**

Estimate changes in land use area and intensity and N leaching rates for the Waikato catchments decennially from 1940 to 2000 and quinquennially thereafter

Background

One of the most critical components to enable realistic policy to restore and protect the Waikato and Waipa rivers is an understanding of whether the water quality in the rivers reflects the current intensity of land use in the catchments particularly for nitrogen. Preliminary work has already been completed in the Upper Waikato catchment to clarify the relationships between land use intensity and ground water and surface water nitrogen loads to the river (Aqua*linc*, 2013). However, this work concludes that…

> *It is reasonable to expect that ground water's contribution to nitrogen to surface water quality at the monitoring sites will continue to increase…. and that the rate of increase and the time over which it occurs in poorly understood.*

A recent economic analysis of the costs of meeting national water quality objectives for the Upper Waikato shows the main determinant of cost is the extent to which river water quality (especially nitrate nitrogen) is in equilibrium with catchment land use (Doole, 2014).

Project description

This study is to provide information on changes in land use and intensity and estimated nitrogen leaching rates over time for the entire Waikato catchment downstream of Huka Falls, including the Waipa catchment. Estimates of these factors are required over a period that represents the likely travel times of infiltered ground water to discharge points along the rivers and streams of the Waikato catchment. Thus, estimates of each of these factors are required every decade from 1940 to 2000 and every five years thereafter.

Land use and intensity statistics have been poorly recorded over time and even today are surprisingly incomplete and difficult to access. It is appreciated that historical estimates of these statistics may involve significant errors

Sources of information

There may be many sources of information available to fulfil this work brief.

- Historical aerial imagery is available from several air photography companies.
- Historical primary production statistics may be available from MPI or the national library or other sources such as the NZ year book including statistics for representative pastoral farm types.
- More recent dairy statistics may be available from MPI, DairyNZ and Fonterra.
- Area and production statistics for drystock enterprises may be available from Beef and Lamb New Zealand.
- Area and production statistics for commercial vegetable growing may be available from HortNZ.
- Forestry area and production statistics may be available from forestry companies.
- Information from Agribase on land use intensity is available for the last 15 years or so.
- Information from the Land Resource Inventory is available for the mid 1980s.
- The Land Cover Database series (1-4) provide information on land use from 1980 onward.
- Detailed information on land use and land use intensity from 2002 to 2008 and for 21012 is available from Waikato Regional Council.

- NIWA hold some information about land use and land use intensity for the Waikato catchment.
- The Waikato Regional council holds information on point source loads to the Waikato and Waipa rivers.

Method

For each decade from 1940 to 2000 and every five years thereafter and for the specific catchments identified[4]:

a) Estimate, using the best sources of information available, the area of the main land uses in the Waikato catchment including: forests (plantation and indigenous); pasture including drystock (sheep and beef and deer) and dairying separately; commercial vegetable growing; arable crops; and urban areas.
b) Using representative land use types estimate the loss of nitrogen from each area of land use for each time period.
c) Estimate the point source N load from urban centres and industry for each time period.
d) Provide a report describing in tabular and pictorial form the methods and estimated nitrogen leaching loads leaving the soil root zone for each of the times and catchments identified and the history of point source loads of N to the Waikato and Waipa rivers and streams.

Performance measures

The quality of the available information is agreed by the client before analysis and reporting

Timelines and milestones

Information for this investigation collated and agreed with client by 19 Dec 2014
Draft report completed by 27 February 2015
Final report completed by 27 March 2015

Indicative cost
$100,000 to $200,000 depends on scale and scope
Note: we are advised that a similar study for Southland cost $500,000 but this is unverified.
WRC staff say this is a ‘large’ job

Contracting Agency: Unknown
Staff contact: Unknown
E: unknown

[4] *Catchments and sub-catchments will be identified by the client*

Work brief covering Investigation Four (Appendix 5**)**

Undertake an extensive field programme during the 2014/15 summer to provide additional information on basic hydrology, hydrogeology, regional piezometric levels, water chemistry (especially N), and ground water/surface water age and age distribution.

Project description

A summer field work programme will be undertaken to improve the understanding of the state of equilibrium between current land use intensity and river water quality. The field programme will be guided by desktop reviews of current hydrogeological information. The additional information will support other aspects of an integrated programme of work to understand and model N attenuation and transport from land to surface water including developing robust conceptual models of the ground water systems in the Waikato and Waipa catchments and enhancement of the regional surface water quality estimation tool developed by NIWA. The information will also help define the changes in land use intensity required to restore and protect the Waikato and Waipa rivers and define the costs of achieving those changes.

Information required

At selected and agreed locations the following types of information are required[5]

a) basic hydrology, including low flow gauging and stream head elevations associated with low flow conditions, aquifer pumping tests for T, S and k if available, ground water levels, surveyed regional piezometric levels and ground water flow paths;
b) ground water chemistry (especially N) and silica, also N_2 gas and radon where justified
c) ground water/surface water (springs) age and age distribution (over a range of flow conditions)
d) geological and redoxycline information from well logs and shallow drilling in critical parts of the region.

Method

Establish a 2014 summer field work to provide the additional information identified.
Agree the sites and information necessary in selected sub-catchments with ground water experts involved in developing the conceptual ground water models and water quality models that this project contributes to. Previously sampled sites will be resampled and new monitoring sites will be established.

Performance measures

The location of sampling sites and other observations and tests as agreed by the client and other ground water experts before beginning the programme.
Sampling and other observations undertaken using standard hydrogeological methods.
Waikato Regional Council's HS&E policies adhered to.

Timelines and milestones

Information for this investigation collated and agreed with client by 19 Dec 2014
Field work completed by 20 March 2015
Results and observations forwarded to modellers immediately they become available[6]

[5] Location of sampling sites and the work necessary will be determined by the client in discussion with other experts working on related projects.

Draft report completed by 28 May 2015
Final report completed by 26 June 2015

Indicative cost
$208,000

Contracting Agency: Waikato Regional Council
Staff contact: John Hadfield
E: john hadfield@waikatoregion.govt.nz

Budget breakdown

Project management	$54,000	45 days at $1200 per day
Student labour	$72,000	4 students @200 per day for 90 days
Accommodation and meals	$12,000	30 overnights@$200 per room and meals for two rooms
Travel	$15,000	20,000 km @$0.75 per km
Materials	$5,000	
Ground water MRT	$45,000	30 samples @$1,500 per sample
Laboratory services	$5,000	300 samples (NO_3 and SiO_2) @$8 per analysis.
Total	**$208,000**	

[6] Ground and surface water ages and age distributions may not be available for up to 60 days following receipt of samples by the laboratory