THE ROLE OF CURRENT AND FUTURE GROUNDWATER RESEARCH IN COLLABORATIVE MANAGEMENT OF WATER QUALITY

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Abstract
New Zealand has embarked on a process of fresh water management reforms. Each region has a differing approach, but all must comply with national standards and bottom lines. Collaborative processes are increasingly being adopted in water management, in planning, setting limits and in catchment-scale implementation. These reforms have created extraordinary demands on science, but more so on groundwater understanding. Collaborative management requires all participants to share a common platform of understanding of the biophysical world and the legislative framework.

This presentation will look at what we know, what we need to know, and how current research is addressing the gaps. From the experiences with the Canterbury Regional Water Management Strategy, the Land and Water Forum and subsequent development of policies and regional plans, some of the limitations imposed by insufficient knowledge of groundwater processes will be discussed. The cause and effect relationships between land use practices and receiving water quality are managed using tools that are "best we've got" but what else do we need? How will groundwater research address those needs? Another consideration is the increasing acceptance that water, even in New Zealand, is not a limitless resource, and that water quality is emerging as a primary constraint to further agriculture development. Land users are expected to manage to limits, but do they have sufficient or appropriate tools to achieve those limits? What is the role of the regulators, the regional councils? How will the relationship between regulator and land user change over time? How can science support and enable water management to achieve the multiple and sometimes competing demands of cultural, social, environmental and economic values?

Fresh Water Reforms in New Zealand

The Ministry for Environment's National Objective Framework (NOF) developed under the National Policy Statement - Freshwater Management (NPS-FM) determines bottom line values for water quality and quantity across the country to which regional councils must deliver. The principal contaminants in New Zealand arise from diffuse agricultural contamination in the form of the leached or surface water losses of the nutrients nitrogen (N) and phosphorus (P). Regional councils are responding to these national policy challenges by creating community-based collaborative processes in the form of catchment committees, which set water quality limits in freshwater bodies at sub-catchment scale under the NOF, and then devise implementation plans to manage water resources. Council staff use models to calculate catchment-scale nutrient loads, which are translated into catchment-scale nutrient limits typically as total mass of N transported via groundwater and surface water, and nutrient leaching limits, (expressed as Kg/ha), which apply at farm scale.

Collaborative Processes
From my observations of the collaborative process embodied in the Land and Water Forum in which I was a member of the Small Group, and search of the literature, collaborative planning or management has a number of critical success factors.

- A continuous problem solving process
- Consensus-based
- Knowledge generating, social learning and adaptation
- Requires a shared understanding of the biophysical reality and its behaviour to changing inputs.
- Rights and responsibilities are shared

Collaborative planning and management for water requires all participants to share a common platform of understanding of

- the biophysical world, in this case the hydrosphere.
- the relationships between land uses and water, and,
- a broad understanding of the multiple interactions between water and natural and anthropocentric contaminants that flow through soils to ground and in surface waters, and,
- their effects on the natural environment.
- the legislative framework.

Because collaborative processes involve a range of stakeholders with widely disparate levels of science education the science needs to be communicated in an understandable way. This is its own challenge, as it involves inherent abstraction from empirical evidence (measurements and data), representation of the phenomena (typically conceptual models), and analytical or causal characteristics.

The NPS-FM reforms have created extraordinary demands on science, but more so on groundwater understanding. Setting limits for both uses (water takes and allocation) and then managing to limits (water quality management) require different science knowledge. Managing water quality presents significant challenges due to uncertainties in our collective knowledge of contaminant pathways through the land surface, soil, vadose zone, saturated zone to surface water continuum. In particular we often lack defensible, numerical information on nutrient loads, their time lags, natural attenuation and storage in the groundwater, in our many and varied catchments. If nutrient limits are based on uncertain science then stakeholders may contest the numerical provisions for nutrient leaching set in Regional Plans. This uncertainty has led to adversarial litigious processes.

Looking firstly at **time** as a key variable, we know that groundwater flowpaths represent the single biggest uncertainty. Groundwater can take centuries, decades, or months or weeks to manifest input/output cause and effect, depending on sub-surface lithology, terrain, rainfall, and land cover. We use models based on data that may or may not provide certainty at the resolution in time or space that is appropriate for catchment-scale water quality management. “How long before we know what’s going on, or whether we’ve made a difference?” are the most common questions in community meetings on water issues. Our environmental planning acknowledges the time lag questions but the management plans rarely have definitive timeframes as to performance of initiatives or investments in mitigation. Our planning tools function on annual time frames for inputs and deliver medium term (3-6 years) moving averages for outputs. In short we plan, measure, model and manage for water quality in different time-frames.

There is also the issue of sampling intervals. There are a lot of papers[i] that show how sampling say every two hours can give you a very different amount of total contaminant compared to the more common monthly sampling. This is more marked in flashy catchments, where infrequent sampling typically produces under-estimates of total load. Monitoring needs to be matched to catchment characteristics and modelling methodology likewise.

The theory tells us that fast variables function at a small scale, provide opportunities for novelty and experimentation, and precipitate cascading changes (in structure and function) of the system by overwhelming slower variables (Holling et al. 2002). Slow variables function at larger temporal and spatial scales and foster stability and legacy to systems (Holling et al. 2002). This is an easy analogy fit with groundwater. Slow variables include climate change, deep groundwater mass fluxes, government processes, regional plans, human conservatism, and mortgages. Fast variables include seasons, shallow groundwater, markets, weather, and biosecurity incursions.

We manage the environment for the medium and long term, but we are constantly faced with responding to fast variables along the way. There is also a scale factor.

We are managing the environment for the long term at catchment scale by influencing short term inputs at farm scale. We have some big challenges because our measurement and modelling tends to be based on insufficient data temporally and spatially. Each of the multiple pathways by which contaminants are transported has a different time lag, and a different set of attenuation processes.
The analogy might be – it’s 7am and we want to drive 210km to Auckland to arrive at 10am and that means driving at an average speed of 70km/h, but we have many events that can impact on our management – choice of route, traffic, weather, road works, and restrictions. Our driving (management) will have to adapt accordingly. We manage at intervals of seconds to achieve a goal three hours hence. We cannot drive at 70km/h and merely check the road at hourly intervals. The uncertainty of our eventual arrival on time or at all may be rather high.

The Actors – Land Users
Economic land uses create water quality issues, and only changes to land use practices will remediate or maintain desired water quality. Regional councils can make all the rules they wish, however collaboratively determined, but unless land users change something on the land, nothing will change in water quality. Land users are now being confronted with rules in regional plans that set total nutrient loads across a catchment, with nutrient leaching allowances expressed in Kg/Ha. This raises many questions in land users’ minds.

- How much N is my farm leaching?
- What is my contribution to the total load?
- Can’t you measure the actual leaching from my farm?
- What is the time lag before I can detect an effect in the environment?
- What will this cost in lost production or investment in mitigation?

Regional councils are working their way through transitional arrangements and are trying to navigate issues of equity, incentives, disincentives and fairness across sectors and community interests. In over-allocated catchments the general expectation is to reduce inputs of nutrients through reductions in fertiliser, de-stocking, changing land use, and a raft of new management practices, most of which require an investment of cash or effort and time.

Iwi manage an additional set of cultural values associated with wahi tapu and mahinga kai in groundwater springs, streams and lakes. These often more stringent kaitiaki obligations demand seasonal, highly resolved information specific to their needs.

The Role of Management Information
We are familiar with financial management information systems.(MIS) They are more about use of data to enable better management than they are about the technological enablers of computer hardware and accounting software.

Financial MIS	**Environmental MIS**
Action. Management makes changes and improvements to business practice.	**Action**. Land users can introduce changes with more certainty as to environmental outcomes.
Response. The effects of the changes are measured.	**Response**. Land users receive measured feedback signals in more appropriate time frames.
Adapt. Forward planning (business plans) are continuously refined on the basis of measured performance over time. MIS is continuously updated.	**Adapt.** Nutrient budgets (OVERSEER) and Farm Environmental Plans (FEP) can be continuously refined based on feedback from a comprehensive water quality MIS

Why is groundwater the issue?
Groundwater flows involve transformations;

- Dilution
- Biogeochemical transformations (denitrification)
- Time lags
- Storage
- Interactions with surface waters

Groundwater contributes contaminants to base-flow in surface waters and it’s hidden, complex, and expensive to measure. Groundwater always requires modelling – an esoteric science to laypeople. Data is expensive – monitoring wells and instrumentation is expensive and this leads to poor or scarce data. Uncertainties mean that investment risk is high, which is a barrier to action to embark on actions to resolve water quality issues because people don’t know with sufficient certainty what a certain action at the input end will result in what, where, by how much, and when a result can be observed.

If, for example, we mapped time lags from input to output (cause and effect) regional councils could tell land users in a ‘fast’ catchment that relatively flexible rules can be set and the effects monitored and everyone will be able to measure impacts of mitigation measures relatively soon – say 2-3 years. In other catchments that lag time may be 50 years, in which case everyone will understand why precautionary planning rules would need to apply.

We also need to create trust in the data. The difference between 2500 tonnes of N and 3500 tonnes in a catchment means what?

To **water quality** – whether we reach a limit in 10 years, or overshoot, have to make draconian corrections, and take 30 years to correct it.

To **land users** – this could mean a loss in income of between $100 to $350m pa, with flow-on effects to the regional economy and the national export receipts.

Uncertainty in estimating nutrient load-to-come in groundwater therefore offers very significant investment risk and the water quality aspirations of this generation may not be met until the next generation, or the one after that.

The Future

At present the regional councils monitor the environmental water quality. They also manage it, directly and through more indirect processes, guidance and facilitation. Regional councils have science staff with data, skills and understanding of the complexities. Land users do little environmental water quality monitoring, and rarely engage in the science, being receivers and partial funders through targeted rates of the investigatory work such as monitoring and modelling. In other industries regulators set rules and expect businesses to meet the numbers in those rules, rarely advising the businesses the detail of how to comply. Clean air is an example. Do not exceed X % of PM_{10} particulate. Do not emit visible smoke. SO_2 emissions $< Y$ ppm and so forth. The councils do not advise businesses whether to use an electrostatic scrubber or a wet scrubber and which brand.

Our current situation is;

- few nitrate monitoring sites. Mainly at the bottom of catchments
- typically sampled only monthly
- insufficient data
- load calculations have wide uncertainty bounds

We are approaching a time where fresh water management will mean that land users start to take more responsibility for managing their own leaching and therefore will want to develop a better understanding of what effects their actions have on water quality. Land users will want to have more influence on limit-setting and water quality management, but this will need to be backed with transparent, defensible, mutually shared science across the various collaborative processes in regions and sub-catchments. Land users’ monitoring and science will need to contribute its share of understanding to the regional processes of evidentially-based decision-making.

- Monitoring streams and groundwater more closely on and around their properties
- Collaborate with neighbours at sub-catchment –scale – e.g. irrigation schemes
- Share data that matters – applies to all stakeholders
- Develop <u>trusted</u> cause and effect sub-catchment models – what/where/when

Land users already have adopted nutrient management using nutrient budgeting tools like OVERSEER and Farm Environmental Plans. These function in management terms at the annual strategic time scale. What's needed is tactical management tools that function seasonally, which is how most farmers manage land uses. To develop such management tools will require cost effective acquisition of more finely resolved data and the modelling enhancements to derive useful information from that data.

Technology does not stand still, and new sensing technology is being developed that disrupts the cost per data point by orders of magnitude.

Nitrate

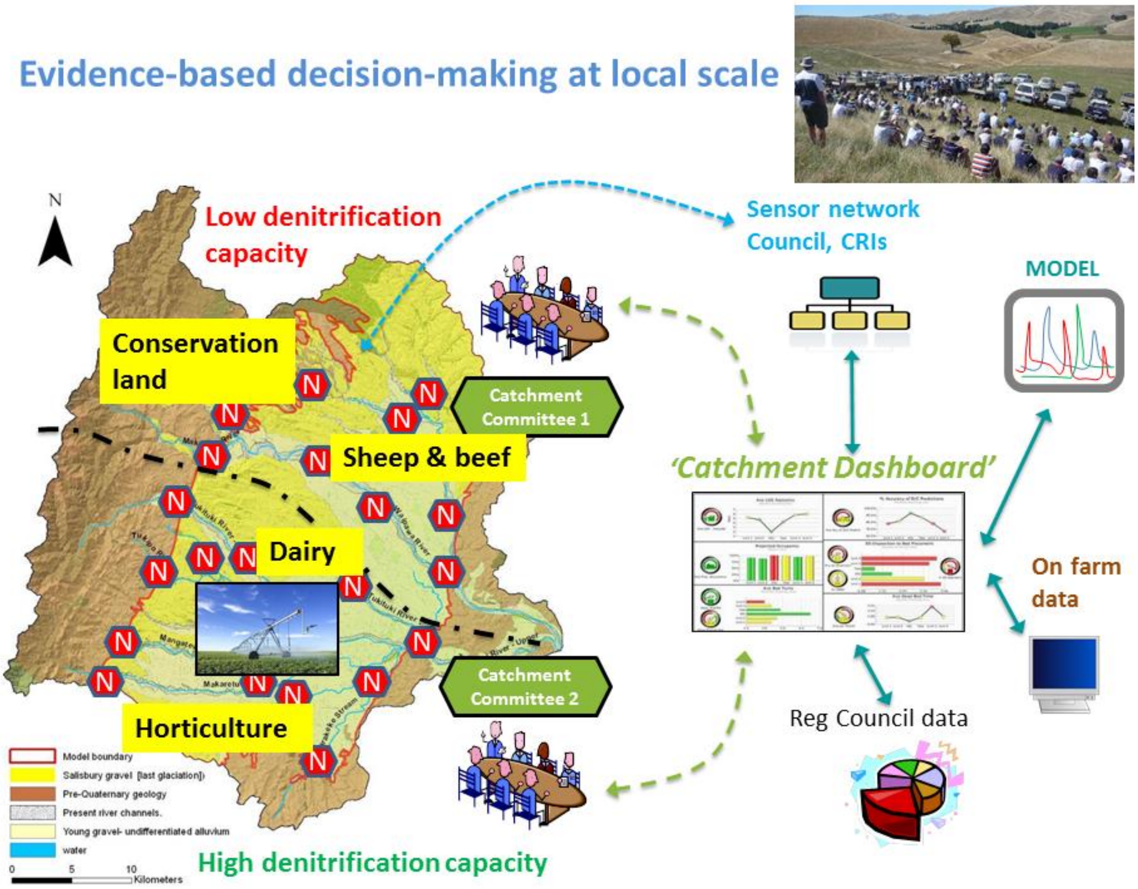
- Fit-for-purpose – in wells, small streams
- Can read in micro-seconds
- Automatic correction for turbidity and bio-fouling
- Low power consumption
- Data logging
- Accurate over wide range
- Reliable and repeatable measurements
- Affordable – means ability to measure at more sites, more often.

Groundwater velocity

- Measures ultra-slow GW velocity directly.
- Much cheaper method than conventional hydrological methods.
- In conjunction with the N sensor can directly measure groundwater nutrient fluxes.
- Affordable
- Operates in wells
- Automatic

Software and modelling and data management is being developed to utilise this richer data. These trusted models will;

- account for groundwater flow and attenuation processes – the black box below the root zone
- include fit-for-purpose complementary tools to OVERSEER that are web-based and accessible to all stakeholders
- be based on sensor networks and process research to develop and validate trusted catchment-scale models – more data, more places, more often.
- include integration of all measured data to enable evidence-based decision-making at the local scale, based on models with reduced uncertainty.



Such hardware and software will become available in the near future, and in the medium term will increasingly be the subject of investment by land users as a part of their wider management of the environment. If land users started to take a lead in environmental management, investing in their own monitoring, regional councils could then revert to a more regulatory role. Everyone will be better equipped to manage water through sharing data and using models and tools that offer a shared and mutually trusted representation of the biophysical catchment and its behaviour under changes in land use.

The end goal is to manage water quality to the standard the community desires. Groundwater research will be central to this challenge.

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[i] Jones, A. S.; Horsburgh, J. S.; Mesner, N. O.; Ryel, R. J.; and Stevens, D. K. 2012. "Influence of sampling frequency on estimation of annual total phosphorus and total suspended solids loads." Journal of the American Water Resources Association 48: 1258-1275.