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INVITED EDITORIAL

Some future research directions in hydrology

Science and technology are constantly evolving and the science of hydrology is no exception. In this invited editorial, I review some future trends in society and technology that may affect hydrology in New Zealand and speculate on some future directions for the science of hydrology in New Zealand.

Future influences on hydrological science in New Zealand

1) *An ageing population.* For example, localities such as Tauranga face significant increases in water demand for municipal supplies (White, 2005) as their populations grow, partly because of their popularity for retirement.

2) *An ageing infrastructure.* Much infrastructure is heading towards the end of its life because of population growth, improving standards and the age of the structures. For example, bridges built in the 1960s, and before, were typically narrow and not designed for today's faster speeds and higher traffic volumes. It follows that today's designers of infrastructure will demand a higher standard of engineering design than in the past and therefore better hydrological data will be required in the future for design purposes.

3) *Increased market pressure for responsible (e.g., environmental) production.* Consumers of New Zealand's largely agricultural produce are becoming more aware of what, in economic terms, are called the 'externalities' of food production. Externalities include the environmental effects of production, such as water quality, and environmental effects of transporting food to the market; externalities are typically not represented in the product price. Moves toward inclusion of externalities in product prices could result in, for example, higher standards of environmental care.

4) *Demands for improved environmental quality by citizens.* There is evidence to suggest that wealthier economies, or the wealthier parts of economies, demand higher environmental standards (White, 2002). Therefore a stimulus for improvements in water quality could include New Zealand's growth in wealth. Increasingly, this wealth will be held in New Zealand's major cities and their rural fringes. With wealth and agricultural food production geographically separated, some commentators predict increased divisions between town and country. However, in my opinion, the mutual needs of cities and of farmers (e.g., cities need food and farmers need to listen to their customers) will act to dampen divisions.

5) *Climate change.* In my opinion significant variability in climate is inevitable in the future. You may or may not ascribe to the view that mankind is altering the global climate, but it is a fact that that the earth's climate has been hugely variable in the past and, by inference from the historical record, will be hugely variable in the future.

6) *Increasing pressure on water resources.* Water allocation in New Zealand increased by about 50% during the period 1999 to 2006 (Ministry for the Environment, 2006) and there is every likelihood that water allocation will increase further in the future. Water use by the productive sector is fundamentally an economic activity. For example, water demand by agriculture increases because a growing population wants more food. Water demand also increases because farmers have to grow more food to maintain their revenue over time. For example, a long-run increase in average dairy herd size in New Zealand, and therefore an increase in water demand by the dairy sector, is matched approximately by a reduction in dairy prices over time. A reduction in dairy prices over time is consistent with dramatic reductions in food prices over the last 200 years (Lomborg, 2001).

7) *Technology.* We have an increasing capability to collect environmental data because the unit costs of data collection are reducing over time. We also have an increased capability to process and model environmental data, largely because the unit costs of computing are reducing over time.

8) *Curiosity.* Humans are intensely curious and scientists are no exception—many research developments will come from the passion and creativity of scientists themselves.

Current knowledge and research

Current knowledge of water resources in New Zealand and developments in water research are reviewed by Harding *et al.* (2004) for surface water and by Rosen and White (2001) for groundwater.

Future research directions

My speculations on future research directions consider some of the future influences on hydrology. These speculations draw partly on my personal research interests, that include groundwater resources, groundwater–surface water interaction; land use and water quality; and water economics. Future research directions are grouped into five broad categories.

1) *Historic records of water flows.* Allocation of water for use currently faces at least two unknowns—future water availability and future water demand. Future water availability is assessed from historical records (e.g., of river flow and groundwater level), yet our historical records are short. Approximately 90% of surface water sites have records of less than 45 years duration (Keane, 2001) and the longest record of surface water level in New Zealand goes back to 1905 (Lake Taupo; Freestone, 2005). Approximately 90% of groundwater level records are less than 35 years in duration (Keane, 2001) and the longest record of groundwater level in New Zealand goes back to 1894 (Canterbury Museum, Weeber *et al.*, 2001).

   These records are short in relation to the timescales of climatic systems and hydrological systems. For example the world climate is currently in an interglacial period. Climate and sea level have been much different in the geologically-recent past (White, 2001); a mere 10,000 years ago the sea level was about 25 metres lower than present day and (Gibb, 1986).

I propose that research into past climate be translated into estimates of past river flows and groundwater flows, with the aim of establishing the variability of water availability in New Zealand. Time periods of studies fall naturally into two groupings—the current interglacial period of roughly the last 7,000 years, when sea level has been at current levels, and the glacial period immediately before that. Much data is now available, particularly from paleoclimate research in the northern hemisphere, that will be a useful guide to the climatic factors affecting water flows in New Zealand.

2) *Historic records of land use*. Land use has a significant impact on water flows and water quality. The timescales of catchment response to this land use can be decades, or longer. Therefore data on historic land-use patterns are very important to understanding current water quality. However our records of historic land use are poor. In my opinion we need to assemble historic land use data as soon as possible. Much of this information is held in the heads of land owners. We now have a window of opportunity to collate this information whilst many of the individuals who developed land in New Zealand in the period after World War II are still alive.

3) *Characterisation*. Characterisation of the hydrological system in New Zealand is relatively poor in my opinion. Partly this is because New Zealand is located in an exciting climatic zone and has an active geological environment; partly this is because research effort has been weak in a few key areas.

   Poor characterisation of the hydrological system is one reason why the legal system commonly struggles with resource allocation decisions. I suggest that in the future characterisation will need to improve dramatically to meet the future demands of a legal system facing an increasing volume of litigation associated with water resources. Characterisation of the system to a high standard is of vital importance in water allocation and water quality. For example, we will need to know the details of the effects of agriculture on water. Where does water go from a farm—via surface water or via groundwater, or both? What are the time scales of response by surface water and groundwater to changes in land use? What are the options, costs and benefits of changing the intensity of land use? The answers to these questions require much better characterisation of hydrological systems than are presently available.

   In my opinion, much research is needed to improve our understanding of two key components of our hydrological cycle—water inputs to catchments and groundwater. Our estimates of water inputs to catchments need improvement, with studies of rainfall, evaporation and climate. For example evaporation is very important to the hydrological cycle, yet the research effort on evaporation is slender in New Zealand.

   Groundwater resources are poorly understood in New Zealand, yet they are being increasingly used as a water supply and are coming under increasing pressure from land use. Certainly significant advances in knowledge have occurred in the last few decades, however, the models we need to meet future resource management challenges will have to be much better than the models we currently use. We need a better understanding of all the classic components of the groundwater system. In geology, for example, we need to estimate the storage characteristics of groundwater systems. In groundwater recharge, we need to estimate recharge from rainfall into an aquifer; and in groundwater discharge, to identify the locations and rates of discharge from groundwater to surface water. We need more information on groundwater flow and groundwater age, for example, to assess water residence times in groundwater systems. In groundwater chemistry, for example, we need to assess ambient chemistry in a groundwater systems and therefore to identify the effects of land use on groundwater quality. We need to know more about groundwater–surface water interactions, for example to assess the effects of reductions in surface water base flow on groundwater recharge from rivers. In groundwater ecology, we need to determine the role that ecology plays in groundwater chemistry.

Opportunities to improve characterisation of hydrological systems come from improved data sets provided by cheaper data collection and cheaper data processing. The cost of collecting data both above, and at, the ground surface is coming down in price over time. For example LIDAR ground elevation data is extremely cheap to collect, on a per-point basis, and offers considerable opportunities in the analysis of terrain for surface hydrology and for shallow lithology. Groundwater investigations are still expensive where drilling is required. However, the price of drilling will probably drop as groundwater investigations become more common. For example, the costs of drilling shallow holes in the United States are around 30% of what they are in New Zealand (Zemansky, pers. comm.) because US drilling technology is a little ahead of New Zealand and the US market size is larger than in New Zealand.

4) *Better models.* Our models of hydrological system components will improve as new data and new modelling approaches are developed. Water managers may become more confident with water allocation as their confidence in model calculations improves. An example of model improvement comes from recent research on rainfall recharge to groundwater in Canterbury. Typically, models of rainfall recharge to groundwater include components of rainfall, evaporation, and soil properties in a water balance model. These models are shown by White *et al.* (2003) to reasonably represent rainfall recharge observations. However a neural network model of rainfall, evaporation and observed rainfall recharge represents the observed rainfall recharge data better than a water balance model (White *et al.*, 2003) and a model developed by genetic programming (Hong *et al.*, 2005) represents the observed data better still. Therefore the neural network model and the genetic programming model are 'better' models of the dynamics of rainfall recharge.

   Research into the derivation of regional models from site-specific models will become increasingly important as our water resources come under increasing pressure for use. Regional models are important to water management, because water allocation decisions often start with water availability at the regional scale. Regional models are typically derived by up-scaling site-specific models. For example models of rainfall recharge to groundwater in the dry year 1997/98 in the area between the Waimakariri River and the Rakaia River (White *et al.*, 2003), based on four rainfall recharge sites, calculate a mean rainfall recharge of 13.8 m^3/s (neural network model) and 10.8 m^3/s (water balance model). The difference in calculated rainfall recharge is quite significant at the regional scale in this dry year, yet these calculations used the same approach to regionalisation. Other approaches to regionalisation would probably yield a greater range of estimates of rainfall recharge to groundwater, with a significant impact on potential allocations of groundwater in a dry year.

Links between models of hydrological system components will become more developed in the future. For example ‘sustainability’ is the aim of current resource management legislation; this approach takes account of resource, social and economic factors in managing resources, and models play key roles in integrating these factors. An attempt at linking models of resource and economic factors to assess the sustainable use of groundwater resources (White, 2001) will be much built on in the future, I predict. Currently the models to understand the social and economic factors influencing water use are very poorly developed in New Zealand and we must see more research activity in these areas in the future.

Tests of hydrological models must improve over time as hydrological data sets improve and model uncertainty is characterised. Models are a key to understanding hydrology, yet these models occupy a somewhat grey area in science, because models of a hydrological system cannot be tested in the same way that models can be tested at a laboratory bench. Testing of hydrological models is difficult because hydrological systems have significant natural variability over short and long time scales; hydrological systems are extremely complex over small and large spatial scales, and data is often sparse.

5) *Publish.* Scientists must publish their work.

Science must have its ideas in front of fellow scientists, science users and the wider community. Communication with each of these groups requires different approaches, but always the first communication step is science publication. The New Zealand Hydrological Society’s Journal of Hydrology goes to all members of the Society—about 500 people—and to many of the science libraries in New Zealand. Therefore the Journal provides an excellent way to keep your ideas in front of those who manage and monitor New Zealand’s water resources.

Today’s market for ideas is relentless; water resources management is no exception. Scientists must always keep themselves in the ‘supermarket’ of options for maintaining and improving New Zealand’s wonderful water resource.

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