On Water Allocation Modelling and the Context within New Zealand

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Water allocation modelling is relatively new to the scene in New Zealand. However, it is rapidly becoming a hot topic. Increasing pressures on our freshwater systems from population and industry growth, and a changing climate, have motivated recent mandates on freshwater quantity accounting in the National Policy Statement for Freshwater Management (NPSFM). The NPSFM calls for regional councils to adopt policies and tools to "sustainably manage the taking, using, damming, or diverting of fresh water". Objectives of such management include safeguarding of ecosystems, maximizing efficiency in water use, avoiding over-allocation of resources, and providing for productive economic opportunities. Regional councils are also called to improve their information on freshwater takes by developing "freshwater quantity accounting systems". Presumably, envisioned here are databases, spreadsheet calculations, and more sophisticated computational tools - like water allocation models.

Water allocation models are, generally speaking, a category of water resources models that aim to simulate exactly what councils are called to manage by the NPSFM: the taking, using, storing, and diversion of freshwater. They differ from traditional hydrologic models in that they don't typically apply rainfall-runoff, or similar, calculations to generate flows in a river system. Rather, they rely on prescribed flows at key locations and move these flows downstream through a dendritic network, combining, augmenting, storing, and allocating to water users, as programmed. Hydrologic gains (or losses) may feature in the models but are calculated relatively simplistically and are grounded in empirical gauge data, to the extent possible. Water allocation models don't typically include any sort of sophisticated river or reach routing (e.g. wave propagation) or groundwater hydrogeologic calculations. They do, however, often provide for the simulation of surface reservoir operations of varying levels of complexity.

In contrast, traditional hydrologic models don't typically allow for the simulation of node-based water use or the legal and operational constraints that might drive water allocation. Hydrologic models can, however, be used as supporting tools in water allocation studies. They might provide, for example, naturalized flow projections at key basin locations that then serve as inputs to a water allocation model.

The true value added, compared (for example) to simple spreadsheet accounting calculations, comes from the spatial and temporal resolution offered by such models. Water allocation models typically simulate an extended period of variable climate and hydrology. This allows for projections of river flows, and allocation impacts, for a range of potential environmental conditions and inclusive of back-to-back events and realistic hydrologic sequencing. The models are typically node-based, with a high level of spatial resolution. This allows for a comprehensive assessment of the downstream impacts of a change in water use, or storage operations, or of the upstream impacts of a downstream prioritisation. The spatial domain can encompass an entire river basin or can be focused on a specific reach, or reservoir, with a small number of water users.

The calculation of legally available flow, at any point in the river network, is also a key feature of most water allocation models. This calculation might consider withdrawal consent limits, instream or environmental flow requirements, storage consents, and/or downstream priority users. As an example, in the arid west of the United States, the calculation of legally available flow is typically guided by the "prior appropriations" doctrine, which essentially states, "first in time, first in line". In other words, the original date of each water rights appropriation dictates the order of priority of water users. As a contrasting example, in Tanzania, water user priorities are set based on category of use type. User groups are prioritized in the following order: domestic users, environmental/ecological flow targets, irrigation, and industrial. Water allocation models often include some sort of optimisation routine to satisfy water demands in order of user-prescribed priority. Such a routine is part of the calculation of legally available flow for each water user.

Water allocation modelling, as a specific discipline, has been around for decades in the USA. As noted above, the western water-short states, particularly, have relied on modelling for decision support in water appropriations. These models have primarily been used in one of three ways: 1.) long-term planning, 2.) consenting/permitting decision support, or 3.) basin operational support. For example, in Oklahoma, CDM Smith's Simplified Water Allocation Model (SWAM) software was used to help the State plan for long term water demand increases and supply-side climate change impacts. The focus of this work was primarily on quantifying reservoir water supply firm yield, defined as the minimum annual demand that could be satisfied by reservoir withdrawals, during critical drought periods, without violating minimum pool constraints. In Colorado, the SWAM software was used to investigate water rights transfer options, from agriculture, to maintain reservoir water levels for endangered migratory bird habitat. Keeping the piping plover happy!

With a changing climate, and increasing demands for water, water allocation modelling is rapidly moving into the eastern states. In South Carolina, water allocation models were developed for each of the eight major river basins in the state. The models are being used for both regional planning, with demand projections, and for water permitting. Traditionally, the State has used statistical metrics, based on historical gauge data, to determine whether to issue a permit or not. A "safe yield", for defining the maximum allowable total withdrawal at any location, is calculated simply as 80% of the estimated natural mean daily flow at the given location. Mean daily flow is calculated based on available gauge records. The limitations of this approach, as recognized by the State, are mainly associated with a lack of temporal and spatial resolution in the calculations. Spatially, the approach lacks a holistic catchment view, with the potential impacts on existing downstream users not considered. Temporally, the approach often results in the defined safe yield exceeding the actual total flow in the river at certain times of the year, particularly during dry years. The State is now using their newly developed water allocation models to provide a more comprehensive assessment of a permit application and to make a better-informed decision on the application.

As a final example, the SWAM software was used to develop basin water allocation models for the Rufiji River Basin Water Board in Tanzania to assist with both planning and permitting. On the planning front, the Board is using the models to analyze the ramifications of newly quantified prioritised environmental flow "reserves". These reserves are particularly important for the national parks and game reserves in the basin. The models are being used to answer important questions, like, "if a minimum flow of X is to be maintained at location Y, what are the implications for upstream irrigators and industrial users?" Regarding permitting, to-date the water board has made decisions about new permit applications based either on gauged flow statistics (with limited data availability) or on manual spot checks of river flow during the low-flow season. Going forward, the models will allow the water board to make better informed decisions, including providing for modelled estimates of naturalised flows at any location in the basin.

In both the South Carolina and Tanzania examples, the models were developed with the intention of being used by a wide range of end users with varying levels of relevant experience. As such, they required a certain level of usability. End-user expertise is an important consideration in any model, or software, development, but is particularly important for water allocation models, given their multi-purpose objectives and potential use as regulatory tools. The State of Colorado has spent millions of dollars on their water allocation decision support system. Unfortunately, the software is so complex that only a small handful of expert consultants are able to use it with any confidence. That's not to say it's not powerful and very useful, it's just not particularly usable. Usability can be enhanced with the allowance of varying layers of complexity, with layers added only as needed. With SWAM, we often define such user complexity levels for our end users (Table 1). As you move down the table, the number of active model features and parameters (complexity), and/or expertise requirements, increase and the intended range of end users narrows. Usability is also closely tied to the software's user interface. For water allocation models, a graphical user interface is often critical to the user's spatial visualization and understanding of the modelled system. We'd generally expect to see, in a water allocation model interface, a series of water user nodes, reservoir icons, stream reaches, and a sense of the directional flows being represented in the modelled catchment. An example (SWAM) is shown in Figure 1.

In New Zealand, a cursory review of regional council websites reveals a mix of water allocation and accounting practices currently being employed. Waikato Regional Council (WRC) have developed the "Surface Water Allocation Tool", which is a web-based accounting and database tool. The tool graphically (GIS) provides a spatial summary of all existing water takes and filed consent applications. In other words, the tool provides demand-side summaries of water takes in the catchment. It is also used to directly support their consenting review process. This process involves a calculation of water allocation "pressure levels" at predefined locations throughout the catchment. Essentially, the tool calculates the total consented take upstream of a given checkpoint, including any newly proposed direct takes, and compares this total take to a previously determined allocable flow limit for the checkpoint. This allocable flow limit is defined as a percentage of the 5-year 7-day low flow (Q5). The Q5 statistic is calculated directly from gauge data, where available, or, elsewhere, based on ungauged flow estimates. A decision is made regarding new consent applications based on calculated pressure levels. For reservoir takes, newly proposed takes are only indirectly considered in the pressure level calculations, implicitly captured in "promised" minimum reservoir releases. In this case, water allocation models could be used to provide for a more rigorous and direct calculation of catchment flow impacts, including impacts on reservoir levels and operations. A water allocation model would provide improved spatial and temporal resolution in the assessment, with impact calculations extending to any location of interest in the catchment and across a range of hydrologic conditions. However, it may be that such resolution is not required, at this time, for WRC to make well-informed decisions.

Bay of Plenty Regional Council (BOPRC) and Taranaki Regional Council (TRC) both use statistical methods to assess consent applications. BOPRC considers 10% of the 5-year, 7-day low flow to be allocable. Gauge data, in combination with area-ratio transposition methods, are used to calculate this allocable volume at the point of take. TRC appears to be in the process of revising their process, but currently quantifies total allocable flow as either 30% or 50% of the minimum 7-day annual low flow. Environment Canterbury (ECAN) developed a spreadsheet-based accounting tool for investigating the impacts of new environmental flow targets on supply availability and existing targets.

On the surface, it appears that each of these New Zealand examples could benefit from the added rigor of water allocation models to support decision-making and planning. For example, in the Waikato, we developed water allocation models of the upper and lower river basins for industry as part of two separate studies. For both projects, the developed models were used to simulate "what if" scenarios associated with hypothetical demand increases and the prioritization of minimum river flows. Because of the spatial resolution in the model, the demand change simulations allowed us to easily investigate impacts on river flows at any location in the basin and to identify impacts (shortages) on other water users. Using the prioritization scheme in the models, we were able to quantify the impacts of downstream minimum river flow requirements on the ability of upstream water users to satisfy their demands. As a final set of simulations, we investigated the impacts of Variation 6 of the Waikato Regional Plan, which calls for a prioritization of municipal supplies and stock water needs. This analysis identified vulnerabilities for major industrial users in the basin, during critical low-flow periods, as a consequence of this regulation. It does not appear that such predictive simulations could be performed with the tools currently in WRC's toolbox.

Going forward, we anticipate that regional councils will take a more comprehensive approach to decision support for water planning and consenting. The need to accurately quantify catchment-wide impacts of a new consent, or to quantify the cumulative impacts of projected increased water demands, dictates the need for more sophisticated numerical tools. Consequently, water allocation models may play a greater role. Similarly, as described above, industry may employ such models to support their own planning efforts and to inform negotiations with councils. Industry, often better resourced than government agencies, may benefit from a more rigorous technical analysis of water allocation. This is particularly true when the alternative is to rely on more simplistic methods offered by Council, which are often based on conservative assumptions. A relatively small investment in a robust modelling study could pay large dividends down the road for industrial stakeholders.

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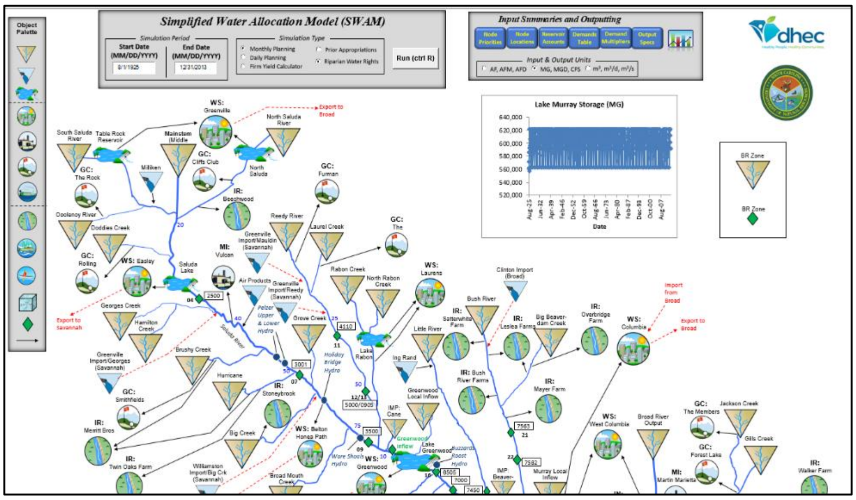
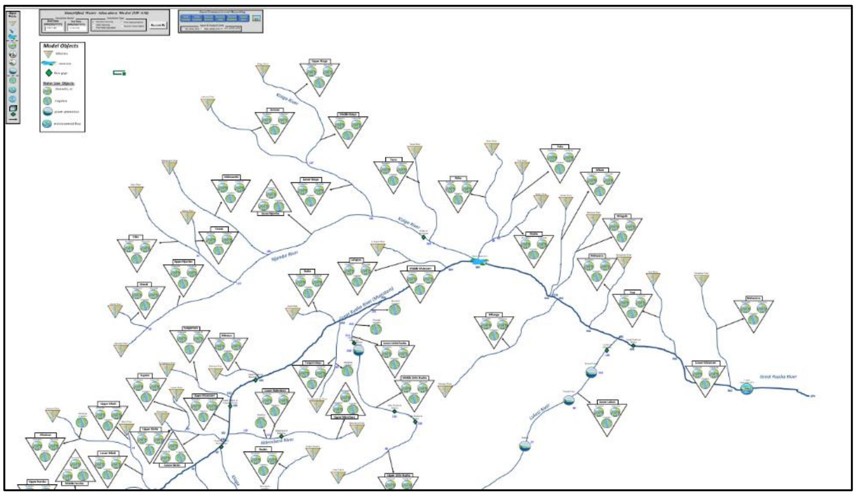
Table 1. Water allocation modelling applications

Level 0 applications (anyone) Data management and queries using the interface to access underlying data answering questions like, "what is the approximate total irrigation water take above gauge X?, "what is the approximate mean annual flow at location Y?", or "what is the total consented take for industry Z?"
Level 1 Applications (trained Council or industry staff, with relevant background and software documentation) Demand change projections "how do projected changes in demand impact catchment flows, water availability, and yield?" New consenting "how do changes in existing consents, or the addition of a new consent, impact flows, water availability and yield?" "can the water use demands of a new consent be reliably met without impacting other users?" Naturalised flow simulation "what does the naturalised flow regime (without upstream takes or storage) look like at location X?" Environmental flow assessment "how frequently will an environmental flow target be violated at location X, given current or future water use?"
Level 2 Applications (hydrologic modelers with training and experience) Water supply alternatives analysis "what combination of actions could be taken to more reliable meet downstream environmental flow targets while still satisfying upstream demands?" Reservoir yield and design analysis design support for new reservoir construction, existing reservoir safe yield analysis Reservoir operations analysis "how can we optimally manage reservoir releases to best achieve downstream environmental flow targets?" Prioritisation simulations "what are the implications of a prioritised environmental flow on other water users in a catchment?" Climate change analysis "how might future climate change impact water supply availability and river flows in a catchment?"
Level 3 Applications (experienced water allocation modelers with knowledge of software) Model construction and calibration/parameterisation exercise.

1. South Carolina:



2. Tanzania:



3. Lower Waikato:

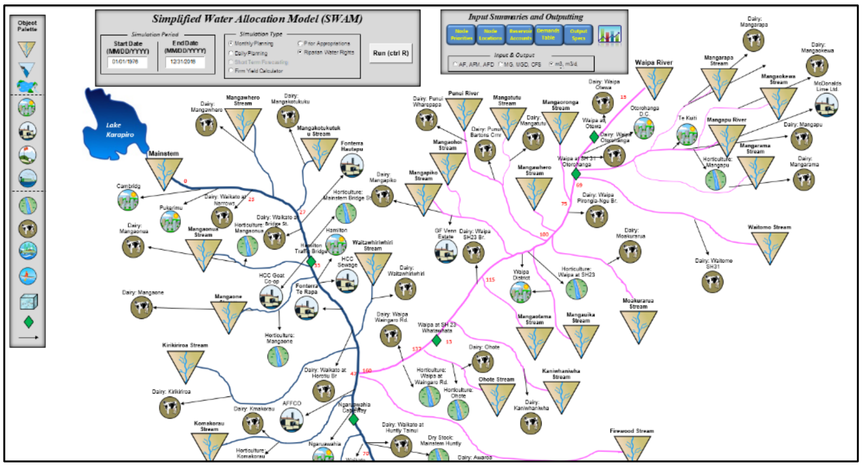


Figure 1. Screen capture examples of water allocation software interface (SWAM)