Creating Futures

WISE Scoping Study:

Enhancing and Extending the Role of the Hydrology Model

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Product information
WISE (Waikato Integrated Scenarios Explorer) is an Integrated Spatial Decision Support System (ISDSS) designed especially for the Creating Futures project funded by the New Zealand Foundation for Research, Science and Technology (FRST). WISE has been developed for the Waikato region to support Waikato Regional Council's long term integrated spatial planning and decision-making. Information about the 'Creating Futures' project is available on the Internet, including an electronic copy of this report: http://www.creatingfutures.org.nz.

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Waikato Integrated Scenario Explorer Scoping Study: Enhancing and Extending the Role of the Hydrology Model

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Overview

The hydrological processes embodied in WISE are currently stand-alone, yet most of the modules within WISE are in some way water-dependent. The water quality module relies on surface flows to route contaminants; irrigated agriculture requires a reliable source of water; and economic output of many industries depends on water used either consumptively or non-consumptively. Furthermore, there are other elements of Waikato's socio-economic system that relate to water but are not currently considered in WISE, such as aquatic biodiversity and recreation. These limitations highlight a need to develop and prioritise a list of options for augmenting the utility of the hydrology module within WISE as a whole.

The present scoping study was requested to provide options for such a list. Specifically, the stated aims are to:

- Identify the desirable extensions to the hydrology component in WISE
- Assess their feasibility, cost, delivery date, and relevancy.

Existing Hydrology Model

The hydrology model currently included within WISE is an analytical model based on the theoretical analysis of Woods (2003).[1] Simplified representations of climatic drivers and hydrological responses are integrated to provide mean annual water yield from spatial units 500 m by 500 m in size. Necessary input for the model includes mean annual rainfall and evaporative demand as well as land use. The simulated water yield aggregates both surface runoff and recharge to any underlying aquifers. Annual water yields can be disaggregated into shorter time periods based on pre-defined partitions of flow seasonality, which are derived from historical analysis; this is currently done for summer. While the model has undergone initial calibration for the Waikato region, it has not been verified.

The hydrology model is currently linked to two other components of WISE. On the one hand, climatic drivers can be varied based on imposed climate change scenarios; on the other, land use descriptors can be varied based on land use change scenarios. No components within WISE rely on the hydrology model in any way.

User needs

In order to enhance the utility and predictive ability of WISE, enhancements to the manner in which the hydrology model component is included and interacts with other components would be very beneficial. In so doing the drawbacks noted in the Overview section could be overcome. Users would then gain a better understanding of the manner in which, and conditions under which, water availability can limit the utilisation of land resources.

1 Woods, R.A. (2003). The relative roles of climate, soil, vegetation and topography in determining seasonal and long-term catchment dynamics. *Advances in Water Resources* **26**(3): 295–309. Erratum **30**(5): 1061.

Possible Enhancements and Extensions

Outlined below are possible enhancements and extensions of the current hydrology model or of other models where they may interface with the hydrology model. Several steps are not stand-alone, but require, or at least benefit from, other developments. Following the list, the feasibility, cost and relevance of each extension are summarised in Table 1.

1. Validation of the hydrology model

The current hydrology model is not validated. Validation is a necessary phase of model development that assesses whether the model is a useful representation of reality. It helps to constrain the model's inevitable errors, and provides information to users on how much the model's results can be trusted. Validation may also highlight development needs for the hydrology model.

2. Refinement of the temporal resolution

This may be desirable in the context of bridging to the economic model and the land use model (especially the land suitability component for agricultural uses). For the current hydrology model, the same method used to downscale annual to summer water yields can theoretically be achieved for any season or time period. Increased uncertainty would be inevitable, and verification is advised. Time periods that are particularly fine (<1-2 months) will require a temporally explicit routing scheme to be added, at significant cost.

3. Partitioning of water yield into stream flow and groundwater

The current model considers surface runoff and groundwater recharge together. Indeed, much surface runoff would have temporarily been groundwater flow. Separating the two resources, however, would assist in routing water from the source through the catchment, which opens up several opportunities listed below. How this would be achieved is not initially obvious; for a robust solution, this may be quite time-consuming.

4. Routing of stream flow and groundwater flow through the catchment

If water resource availability is to be considered for abstraction or hydropower uses, water yield must be accumulated down-river or down-aquifer. Partitioning local water yield into river flow and groundwater flow is thus necessary; also necessary is consideration of how surface flow is fed by groundwater flow at different scales. A simple accumulation of surface flow may suffice if the temporal resolution is not particularly fine, but would need to be verified in any case. It would be valuable to develop a routing scheme in harmony with the water quality module.

5. Probabilistic downscaling of seasonal flows to consent-relevant flow conditions

No hydrology model with the appropriate complexity for WISE would be able to directly simulate river flow conditions at a daily or even weekly scale. However, this may be circumvented by using probabilistic downscaling techniques. These use historical flow conditions to build probability distributions of flows conditional on longer-period flow volumes. Doing so inevitably introduces uncertainty, but allows a connection to be made between the current hydrology model and critical flow conditions for consents or aquatic habitat. The inevitable uncertainties may be treated in an ensemble approach.

6. Ensemble simulations

The drivers of the hydrological model – rainfall and evaporative demand – are variable and uncertain. In terms of economic behaviour, it could be that it is the extreme events are what matters, rather than average conditions. This may be seen, for example, in the use of reservoirs to store water for times of drought. To account for this uncertainty, one may consider water resources in a time-varying and probabilistic context. One means of doing so is by using an ensemble of parallel simulations, with each simulation representing an alternative possible hydrological future. By encapsulating the inherent uncertainty of future climatic conditions in this way, a probability distribution of planning responses may arise, and allow risk-based planning. Implementing this feature into WISE would require some representation of the hydroclimatic probabilities, which could be inferred from historical data. A shortcoming of this inclusion is that it would substantially increase simulation time.

7. Inter-annual variability through ENSO and IPO

ENSO (El Nino-Southern Oscillation) and the Interdecadal Pacific Oscillation (IPO) drive variations in weather that, currently and for some decades to come, would likely be larger than any expected climate changes. If planning is to take place in the context of an uncertain future hydroclimate, it is sensible to consider ENSO and the IPO, as their variability could affect inter-annual or inter-decadal planning decisions, much as emerging knowledge of the IPO did for South Island hydropower reservoirs in the 1990s. Their inherent uncertainty may be accounted for within an ensemble framework.

8. Inclusion of reservoirs into the routing model

Reservoirs may be added in-stream or off-stream. They are relevant to most hydropower generation and possibly also to seasonal irrigation. For the current hydropower system, Lake Taupo provides 9 weeks of storage at the mean flow, while the dams down-river provide no effective storage at all. Modification of the surface routing scheme would require locations, volumes and operational rules for each reservoir modelled. The time-steps of the hydrology model and any reservoir-dependent model need to be sufficiently fine to be meaningful.

9. Use of simulated stream flow to drive the water quality module

Two potential shortcomings of the current water quality module are that it is independent of hydrological variability. Neither interannual variability nor climate change can be accounted for in the long-term model. This stems from the paucity of data with which to fine-tune the model. The implications of this are that long-term climate trends are overlooked, as are shorter-term variations. With modelled water yield partitioned into surface flow, and with the inclusion of a surface routing model, this connection should be straight forward.

10. Development of a hydropower generation model

Hydropower is a significant element of Waikato's economy, with output around $300M in wholesale prices and $900M in retail prices in 2009, and the major user of the region's water, albeit for non-consumptive use. A desired time-step for hydropower generation would be monthly. In most instances, reservoirs would have had to be included in the surface routing scheme. The economic modelling involved would be substantially more complicated than the hydrological modelling, particularly as the main competition for water is with irrigators for whom water is difficult to value. As an intermediate solution (in case the economic modelling is too difficult), WISE could just provide an indicator with the amount of electricity generated. Future hydropower generation would depend on upstream consumptive water uses (including non-irrigated land use) as well as climate change.

11. Augmentation of the land suitability curves to account for water availability

The land suitability curves currently implemented make no mention of hydrology or climate. Landcare Research has conducted some research along these lines that may be useful in extending the curves' applicability. What hydrological modifications are necessary, if any, would depend on this research. A second approach would be to quantify the reliability of water takes, subject to flow and consent conditions; water-using activities become less viable as reliability declines. Land suitability can be seen as a proxy for yield. As such a link can be made from the land use model (through the suitability and land use maps) to the economic model. Yields can be used as input here and can in the economic model be translated into dollar value.

12. Inclusion of water trading

Water trading is currently being explored as a means to manage Waikato's limited water resources. If or when trading becomes active, a possible inclusion into WISE is the embodiment of the regulations and associated consumer behaviour. It is not a consideration for the hydrological model or for the economic model at this time. However, WISE may offer a valuable platform to analyse implications of any water trading.

13. Inclusion of irrigation and abstractions to the water storage/routing models

Should irrigation be modelled, for the purposes of driving a water-based agricultural economic model, any associated abstractions should be accounted for in the hydrology model. The same should be considered for other abstractions. This should be straight forward, provided the volumes are known.

14. Quantification of water demand for different activities or sectors

This is not an extension of the hydrology module per se but rather a valuable step in linking hydrology to the socio-economics model. Knowing how much water an activity requires allows one to assess its impacts on water resource availability, and may be inferred from resource consents and monitoring records held by Waikato Regional Council. A typical limitation of the consent data, however, is that only maximum allowed takes are recorded rather than actual takes. With this link, the effects of demographic and land use changes may be translated into water resource pressures. To an extent, this falls within research already conducted by Garry McDonald (i.e., 1999 EcoLink report on water use and economic activity) as well as research currently being conducted by Basil Sharp of Auckland University. The emerging technique of life cycle assessment, in so much as it relates to water, has yet to be fully adopted in New Zealand and thus cannot provide useful information at this time.

15. Linking economic productivity to water use

Once the water demand for different activities is known, the next step is to link it with the economic output of these activities. Again, this is not a development for the hydrological model but of the economics model, along the lines of the work of Garry McDonald, Basil Sharp and Agresearch.

16. Environmental flows and aquatic biodiversity

While WISE currently accounts for terrestrial biodiversity, a module that considers aquatic biodiversity is absent. Products of any augmented hydrology module would be necessary in driving any aquatic ecology assessment, even though the development of such a module is outside the current scope. An intermediate step would be to factor environmental flow requirements into water allocation rules when the economics model accounts for water availability.

17. Interaction with CLUES

The hydrology model used to calculate stream runoff in WISE can account for impacts of land use change and also climate change. In contrast, the model used in CLUES (i.e., SPARROW) does not. In principle it is a relatively straightforward matter to have the SPARROW flows made compatible with WISE (the runoff layer in SPARROW reads an annual average flow for each reach from a table of flows—that table could be made the subject of re-calculation by explicitly accounting for land use change and climate change). Achieving this compatibility is likely to be especially important were WISE to be extended to calculate seasonal and average concentrations, as is now available in CLUES, because concentrations are calculated from the mass flux divided by flow rate. Apart from the mechanics of connecting the flow rates between models, there would be a need to check the calibration of SPARROW to determine whether using flows from the hydrology model upsets the calibration, and adjusted SPARROW parameters might need to be introduced into WISE. It is unlikely that the parameters would need to change much, because mass flux in SPARROW is fairly insensitive to flow rates and the flow rates will not be much different.

Table 1: Indicative or approximate feasibility, cost and relevance of each proposal. Where the cost is known, delivery time is roughly proportion to cost.

#	*Topic*	*Feasibility*	*Cost**	*Relevance*	*Depends on*	*Comments*
	IMPROVEMENT TO HYDROLOGY MODEL ONLY					
1	Validation	High	$6000	High	–	Highly desirable to do this.
2	Temporal resolution	High	$6000	Medium-High	–	Desirable when bridging to an economic model in which seasonal water use can be a constraint. Could also be appropriate when using WISE outputs to assess compliance with water quality standards (which commonly have a seasonal component); or maybe best to leave that to CLUES?
3	Partitioning	Medium	$25000	Medium	–	A challenging task. Early CLUES reports contain discussions of how this might be done, including relevant formulae.
4	Routing	High	$10000	High	–	This would enhance the consistency of the entire integrated system. If the link to the water quality model is made, we should also look into the time steps and underlying paradigms of both models (simulation vs. long-term equilibrium). Both could work together but we have to find a good way to communicate the water quality results and to update them correctly through the simulation period (i.e. include the water quality in lakes from previous years).
5	Downscaling	Low-medium	$20000	Low-medium	–	Most applicable to critical flow conditions, particularly low flows. May be better to mount special investigations in waterways where this is perceived to be a potential issue. Should critical flow conditions be linked to water use/extraction? For example, is river flow insufficient for abstraction? Or should it be directly linked to land use, e.g. if there is the expectation that another dairying farm or factory would use an amount of water that would give a critical flow than this new farm or factory is not allowed?

*Estimate does not include programming costs to incorporate any enhancements or new models into WISE.

Table 1—continued:

#	*Topic*	*Feasibility*	*Cost*	*Relevance*	*Depends on*	*Comments*
6	Ensembles	Medium	$20000	Medium	–	Makes an accounting for uncertainty in predictions.
7	ENSO/IPO	High	$6000	Medium	–	Relevant to long-term planning
8	Reservoirs	High	$10000	High	–	Relevant to hydropower and irrigation demand
	IMPROVEMENTS TO HYDROLOGY MODEL AND OTHER WISE MODEL COMPONENTS					
9	Flow-quality link	High	$6000	Medium	1, 3, 4 (5?)	To include hydrologic variability
10	Hydropower	High	$10000	High	1, 2, 3, 4, 6, 7, 8	Future generation will depend on upstream consumptive water use, land use change and climate change
11	Land suitability	Unknown	Unknown	Medium	–	Requires an empirical approach, depending on availability of relevant data (so feasibility unknown at this stage).
12	Water trading	Medium	Unknown	Low	Potentially 1 – 8	Largely experimental. From an economics perspective an ABM, choice model or SD model simulating trading would probably need to be developed an incorporated directly into WISE. Would need to be linkage to the existing models within WISE. At current this seems beyond the resources available for extension.
13	Irrigation/ abstraction	Medium	$10000	High	Potentially 1 – 8	Straightforward task
14	Demand	Medium	$20000	High	13	Several attempts have been undertaken to estimate water demand by industrial activity. Based on Garry McDonald's EcoLink experience this could include: (1) calculation by a mixture of top-down (studies of selected industries) and bottom-up (additional data of inferred from local estimates or factors) of sector demand, and (2) modification of the economic model to incorporate supply side limitations.

Table 1—continued

#	Topic	Feasibility	Cost	Relevance	Depends on	Comments
15	Economic productivity	Medium	$5000	High	14	Relatively straightforward once item 14 had been completed
	NEW MODELS					
16	Aquatic ecology	Medium	$10000	Low-medium	?	Experimental at this stage. Would need to calculate concentrations from calculated loads calculated..
17	Interface with CLUES	High	Nil–$6000	High	–	Cost is nil if the only change is made to CLUES. Otherwise the stated amount would apply were the hydrology component of WISE to be extended to calculate annual-average and seasonal-average concentrations (at present WISE computes only loads, but CLUES calculates these concentrations).