

Modelling to assess water resources availability and use – How does it relate to weather and climate modelling?

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Why is water resources information needed?

Recent droughts have painfully exposed the scarcity and often unsustainable level of reliance on surface and groundwater resources in Australia. The new responsibilities of the Bureau of Meteorology reflect a wide appreciation that to manage a scarce resource like water, information on its use and availability in space and time needs to be provided better, faster and cheaper. Some possible examples by which water information can contribute to more efficient and sustainable water management are listed in Table 1, along with suggested key issues with regards to the techniques, challenges and avenues open to deliver this information. The listed applications probably only represent a subset of all conceivable needs, however. Below, the role of modelling in developing water resources information is explored, with emphasis on linkages to weather and climate modelling.

Modelling of past and current water resources availability

In retrospective and monitoring applications, the greatest technical challenge requiring modelling is probably to overcome the sparse and partial observation of diffuse or highly distributed water stores and fluxes. Examples include surface and groundwater pumping and diversion (e.g. floodplain harvesting), and diffuse water exchanges between soil, groundwater and surface water systems. Extended metering networks can reduce some of the uncertainty in distributed fluxes, but inference and modelling will continue to be required to interpolate and extrapolate observations in space and time.

Satellite instruments do not directly meter water fluxes and alone do not provide an accurate alternative to on-ground observations, particularly in Australia's drier environments. Currently, the apparent error of various available satellite-based ET and streamflow estimation methods are in the order of 50–100 mm/y (taking streamflow and flux tower records as a reference; Van Dijk and Mattersdorf, 2007; Raupach et al., 2007; Zhang et al., submitted; Guerschman et al., in prep.). This is typically within 10% of annual average ET, but because net influx into the surface and groundwater systems is the difference between two large terms (rainfall minus ET) this relative error becomes similar or larger than the flux itself. Uncertainty is the accumulation of errors in on-ground rainfall and meteorological observations, their interpolation in space, and the model used to combine these with satellite data.

Despite their indirect nature, the good spatial and temporal coverage of satellite observations does make them an ideal data source to integrate with streamflow and metering records in model-data assimilation (MDA) applications. MDA can also help to reconcile inconsistencies in on-ground observations by explicitly considering gauging and metering errors that are presently largely left unaddressed.

Table 1: Examples of potential water information uses, with the suggested most suitable technology, key obstacles and avenues to overcome these. This assumes that all existing data, technology and science can be deployed to their full potential - in reality, pervasive additional obstacles exist associated with modelling technology and data management and delivery.

<i>Purpose</i>	<i>Information ideally required</i>	<i>Time scales</i>	<i>Most suitable technology (in theory)</i>	<i>Key obstacle</i>	<i>Possible solutions</i>
Accounting of regulated water use against entitlement	Up to date and accurate water use records	Recent	Full and ongoing metering and gauging	Infrastructure costs, acceptance/implementation	cheaper metering, up-scaling methods, earth observation
Accounting of unregulated and environmental water use	Up to date and accurate water use records	Recent	Water use estimation based on remote sensing and modelling	Accuracy of remote sensing based ET estimates	Integration of multiple data sources (satellite, on-ground, radar)
Compliance with water affecting land use regulations	Ongoing robust data on land use by land holder	Present	Ongoing satellite observation	Costs of imagery and accurate classification and interpretation	Merge complementary data, automated analysis methods
Decision making for more efficient day-to-day water use	Forecasts of rainfall and crop water demand	Days/weeks	Weather, rainfall and flow forecasts	Uncertainty in short-medium term weather and rainfall forecasts	Improve weather and rainfall forecasting skill
Decision making for efficient water management by suppliers, supporting water trade	Forecasts of water orders, water in store and flows at key points	Days/months	Weather and rainfall forecasts combined with surface water gauging in modelling	Uncertainty in short-medium term rainfall forecasts and outlooks. Unsuitable current hydrological modelling techniques	Improve rainfall forecasting skill, introduce model-data assimilation in hydrological modelling
Early response to emerging threats to water availability	Detected trends in water resources, use or climate response	Months/years	Comprehensive and continuous statistical analysis of observed and inferred data	Too short and incomplete data on surface and groundwater resources	Correlation analysis, systems modelling
Improved water resources planning and sharing	Capacity to test options under latest climate predictions	Months/years	River and groundwater planning models updated with current state and predicted climate	Uncertainty in climate change predictions and downscaling	Improve climate modelling and downscaling

Comparison of modelling approaches

Despite some commonalities between hydrological models and weather and climate models through near-surface processes, there are important discrepancies. Water resources modelling requires coupling of descriptions to vertical and lateral fluxes in the landscape (between available

and unavailable soil water and groundwater flows), the river system (between impoundments, irrigation areas and floodplains, including routing, regulation, diversion, and breakout flows) and the groundwater system (between layered or adjoining aquifers and localised extractions). Exchanges between these components also need to be represented (e.g. groundwater recharge and surface-groundwater exchanges). The different model components vary in their representation of space and time. For example, spatial structure can vary from a relatively simple one-dimensional node-link network to describe a river, to a complex three-dimensional raster to describe a multi-layered groundwater system. In an efficient modelling framework, the spatial resolution also varies as a function of the importance of hydrological processes. For example, two-thirds of all surface water resources in the Murray-Darling Basin is generated from only 15% of the area, whereas irrigated areas and water bodies represent less than 2% and 1% of the total basin area, respectively. These components need to be represented in greater detail than the remaining 82%. In summary, the strong heterogeneity of the hydrological system and processes requires a modelling paradigm and spatial structure that is largely incompatible with the homogenous, large scale, and grid based structure of land surface schemes in weather and climate models.

Model linkages in forecasting and prediction

Forecasting of water availability can obviously only be as good as the weather and rainfall forecasts that feed into it and this is the strongest (but one-way) link between weather and flow forecasting models. Similarly, the large uncertainty in projections of rainfall patterns due to global change and the transformation of these into data useable in hydrological modelling are by far the greatest source of uncertainty in projections of water resources availability and use.

There are some (potentially important) feedbacks between the climate and water system through changes in the surface water and energy balance. It seems unlikely that explicit inclusion of the hydrology of irrigation areas and wetlands would markedly improve weather or climate forecasts due to the relatively small size of the fluxes involved. For example, the amount of water in the Murray-Darling Basin returned to the atmosphere from irrigation areas, water bodies and wetlands in second instance (i.e. derived from surface water or groundwater resources) is equivalent to approx. 20 mm/y or 4% of total evapotranspiration from the Basin (Kirby et al., 2006).

A more important area of overlap between hydrological and weather forecasting is the influence of dry land soil moisture status on both weather and streamflow processes. Success so far has been modest, but in principle soil moisture observations should help to better forecast catchment response to (forecasted) rainfall. The nature of this relationship depends on the relative importance of different runoff generating processes, and can be a complex combination of groundwater level and unsaturated zone, root zone and surface wetness, with strong spatial heterogeneity. This leads to discrepancies between weather and streamflow forecasting with regard to the type of soil moisture information required and the way it is interpreted in the model. In addition, the intra-storm rainfall intensity distribution is typically an equally or more important control on runoff response and therefore would also need to be forecasted with greater skill before the benefits of catchment and soil wetness data can be realised. This information can be developed through integration of point-gauged rainfall intensity and totals, rainfall radar, and satellite observations (e.g. TRMM).

The greatest link between the climate and hydrological systems is probably the role of longer-term land cover dynamics in both systems. An important uncertainty in predicting climate change impacts on water resources is the change in the transformation of rainfall into streamflow or groundwater due to changes in vegetation function. Ecohydrology can change due to the effects of average and extreme weather and CO₂ fertilisation (dieback and recovery from droughts,

bushfires, and associated changes in agricultural land use, water harvesting and water conservation). This in turn may have repercussions for the surface water and energy balance and the carbon balance, and therefore there is a potentially strong linkage between climate and hydrology through vegetation dynamics. In low to medium rainfall areas (e.g. <1500 mm/y), evapotranspiration rates usually exceeds water resource generation rates several times, and therefore a relatively small ecohydrological change can have a significant impact on water resources. This is complicated by the episodic nature of streamflow generation and groundwater recharge in this rainfall regime, which requires reliable predictions of changes in the distribution of rainfall as much as or more than changes in average conditions.

Summary

At first glance, weather and climate modelling appears to have many areas of overlap with hydrological modelling to develop water resources information. Indeed, in many cases the quality and usefulness of water resources information critically depends on weather or climate information, and importantly often require greater temporal detail and skill than presently achieved. Research needs include (1) accurate and timely spatial estimates of recent meteorology, rainfall and rainfall intensity through integration of multiple data sources; (2) greater skill in rainfall forecasts, and forecasts of rainfall intensity characteristics; and (3) reduced quantitative uncertainty in changes in rainfall and its temporal distribution due to global climate change. These are one-way data linkages.

The requirements of modelling to assess water resource availability and use are too specific and different to be addressed using weather and climate modelling approaches. Closer scrutiny suggests that most overlapping processes are too different, and feedbacks too insignificant, to warrant a common modelling approach. In particular: (1) small bias and uncertainty in rainfall and evapotranspiration in climate and weather modelling can be greatly amplified in hydrology, requiring models that can use a multitude of on-ground point data in water resources applications; (2) the nature of the role of soil and catchment wetness in atmospheric and hydrological modelling requires different modelling paradigms; and (3) the influence of (changes in) river or groundwater derived ET on atmospheric processes appears negligible on the larger scale.

However, an area of true and important overlap relates to potential changes in dry land ecohydrological processes due to climate variability or change, which could impact on local water resources generation, the surface water and energy balance and global carbon cycle alike.

References

- Kirby, M. et al. (2006). The Shared Water Resources of the Murray-Darling Basin. Report to the Murray-Darling Basin Commission, Part 1. CSIRO Water for a Healthy Country.
- Raupach, M.R., Briggs, P.R., King, E.A., Paget, M. and Trudinger, C.M. (2007). Australian Water Availability Project (AWAP). Final Report for Phase 2, CSIRO Marine and Atmospheric Research.
- Van Dijk, A.I.J.M. and Mattersdorf, G. (2007). Comparison of MODIS-based scaling of potential evapotranspiration with on-ground observations. EGU 2007, *Geophysical Research Abstracts*, 9: 11692.