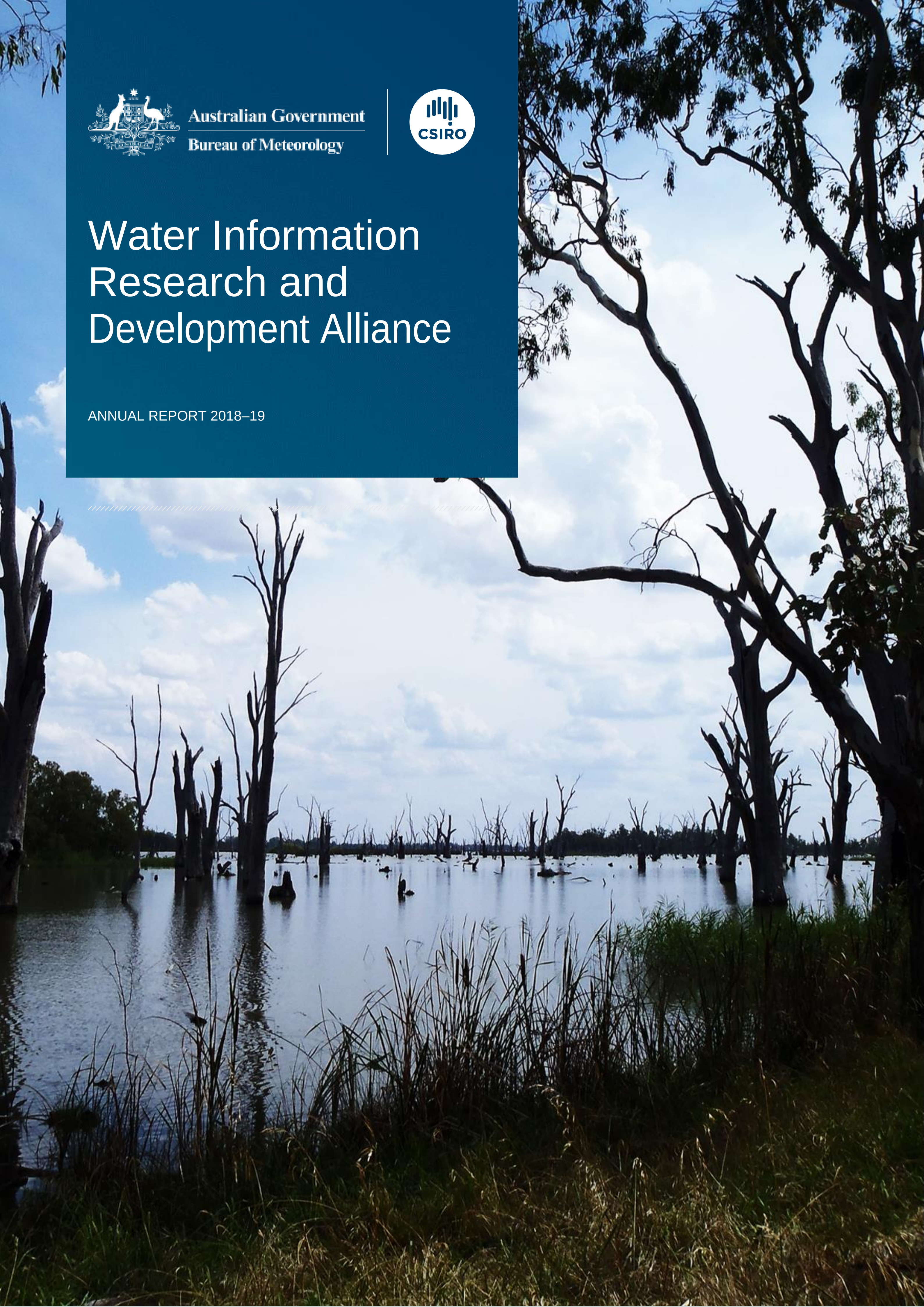
Australian Government
Bureau of Meteorology

CSIRO

Water Information Research and Development Alliance

ANNUAL REPORT 2018–19



Cover photograph: Merryn Coutts

www.bom.gov.au/water
www.csiro.au/en/Research/LWF/Areas/Water-resources

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EXECUTIVE SUMMARY

ABOUT WIRADA

For over ten years the Water Information Research and Development Alliance (WIRADA) has been the innovative force behind the delivery of national water information products and tools.

Our research partnership brings together CSIRO's scientific expertise in water and information sciences and the Bureau's knowledge and operational role in hydrological analysis and prediction.

2018–19 WIRADA ACHIEVEMENTS

This year WIRADA has undertaken targeted research projects to improve the use, performance, and accuracy of operational products.

WATER RESOURCES MODELLING

Australia is the driest inhabited continent on earth and has higher year-to-year changes in streamflow than most countries in the world. Expanding the capability of the Bureau's water modelling to simulate the past, present and future is critical for us to understand changes in the availability and movement of water across Australia to support better water management.

In particular, water managers require more robust estimates of water availability into the future. To this end WIRADA has undertaken a thorough investigation of the Australian Water Resources Model as a platform for estimating water availability for future climate projections.

The AWRA model was evaluated together with the Sacramento model at climatically diverse locations across Australia using techniques that allow the trade-offs in model performance to be quantified, for example performance during drier periods vs performance in wetter periods.

Using this knowledge, a subset of model parameters that allow the modeller to select "fit for purpose" parameters of known characteristics for any specific modelling task was stipulated.

A further output was as assessment of how different the impacts of climate change come out when simulated using the regional Sacramento or the national scale AWRA model.

For mean runoff, an indicator of catchment yields, there was very little difference in climate change signal magnitude. For other variables and for very dry or wet levels of these variables, the direction of change was still the same for both models, but the magnitude of the differences was slightly larger.

Knowing the contribution of the hydrological model to the uncertainty in predicted climate change impacts on water will allow users to interpret hydrological projections with greater confidence. Ultimately, this will lead customers to understand key climate change impacts on water resources for their region and understand the confidence with which these changes are associated.

STREAMFLOW FORECASTING

Good estimates of expected rainfall are critical to make reliable streamflow forecasts. This year our research has focused on delivery of ensemble forecasts that allow water managers to assess the risks of their decisions. We asked the question of how to make best use of rainfall forecasts from the new generation of climate and numerical weather prediction models. These models run on the Bureau's new supercomputer and promise to vastly improve the accuracy and resolution of rainfall forecasting.

WIRADA has focused on supporting service enhancements and improving the accuracy of ensemble streamflow forecasts by adapting methods that make use of the rapidly evolving numerical weather prediction models; and correcting hydrological model variables representing catchment moisture stores.

WIRADA has shown ensemble 7-day streamflow

forecasts are more accurate at predicting floods than deterministic streamflow forecasts, particularly for longer lead times.

- WIRADA science has led to new software, systems, and toolkits that:
- increased forecast accuracy of new and emerging 7-day forecast services which will provide water managers with greater confidence in water management decisions.
- produced 7-day ensemble streamflow forecasts that also have the potential to inform flood watches and warnings.

WIRADA
ACHIEVEMENTS 2008–19

More than $69 million invested over 10 years to advance national water information science

One arc-second (~30 m resolution) Digital Elevation Model developed for Australia to understand our landscape and water resources

200 of Australia’s top water scientists working together over 10 years—representing over 250 person-years

New hydrological models that produce daily estimates of soil moisture, runoff, evapotranspiration and deep drainage at a 25 km^2 or 1 km^2 resolution across Australia

More than 30 research projects to deliver the science behind the Bureau’s Water information functions

Daily streamflow forecasts for the next 7 days issued at more than 210 sites across Australia

Five international data exchange standards developed to help users to share, analyse and compare water information

Australia’s first national seasonal streamflow forecast service running at more than 340 sites, issued every month

Improved rainfall forecasts at scales required for streamflow forecasts and accurate estimates of evapotranspiration across the continent

Spatial model to map relationships between more than 3 million unique hydrological features across Australia—such as storages, monitoring points, streams and catchments[5]

SolidGround: tools to create and manage information models in a consistent way

Water Data Transfer Format to automate sharing of Australia's water information adopted by industry and lead water agencies

Over 40 million data files transferred to the Bureau using WDTF since 2009

Over 20 operational water information products developed, tested or supported with WIRADA science

Over 130 international science journal papers published, 450 conference presentations given, 280 reports written

World-class science in partnership with nearly 50 national and international research collaborators

AWRA Development and Benchmarking – to support Hydrological Projections

BUREAU SPONSOR Robert Argent
COLLABORATORS CSIRO, Canberra
PROJECT LEADERS Jai Vaze and Justin Hughes

Objective: Assessing the confidence of the AWRA-L model in simulating future climate impacts on water

CHALLENGE

Changes in climate have already been shown to impact on Australian rainfall. As these observed climate changes impact on our ability to make long-term strategic decisions for water management, assessments of the future impacts of climate change on water are needed to support these decisions. The Australian Water Resource Assessment (AWRA) modelling system has demonstrated its utility in estimating fluxes and stores of water in the environment across space and time. Hence, it would be useful to simulate future climate impacts on water using the AWRA modelling system. Future climate impact modelling tends to be very uncertain and state-of-the-art approaches tend to sample multiple climate models, downscaling techniques and sometimes even hydrological models. Furthermore, there is a risk that customers who frequently use local catchment models may not trust the future climate impacts simulated by a national hydrological model. Finally, there has been concern that hydrological models aren't sufficiently capturing the catchment changes observed in Australia after the Millennium Drought. We therefore need to investigate the suitability of the national AWRA-L model for climate impact projections and how the hydrological model or the scale of the model influences the variability of impact responses.

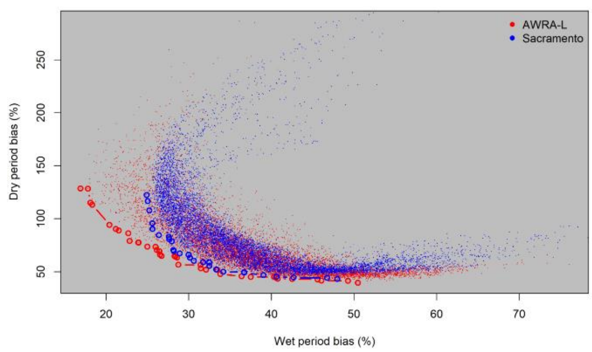
SOLUTION

The AWRA model was rigorously tested for its performance at various spatial scales against the Sacramento model.

Its performance in wetter and drier periods was assessed as a surrogate for possible wetter or drier climate futures. The strengths and weaknesses of the model were documented along with an extensive list of parameters and characteristics that could be applied to various modelling applications. Finally, the direction and magnitude of impacts of climate change on all water balance variables simulated using the Sacramento and AWRA model were compared to determine the suitability of the national model for hydrological impact assessment and to inform our confidence in those assessments.

2018–19 ACHIEVEMENTS

We simulated runoff using the AWRA model for a selection of 80 catchments Australia-wide and for over 10 000 different parameter sets to understand strengths, weaknesses and possibilities of the AWRA model in a future climate context. A major output of the project was a subset of model parameters that allow the modeler to select "fit for purpose" parameters of known characteristics for any specific modelling task.



Clouds of wet and dry period bias for 10000 simulations of Sacramento (blue points) and AWRA-L (red points) sampled across the

parameter range. Hollow circles indicate the non-dominated Pareto front.

We showed that for mean runoff, an indicator of catchment yields, there was very little difference in the direction and magnitude of the changes resulting from climate predicted by the different hydrological models. But for other variables, e.g. soil moisture, and for very dry or wet levels of all variables (e.g. high flows, low soil moisture), the direction of change in the indicator caused by climate change was still the same across the models, but the magnitude of the changes varied between them.

'We provided analysis to support the robustness of AWRA-L for producing national climate change impact assessments.'

In particular, we:

- analysed aspects of performance including low and high flow performance, of two hydrological models for a range of parameter sets optimized to both wet and dry periods
- documented the process and results of these experiments together with a list of best performing parameter sets.
- provided an 'all-round' parameter set with the least compromise between wet and dry period performance
- provided analysis to support our knowledge of the robustness of AWRA-L for producing national climate change impact assessments.
- The outputs of this research were supplied as a report and parameter list file to the Bureau.

OUTCOME

To aid water resource planning for possible future water resource estimates, the Bureau now has the ability to choose parameter sets that are considered to be better suited to particular tasks, and to understand how the AWRA model may behave given certain future climate characteristics.

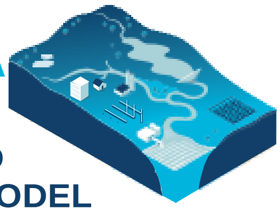
Furthermore, the choice of hydrological model was shown to have minimal impact on simulated catchment yields, although further work is needed to fully support this.

This will inform and improve our confidence in the outputs from AWRA when used to simulate future climate impacts on water.

CONTINENT-WIDE ESTIMATES OF KEY WATER BALANCE TERMS AT A SPATIAL RESOLUTION OF 1-5 KM

OUR MODEL OUTPUTS ARE TESTED AGAINST OBSERVATIONS FROM OVER

700 CATCHMENTS ACROSS AUSTRALIA



AWRA

A NATIONAL LANDSCAPE AND RIVER SYSTEM MODEL

FLOOD AND SHORT-TERM STREAMFLOW FORECASTING

BUREAU SPONSOR Shoni Maguire
COLLABORATORS The University of Melbourne
PROJECT LEADER David Robertson

Objective: to expand coverage of 7-day streamflow forecast services and establish methods for ensemble flood and 7-day streamflow forecast services

CHALLENGE

Reliable streamflow forecasts with lead-times from hours to 7 days are crucial to optimise river and water resource operations and to assist in anticipating floods. To assist water managers, the Bureau now provides to the public a 7-day streamflow forecast service for more than 100 catchments across Australia.

The increase in accuracy of ensemble streamflow predictions over their deterministic counterparts could allow ensemble 7-day forecasts to inform flood watches, however prior to this study, the ability of the ensemble forecasts to predict floods had not been assessed.

The Bureau wants to use the most advanced weather forecasting models to power the ensemble 7-day streamflow forecasts. Existing statistical pre-processing methods require long archives of retrospective forecasts produced using the operational weather forecasting model to estimate parameters. The computational expense of weather models means that long archives of retrospective forecasts are not generated when models are upgraded, making it difficult to apply existing statistical pre-processing methods.
Quantifying uncertainty in the streamflow predictions for catchments with sub-optimal observations and/or hydrological models at longer lead times is extremely challenging, often leading to uncertainty estimates in the forecast streamflow that are too wide.

SOLUTION

- Our approach to addressing these challenges has been to:
- Comprehensively assess the performance of ensemble 7-day forecasts for predicting floods and high flow events.
- Reduce the number of parameters in our weather forecast pre-processing methodology to allow the use of shorter archives of weather forecasts.
- Combine correcting variables representing catchment soil moisture and groundwater stores with our existing error modelling approach to improve hydrological modelling and uncertainty quantification.
- Enhance hydrological modelling and forecasting software SWIFT to meet the requirements for flood prediction.

2018–19 ACHIEVEMENTS

We assessed the performance of the 7-day ensemble streamflow forecasting system by

- generating a long (> 9 year) archive of retrospective forecasts
- applying a new flood forecast evaluation method to rigorously test the ability of forecasts to accurately predict flood magnitude and timing.

We developed and tested a new method of pre-processing weather forecasts for use as input to hydrological models. The method simplifies the existing procedure, substantially reduced the number of parameters to be estimated, and can be applied to short archives of weather forecasts. We showed the method was highly effective at correcting and processing rainfall forecasts from weather models with different resolutions.

We developed a new method of correcting variables

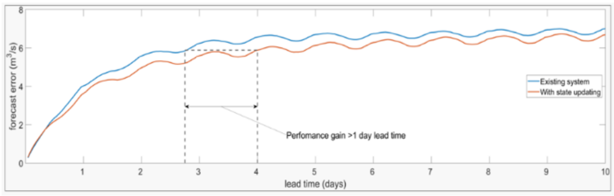
representing catchment soil moisture and groundwater stores that combines with our existing error modelling method. This method substantially improves the underlying hydrological model performance, allowing a more precise estimate of streamflow forecast uncertainty.

OUTCOME

We have demonstrated that the new ensemble 7-day streamflow forecasts offer substantially more accurate predictions of streamflow than the existing deterministic 7-day forecasts for a wide variety of catchments.

Pre-processing of weather forecasts for input into hydrological models is a crucial step to producing accurate and usable forecasts. We have developed a method that both i) effectively pre-processes weather forecasts for use in catchment hydrological models and ii) allows the forecasting system to be upgraded rapidly.

We showed that our new state updating method, in combination with our existing error modelling method, substantially increases the accuracy of streamflow forecasts, particularly at long lead times.



Example of improvement in streamflow forecast accuracy with the new state updating method for the Barnard River in northern New South Wales. Forecast errors with the existing forecast system (blue line) are higher than when state updating is used (red line) at longer lead times. Performance gain can be substantial: forecasts generated with state updating are now more accurate at a lead time of 4 days than the previous forecasting system at a lead time of 3 days.

OUR RESEARCH

HAS MADE FORECASTS POSSIBLE ACROSS THE RANGE OF CONDITIONS **EXPERIENCED IN AUSTRALIA**

OUR FORECAST TECHNIQUES SUPPORT

BETTER MANAGEMENT AND USE OF **SCARCE WATER**

OVER **200** OPERATIONAL 7-DAY STREAMFLOW FORECAST

LOCATIONS ACROSS AUSTRALIA

WIRADA REPORT CARD
2018–19

BUDGET, FINANCE AND RESOURCES

The 2018–19 investment of $1.2 million was allocated to:

- water resource assessment modelling (32 per cent)
- streamflow forecasting (68 per cent).

The end-of-year financial position for WIRADA was an over-expenditure of $151 556.

DELIVERY AND PRODUCTIVITY

WIRADA delivered the 5 deliverables across two projects scheduled for completion in 2018–19.

In addition, over 2018–19 WIRADA produced:

- 5 journal papers published;
- 21 conference papers, and
- 9 technical reports.

Total WIRADA output since 2008 is summarised in the table below.

PERIOD	JOURNAL PUBLISHED	JOURNAL SUBMITTED	BOOKS	CONFERENCE PAPERS[1]	PUBLISHED REPORTS	INTERNAL REPORTS	TOTAL
0809	17		1	45	41	21	**125**
0910	13		0	32	26	41	**112**
1011	11		0	91	16	4	**122**
1112	22		1	79	7	7	**116**
1213	11		0	30	10	1	**52**
1314[2]	15		5	50	14	10	**94**
1415	15		0	27	10	11	**63**
1516	9		1	47	13	3	**82**
1617	12	6	0	16	18	0	**52**
1718	9		1	20	18	0	48
1819	5		2	21	4	5	37
Total	**139**	**6**	**11**	**458**	**177**	**103**	**903**

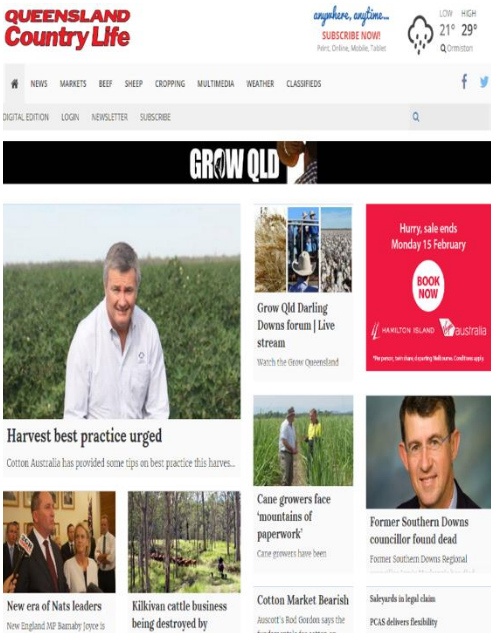
1 includes abstracts*

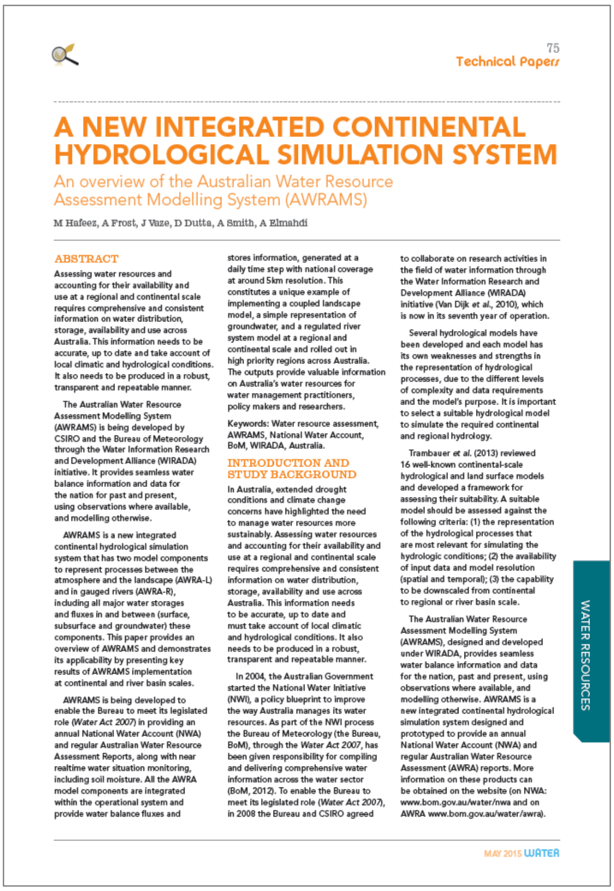
2 The decrease in total outputs for the 2013–16 phase of WIRADA reflects a reduced investment by the partners

To maximize impact, streamline delivery and evolve research the WIRADA portfolio has three core strategies:

- Targeted research
- Quality relationships and collaboration
- Quality delivery and impact

OBJECTIVE	ACHIEVEMENT
OBJECTIVE 1: Define research direction	
Design a coordinated research portfolio that delivers knowledge, information and tools to vastly improve water data integration, water resource assessments, national water accounts, flood forecasts and water availability outlooks	ACHIEVED: New project agreements for 2018–19 developed and approved by Management Committee 100 per cent of WIRADA deliverables have been accepted
OBJECTIVE 2: Align research for impact	
Determine the priority between research investments and develop path to impact	ACHIEVED: Research transition plans embedded in all individual project plans for 2018–19
OBJECTIVE 3: Develop relationships	
Define and develop relationships to enhance delivery of WIRADA outcomes and establish the necessary governance arrangements	ACHIEVED: Project roles defined and implemented through planning templates and guidance, progress reporting and review, and deliverable submission and approval workflows
OBJECTIVE 4: Harness collaboration	
Harness and value-add from relevant research investment	ACHIEVED: All projects have strong collaboration with state and national research partners.
OBJECTIVE 5: Manage science quality	
Ensure sound science quality management practices maintained	ACHIEVED: 100 per cent of WIRADA deliverables achieved and 100 per cent accepted for the year ACHIEVED: 5 peer reviewed journal articles accepted for publication
OBJECTIVE 6: Champion, evaluate and feedback	
Champion the research outcomes, assess impact, and adapt the WIRADA research plan	ACHIEVED: Twenty-one papers accepted and presented at leading national and international conferences 2018–19 Annual Report drafted for approval 2019–20 investment approved in July 2019





75 Technical Papers

A NEW INTEGRATED CONTINENTAL HYDROLOGICAL SIMULATION SYSTEM

An overview of the Australian Water Resource Assessment Modelling System (AWRAMS)

M Hafeez, A Frost, J Vaze, D Dutta, A Smith, A Elmahdi

ABSTRACT

Assessing water resources and accounting for their availability and use at a regional and continental scale requires comprehensive and consistent information on water distribution, storage, availability and use across Australia. This information needs to be accurate, up to date and take account of local climatic and hydrological conditions. It also needs to be produced in a robust, transparent and repeatable manner.

The Australian Water Resource Assessment Modelling System (AWRAMS) is being developed by CSIRO and the Bureau of Meteorology through the Water Information Research and Development Alliance (WIRADA) initiative. It provides seamless water balance information and data for the nation for past and present, using observations where available, and modelling otherwise.

AWRAMS is a new integrated continental hydrological simulation system that has two model components to represent processes between the atmosphere and the landscape (AWRA-L) and in gauged rivers (AWRA-R), including all major water storages and fluxes in and between (surface, subsurface and groundwater) these components. This paper provides an overview of AWRAMS and demonstrates its applicability by presenting key results of AWRAMS implementation at continental and river basin scales.

AWRAMS is being developed to enable the Bureau to meet its legislated role (*Water Act 2007*) in providing an annual National Water Account (NWA) and regular Australian Water Resource Assessment Reports, along with near realtime water situation monitoring, including soil moisture. All the AWRA model components are integrated within the operational system and provide water balance fluxes and stores information, generated at a daily time step with national coverage at around 5km resolution. This constitutes a unique example of implementing a coupled landscape model, a simple representation of groundwater, and a regulated river system model at a regional and continental scale and rolled out in high priority regions across Australia. The outputs provide valuable information on Australia's water resources for water management practitioners, policy makers and researchers.

Keywords: Water resource assessment, AWRAMS, National Water Account, BoM, WIRADA, Australia.

INTRODUCTION AND STUDY BACKGROUND

In Australia, extended drought conditions and climate change concerns have highlighted the need to manage water resources more sustainably. Assessing water resources and accounting for their availability and use at a regional and continental scale requires comprehensive and consistent information on water distribution, storage, availability and use across Australia. This information needs to be accurate, up to date and must take account of local climatic and hydrological conditions. It also needs to be produced in a robust, transparent and repeatable manner.

In 2004, the Australian Government started the National Water Initiative (NWI), a policy blueprint to improve the way Australia manages its water resources. As part of the NWI process the Bureau of Meteorology (the Bureau, BoM), through the *Water Act 2007*, has been given responsibility for compiling and delivering comprehensive water information across the water sector (BoM, 2012). To enable the Bureau to meet its legislated role (*Water Act 2007*), in 2008 the Bureau and CSIRO agreed to collaborate on research activities in the field of water information through the Water Information Research and Development Alliance (WIRADA) initiative (Van Dijk *et al.*, 2010), which is now in its seventh year of operation.

Several hydrological models have been developed and each model has its own weaknesses and strengths in the representation of hydrological processes, due to the different levels of complexity and data requirements and the model's purpose. It is important to select a suitable hydrological model to simulate the required continental and regional hydrology.

Trambauer *et al.* (2013) reviewed 16 well-known continental-scale hydrological and land surface models and developed a framework for assessing their suitability. A suitable model should be assessed against the following criteria: (1) the representation of the hydrological processes that are most relevant for simulating the hydrologic conditions; (2) the availability of input data and model resolution (spatial and temporal); (3) the capability to be downscaled from continental to regional or river basin scale.

The Australian Water Resource Assessment Modelling System (AWRAMS), designed and developed under WIRADA, provides seamless water balance information and data for the nation, past and present, using observations where available, and modelling otherwise. AWRAMS is a new integrated continental hydrological simulation system designed and prototyped to provide an annual National Water Account (NWA) and regular Australian Water Resource Assessment (AWRA) reports. More information on these products can be obtained on the website (on NWA: www.bom.gov.au/water/nwa and on AWRA www.bom.gov.au/water/awra).

WATER RESOURCES

MAY 2015 WATER

Customer Testimonials

'I have been blown away by how perfectly the website answers the most needed questions for farmers and makes the data so easily accessible.'

–Warwick Holmes, Engineer