Australian Government
Bureau of Meteorology

CSIRO

Water Information Research and Development Alliance

ANNUAL REPORT 2014–15

Water Information
DATA › INFORMATION › INSIGHT

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www.bom.gov.au/water
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CONTENTS

EXECUTIVE SUMMARY

This year we built upon our previous scientific achievements and operational outcomes, and delivered research and development results that have advanced the quality, breadth, timeliness and utility of Bureau water information products and services.

Our research portfolio included four projects across our three research themes: water informatics, water balance modelling and streamflow forecasting.

HIGHLIGHTS OF 2014–15

Informatics—data services

Our informatics research focused on two primary topics—international standards development and Linked Data. The standards work delivered three proposed international water data markup language standards to the Open Geospatial Consortium, being GroundwaterML2.0, WaterML2.0 part 2 (covering ratings, gaugings and sections), and TimeseriesML. These are being adopted internationally by water information agencies such as the Bureau of Meteorology, and provide a foundation for effective and efficient exchange of water data and information.

Linked Data standards and technologies are the foundation of future web-based data services, as we move away from HTML-linked documents to a web of linked data. WIRADA research used Linked Data technologies to publish current water observations and link these with previously unconnected web-based data sources. The Bureau was also provided with base technologies to manage terminology and definitions of water-related concepts to increase interoperability, and overcome the heterogeneity challenges, of Australian water information systems.

Flow forecasting

Significant scientific advances were made in both short-term and seasonal forecasting areas. Short-term forecasting improvements included increased accuracy of rainfall forecasts as an input to hydrological models; improved estimates of rainfall uncertainty; a better understanding of relative performance of alternative rainfall-runoff models; improved estimation of hydrological model errors; and a more functional and effective version of the model suite used for short-term forecasting—Short-term Water Information and Forecasting Tools v2 (SWIFT2).

Seasonal flow forecasting research focused on the science needed to increase accuracy, extend lead time, distribute forecasts into shorter time periods, and expand the number of sites across Australia for which reliable seasonal forecasts can be made. Achievements this year included further development of the Forecast Guided Stochastic Scenarios (FoGSS) model and significant improvements in merging statistical and dynamical forecasts, offering the Bureau a forecast product that is better and easier to interpret and communicate.

Australian Water Resources Assessment modelling system

An improved landscape component of the Australia Water Resources Assessment (AWRA) modelling system was implemented across continental Australia. It was tested against peer models and performed better than other continental-scale models and similar to or better than individually calibrated lumped conceptual models, supporting more timely and efficient catchment-scale rainfall-runoff modelling for all of Australia.

The AWRA river system component was implemented across the Murray–Darling Basin and other National Water Account regions. The model takes account of the fluxes and stores associated with regulated and unregulated river systems, and includes surface and groundwater interactions. Although calibrated regionally rather

than at river-reach scale, performance within various Murray–Darling Basin catchments was found to be comparable to that of the models used for Murray–Darling Basin planning.

WIRADA MANAGEMENT

The year ran well and efficiently, due in large part to the foundation guidance set in place in 2013–14 through our new science plan, and implementation and communication strategies. There were also no personnel changes in either the Management Committee or the WIRADA director position.

COMMUNICATION FOCUS

This year we increased focus on communication—from scientific publications to workshops with end users on the operational outcomes of WIRADA research. In line with the WIRADA communication strategy all major activities were planned with consideration of activity, objective, audience, key messages, timing and method.

Notable achievements included research papers in hydrology and Earth system sciences and water resources research. Stakeholder meetings were held with Seqwater, Goulburn–Murray Water, the Goulburn–Broken and North Central Catchment Management Authorities, the State Water Corporation of New South Wales and the Coleambally Irrigation Cooperative Limited.

Overseas engagement included a seminar to the Nanjing Hydraulic Research Institute on the FoGSS model (see page 16). I was also invited to present to Californian environmental managers on water modelling and environmental intelligence.

THE YEAR AHEAD

Our focus for next year is to wrap up current research activities and ensure the legacy of WIRADA is preserved and available for the future. This includes the scientific and operational achievements of the past eight years of WIRADA, and the knowledge of how to create, maintain, manage and deliver a successful research and development partnership.

I congratulate all WIRADA people on this year's achievements, and look forward to a great year ahead.

Dr Robert Argent
WIRADA Director

MESSAGE FROM THE CHAIR

Innovation is central to the success of the Bureau's Water Information Programme. Our seven-year research and development partnership with CSIRO has helped us to develop information products, services and infrastructure that deliver real value to Australia.

Recent severe rainfall deficiencies and the 2015 El Niño again stress the importance of government working together to support policy and decision-making in many industries and sectors.

As chair of the Management Committee, I recognise the value in bringing together the research and operational expertise of both organisations. Seven years into an impressive programme of work, our researchers continue to deliver valuable innovation to support the nation in managing its precious water resources.

An exciting year is also ahead as WIRADA continues to deliver research of direct and immediate application to the Bureau's operational systems and services.

Streamflow forecasting continues to expand to more sites across Australia, with the public gaining access to a new short-term forecast service in the near future. WIRADA research continues to help the Bureau to refine its forecasts into a nationwide service that extends from flood warnings to streamflow outlooks three months ahead. Research continues to develop seasonal forecasts beyond three months.

This June the Bureau began to share AWRA modelling system data with State and Australian Government agencies. A new website will be developed to provide public users with daily estimates of water movement through the landscape and across the continent.

In December 2015, a special WIRADA-themed session is planned for the international Hydrology and Water Resources Symposium, in Hobart. This will be an opportunity to showcase to industry the Bureau's key water information services and the world-class research behind them.

I thank all those involved in WIRADA for their effort during the year. The Management Committee looks forward to successful completion of the current phase of WIRADA next year.

Graham Hawke
Deputy Director, Environment and Research

Water resources are one of the bigger challenges and opportunities the nation faces—whether in the extremes of drought or flood, or managing for social, economic and environment outcomes. Through our strategic collaboration with the Bureau, we are proud to be delivering science solutions that will inform a more secure water future.

WIRADA continues to provide high-value research that makes a real difference to Australia. The quality research that underpins these successes has the recognition of our international collaborators confirmed by their desire to apply these novel methods.

In 2014–15 we have seen our long-term investment deliver new and refined forecasting and water balance modelling capabilities.

Through collaboration, we have also seen wider international uptake of our standards work—including in domains other than water—this is an area where Australia can proudly claim international leadership.

WIRADA is a team effort. I congratulate the CSIRO and Bureau teams on their achievements of the past year and look forward to continued success and impact.

Warwick McDonald
Research Director,
Water Resource Management, CSIRO

WIRADA SUCCESSES

Our research on standard and persistent identification of monitoring points reduces errors in collecting and sharing monitoring data.

WIRADA developed an authoritative national information system of water features that helps to standardise water resources information for sharing and reporting.

Explore the Australian Hydrological Geospatial Fabric

Water resources and aquatic ecosystems

International data standards that incorporate WIRADA research reduce errors and help us to share and understand Australia's national water data.

Understand the international WaterML standard

The Australian Water Resources Information System underpins collection, management and reporting of water data

Data ingestion and storage

COLLECT | DISCOVER | INGEST | ASSEMBLE | POLISH

Climate and water monitoring and data collection

Understand the Water Data Transfer Format

Our contributions to standards for river gaugings and ratings data increase the opportunity to share information between users.

Water balance analysis

The Australian Water Resources Assessment modelling system provides continental-scale analysis of key water balance terms

Our standardised water balance analysis methods increase Australia's capacity to explain and understand of our past use of water.

The increased detail we provide in analysis helps to identify areas where water management could be improved to deliver societal benefits.

WIRADA research contributes to increases in the quality and standard of analysis and reporting, providing better water information services.

Our research supports easier and broader access to Australia's water data.

Access water data online

Compare water market information

Access high-quality data for hydrologic reference sites

Water data services

National water reports use WIRADA research to give Australians greater insight into the nature of our national water resources and how they are used.

Read the National Water Account

Read the Australian Water Resources Assessments

National water resources reporting

AUGMENT | SHARE | ANALYSE | PREDICT | REPORT

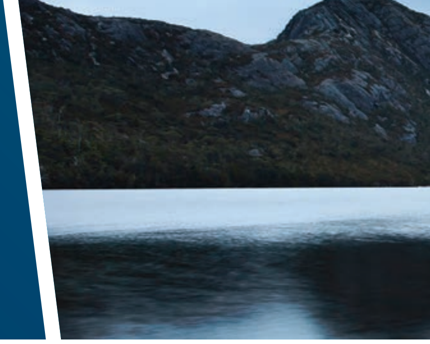
Streamflow forecasts and flood warnings

View seasonal streamflow forecasts

View short-term streamflow forecasts (registered user access)

Seasonal streamflow forecasts based on WIRADA research support water management decisions across more than 100 sites in six States and Territories.

Our outputs provide emergency services with improved warnings of extreme events.



LET'S TALK ABOUT WATER
STANDARDS FOR DATA EXCHANGE

BUREAU SPONSOR	Tony Boston
COLLABORATORS	U.S. Geological Survey; Aquatic Informatics; Open Geospatial Consortium; World Meteorological Organization; KISTERS; UK Centre for Ecology and Hydrology; Geological Survey of Canada; European Commission, Directorate General–Joint Research Centre; Federation University Australia; Geological Surveys of Germany; British Geological Survey; Bureau de Recherche Géologiques et Minières; International Groundwater Resources Assessment Centre; UNESCO; Salzburg University; Polish Geological Institute
PROJECT LEADER	Peter Taylor

Objective: To improve access to hydrological data within Australia through new internationally recognised exchange standards and services.

CHALLENGE

To understand freshwater resources at a national level requires integration of data from many diverse stakeholders. Much of these hydrological data are stored within systems that have unique structures, definitions and means of access. For example, one water agency may measure water in an aquifer using a method that varies considerably from that used by another. To compare and integrate such data across Australia is a huge challenge.

Having technical experts manually convert data for analysis or reporting wastes time and resources. Computer software can assist by automating processes of data exchange. However, this requires a common language, or data exchange standard, in which data may be transmitted and more easily understood.

'Development of the WaterML2 Part 2 standard will help improve interoperability between systems and support greater water data sharing in Australia and internationally.'

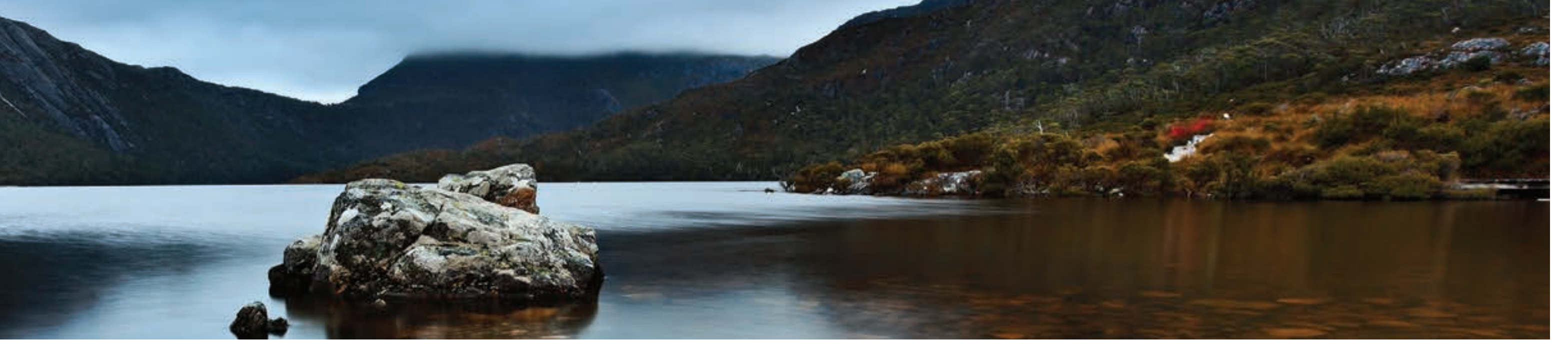
MARTIN READ, Manager of Water Assessment Branch, Department of Primary Industries, Parks, Water and Environment, Tasmania

A common language with agreed definitions for concepts and terminology supports the combination of data from disparate sources, valid comparisons and hydrological analyses. Development of such standards requires understanding of each specific hydrological data type: groundwater features, such as aquifers and boreholes; observation processes; surface water measurements, such as river rating tables; continuous observations of stream sections; storage calculations; and so on.

SOLUTION

We are developing data exchange standards in three important areas of hydrology: groundwater features and observations, river and storage calculations, and continuous time-series observations.

Developing exchange standards requires expression of real work concepts in a way a computer can understand. For example, how do you tell a computer that someone waded into a river, held onto a flow meter and measured the velocity of the water at a specific location? This must be done in a way that is consistent across practices in different countries. To do this, we bring together international experts in computer science, geospatial information systems and hydrology. Together we capture and harmonise our definitions of these concepts and express them in a way computers can understand.



Through international collaboration this activity is driving long-term change in how countries around the world exchange hydrological data.

ACHIEVEMENTS

In collaboration with our international partners, we have developed three proposed international standards:

- GroundwaterML2.0 is a standard for exchange of groundwater features (aquifers, boreholes, wells, construction components etc.) and observations. The draft is undergoing testing, with submission to the Open Geospatial Consortium (OGC) expected in 2016. This project has developed software to deliver data from Australia's National Groundwater Information System using this standard.
- WaterML2.0 part 2 is a standard to exchange rating tables, river gauging observations and cross-sections. We have progressed to the final stage of adoption, with a final OGC vote to conclude in two months.
- TimeseriesML builds on previous work in WaterML2.0 part 1, by developing a standard for time-series data exchange that is not specific to hydrology. It has recently been submitted to the OGC as a 'Request for Comment'. Following consideration of comments from the broader public, it will be proposed as a standard in early 2016.

Our standards are being adopted by the Bureau and water agencies around the world. This provides the Bureau, and Australian water agencies, with a solid foundation to automate the exchange of data and improve understanding of our precious water resources.

NEXT STEPS

Next year will see the adoption of WaterML2.0 part 2 and TimeseriesML as standards. We will also finalise drafting of the GroundwaterML2.0 standard and submit it for adoption.

From WIRADA to the world

Most environmental monitoring programs undertake continuous observations that produce time-series data. WaterML2.0 part 1, developed within WIRADA, defined an exchange format for hydrological time-series data. It has been identified as a potential solution to time-series exchange within and across other science domains, such as oceanography, air quality monitoring and meteorology.

The World Meteorological Organization (WMO) saw this potential. It moved to establish the Open Geospatial Consortium TimeseriesML working group, led by WIRADA Informatics, with the aim to standardise the time-series parts of WaterML2.0 part 1. We anticipate that the WMO Commission for Basic Systems will endorse TimeseriesML as a WMO standard for data encoding at the CBS-16 meeting in 2016.

WaterML2.0 part 1 has been adopted by key organisations including the USGS[1] and has been endorsed by the United States National Strategy for Civil Earth Observations[2], the Federal Geographic Data Committee[3] and for cross-domain exchange by the European Union's large-scale data exchange initiative—INSPIRE (Infrastructure for Spatial Information in Europe).

WIRADA work that was initially focused on hydrological data is now being applied in a much broader area of application—worldwide monitoring and management of our environment.

1. http://help.waterdata.usgs.gov/news/april-10-2014
2. www.opengeospatial.org/pressroom/pressreleases/1831
3. www.fgdc.gov/standards/news/WaterML

CONNECTING WATER DATA
USING LINKED DATA

BUREAU SPONSOR	Tony Boston
COLLABORATORS	World Meteorological Organization
PROJECT LEADER	Peter Taylor

Objective: Improve understanding of water resources by connecting hydrological data to relevant context and definitions.

CHALLENGE

Water observation data published or exchanged without sufficient context can be difficult or even impossible to interpret. For example, 'the river is flowing at 3 cumecs'. Which river? How much is 3 'cumecs' and how accurate is the value? Is that high or low? How does that relate to expected flow?

As the volume of data on the internet grows, it is increasingly important that data we publish are sufficiently described. Data that lack description and context are hard to reuse, and can mislead. However, when we publish and exchange data there is a delicate balance between simplicity and complexity. The public and decision-makers require information that is simple, but also contextually meaningful and accurate.

A national platform to define environmental terms used online

The Linked Data Registry tool is used at the Bureau to help it manage a range of water-related terminology, or vocabularies. Work has also progressed with using the environment.data.gov.au web domain to identify and discover data assets. Together, these two technologies offer a national platform for online publication of environmental data and definitions. This will improve publication and interpretation of environmental data within Australia.

For the Bureau to integrate and publish water data, it must understand the terminology used by different water agencies as well as manage its own, harmonised definitions. Additionally, these definitions must be consistent and transparent.

SOLUTION

To tackle this problem we:

- Used 'Linked Data' to publish data with relevant context to aid interpretation, in a way that is machine-readable.
- Developed tools and techniques to allow the Bureau to manage and publish definitions of key terms and concepts online in a well-controlled manner. For example, by publishing formal definitions of units of measure, measured properties, instrument types, and datums.

Linked Data offers a means to distribute data on the internet with links to other related data that can help with interpretation. It uses foundational concepts that make web pages work, but extends them to work with data.

We are using Linked Data to publish hydro-meteorological observational data with links to context around long-term averages and relevant spatial relationships. This has involved developing a trial data service that publishes current weather observations with links to long-term averages from Bureau data products. This provides useful context observations—how hot is it today compared to normal? Is today's normal different from the normal 50 years ago?

While these are simple examples, the underlying concepts are changing the way in which data are used on the internet.

We are using Linked Data approaches to publish the definitions of concepts online, which allows both humans and computers to understand exactly what is described within data. To do this we use a software product called the Linked Data Registry, which has been pioneered by the World Meteorological Organization (WMO) through development of the WMO Codes Registry.

ACHIEVEMENTS

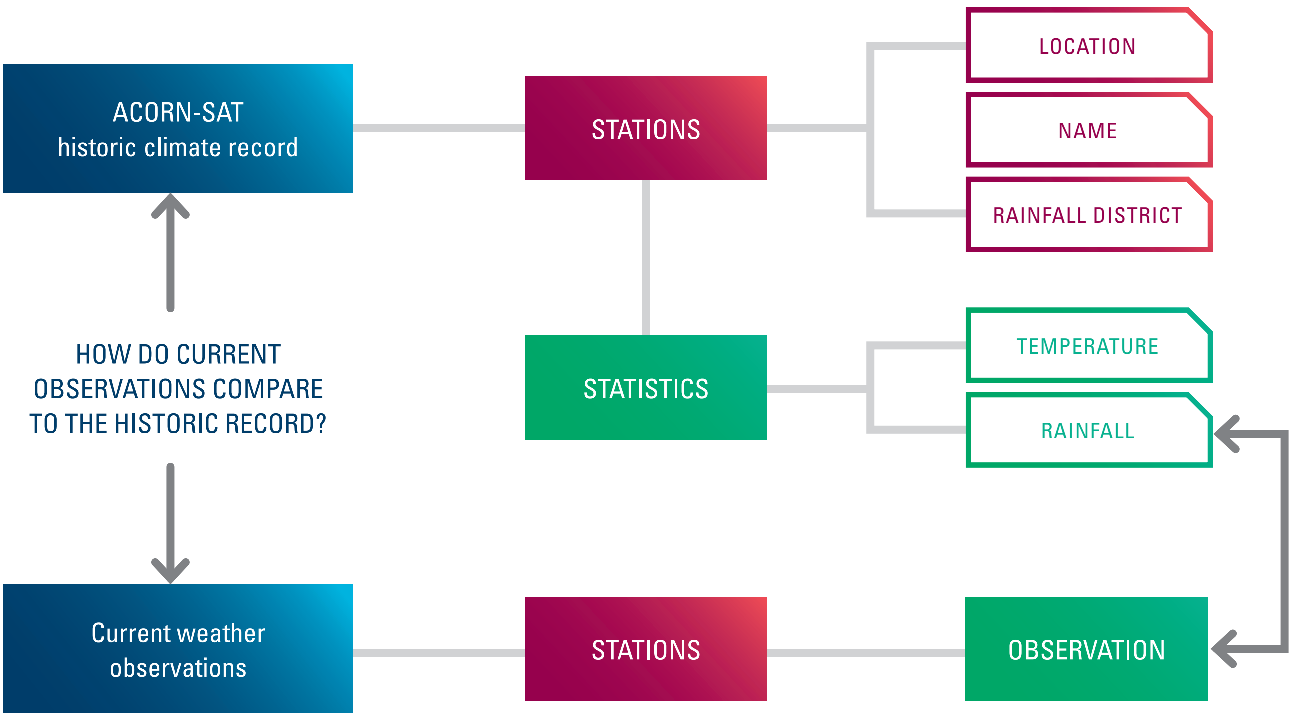
Through WIRADA Informatics we have developed services to publish current weather observations using Linked Data, bringing together previously unconnected data.

Context is now available with these observations that provide opportunities for new applications and services. This research positions the Bureau to use these approaches to bring together many of its data publishing platforms, resulting in an improved user experience and new opportunities for using its data.

Software to allow the Bureau to manage its terminology and definitions of water-related concepts has also been delivered. The Linked Data Registry has been tested and customised to give the Bureau a platform to consistently manage and publish terminology. This will assist Australian water information systems to be more interoperable by ensuring everyone understands when they are talking about the same thing.

NEXT STEPS

We will extend the current prototype data services to include water level and storage information and other hydrological data products, such as the Geofabric. This will allow navigation between these data products, and build awareness of other Bureau data products.



Linked Data provides users with access to related information, delivering additional context and increasing efficiencies through data reuse. For example, how do this month's current weather observations compare to the long-term average in the ACORN-SAT climate record?

FLOOD AND SHORT-TERM STREAMFLOW FORECASTING

BUREAU SPONSOR	Dasarath Jayasuriya
COLLABORATORS	Collaboration for Australian Weather and Climate Research, The University of Melbourne
PROJECT LEADER	David Robertson

Objective: Generating continuous ensemble short-term streamflow forecasts to complement flood forecasting capabilities.

CHALLENGE

Forecasts of streamflow assist Australia to manage extreme events and optimise water resource use. The Bureau is operationalising a new continuous short-term streamflow forecasting service that issues a prediction of streamflow every day for the coming seven days. It complements existing flood forecasting and warning services that focus on high-flow events. The service will also provide estimates of forecast uncertainty using ensembles, or multiple realisations of equally likely forecasts.

Generating accurate short-term forecasts that correctly describe forecast uncertainty is a challenge. It requires integration of a number of components:

- quality-controlled rainfall and streamflow observations available in real-time;
- accurate rainfall forecasts and an estimate of their errors;
- continuous hydrological models running at hourly time steps that are robust across Australia's diverse catchments;
- adaptable methods to update streamflow predictions and forecasts based on recent observations, and quantify remaining prediction errors, and
- efficient computational systems.

SOLUTION

This year we have improved both forecast accuracy and our estimates of uncertainty through targeted improvements in the prototype forecasting system. Specifically we have tested:

- alternative sources of forecast rainfall—good rainfall estimates are critical for accurate streamflow forecasts and are a source of significant uncertainty;
- the performance of alternative hydrological models, which transform observed and forecast rainfall into streamflow predictions; and
- new methods to describe the complex errors of hourly streamflow simulations. As hydrologic models simulate streamflow to various levels of accuracy, it is necessary to characterise error in these predictions.

ACHIEVEMENTS

We have tested the performance of streamflow forecasts generated with either raw or post-processed rainfall forecasts from the ACCESS-G numerical weather prediction system and the Poor Man's Ensemble (PME) system. Post-processing increases the accuracy of the rainfall forecasts, and generates a reliable estimate of rainfall forecast uncertainty. Streamflow forecasts produced using the post-processed PME rainfall forecasts are more accurate than those produced using post-processed ACCESS-G forecasts. The Bureau will adopt rainfall forecast post-processing methods for its new ensemble short-term forecasting service and will further evaluate the PME.

The performance of the hydrological model used in the current forecasting system (GR4H) was compared to a suite of alternatives using operational model configurations. While GR4H produces the best independent simulations for the majority of catchments, alternative models do better for some catchments and streamflow hydrograph components.

A staged error-modelling approach has been developed to incrementally characterise features of hydrological model errors. This approach corrects long-term biases, updates model forecasts using recent prediction errors and describes the distribution of residual errors. The Bureau is adopting this error-modelling approach as it transitions the service to produce ensemble forecasts.

We have also delivered the Short-term Water Information and Forecasting Tools version 2 (SWIFT2). This is a redesigned forecasting software package that improves computational efficiency and functionality.

NEXT STEPS

Work in the next year will:

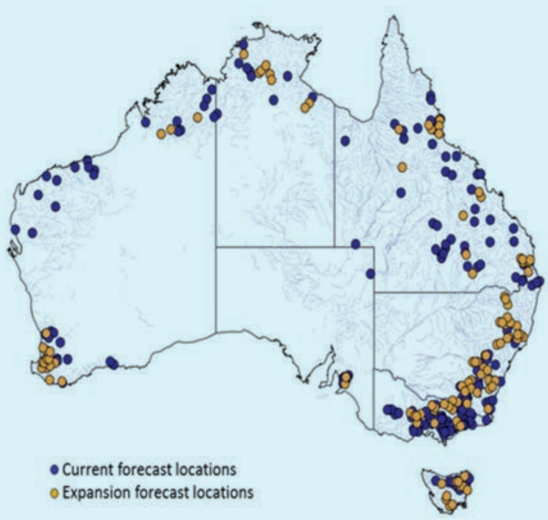
- extend the rainfall post-processing approach to deal with rainfall forecasts from ensemble numerical weather prediction models;
- refine and evaluate the performance of the staged error-modelling approach for ephemeral and intermittent catchments that periodically cease to flow; and
- transition SWIFT2 into the operational environment.

A national short-term streamflow forecast service

During the last year, the Bureau has expanded its prototype deterministic short-term streamflow service to an additional 51 catchments across Australia. It now includes 114 forecast locations in 62 catchments spread throughout all States and Territories. The current service is available to 150 registered users for testing and will be available to the public in mid-2015.

In future we will:

- expand the service to additional catchments and extend the modelling capability of the existing SWIFT2 software;
- develop probabilistic short-term streamflow forecasts that are based on ensemble rainfall forcing. These will provide users with estimates of forecast uncertainty; and
- enhance the experience of forecast users with improved web interfaces that also incorporate the new probabilistic streamflow forecasts.



SEASONAL STREAMFLOW FORECASTING

BUREAU SPONSOR	Dasarath Jayasuriya
COLLABORATORS	Collaboration for Australian Weather and Climate Research
PROJECT LEADER	Q. J. Wang

Objective: To increase forecast accuracy, extend lead time and provide easy-to-use forecast products for water managers.

CHALLENGE

The Bureau now has seasonal streamflow forecasts for more than 100 locations across major storages and river systems in Australia available to the public. Forecasts are issued at the start of each month and provide the likelihood for a given volume of water flowing in the next three months.

Feedback from water managers shows that the service already supports water-resource planning and operational decisions. However, users have identified a number of required improvements, setting a clear path for research:

- expand the number of forecast sites;
- improve forecast performance;
- extend forecasts out to 12 months; and
- provide forecasts in monthly volumes, rather than just seasonal totals.

> **'Seasonal streamflow forecast information gives us confidence that we are making the best decisions possible to efficiently manage our water.'**
>
> KATHERINE LARKINGS,
> Water Strategic Planning Engineer, Icon Water, ACT

SOLUTION

The Bureau has two models that produce seasonal streamflow forecasts. Current public forecasts use a statistical approach, which captures relationships shown in the past between climate and catchment conditions and observed streamflows. A prototype dynamical model—which simulates processes of climate and hydrological systems—also provides forecasts to registered users at nearly 100 sites across Australia. Last year we developed a quantile model averaging (QMA) method to merge the forecasts from these two models. Merging allows us to take advantage of the different strengths of the statistical and dynamical approaches. This year we rigorously tested how effective the QMA method is to ensure it is robust to use within the Bureau's streamflow forecast service.

It is a major task to develop a service that extends streamflow forecasts out to 12 months and provides monthly volumes. Last year we developed the Forecast Guided Stochastic Scenarios (FoGSS) model. This model uses outputs from seasonal climate models to generate monthly rainfall forecasts, which feed into a monthly water balance model. A further algorithm allows us to correct for error and quantify uncertainty. This year we continued to develop and test the FoGSS model in a wider range of catchments typical for Australia.

ACHIEVEMENTS

We tested the ability for the QMA method to merge forecasts from statistical and dynamical models in a further 40 sites. These included a variety of geographic and climatic regions. The QMA merged forecasts were

found to consistently improve forecast skill. The QMA method also results in forecast distributions with a unimodal shape, even when the statistical and dynamical forecasts are not in agreement. A unimodal shape is easier to communicate, interpret and apply in forecasts. The Bureau has now integrated an improved algorithm and computer code for QMA into their forecast system. These new developments will be released to registered users to undergo testing in an operational environment, and to seek feedback from key stakeholders.

The FoGSS model has been simplified and improved, and now requires fewer parameters. Its performance in a large majority of the 63 catchments we evaluated, was robust. This included a number of ephemeral and intermittent catchments. Forecasts are usually skilful only to short lead times (zero to three months ahead), and successfully transit to stochastic scenarios thereafter. Forecasts of cumulative streamflow are usually much more skilful than forecasts for individual months. Computer code for the FoGSS model is now with the Bureau for operational deployment.

Our work is being recognised internationally, with invited presentations to the APEC Climate Symposium and the Nanjing Hydraulic Research Institute in October 2014, and a keynote talk at the HEPEX workshop on seasonal hydrological forecasting in Sweden in September 2015.

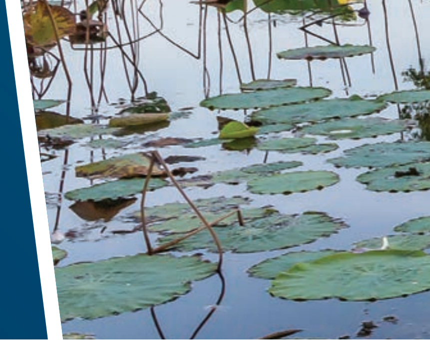
NEXT STEPS

In the next few years the Bureau will transition to an improved seasonal climate forecasting model—ACCESS-S. Climate model outputs, such as precipitation and sea surface temperature, are needed as input to streamflow forecast models. The priority for research will be to support the transition of the Bureau's streamflow forecast service to use the new outputs from ACCESS-S.

Merging statistical and dynamical forecasts improves forecast accuracy

The Bureau operates a seasonal streamflow forecast service based on a statistical approach. A new dynamical method has been developed which uses outputs from a physical climate model to force conceptual hydrological models. Both approaches rely on current catchment conditions and forecasts of future climate conditions. They also produce probabilistic forecasts in the form of a large number of ensemble members, each representing equally probable future outcomes. A comparison of overall model skill (or accuracy) scores reveals that the statistical modelling approach yields higher forecast skill for some catchments and seasons, while the dynamical approach yields higher forecast skill for others.

Given the variable skill of the statistical and dynamical forecasting approaches, the Bureau is increasing the overall skill of its service by taking advantage of their individual strengths. This is done objectively by weighting and merging forecasts. Our research has developed a method of quantile model averaging to merge the forecasts. It applies averaging to forecast variable values (quantiles) for a given cumulative probability (quantile fraction). The method was evaluated on 52 forecast sites. It was shown to consistently improve forecast skill across catchments and seasons, while maintaining statistical reliability in forecast uncertainty spread. After testing forecasts in a registered-user service, the merging method will be extended to the publicly available seasonal streamflow forecast service.



INTEGRATED MODELLING SYSTEM FOR WATER RESOURCE ASSESSMENTS AND ACCOUNTS

BUREAU SPONSOR	Ian Prosser
COLLABORATORS	Monash University, The University of Melbourne, University of New South Wales, University of Newcastle, NSW Office of Water, NSW Office of Environment and Heritage, NSW State Water
PROJECT LEADER:	Jai Vaze

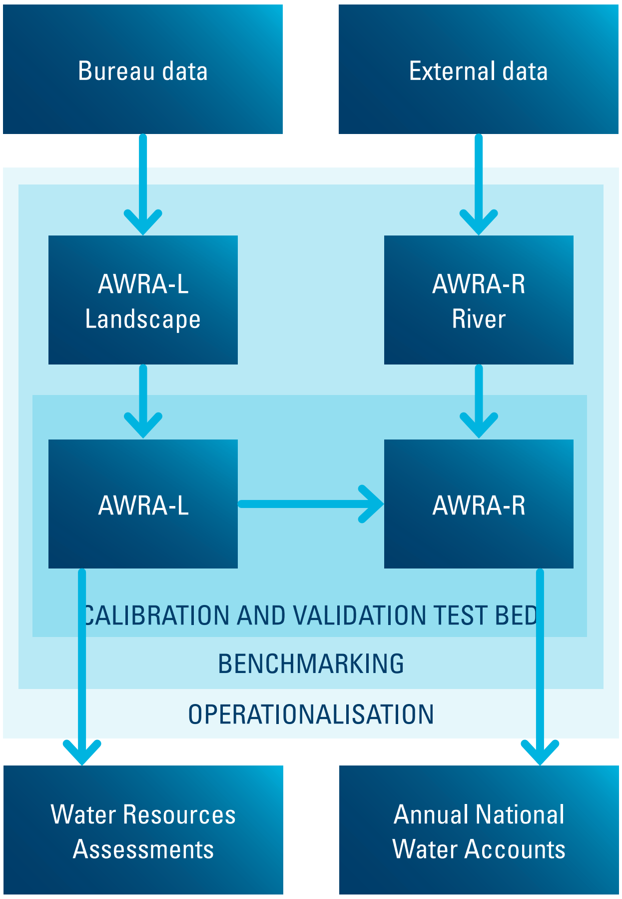
Objective: Underpinning Australian Water Resources Assessments, the National Water Account, and sub-annual water resources situation reports with an integrated hydrological modelling system.

CHALLENGE

To support water assessments and accounting for water resource policy and planning at catchment, regional and continental scales, Australia needs comprehensive, consistent and robust information on water generation, distribution, storage, availability, and use. This information needs to be produced using all the available data in a robust, transparent and repeatable manner, to minimise inconsistency across different scales.

SOLUTION

The Australian Water Resources Assessment (AWRA) modelling system has been developed with state-of-the-art hydrological science and computing technology. It can quantify water flux and storage terms and their respective uncertainties using a combination of in-situ and remotely sensed observations, and model outputs. The AWRA system is applicable across the continent and flexible enough to be able to use all available data sources. It uses novel modelling techniques and tools to provide nationally consistent and robust estimates of water fluxes and stores at a 5 km spatial resolution and daily time-step.



The Australian Water Resources Assessment modelling system has two key components—a landscape model (AWRA-L) and a river model (AWRA-R). A calibration and validation test bed is used to ensure that the system matches reported/available data. Benchmarking ensures that the system improves estimates after comparing with the real-world observed data across Australia. The Bureau runs an operational system to provide input to Water Resources Assessments and annual National Water Accounts.

For the first time we have a tool that can account for important aspects of water resources for all areas in Australia. The estimates for soil water storage, streamflow, groundwater recharge and vegetation water use from the operational system in the Bureau inform the National Water Accounts and the upcoming Water in Australia reports. These Bureau products provide a national water perspective and help Australia understand the present state of water resources across the continent and its variation over the last century.

'We will continue to use evaporative loss estimates provided by the Australian Water Resources Assessments in future hydrodynamic and water-quality modelling projects.'

CHRIS O'NEILL,
Operations Manager and Water Resources Engineer,
HydroNumerics

ACHIEVEMENTS

The landscape component of AWRA has been improved and implemented across continental Australia and tested against peer models. Our results show that the model performs better than other continental models and similar to or better than time-consuming individual lumped conceptual rainfall-runoff models.

The river system component of AWRA has been implemented in the entire Murray–Darling Basin and several other regions. It produces fluxes and stores associated with different components of regulated and unregulated river systems and includes surface and groundwater interactions. Although requiring much less development effort, model performance was found to be comparable to the models used by the Murray–Darling Basin Authority for basin planning in various Murray–Darling catchments.

We have developed a new version (v5.0) of the AWRA modelling system that successfully couples the landscape and river modelling components. The Bureau is currently implementing the models operationally into a unified system based on the Python language.

All components of the system continue to be improved through calibration and evaluation against a range of surface and satellite observations. These observations include in-situ measurements such as river gauges, irrigation diversion metering, vegetation water-use, flux towers and soil moisture sensors. Observations also include satellite measurements of vegetation cover, soil moisture, and evapotranspiration.

The major achievements for this year include:

- improvements to the vadose zone conceptualisation in the landscape modelling component and implementation across the continent;
- preliminary experiments to constrain landscape model calibration against multiple data sources, rather than just unregulated river gauges;
- an extended river model that can calculate fluxes and stores in catchment headwaters; and
- a new conceptual approach for a system calibration of the river model. This has been implemented across the Murray–Darling Basin and enables system-wide optimisation of model parameters to reduce unaccounted differences.

NEXT STEPS

Next year we will finalise development for AWRA and complete the transition of research to the Bureau. Our priorities are to:

- move to a single code base across CSIRO and the Bureau to streamline future development and applications;
- develop case studies that demonstrate the adoption and value of AWRA for different users and stakeholders; and
- develop a reliable groundwater recharge database for AWRA benchmarking.

The Bureau's operational AWRA modelling system for water assessment and accounts

In the past year the Bureau has implemented an operational AWRA modelling system (AWRA MS) that is platform-independent, efficient, functional, and easy to maintain. The project will conclude in June 2015 with operational AWRA MS v5.0 functionality in the Python language.

The AWRA MS can now run in three primary modes:

- interactive: allows simulation, plotting and benchmarking over arbitrary areas and time periods from the past century to today;
- calibration: using specified observations, statistics, time periods and areas; and
- scheduled run: providing automatic updates of model output with live data feeds.

The AWRA MS underpins Bureau water information services, which are mandated through the *Water Act 2007*, and includes the National Water Account. It also sets a strong foundation for the Bureau to develop further enhanced water information products and services such as the Water in Australia situation report.

External clients are routinely using outputs from the AWRA-L (landscape) model component via a registered user service. The Bureau team is also working with several State and Australian Government water and agriculture agencies on how to best use the model outputs. For example, AWRA-L-based soil moisture (shallow layer—top 1 m) output is used by the Victorian Government to summarise climatic conditions and seasonal climate updates for the State.

The scheduled run lends itself to automatically updated data services and a website of the AWRA model inputs and outputs. Outputs from the AWRA-L model will be available to the wider community in late 2015 via a new interactive Bureau website.

ABOUT THE WATER INFORMATION RESEARCH AND DEVELOPMENT ALLIANCE

Through the *Water Act 2007*, the Bureau of Meteorology has responsibility to compile and deliver comprehensive information on national water resources in Australia.

Severe droughts and recent extreme climate events in Australia show the major challenges we face in managing our water resources. The need to accurately monitor, assess and forecast the availability, condition and use of these resources is an ongoing national priority.

To this end more than 200 organisations across Australia provide data to the Bureau for use in a range of new services. Vital information on the nation's water resources is now integrated, accessible and easy to use. This is helping policy, infrastructure and operational decision-makers to respond more quickly and confidently to water management challenges.

Improving water information outcomes continues to require substantial innovation. This is achieved through a world-class alliance between the Bureau and CSIRO: the Water Information Research and Development Alliance (WIRADA). WIRADA brings together CSIRO's leading expertise in water and information sciences and the Bureau's operational role in hydrological analysis and prediction to deliver value-added water information products and tools.

WIRADA is transforming how Australia manages its water resources. Over the five years from 2008 to 2013, WIRADA delivered much of the scientific and research innovation required by the Bureau to fulfil its national water information mandate. Further investment in WIRADA over the three years from 2013 to 2016 will allow earlier successful research to be refined, expanded and delivered to operation. Current research themes focus on water information systems, water accounting and assessment, and water forecasting and prediction.

GOVERNANCE

WIRADA is established under an umbrella agreement and is governed by a management committee. Research is guided by a science plan, which outlines the scope and themes of research, and an implementation strategy, which describes the approaches used to ensure the success of research, development and implementation.

MANAGEMENT COMMITTEE

The management committee's key role is to set the strategic direction for WIRADA. It also approves the annual research programme and budget, and oversees the effective delivery of the research. The committee is comprised of two executive representatives from the Bureau and two from CSIRO. The members of the committee in 2014–15 were:

Bureau of Meteorology

Graham Hawke (Committee Chair), Deputy Director Environment and Research

Dr Dasarath Jayasuriya, Assistant Director, Flood Forecasting and Warning

CSIRO

Warwick McDonald, Research Director, Water Resource Management

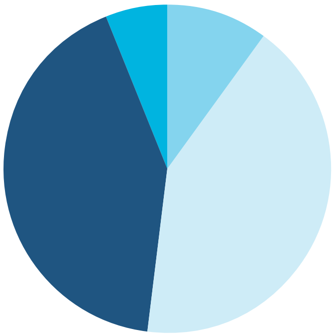
Dr Francis Chiew, Group Leader, Water Resources Assessment and Prediction

The committee meets at least quarterly and met on 25 July 2014, 24 October 2014, 5 February 2015, 23 April 2015 and 18 June 2015.

PERFORMANCE REPORT

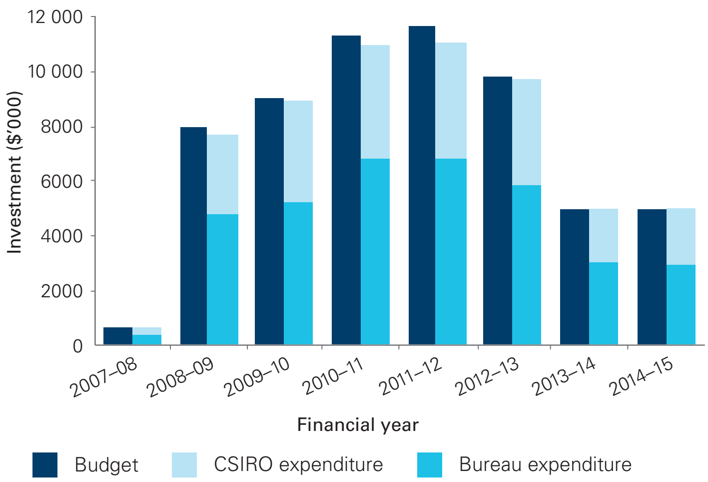
FINANCE AND RESOURCES

The 2014–15 investment of $5 million was allocated to water informatics (10 per cent); water resource assessment modelling (42 per cent); streamflow forecasting (42 per cent); and management and communication (6 per cent). The end-of-year financial position for WIRADA was an over-expenditure of $0.016 million.



WIRADA BUDGET PERFORMANCE

The WIRADA budget plan for 2014–15 proposed 16.88 full-time equivalents to be allocated to the four research projects. Total expended effort for the programme was 16.84 full-time equivalents. In addition, the Bureau contributed 6.45 full-time equivalents in kind.



DELIVERY AND PRODUCTIVITY

WIRADA had 64 deliverables across five projects scheduled for completion in 2014–15. Two deliverables were stopped, based upon changes agreed with project sponsors. At year's end, all deliverables had been submitted, with 59 (95 per cent) of those accepted, and three under review. All remaining deliverables were due for completion in July 2015.

Over 2014–15 WIRADA produced:

- 11 journal papers published;
- 1 journal paper in press;
- 27 conference papers; and
- 21 technical reports.

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

WIRADA outputs	08–09	09–10	10–11	11–12	12–13	13–14[4]	14–15[4]	TOTAL
Journal papers published	17	13	11	19	12	15	11	**98**
Journal papers in press	0	0	0	0	0	0	1	**1**
Books	1	0	0	1	0	5	0	**7**
Conference papers	45	32	84	79	30	50	27	**347**
Published reports	41	26	16	7	10	14	10	**124**
Unpublished reports	21	41	4	7	1	10	11	**95**
Total	**125**	**112**	**115**	**113**	**53**	**94**	**60**	

4. The decrease in total outputs for the 2013–16 phase of WIRADA reflects a reduced investment.

WIRADA REPORT CARD
2014–15

STRATEGY	KEY PERFORMANCE MEASURE	ACHIEVEMENT
1. TARGETED RESEARCH	**Goal: Design an integrated and coordinated research portfolio that targets medium to longer-term end-user needs.**	
1.1 Define research direction	OBJECTIVE 1: 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.	
	Confirmation by the Bureau that WIRADA outputs meet their and their user needs.	ACHIEVED: Over 95 per cent of WIRADA deliverables have been accepted by the Bureau.
	WIRADA project agreements refreshed and approved annually by the management committee.	ACHIEVED: New project agreements for 2015–16 were all approved by the Management Committee.
	WIRADA communication plan aligned with Bureau's product adoption plans.	ACHIEVED: WIRADA communication activities are a subset of the Bureau's broader product adoption.
1.2 Align research for impact	OBJECTIVE 2: Determine the priority between research investments and develop path to impact.	
	WIRADA research transition plans developed for all projects.	ACHIEVED: Research transition plans embedded in all individual project plans for 2014–15.
	WIRADA communication plan developed, reviewed quarterly and progressively being implemented.	ACHIEVED: The 2014–15 communication implementation plan was approved in July 2014, and implementation was reviewed quarterly.
2. QUALITY RELATIONSHIPS AND COLLABORATION	**Goal: Develop quality relationships and harness added value from related research investments, particularly across the CSIRO Land and Water portfolio, and build enduring partnerships with supporting initiatives.**	
2.1 Develop relationships	OBJECTIVE 1: Define and develop relationships to enhance delivery of the WIRADA programme and establish the necessary governance arrangements.	

WIRADA REPORT CARD
2014–15

STRATEGY	KEY PERFORMANCE MEASURE	ACHIEVEMENT
	Processes for Bureau engagement in project design, development and delivery defined, agreed and implemented—i.e. project sponsor, business lead, implementation lead, Bureau research team members.	ACHIEVED: Roles defined and implemented through project planning templates and guidance, progress reporting and review, and deliverable submission and approval workflows.
	Bureau staff actively engaged in the research design and development. CSIRO researchers actively participating in R&D transition processes to operations.	ACHIEVED: Joint project governance arrangements operate for all research projects. Dedicated project activities exist to transfer research to Bureau operations and information technology systems.
	Outcomes specified and monitored for collaboration with CAWCR, eWater, and GA.	NOT APPLICABLE: No formal collaborations in place in 2014–15.
	Outcomes specified and monitored for collaboration with international initiatives including CUAHSI, OGC and WMO.	ACHIEVED: WIRADA leadership and milestone completion in GroundwaterML2.0, WaterML2.0 part 2, and TimeseriesML international standards development.
	No skills gaps or shortage of capabilities to meet demand.	ACHIEVED IN PART: Changes to staff availability affected scope and timing of deliverables within the Informatics project.
2.2 Harness collaboration	OBJECTIVE 2: Harness and value-add from relevant research investment.	
	Action plans for research collaboration implemented with particular regard to eWater, CAWCR, GA, CUAHSI and relevant CSIRO Land and Water themes.	ACHIEVED: Water data exchange standards development centre in partnership with CUASHI, USGS, CEH, Kisters, Aquatic Informatics and Australian research partners.

STRATEGY	KEY PERFORMANCE MEASURE	ACHIEVEMENT
	Jurisdictional and industry participation in WIRADA research projects and pathways for adoption specified (including training).	ACHIEVED IN PART: WIRADA scientific progress presented to influential end users through meetings of the Jurisdictional Reference Group on Water Information. Adoption-related briefings include the monthly National Climate and Water Briefing, and water information stakeholder briefings.
	WIRADA research project participation and leadership in communities of practice.	ACHIEVED: WIRADA research project members are active within research community groups including the OGC Hydro Domain Working Group, HEPEX[1] and OzEWEX[2]. Note: 1. Hydrological Ensemble Prediction Experiment. 2. Australian Energy and Water Exchange research initiative.
3. QUALITY DELIVERY AND IMPACT	**Goal: Deliver quality science with real-world impact and positive peer recognition.**	
3.1 Manage science quality	OBJECTIVE 1: Ensure sound science quality management practices maintained.	
	More than 80 per cent of the WIRADA deliverables achieved and accepted to time and budget, with the delayed deliverables completed within 30 days.	ACHIEVED: All WIRADA deliverables achieved and 95 per cent accepted for the full year, with remaining deliverables due for completion early in the following quarter.
	The majority of WIRADA research outputs embedded in, or influential on the implementation of Bureau operational systems.	ACHIEVED: Short-term water forecasts released to registered users; Seasonal streamflow forecasting service expanding; AWRA version 5 transferred to the Bureau for use with National Water Account and Australian Water Resources Assessment.

WIRADA REPORT CARD
2014–15

STRATEGY	KEY PERFORMANCE MEASURE	ACHIEVEMENT
	WIRADA portfolio subject to periodic independent peer review and aligned with formal reviews of the Improving Water Information Programme and CSIRO Land and Water.	NOT APPLICABLE: No formal independent reviews held in 2014–15.
	Scientific publication productivity and citation index at or above the CSIRO benchmark (two journal papers per research scientist).	NOT ACHIEVED: WIRADA included 12.3 research scientist equivalents in 2014–15 while 11 journal papers were published.
3.2 Champion, evaluate and feedback	**OBJECTIVE 2:** Champion the research outcomes, assess impact and adapt the WIRADA research programme.	
	WIRADA research outcomes reported in media coverage, participation in key jurisdictional and industry forums and contribution to international initiatives.	ACHIEVED: 27 conference papers at 11 key national and international conferences.
	Research impact assessment undertaken and reported in the WIRADA Annual Research Report.	ACHIEVED: 2014–15 Annual Report drafted for approval by the Management Committee.
	A rolling implementation strategy and investment profile agreed by Bureau and CSIRO through the WIRADA management committee.	ACHIEVED: 2015–16 investment approved in June 2015.

Note: OGC (Open Geospatial Consortium), CUASHI (Consortium of Universities for the Advancement of Hydrologic Science, Inc), WMO (World Meteorological Organization), USGS (U.S. Geological Survey), CEH (UK Centre for Ecology & Hyrdrology), CAWCR (Collaboration for Australian Weather and Climate Research)