WATER INFORMATION RESEARCH & DEVELOPMENT ALLIANCE (WIRADA)

SCIENCE PLAN 2013-16

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WIRADA Science Plan 2013-16

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WIRADA Science Plan 2013-16

1. Purpose

This plan describes the high-level science objectives, processes, and activities of the Water Information Research and Development Alliance (WIRADA) for 2013-2016. It maps the opportunities for investment in water Information research to support the joint vision of the Bureau of Meteorology (the Bureau) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO). It is a companion document to the WIRADA Implementation Strategy (2013-16) and the Umbrella Research Collaboration Agreement.

2. Background

WIRADA is a co-investment partnership between CSIRO and the Bureau. WIRADA unites CSIRO's research and development expertise in water and information science with the Bureau's operational role in hydrological data management, analysis, and prediction. Water research and development supports the Bureau's mission to provide Australians with environmental intelligence for safety, sustainability, well-being, and prosperity. It also provides a defined pathway to impact for CSIRO research.

WIRADA was formed in 2008 in response to new legislated responsibilities for the Bureau under the Water Act 2007 (the Act). The Act requires the Bureau to:

- collect, hold, manage, interpret and disseminate Australia's water information;
- report on the status of Australia's water resources, patterns of water use and forecasts of future water availability;
- maintain a comprehensive set of water accounts for the nation;
- set national standards for water information;
- influence and support state-based investments in water monitoring and water use metering programs; and
- commission strategic investigations and procure special data sets to enhance our understanding of Australia's water resources.

Time to capitalise on research

The initial five-year $50 million WIRADA program ended in mid-2013. The partners agreed to extend WIRADA for three years to June 2016, with an additional investment of $15 million. The focus from 2013 is to refine and build on earlier achievements in water informatics, water balance modelling, and streamflow forecasting.

The primary goal for 2013-16 is to transition research to operational services within the Bureau in a way that allows for ready ongoing operation and maintenance. As these projects conclude towards 2015-16, there may be opportunities for small, future looking investments.

3. Vision, Motivation and Objective

Vision

The shared vision of the Bureau and CSIRO in Australian water information is:

TO PROVIDE HIGH QUALITY VALUE-ADDED, SCIENCE-BASED WATER INFORMATION FOR AUSTRALIA

Motivation

The sustainable and productive management of Australia's water resources faces many challenges. These include meeting agricultural, environmental and urban demands, impacts of over-allocation and resource extraction, uncertainty in resource availability, and the effects of climate variability and change.

Nationally consistent, but regionally relevant, water information products and services are needed to support good decision making across national, regional, state and local levels. To be effective, these services require high quality data and sound science that are provided to decision makers through robust and timely delivery systems.

Since 2008, the Bureau has developed a national water information system (AWRIS) to collect and hold water data from formally disparate sources. AWRIS helps to standardise, organise, and deliver high quality national data and information to end-users. These water data also support new products delivered by the Bureau. Products include periodic assessments of the status of water resources in Australia (AWRA), the annual National Water Accounts (NWA), and water forecasting and prediction services.

Through the Bureau, Australia needs to capitalise on the opportunities offered by a consistent, national, authoritative, and unbiased view of our past, present and future water resources. Specifically, the Bureau needs to continue to deliver operational products and services that impact on end user ability to improve water productivity and enhance environmental outcomes.

The research needed to underpin operational products is delivered through CSIRO's leading researchers in data interoperability, hydrological modelling, and water accounting, assessment, and forecasting. Increased impact for CSIRO research comes through a well-defined delivery pathway into Bureau operational services.

Objective

To achieve our shared vision the Bureau and CSIRO though WIRADA will:

PROVIDE RESEARCH, DEVELOPMENT AND SUPPORT NEEDED TO DELIVER EFFECTIVE, SCIENCE-BASED, END-USER RELEVANT, WATER INFORMATION PRODUCTS AND SERVICES

4. WIRADA – Scope and Governance

The Bureau has a challenging set of obligations to deliver under the Water Act. To meet expectations, the Bureau must push the boundaries of existing knowledge and methods, and successfully transition research from the desktop to robust operational products and services. WIRADA was formed as the vehicle to provide much of the R&D capacity and capability to achieve this. WIRADA seeks to develop, through CSIRO, new methods, tools, techniques and knowledge to deliver the Bureau's operational water information systems.

Scope of activities – a transition to operational services

Following completion of significant amounts of research over 2008-2013 and an external review of WIRADA in 2013, there is a need in the 2013-2016 period to refine both the scope of activities and the science objectives. Work will continue in areas where the Bureau can best leverage CSIRO science and development expertise. The focus will shift from medium to long term concept development and testing (Horizon 2 & 3) into activities to refine and translate knowledge (Horizon 1) into operational systems.

Part of this innovation will require increased engagement between CSIRO and those within the Bureau that transition the research to produce robust operational services. Projects will need to be more aware of the operational environment and transitioning process as part of project planning (Figure 1). This will be essential to delivery by June 2016. This shift is also reflected in the investment profile.

As detailed in the Implementation Strategy 2013-2016 and its attached checklist, to achieve a successful transition each project will need to have:

- regular and effective communication;
- clearly defined and agreed project needs and acceptance criteria – ensuring that success is recognisable;
- project phases mapped, with clear staging gates and feedback processes;
- clearly defined roles and responsibilities and effective governance; and
- ongoing liaison with people responsible for operationalizing research in the Bureau. This includes processes to transfer technical documentation and the knowledge to develop, test, maintain, and support products.

Due to changes in organisation, roles and functional responsibilities in the Bureau and CSIRO, the last point noted above will need ongoing attention, facilitated by regular and effective communication.

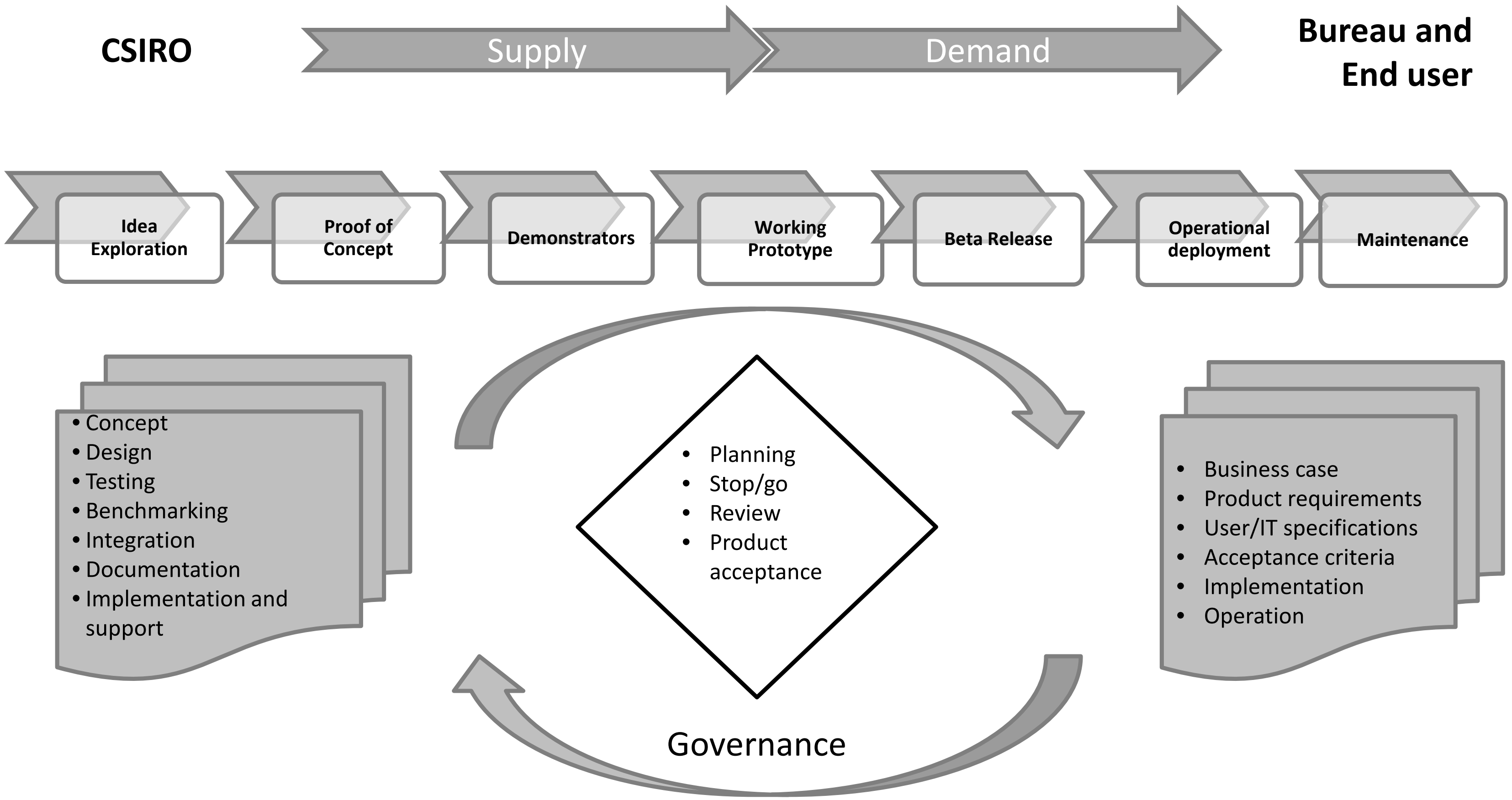

Figure 1. Research to operations – transitioning research into robust operational services

WIRADA resource investment profile

WIRADA effort needs to support innovations that have a path to operational deployment within the Bureau. Project activities are categorised as being of a Horizon 1, Horizon 2, or Horizon 3 nature, with the approximate balance between these shown in Figure 2.

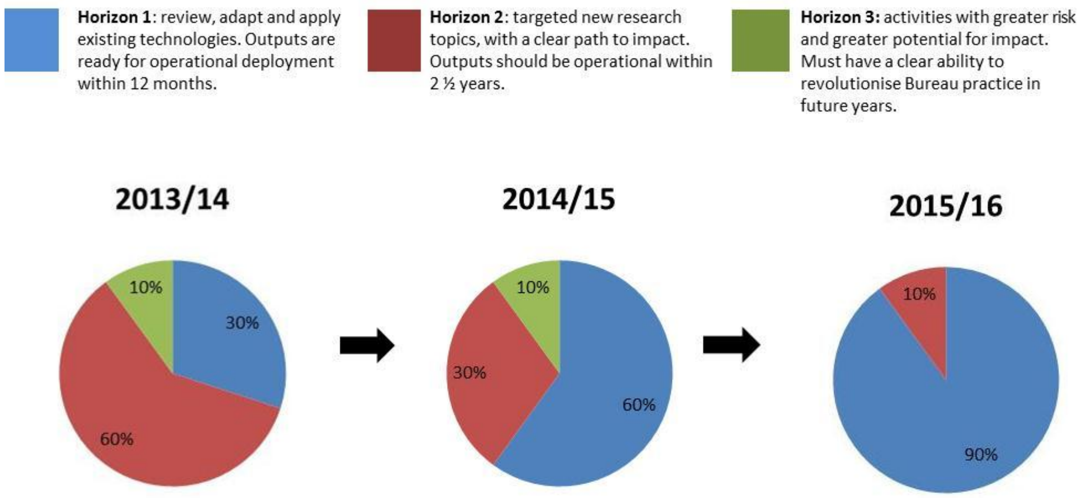

Figure 2. WIRADA resource investment profile for 2013-2016

Benefits of partnership

The Bureau and CSIRO both gain benefits from investing in WIRADA. WIRADA aligns much of CSIRO's Flagship investment in water research with the Bureau's needs. By bringing together the capabilities of each, the Australian government and the public benefit through additional value delivered and efficient and effective use of public funds.

Benefits to CSIRO	Benefit to the Bureau
• Increased research impact through a well-defined delivery pathway into Bureau operational services and systems • Access to Bureau science infrastructure and data • Funding security for nationally important water information research	• Direct R&D expertise to focus on Bureau requirements for water information • Ability to refocus research in new and/or different directions via CSIRO's large capability across water information and information technologies • Capability to develop and evolve water information systems and applications at a skill comparable to leading international counterparts • Support in the delivery of mandated products

Governance structure

A Management Committee and the WIRADA Director govern the portfolio of WIRADA research projects. Each project has a Sponsor, a Project Sponsor's Agent, business and technical leads from the Bureau, and a Project Leader and activity leads from CSIRO. Program, Theme and Stream Leaders from CSIRO also provide support and direction to projects. The WIRADA Implementation Strategy (2013-2016) and the Umbrella Research Collaboration Agreement describe the roles and responsibilities in WIRADA governance.

Additionally, project and portfolio management and coordination activities operate within and across WIRADA. These include:

- a CSIRO-Bureau research leadership group (the WIRADA Extended Research Leadership group);
- regular Sponsor briefings on project progress and performance;
- science panels, technical steering groups, and weekly activity meetings;
- established international collaboration and standard setting processes through the Open Geospatial Consortium (OGC); and
- an established process for review and acceptance of project deliverables.

5. Scientific Objectives and Outputs

Objectives

The research framework in this Science Plan is based on the primary water information business needs of the Bureau (Figure 3). These reflect the Bureau's responsibilities under the Water Act, national expectations and the Bureau's mission[1]. This gives rise to three WIRADA research streams:

- water balance modelling;
- streamflow forecasting; and
- water informatics.

Alternative small research investments may occur in 2015/16 if they are identified as delivering high value outcomes within the planning horizon.

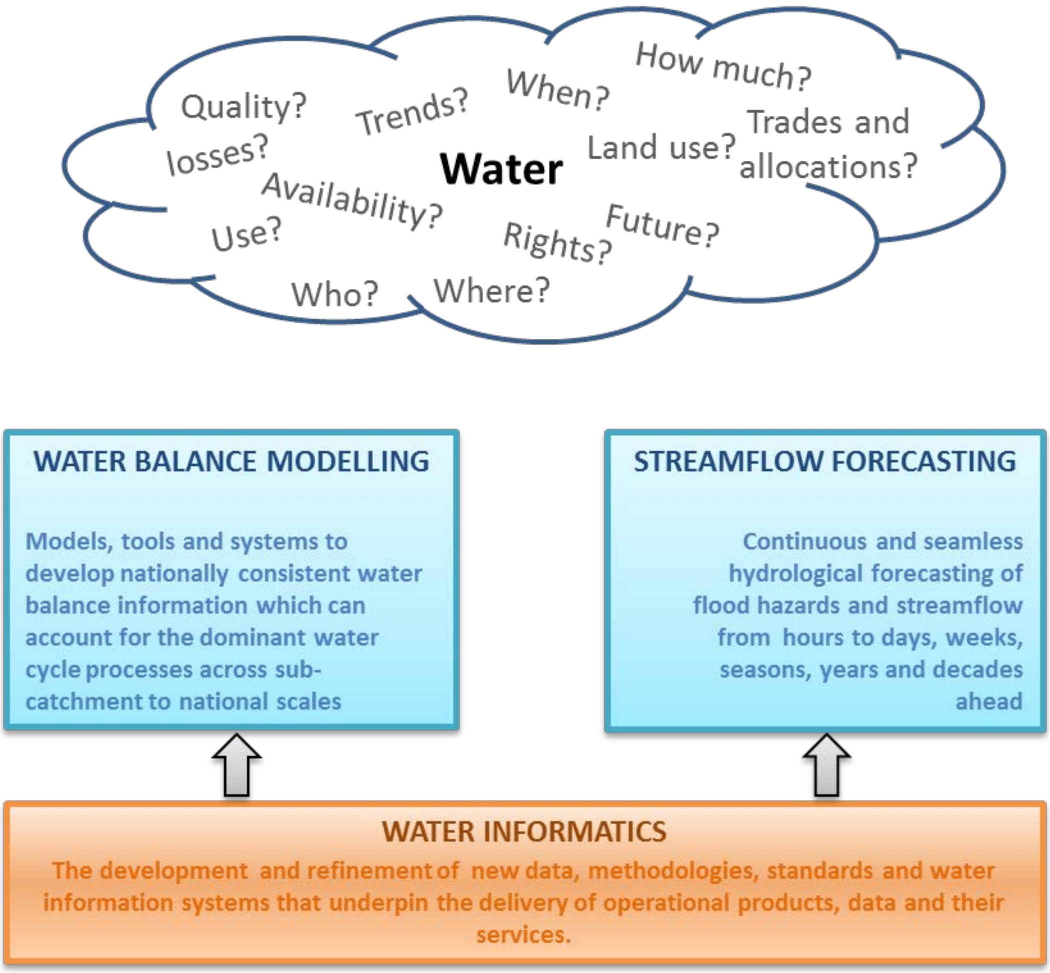

Figure 3. Research streams and information needs

[1] To provide Australia with environmental intelligence for safety, sustainability, well-being and prosperity

Major research outputs

The following table provides an overview of the major outputs WIRADA will deliver from 2013-16:

STREAM	MAJOR RESEARCH OUTPUT
Water Balance Modelling	
Integrated Catchment Water Balance Model (AWRA-LG and AWRA-LGR)	Water balance models (AWRA-LG and AWRA-LGR) that can be applied at continental and catchment scale, and which provide consistent and reliable estimates of key water stores and fluxes from past to present, and to a standard that meets end-user needs
Operational transitioning of AWRA-MS	Support for a complete AWRA model infrastructure within the Bureau. This includes capability for model development, calibration, testing, and maintenance to occur in a well-managed and auditable way.
Streamflow Forecasting	
Short-term flow and forecasting	A continuous probabilistic short term streamflow forecast product with lead times of up to 7 days
Seasonal streamflow forecasting	A seamless (from 1 to 9-12 months lead time) integrated (statistical/dynamic) seasonal forecast product with high skill and multi-site application
Water Informatics	
Water information standards	Adoption and publication of WaterML2.0 Part 2 as an Open Geospatial Consortium (OGC) standard to cover the data elements required by the Bureau. Profiling of the standard as WDTF 2.0 by the Bureau and use of this for collation and transfer of national water information.
Australian Hydrological Geospatial Fabric	A high resolution Geofabric (version 3.0) that includes a monitoring point network product. This will include a stream topology-based network of anthropogenic features (monitoring points, canals, inlet gauging stations, pipelines) and river junctions. Handover of software infrastructure and supporting documentation to the Bureau.
Delivering connected data services	i) Delivering groundwater features using GroundWaterML 2.0 and a web feature service ii) Delivering water information vocabularies and Linked Data iii) Using a Linked Data API to connect environmental data services.

6. Research Stream Details

The following sections present the overall objectives and research areas of each stream. These will be supported by annual research plans that detail project-level activities, investments and deliverables.

Water balance modelling stream

Overall objective

This stream will produce a consistent national continental-to-regional scale water balance modelling system that supports comparison across time and space. It will be driven by user needs, based on sound science principles, and meet operational requirements for the Bureau.

To properly manage limited water resources it is essential to accurately report on and account for water location, volume and use. Over time, changes in accounts can be used to identify pressures on water resource conditions and water use. Comparable information across time, catchments and jurisdictions is of value in inferring causes and developing interventions. To support decision makers, the Bureau is required to deliver National Water Accounts, resource assessments, and information for managers, planners, and policy makers. These products need to be unaffected by jurisdictional boundaries.

Data on Australia's water resources are patchy and of varying quantity and quality, and in many areas, non-existent. A robust water balance model system that can be reliably applied across Australia and through time will support the Bureau by providing complete and nationally consistent water balance estimates. System design needs to be based on end user needs, and follow hydrological and water resource science principles. It also needs to be flexible to incorporate future innovation as new technologies emerge for monitoring, data collection, model-data fusion and processing.

This stream consists of the following areas of R&D:

- integrated catchment water balance modelling (landscape, groundwater, river); and
- support to the Bureau as they build and implement an in-house operational AWRA-MS (modelling system).

Integrated catchment water balance model (AWRA-L-G-R)

Accounting of Australia's water resources requires reliable assessment of past rainfall, surface and groundwater inflows and losses from use, evapotranspiration and outflows. However, most catchments in Australia are ungauged. Flows are a function of complex water cycle processes that interact with landscape biology, geology and geomorphology. Model structures that consider spatial variability and landscape connectivity with integrated surface - groundwater - river modelling can improve estimates of runoff and other variables (e.g. soil moisture, diffused groundwater recharge). Constraining model

parameterisations by the use of new and existing data such as remote sensing may improve estimates.

Much of the conceptual framework for a national water balance model has been developed and tested. The challenge is to integrate, consolidate and validate the water balance sub-models that have been developed over the last 5 years into a reliable and internally consistent, seamless, integrated water balance model.

Provision of a robust national water balance model requires:

- refinement of the AWRA-L sub-model structures and parameterisation to reduce uncertainty in the partitioning of rainfall into evapotranspiration, groundwater recharge, catchment runoff, and changes in soil water storage;
- appropriate and robust model parameterisation to capture within-catchment variability of physical and climate properties;
- implementation of whole river "system" (simultaneous reach by reach) calibration in AWRA – R;
- improvements in spatio-temporal estimates of floodplain inundation, irrigation, and groundwater through more realistic integration of model linkages between reaches;
- coupling and calibration of AWRA-L-G-R with linked sub-models that exchange fluxes between landscape, groundwater and river stores at relevant time steps;
- methods to test, validate and demonstrate the fully coupled AWRA-L-G-R; and
- optimal model performance in terms of both prediction skill and operational efficiency.

The key output of this research will be:

- water balance models (AWRA-L-G-R) that can be applied across scales from continent to catchments, with weekly to monthly and annual outputs. These will provide consistent and reliable estimates of key water stores and fluxes from past to present, and to a standard that meets end-user needs.

End user outcomes from this will be:

- land and water management, planning, and policy decisions are informed by comparable and reliable accounts and assessment of whole-of-catchment water balances.

The path to impact/operationalization will be:

- implementation of the research by the Bureau through building of a robust operational service via the Bureau's internal AWRA-MSI (Modelling System implementation) project. This model will be a key tool used to populate the National Water Accounts and the Australian Water Resource Assessment reports.

Operational transitioning of AWRA-MS

Successful operation of AWRA-L-G-R within the Bureau will require the capability to develop and build new models, test, and maintain the model infrastructure

and supporting software and tools. To do this much of the model infrastructure needs to be migrated or transitioned to IT systems within the Bureau – this is a complex task given that the organisations use different IT environments and operating systems. This work is critical to translate research from the last 5 years into an operational system.

The Bureau ARWA-MSI project is delivering AWRA to operational readiness in the Bureau. The WIRADA activity on operational transitioning of AWRA-MS supports the Bureau activity through:

- delivering new versions of the AWRA software as new features, data and improvements to model structure and parameterisation are implemented;
- incorporating AWRA-R river networks, streamflow, diversion data and parameters within a workflow system for operational support;
- translation of model calibration tools to a platform accessible to the Bureau; and
- training of application support staff at the Bureau to support the operational system software.

The key output of this activity will be:

- support for a complete AWRA model infrastructure within the Bureau. This includes capability for model development, calibration, testing, and maintenance to occur in a well-managed and auditable way.

End user outcomes from this will be:

- capability within the Bureau to independently upgrade and improve water balance modelling and systems when the need requires.

Streamflow forecasting stream

Overall objective

This stream will extend hydrologic forecasting beyond individual flood events to continuous streamflow predictions that are:

- seamless over lead times out to seasonal or annual timescales;
- dynamic, where models account for changes in system condition over time; and
- accompanied with an estimate of uncertainty (i.e. probabilistic)

The Bureau is Australia's national weather forecasting and flood warning agency, supporting these functions through a range of modelling approaches over different time scales. In addition to flood warning support, continuous short-term forecasting of river flow can be used for river operation to improve water use efficiency and environmental flow outcomes through better release scheduling. Medium-term forecasting (month to annual timescales) provides information required for understanding effects of climate variation on flows and water demand. This can be used to optimise water management, manage risks, and inform water trading and water futures markets. Other research interests include extreme events, flash flooding and estimation of inundation extent.

Software, systems and toolkits for both short term and seasonal forecasts have been developed or upgraded through WIRADA. These integrate new sources of data, including better prediction of precipitation, assist data management and analysis, and run new modelling techniques and routines. Seasonal probabilistic forecasts are now available for 70 locations across Australia. A pilot for a new probabilistic short term (up to 7 days) streamflow forecast is also being tested.

This research stream will continue to develop the science and technology required to increase the accuracy and precision of short-term, medium-term and long-term streamflow forecasting through investment in:

- short-term flow forecasting; and
- seasonal streamflow forecasting.

Short-term flow forecasting

Reliable streamflow forecasts with lead-times from hours to 5-7 days are critical to manage floods and to optimise water resource planning and operations. Advances in weather observations and forecasting, particularly for rainfall and hydrological modelling, provide an opportunity to improve accuracy, extend lead times and to quantify uncertainty.

The Bureau has an operational modelling system in place for flood forecasting. The system is event-based and uses gauged rainfall and upstream river flows (if available) to forecast downstream flows. Research to date has provided prototype systems for producing both deterministic and ensemble streamflow forecasts. These use improved rainfall prediction (from the Australian Community Climate and Earth-System Simulator - ACCESS) and new hydrological streamflow modelling which better accounts for spatial and temporal variation in catchment soil moisture and runoff. The challenge is to refine this system to provide more accurate and continuous streamflow forecasts across a range of flow conditions.

Provision of a short-term forecasting system requires:

- specification of an ensemble forecasting system;
- more accurate prediction of flow and flood (level) at both catchment outlet and internal points through improved hydrological modelling;
- optimisation of the use of raw and processed Numerical Weather Prediction products and improved rainfall post-processing;
- methods and experiments to verify streamflow forecasts;
- new algorithms to estimate historical sub-catchment rainfall data from gauge observations to better predict sub-catchment and sub-daily rainfall and streamflow;
- methods to better quantify uncertainty including the influence of factors such as hydrological error on ensemble streamflow forecast performance
- modelling system improvements to incorporate metrics to evaluate performance specifically for continuous flood forecasting (i.e. river level, rate of rise and fall) and strategies for model calibration; and
- performance measurement, assessment and presentation metrics for flood and short term flow forecasts to test and quantify the efficacy of continuous modelling compared to event based flood forecasting.

The key output of this research will be:

- a continuous probabilistic short term streamflow forecast product with lead times of up to 7 days.

End user outcomes from this will be:

- improved flood warning systems, leading to enhanced emergency response; and
- improved inflow forecasts for river operations, leading to efficient consumptive water use and enhanced environmental outcomes.

The path to impact/operationalization will be:

- research will use and extend the capability of the existing system. The stream will also be closely linked to and support a Bureau project to deliver a next-generation hydrological forecast service.

Seasonal streamflow forecasting

Skilled forecasts of river flow several months or seasons ahead can be highly valuable for water resources management. They can be used to produce water outlooks for water users to assist with water trading and allocation decisions. They can provide the water market with information to facilitate water trading and thus increase water use efficiency. They can also provide vital information for government to prepare for extreme drought and other crises situations.

Independent statistical and dynamic streamflow modelling approaches have been developed. The statistical Bayesian Joint Probability (BJP) modelling system forms the basis for the current service at 70 locations around Australia. It provides probabilistic streamflow predictions from a statistical distribution; it uses Bayesian methods to infer model parameters and their uncertainties.

One challenge is to increase forecast skill by utilising the advantages of the dynamic modelling approaches use in seasonal climate forecasts. Other challenges include extending lead times out to provide continuous and seamless forecasts over daily to seasonal to annual timescales, and for any point on a river network.

Improving seasonal streamflow forecasts requires:

- increasing forecast skill by integrating the best features of the current statistical models with the improved dynamic models, such as provided by downscaled long-term POAMA (Predictive Ocean Atmosphere Model for Australia) modelling outputs;
- approaches developed to extend streamflow forecast lead times past three months, that can also be broken down into monthly volumes;
- an ability to communicate the meaning of seasonal forecasts in a way that is accessible to end users;
- a method to enable streamflow forecasting at all water supply nodes across a valley with a focus on forecasting for poorly gauged or ungauged sites by adapting the method developed for well gauged sites; and
- a method to bridge short-term and seasonal streamflow forecasts. That is, to deliver contiguous and consistent forecasts across time scales,

taking advantage of weather forecasts, and multi-week and seasonal climate forecasts to produce the best possible forecast skill.

The key output of this research will be:

- a seamless (from 1 to 9-12 months lead time) integrated (statistical/dynamic) seasonal forecast product with high skill and multi-site application.

End user outcomes from this will be:

- an understanding of future stream inflows leading to better water resources management decisions;
- better management of water resource risk for the agricultural industry; and
- better flood emergency planning.

The path to impact/operationalization will be:

- inclusion of improved methods within the existing operational seasonal forecasting service.

Water informatics stream

Overall objective

This stream will deliver robust and evolvable water information systems, covering data, standards, tools, services, interfaces, and architecture.

Delivery of operational products, data, and services such as the NWA, AWRA and forecasting must be underpinned by high quality and timely water information. This stream covers development of foundational water information systems (standards, tools, services, interfaces, and architecture) to support collection and management of existing data and creation of new data products.

Water Informatics research will extend to new areas to underpin the future direction for data delivery by the Bureau, and will encompass:

- water information standards, including open standards, interfaces and services for the discovery, sharing, access and delivery of water information and metadata;
- development of the Australian Hydrological Geospatial Fabric which provides the framework for connecting data components of the physical water cycle; and
- delivering connected data services, including delivering groundwater features using GroundWaterML 2.0, water information vocabularies and Linked Data, and using a Linked Data API to connect environmental data services.

Water information standards

The Bureau must collate, manage and distribute a range of water information, from numerous public and private organisations that currently manage it. Standard approaches that cover both the form of the data (syntactic standards), and the content of the data, including metadata, are needed to ensure effective information flows. Standards for observation time series data (WaterML2.0 part 1) have been completed. These standards need to be extended to ratings,

gauges and sections (WaterML2.0 part 2) and, potentially, to water quality, groundwater and water transactions.

Delivering workable international water data standards requires:

- syntactic data standards for use in the automatic ingestion of data by the Bureau's information systems and for the consumption of data by subsequent applications such as water forecasting models;
- inter-operability experiments to assess the practical performance of draft standards in transferring information; and
- reference implementations (i.e. versions of the Water Data Transfer Format - WDTF) for each concept within the standard to validate and facilitate adoption of the standards.

The key outputs of this research are:

- adoption and publication of WaterML2.0 part 2 as an Open Geospatial Consortium (OGC) standard to cover the data elements required by the Bureau; and
- profiling of the standard as WDTF 2.0 by the Bureau and use of this for collation and transfer of national water information.

Outcomes for end users are:

- a common data language to efficiently transmit water information between data collectors and the Bureau and onward to data and product users;
- effective and timely uptake of the Bureau's water information products by end users facilitated through the use of a common language;
- open standards, freely available to both data providers and consumers, that enhance the sharing of information among organisations, allow for third party leveraging of data, and a more competitive IT marketplace for water information software; and
- adoption of international standards led by Australia with Australian-specific needs addressed.

The paths to impact/operationalization are:

- WaterML2.0 will be implemented within AWRIS through WDTF 2.0, as the communication protocol for ingesting data into AWRIS from providers and as one method for providing data to users;
- standards for the management and transmission of water information will be incorporated in the Regulations associated with the Act (the Regulations); and
- uptake of international Open Geospatial Consortium (OGC) Standards by leading water data software companies with products used by Australian organisations.

Australian hydrological geospatial fabric (Geofabric)

An important element of a national water resources information system is the relationship between incoming temporal data streams and corresponding spatial features: the catchments, streams, aquifers, floodplains, storages, and wetlands that make up the hydrological system. Developing and delivering water resources

information requires linking these features with information about the interactions between features.

Geofabric version 2.1 has been publically released; v3.0 with finer spatial resolution is being developed. Version 2.1 does not directly relate anthropogenic features such as monitoring points to underlying stream networks and spatial data. Such relationships will allow for advanced hydrologic analyses that require an understanding of river networks and observations. The transition to finer resolution may also provide more robust data and will test the data modelling and supporting software infrastructure and tools developed for v.2.1. Ongoing Geofabric delivery and successful transition to the Bureau may need considerable support from CSIRO.

Successful implementation of v3.0 of the Geofabric requires:

- specifications, user needs, methodologies and a data model to describe monitoring points and anthropogenic features and their relationship within the Geofabric; and
- a modelling methodology that relates and/or maintain relationships of features within the Geofabric from products across multiple scales (e.g. Geofabric V2.1 and 3.0).

Key Geofabric outputs are:

- a high resolution Geofabric (version 3.0) that includes a monitoring point network product, with a stream topology-based network of anthropogenic features (e.g monitoring points, canals, pipelines) and river junctions; and
- handover of software infrastructure and supporting documentation to the Bureau.

Outcomes for end users are:

- a nationally consistent and linked spatial dataset that integrates products across scales, leading to more efficient and robust catchment modelling and water resource assessments; and
- a national operational service (the Bureau) with the capacity to maintain and further develop the Geofabric.

The path to impact/operationalisation of the Geofabric is via the complete handover of ongoing development and maintenance to the Bureau.

Delivering connected data services

The Bureau is fundamentally a data-driven organisation. Environmental data are the Bureau's currency and legacy. Delivering robust and integrated enterprise data services is a fundamental requirement to support Bureau data products and services providing Australians with environmental intelligence for safety, sustainability, well-being and prosperity.

This activity will work across a number of related areas to deliver connected data services. These will range from development and implementation of information models and markup languages that standardise the meaning and exchange of data, delivery of groundwater features (e.g. boreholes and aquifers) utilising one of these standards, adopting the Linked Data Registry service

approach to standardise the publication of the Bureau's water information vocabularies, and testing the use of the Linked Data API as a method for connecting some of the Bureau's environmental data services.

Successful implementation of connected data services requires:

- mapping the National Groundwater Information System (NGIS) database schema to the GroundwaterML 2.0 application schema;
- setting up and configuring Geoserver Web Feature Services and connecting these to the National Groundwater Information System;
- prototype deployment of Linked Data Registry technology and test deployments of Bureau water information vocabularies; and
- creation and deployment of prototype Linked Data services with Bureau environmental data.

Key connected data service outputs are:

- Web Feature Services delivering NGIS data;
- water information vocabulary services using Linked Data Registries; and
- connected Bureau environmental data services using the Linked Data API.

Outcomes for end users are:

- increased availability to Bureau data through automated machine-to-machine and person-to-machine technologies utilising emerging international standards.

The path to impact/operationalisation for this research activity occurs directly through the output data services.