Water Resources Assessment Framework-WRAF to Better Prepare for Water Security and Future Challenges: The Australian Experience

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Abstract

Globally, water data, information and assessment are in needs for sustainable planning and management for water resources taking into account climate changes. Availability of affordable and good quality water is critical for the global environment, the economy, for industry and food production, and for the community's health and lifestyle. Sustainable management of natural water resources to ensure adequate quantity and quality is fundamental since the most feasible sources of good quality water are natural surface water and groundwater.

Equitable allocation of water resources is a growing challenge due to the increasing demand for water, the competing triple-bottom-line values placed on its use, population and climate change. Sustainable management of water resources comes with compromises and trade-offs of the other sub-systems such as environment, economic and social and almost ignores stakeholders' objectives and benefits. However, consistent and adaptable water resources assessment framework is missing. The aim of this paper is to provide a step-wise Water Resources Assessment Framework-WRAF that educates users (Water managers, policy makers, water professionals, etc) to conduct water resources assessment at the temporal and spatial scale for their case study. The paper will also discuss the Australian experience in national water resources assessment and lesson learnt.

1. INTRODUCTION

Availability of affordable and good quality water is critical for the global environment, the economy, for industry and food production, and for the community's health and lifestyle. Sustainable management of natural water resources to ensure adequate quantity and quality is fundamental since the most feasible sources of good quality water are natural surface water and groundwater. Equitable allocation of water resources is a growing challenge due to the increasing demand for water, the competing triple-bottom-line values placed on its use, population and climate change. Sustainable management of water resources comes with compromises and trade-offs of the other sub-systems such as environment, economic and social and almost ignores stakeholders' objectives and benefits. These factors highlighted the needs for a consistent procedures for hydrological practices in assessing the water resources with due consideration for local conditions and specific regions. Better understanding and address all these challenges required a detailed water resources assessment. However, consistent and adaptable water resources assessment framework is missing.

Another challenge is where the water resources are shared as trans-boundary water bodies where treaties, agreements or memoranda of understandings have to be part of the appraisal process. These treaties may require assessing a state of nature condition or some pre-determined state of hydrology. Again, the nature of assessment would differ if the water body forms the boundary between the two or more countries versus if the river flows across the boundary and certain proportion of natural flow is to be maintained after watercourse is altered over time or the stream is contained through storage.

The establishment of the National Water Initiative in 2004 provided a blue print for water reform in Australia. This was followed by prolonged drought which required better water reporting and assessment to better understand the status of the water resources by compiling information and assess and report on the availability, condition and use of water resources in Australia. This information is aimed at informing public policy, programs and practices for better management of the nation's water resources.

National water resource aassessments in Australia were undertaken by various Australian Government agencies and partners at irregular intervals over the last 50 years, each with a slightly different purpose, spatial coverage and approach (**Figure 1**).

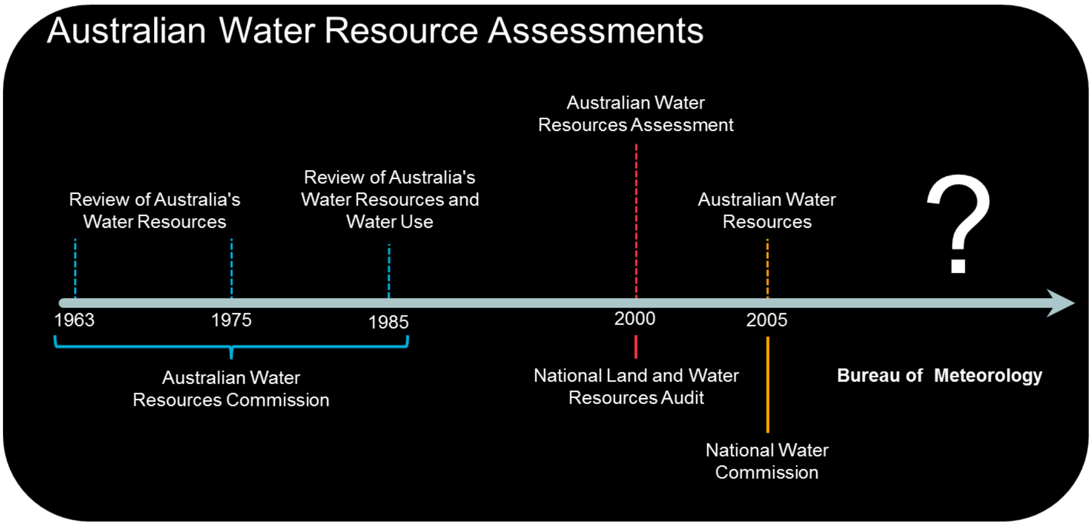

Figure 1: Historical Water Resources Assessment in Australia

The Australian Water Resources Assessment 2000 report, AWRA 2000 (Commonwealth of Australia 2001), was undertaken by the Australian Government in partnership with State and Territory Government agencies for the National Land and Water Resources Audit. It was published in 2001 and presented a snapshot of the quantity, quality, use, allocation and management of Australia's water resources. The most recent assessment, Australian Water Resources 2005 (National Water Commission 2007), was undertaken as a baseline for measuring the success of reforms under the National Water Initiative. It reported on the 2004–05 water year. Baseline information on water availability, water use and river/ wetland health was assembled for future comparisons. Regional water resource assessments were undertaken for a number of surface water management areas and groundwater management units. From 2005, water agencies around the country started delivering a range of water data and information products that provide certain components of the information included in previous water resource assessments.
This raised again the question of a consistent framework that can be applied as enduring function and meets the need.Through strategic water research and development investments, new assessment methodologies were developed that enhance Australian assessment capabilities. The aim of this paper is to provide a step-wise framework that educates users (Water managers, policy makers, water professionals, etc) of this proposed WRAF framework to conduct water resources assessment at the temporal and spatial scale for their case study. The paper will also discuss the Australian experience in national water resources assessment and lesson learnt.

2. WATER RESOURCES ASSESSMENT FRAMEWORK

Sustainable management of water resources comes with compromises and trade-offs of the other sub-systems such as environment, economic and social and almost ignores stakeholders' objectives and benefits. A consistent water resources assessment framework such as WRAF can help addressing these challenges and providing better understanding of the water status and its management's trade-offs.

The proposed framework is presented in a step-wise framework that educates users (Water managers, policy makers, water professionals, etc) to conduct water resources assessment at the temporal and spatial scale for their case study. This WRAF framework has been successfully demonstrated in several case studies including Australia. The framework has 11 steps (**Figure 2**); these steps are described below in brief. The framework should lead users to answer their critical and challengeable questions and perform a water resources assessment at any spatial and temporal scale of interest.

Figure 2: Water Resources Assessment Framework

2.1. Formulating Objective(s) for the Assessment

The first and main step is to formulating the objective of the proposed assessment. Provide an answer to: Why do you need to conduct a Water Resources Assessment-WRA. Setting the right objective of the assessment is critical step to identify:

- What are the key questions that the assessment will endeavour to provide an answer?
- Who are the main stakeholders and key players involved in this assessment?

To complete this step, it requires conducting a workshop with key players in the industry, area/region, government departments, etc. The workshop should aim to identify what are the main issues and objectives that the water resources assessment will need to answer. Reaching an agreement on the main objective is crucial factor that support the water resources assessment processes. The water resources assessment process is a data driven analysis and modelling otherwise whereas require support by all players and interested and beneficial parties. The set of objectives may be derived from a shared vision planning process through the workshop where a variety of stakeholders provide input into framing of the metrics to evaluate them. This step would also ensure a collective input into the assessment and future management of water resources as all stakeholders will have ownership of assessment results. Similarly, the assessment could be based on a single objective, for example, the impact of climate change on the ground water resources or changes in flood potential under alternative water availability sequence. Additionally, there could be multiple objectives that may require a collective weighting by the community and stakeholders' examples of objectives from case studies will be provided. Agreed on the objective of the WRA is a leading step for the following step "institutional and legislation setting".

For illustration purpose only for the following steps, a hypothetical catchment (**Figure 3**) is used to help understanding how to apply and use this manual. The proposed catchment is a regulated in the lower part of the catchment and upstream sub-catchment is unregulated. The catchment is monitored by a number of gauge stations (A to G). The catchment is delivering water to two urban towns (U1 and U2) and two irrigation areas (I1 and I2). The catchment is regulated by two dams (D1 and D2). The assumptions here are no groundwater or other sources of water are available. The objective for this hypothetical catchment is to assess the water resources in the catchment.

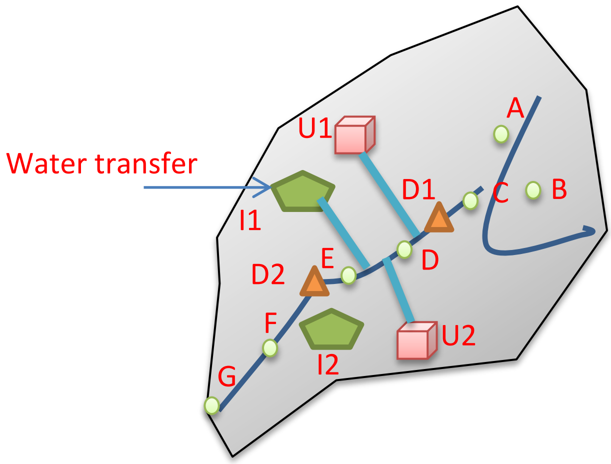

Figure 3: Hypothetical Catchment for Illustration Purpose

2.2. Institutional and Legislative Settings

Agreement on the objectives of the proposed or planned WRA is leading to investigate the institutional and legislative that related to the planned study. These institutional and legislatives are including the existing mandates and constraints on water sharing and allocations on the system, area, region, basin of interest. Listing, reporting and understanding the existing institutional and legislative will governing the objective and could be enunciated as constraints to the system that under study. These institutional and legislative can be sharing rules, allocation, trades, specific needs, environmental and cultural, monitoring, frequency of data collection, standard, etc.

For the hypothetical catchment, there is need to identify and collect water allocation and sharing rules for urban and irrigation. Also, the dams releasing and operational rules are important plus the water trading or transfer rules.

2.3. Spatial Unit Configuration

Spatial configuration is critical to the assessment and it set the boundaries for the area of interest and drives the data collection and identifies stakeholders and community groups to be consulted. The best approach to define the spatial unit or region/area boundary that will be the focus of the assessment is to conduct a workshop with main stakeholders using the participatory approach (Elmahdi and Mcfalarne 2011). They have described a step approach to bring multi-agency together to achieve long-term objective including sustainable water management. The spatial configuration can be hydrological, geological or administration boundaries such as catchment, aquifer or local council area. It may be expanding to states or national level or even drainage division regions and transboundary of nation and basin. Again, it depends to the first step of defining the objective and questions that need to be answered where the spatial scale of configuration is the appropriate scale to answer or achieve these objectives that defend in step one.
For the hypothetical study, the use of catchment/hydrological boundaries is selected. The hierarchy of the spatial scale is ranged from global to local scale (**Figure 4**). Defining and agreeing on unbiased hydrological spatial boundaries for the assessment is a leading step that will help in identifying the data by dividing the defined region into manageable unit (where administration boundaries play a major role in data collection).

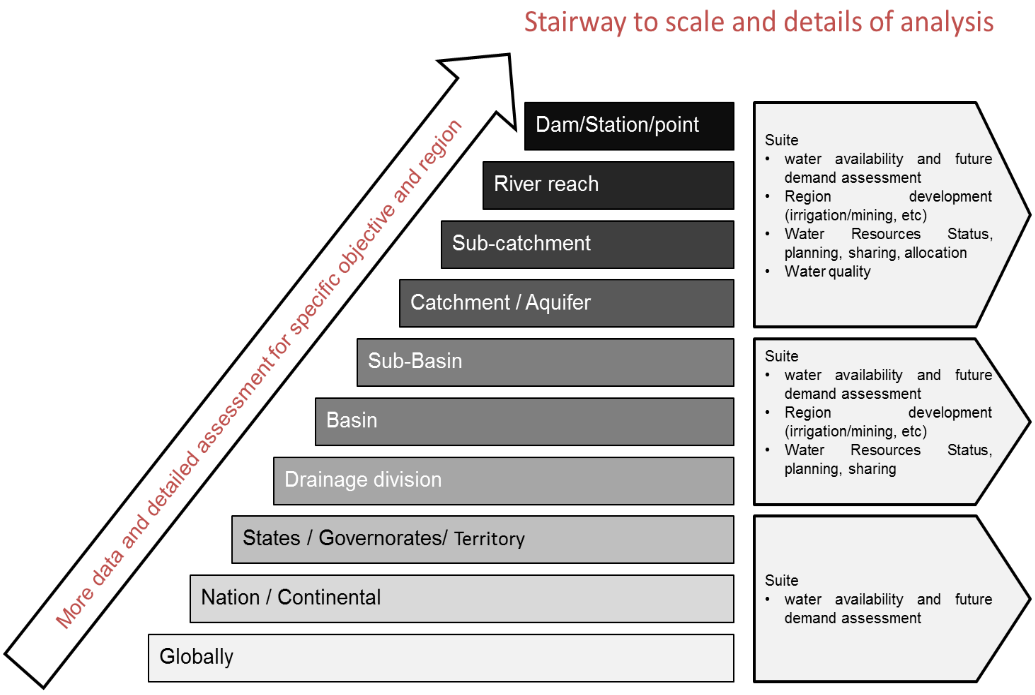

Figure 4: The Hierarchy of the Spatial Scale

2.4. Establishing Base Time Period

This step is very dependent on the previous step in terms of spatial boundary and objective or system that under the assessment. For example, if the question is to assess surface water availability it could be daily to monthly to annually. However, if the system under study is groundwater it could be a decadal to assess impact and stainability. Even it could be less than a day if the assessment is looking for rainfall intensity and frequency and duration to urban or water infrastructure design. The spatial and temporal configurations are mainly depending on the objectives, questions and system considered for the assessment. Combining the above two steps in one workshop with stakeholders is appropriate. On top of defining the temporal scale for the analysis or the assessment; defining the base time period is critical too which sometime called the baseline period where the results of the assessment benchmarked against. It could be specific to special climatic period like drought or wet years/period or before agricultural and irrigation system development, other example could be before land use change such as deforestation, replantation, drylands, etc. All these aspects need to be considered in defining the baseline period. Also, it could be different baseline defined for different questions or objective to be assessed against.
For the hypothetical case, the monthly time step for the recent year and last 50 years of data including the 10 years of the drought. The water financial year is adopted from 1st July-30 June.

2.5. Data Requirements and Availability

The assessment process is largely dependent on data availability. Completing the previous steps clarify the need for the data on what spatial and temporal scale. Also, by defining the objective or question including the stakeholders, data sharing is the critical step “without data nothing can be done-better and more data lead to better analysis and good decision”. However, some critical data are not existing or collected; this where the gap analysis technique come into picture and also modelling to estimate the values in spare data regions. This step should define any data gaps and recommend for where and when data monitoring is required. The key to a sound water resources assessment lies in the availability of the required data. Selection of the right data points is critical for the assessment. For example, assessing water availability for one year in a long term context like 50 or 100 years, the selection of unimpaired catchment and upstream gauge station will be critical to isolate the diversion or irrigation regulations impact on stream flow by looking for station before dams or for catchment that had not regulated.

For the hypothetical case, the selective of gauge station (A, B and C) to understand and assess the streamflow and the impact of climate change. However, the rest of the gauge stations will be used to assess the resource status including the two dams as a storage capacity in the catchment.

2.6. Water Balance - Approach / Scope / Methodology

Water Resource assessment can be done in many ways; however, the main and common approach is the water balance. In other means accounts for all fluxes and terms of water system or cycle including change in the storage. In simple mathematics is Inflow = outflow and change in the storage. For example, for landscape area; inflow represents rainfall/precipitation, outflow represents evaporation and change in the storage is the landscape water store (soil moisture). The concept of water balance can be extended and applied to any water source (surface water, groundwater), system (urban system, irrigation) or combination of sources and systems as for catchment or river basin. According to the level of complexity and data availability the water balance can be simple or complex. In a region concept, the inflow side can be extended to include importing water from other region, system (surface water or groundwater) or water purchase/trading or sourcing water from desalination or recycled. The outflow can also be extended to include, exporting water or trading out or all diversion for urban, irrigation and environment including cultural water. It is worth to note that based on the objective and defining the spatial and temporal setting, the water balance components/fluxes changes. The time base is critical for the water balance as accounting the balance by financial year or water year to identify or estimate the storage volume at the beginning of the time.

For the hypothetical case, the inflow represented by precipitation that created run off and inflow to the river system and the volume of water transferred from other catchment to the irrigation area. The outflow is represented by downstream flow at gauge station G, evapotranspiration, within the river system all diversion to urban and irrigation areas. The change in the storage is represented by the storage volume in the two dams. The water balance can be applied to each river reach between two gauge stations to account for inflow and out flow of each river reach. The outflow from the upper gauge station will be inflow to the below gauge station and so on.

2.7. Data Analysis

This step is the first cut of the analysis after defining the objective, spatial and temporal settings and conceptualise the water balance approach that will be conducted. Understanding the data that has been collected along he above steps as it is observed, recorded or estimated data. Is the data continuous or is there a gap? If so what technique will be used to fill the data gap including modelling. Analysing the data set and understands the trend in the water resources availability is a major outcome of this step. However, it is not just enough to look at the results of the data analysis, it is crucial for results interpretation is considering the uncertainty. Data analysis can include trend, decile, moving average, etc analysis.

Before defining the uncertainty and conduct uncertainty analysis; precautions need to be paid for defining the baseline conditions or in other words (the concept of a basis of comparison (BOC). The user need to define what period of months/years or dataset that will be used as baseline condition where conducted the WRA to compare the current situation to the baseline condition (BOC). Uncertainty can result from many aspects, it can be related to: data, measurements, instruments, handling error, modelling setting, etc. The users of the framework need to assess what level of uncertainty analysis that needs to be conducted.

For the hypothetical case, the BOC will be the period of drought during 1980 to 2000 as baseline condition and conducted a trend analysis for the streamflow data at gauge stations upstream before regulation to understand the impact of climate change. The trend analysis for the downstream gauge stations will assist in assessing the impact of diversion/use during the drought period and the requirement for environmental flow at downstream.

2.8. Developing Scenarios for Testing

This is a major step where it will help the user to establish and develop a list of scenarios that need to be considered to shape the final results and recommendations. The technique for developing scenarios including scenarios analysis is discussed in (Elmahdi 2006 and WMO 2017). It is crucial for this step to be conducted in a full consultation with all stakeholders including cross-agency dialogue and address the triple bottom line (environmental, economic and social) settings and requirements. Reaching this step, means the user have developed fully understanding of its data, system, baseline conditions and the current trend including the status of the water resources. The question for this step is to look into future, what are the expected behaviour and changes that can happen in the future. The future here can be short-term or long-term from a year to decades. Scenarios can address a number of questions such as policy, allocation rules, land use change, industry, environmental needs, social and cultural needs, etc. There is no limit on the number of options or scenarios that the user can test. The main idea here is these proposed scenarios for testing: need to address the current issues that defined during the recent consultations, analysis and assessments of the system and address future needs or how the system behaves under certain conditions such as drought, wet, new infrastructure, new land use, pumping regime, etc. Evaluating a number of scenarios may require developing a set of assessment indicators to ease the communication with stakeholders, policy makers and decision makers.

For the hypothetical case, different climate scenarios are considered as dry, wet and moderate. These three scenarios are analysed and evaluated against the baseline condition dataset. A simple set of indicators is used. These indicators are: Achieving minimum 30%^of low downstream (gauge station G), Satisfy irrigation demand by 65%, satisfying urban demand by 80%.

2.9. Visualization and Interpretation

Finalising the results including data and scenarios analysis needs to be completed by an importance step which is the interpretation and visualization of results; presenting the results using the appropriate tool. These tool are very extensive they included excel, access, business intelligence tool, GIS, etc. Choosing the right format of the results through temporal vs spatial (time series graph vs mapping). Sometime a simple representation could help the message of the analysis to be communicated for example a traffic tool presentation of the scenario and risk analysis is quite useful tool to communicate the acceptable scenario.

For the hypothetical case, using time series graph to show the trend analysis and moving average is a great choice. However, to show the decile analysis for several years using a mapping that can also show the spatial distribution of the decile is another great choice.
Communicated the results including the keep findings are like the icing on the cake.

2.10. Key Findings

In this step the user of this framework needs to go back to the main stakeholders and communicate the findings of the analysis. One main point selecting the interpretation and visualisation tool is essential and need to be tailored by audience and the way of communication (report vs workshop). It is recommended even publishing a report with key findings is still essential to conduct a workshop with the stakeholders and communicate the key findings and get their feedbacks. It might result in identifying some more essential data that need to be considered in further analysis or reaching a level of consensus on the results.

For the hypothetical study: workshop is chosen to communicated the findings of data and scenarios analysis with assistance of traffic light presentation to discuss the pros and cons of each options and reach an agreement on the final findings to assist in the next step of recommendations.

2.11. Recommendations

After discussing and agreed on the key findings, the user is ready to draw out the recommendations of the assessment. The recommendations should be presented in an actions
type. It should be clear what actions can be drawn from the recommendations. The recommendations again can be presented as short-term and long-terms. It should spot light on critical actions or recommendation that need instance interference to all stakeholders. For the hypothetical case: recommendations communicated through a workshop with clear identification of actions and next step.

2.12. Publications and Sharing Information

Conducting a WRA is a great effort, however communicated and sharing the assessment outcomes is more important for awareness and sharing experience. Currently in the world there are many ways to publish and share the information or outcomes. Sharing the information with stakeholders, public and key users supporting achieving the value add of any information through providing insight. However, the level and type of information that will be shared need to be tested and agreed by stakeholders.

Many platforms are existing for publication that range from hard copies to web platform to phone application or GIS based applications. For the hypothetical study: a web application is used to present the information and outcomes of the assessment.

3. APPLICATION OF WRAF: AUSTRALIA CASE STUDY (AUSTRALIAN WATER RESOURCES ASSESSMENTS-AWRA)

The objective of the AWRA is to assess the impact and sustainability of current water management practices and inform the design of water resource plans, supporting the goals of the National Water Initiative. The Australian Water Resources Assessment presents data and information on the extent and magnitude of Australia's water resources for particular year in the context of the long-term record. The Australian Water Resources Assessments evaluates the nation's water resources. It focused on consistency in reporting over time at key sites, highlighting patterns, variability and trends. These assessments aim to:

- monitor the hydrological state of rivers, storages, wetlands and aquifers and publish hydrometric statistics for key sites
- highlight patterns, trends and variability in water availability, water quality and water use (urban and agricultural)
- analyse the climatic conditions and landscape characteristics
- present outputs of varying complexity to meet the information needs of a range of users, predominantly in the form of readily interpretable maps, graphs and tables.

The Institutional and Legislative are water reform 2004, water cap 2004, water act 2007 and water allocation, licences and entitlements per water resources plan for each catchment.
The Spatial and temporal settings, the Australian Water Resources assessments are undertaken at regional and national spatial scales (**Figure 5**) and time scales ranging from months to decades. The Australian Water Resources Assessments-AWRA assess the water resources status and present and publish the information at Continental, national, drainage division, basin, region, catchment scales in addition to reference site for streamflow, water quality, etc.

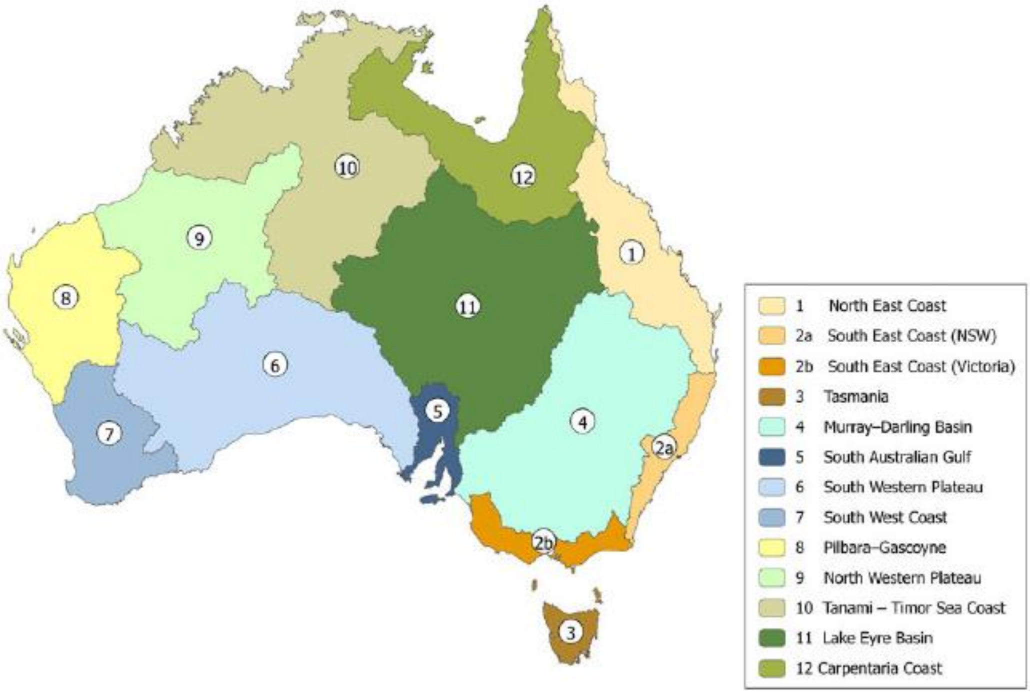

Figure 5: Assessment Reporting Regions and Region Numbers (Bureau 2010)

The Australian Water Resources Assessment-AWRA analyses, assess, presents and publish the assessments information at monthly, seasonal, annual and decadal for long-term context. They use the best available water data, models and analyses to describe the state of the nation's water resources at a point in time and in the context of the long-term record. The Australian Water Resources Assessment is structured around 13 regions covering the Australian continent, based on drainage division boundaries. Drainage divisions represent the catchments of major surface water drainage systems, generally comprising a number of river basins. Within the reporting regions shown in Figure 5, various time-series analyses and reporting techniques were applied depending on the availability of data. Analysis and reporting units at the sub-regional level include hydrological units
(surface catchments and groundwater aquifers), water management and planning areas, water supply systems and reference or monitoring sites or clusters of sites (e.g. stream gauges on tributaries flowing into a dam).

Data and information presented are generally for the 12 months for example from July 2009 to June 2010 and/or months and seasons therein. Time-series analyses were restricted to consideration of the past 30 years where data permits, in order to focus on variability and trends in recent decades.

For the first time in a national water resources assessment, insights into landscape water balances for each region are provided. This development supports the need for consistent information on water resources across the whole country on a continuing basis. A landscape water balance has a number of standard variables:

- inflows (e.g. rainfall)
- outflows (e.g. evaporation, transpiration, run-off)
- change in storage (e.g. soil moisture).
- these variables can be broken down further to explore detail with regards to run-off, infiltration, and recharge and discharge values.

The nature of a water balance depends primarily on three factors (Elmahdi et al 2015): (i) the water system boundary; (ii) the degree to which water flow and store components of the water balance are disaggregated into smaller components; and (iii) the selected timescale. The primary water flows and water stores that the Bureau aims to qualify or quantify in Australian water resources reporting are shown in **Figure 6**.

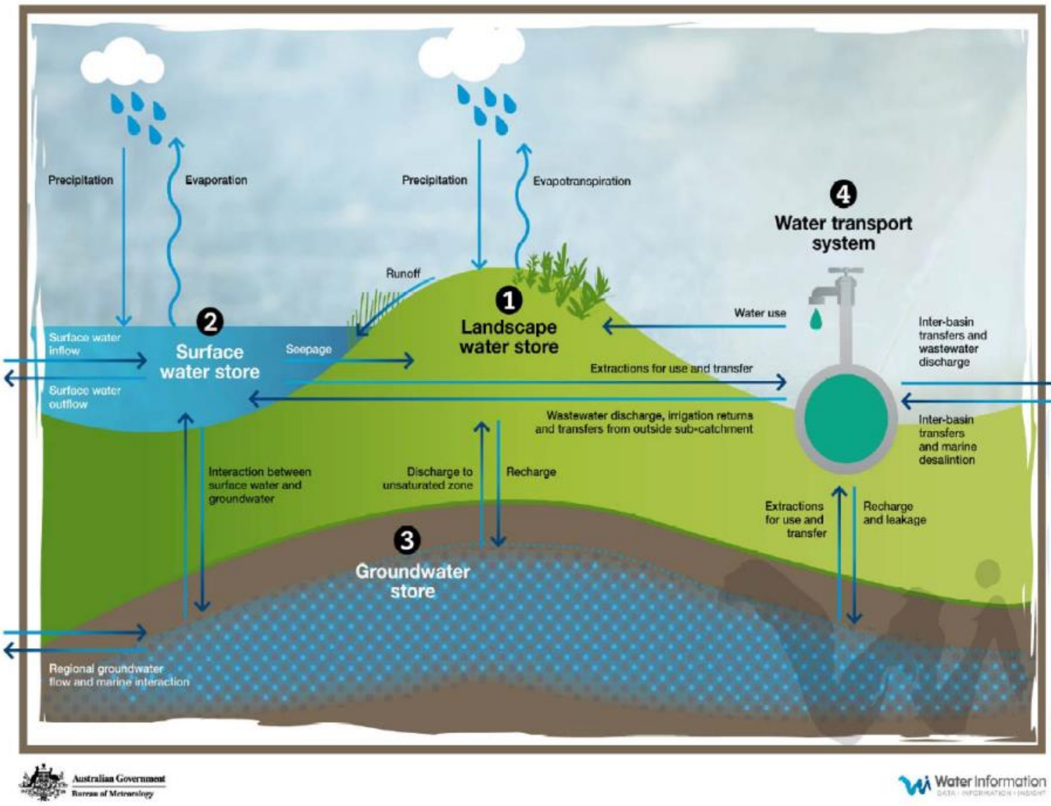

Figure 6: Australian Water Balance Approach

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 (Elmahdi et al 2015). 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 using the water balance approach.

The Australian Water Resource Assessment (AWRA) modelling system is a new integrated continental hydrological simulation system designed and prototyped by CSIRO and the Bureau through the Water Information Research and Development Alliance initiative (Elmahdi et al 2015 and Hafeez et al 2015). It is being developed to enable the Bureau to meet its legislated role (as per the Water Act 2007) in providing an annual National Water Account (NWA) and regular Australian Water Resource Assessment (AWRA) reports. The AWRA Modelling System (AWRAMS) provides nationally consistent and robust water balance estimates at a national to regional and catchment scale for the past and present using observations where available, and modelling otherwise. The AWRAMS has two modelling components including a landscape water balance (AWRA-L) and a river balance (AWRA-R) (**Figure 7**). It is flexible enough to use all available data sources, whether modelling data-rich or data sparse regions, to provide nationally consistent and robust estimates of water balance terms.

The AWRA Modelling System runs nationally at a daily time step and on a 0.05 degree grid (approximately 5 x 5 km), consistent with the resolution of available climate data required as inputs to the models.

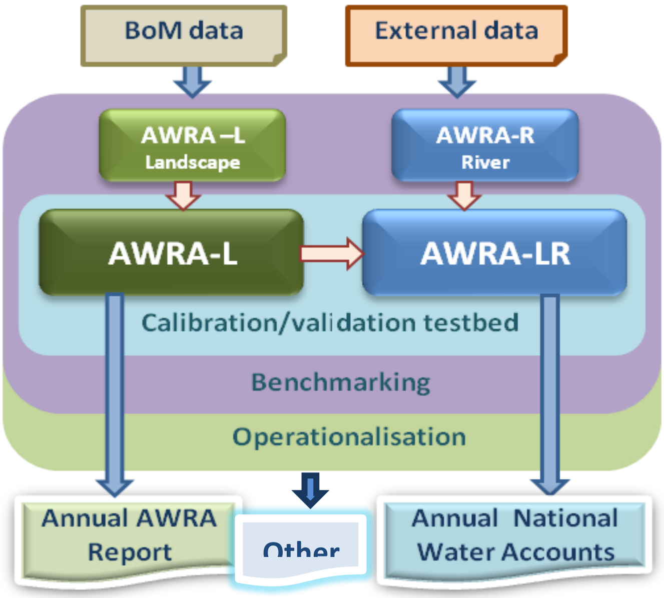

Figure 7: The AWRA Modelling System. Where, AWRA-L: AWRA-Landscape Model; AWRA-R: AWRA-River Model; AWRA-LR: AWRA Integrated Regulated River System Model

AWRA-Landscape Model-AWRA-L is a one dimensional, 0.05 degree grid based water balance model over the continent that has semi-distributed representation of the soil, groundwater and surface water stores. Outputs are spatio-temporally aggregated to provides daily, monthly and annual gridded estimates of landscape water yields, runoff, evapotranspiration, soil moisture, and groundwater recharge/storage/lateral flow at the regional and continental (national) scale seamlessly from the past to the present (100 + years). It also provides the option of lateral exchanges of groundwater between grid cells at the continent scale.
AWRA-R (River) Model-AWRA-R, the river system component of AWRAMS, is a conceptual river model designed for both regulated and unregulated river system (Lerat et al., 2013). AWRA-R uses a node link flow network to accumulate catchment runoff (recorded at gauge or modelled by AWRA-L), route streamflow including river losses; incorporate reservoirs and model flooding and irrigation. It also includes pumping to and from the groundwater store where data is available and transfer of river/floodplain/irrigation losses from AWRA-R to be input into AWRA-L groundwater store.

Water balance analysis outputs are presented in the form of monthly, seasonal and annual totals and their decile rankings against long-term records. Percentiles and deciles denote the position of the reporting period observations or water balance term estimates in comparison to all values in the record. They provide a clear indication of above or below average values at a location.

No scenario used in the Australian Water Resources Assessment. The scenario analysis step is left for water resources manager and policy makers. The bureau’s role is to present authoritative and independent assessment information to assist decision making processes.

Key information and findings regarding the climatic conditions and water outcomes for Australia over 2009–10 is provided in **Table 1**.

Table 1: Key Information on the Water Flows, Stores, Use and Climatic Condition in Australia for 2009–10 (Bureau 2010)

Landscape water balance in 2009–10	Australian average	Difference from long-term mean	Rank (out of 99)*
Rainfall	536 mm	+13%	80
Evapotranspiration	415 mm	+4%	71
Landscape water yield	96 mm	+40%	86

Soil moisture in 2009–10	Regions that became drier	Regions that became wetter
	North Western Plateau, Pilbara–Gascoyne, South West Coast, South Western Plateau, South East Coast (NSW) and Tasmania	Carpentaria Coast, Lake Eyre Basin, Murray–Darling Basin, North East Coast, South Australian Gulf, South East Coast (Victoria) and Tanami – Timor Sea Coast

Surface water storage (comprising approximately 94% of Australia's total surface water storage)

Total accessible capacity	July 2009		June 2010		
	Accessible volume	% of accessible capacity	Accessible volume	% of accessible capacity	% Change
78,500 GL	36,000 GL	46%	40,500 GL	52%	+6%

Comparison of water use between 2008–09 and 2009–10

Urban water use		Agricultural irrigation water use (natural resource management regions)	
Volume	Change	Volume	Change
1,568 GL in 2008–09 1,497 GL in 2009–10	-4.5%	6,530 GL in 2008–09 6,600 GL in 2009–10	+1%

Drivers of climatic condition in 2009–10	
El Niño-Southern Oscillation	Central and eastern equatorial Pacific Ocean was warm (El Niño conditions) until February 2010 then cooled to La Niña conditions by April 2010. As a result the Southern Oscillation Index was negative until March 2010 then strongly positive
Indian Ocean Dipole	Positive during 2009 and negative during 2010

Major rainfall events in 2009–10

Timing	Location	Characteristics
22 February – 3 March 2010	Northern Territory, Queensland and far northern New South Wales	Monsoon low triggered very widespread heavy rainfall: 28 February – wettest day on record for the Northern Territory, 2 March – wettest day on record for Queensland

Major flood events in 2009–10

Timing	Location	Characteristics
February– March 2010	Gulf of Carpentaria, Lake Eyre Basin, North East Coast, Murray–Darling Basin	Short but large flood peaks in the major tributaries of the Darling River, with an estimate of only 15% reaching Menindee Lakes in western New South Wales

The key findings and recommendations are:

- Australia has extensive water supplies and their use is managed by various institutional arrangements. Availability is being increased by using recycled and desalinated water. At the same time, greater protection is being afforded to the environment through the purchase of entitlements from water users and investments in water-saving infrastructure.
- Water is used for various purposes across Australia, including agriculture, industry and human consumption. The estimated total water use across Australia was 23 500 GL in 2013–14. The top two water uses were irrigation (57 per cent of total use) and urban consumption (17 per cent of total use).
- Most water use in Australia occurs in the Murray–Darling Basin and around the major metropolitan cities.
- At the time of writing (October 2015), most water storages are in reasonable condition. However, in the Murray–Darling Basin, where much of Australia's irrigation occurs, storage levels are below average.
- High pressure systems have intensified and shifted south, which forces rain-bearing weather systems south of Australia and brings dry weather.
- There is evidence that runoff has been reduced in southern Australia even more than expected from the rainfall decline. The decline in rainfall seems to be drying the landscape and dropping groundwater levels.

- At the end of 2013–14, the rainfall deficiencies were not as severe as at the peak of the Millennium Drought. More importantly, water supplies were more secure for the major metropolitan cities.
- Water supplies have been augmented in all cities since the Millennium Drought—desalination plants can supply 10–60 per cent of urban water supplied to all capital cities in mainland southern Australia except Canberra, which has augmented its supplies in other ways.
- In the Murray–Darling Basin, where much of Australia's irrigation occurs, storage levels were lower than average at the end of 2013–14 across the entire Basin.
- In the southern Murray–Darling Basin, storage levels in the drier months are not as low as at the peak of the Millennium Drought and, since the drought, there has been a maturing of the water market.
- The river ecosystems of the Basin have been better catered for since the Millennium Drought as a result of nearly 70 per cent of the Basin-wide water recovery requirements being met by 30 June 2014. Some of this has come from purchase of entitlements from irrigation, so less surface water is now used for irrigation.

4. CONCLUSION

The water resources assessment framework-WRAF discussed in this paper presented a comprehensive step-wise framework, that educate water managers and policy makers to conduct water resources assessment to be able to answer the key critical questions for the area of interest.

Water resource assessments needs to provide a comprehensive and integrated evaluation of the water resources status at the right spatial and temporal scale. From its several definitions, it is a tool to evaluate water resources in relation to a reference spatial and temporal frame. The spatial unit should be hydrological based such as catchment, sub-catchment or groundwater reservoir or aquifer, etc. Depending on the objective of the assessment, WRA may look at a range of physical, chemical, and biological features in assessing the dynamics of the resources which in turns can change the spatial scale to point source, gauge station, dams, etc. Hydrological boundaries represent clear boundaries where both surface water and groundwater and any other water sources flows can be measured or estimated with high level of confidence. However, care is needed when defining the hydrogel boundaries where:

- Groundwater is presented, as the geological formation/boundaries are not always aligned with surface hydrological boundaries;
- Shared basin between countries and or states; or
- Administration boundaries are dominated the assessment objective or very local issue

An Australian case study briefly presented and discussed to test the applicability of the presented framework. It is very clear from the discussion by following the proposed WRAF framework; the user can conduct a successful water resources assessment at different spatial and temporal scale and can answer many critical questions. The Australian Water Resources Assessment presents data and information on the extent and magnitude of Australia's water resources for particular year in the context of the long-term record. The Australian Water Resources Assessments successfully evaluates the nation's water resources and applicability of WRAF by adopted the proposed WRAF framework that focused on consistency in reporting over time at key sites, highlighting patterns, variability and trends.

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