

## TRANSFORMATION OF AUSTRALIAN IRRIGATION WATER MANAGEMENT UNDER CHANGING CLIMATE

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### ABSTRACT

In Australia, extended recent drought conditions and climate change concerns have highlighted the need to manage water resources more sustainably. Assessing water resources and accounting for their availability and use at a regional and continental scale requires comprehensive and consistent information on water distribution, storage, availability, and use across Australia. This information needs to be accurate, up-to-date and take account of local climatic and hydrological conditions. It also needs to be produced in a robust, transparent and repeatable manner. This has also highlighted the need to manage agricultural water resources more sustainably especially in the Murray Darling Basin (MDB) which utilizes more than 70% of water for food production. In 2004, the Australian Government started the National Water Initiative (NWI) which is a policy blueprint to transform and improve the way Australia manages its water resources. Under this NWI program, Australian Government has invested in modernising irrigation sector to improve the water productivity of irrigation system across all scales (on—farm and off-farm) so that more water is available for the environment sector.

This paper provides a major review of recent water policies, structural and non-structural changes implemented as well as technological innovations (non-traditional including application of information technology, satellite remote sensing) coupled with hydrology-hydraulic models across multiple scales ranging from continental, catchment and irrigation systems in Australia. Typically, improving water management in irrigated areas require the analysis of real time water demand in order to determine the possibilities in which it may be modified and rationalised. Real time water demand information in irrigated areas is a key for planning about sustainable use of irrigation water. These activities are needed not only to improve water productivity, but also to increase the sustainability of irrigated agriculture by saving irrigation water. This presentation will provide in-depth analysis on managing water resources in Murrumbidgee river basin, a major food bowl in the MDB, by providing examples from the project including Australian Water Resources Assessment (AWRA), Computer Aided River Management (CARM) and Coleambally Irrigation Demand management (first world irrigation system with 95% delivery efficiency). Examples of innovative projects will also include development of decision support systems using Information and Communication Technology (ICT) and remote sensing to monitor and predict yield and water supply-demand balance in a near real-time environment for irrigation areas.

Second half of the paper is mainly focussing on major technical and non-technical issues for a poor performance of irrigation system in many Asian countries where more than 80% of freshwater is diverted for food production. However, the irrigation efficiency is very low ranging from 30-50% meaning a large part of the water devour for irrigation is wasted due to poor management of irrigation systems. The author presents the current challenges faced in many irrigation systems located in Yellow and Yangtze River Basin (China), Indus River Basin (Pakistan), Pampanga River

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Basin (the Philippines), Mekong River Basin (Lao PDR), and Amu Darya River Basin (Uzbekistan). Based on practical insights and in-depth rich knowledge, the author will discuss pathways and opportunities to improve water and food security through enhancing water use efficiency and water productivity of irrigation sector across the Asian countries.

Keywords : Irrigation Water Management, Decision Support System, Murray Darling Basin, Water Productivity, Australia and Asian Irrigation System.

## 1. INTRODUCTION

Water scarcity is rapidly becoming a vital issue for many countries in the developed and developing world and could lead to a severe global water crisis (IWMI, 2014). Pressure to meet the growing water demands have resulted in greater competition among traditional water consumers namely agriculture, industry and cities for available water resources. Among all users, irrigated agriculture is the largest consumer, accounting for 70% of global water withdrawals; from this water, nearly 40% of the world's food is produced. Maintaining enough freshwater for agricultural production will become increasingly difficult in the near future due to climate change, growing water competition among various sectors and rapid population growth. Water scarcity will force irrigated agriculture to produce more with less water in the future, which requires effective management of water.

Similarly, extended recent drought conditions and climate change concerns have highlighted the need to manage water resources more sustainably. Assessing water resources and accounting for their availability and use at a regional and continental scale requires comprehensive and consistent information on water distribution, storage, availability, and use across Australia. This information needs to be accurate, up-to-date and take account of local climatic and hydrological conditions. It also needs to be produced in a robust, transparent and repeatable manner. This has also highlighted the need to manage agricultural water resources more sustainably especially in the Murray Darling Basin (MDB) which utilizes more than 70% of water for food production. In 2004, the Australian Government started the National Water Initiative (NWI) which is a policy blueprint to transform and improve the way Australia manages its water resources. Under this NWI program, Australian Government has invested in modernising irrigation sector to improve the water productivity of irrigation system across all scales (on—farm and off-farm) so that more water is available for the environment sector (Hafeez et al., 2018).

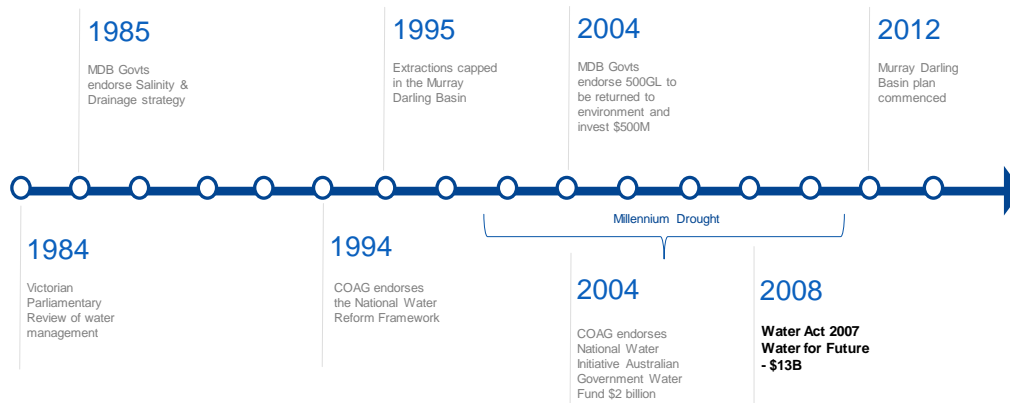
This paper provides a major review of recent water policies, structural and non-structural changes implemented as well as technological innovations (non-traditional including application of information technology, satellite remote sensing) coupled with hydrology-hydraulic models across multiple scales ranging from continental, catchment and irrigation systems in Australia. Typically, improving water management in irrigated areas require the analysis of real time water demand in order to determine the possibilities in which it may be modified and rationalised. Real time water demand information in irrigated areas is a key for planning about sustainable use of irrigation water. These activities are needed not only to improve water productivity, but also to increase the sustainability of irrigated agriculture by saving irrigation water.

## 2. AUSTRALIAN CASE STUDY

This section will first provide an overview of water policy journey and then provide examples of state-of-the-art innovative tools and models at various spatial scales (Continental, River and Irrigation) being used to improve water productivity of irrigation systems across Australia.

### A. Australian Water Policy Journey

Australian major water policies journey could be divided in two phases (Doolan, 2007) as presented in Figure 1.



**Figure 1.** Australian Water Reform Policy Journey (Doolan, 2007).

Development decades – 1880's to 1980's (also called Built and Supply Decade) where major water storage capacity were increased through building dams from 240 GL (1900) to 84,800 GL (2005). During this policy era, there was no information who was entitled to what water, poor pricing policy and inefficient water use led to poor return to economy from water use, and environmental degradation from irrigation sector.

Water reform journey from 1980's which is a transformation era for modernising irrigation sector (technical and institutional) across Australia. Major accomplishments include introducing of CAPS on water use to match sustainable yield, establishment of functional water markets for cost effective pricing, and development of integrated water sharing plans for all catchments which led to improve water use efficiency and economic productivity of irrigation system across Murray Darling Basin of Australia.

### B. Continental Hydrological Model

At the peak of Millennium Drought (2000's onwards), Australian Government decision-makers were faced with seemingly simple questions, which couldn't be answered easily due to lack of consistent water information about water availability, usage and losses from surface water and groundwater across Australia (Hafeez et al., 2015). To answer these questions, the Australian Government started the National Water Initiative (NWI) to transform and improve the way Australia manages its water resources. As part of the NWI process the Bureau of Meteorology (the Bureau), through the Water Act 2007, has been given the responsibility for compiling and delivering comprehensive water information across the water sector (BoM, 2012). To enable the Bureau to meet its legislated role (the Water Act 2007), in 2008, the Bureau and CSIRO agreed to collaborate on research activities in the field of water

information through the Water Information Research and Development Alliance (WIRADA) initiative (Van Dijk et al., 2012) for 10 years (Hafeez et al., 2015).

The Australian Water Resource Assessment Modelling System (AWRAMS) designed and developed under WIRADA provides seamless water balance information and data for the nation for the past and present using observations where available, and modelling otherwise (Hafeez et al., 2015). The AWRAMS is a new integrated continental hydrological simulation system designed and prototyped to provide an annual National Water Account (NWA) and regular Australian Water Resource Assessment (AWRA) reports. More information on these products can be obtained on the website (on NWA: [www.bom.gov.au/water/nwa](http://www.bom.gov.au/water/nwa) and on AWRA [www.bom.gov.au/water/awra](http://www.bom.gov.au/water/awra)). The AWRAMS has two main modelling components (Figure 2):

A Landscape water balance component (AWRA-L: Hafeez et al., 2015) 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. The model provides daily, monthly and annual gridded estimates of landscape 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 option for lateral exchanges of groundwater between grid cells at the continent scale.

A River system component (AWRA-R: Dutta et al., 2013; Lerat et al., 2013) is a regulated river system model and uses a node link flow network to accumulate catchment runoff from 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 (c) transfer of river/floodplain/irrigation losses from AWRA-R to be input into AWRA-L groundwater store (Hafeez et al., 2015).

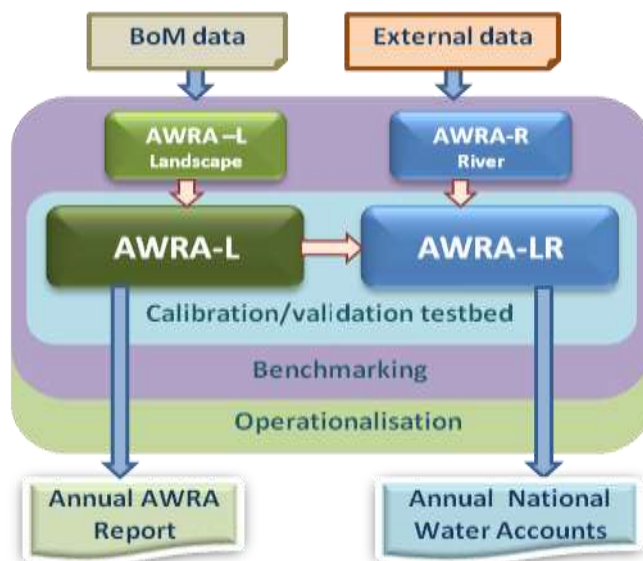


Figure 2. The AWRA modelling system. Where, AWRA-L: AWRA-Landscape model; AWRA-R: AWRA-River model; AWRA-LR: AWRA Integrated Regulated river system model (Hafeez et al., 2014)

The AWRAMS uses on-ground observations and remotely sensed data sets, combined with hydrological science and computing technology, to estimate water

balance fluxes and stores. This includes all major water storages, and the movement of water in and between these, at a 0.05 degree (~5 km) spatial resolution and daily time step (Vaze et al., 2013). 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 AWRAMS has been operationally used for reporting purposes by the Bureau since 2011-12 onwards (Hafeez et al., 2015). Key outputs from the AWRA-L model include surface runoff, soil moisture, evapotranspiration and deep drainage are available on [Australian Landscape Water Balance](#) website. The AWRA-L model is running operationally in the Bureau on a daily schedule (Smith et al., 2015). Since March 2014, the Bureau's AWRA modeled daily outputs has successfully been used by a wide range of stakeholders across Australia for hydrological and water resources studies. These stakeholder organisations include Commonwealth (Murray Darling Basin Authority (MDBA) and Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES)) and State government (NSW Department of Primary Industries (NSW DPI); QueenslandSeqWater; Victorian Department of Primary Industries (VIC DPI); QLD Department of Science, Information Technology and Innovation (DSITIA); NSW State Water Corporation (WaterNSW); NSW Office of Water (NOW)) water and agriculture agencies, catchment management authorities, consultancies, water industry professional groups and research organizations across Australia (Hafeez et al., 2015). Outputs from the AWRA-L model are used routinely by external clients through a registered user service. The Bureau has also successfully worked with several states and commonwealth water and agricultural agencies on how to best use the model outputs. For example, AWRA-L based soil moisture (shallow layer – top 1m) output is being used by DPI Victoria (DEDJTR) to summarise climatic conditions for the seasonal climate update of Victoria (Figure 3: Hafeez et al., 2015b).

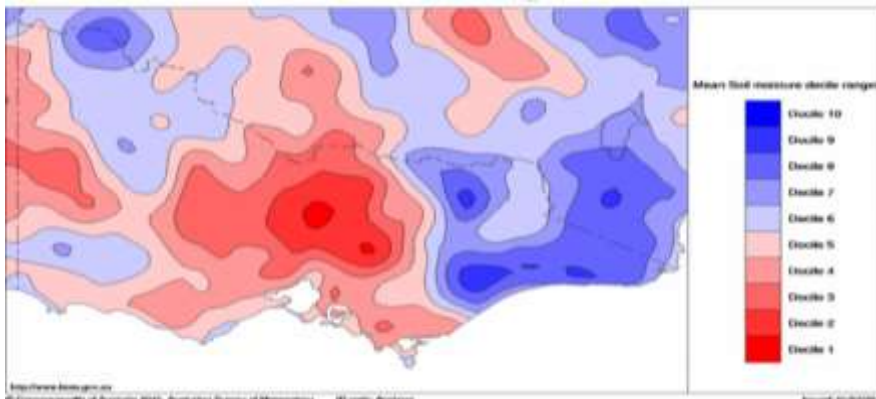


Figure 3 VIC DPI (DEDJTR) registered user product from the AWRAMS. Monthly deciles for shallow soil moisture in Victoria. June 2015 is shown and was used for the seasonal climate update for Victoria (<https://www.youtube.com/channel/UCIDCII7gRZhUs03opGqH1g>). (Hafeez et al., 2015b).

The AWRAMS is the first national operational integrated water balance model representing coupled landscape, groundwater and regulated river systems to consistently estimate water fluxes and storages at around 5 km resolution across the continent. Vigorous model testing and evaluation of ARWAMS with other peer landscape and hydrology river basin models has been done in-house to get the confidence of AWRAMS performance to quantify water fluxes in NWA reporting regions. The outputs provide valuable information on Australia's water resources for water management practitioners, policy makers and researchers. The outputs from the operational AWRA-L model are being regularly provided to registered users from

several water and agriculture agencies to improve the water productivity across Australia.

### C. Murrumbidgee River Basin

In the Murray Darling Basin (MDB), 25% of diversions for irrigation are lost during conveyance in rivers, 15% are lost from canals and 24% are lost on the farms, resulting in only 36% of the water initially diverted being available to crops (Chartres and Williams, 2006). The Murrumbidgee river catchment covers an area of approximately 84,000 km<sup>2</sup>, located in central New South Wales (NSW) and is considered food bowl of Australia. The Murrumbidgee Irrigation and Coleambally Irrigation areas are located in the Murrumbidgee catchment which utilizes bulk water for food production, industry and urban water supplies. Improving water management in the catchment is needed not only to improve water use efficiency, but also to increase the sustainability of irrigated agriculture and to generate water savings and assist in bridging the gap to Sustainable Diversion Limits. However, the definition of potential water saving requires the complete understanding of all aspects of the water balance of the river basin at various spatio-temporal scales (Hafeez and Smith, 2013).

Since 2000, there has been several water balance studies carried out in the Murrumbidgee River and these studies have highlighted that major water savings could be realised through infrastructure upgrades and tighter river operations. In order to improve river operational efficiency Water for Rivers (WfR) developed the concept of Computer Aided River Management (CARM) with DHI Pty Ltd following an international tender process including a 'proof of concept' phase (Hafeez and Smith, 2013). The WfR funded the roll out of CARM through a partnership with State Water Corporation (SWC) in the Murrumbidgee Valley. CARM is underpinned by an 'internationally' recognized suite of MIKE Hydraulic software. A hydraulic model offers additional benefits over hydrological models by more adequately representing the operational nature of river and channel systems as it captures and reflects the driving head, and operating environment in influencing water travel times. CARM is designed as 'open architecture' and can readily have other modules incorporated (DHI, 2012). More details about the CARM assessment of the models can be found in DHI (2012) and GHD (2012).

This assessment (GHD, 2012) has concluded that CARM when fully operational with comprehensive real time data feeds (e.g. metering, rainfall, gauging data etc) offers the following benefits (Hafeez and Smith, 2013):

- Improved delivery of environmental water including:
- Capacity to assess the merits of proposed environmental works and measures;
- Identification of system chokes;
- Piggybacking and shepherding opportunities;
- Opportunity to identify areas of high water loss for other potential remediation measures;
- Streamlined State Water business and information flow to customers;
- Greater transparency of accounting and reporting;
- Improved community communication potential;
- Maximisation of environmental benefits; and
- Enabling of operational surplus by creating a robust platform for management efficiency.

In summary, the assessment (GHD, 2012) found that CARM system developed for the Murrumbidgee River system is based on sound scientific principles and state of the art models to better understand hydraulic and quantify the hydrological processes in the river and it will help significantly to reduce operational surpluses in the river and generate a range of further benefits. Continued refinement and enhancement of the CARM DSS model will lead to more efficient river operations in which water is released only when required, improving control, reducing non-beneficial river losses, increasing transparency and improving services to customers – including the environment. CARM is an innovative response that will assist align policy decisions with operational objectives and offers a positive step change in regulated river operations and improves the ability of SWC to deliver the right volume of all forms of water - consumptive and environmental, to the right place at the right time in other regulated river systems in NSW and Australia wide (Hafeez and Smith, 2013).

#### D. Coleambally Irrigation System

The recent drought, a significant reduction in water allocations and concerns about climate change have all highlighted the need to manage water demand and supply more sustainably, especially in the CIA. The Coleambally Irrigation Area (CIA) is located in the lower part of the Murrumbidgee River catchment in the southern part of the Murray Darling Basin (Figure 4a). The CIA contains approximately 79,000 ha of intensive irrigation, 42,000 ha of irrigation/dryland farms and 297,000 ha of the Outfall District area, supplying water to 478 farms owned by 362 business units (CICL, 2007).

The CIA is a large irrigation area using a gravity flow system; water released from the dams takes seven days to reach the system, which makes the development of a robust methodology for water demand forecasting for the period of highest evaporative demand a necessity. High evaporative demand occurs in the months of December to February, when 75% of the area is planted to rice. The irrigation system comprises of one main canal and a number of secondary and tertiary canals. As an initial step in water demand forecasting, spatial and temporal boundaries of the domain were specified and further divided into 22 nodes based on direction of flow and connectivity (Figure 4b). Due consideration was given to spatial distribution of rainfall, potential ET, soil texture and rooting depth of land cover.

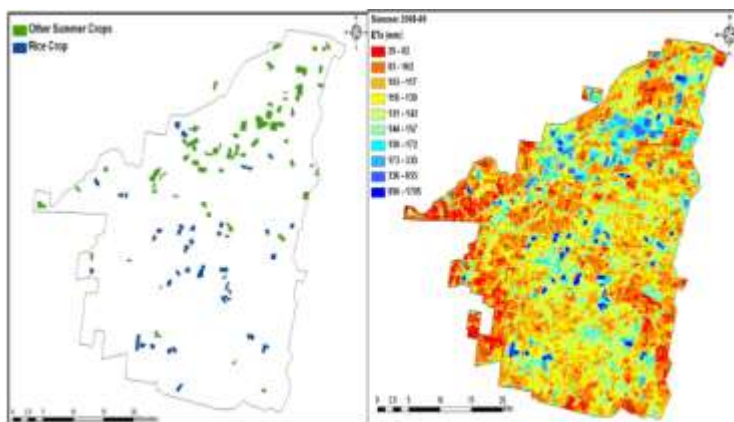


Figure 4. a (left) CICL operational area including CIA and outfall district (CICL, 2009); and b) (right) spatial distribution of nodes with supply and drainage channels and selected control points

For demand forecasting, irrigated crops in the CIA were clustered into rice and non-rice crops (others) in order to derive different hydrological and crop parameters. This developed methodology is not only based on analytical and empirical approaches, but also takes into account the physical processes as well as the spatial variability of different physical parameters influencing crop water requirement. A new and simplified methodology has been developed using remote sensing technology and field based estimates for forecasting irrigation demands for the CIA (Ullah, 2011). This methodology was applied in two steps; in the first step, efficiencies at the field scale as well as the system level were determined using remote sensing derived  $ET_a$  for different irrigated crops, and in the second step irrigation demand was forecast based on remote sensing derived crop coefficients and forecasted meteorological data. More details can be found in Ullah (2011) and Ullah & Hafeez (2011).

Results of irrigation demand forecasting indicate that the net irrigation demand forecast for fields at the node level (NIDFFN) shows a relatively high difference across the nodes. However net irrigation demand forecast for fields at the system level (NIDFFS) shows no significant difference and has good agreement with actual water being delivered to fields. For 2008-09, NIDFF at the system level (NIDFFS) was 4,364 ML, 9,387 ML and 9,073 ML with demand supply ratio (DSR) of 0.69, 1.06 and 1.20 for December 2008, January 2009 and February 2009 respectively. In terms of net irrigation demand forecast at system level NIDFS, making an allowance for conveyance system loss, results indicate that monthly forecasted irrigation water demand was higher for the selected months of 2008-09 compared to actual water diverted into the system (Figure 5). It was found that the forecasted demand was higher by 57%, 25% and 22% in December, January and February respectively.

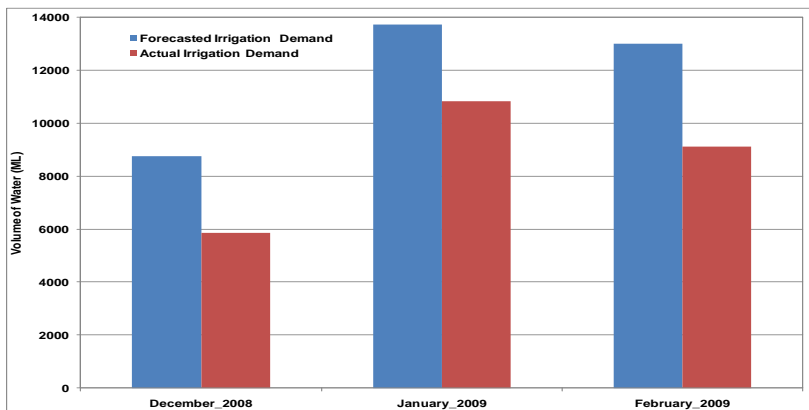


Figure 5. Comparison of forecasted irrigation demand and actual diverted water in the high evaporative months of 2008-09

The main reason for the higher values of net irrigation demand at the system level is due to the use of a fixed value of conveyance system loss to maintain system operation. The fixed value of conveyance system loss is proportionally significant as compared to total water diverted due to extremely limited irrigation supplies in this season. In addition to conveyance system loss, the lower forecasted demand is attributed to lower values of NIDFFN and NIDFFS, which was influenced by a lag time in updating  $K_c_{act}$ , inaccurate assessment of groundwater, change in water use efficiencies and remote sensing image analysis for  $ET_a$  estimation. However, overall the demand forecasts have reasonable agreement with actual water diverted to the system and can help in improving irrigation water management.

The applied methodology is very simple and cost effective for a demand driven irrigation system that has a good database, and daily demand can be forecasted and

updated by using remote sensing image analysis with minimum time input. This demand forecasting tool is based on a sound understanding of hydrological behaviour, novel remote sensing technology and forecasted meteorological data, and is useful for improved irrigation water management ranging from node to system levels. It may reduce the risks associated with over and under irrigation application by more accurately matching demand and supply. This methodology for demand forecasting will be tested for another cropping season in the near future.

#### E. Scientific Learning and Opportunities from Australia

Key message of learning from Australian policy initiative is a need to recognise water as a scarce economic good, to be allocated and used wisely for economic, social and environmental benefit of all, while protecting fragile aquatic ecosystem for Australia. Other main learnings and opportunities are:

- Need to focus on both demand and supply management, balanced engineering, policy, planning, regulatory and legal tools for reforms
- Need of drastic water reforms and implementation of water policies
- Preserve and modernize the existing irrigation systems
- Reshape irrigation system for demand-driven water requirements
- Increase investment in irrigation and drainage infrastructure
- Manage groundwater sustainably
- Improve water and land productivity
- Expand irrigation wherever opportunities exist through new smart irrigation system
- Realignment and strengthening of national institutions and regulatory environments
- Improving data capture to assist inform water policy formulation
- Monitoring and reporting of policy implementation: ensuring plans and agencies held accountable

### 3. CASE STUDIES OF IRRIGATION SYSTEM IN ASIAN COUNTRIES

In many Asian countries, more than 80% of freshwater is diverted for food production. Therefore, the irrigation efficiency is very low and ranging from 30-50% meaning a large part of the water devour for irrigation is wasted due to poor management of irrigation systems. The authors have carried out technical studies to understand the current challenges facing in many irrigation systems located in Yellow and Yangtze River Basin (China), Indus River Basin (Pakistan), Pampanga River Basin (the Philippines), Mekong River Basin (Lao PDR), and Amu Darya River Basin (Uzbekistan). Based on practical insights and in-depth rich knowledge of the above mentioned irrigation systems, the main issues and challenges faced by the irrigation system in Asia are:

- Aging infrastructure, inadequate operation and maintenance, and high risk of failure
- Outdated technology- not fulfil the requirement of a modern agricultural production system
- Inequity, inefficiency and low water productivity
- Poor drainage, water logging and salinity
- Declining water and land quality and health and environmental consequences

- Reducing water availability due to climate change
- Lack of coordination of irrigation, water and agriculture departments
- Weak institutions especially transferring skills and knowledge to farming base
- Shortage of skilled manpower - latest scientific knowledge & state of the art scientific tools available to carryout assessment
- Poor uptake of research by operational agencies especially NARS
- Poor availability of hydrological data – make sound decisions
- Water policies are based on outdated scientific knowledge
- The authors concluded that there are many pathways and opportunities to improve water and food security through applying remote sensing techniques for enhancing water use efficiency and water productivity of irrigation sector across the Asian countries.

#### 4. CONCLUSIONS

Remote sensing application in managing water resources for agriculture is an emerging field and it has a huge potential to identify non-beneficial use of water ranging from individual farm to whole irrigation system for growing agriculture crops in water stressed regions across Asia Pacific regions. For the application in most of Asia Pacific countries, the most enabling environment is availability of skilled persons in national water agencies who have an updated scientific knowledge on remote sensing applications for estimating mapping of actual water use consumption from various land use and land cover classes. This information will help us to identify non-beneficial water consumption so that appropriate actions could be taken to improve water use efficiency and productivity of irrigation system in most Asian countries. For development of matching irrigation demand and supply model in a near real time environment, it is essential to have weather forecast data available for any irrigation system. However, it is possible to get weather forecast data for a pilot region in China.

To scale-up application of the innovation in the Asia Pacific region, the following steps are required.

- Availability of skilled manpower in national water agencies who are equipped with state-of-the-art scientific knowledge on remote sensing application for water resources
- Availability of weather forecast data – 10 days in advance
- Availability of accurate and reliable hydrological data especially inflows and outflows
- Selection of pilot region with identified champions from respective national water agencies for successful implementation.

#### 5. REFERENCES

- CICL, (2007) Annual report, Coleambally Irrigation Cooperative Limited (CICL), Australia.
- CICL, (2009) Annual compliance report, Coleambally Irrigation Cooperative Limited (CICL), Australia.
- DHI (2012) Murrumbidgee Computer Aided River Management System (CARM) System Optimisation Long Term Testing-Interim Report, August 2012
- GHD (2012) Water for Rivers - Water Savings in NSW River Basins Final Report for Validation of CARM Model, Oct. 2012.

- Hafeez M., Frost A., Vaze J., Dutta D., Smith A., and Elmahdi, A. (2015). A New Integrated Continental Hydrological Simulation System: An overview of the Australian Water Resource Assessment Modelling System (AWRAMS), *Water Journal*, 42 (3), 75-82.
- Hafeez, M., Smith, A. Frost, A.J, Srikanthan, R., Elmahdi, A., Vaze, J. and Prosser, I. (2015). The Bureau's Operational AWRA Modelling System in the context of Australian landscape and hydrological model products. 36th Hydrology and Water Resources Symposium, Hobart, Tasmania. 7-10 December.
- Smith, A., Hafeez, M., Rahman, J., Baron-Hay, S. and Shipman, D. (2015) A New Web Based Water Information Service Leveraging the Australian Water Resources Assessment Modelling System. 36th Hydrology and Water Resources Symposium, Hobart, Tasmania. 7-10 December.
- IWMI (2014) Water for a food secure world. International Water Management Institute (IWMI) Strategic Plan 2014-2018.
- Ullah M K (2011) A geoinformatics approach for spatial water accounting and irrigation demand forecasting for a gravity irrigation system. Charles Sturt University, PhD Thesis (page 315).
- Ullah, K., and Hafeez MM (2011) Real time irrigation demand forecasting using remote sensing and meteorological data in semi-arid regions. *Remote Sensing and Ground-based Methods in Multi-Scale Hydrology International Association of Hydrological Sciences (IAHS) Red Book Series*, Publ. 343, 2011, pp 157-162
- Viney N., Vaze J., Crosbie R., Wang B., Dawes W., and Frost, A. (2015). AWRA-L v5.0: Technical description of model algorithms and inputs. CSIRO, Australia.