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AWRA-R version 5.0 Technical Report

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Important disclaimer

This report was reviewed by John Shi (CSIRO), Shishutosh Barua (BoM) and Mohsin Hafeez (BoM).

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Executive summary

This report describes the AWRA-R v5.0 model and its application and benchmarking. The core objective of the AWRA-R model is to produce various fluxes and stores associated with river systems in regulated and unregulated systems to support the production of the national water accounts (NWA) by the BoM. The research and development of AWRA-R model started in FY2011-12 (Lerat et al., 2012) as part of WIRADA and since then four different versions of AWRA-R [versions 3.0 (Lerat et al., 2013), 4.0, 4.5 and 5.0] have been developed, tested and implemented so far. The AWRA-R model produces a large number of fluxes and stores for surface water accounts. This quantitative information provides a detailed understanding of major components of water balances at a reach level for water resources accounting, analyses and reporting purposes.

The technical details of different components of AWRA-R v5.0 model and their governing equations are presented in section 2. The improvements/changes in AWRA-R over the period of the development since 2011 are also summarised in this section. A large amount of spatial and temporal data are required for AWRA-R modelling. The list of all input temporal variables, spatial and other parameters are listed in section 3 with the reference to appropriate governing equations presented in section 2. The model has eight calibration parameters, which are listed in section 3. The two calibration approaches (reach-by-reach and system calibration) used for model parameterisation are also described in this section. The system calibration approach has been newly developed and implemented in AWRA-R v5.0. The AWRA-R v5.0 model has been calibrated and validated in the MDB using both the reach-by-reach and system calibration approaches. Section 4 presents the collation of input data for the application of the model in the MDB. The AWRA-R v5.0 model in the MDB region included a total of 485 gauges and 33 large and medium size storages. The results of the model calibration and validation against the observed daily streamflow data are presented in section 5. A comprehensive benchmarking of AWRA-R v5.0 results was undertaken using available data from ground based and remotely sensed observed as well as the results of the earlier version of the model. The results of benchmarking are also presented in this section. A set of benchmarking scripts have been prepared to benchmarking AWRA-R results in both reach and regional scales for comprehensive understanding of the model performance and water balance.

The results of the reach-by-reach calibration and validation of the model in the MDB show highly satisfactory performance of the model with median daily NSE of 0.60 and median annual bias of less than 1% for the period of calibration (1970-1991) and median daily NSE of 0.69 and median annual bias of 16%for validation period (1992-2014) for the MDB. Within the MDB region, median daily NSE varied between 0.54-0.83 in 18 different sub-regions under the calibration mode and the variation of median daily NSE was between 0.39-0.83 in the 18 sub-regions under the validation mode. The model performed best in the Murray catchment and worst in Loddon Avoca, where the quality of the observed stream data was poor with many missing data points. The mass balance error of the AWRA-R model was negligible.

Overall, the performance of the system calibration in the MDB is poorer than the reach-by-reach calibration with patched observed inflow as it is obvious to have better model performance with patched inflow in the MDB with high quality observed streamflow data. However, the model with the system calibration showed better performance than the reach-by-reach calibration without patched observed inflow data. This shows that the system calibration is better suited for any predictive analysis by AWRA-R without observed data. The application of the system calibration with patched inflow in Campaspe region shows that the model performance with the system calibration is similar to that with the reach-by-reach calibration. It is important to note that the computational time of the system calibration is quite large compared to the reach-by-reach calibration.

The benchmarking results show that the overall performance of AWRA-Rv5.0 (with calibrated parameters from reach-by-reach calibration) is slightly better than AWRA-Rv4.5.The median monthly NSE of the AWRA-

R irrigation model performance are reasonable and median annual bias was very low. The simulated ET by AWRA-R irrigation model shows good correlation (> 0.5) with the actual ET from CMRSET product at monthly scale. The simulated inundation maps by Approach 2 inundation model show reasonably high cell-to-cell correlation (>0.6) with the flood maps derived from Landsat imagery for most of the modelled reaches in different floodplains across the MDB. Overall, the performance of different components of AWRA-R v5.0 model satisfies the performance evaluation criteria set by BoM.

The AWRA v5.0 model has been operalisationalised in the Bureau of Meteorology using Delft-FEWS in March 2015.

Abbreviations

AWRA	the Australian Water Resources Assessment
ABARES	the Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	the Australian Bureau of Statistics
AWRA-L	AWRA Landscape model
AWRA-Lv3.5.6	AWRA-L model version 3.5.6 released in FY2012-13
AWRA-Lv4.0	AWRA-L version 4.0 released in FY2013-14
AWRA-Lv4.5	AWRA-L version 4.5 released in FY2014-15
AWRA-Lv5.0	AWRA-L version 5.0 released in FY2014-15
AWRA-R	the Australian Water Resources Assessment – River model
AWRA-Rv3.0	AWRA-R version 3.0 released in FY2012-13
AWRA-Rv4.0	AWRA-R version 4.0 released in FY2013-14
AWRA-Rv4.5	AWRA-R version 4.5 released in FY2014-15
AWRA-R v5.0	AWRA-R version 5.0 released in FY2014-15
AWRAv3.5	the AWRA modelling system version 3.5 released in FY2012-13
AWRAv4.0	the AWRA modelling system version 4.0 released in FY2013-14
AWRAv4.5	the AWRA modelling system version 4.5 released in FY2014-15
AWRA v5.0	the AWRA modelling system version 5.0 released in FY2014-15
BAWAP	Bureau of Meteorology Australian Water Availability Project
BoM	the Bureau of Meteorology
CLUM	Catchment scale land use mapping (ABARE-BRS)
CSIRO	the Commonwealth Scientific and Industrial Research Organisation
ET	Evapotranspiration
GA	Geoscience Australia
IQQM	Integrated Quantity and Quality Model
LiDAR	Light Detection and Ranging
LT	Landsat Thematic Mapper or Landsat 5 sensor
MDB	Murray Darling Basin
MDBA	the Murray Darling Basin Authority
MODIS	Moderate-Resolution Imaging Spectroradiometer
NSE	Nash-Sutcliffe Efficiency
NSW	New South Wales
NWA	National Water Accounts
OFS	On-farm storage
PET	Potential Evapotranspiration
QLD	Queensland
RS	Remote Sensing
SRTM	Shuttle Radar Topography Mission
TM	Thematic Mapper
VIC	Victoria
WIRADA	the Water Information Research and Development Alliance

1. Introduction

1.1 Background and objectives

In response to multiple concomitant pressures on Australia's water resources, the Australian Government, through the Commonwealth Water Act 2007, has given the Australian Bureau of Meteorology, responsibility for compiling and delivering comprehensive water information across the water sector (BoM, 2012). To fulfil its legislative responsibilities, the Bureau requires a water balance modelling system developed using state-of-the-art hydrological science that quantifies water flux and storage terms and their respective uncertainties (where applicable and possible) using a combination of data sets (on-ground metering, remotely sensed data and model outputs). The system need to be applicable across the continent and it should be flexible enough to be able to use all available data sources (when modelling data rich and data limited regions) with the most appropriate modelling techniques and tools suitable for use with the available data to provide nationally consistent and robust estimates. The outputs from the water balance modelling system are used to underpin a range of water information products delivered by the Bureau and thus the system needs to generate all the necessary water flux and storage terms at a spatial and temporal scale appropriate for aggregated reporting.

The Bureau and CSIRO through the Water for a Healthy Country National Research Flagship established Water Information Research and Development Alliance (WIRADA) in 2008 to collaborate on research activities in the field of water information (BoM & CSIRO, 2013). As part of this alliance, a continental scale modelling system representing the Australian terrestrial water cycle, called Australian Water Resource Assessment (AWRA), was built and operationalised at the BoM for producing Australia's national water assessments and water accounts (Vaze et al., 2013). The AWRA modelling system consists of two major modelling components (Figure 1.1):

i) AWRA landscape (AWRA-L), the landscape component of the AWRA system, is a daily grid-based biophysical model of the water balance between the atmosphere, the soil, groundwater and surface water stores (Viney et al., 2014), and
ii) AWRA river (AWRA-R), the river system component of the AWRA system, is a conceptual hydrological model designed for both regulated and unregulated river systems.

AWRA-L is a raster model and run on a uniform 0.05 degree x 0.05 degree resolution grid network (approximately 5km x 5km) covering the entire Australian continent at a daily time step. Details of AWRA-L model are presented in Viney et al. (2014) and not discussed in this report.

AWRA-R is a vector model and it uses non-uniform sets of nodes and links for routing flows along a river system and modelling associated components at a daily time step. The core objective of the AWRA-R model is to produce various fluxes and stores associated with river systems in regulated and unregulated systems to support the production of the national water accounts (NWA) by the BoM. The model has been developed using the following three development principles as identified in Van Dijk et al. (2012).

- Observation-driven design: the water accounting exercise is essentially retrospective, with the objective of estimating fluxes and storage for the past recent years. The amount of data available in such a context is much larger than for other traditional modelling exercise (e.g. scenario modelling).

As a result, observations play a critical role in the AWRA-R system and are preferred to modelled quantities.

- Modular architecture: the AWRA-R system integrates several components targeting the different fluxes and stores associated with a river system. A modular architecture recognises the heterogeneity in a river system and enables users to implement the model in a modular way using the components that are required for any particular river reach (e.g., a river reach with or without river storage or irrigation diversion).
- Iterative development: the AWRA-R system constitutes a complex modelling framework incorporating all key hydrological processes and anthropogenic water uses/demands and the model has been built and implemented progressively over the duration of WIRADA. The iterative development process loops through three phases starting from the model development, moving to its deployment on a large number of test cases and finally its evaluation against benchmarks. This process ensures that the performance of the model keeps improving with the addition of any new components.

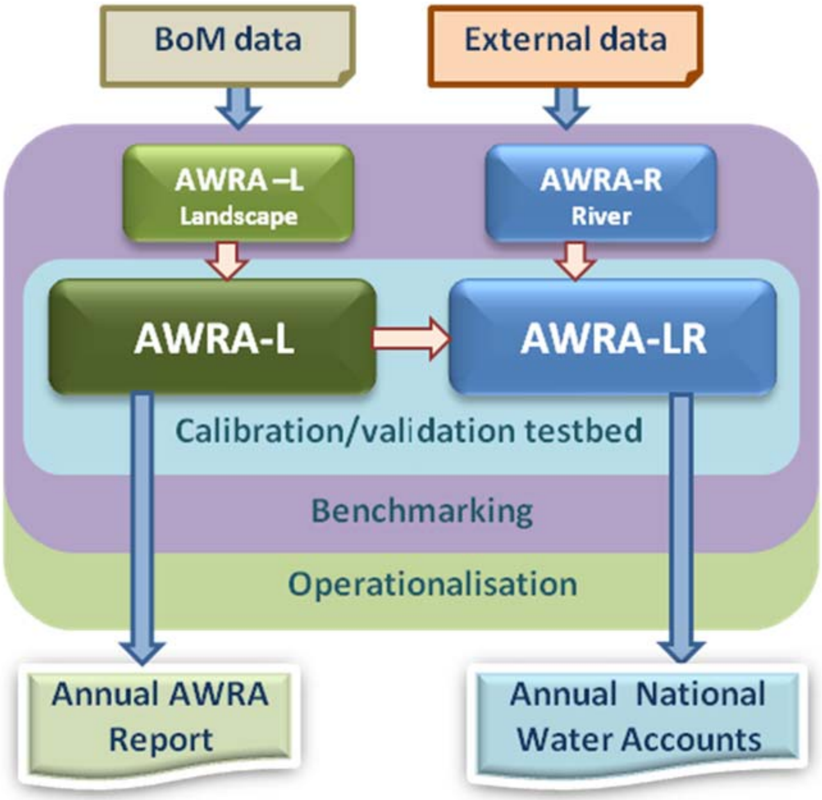

Figure 1.1.AWRA modelling system

The research and development of AWRA-R model started in FY2011-12 (Lerat et al., 2012) and since then four different versions of AWRA-R (versions 3.0, 4.0, 4.5 and 5.0) have been developed, tested and implemented until end of this financial year (FY 2014-15). The latest version (AWRA-R v5.0) has been operationalised at the BoM in March 2015.

The focus of this technical report is AWRA-R v5.0. The report describes different components of the model, the calibration systems, implementation of the model in the Murray-Darling basin and benchmarking results.

1.2 Purpose of Report and Outline

This report has been prepared to provide technical information on the AWRA-R model version 5.0 and to present the results of calibration, validation and benchmarking of the model in the Murray Darling Basin. The report incorporates the following:

- the background and objectives (Section 1)
- Description of AWRA-Rv5.0model (Section 2)
- Input variables, parameters and method for model parameterisations (section 3)
- the study area and data collation (Section 4)
- the results of calibration and validation and benchmarking (Section 5)
- the conclusions and recommendations (Section 6)

2 Description of AWRA-R model version 5.0

2.1 Conceptual background (history of development and different versions)

The AWRA-R model has been designed using a node-link concept (Welsh et al., 2013; Dutta et al., 2013a), where a river system is schematised into a simplified river network using a node-link structure. The river network begins and ends with a node, and all nodes are interconnected by links. A link is used for transfer of flow between two nodes with routing and transformation. Runoff from gauged or ungauged tributaries or local contributing area between two nodes is fed into the connecting link as an inflow at the relevant location and all other physical processes (such as diversions, groundwater fluxes, overbank flow) occurring between the two nodes are incorporated in the link. For implementation of AWRA-R, a river basin is schematised into a number of spatial units (called AWRA-R catchments) based on the river network and locations of streamflow gauges. AWRA-R catchments in a river basin can be divided into two categories:

i) Headwater catchment (Figure 2.1a): this type of area corresponds to classical catchments with an outlet materialised by a gauging station or a storage outlet.

ii) Residual catchments (or, river reach intermediate area) (Figure 2.1b): this type of area corresponds to the drainage area between a set of upstream points and a downstream point materialised by a gauging station or a storage outlet.

Within these areas, AWRA-R is built as a node-link network that connects the different components. Each component can be a source or a sink. It can also route water to the next component. It is important to note that this set-up allows AWRA-R to link the simulations from upstream to downstream areas and build a catchment model as illustrated in Figure 2.1c.

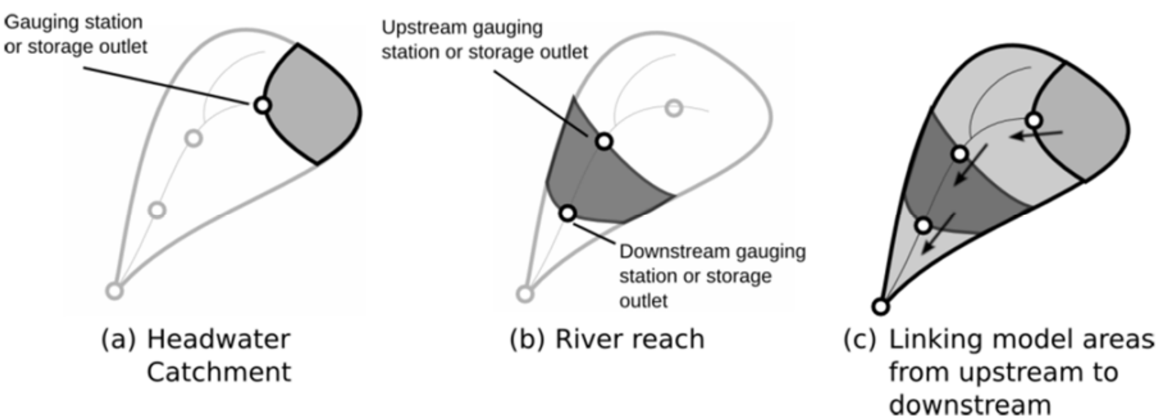

Figure 2.1. AWRA-R spatial units

AWRA-R has evolved over the past three years with incremental development. Developments include conceptualisation and building of different components, improvements to some of the existing components and incorporation of additional components to extend the model application to produce various fluxes and stores for water accounting. During this period, four versions of the AWRA-R model have been released (versions 3.0, 4.0, 4.5 and 5.0).

The current version of the AWRA-R model (version 5.0) consists of the following components.

i) Streamflow routing
ii) Local ungauged runoff
iii) Storage contribution modelling
iv) Irrigation modelling
v) Urban water use
vi) Water use for stock and domestic
vii) Rainfall to and evaporation from river
viii) Anabranch flow
ix) Floodplain inundation modelling
x) River and groundwater interaction modelling
xi) Headwater catchment modelling

The components i) – x) are developed and implemented in residual catchments/reaches and the component xi) is built for headwater catchments only.

Table 2.1shows the differences in this version compared to the previous versions in terms of model components.

Table 2.1. Modelling components of different versions of the AWRA-R model

Components		AWRA-Rv3.0	AWRA-Rv4.0	AWRA-Rv4.5	AWRA-Rv5.0
i)	**Streamflow routing**	Muskingum routing	Same as earlier version	Same as earlier version	Same as earlier version
ii)	**Local ungauged runoff**	Yes (scaled cookie-cut runoff from AWRA-L)	Same as previous version	Same as previous version	Same as previous version
iii)	**Storage contribution modelling**	Use storage balance concept	Same as previous version	Same as previous version	Updated to incorporate urban diversion from storage
iv)	**Irrigation modelling**	Irrigation model using FAO concept	Irrigation model updated for groundwater interaction	Same as previous version	Same as previous version
v)	**Urban water use**	Option for incorporating observed time series	Same as previous version	Same as previous version	Same as previous version
vi)	**Water use for stock and domestic**	None	None	None	Option for incorporating observed time series
vii)	**Rainfall to and evaporation from river**	Based on surface area of river store	Same as previous version	Same as previous version	Same as previous version
viii)	**Anabranch flow**	Based on flow ratio between main and anabranch	Same as previous version	Same as previous version	Same as previous version

Components		AWRA-Rv3.0	AWRA-Rv4.0	AWRA-Rv4.5	AWRA-Rv5.0
ix)	**Floodplain inundation modelling**	Simple concept without partitioning river and floodplain storages	Updated method (Approach 1, Teng et al., 2014) with separate store for river and floodplains	Same as previous version	Same as previous version
x)	**River and groundwater interaction modelling**	Simple Monod concept	Updated to incorporate soil and groundwater characteristics	Same as previous version	Same as previous version
xi)	**Headwater catchment modelling**	Yes (cookie-cut runoff from AWRA-L)	Same as previous version	Same as previous version	Updated to calculate groundwater fluxes from river

2.2 Governing equations of different components of AWRA-Rv5.0

Figure 2.2shows a conceptual diagram of a river reach (in a residual catchment) with different components of the model. In a headwater catchment, none of the processes (shown in the figure) are modelled except the back calculation of rainfall to and evaporation from river surface, river volume and groundwater losses based on the observed or gap-filled flow data at the outlet of the catchment as explained in section 2.2.11. As shown in Figure 2.2, in an AWRA-R simulation of a residual reach, all upstream inflows are routed first and then, local inflows are added and losses are subtracted to calculate the outflow at the end of the reach.

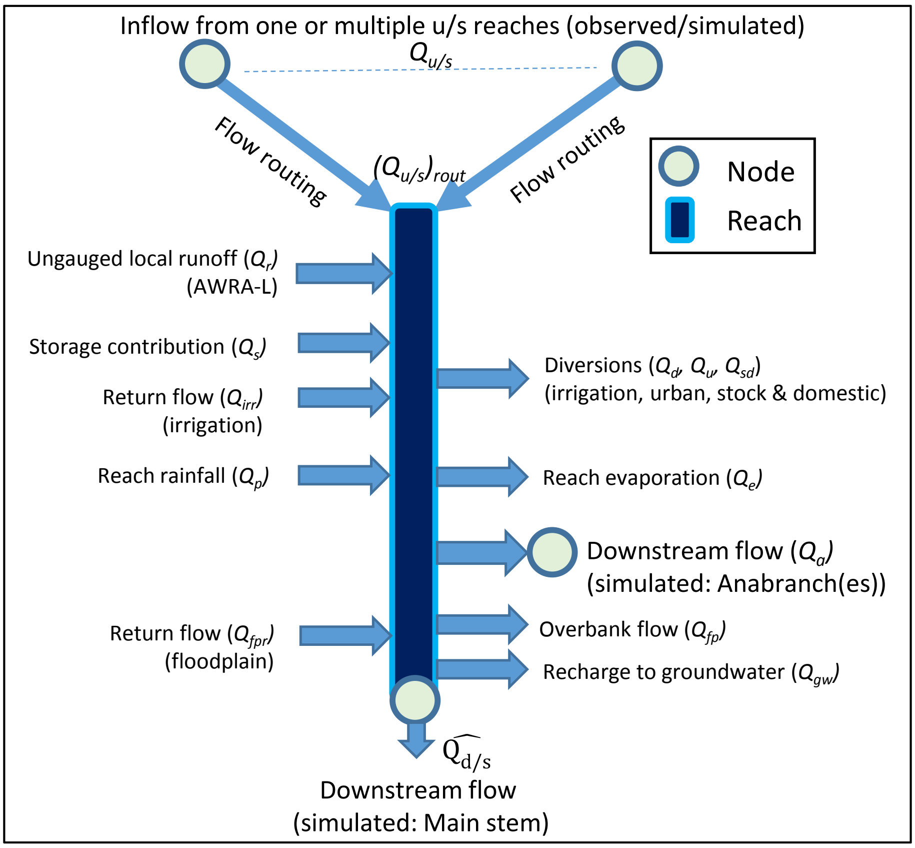

Figure 2.2. The conceptual diagram of AWRA-R v5.0 reach with different modelling components (the symbols are described in relevant sections of the model descriptions in this chapter)

The general form of water balance for a reach (with routed upstream flow) for AWRA-Rv5.0 can be described as follows:

$$\widehat{Q_{d/s}} = (Q_{u/s})_{rout} + Q_r + Q_s - Q_d + Q_{irr} - Q_u - Q_{sd} + Q_p - Q_e - Q_a - Q_{fp} + Q_{fpr} - Q_{gw} \tag{1}$$

Where,

$\widehat{Q_{d/s}}$ = simulated flow at the downstream gauge (m^3/sec),

$Q_{u/s}$ = concurrent flow at the upstream gauges (including gauged tributaries) (m^3/sec),

$(Q_{u/s})_{rout}$ = upstream inflow following routing (m^3/sec),

Q_r = runoff locally generated from the local ungauged catchment (m^3/sec),

Q_s = contribution from any storages including rainfall on storage area, evaporation from storage area and change in storage volume (m^3/sec),

Q_d = loss due to irrigation diversion (m^3/sec),

Q_{irr} = total return flow from irrigated area (m^3/sec),

Q_u = net loss due to urban diversion (m^3/sec),

Q_{sd} = rural water use (other than irrigation) for stock and domestic (m^3/sec),

Q_p = the flux to the river store due to rainfall (m^3/sec),

Q_e = the flux from the river due to evaporation (m^3/sec),

Q_a= the flow diverted to anabranches (m^3/sec),

Q_{fp} = overbank flow to floodplain (m^3/sec),

Q_{fpr} = return flow from floodplain (m^3/sec),

Q_{gw} = the flux from river to groundwater (m^3/sec).

2.2.1 STREAMFLOW ROUTING [$(Q_{u/s})_{rout}$]

The streamflow from an upstream gauge of a reach is routed along the reach to the downstream gauge using a lagged Muskingum routing (Koussis, 1980) method, which can be described by the following set of equations:

$$\frac{dV}{dt} = Q_{\frac{u}{s},(t-Lag)} - \left(Q_{u/s}\right)_{rout} \tag{2}$$

$$V_{musk} = K\left[xQ_{\frac{u}{s},(t-Lag)} + (1-x)\left(Q_{u/s}\right)_{rout}\right] \tag{3}$$

where,

V_{musk} = routing volume (m^3) (*estimated*)

K, x and *Lag* = Muskingum routing parameters (these three parameters are calibrated)

t = the current timestep.

2.2.2 LOCAL UNGAUGED RUNOFF (Q_r)

AWRA-R does not include any local rainfall-runoff model for estimating ungauged local runoff. Instead, locally generated runoff (Q_r) from an ungauged catchment is computed in AWRA-R using the output from the AWRA-Landscape model (AWRA-L) (Viney et al., 2014). AWRA-L is run on a 0.05° x 0.05° grid (approximately 5km x 5km) at a daily time step. For each reach in AWRA-R, a single runoff input is obtained by averaging the gridded AWRA-L runoff over the AWRA-R catchment boundaries of the contributing sub-catchments. The AWRA-L model is continentally calibrated to optimise one set of 21 model parameters for the entire Australian continent. The final runoff Q_r used in AWRA-R for a reach from the contributing ungauged catchment is given by the following expression:

$$Q_r = SF * \left(\sum_{i=1}^{n} w_i Q_{tot}(i) \right) * A \quad (4)$$

where,

SF = scaling factor (dimension less) (this parameter is calibrated)

w_i = weighting factor (dimension less). This weighting procedure assumes that the contribution of a grid to the runoff Q_r is proportional to the area of the cell over the total area of the catchment

$Q_{tot}(i)$ = gridded runoff simulated by AWRA-L at any grid *I* (m/sec)

A = catchment area (m^2)

2.2.3 STORAGE CONTRIBUTION MODELLING (Q_s)

In AWRA-R v5.0, the storage contribution modelling method of AWRA-R v4.5 has been updated to incorporate the additional process of water transfer (mainly for urban water use) directly from/to a reservoir or storage. Thus, the contribution from a storage or reservoir located within a reach is computed in AWRA-R v5.0 using the following two equations for a modelling time step:

$$Q_s = Q_{s1} - Q_{net\_transfer}$$

$$\text{Where, } Q_{net\_transfer} = Q_{transfer\_out} - Q_{transfer\_in} \quad (5)$$

$$Q_{s1} = -\frac{S(\delta) - S(0)}{\delta} + (P_S - E_S)\frac{a(\delta) + a(0)}{2} \quad (6)$$

where,

$Q_{transfer\_in}$ = water directly transfer into the storage (m^3/sec) (*observed data*)

$Q_{transfer\_out}$ = water directly transfer out of the storage (m^3/sec) (*observed data*)

$S(\delta)$ = storage volume at the end of the time step (m^3) (*observed data*)

S(0) = storage volume at the beginning of the time step(m^3) (*observed data*)

δ = modelling time step duration (sec)

a(δ) = storage area at the end of the time step(m^2) (*available data or calculated based on observed volume and level data*)

a(0) = storage area at the beginning of the time step(m^2) (*available data or calculated based on observed volume and level data*)

P_S = areal rainfall over the time step (m/sec) (*used AWRA-L outputs*)

E_S = areal evaporation over the time step (m/sec) (*used AWRA-L outputs*)

2.2.4 IRRIGATION MODELLING

AWRA-R irrigation model has been designed to estimate diversion of surface water from river to irrigated area (Q_d), return flow from irrigated area to river (Q_{irr}) and other fluxes and stores associated with irrigated area. AWRA-R v5.0 model uses the same irrigation model (except two minor changes, which are explained in this document) that was implemented in AWRA-R v4.0 (Hughes et al., 2014). A schematic diagram of AWRA-R irrigation model is shown in Figure 2.3.

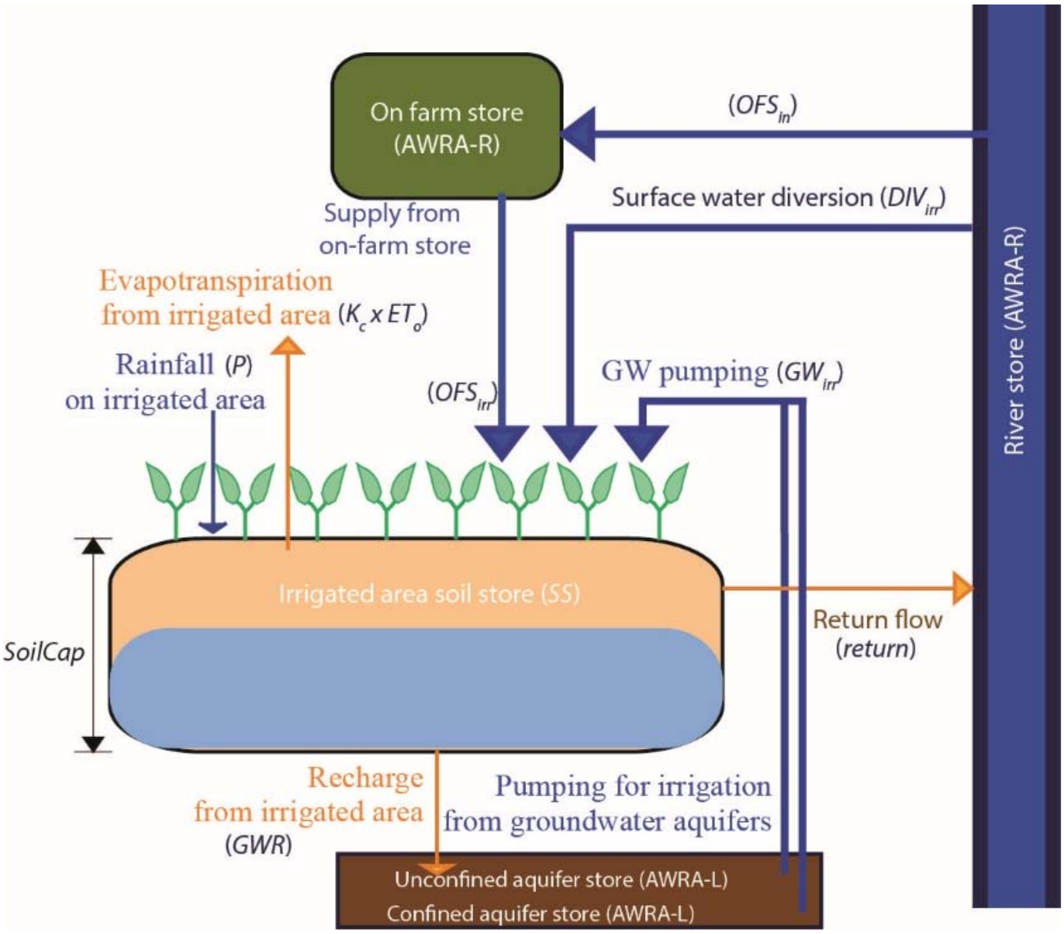

Figure 2.3. The conceptual diagram of AWRA-R irrigation model

In the irrigation model, the general form of daily water balance equation used for an irrigated area is as follows:

$$SS_i = SS_{i-1} + \left(\frac{irri_i * timestep}{areaC_i * areaActivePro_i * efficiency}\right) - \frac{K_{cw,i}}{areaActivePro_i} * ET_{o,i} + P_i - \left(\frac{(GWR_i + runoff_i) * timestep}{areaC_i * areaActivePro_i}\right) \quad (7)$$

where,

SS_i= depth of water in the irrigated area soil moisture store on day of year *i* (m)

SS_{i-1}= depth of water in the irrigated area soil store on previous day (*i*-*1*) (m)

$irri_i$= total supplied water for irrigation from SW, GW and OFS (m^3/sec, estimated)

timestep = modelling timestep (sec)

$areaC_i$= area planted on decision date *i* (there are 5 decision dates, these are at days 80, 120, 270, 310 and 365) (m^2, estimated). It includes crops to be sown later in the current season.

$K_{cw,i}$= area weighted crop factor for crops growing on day *i* (dimensionless, estimated)

$ET_{o,i}$= reference evapotranspiration (m, it is replaced by E_o obtained from AWRA-L due to absence of reference ET data)

P_i= precipitation on irrigated area (m, obtained from AWRA-L outputs)

GWR_i= groundwater recharge from irrigated area (m^3/sec, estimated)

$areaActivePro_i$= proportion of $areaC_i$ actively growing crops on day *i* (dimensionless)

$runoff_i$= surface runoff from irrigated area (m^3/sec, estimated)

$efficiency$= irrigation efficiency term (dimensionless).

At the start, an initial assessment of soil water (SS_{i-i+} in m) is calculated before irrigation on the current time step is calculated or accounted for;

$$ss_{i-1+} = SS_{i-1} + \left(\frac{irri_{i-1} * timestep}{areaC_i * areaActivePro_i * efficiency}\right) - \left(\frac{K_{cw,i} * ET_{o,i}}{areaActivePro_i}\right) + P_i \quad (8)$$

$$K_{cw,i} = \sum_{c=1}^{n} (K_{c,i} * Pro_{c,i}) \quad (9)$$

$$areaC_i = \frac{volA_i}{volMax} * areaMax * \alpha \left(\frac{volA_i}{volMax} + \beta\right) \quad (10)$$

$$volA_i = (allocation_i * licVol) + volOFS_{i-1} + volGW_{max} \quad (11)$$

where,

$irri_{i-1}$ = supplied water for irrigation on previous day (*i*-*1*) (m^3/sec)

$K_{c,i}$ = crop factor for crop *c* on Day of year *i* (dimensionless, obtained from Table 2.1, Hughes et al., 2014)

$Pro_{c,i}$ = proportion of area sown to crop *c* on Day of year *i* (dimensionless).

n = number of crop type (dimensionless, known data from field)

$volA_i$= total volume of water resources available at decision date *i* (m^3, estimated)

volMax = maximum available water in any single year (m^3, this term is currently derived from time series of historical records). However, note that in the case of data available, it should be the surface water licence + groundwater licence + OFS capacity, as these are the maximum water entitlements that irrigator can use water.

areaMax= maximum area that can be planted in any year (m^2, obtained from irrigated area map if available or estimated)

α and β = irrigation model parameters (dimensionless) that are calibrated for each reach against observed diversion data (these two parameters are calibrated)

$allocation_i$= allocation available for surface water diversion licence on day *I* (dimensionless, known data from field)

$licVol$= annual licence volume for surface water diversion (m^3, known data from field)

$volOFS_{i-1}$= volume of on-farm storage at the end of day *i-1* (m^3, known through OFS sub-model) (Note: this is a sub-component of the irrigation model, further described below)

$volGW_{max}$= annual licence volume for groundwater diversion (m^3, known data from field)

OFS at the end of timestep, which is available at the beginning of the following timestep is calculated as follows;

$$volOFS_i = volOFS_{i-1} - (volOFSout_{i,} * timestep) + (volOFSin_i * timestep) - ((evap - rainfall) * areaOFS_{i-1}) \quad (12)$$

$$volOFSin_i = \min\left(((\mathrm{volOFSmax} - \mathrm{volOFS_{i-1}})/86400), \max\left(0, \left((Q_i - OFSthresh) * \frac{maxPump}{((Q_i - OFSthresh) + pumpBeta)}\right)\right)\right) \quad (13)$$

$$areaOFS_{i-1} = volOFS_{i-1} / ringtankAvgDepth \quad (14)$$

where,

$volOFS_{i-1}$= amount of on-farm storage remaining on day (*i-1*) (m^3)

$volOFS_{outi,}$= amount of on-farm storage used on day (*i*) (m^3/sec, estimate; i.e. $OFSI_i$, will be discussed later in this section)

$volOFSin_i$= inflow to on-farm storage on day (*i*) (m^3/sec)

$volOFSmax$= maximum capacity of OFS (m^3, observed data) (Note: at the moment it is guesswork, more specifically, estimations based on imagery and mapped CLUM polygons (by reach))

evap and rainfall= fluxes to and from the OFS due to evaporation and rainfall respectively (m, *calculated based on AWRA-L outputs*)

$areaOFS_{i-1}$ = area of on-farm storage on day (*i-1*) (m^2, estimated)

$ringtankAvgDepth$ = average on-farm storage depth (m, assumed to be 4-m)

Q_i= volume of river flow on day *i* (m^3)

$OFSthresh$= threshold river flow above which water is diverted from the river into storage (m^3, OFS sub-model parameter)

$maxPump$= maximum daily pump capacity for the district/reach (m^3, OFS sub-model parameter) (Note: ideally, it should be used from the observed data if available)

$pumpBeta$= OFS sub-model parameter which determines the daily rate at which pumping rises to its maximum rate (m^3)

Maximum area that can be planted in any year (*areaMax*) is calculated as follows:

$$areaMax = \begin{cases} Observed\ data\ based\ on\ the\ GIS\ layer \\ of\ irrigated\ area\ (if\ available) \\ OR \\ volMax / \left(\sum_{i=1}^{n} \overline{ET}_{o,i} * K_{cw,i} * efficiency \right) \end{cases} \quad (15)$$

where,

$\overline{ET}_{o,i}$= average ET_o by day of year *i*(m) (i.e. there will be 365 values for each day based on AWRA-L outputs)

$efficiency$= irrigation efficiency (dimensionless, currently used as 2, but can be replaced with observed data if available)

n= total number of days in a year

At this stage, total irrigation (m^3/s) on day *i* is calculated based on ss_{i-1+} as follows:

$$irri_i = \begin{cases} \left(\left(\frac{\gamma}{\delta\sqrt{2\pi}} \right) e^{-\frac{(ss_{i-1+} - \mu)^2}{2\sigma^2}} \right) * areaC_i * areaActivePro_i * eff/timestep & if\ soilCap > SS_{i-1+} > 0 \\ \left(\frac{\gamma}{\delta\sqrt{2\pi}} \right) * areaC_i * areaActivePro_i * eff/timestep & if\ SS_{i-1+} < 0 \\ 0 & if\ SS_{i-1+} > soilCap \end{cases} \quad (16)$$

where,

μ and Ω = parameters of normal distribution function

γ= soil store function parameter (m^2) (currently used 7.0e^{-04})

σ= soil store function parameter (dimensionless, currently used 0.02)

$soilCap$= maximum capacity of the soil (m). This is reasonably arbitrary but should reflect the allowable depletion of the dominant soil types of the district.

At this stage, soil water from the previous time step is updated with the depth of irrigation, rainfall and crop demand;

$$ss_{i-1++} = SS_{i-1} - \left(\frac{K_{cw,i} * ET_{o,i}}{areaActivePro_i}\right) + P_i + ((irri_i * timestep)/(areaC_i * areaActivePro_i * efficiency)) \quad (17)$$

Any excess water i.e., SS_{i-1++} greater than *soilCap*, is considered to be groundwater recharge and runoff, therefore;

$$if \;\; SS_{i-1++} < \; soilCap, \quad then \; GWR_i = 0, \quad runoff_i = 0 \; and \;\; SS_i = \; SS_{i-1++} \quad (18)$$

$$if \;\; SS_{i-1++} \geq \; soilCap, \quad SS_i = soilCap \quad (19)$$

Leftover water (i.e. "(SS_{i-1++}- $soilCap$)) is balanced through *GWR$_i$*, and *runoff$_i$* components. Note that the balance first done through *GWR$_i$* component in the model as follows;

$$GWR_i = \min[\{(SS_{i-1++} - \; soilCap) * \; areaC_i * Pro_i/\text{timestep}\}, min\{(I_{irr}, \Delta S_{irr} + Q_{irr}) * L\}] \quad (20)$$

$$I_{irr} = \; K_c x_{w\_irr} \left(\frac{h_{w\_irr}}{d_c} + 1\right) t_w \quad (21)$$

if $h_{w\_irr} = 0$, $I_{irr} = \; K_c x_{w\_irr} t_w$

$$\Delta S_{irr} = \; d_{gw} S_y x_{w\_irr} \quad (22)$$

$$Q_{irr} = \; K_{aq} d_{aq} t_w \frac{h_{w\_irr}}{x_{w\_irr}/2} \quad (23)$$

If $h_{w\_irr} = 0$, $Q_{irr} = 0$

where,

I_{irr} = potential infiltration rate from irrigated area m^2/day, estimated)

ΔS = total storage available per unit length (m^2/day, estimated)

Q_{irr} = maximum volume of water discharging from the aquifer (considered zero, see the above assumption)

K_c = saturated conductivity of surface layer (m/sec, catchment average value obtained from AWRA-L)

x_{w_irr} = lateral extent of irrigated area (m, i.e. total irrigated crop area (i.e. areaC/Pro)/length of the river)

t_w = duration of modelling time step (day)

d_{gw} = depth to groundwater (m, currently used as 5m)

S_y = aquifer specific yield (dimensionless, catchment average value obtained from AWRA-L)

Ponding (h_{w_irr}) is assumed to be minimal (or zero) under irrigation management. Therefore, Equation 21 is further simplified and Q_{irr} in Equation 23 becomes zero.

If (SS_{i-1++}- $soilCap$) < GWR_i, then $runoff_i$= 0

If (SS_{i-1++}- $soilCap$) >GWR_i, then;

$$runoff_i = (SS_{i-1++} - soilCap - GWR_i) * areaC_i * areaActivePro_i/timestep) \quad (24)$$

Total simulated irrigation diversion ($irri_i$) volume is partitioned into three sources includes surface water, groundwater and on-farm storage using the following equations:

$$DIV_i = \min\left(Q_i,\ irri_i * \left(\frac{surf_d}{surf_d + gwe_d + ofs_d}\right)\right) \quad (25)$$

$$GW_i = \min\left(volGW_i,\ irri_i * \left(\frac{gwe_d}{surf_d + gwe_d + ofs_d}\right)\right) \quad (26)$$

$$OFSI_i = \min\left(volOFS_i,\ irri_i * \left(\frac{ofs_d}{surf_d + gwe_d + ofs_d}\right)\right) \quad (27)$$

where,

DIV_i = irrigation diversion from surface water on day *i* (m^3/sec)

Q_i= u/s observed streamflow with gap-filled by simulated flow in the reach on day *i* (m^3/s, estimated)

$surf_d$= surface water entitlement (i.e. $licVol$) available on the most decision date, *d* (as mentioned before, there are 5 decision date, these are at days 80, 120, 270, 310 and 365) (m^3)

gwe_d= volume groundwater entitlement available on the most decision date, *d* (m^3)

ofs_d= volume on-farm storage available on the most recent decision date, *d* (m^3)

GW_i= irrigation diversion from groundwater on day *i* (m^3/s)

$OFSI_i$= irrigation diversion from OFS on day *i* (m^3/s)

GW_i and $OFSI_i$ (in Equations 26 and 27, respectively) have been updated in AWRA-R v5.0 to limit the GW and OFS extraction based on water availability from these two sources.

The surface water diversion on any day *i* is calculated as follows:

$$diversion_i = DIV_i + diversionCarryOver_{i-1} \quad (28)$$

This is the updated equation in AWRA-R v5.0 to account for shortfall of surface water diversion in the previous timestep.

In the case of not enough water available from the river to divert as surface water (i.e.,$Q_i < irri_i * \left(\frac{surf_d}{surf_d+gwe_d+ofs_d}\right)$), shortfall is recorded as *diversion Carry Over* and added to the following time step surface water diversion;

$$diversionCarryOver_{i-1} = \left[irri_{i-1} * \left(\frac{surf_d}{surf_d+gwe_d+ofs_d}\right)\right] - Q_{i-1} \tag{29}$$

The final surface water diversion (Q_d) on any day *i* is calculated as follows;

$$Q_d = \begin{cases} Q_i & if\ diversion_i \geq Q_i \\ diversion_i & if\ diversion_i < Q_i \end{cases} \tag{30}$$

Irrigation return (Q_{irr}), which is considered as part of irrigation *efficiency*, is calculated based on the simulated surface water diversion;

$$Q_{irr} = kQ_d \tag{31}$$

where,

k= a dimensionless parameter (currently set 0.1)

2.2.5 URBAN WATER USE (Q_u)

AWRA-R model does not simulate urban water use. Instead, the model provides option to incorporate daily time series of observed urban diversion from a river reach (Q_u) as input data.

2.2.6 WATER USE FOR STOCK AND DOMESTIC (Q_{sd})

AWRA-R v5.0 model does not simulate any other water diversion except irrigation diversion. The model provides the option to incorporate daily time series of observed diversion for stock and domestic (Q_{sd}) as input data.

2.2.7 RAINFALL TO AND EVAPORATION FROM RIVER (Q_p AND Q_e)

Rainfall to river (Q_p) and evaporation from water surface (Q_e) along a river reach are estimated using the following three equations:

$$Q_p = P * a \tag{32}$$

$$Q_e = E * a \tag{33}$$

$$a = \alpha\left[\left(Q_{u/s}\right)_{rout} + Q_r + Q_s - Q_d + Q_{irr} - Q_u - Q_{sd}\right]^{\beta} \tag{34}$$

where,

P = Precipitation rate on river surface (m/sec)

E = Evaporation rate from river surface (m/sec)

a = water surface area of a river reach (m^2)

α and β = parameters obtained by fitting a power law against the rating curve at the streamflow gauges (these parameters are obtained during model setup using cross-section data and river length). Note: in the case of having multiple gauges in a single catchment, the median alpha and corresponding beta for all available gauging stations (u/s and d/s) is used for residual reaches. However, for the headwater reaches alphas are scaled by 0.5 as there is only a d/s gauge and it is assumed that headwater reaches narrows towards zero width at the start point of the river.

2.2.8 ANABRANCH FLOW (Q_a)

Many river reaches mostly in flat terrains include anabranches and it is required to partition the flow between the main stem of the river and anabranches. In AWRA-R, the partition between the main stem and anabranch flow (Q_a) is computed as a linear relationship expressed as:

$$Q_a = C_a \left[(Q_{u/s})_{rout} + Q_r + Q_s - Q_d + Q_p - Q_e + Q_{irr} - Q_u - Q_{sd} \right]^{B_a} \tag{35}$$

where,

C_a= partition factor (dimensionless) determined based on the observed flow at the gauge located at the main stem below an anabranch and gauge at the anabranch.

B_a= exponent (dimensionless) determined based on the observed flow at the gauge located at the main stem below an anabranch and gauge at the anabranch.

Both C_a and B_a are estimated by establishing best-fit power function between observed flow at the gauge located at the main stem below an anabranch and gauge at the anabranch.

2.2.9 FLOODPLAIN INUNDATION MODELLING

Floodplain inundation modelling is undertaken using approach 1(described in detail in Dutta et al., 2013b; Teng et al., 2014), which is used in AWRA-R for estimating fluxes and stores associated with floodplain. A schematic diagram of flood model component of AWRA-R is shown in Figure 2.4.

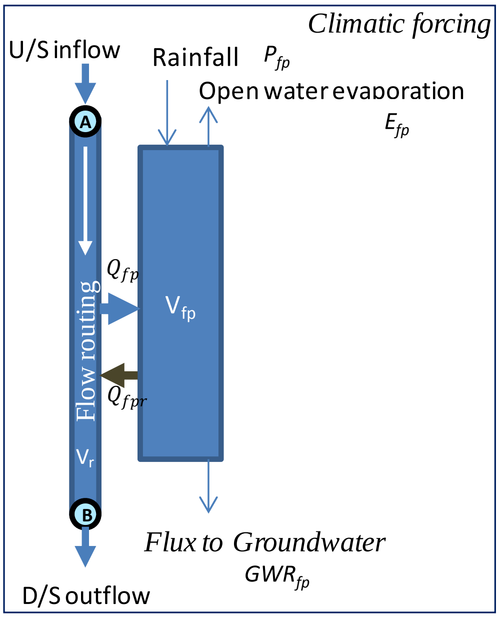

Figure 2.4. The conceptual diagram of AWRA-R irrigation model

Overbank flooding (Q_{fp}) and flood return (Q_{fpr}) are two components of overall floodplain water balance equation, which can be presented for a river reach as:

$$\widehat{V_{fp(t)}} = V_{fp(t-1)} + (Q_{fp} - Q_{fpr})\mathrm{dt} + \left[\left(P_{fp} - E_{fp}\right)\mathrm{A_{fp}} - GWR_{fp}\right]\mathrm{dt} \qquad (36)$$

where,

$\widehat{V_{fp(t)}}$= estimated floodplain storage at current time step *t* (m^3)

$V_{fp(t-1)}$= floodplain storage at previous time step*t-1* (m^3)

dt= modelling time step (sec)

P_{fp}= precipitation on floodplain (m/sec) (used AWRA-L outputs)

E_{fp}= evaporation from floodplain (m/sec) (used AWRA-L outputs)

A_{fp}= average floodplain inundated area (m^2) (estimated based on the volume-area relationship)

GWR_{fp}= groundwater recharge rate from floodplain (m^3/sec)

Q_{fp}, Q_{fpr} and V_{fp} in Equation (36) are calculated using the following equations:

$$Q_{fp} = \begin{cases} \max(0, q^* - OT), \max(0, q^* - OT) < 1 \\ \sqrt{\max(0, q^* - OT)}, \max(0, q^* - OT) \geq 1 \end{cases} \qquad (37)$$

$$V^{+}{}_{fp} = V^{-}{}_{fp} + Q_{fp} * dt \qquad (38)$$

$$A_{fp} = C_{fp} V^{+}{}_{fp} \qquad (39)$$

$$V^{++}{}_{fp} = V^{+}{}_{fp} + A_{fp}\left(P_{fp} - E_{fp}\right) * dt - GWR_{fp} \qquad (40)$$

$$Q_{fpr} = \frac{FR}{dt} V^{++}{}_{fp} \qquad (41)$$

$$V_{fp} = V^{++}{}_{fp} - Q_{fpr} * dt \quad (42)$$

where,

q^*= estimated flow at the downstream gauge of the modelled reach (i.e., $\widehat{Q_{d/s}}$ in Equation 1). Note: at this stage, the components are considered in Equation 1 to get the q^* values are: $(Q_{(u/s)})_{rout}+Q_r+Q_s-Q_d+Q_{irr}-Q_u-Q_{sd}+Q_p-Q_e-Q_a$

OT= overbank flow threshold (or, in-stream capacity) (m^3/sec) (this parameter is calibrated). Initial estimate of this value is done using the river cross-section, observed flow and water level data during model setup. For this purpose, the bank height is first identified based on the shape of the cross-section. The corresponding flow for the bank full water level from the rating curve for the cross-section represents in the initial threshold.

V^-_{fp} and V_{fp}= floodplain inundation volume at the beginning and end of the time step (m^3)

A_{fp}= floodplain inundated area (m^2)

C_{fp}= inverse of the average floodplain depth (m^{-1}) (assumed constant and derived from floodplain inundation volume-area linear relationship which is derived during model setup)

FR= return flow rate (dimensionless) (this parameter is calibrated)

GWR_{fp} in Equation (36) is calculated using the following equation based on Doble et al. (2014):

$$GWR_{fp} = [\min(I, \Delta S + Q)] * L \quad (43)$$

$$I = K_c x_w \left(\frac{h_w}{d_c} + 1\right) t_w \quad (44)$$

$$\Delta S = d_{gw} S_y x_w \quad (45)$$

$$Q = K_{aq} d_{aq} t_w \frac{h_w}{x_w/2} \quad (46)$$

where,

I = potential infiltration rate (m^2/sec)

ΔS = total storage available(m^2/sec)

Q = maximum volume of water discharging from the aquifer(m^2/sec)

K_c = saturated conductivity of surface layer (m/sec) (catchment average, obtained from AWRA-L)

x_w = lateral extent of flooding (m) (calculated as "flooded area (i.e. A_{fp}) /length of the river reach")

h_w = depth of flood (m) (assumed constant and derived from floodplain inundation volume-area linear relationship which is derived during model setup)

d_c = thickness of the surface layer (m)

t_w = duration of modelling time step(sec) (i.e. daily)

d_{gw} = depth to groundwater (m)

S_y = aquifer specific yield (dimensionless) (catchment average, obtained from AWRA-L)

K_{aq} = hydraulic conductivity of the aquifer (m/sec) (catchment average, obtained from AWRA-L)

d_{aq} = saturated thickness of the aquifer (m) (catchment average, obtained from AWRA-L)

2.2.10 RIVER AND GROUNDWATER INTERACTION MODELLING

This module is used in AWRA-R to calculate the flux from river to groundwater (Q_{gw}) along a reach. Gain from groundwater to a river reach (i.e., baseflow) is calculated as part of the total runoff estimated by AWRA-L. The following equations, based on Doble et al. (2014), are used to calculate the flux from a river reach to the underlying groundwater store of AWRA-L.

$$Q_{gw} = \left[\min(Q_{gwmonod}/L, I_{riv}, \Delta S_{riv} + Q_{riv})\right] * L \quad (47)$$

$$Q_{gwmonod} = M_1 \frac{Q_{stream}}{M_2 + Q_{stream}} \quad (48)$$

$$I_{riv} = K_{rivc} x_{rivw} \left(\frac{h_{rivw}}{d_c} + 1\right) t_w \quad (49)$$

$$\Delta S_{riv} = d_{gw} S_y x_{rivw} \quad (50)$$

$$Q_{riv} = K_{aq} d_{aq} t_w \frac{h_{rivw}}{x_{rivw}/2} \quad (51)$$

where,

$Q_{gwmonod}$ = groundwater loss (m^3/sec) as function of streamflow (Q_{stream}) (i.e. $\widehat{Q_{d/s}}$ in Equation 1) using a Monod function. At this stage, all the components are considered except the Q_{gw} in Equation 1 to get the $\widehat{Q_{d/s}}$ value.

I_{riv} = potential infiltration rate from river (m^2/sec)

ΔS_{riv} = total storage available(m^2/sec)

Q_{riv} = maximum volume of water discharging from the aquifer (m^2/sec)

$M_1$and M_2 = Monod parameters (m^3/sec) (these two parameters are calibrated)

K_{rivc} = river bed hydraulic conductivity (m/sec) (in AWRA-R v5.0, this value is derived from the hydraulic conductivity value of AWRA-L v5.0 soil layer).

x_{rivw} = width of the river (m). This is obtained from flow-width relationship (α_d*(streamflow)$^{\beta d}$, where α_d: river depth alpha, β_d: river depth beta]. It is the median width of all the gauging stations available within the catchment.

h_{rivw} = depth of river water (m). Used from observed data if available, otherwise, obtained from flow-depth relationship. It is the median depth at all the gauging stations available within the catchment.

2.2.11 HEADWATER CATCHMENT MODELLING

This method is designed to calculate some of the fluxes and stores in headwater (HW) catchments in AWRA-R v5.0 modelling.

As there is no upstream observed data in HW catchment, we can't calibrate any AWRA-R parameters (*k*, *x*, *lag*, floodplain return flow coefficient, GW monod alpha, beta and overbank flow threshold) except the runoff scaling factor for AWRA-L runoff based on the observed d/s gauge flow. Instead, the following fluxes/stores are back calculated using AWRA-L runoff, PET and observed data (streamflow and water level).

- Rainfall on river water surface
- Evaporation from river water surface
- River storage
- Groundwater seepage from river

The first two items (rainfall and evaporation) are calculated using Equations 32 and 33. Where, water surface area for a headwater catchment (a_{hw}) for this calculation is obtained using the following equation.

$$a_{hw} = 0.5 L_{hw} W_{d/s} \quad (52)$$

Where,

L: Length of stream in a headwater catchment (m)

$W_{d/s}$: width of river at downstream of a headwater catchment (m)

Equation 53 is used to estimate headwater catchment river reach water volume using the river depth alpha, river depth beta, river area alpha and river area beta (these are adjusted to account for streams decreasing in size as you go upstream). These parameters are derived from flow and water level data.

$$V_{riv\_hw} = \alpha * \alpha_d{}^{\beta}\left(D^{(\beta_d * \beta + 1)}\right)/(\beta_d * \beta + 1) \quad (53)$$

Where,

α: river area alpha

α_d: river depth alpha

β: river area beta

β_d: river depth beta

D: river depth

The method used for modelling groundwater seepage from river in a headwater catchment is the same as that used for residual river reaches (described in section 2.2.10) except that MONOD parameters are not calibrated but taken from the immediate downstream reach.

3 Input and output variables and parameters and model parameterisation methods

3.1.1 INPUT AND OUTPUT VARIABLES AND PARAMETERS OF AWRA-R V5.0

The input data required for AWRA-R v5.0 are of two categories: variables (time series) and parameters. Table 3.1 presents the time series variables and Table 3.2 presents the parameters, including the parameters that are calibrated. In these tables, the inputs for the AWRA-R irrigation model are not included as those are listed in Hughes et al. (2014). Table 3.3 presents the list of outputs simulated by AWRA-R v5.0. This list doesn't include the list of irrigation model outputs, which are listed in Hughes et al. (2014).

Table 3.1. Time series variables of AWRA-R v5.0

Temporal variable (symbol)	Unit of input data	Reference equation
Rainfall at river (*P*)	mm/day	Equation 32
Evaporation from river (*E*)	mm/day	Equation 33
Rainfall at floodplain (P_{fp})	mm/day	Equation 36
Evaporation from floodplain (E_{fp})	mm/day	Equation 36
Irrigation diversion (Q_d)	m^3/s	Equations 1, 30
Irrigation return flow (Q_{irr})	m^3/s	Equations 1, 31
Urban diversion (Q_u)	m^3/s	Equation 1
AWRA-L runoff (Q_r)	m^3/s	Equations 1, 4
Reservoir volume (*S*)	m^3	Equation 6
Reservoir area (*a*)	m^2	Equation 6
Depth to groundwater (d_{gw})	m	Equations 22, 45, 50
River water depth(h_{rivw})	m	Equations 49, 51
River water width (X_{rivw})	m	Equation 49, 50, 51
Reservoir net diversion ($Q_{net\_transfer}$)	m^3/s	Equation 5
Other river diversion(Q_{sd})	m^3/s	Equation 1
Inflow from each of the upstream nodes ($Q_{u/s}$)	m^3/s	Equations 1 & 2
Rainfall at reservoir (P_s)	mm/day	Equation 6
Evaporation from reservoir (E_s)	mm/day	Equation 6
Outflow at downstream nodes	m^3/s	For calibration

Table 3.2. Parameters of AWRA-R v5.0 included the calibrated parameters

Parameter (symbol)	Unit	Reference equation
River area alpha (α)	-	Equation 34
River area beta (β)	-	Equation 34
Flood beta (C_{fp})	m^{-1}	Equation 39
Anabranch partition factor (C_a)	-	Equation 35
Anabranch exponent(B_a)	-	Equation 35
Total river length (*L*)	m	Equations 34, 43

Parameter (symbol)	Unit	Reference equation
River depth alpha (α_d)	-	Equation 49 (to determine h_{rivw})
River depth beta (β_d)	-	Equation 49 (to determine h_{rivw})
Overbank flow threshold (*OT*) [calibrated]	m^3/sec	Equation 37
Floodplain surface layer conductivity (K_c)	m/sec	Equation 44
Aquifer specific yield (S_y)	-	Equation 45
Aquifer hydraulic conductivity (K_{aq})	m/sec	Equations 46, 51
Aquifer thickness (d_{aq})	m	Equations 46, 51
Surface layer thickness (d_c)	m	Equations 44, 49
Riverbed conductivity (K_{rivc})	m/sec	Equation 49
Area of residual catchment (*A*)	m^2	Equation 4
Length of reach inflow stream	m	Equation 34
Flood return flow coefficient (*FR*) [calibrated]	-	Equation 41
Monod parameter (M_1) [calibrated]	m^3/sec	Equation 48
Monod parameter (M_2) [calibrated]	m^3/sec	Equation 48
Runoff correction factor (*SF*) [calibrated]	-	Equation 4
Lag [calibrated]	sec	Equation 3
K [calibrated]	sec	Equation 3
X [calibrated]	-	Equation 3

Table 3.3. AWRA-R v5.0 outputs

Variables (symbol)	Unit	Reference equation
Outflow ($\widehat{Q_{d/s}}$)	m^3/sec	Equation 1
Overbank flow (Q_{fp})	m^3/sec	Equations 1, 37
Floodplain volume (V_{fp})	m^3	Equation 42
Flood plain area (A_{fp})	m^2	Equations 39, 40
Flood plain return flow (Q_{fpr})	m^3/sec	Equations 1, 41
River rainfall flux (Q_p)	m^3/sec	Equations 1, 32
River evaporation flux (Q_e)	m^3/sec	Equations 1, 33
Floodplain rainfall flux	m^3/sec	Equation 36
Floodplain evaporation flux	m^3/sec	Equation 36
Floodplain groundwater loss (GWR_{fp})	m^3/sec	Equations 36, 43
River groundwater loss (Q_{gw})	m^3/sec	Equations 1,
Anabranch loss (Q_a)	m^3/sec	Equations 1, 35
Reservoir rainfall flux	m^3/sec	Equation 6
Reservoir evaporation flux	m^3/sec	Equation 6
Reservoir contribution (Q_s)	m^3/sec	Equations 1, 5
River water volume	m^3	
Floodplain groundwater max change storage (ΔS)	m^2/sec	Equation 43
Floodplain groundwater outflow (Q)	m^3/sec	Equation 43
Floodplain groundwater max potential infiltration (*I*)	m^2/sec	Equation 44
River groundwater max change storage (ΔS_{riv})	m^2/sec	Equation 47, 50
River groundwater outflow (Q_{riv})	m^3/sec	Equation 47, 51
river.groundwater.max.infiltration (I_{riv})	m^2/sec	Equation 49
River groundwater max monod loss (Q_{gwmond})	m^3/sec	Equation 48

3.1.2 AWRA-R V5.0 PARAMETERISATION

AWRA-Rv5.0 model has the following two auto-calibration tools to calibrate model parameters of different components.

1. Irrigation model calibration tool
2. River model calibration tools

Irrigation model calibration tool

AWRA-R irrigation model is designed to produce a number of fluxes and stores related to irrigated area connected to a model reach. For any reach with irrigation diversion, the irrigation model is calibrated first using monthly diversion data and then, the simulated daily diversion time series from the calibrated irrigation model is used to calibrate AWRA-R parameters for the reach. The irrigation model has 2 calibration parameters. The irrigation model calibration tool is used to calibrate those parameters against monthly observed diversion data. The details of AWRA-R irrigation model, the irrigation model calibration tool, and the model application in the MDBA irrigation districts are described in the irrigation model report (Hughes et al. 2014) and are not repeated here.

River model calibration tools

AWRA-R model has 8 calibration parameters: *Lag, K, x, OT, FR,* M_1*,* M_2*, SF*.

Two calibration approaches have been developed for optimising reach-level model parameters using user-defined objective functions. They are:

- Reach-by-reach calibration
- System calibration

Reach-by-reach calibration approach

This approach was first developed for AWRA-R v3.0 and subsequently updated for AWRA-R v4.0 and v4.5. The reach-by-reach calibration approach used in the current version of AWRA-R is the same as the earlier version (v4.5) except the objective function. The objective function in AWRA-R v4.5 is changed to the following objective function (OF) to align it with the newly developed system calibration approach.

$$OF = \left(1 + \frac{\sum_{i=1}^{n}\left(\sqrt{\widehat{Q}_i} - \sqrt{Q_i}\right)^2}{\sum_{i=1}^{n}\left(\sqrt{Q_i} - \overline{\sqrt{Q}}\right)^2}\right)\left(1 + \left|\frac{\sum_{i=1}^{n}\widehat{Q}_i - \sum_{i=1}^{n}Q_i}{\sum_{i=1}^{n}Q_i}\right|\right) \quad (54)$$

Where,

Q_i= observed stream flow on day *i*,

$\widehat{Q}_i$= simulated streamflow on day *i*,

n= total number of days.

Following Coron et al. (2012), the objective function used a combination of square error applied to the square root transform of flow and bias. The function is minimised in optimisation and a perfect goodness of fit will return a score of 1. The higher the score the poorer the fit.

In this calibration approach, reach-level model parameters for every reach are optimised at the downstream main gauge of the reach in a cascading manner from upstream to downstream reaches using the Nelder-Mead optimiser (Nelder and Mead, 1965).Observed daily streamflow data at the downstream gauge corresponding to the main stem outflow of the reach is used for parameter optimisation.

System calibration approach

The system calibration approach is newly designed and implemented for AWRA-R v5.0. In this approach, all model parameters for a region (consisting of multiple reaches) are optimised simultaneously using a system-wide global objective function and the Shuffled Complex Evolution (SCE) optimiser (Duan et al., 1992).There are a number of advantages of the new approach, such as it allows to optimise parameters for multiple reaches in a given region and it uses relative weights for calibrating nodes. In addition, a single regional objective function can be easily combined with the objective function of AWRA-L for the joint calibration of AWRA-R and AWRA-L at a regional scale towards their integration from calibration through to operational use in the future.

Due to high computational requirements for optimising a large set of parameters using SCE optimiser, in the current version of system calibration, four of the eight reach parameters (FR, M_1, M_2, SF) are calibrated in system calibration using the global objective function (GOF), the rest are obtained from initial reach-by-reach calibration (*Lag, K, x, OT*).

$$GOF = \sum_{i=1}^{m} w_i OF_i \tag{55}$$

$$w_i = \frac{\sum_{j=1}^{nx} Q_{j,i}}{\sum_{i=1}^{n} \sum_{j=1}^{nx} Q_{j,i}} \tag{56}$$

Where,

m = total number of gauges for optimisation

w_i = weight assigned for gauge i (refer to Equation 56). The sum of all weights of m gauges will be 1.

OF_i = objective function for model parameter optimisation at any gauge i (shown in Equation 54)

$Q_{j,i}$ = Observed flow at gauge i on each day j.

nx = Total number of days for period of calibration.

This approach has been termed "utility" function (Cohon, 1978), and aims to improve goodness of fit at observation points both individually and system-wide.

The two calibration approaches are presented in detail in the companion report on AWRA-R calibration (Dutta et al., 2015).

4 Study Area and Data collation

4.1 Study Area

AWRA-R v5.0 model was applied to 39 large catchments (with median catchment area > 15,000 km^2) covering seven regions with different climatic characteristics across Australia. The regions are: Carpentaria Coast (CC), North East Coast (NEC), Pilbara-Gascoyne (PG), Tasmania (TAS), Lake Eyre Basin (LEB), Murray-Darling Basin (MDB) and Tanami – Timor Sea Coast (TTSC). Table 4.1 presents the spatial density of AWRA-R networks in the selected catchments within the seven regions, which include 624 nodes covering a total contributing catchment area of about 1.5 million km^2. In addition, AWRA-R v5.0 is being implemented in a number of other national water accounting regions by the BoM. Figure 4.1 shows the geographic locations of the modelled catchments. The spatial resolutions of node-link networks in different catchments were based on the number of available observed streamflow gauges, which varied significantly from catchment to catchment.

Table 4.1. Number of reaches for different modelling regions in AWRA-R v5.0

Catchment (Region)	Modelled area (km^2)	Number of nodes	Average sub catchment area (km^2)
Flinders (CC)	105872	22	4812
Gilbert (CC)	38679	23	1682
Lynd (CC)	4434	2	2217
Walsh (CC)	8468	2	4234
Wenlock (CC)	3209	2	1605
Bulloo (LEB)	27061	2	13531
Thomson (LEB)	75571	2	37785
BarwonDarling (MDB)	108151	19	6759
BorderRivers (MDB)	44190	35	1381
Campaspe (MDB)	3496	11	318
CondamineBalonne (MDB)	147288	36	4603
GoulburnBroken (MDB)	19907	34	603
Gwydir (MDB)	21602	27	900
Lachlan (MDB)	79002	45	2026
LoddonAvoca (MDB)	15140	34	459
MacquarieCastlereagh (MDB)	83671	58	1641
Moonie (MDB)	15424	3	5141
Mountlofty (MDB)	1475	13	113
Murray (MDB)	213363	80	3138
Murrumbidgee (MDB)	66054	58	1201
Namoi (MDB)	39793	30	1421
Ovens (MDB)	6242	17	367
Paroo (MDB)	36731	4	9183
Warrego (MDB)	53203	10	6650
Wimmera (MDB)	8523	19	473
Barron (NEC)	1938	3	646
Burnett (NEC)	5441	4	1360
Mary (NEC)	679	2	340

Catchment (Region)	Modelled area (km^2)	Number of nodes	Average sub catchment area (km^2)
Nogoa (NEC)	27514	2	13757
Greenough (PG)	10793	3	3598
Leven (TAS)	470	2	235
Meander (TAS)	1018	2	509
SouthEsk (TAS)	3233	2	1616
Swan (TAS)	452	2	226
Adelaide (TTSC)	1013	2	507
Daly (TTSC)	40481	2	20240
Finniss (TTSC)	1136	2	568
Fitzroy (TTSC)	90939	6	15156
Lennard (TTSC)	1143	2	572

Out of the different modelled regions, the Murray-Darling Basin (MDB) is the largest region with an area of approximately 1 million km^2. The MDB river system is a highly complex and mostly regulated system covering four states (Queensland, New South Wales (NSW), Victoria and South Australia) and one territory (Australian Capital Territory) (CSIRO, 2008). Out of all modelled regions, the MDB region has the best available data and hence, the MDB was selected for the model calibration, validation and benchmarking. For the purpose of AWRA-R modelling, the entire MDB was divided into 18 contiguous regions based on the divisions used in the Murray-Darling Basin Sustainable Yields Project (CSIRO, 2008). These regions, namely Paroo, Warrego, Condamine-Balonne, Moonie, Border Rivers, Gwydir, Namoi, Macquarie-Castlereagh, Barwon-Darling, Lachlan, Murrumbidgee, Murray, Ovens, Goulburn-Broken, Campaspe, Loddon-Avoca, Wimmera and Eastern Mount Lofty Ranges, are primarily the drainage basins of the Murray and the Darling rivers and their tributaries (Figure 4.2). All 18 regions are included in AWRA-Rv5.0 model. Within the MDB, the irrigated areas are mainly located within Condamine-Balonne, Border Rivers, Gwydir, Namoi, Barwon Darling, Macquarie Castlereagh, Lachlan, Murrumbidgee, Murray, Goulburn-Broken and Loddon-Avoca.

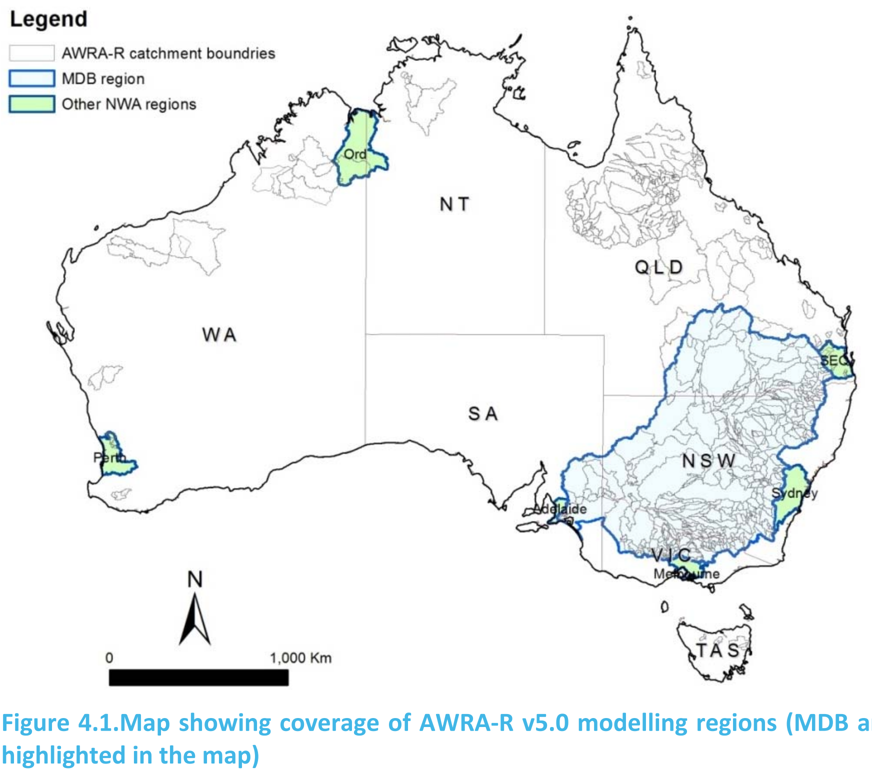

Figure 4.1.Map showing coverage of AWRA-R v5.0 modelling regions (MDB and other NWA modelling regions are highlighted in the map)

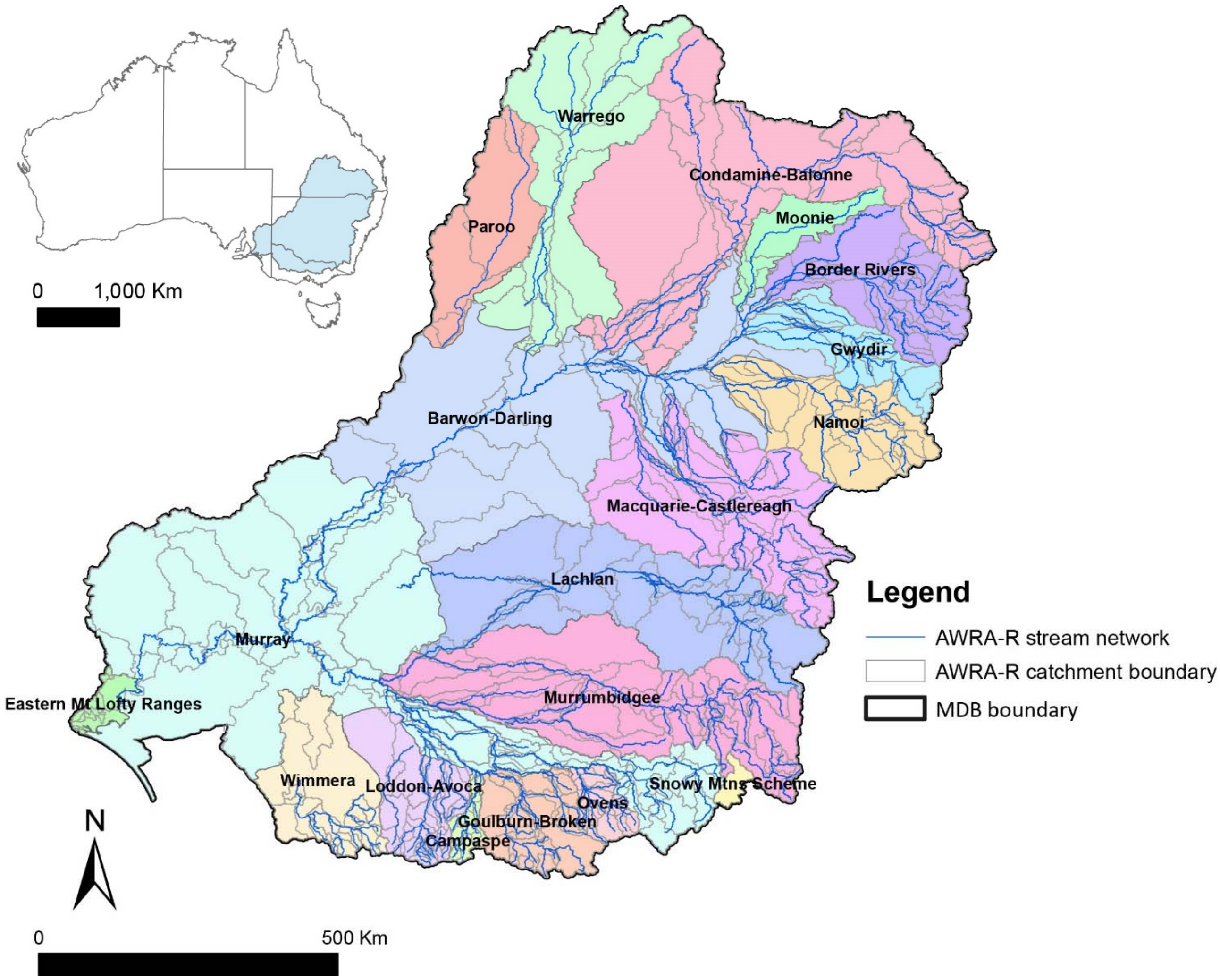

Figure 4.2. Map showing different modelling regions within the Murray-Darling Basin

4.2 Data collation

4.2.1 CATCHMENT BOUNDARIES AND NODE-LINK NETWORK

The locations of the streamflow gauges and the stream network were used to define the node-link setup and contributing local catchment areas. The locations of streamflow gauges and cross-section data at gauging nodes were obtained from HYDSTRA databases, and the location of storages from Geofabric databases. The AWRA-R v5.0 model in MDB included 171 headwater catchments, 275 non-headwater (or, residual) catchments and 33 large and medium size storages. The Australian Hydrological Geospatial Fabric (Geofabric) version 2 (BoM, 2013), a specialised Geographic Information System, was used to define the catchment boundaries for the selected gauges. In a number of areas with relatively flat terrain (particularly, in floodplains), the catchment boundaries obtained from Geofabric were manually adjusted to align with the stream network derived from Google Earth. The links (defining flow paths between nodes) were established and their lengths were calculated using both Geofabric and Google Earth. Figure 4.3 shows the AWRA-R v5.0 node-link network for the MDB.

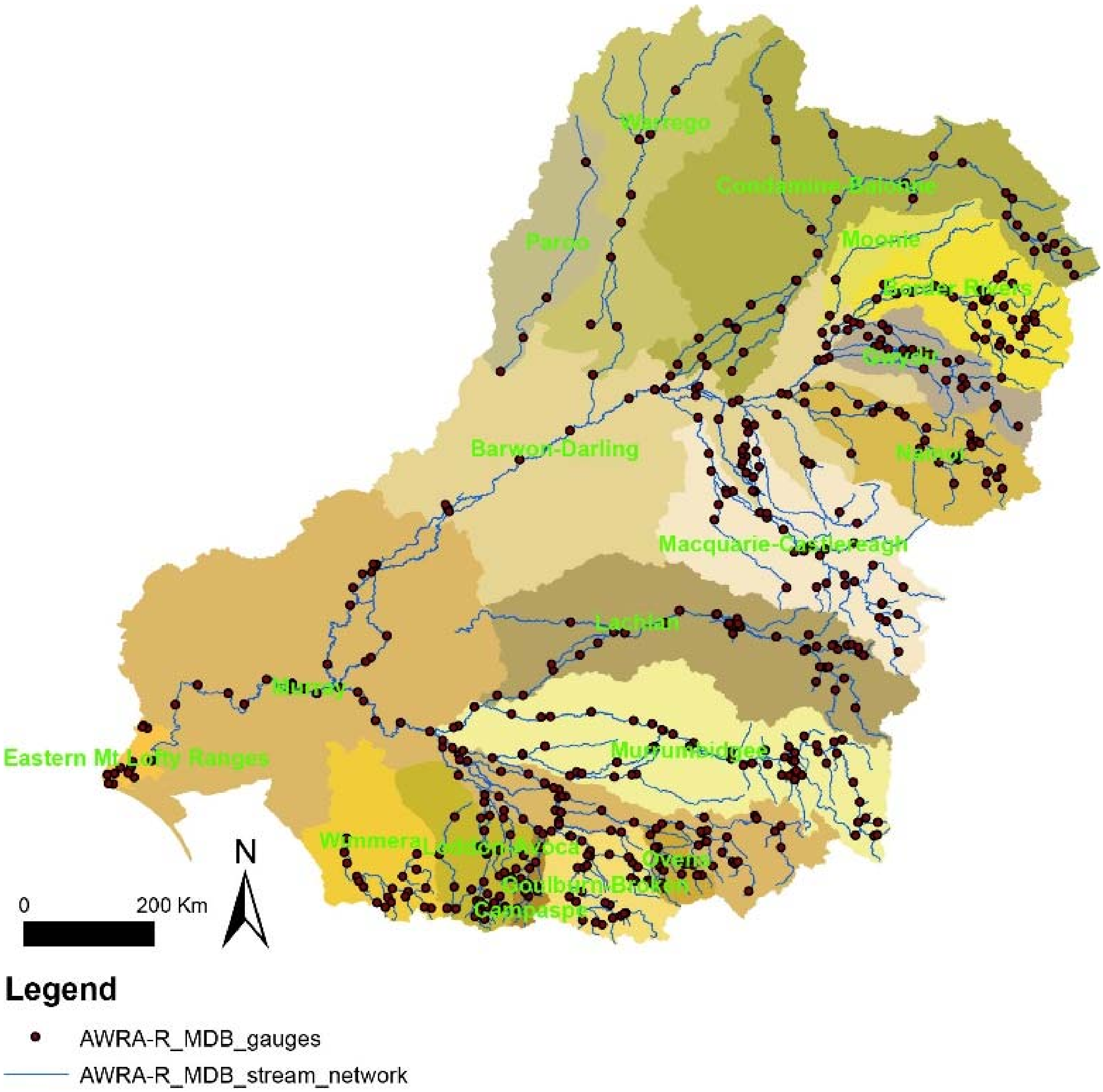

Figure 4.3. AWRA-R v5.0 node-link network for the Murray-Darling Basin

4.2.2 TEMPORAL DATA

The AWRA-R v5.0 model in the MDB region included a total of 485 gauges and 33 large and medium size storages. The characteristics of the modelled reaches within MDB are summarised in Appendix 1. The streamflow gauges and storages were selected based on the data quality and duration of records available. Daily time series of streamflow and water level data at the selected gauges and storage volume, area and water level data at selected storages were provided by the Bureau of Meteorology. Gridded daily rainfall data (at about 5 km spatial resolution) was obtained from the Bureau of Meteorology Australian Water Availability Project (BAWAP) (Jones et al., 2009). Gridded daily time series of potential evaporation, ungauged runoff and depth to groundwater (at about 5km spatial resolution) were calculated by AWRA-L model (Viney et al., 2014) and subsequently upscaled to catchment resolution by mapping cells to catchment polygons. Due to the quality issue of the simulated depth to groundwater by AWRA-L model, it was decided in consultation with the BoM to use a fixed groundwater depth of 5m instead in AWRA-R calibration. The irrigation diversion time series were obtained from various responsible jurisdictional authorities such as NSW State Water Corporation and Goulburn-Murray Water. In many of the locations in NSW and Queensland, quality of irrigation diversion data was very poor and duration of the data was very short. In those locations, the simulated diversion by the jurisdictions' calibrated river models (IQQM) were the only available data for the model calibration. The details of the temporal data used in the irrigation model are presented in Hughes et al. (2014).Urban diversion and water use for stock and domestic were not available. Similarly, there was no data on urban diversion from reservoirs. Table 4.2summarises the sources of temporal data used in AWRA-R v5.0 modelling.

Table 4.2. Sources of Temporal data used in AWRA-R v5.0 modelling

Temporal data	Data source for AWRA-R v5.0
Rainfall at river (P_s)	BAWAP
Evaporation from river (E_s)	AWRA-L
Rainfall at floodplain (P_{fp})	BAWAP
Evaporation from floodplain (E_{fp})	AWRA-L
Irrigation diversion (Q_d)	Jurisdiction authorities, IQQM
Urban diversion (Q_u)	Not available
AWRA-L runoff (Q_r)	AWRA-L
Reservoir volume (S)	BoM
Reservoir area (a)	BoM
Depth to groundwater (d_{gw})	Fixed at 5m
River water depth (h_{rivw})	BoM
River water width (X_{rivw})	BoM
Reservoir net diversion ($Q_{net\_transfer}$)	Not available
Other river diversion	Not available
Inflow at u/s node	BoM
Rainfall at reservoir (P_s)	BAWAP
Evaporation from reservoir (E_s)	BAWAP
Outflow at downstream nodes	BoM

4.2.3 OTHER DATA

Data for irrigation modelling

The reaches with irrigation diversion (in total 58) were identified from the irrigated area maps derived from the National Dynamic Land Cover Dataset of Australia (Lymburner et al., 2010), Catchment scale land use data collected by the state partners of the Australian Collaborative Land Use and Management Program of the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES, 2012) and the basin irrigation and salinity mapping atlas produced by the Murray-Darling Basin Commission (MDBC, 2002) (Figure 4.4). The crop types for different irrigated areas were obtained from the catchment scale land use data of ABARES. The areas of on-farm storages used for irrigation in different irrigation districts were derived from the on-farm storage area map obtained from satellite imagery (GA, 2007). Refer to Hughes et al. (2014) for further details.

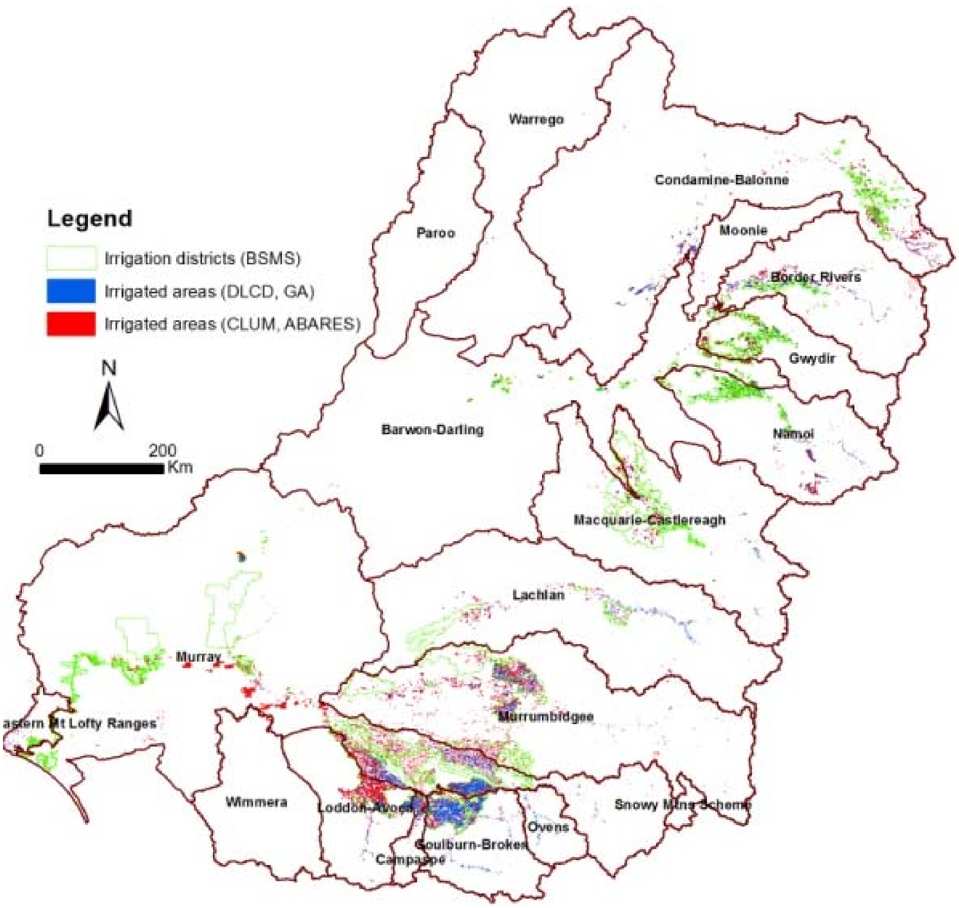

Figure 4.4. Irrigated area mapwithin the Murray-Darling Basin

Data for floodplain modelling

Two sets of data are required for overbank flow modelling in AWRA-R: the locations of floodplain reaches and floodplain inundation volume-area relationships. The 1:100 year return period maximum flood inundation extent map derived from MODIS satellite imagery (Chen et al., 2012) was used to define the reaches with floodplains (Figure 4.5) (in total 166). For a selected few floodplains, where LiDAR data was available, the relationships between floodplain area and volume were derived based on a multi-storage inundation modelling approach (Approach 2, Dutta et al., 2013b; Teng et al., 2014). Where LiDAR data was not available, daily inundation area time series derived from MODIS imagery between 2000-2007 and SRTM DEM of 30-m resolution were used for establishing the relationship (Gouweleeuw et al., 2011).

Soil properties for modelling groundwater interaction with floodplain and river

The soil properties that are required for AWRA-R groundwater interaction modelling are: thickness of top soil layer; conductivity of top soil layer in floodplain and river bed conductivity. The thickness of ASRIS soil layer was used as the top soil layer thickness and 5km x 5km gridded ASRIS data was upscaled to AWRA-R catchment. The soil layer conductivity data derived for AWRA-L v5.0 modelling using pedotransfer functions was used to determine floodplain and river bed conductivity. The pedotransfer function estimated conductivity for the second soil layer was found to be most suitable for AWRA-R modelling based on a sensitivity analysis. Figure 4.6 shows the spatial map of hydraulic conductivity estimated using pedotransfer functions for the second soil layer between 10-100cm used in AWRA-L v5.0 modelling. This 5km x 5km gridded layer was upscaled using AWRA-R catchment boundaries to derive the conductivity values for floodplain and river for different AWRA-R modelling reaches.

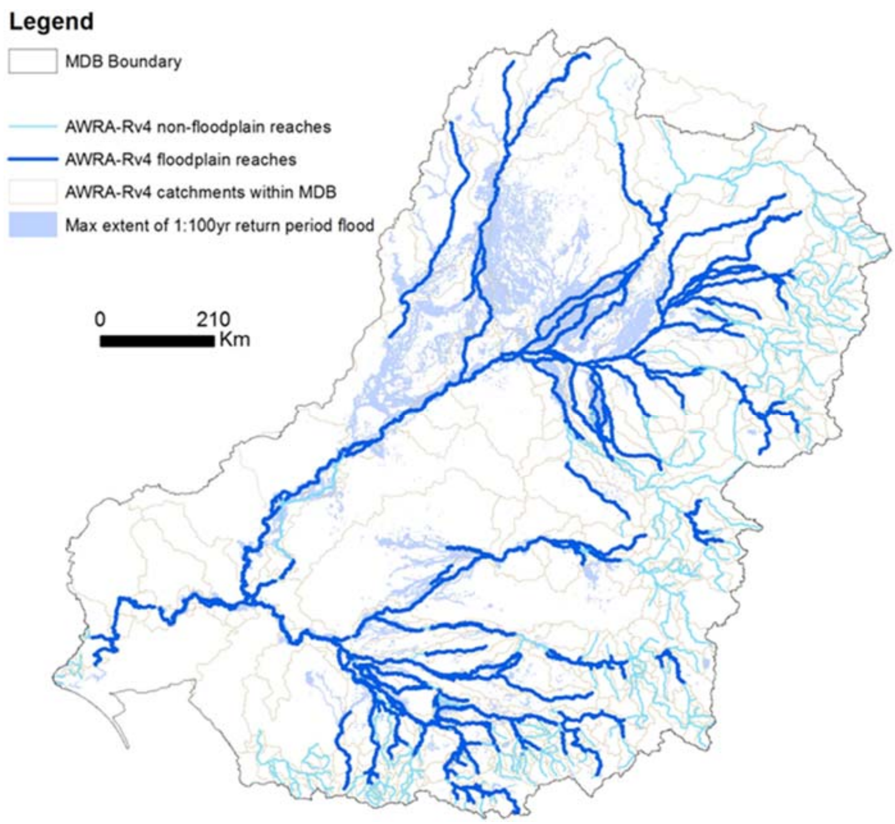

Figure 4.5. 1:100 yr return period maximum inundation extent map for the Murray-Darling Basin

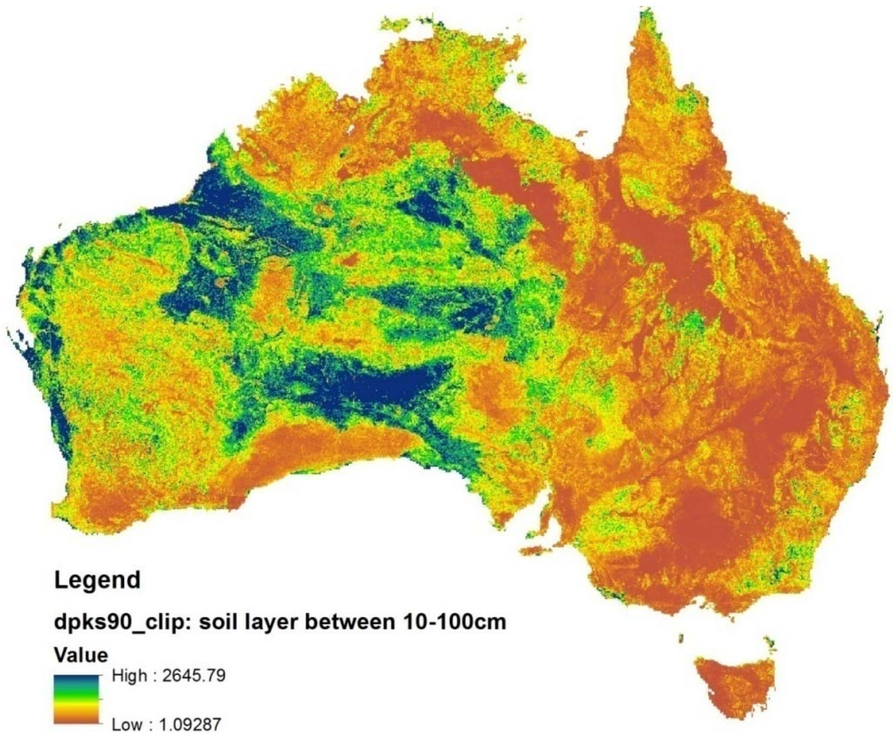

Figure 4.6. Saturated hydraulic conductivity of soil layer between 10-100 cm (from AWRA-L v5.0) (Unit of the values shown in the map: mm/day)

Aquifer properties for modelling groundwater interaction with floodplain and river

The aquifer properties that are required for surfacewater-groundwater interaction modelling in AWRA-R v5.0 are: aquifer conductivity, thickness and specific yield. These parameter values are derived from the aquifer properties of AWRA-L aquifer layer. The 5km x 5km gridded layers were upscaled using AWRA-R catchment boundaries to determine average values for AWRA-R reach scale modelling.

River reach parameters

The parameters related to river reach are: river area alpha, river area beta, river length, river depth alpha and river depth beta. River area alpha and beta are obtained by fitting a power law against the rating curve at the streamflow gauges and uses cross-section and river length data. Rating curve data for different streamflow gauges were obtained from the BoM. In the case of having multiple gauges in a single catchment, the median alpha and corresponding beta for all available gauging stations (u/s and d/s) is used for residual reaches. However, for the headwater reaches alphas are scaled by 0.5 as there is only a d/s gauge and it is assumed that headwater reaches narrows towards zero width at the start point of the river. River length was derived from the spatial layer of the river network derived from Geofabric 2 and Google Earth. River depth alpha and beta were derived from streamflow and water depth relationships.

Anabranch parameters

The parameters related to anabranch flow modelling are: the partition factor and exponent. These two parameters are derived from the relationship derived from the gauged streamflow at the main stem and the anabranch of an AWRA-R catchment.

Table 4.3summarises the sources of different parameters used in AWRA-R v5.0 modelling.

Table 4.3. Sources of parameter values used in AWRA-R v5.0 modelling

Parameter (symbol)	Data Source
River area alpha (α)	Derived from River cross section data from BoM
River area beta (β)	Derived from River cross section data from BoM
Flood beta (C_{fp})	From MODIS flood map and SRTM DEM
Anabranch partition factor (C_a)	Derived from streamflow data (BoM)
Anabranch exponent (B_a)	Derived from streamflow data (BoM)
Total river length (L)	GeoFabric 2.0 and Google Earth
River depth alpha	Derived from Streamflow and water level data (BoM)
River depth beta	Derived from Streamflow and water level data (BoM)
Floodplain surface layer conductivity (K_c)	AWRA-L
Aquifer specific yield (S_y)	AWRA-L
Aquifer hydraulic conductivity (K_{aq})	AWRA-L
Aquifer thickness (d_{aq})	AWRA-L
Surface layer thickness (d_c)	ASRIS
River bed conductivity (K_{rivc})	AWRA-L
Area of residual catchment	GeoFabric 2.0 and Google Earth
Length of reach inflow stream	GeoFabric 2.0 and Google Earth
Floodplain surface layer conductivity (K_c)	AWRA-L
Aquifer specific yield (S_y)	AWRA-L
Aquifer hydraulic conductivity (K_{aq})	AWRA-L
Aquifer thickness (d_{aq})	AWRA-L

Parameter (symbol)	Data Source
Surface layerthickness (d_c)	ASRIS
River bed conductivity (K_{rivc})	AWRA-L

5 Model calibration, validation and benchmarking

Similar to previous versions (v3.5, v4.0 and v4.5), AWRA-L v5.0 was first calibrated and then, AWRA-Rv5.0 was calibrated using the simulated AWRA-Lv5.0 outputs. The gridded input rainfall from AWRA-L v5.0 (source: BAWAP) and simulated AWRA-L v5.0 gridded runoff and PET daily timeseries were cookie-cut to produce AWRA-R catchment average daily time series of runoff and PET as input data for AWRA-R calibration and validation. In addition, soil and aquifer property data were also obtained from AWRA-L v5.0.

The AWRA-R irrigation model was first calibrated independently using the available monthly diversion data from multiple sources and then, the irrigation model inputs and parameters were used in AWRA-R to calibrate the parameters for the other components of the model using the observed daily stream flow data. The calibration of the irrigation model is detailed in Hughes et al. (2014) and not repeated here. The calibrated model outputs were benchmarked against data from both ground and satellite based observations and the previous version (version 4.5) for evaluation of the model performance using the benchmarking criteria set by the BoM as shown in Table 5.1.

Table 5.1. AWRA-R evaluation criteria

Variable	Assessed against	Assessment criteria	Comparison with simulations from alternative models	Performance threshold
Streamflow	• Gauged streamflow at ~430 sites (calibration and validation)	• Daily NSE • Monthly NSE • Bias	• IQQM (in Murrumbidgee[2])	• Median Daily NSE > 0.5, Median Monthly NSE > 0.7, • Median absolute bias < 20%
Irrigation diversion	• Observed diversion	• Monthly NSE • Bias		• Median monthly NSE > 0.45 • Median absolute bias < 10%
Floodplain inundation extent	• Satellite flooded extent	• Inundation extent correlation		• Correlation > 0.6
ET from irrigated area	• Remotely sensed ET	• Long-term correlation		• Similar to AWRA-Rv4.0

5.1 AWRA-R v5.0 Calibration and validation

5.1.1 AWRA-R V5.0 REACH-BY-REACH CALIBRATION

The AWRA-R v5.0 model was first calibrated using the reach-by-reach calibration approach and validated against the observed streamflow data. Based on the lengths and quality of the streamflow data at the selected gauges and climatic variability in the MDB region, the period of 1970-1991, covering both wet and dry climate, was selected for calibrating the AWRA-R model. A more recent period of 1992-2014 was selected for validating the model. This period included the millennium drought in the MDB from 2000-2009 (Kirby et al., 2012), which was followed by an intense wet period (2010-2013).In reach-by-reach calibration and validation, the upstream inflows in a reach are gap-filled with observed data where available.

The summary statistics (daily NSE and absolute bias in %) of the model performance during the calibration and validation periods are presented in Figure 5.1 through to Figure 5.4. In the calibration, the model performed reasonably well in all regions within the MDB with the median daily NSE of 0.60 as shown in Figure 5.2. The lowest median daily NSE was greater than 0.5. The model performance varied from region to region with median daily NSE ranging between 0.54-0.83. The model performed best in the Murray and worst in Loddon Avoca, where quality of the observed streamflow data was poor with many missing data points. The median values of annual bias during the calibration were very low (< 1%) for all modelled regions within the MDB. The median bias was less than 5% for all sub-regions except Barwon-Darling as shown in Figure 5.3. The calibrated model performed very well under the validation mode with the median daily NSE of 0.69 for all modelled regions within the MDB. Between the regions, the daily median NSE varied between 0.39-0.83 with the highest value in Murray and worst in Loddon Avoca as shown in Figure 5.2. This was consistent with the results obtained under the calibration mode. In the validation, the median value of annual bias was 16% for all modelled regions within the MDB (Figure 5.4), which was relatively higher than the calibration period. Similar was the case for different regions within the MDB where the median values of annual bias varied between 4-30% except for four sub-regions (Campaspe, EMLR, Lachlan and Wimmera) with bias of over 30%. The highest value of bias was in Campaspe (38%) and lowest in Goulburn (4%).

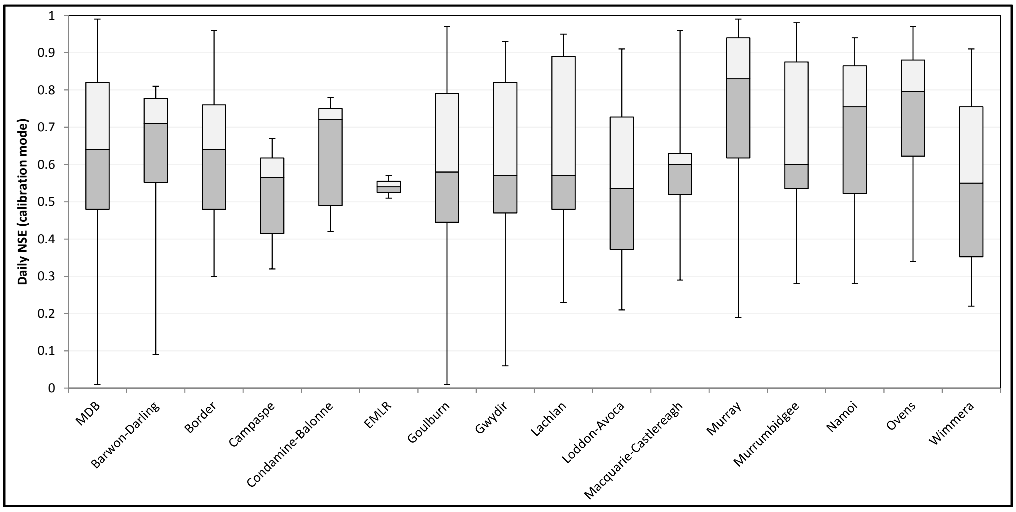

Figure 5.1. Boxplots of daily NSE for different regions within MDB in calibration (period: 1970-1991) of AWRA-R v5.0

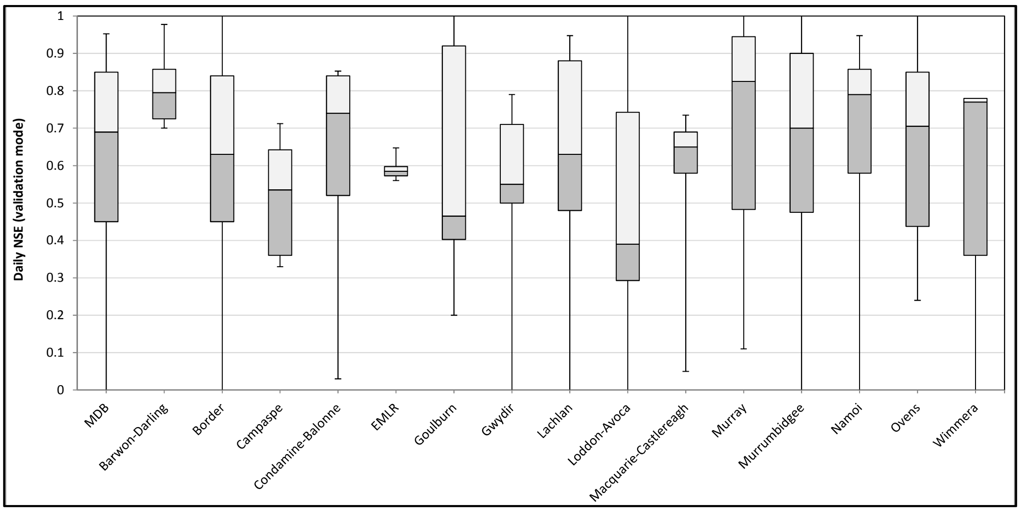

Figure 5.2. Boxplots of daily NSE for different regions within MDB in validation (period: 1992-2014) of AWRA-R v5.0

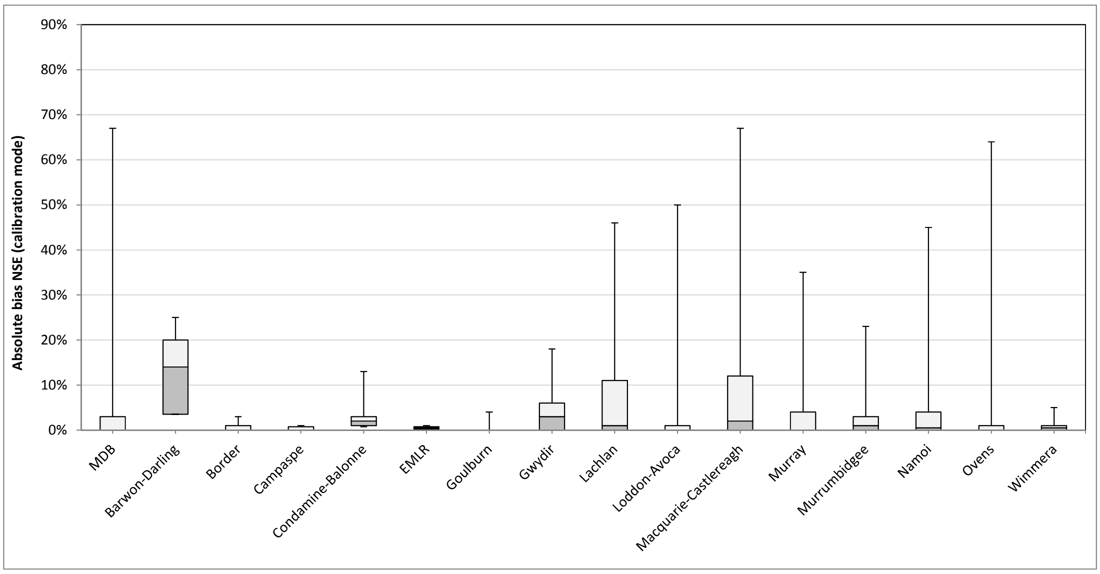

Figure 5.3. Boxplots of annual bias for different regions within MDB during the calibration (period: 1970-1991) of AWRA-R v5.0 model

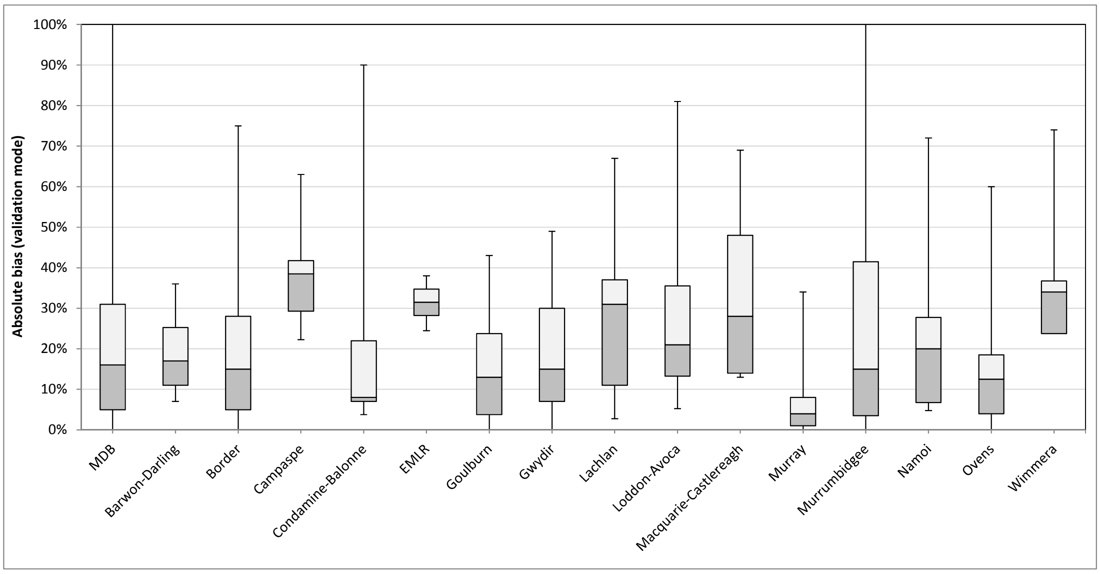

Figure 5.4. Boxplots of annual bias for different regions within MDB during the validation (period: 1992-2014) of AWRA-R v5.0 model

Table 5.2 presents the long term mass balance error during the calibration and validation periods for different sub-regions within the MDB. The annual mass balance error for each modelled sub-catchment was calculated using Equation 1 and then, added to obtain the total annual average mass balance error for each sub-region. The annual average mass balance error was negligible for all sub-regions (<1%) during the calibration period and the error was similar for the validation period for most of the sub-regions except for Campaspe and Goulburn-Broken regions. The mass balance errors in these two sub-regions were also below 4%.

Table 5.2. Long term mass balance in different sub-regions within the MDB during the calibration and validation periods

Sub-region (within MDB)	Annual average mass balance error (%)	
	During calibration (1971-1991)	During validation (1992-2014)
Barwon-Darling	0.00%	0.10%
Border Rivers	0.00%	0.80%

Sub-region (within MDB)	Annual average mass balance error (%)	
	During calibration (1971-1991)	During validation (1992-2014)
Campaspe	0.60%	3.50%
Condamine-Balonne	0.00%	0.00%
Eastern Mount Lofty Range	0.00%	0.00%
Goulburn-Broken	0.30%	2.30%
Gwydir	0.10%	0.50%
Lachlan	0.60%	1.40%
Loddon-Avoca	0.20%	1.10%
Macquarie-Castlereagh	0.00%	1.50%
Moonie	0.00%	0.00%
Murray	0.10%	0.30%
Murrumbidgee	0.00%	0.50%
Namoi	0.30%	0.60%
Ovens	0.00%	0.00%
Paroo	0.00%	0.00%
Warrego	0.00%	0.00%
Wimmera	0.00%	0.00%
EMLR	0.00%	0.00%

5.1.2 AWRA-R V5.0 SYSTEM CALIBRATION

In the reach-by-reach calibration, the upstream inflows in a reach are gap-filled with observed streamflow data. The system calibration was first undertaken for all regions within the MDB with simulated inflows without gap-filling with available observed inflows. The system calibration was undertaken for each reach from upstream to downstream with the transfer of simulated inflow from upstream boundaries for any downstream region. Several large regions were sub-divided into two or three sub-regions to handle the computational time. In the case of sub-regions, the uppermost sub-region was first calibrated and then, the boundary condition was set for calibration of the lower sub-region using the simulated flow from the upper region. In a number of selected regions, system calibration was also undertaken with gap-filled simulated data (where simulated streamflow was replaced with observed available data).

Figure 5.5 presents the system calibration performance statistics for entire MDB together with a comparison with reach-by-reach calibration statistics. For a fair comparison, reach-by-reach calibration was repeated with simulated inflow without gap-filling with observed data. The figure includes the performance statistics of reach-by-reach calibration with and without gap-filled (or patched) simulated data. Overall, the performance of the system calibration is lower than reach-by-reach calibration with patched inflow as it is obvious that better model performance has achieved with patched inflow in the MDB when high quality observed streamflow data is available. However, the model with system calibration showed better performance than reach-by-reach calibration without patched inflow data.

Figure 5.6 presents the statistics of model performance in the Campaspe region with both system calibration and reach-by-reach calibration with and without patched inflow. Similar to the entire MDB results, the model performed better with reach-by-reach calibration with patched inflow. The system calibration without patched inflow performed better than the reach-by-reach calibration without patched inflow. The performance of the system calibration with patched inflow was very close to the performance of reach-by-reach with patched inflow.

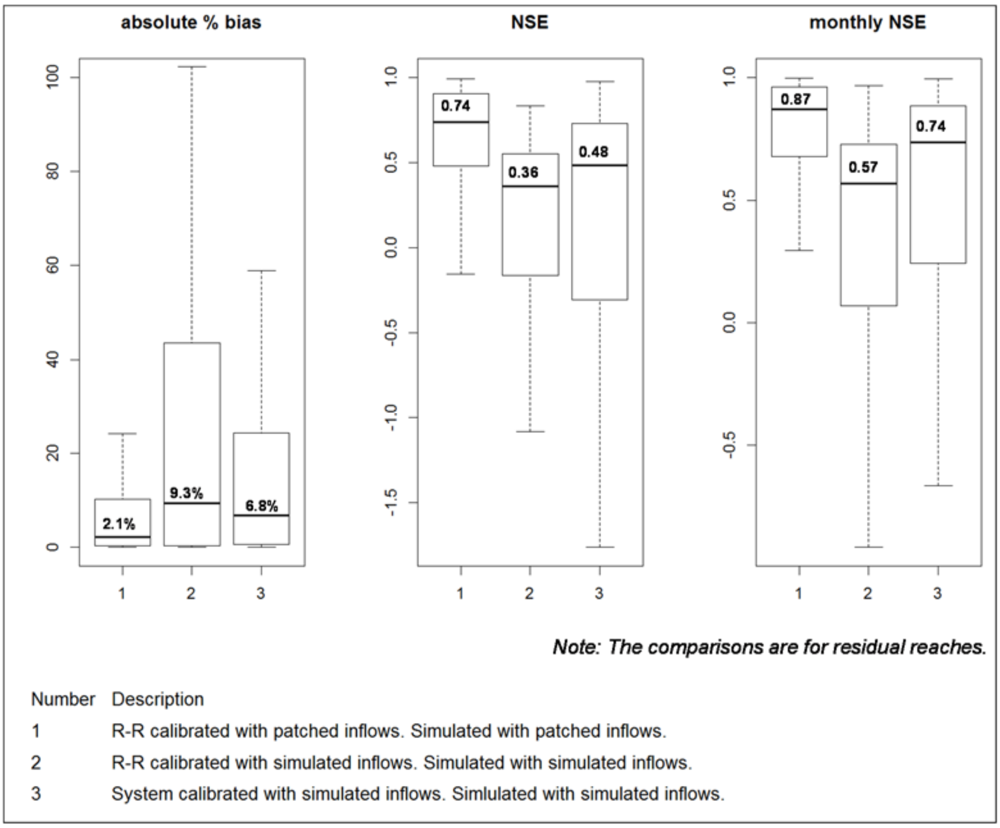

Figure 5.5. Summary statistics for system calibration and comparison with that from reach-by-reach calibration for the MDB

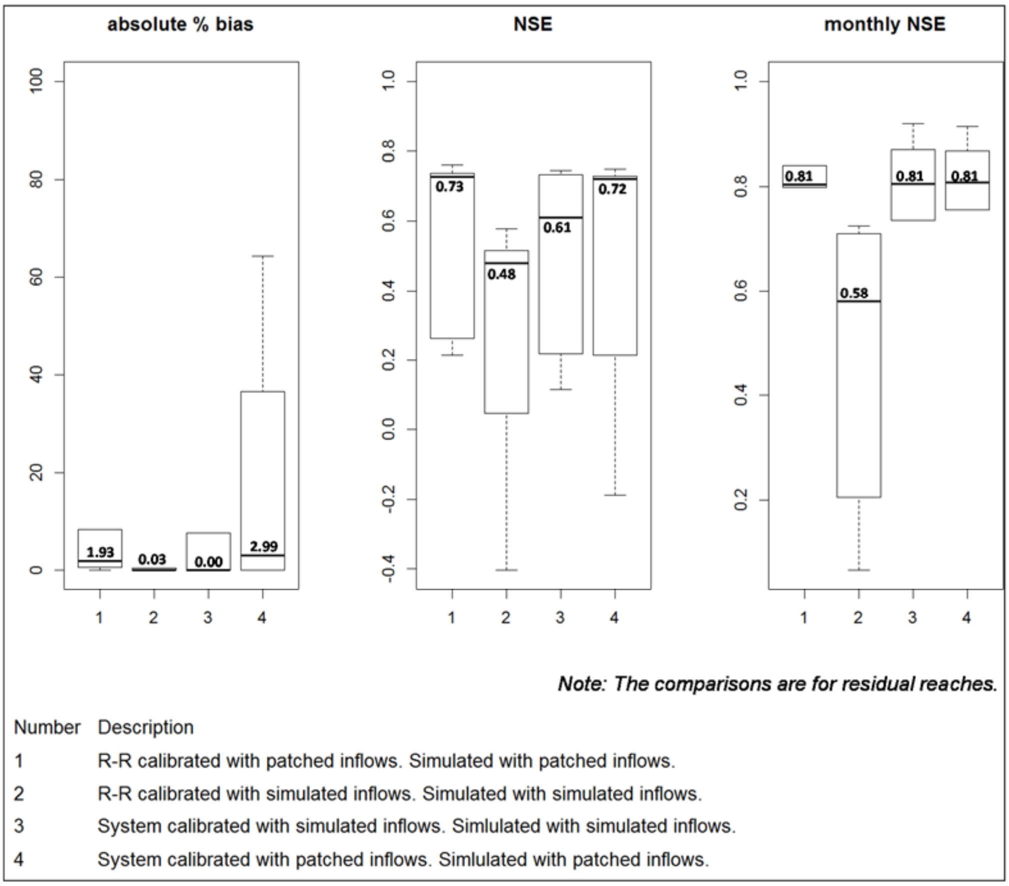

Figure 5.6. Summary statistics for system calibration and comparison with that from reach-by-reach calibration for Campaspe

The computational time of system calibration is significantly higher than reach-by-reach calibration. It took about 12 hours in a standard desktop computer to optimise model parameters by using reach-by-reach auto-calibration tool for the period of 1970-2014. However, it took more than 3 days for parameter optimisation using the system calibration tool in several sub-regions within the MDB as shown in Table 5.3.

Table 5.3. Computational time for system calibration in different regions/sub-regions within the MDB

Region	Run time (days)
Condamine-Balonne (upper)	0.3
Condamine-Balonne (lower)	1.5
Border	2.5
Gwydir	2.9
Lachlan (upper)	0.2
Lachlan (lower)	3.4
Murrumbidgee (upper)	0.5
Murrumbidgee (lower)	3.7
Goulburn-Broken	1.4
Loddon-Avoca	3.9
Murray (upper)	3.8

5.2 Benchmarking of AWRA-R v5.0 model

Benchmarking is undertaken for AWRA-R v5.0 against observed data from ground based and remotely sensed observed data as well as against the results of the previous version of the model (AWRA-R v4.5). AWRA-R v5.0 results with the calibrated parameters obtained from reach-by-reach calibration were used for benchmarking. The model performance was evaluated based on the agreed performance threshold as shown in Table 5.1 for simulated streamflow, irrigation diversion, crop water ET by AWRA-R v5.0 and the simulated floodplain inundation extent modelled by Approach 2 (Teng et al., 2014).

Streamflow

Figure 5.7 presents the performance statistics of AWRA-R v5.0 for the MDB and compared that with performance of AWRA-Rv4.5. The results show that the performance of AWRA-R v5.0 is slightly better than AWRA-Rv4.5 in terms of daily and monthly NSE. The annual bias is similar for the two versions. The median values of daily NSE, monthly NSE and absolute bias of AWRA-R v5.0 are well above the performance threshold set by the BoM.

In addition, benchmarking report cards were prepared for each modelled reach and region using AWRA-R benchmarking scripts for overall model performance evaluation. A sample of a reach level benchmarking report card is shown in Figure 5.8. Region level report cards for different regions of the MDB are included in Appendix 2.

It was planned to also undertake benchmarking of AWRA-R simulated streamflow against the results of other similar river system models (such as IQQM model). However, there was a significant delay in getting any such data by the BoM from the responsible organisations and hence, it was not possible to complete this task.

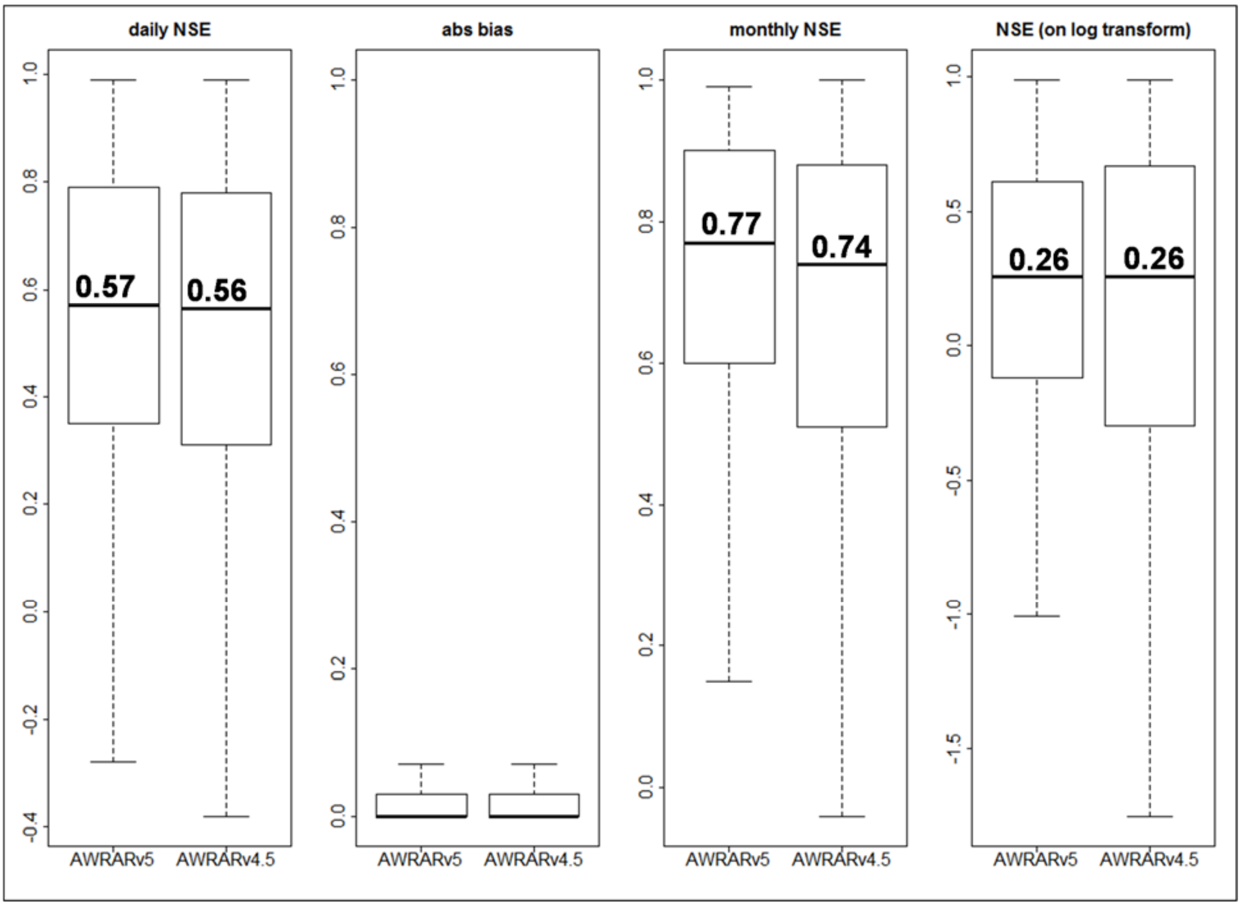

Figure 5.7. Comparison of AWRA-R v5.0 model performance against AWRA-R v4.5 for all model reaches in within MDB

Irrigation diversion

The benchmarking of the AWRA-R irrigation model against diversion data is presented in Hughes et al. (2014) and not repeated here. Figure 5.9 shows the overall performance of the model against available monthly diversion data in 31 modelled reaches. The median monthly NSE and median annual bias of the model performance are above the performance threshold set by BoM for the irrigation model.

Floodplain inundation extent (Approach 2)

The detailed benchmarking of Approach 2 floodplain inundation model results for Murrumbidgee and Murray floodplain reaches are reported in Teng et al. (2014). Here, the results of those two regions and newly modelled Macquarie, Barwon-Darling and Gwydir and are summarised in Table 5.4. The cell-to-cell correlation between simulated inundation maps and flood maps derived from Landsat imagery was above the threshold value 0.6 in most of the modelled reaches.

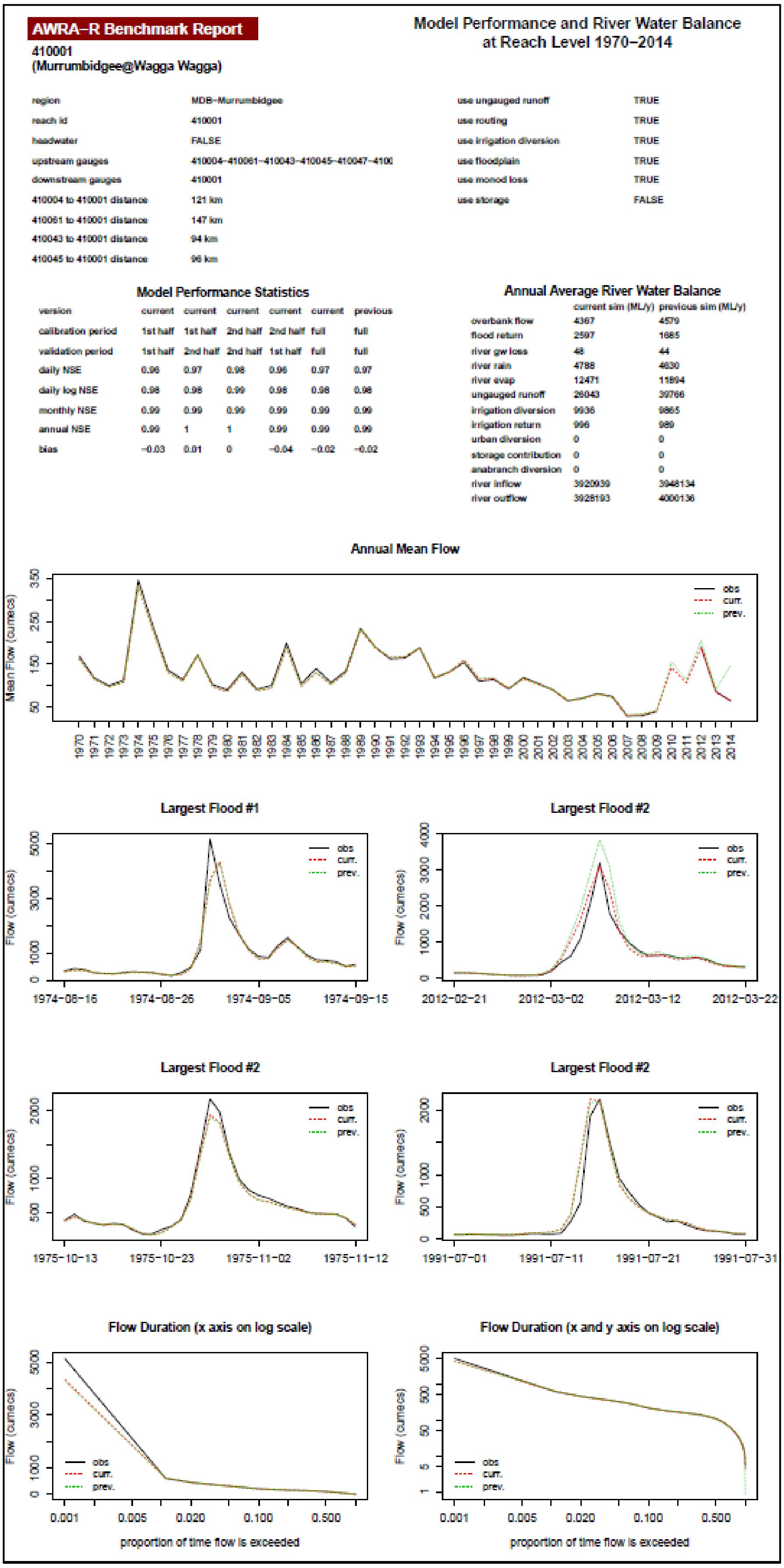

Figure 5.8. An example of a reach-level AWRA-R v5.0 benchmarking report card

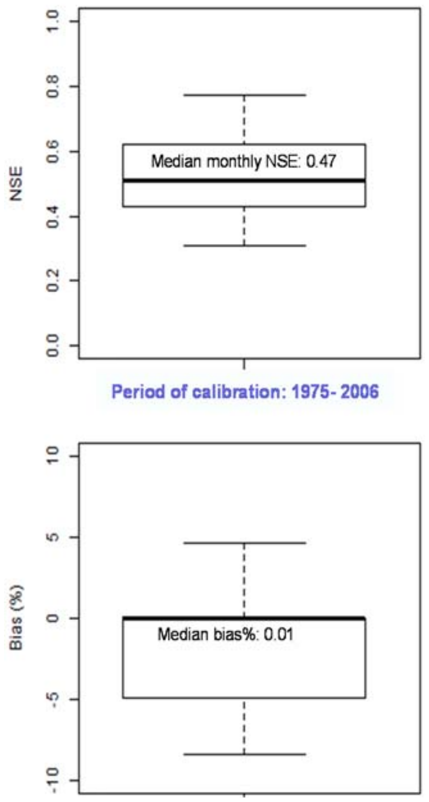

Figure 5.9. Summary of performance of the calibrated AWRA-R irrigation model in 31 irrigation reaches within MDB

Table 5.4. Performance of AWRA-R floodplain inundation model (approach 2) against Landsat flood maps

Reach	Region	Inundation volume-area relationship	R^2	Cell-to-cell correlation with Landsat flood map
421090_421022	Macquarie	y = 1.3372x	0.99	0.61
421147_421135	Macquarie	y = 1.8687x	0.97	0.75
425039_425003	Barwon-Darling	y = 0.4408x	0.96	0.61
425003_425004	Barwon-Darling	y = 0.4039x	0.93	0.69
418004_418063	Gwydir	y = 0.9507x	0.82	n/a
418063_418053	Gwydir	y = 2.7301x	0.94	n/a
418053_418078	Gwydir	y = 2.4555x	0.87	n/a
418076_418079	Gwydir	y = 1.1715x	0.84	n/a
410002_410136	Murrumbidgee	y = 0.4599x	0.99	0.95
410005_410078	Murrumbidgee	y = 0.4623x	0.88	0.86
410023_410005	Murrumbidgee	y = 0.361x	0.81	0.59
410040_410041	Murrumbidgee	y = 1.0265x	0.98	0.49
410041_410130	Murrumbidgee	y = 0.7766x	0.99	0.93
410078_410002	Murrumbidgee	y = 0.4471x	0.98	0.99
410136_410040	Murrumbidgee	y = 1.2695x	0.74	0.60
409026_409202	Murray	y = 0.3673x	0.94	n/a

Reach	Region	Inundation volume-area relationship	R^2	Cell-to-cell correlation with Landsat flood map
409202_409006	Murray	y = 0.657x	0.86	n/a
409006_409215	Murray	y = 0.9068x	0.89	n/a
409207_409005	Murray	y = 0.6646x	0.85	n/a
409005_409204	Murray	y = 0.6646x	0.85	n/a
409204_409235	Murray	y = 0.2575x	0.70	0.60
409235_414200	Murray	y = 0.4203x	0.99	0.51
414200_414201	Murray	y = 0.3715x	0.90	0.85
414201_414203	Murray	y = 0.4952x	0.92	0.62
414207_414204	Murray	y = 0.477x	0.98	0.93
414204_414210	Murray	y = 0.3292x	0.96	0.83
414210_425010	Murray	y = 0.3893x	0.96	0.73

(n/a: the results of the floodplain model could not be compared with Landsat flood map due to non-availability of high quality Landsat data for the area during large flood events.)

ET from Irrigated area

The CMRSET product, which provides estimates of actual evapotranspiration (ET) derived from MODIS reflectance and short wave infra-red data and grid (Guerschman et al., 2009), was also used to benchmark the simulated ET from the AWRA-R irrigation model. Gridded 8-day composite ET from CMRSET was obtained from the BoM (reference: http://dapds00.nci.org.au/thredds/catalog/u39/wirada/cmrset/catalog.html) for the period of 2000-2013. The 8-day data were resampled to monthly resolution and then, spatially averaged for different irrigated areas associated with AWRA-R irrigation reaches for benchmarking. Figure 5.10 presents the summary of correlation between the simulated ET by AWRA-R irrigation model and ET from CMRSET for all modelled reaches within the MDB for the period of 2000-2013. The median correlation coefficient is reasonable (> 0.5) for the MDB including different irrigated areas in North and South. The spatial variation in correlation in different irrigated areas within MDB is shown in Figure 5.11.

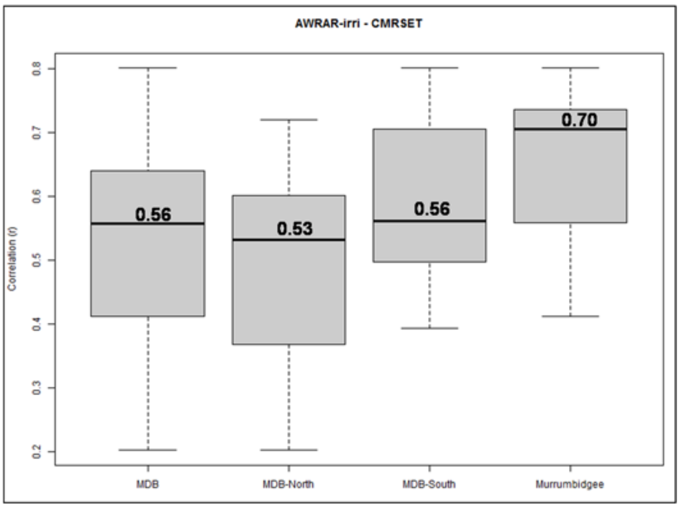

Figure 5.10. Comparison of AWRA-R simulated ET against monthly ET from CMRSET product for the period of 2000-2013.

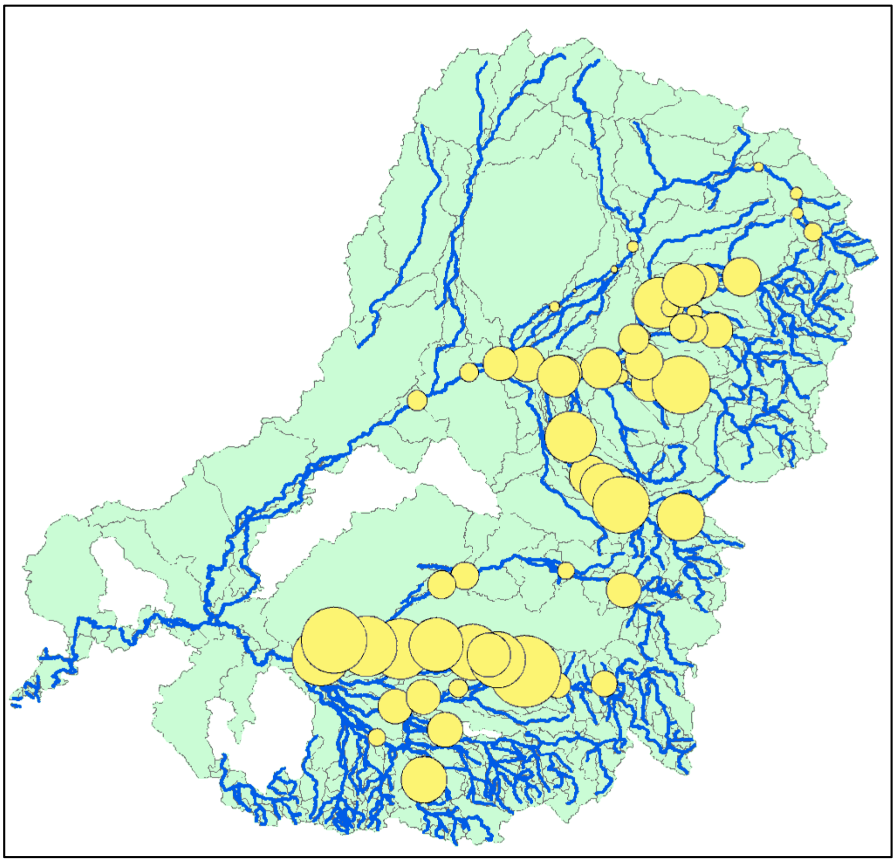

Figure 5.11. Spatial variation in correlations between simulated ET by AWRA-R irrigation model and CMRSET at monthly scale (for the period of 2000-2013). The yellow circles represent the correlations with larger circle representing higher correlation and smaller circle representing lower correlations.

This is the first time ET from AWRA-R irrigation model has been benchmarked against the ET derived from remotely sensed CMRSET product.

6 Conclusions and Recommendations

6.1 Summary

The core objective of the AWRA-R model is to produce various fluxes and stores associated with river systems in regulated and unregulated systems to support the production of the national water accounts (NWA) by the BoM. The research and development of AWRA-R model started in FY2011-12 (Lerat et al., 2012) as part of WIRADA and since then four different versions of AWRA-R [versions 3.0 (Lerat et al., 2013), 4.0, 4.5 and 5.0] have been developed, tested and implemented until end of this FY. The latest version (AWRA-R v5.0) has been operationalised at the BoM in March 2015. This report describes the technical details of AWRA-R v5.0 model, its calibration and validation in the MDB and benchmarking of the model results from different components against various available data.

The background and objectives of the AWRA-R modelling are discussed in section 1. The technical details of different components of AWRA-R v5.0 and their governing equations are presented in section 2. The improvements/changes in AWRA-R over the period of the development since 2011 are also summarised in this section. A large amount of spatial and temporal data are required for AWRA-R modelling. The list of all input temporal variables, spatial and other parameters are listed in section 3 with the reference to appropriate governing equations presented in section 2. The model has eight calibration parameters, which are listed in section 3. The two calibration approaches (reach-by-reach and system calibration) used for model parameterisation are also described in this section. The system calibration approach has been newly developed and implemented in AWRA-R v5.0.

AWRA-R v5.0 model has been calibrated and validated in the MDB using both the reach-by-reach and system calibration approaches. Section 4 presents the collation of input data for the application of the model in the MDB. The AWRA-R v5.0 model in the MDB region included a total of 485 gauges and 33 large and medium size storages. The characteristics of the modelled reaches within MDB are summarised in Appendix 1.

The results of the model calibration and validation against the observed daily streamflow data are presented in section 5. A comprehensive benchmarking of AWRA-R v5.0 results was undertaken using available data from ground based and remotely sensed observed as well as the results of the earlier version of the model. The results of benchmarking are also presented in this section. A set of benchmarking scripts have been prepared to benchmarking AWRA-R results in both reach and regional scales for comprehensive understanding of the model performance and water balance. This is briefly discussed in this section and the regional scale benchmarking plots are included in Appendix 2.

6.2 Conclusions

The results of the reach-by-reach calibration and validation of the model in the MDB show highly satisfactory performance of the model with median daily NSE of 0.60 and median annual bias of less than 1% for the period of calibration (1970-1991) and median daily NSE of 0.69 and median annual bias of 16%for validation period (1992-2014) for the MDB. Within the MDB region, median daily NSE varied between 0.54-0.83 in 18 different sub-regions under the calibration mode and the variation of median daily NSE was between 0.39-0.83 in the same 18 sub-regions under the validation mode. The model performed best in the Murray catchment and worst in Loddon Avoca, where the quality of the observed stream data was poor with many missing data points. The mass balance error of the AWRA-R model was negligible.

Overall, the performance of the system calibration in the MDB is poorer than the reach-by-reach calibration with patched inflow as it is obvious to have better model performance with patched inflow in the MDB with high quality observed streamflow data. However, the model with the system calibration showed better performance than the reach-by-reach calibration without patched inflow data. This shows that the system calibration is better suited for any predictive analysis by AWRA-R without observed data. The application of the system calibration with patched inflow in Campaspe region shows that the model performance with the system calibration is similar to that with the reach-by-reach calibration. It is important to note that the computational time of the system calibration is quite large compared to the reach-by-reach calibration.

The benchmarking results show that the overall performance of AWRA-Rv5.0 (with calibrated parameters from reach-by-reach calibration) is slightly better than AWRA-Rv4.5.The median monthly NSE of the AWRA-R irrigation model performance are reasonable and median annual bias was very low. The simulated ET by AWRA-R irrigation model shows good correlation (> 0.5) with the actual ET from CMRSET product at monthly scale. The simulated inundation maps by Approach 2 inundation model show reasonably high cell-to-cell correlation (>0.6) with the flood maps derived from Landsat imagery for most of the modelled reaches in different floodplains across the MDB. Overall, the performance of different components of AWRA-R v5.0 model satisfies the performance evaluation criteria set by BoM.

The AWRA-R v5.0 model produces a large number of fluxes and stores for surface water accounts. This quantitative information provides a detailed understanding of major components of water balances at a reach level for water resources accounting, analyses and reporting purposes.

6.3 Recommendations

Based on the performance statistics of the AWRA-R v5.0 model in the MDB with the reach-by-reach and system calibration and computational efficiency, it is recommended that the reach-by-reach calibration with the patched flow is the best suitable method for retrospective modelling with patched flow.

For a predictive modelling, where observed data are not available, the system calibration is the most suitable approach for AWRA-R model calibration.

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Appendix 1: Summary of node-link network of AWRA-R v5.0 model built for the MDB

Reach ID	Name of main outlet	Region	ID(s) of inflow node(s)	ID(s) of outflow node(s)	Has Reservoir?	Has floodplain?	Has irrigation diversion?	Headwater catchment?
422001	Barwon@Dangar Br (Walgett)	MDB-BarwonDarling	422003-419091-422018	422001		TRUE	TRUE	
422002	Barwon at Brewarrina	MDB-BarwonDarling	422027-421107	422002-422007		TRUE	TRUE	
422003	Barwon@Collarenebri	MDB-BarwonDarling	422004-418055	422003-422018		TRUE	TRUE	
422026	Barwon @ Boorooma	MDB-BarwonDarling	422001	422026		TRUE	TRUE	
422027	Barwon @ Geera	MDB-BarwonDarling	422026-421011-421012-420020	422027		TRUE	TRUE	
422028	Barwon @ Beemery	MDB-BarwonDarling	422005-422007-422002	422028		TRUE	TRUE	
425003	Darling@Bourke Town	MDB-BarwonDarling	425039-421023-422022	425003		TRUE	TRUE	
425004	Darling@Louth	MDB-BarwonDarling	425003-423001-423002	425004		TRUE	TRUE	
425002	Darling River @ Wilcannia Total Flow	MDB-BarwonDarling	425008	425002				
425008	Darling@Wilcannia Main Channel	MDB-BarwonDarling	425900	425008-425018		TRUE		
416050	Barwon U/S Presbury	MDB-BarwonDarling	416001	416050		TRUE		
422004	Barwon at MogilMogil	MDB-BarwonDarling	416050-416052-417001-416028	422004		TRUE		
416052	Gil Gil @ Galloway	MDB-BarwonDarling	416027	416052		TRUE		
422022	Tarrion @ Brewarrina	MDB-BarwonDarling		422022		TRUE		TRUE
425039	Darling @ Warraweena	MDB-BarwonDarling	422028-422006	425039		TRUE		
425900	Darling @ Tilpa	MDB-BarwonDarling	425004	425900		TRUE		
416001	Barwon@Mungindi	MDB-BorderRivers	416048-416202	416001		TRUE	TRUE	
416043	Macintyre @ Boomi weir	MDB-BorderRivers	416203-416047	416043-416037		TRUE	TRUE	
416048	Macintrye@Kanowna	MDB-BorderRivers	416043	416048		TRUE	TRUE	
416201	Macintyre@Goondiwindi	MDB-BorderRivers	416002	416201			TRUE	
416006	Severn@Ashford	MDB-BorderRivers	416019-416021	416006				
416007	Dumaresq@Bonshaw Weir	MDB-BorderRivers	416011-416008	416007				
416008	Beardy @ Haystack	MDB-BorderRivers		416008				TRUE
416011	Dumaresq@Roseneath	MDB-BorderRivers	416309-416310-416032	416011				
416018	Macintyre @ Dam site	MDB-BorderRivers	416006-416010	416018				
416020	Ottleys @ Coolatai	MDB-BorderRivers		416020				TRUE
416021	Frasers Ck @ Westholme	MDB-BorderRivers		416021				TRUE
416032	Mole @ Donaldson	MDB-BorderRivers		416032				TRUE
416036	Campbells Creek @ Near Beebo	MDB-BorderRivers		416036				TRUE
416040	Dumaresq @ Glenarbon	MDB-BorderRivers	416049-416305	416040				
416049	Dumaresq @ Bonshaw	MDB-BorderRivers	416007-416312	416049				
416305	Brush Creek @ Beebo	MDB-BorderRivers		416305				TRUE
416310	Dumaresq@Farnbro	MDB-BorderRivers		416310				TRUE
416312	Oaky Creek @ Texas	MDB-BorderRivers		416312				TRUE

Reach ID	Name of main outlet	Region	ID(s) of inflow node(s)	ID(s) of outflow node(s)	Has Reservoir?	Has floodplain?	Has irrigation diversion?	Headwater catchment?
416404	Bracker Creek @ Terraine	MDB-BorderRivers		416404				TRUE
416407	Canning Creek @ Woodspring	MDB-BorderRivers		416407				TRUE
416010	Macintyre@Wallangra	MDB-BorderRivers	416016	416010				
416012	Macintyre@Holdfast (Yelarbon Crossin	MDB-BorderRivers	416018	416012				
416016	Macintyre@Inverell (Middle Ck)	MDB-BorderRivers		416016				TRUE
416039	Severn@Strathbogie	MDB-BorderRivers		416039				TRUE
416415	Macintyre Brook @ Booba Sands	MDB-BorderRivers	416402	416415				
416309	Pike Creek @ Glenlyon Dam	MDB-BorderRivers		416309	TRUE			TRUE
416019	Severn@D/S Pindari Dam	MDB-BorderRivers	416039	416019	TRUE			
416402	Macintyre Brook@Inglewood	MDB-BorderRivers	416404-416407	416402	TRUE			
416002	Macintyre@Boggabilla	MDB-BorderRivers	416415-416040-416036-416012-416020	416002-416002002		TRUE		
416028	Boomi @ Neeworra	MDB-BorderRivers	416002002-416037	416028		TRUE		
416202	Weir@Talwood	MDB-BorderRivers		416202		TRUE		TRUE
416047	Callandoon Creek @ Carana Weir	MDB-BorderRivers	416201	416047-416203		TRUE		
406226	Mount Ida Creek at Derrinal	MDB-Campaspe		406226				TRUE
406235	Wild Duck Creek at U-S of Heathcote-Mia Mia Road	MDB-Campaspe		406235				TRUE
406201	Campaspe@Barnadown	MDB-Campaspe	406207-406214	406201				
406213	Campaspe@Redesdale	MDB-Campaspe		406213				TRUE
406214	Axe Creek at Longlea	MDB-Campaspe		406214				TRUE
406215	Coliban River at Lyal	MDB-Campaspe	406200	406215				
406224	Mount Pleasant Creek at Runnymede	MDB-Campaspe		406224				TRUE
406200	Coliban River at Malmsbury	MDB-Campaspe		406200	TRUE			TRUE
406207	Campaspe River at Eppalock	MDB-Campaspe	406215-406213-406235-406226	406207	TRUE			
406202	Campaspe@Rochester	MDB-Campaspe	406201-406224	406202		TRUE		
406265	Campaspe @ Echuca	MDB-Campaspe	406202	406265		TRUE		
422015	Culgoa@Brenda	MDB-CondamineBalonne	422208	422015		TRUE	TRUE	
422201	Balonne@St George	MDB-CondamineBalonne	422213-422404	422201	TRUE	TRUE	TRUE	
422205	Culgoa at Whyenbah	MDB-CondamineBalonne	422201	422205-422204		TRUE	TRUE	
422208	Culgoa at Woolerbilla	MDB-CondamineBalonne	422204	422208		TRUE	TRUE	
422308	Condamine@Chinchilla	MDB-CondamineBalonne	422333	422308			TRUE	
422316	Condamine@Cecil Weir	MDB-CondamineBalonne	422353	422316			TRUE	
422333	Condamine at Loudouns Bridge	MDB-CondamineBalonne	422316-422345-422350	422333			TRUE	
422353	Condamine@Yarramalong	MDB-CondamineBalonne	422355-422319-422334-422338-422352	422353-422345			TRUE	
422202	Dogwood Ck@Miles	MDB-CondamineBalonne		422202				TRUE
422210	BungilCk@Tabers	MDB-CondamineBalonne		422210				TRUE
422310	Condamine@Warwick	MDB-CondamineBalonne	422394	422310				
422319	Dalrymple Creek @ Allora	MDB-CondamineBalonne		422319				TRUE

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422334	Kings Creek@Aides	MDB-CondamineBalonne		422334				TRUE
422337	Bringalock	MDB-CondamineBalonne		422337				TRUE
422338	Canal ck at Leyburn	MDB-CondamineBalonne		422338				TRUE
422350	Oakey Ck@Fairview	MDB-CondamineBalonne		422350				TRUE
422352	Hogson Creek @ Balgownie	MDB-CondamineBalonne		422352				TRUE
422394	Condamine@Elbow Valley	MDB-CondamineBalonne		422394				TRUE
422213	Balonne@Weribone	MDB-CondamineBalonne	422325-422210-422202	422213				
422325	Condamine@Cotswold	MDB-CondamineBalonne	422308-422337	422325				
422401	Maranoa@Mitchell	MDB-CondamineBalonne	422407	422401				
422407	Maranoa River At Forestvale	MDB-CondamineBalonne		422407				TRUE
422355	Condamine@TalgaiTailwater	MDB-CondamineBalonne	422310	422355	TRUE			
422011	Culgoa@U/S Collerina (Mundiwa)	MDB-CondamineBalonne	422017	422011		TRUE		
422005	Bokhara at Goodwin	MDB-CondamineBalonne	422014	422005		TRUE		
422006	Bokhara@Bokhara (Goodwins)	MDB-CondamineBalonne	422011-422010	422006		TRUE		
422010	Birrie River @ Talawanta	MDB-CondamineBalonne	422013	422010		TRUE		
422206	Birrie River @ Goodooga	MDB-CondamineBalonne	422205	422206-422013-422014		TRUE		
422016	Narran at Wilby Wilby	MDB-CondamineBalonne	422206	422016		TRUE		
422017	Culgoa@Weilmoringle	MDB-CondamineBalonne	422015	422017		TRUE		
422029	Narran at Narran park	MDB-CondamineBalonne	422016	422029		TRUE		
422404	Maranoa@Cashmere	MDB-CondamineBalonne	422401	422404		TRUE		
405200	Goulburn@Murchison	MDB-GoulburnBroken	405202-405228	405200	TRUE	TRUE	TRUE	
404224	Broken R at Gowangardie	MDB-GoulburnBroken	4.04E+08	404224				
404204	BOOSEY CREEK @ TUNGAMAH	MDB-GoulburnBroken		404204				TRUE
404208	MOONEE CREEK @ LIMA	MDB-GoulburnBroken		404208				TRUE
404234	WHISKEY CREEK US MCCALLSAY RESERVOIR	MDB-GoulburnBroken		404234				TRUE
404235	RYANS CREEK US MCCALLSAY RESERVOIR	MDB-GoulburnBroken		404235				TRUE
405205	MURRINDINDI RIVER at MURRINDINDI ABOVE COLWELLS	MDB-GoulburnBroken		405205				TRUE
405228	HUGHES CREEK at TARCOMBE ROAD	MDB-GoulburnBroken		405228				TRUE
405231	KING PARROT CREEK at FLOWERDALE	MDB-GoulburnBroken		405231				TRUE
405241	RUBICON RIVER at RUBICON	MDB-GoulburnBroken		405241				TRUE
405261	SPRING CREEK (COLONIAL CREEK) at FAWCETT	MDB-GoulburnBroken		405261				TRUE
405274	HOME CREEK at YARCK	MDB-GoulburnBroken		405274				TRUE
405720	RODNEY MAIN DRAIN @ WELLS CREEK	MDB-GoulburnBroken		405720				TRUE
404203	Broken@Benalla	MDB-GoulburnBroken	404206-404208-404207	404203				
404206	Broken@Moorngag	MDB-GoulburnBroken		404206				TRUE
404207	HOLLAND CREEK at KELFEERA	MDB-GoulburnBroken	404234-404235	404207				

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405202	Goulburn@Seymour	MDB-GoulburnBroken	405201	405202				
405209	ACHERON RIVER at TAGGERTY	MDB-GoulburnBroken		405209				TRUE
405217	YEA RIVER at DEVLINS BRIDGE	MDB-GoulburnBroken		405217				TRUE
405246	CASTLE CREEK at ARCADIA	MDB-GoulburnBroken		405246				TRUE
405257	SNOBS CREEK at SNOBS CREEK HATCHERY	MDB-GoulburnBroken		405257				TRUE
404214	Broken Ck@Katamatite	MDB-GoulburnBroken	404217	404214		TRUE		
405232	Goulburn@McCoy Br	MDB-GoulburnBroken	405276-405720	405232		TRUE		
404210	Broken Creek at Rices Weir (Affra Unit)	MDB-GoulburnBroken	404214-404204	404210		TRUE		
404216	Broken@Goorambat (Casey Weir H. G	MDB-GoulburnBroken	404203	404216		TRUE		
404217	BROKEN CREEK (CHANNEL) @ CASEY WEIR (NEAR GOORAMBAT)	MDB-GoulburnBroken	404216	404217-404224002		TRUE		
405201	Goulburn@Trawool	MDB-GoulburnBroken	405203-405257-405241-405209-405261-405274-405205-405217-405231	405201		TRUE		
405204	Goulburn@Shepparton	MDB-GoulburnBroken	404224-405270-405269	405204		TRUE		
405226	PRANJIP CREEK at MOORILIM	MDB-GoulburnBroken		405226		TRUE		TRUE
405269	Sevens Creek at KIALLA WEST	MDB-GoulburnBroken		405269		TRUE		TRUE
405270	GOULBURN RIVER at KIALLA WEST	MDB-GoulburnBroken	405200-405226-405246	405270		TRUE		
405276	GOULBURN RIVER @ LOCH GARRY	MDB-GoulburnBroken	405204	405276		TRUE		
405203	Goulburn@Eildon	MDB-GoulburnBroken		405203	TRUE	TRUE		TRUE
416027	Gil GilCk@Weemelah	MDB-Gwydir	418052-416054	416027		TRUE	TRUE	
418004	Carole Creek at d/s Regulator(Bells Crossing)	MDB-Gwydir	418042	418004-418011			TRUE	
418052	Carole Creek at Near Garah	MDB-Gwydir	418011	418052			TRUE	
418053	Gwydir@Brageen Crossing	MDB-Gwydir	418063	418053			TRUE	
418055	Mehi@near Collarenebri	MDB-Gwydir	418002-418032	418055		TRUE	TRUE	
418066	Gwydir@Millewa	MDB-Gwydir	418078	418066			TRUE	
418012	Gwydir@Pinegrove	MDB-Gwydir	418026	418012				
418013	Gwydir@Gravesend Rd Br	MDB-Gwydir	418012-418025-418017-418015-418016	418013				
418015	Horton @ Rider	MDB-Gwydir		418015				TRUE
418016	Warialda Warialda 3	MDB-Gwydir		418016				TRUE
418017	Myall Creek at Molroy	MDB-Gwydir		418017				TRUE
418025	Halls Creek @ Bingara	MDB-Gwydir		418025				TRUE
418032	Tycannah Creek at Horseshoe Lagoon	MDB-Gwydir		418032				TRUE
418033	Bakers Creek @ Bundarra	MDB-Gwydir		418033				TRUE
418063	GWYDIR RIVER (SOUTH ARM) AT D/S TYREEL OFFTAKE REGULATO	MDB-Gwydir	418004	418063-418063002				
418078	GWYDIR RIVER AT ALLAMBIE BRIDGE	MDB-Gwydir	418053	418078				
418001	Gwydir@Pallamallawa	MDB-Gwydir	418013	418001				
418008	Gwydir@Bundarra	MDB-Gwydir	418014	418008				
418014	Gwydir@Yarrowyck	MDB-Gwydir		418014				TRUE
418042	Gwydir River at d/s Tareelaroi Weir	MDB-Gwydir	418001	418042-418002				
418026	Gwydir@D/S Copeton Dam	MDB-Gwydir	418008-418033	418026	TRUE			

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418076	Gingham Channel at Tillaloo Bridge	MDB-Gwydir	4.18E+08	418076		TRUE		
416054	Gil Gil @ Boolataroo	MDB-Gwydir		416054		TRUE		TRUE
418079	Gingham Channel at Gingham Bridge	MDB-Gwydir	418076	418079		TRUE		
412038	Lachlan at Willandra weir	MDB-Lachlan	412011	412038-412012	TRUE	TRUE	TRUE	
412039	Lachlan at Hillston Weir	MDB-Lachlan	412038	412039-412039002		TRUE	TRUE	
412057	Lachlan@Nanami	MDB-Lachlan	412002-412169-412165-412073	412057			TRUE	
412058	Lachlan at Island Ck Offtake	MDB-Lachlan	412004	412058		TRUE	TRUE	
412002	Lachlan@Cowra	MDB-Lachlan	412067-412029-412091	412002				
412016	Offtake Island Ck	MDB-Lachlan	412023-412006002	412016				
412029	Prossers Crossing	MDB-Lachlan		412029				TRUE
412030	Mandagery Ck. at Eugowra	MDB-Lachlan		412030				TRUE
412056	Belubula@Needles	MDB-Lachlan	412077-412085-412092-412080-412070	412056				
412068	GoonigalCk at Gooloogong	MDB-Lachlan		412068				TRUE
412070	Cadiangullong Ck. at Panuara	MDB-Lachlan		412070				TRUE
412071	Canodomine Ck. at Canodomine	MDB-Lachlan		412071				TRUE
412072	Back Ck at Koorawatha	MDB-Lachlan		412072				TRUE
412073	Nyrang Ck. at Nyrang	MDB-Lachlan		412073				TRUE
412080	Flyers Ck. at Beneree	MDB-Lachlan		412080				TRUE
412085	Ooma Ck. at Henry Lawson Way	MDB-Lachlan		412085				TRUE
412091	WaugoolaCk U-S Cowra	MDB-Lachlan		412091				TRUE
412092	Coombing Ck. nr. Neville	MDB-Lachlan		412092				TRUE
412165	Belubula @ Bells	MDB-Lachlan	412056-412071	412165				
412169	Back Ck at Cowra	MDB-Lachlan	412072	412169				
412004	Lachlan Forbes	MDB-Lachlan	412057-412068-412030	412004				
412006	Lachlan at Condobolin Br	MDB-Lachlan	412014-412006003	412006				
412024	Dummy node - GoobangCk at Condobolin	MDB-Lachlan	412017	412024-412014002				
412023	Island ck at Fairholme	MDB-Lachlan	412058	412023-412017				
412065	Lachlan@Narrawa	MDB-Lachlan		412065				TRUE
412067	Lachlan@Wyangala	MDB-Lachlan	412065	412067	TRUE			
412077	Belubula@Carcoar	MDB-Lachlan		412077	TRUE			TRUE
4.12E+08	Dummy node - Lachlan at Condobolin Br	MDB-Lachlan	412024	412006002-412006003		TRUE		
412129	Dummy node - Lachlan at Hillston Weir	MDB-Lachlan	4.12E+08	412129		TRUE		
412005	Lachlan at Boologal	MDB-Lachlan	412078	412005		TRUE		
412078	Lachlan at Whealbah	MDB-Lachlan	412039	412078		TRUE		
412011	Lachlan at Lake Cargellico Weir	MDB-Lachlan	412021	412011		TRUE		
412014	GoobangCk at Condobolin	MDB-Lachlan	412014002-412043	412014		TRUE		
412021	Booberoi Ck. Offtake	MDB-Lachlan	412006-412016-412099	412021-412022		TRUE		
412026	Lachlan at Oxley	MDB-Lachlan	412045	412026		TRUE		
412042	Willandra Ck. at Willandra Homestead	MDB-Lachlan	412012	412042		TRUE		

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412043	GoobangCk Darby's Dam	MDB-Lachlan		412043		TRUE		TRUE
412045	Lachlan at Corrong	MDB-Lachlan	412005	412045		TRUE		
412099	Bland Ck. Lake Cowa	MDB-Lachlan		412099		TRUE		TRUE
407289	Nine Mile Ck at Serpentine Ck Offtake	MDB-LoddonAvoca	407232	407289				
408202	Avoca at Amphitheatre	MDB-LoddonAvoca		408202				TRUE
407211	Bet BetCk at Bet Bet	MDB-LoddonAvoca	407288	407211				
407213	McCallumsCk Carisbrook	MDB-LoddonAvoca		407213				TRUE
407221	JIM CROW CREEK @ YANDOIT	MDB-LoddonAvoca		407221				TRUE
407246	BULLOCK CREEK @ MARONG	MDB-LoddonAvoca		407246				TRUE
407288	BET BET CREEK @ LILLICUR	MDB-LoddonAvoca		407288				TRUE
407214	CRESWICK CREEK @ CLUNES	MDB-LoddonAvoca		407214				TRUE
407215	Loddon@Newstead	MDB-LoddonAvoca	407300-407217-407221	407215				
407217	LODDON RIVER @ VAUGHAN @ D/S FRYERS CREEK	MDB-LoddonAvoca		407217				TRUE
407222	TULLAROOP CREEK @ CLUNES	MDB-LoddonAvoca	407227-407214	407222				
407227	BIRCH CREEK @ SMEATON	MDB-LoddonAvoca		407227				TRUE
407230	Joyces Creek at Strathlea	MDB-LoddonAvoca		407230				TRUE
407239	Middle Creek at Rodborough	MDB-LoddonAvoca		407239				TRUE
407253	PICCANINNY CREEK @ MINTO	MDB-LoddonAvoca	407255	407253				
407254	BENDIGO CREEK @ BENDIGO	MDB-LoddonAvoca		407254				TRUE
407255	BENDIGO CREEK @ HUNTLY	MDB-LoddonAvoca	407254	407255				
407258	MYERS CREEK @ MYERS FLAT	MDB-LoddonAvoca		407258				TRUE
407285	NINE MILE CREEK @ COADS ROAD	MDB-LoddonAvoca	407289	407285				
407287	BULLOCK CREEK @ U/S BOX CREEK	MDB-LoddonAvoca	407290	407287				
407290	BULLOCK CREEK AT EAST LODDON	MDB-LoddonAvoca	407246	407290				
407300	MUCKLEFORD CREEK @ MUCKLEFORD NORTH	MDB-LoddonAvoca		407300				TRUE
407248	Tullaroop Creek at Tullarrop Res. (Olet Meas. Weir)	MDB-LoddonAvoca	407222	407248	TRUE			
407210	Loddon R D-S Cairn Curran	MDB-LoddonAvoca	407215-407230-407239	407210	TRUE			
408206	Avoca at Archdale Junction	MDB-LoddonAvoca	408202	408206		TRUE		
408200	Avoca at Coonooer	MDB-LoddonAvoca	408206	408200		TRUE		
408203	Avoca at Quambatook	MDB-LoddonAvoca	408200	408203		TRUE		
407205	Loddon@Appin South	MDB-LoddonAvoca	407224	407205		TRUE		
407224	Loddon River at Loddon Weir	MDB-LoddonAvoca	407229	407224		TRUE		
407202	Loddon@Kerang	MDB-LoddonAvoca	407287-407285-407205-407236	407202		TRUE		
407229	Loddon River at Serpentine Weir	MDB-LoddonAvoca	407203	407229-407232		TRUE		
407236	MOUNT HOPE CREEK @ MITIAMO	MDB-LoddonAvoca	407253-407258	407236		TRUE		
407203	Loddon R D-S Laanecoorie	MDB-LoddonAvoca	407210-407248-407213-407211	407203	TRUE	TRUE		
421004	Macquarie Warren Weir	MDB-MacquarieCastlereagh	421031	421004-421005			TRUE	
421019	Cudgegong@Yamble Br	MDB-MacquarieCastlereagh	421079	421019			TRUE	
421022	Macquarie at Oxley stn	MDB-MacquarieCastlereagh	421090	421022-421146-421145		TRUE	TRUE	
421031	Macquarie at Gin Gin	MDB-MacquarieCastlereagh	421006	421031			TRUE	

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421090	Marebone Break at Marebone regulator	MDB-MacquarieCastlereagh	421004-421063	421090-421088-421097		TRUE	TRUE	
421127	Macquarie at Baroona	MDB-MacquarieCastlereagh	421163-421001-421055	421127			TRUE	
420004	Castlereagh@Mendooran	MDB-MacquarieCastlereagh		420004				TRUE
420010	WallumburrawangCk @ Bearbung	MDB-MacquarieCastlereagh		420010				TRUE
420014	MagometonCk (Site 3) near Coonamble	MDB-MacquarieCastlereagh		420014				TRUE
420015	WarrenaCk @ Warrana	MDB-MacquarieCastlereagh		420015				TRUE
421003	Macquarie at Wellington	MDB-MacquarieCastlereagh	421040	421003				
421018	Bell@Newrea	MDB-MacquarieCastlereagh		421018				TRUE
421026	Turon River @ Sofala	MDB-MacquarieCastlereagh		421026				TRUE
421048	Little at Obley 2	MDB-MacquarieCastlereagh		421048				TRUE
421059	BuckinbahCk at Yeoval	MDB-MacquarieCastlereagh		421059				TRUE
421066	Green Valley Ck Hill end	MDB-MacquarieCastlereagh		421066				TRUE
421072	Winburndale Rivulet Howards Br	MDB-MacquarieCastlereagh		421072				TRUE
421076	Bogan@Peak Hill No.2	MDB-MacquarieCastlereagh		421076				TRUE
421100	PyramulCk U/S Hill end Rd	MDB-MacquarieCastlereagh		421100				TRUE
421101	Campbells River at U/S Ben Chifley dam	MDB-MacquarieCastlereagh		421101				TRUE
421132	Monkeygarck D-S Gibson way	MDB-MacquarieCastlereagh	421169	421132				
421163	Talbragar at Emanon	MDB-MacquarieCastlereagh	421042	421163				
421165	Beni BillaCk D-S Canonba Rd	MDB-MacquarieCastlereagh		421165				TRUE
420005	Castlereagh@Coonamble	MDB-MacquarieCastlereagh	420004-420010	420005				
421006	Macquarie at Narromine	MDB-MacquarieCastlereagh	421127	421006				
421017	GunningbarCk Weir	MDB-MacquarieCastlereagh	421005	421017-421020				
421025	Macquarie@Bruinbun	MDB-MacquarieCastlereagh	421072-421101	421025				
421042	Talbragar@ElongElong	MDB-MacquarieCastlereagh		421042				TRUE
421055	Coolbaggie at Rawsonvil	MDB-MacquarieCastlereagh		421055				TRUE
421063	Ewenmarck at Warren	MDB-MacquarieCastlereagh		421063				TRUE
421129	Monkeygarck u-s western Arm Monkey cr	MDB-MacquarieCastlereagh	421022	421129				
421138	Bogan@Nyngan	MDB-MacquarieCastlereagh	421039	421138				
421164	Duck Ck at Napali	MDB-MacquarieCastlereagh		421164				TRUE
421166	Gunningbar at Fview	MDB-MacquarieCastlereagh	421017	421166				
421001	Macquarie@Dubbo	MDB-MacquarieCastlereagh	421003-421018-421048-421059	421001				
421069	Bogan at Broomfield	MDB-MacquarieCastlereagh	421138-421166	421069				
421169	Breakaway offtake	MDB-MacquarieCastlereagh	421129	421169				
421079	Cudgegong@D/S Windamere Dam	MDB-MacquarieCastlereagh		421079	TRUE			TRUE

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420020	Castlereagh@Gungalmn	MDB-MacquarieCastlereagh	420005-420015-420014	420020		TRUE		
421011	Marthaguyck at Carinda	MDB-MacquarieCastlereagh	421153	421011		TRUE		
421012	Macquarie@Carinda (Bells Br)	MDB-MacquarieCastlereagh	421135	421012		TRUE		
421023	Bogan@Gongolgon	MDB-MacquarieCastlereagh	421158	421023		TRUE		
421039	Bogan@Neurie Plains	MDB-MacquarieCastlereagh	421076	421039		TRUE		
421135	Macquarie@Miltara	MDB-MacquarieCastlereagh	421147	421135-421108		TRUE		
421107	MarraCk@Billybingbone	MDB-MacquarieCastlereagh	421097	421107		TRUE		
421147	Macquarie Pillicawarrina	MDB-MacquarieCastlereagh	421118-421132	421147		TRUE		
421152	Gum Cowal at Oxley	MDB-MacquarieCastlereagh	421146	421152		TRUE		
421153	Terrigal ck u-s Marthaguyck	MDB-MacquarieCastlereagh	421152	421153		TRUE		
421158	Bogan at Monkey Br	MDB-MacquarieCastlereagh	421069-421164-421165	421158		TRUE		
421118	Bulgeragack Gibson way	MDB-MacquarieCastlereagh	421145	421118		TRUE		
421040	Macquarie@D/S Burrendong Dam	MDB-MacquarieCastlereagh	421019-421066-421100-421025-421026	421040	TRUE	TRUE		
417204	Moonie@Fenton	MDB-Moonie	417201	417204		TRUE		
417001	Moonie@Gundablouie	MDB-Moonie	417204	417001		TRUE		
417201	Moonie@Nindigully	MDB-Moonie		417201		TRUE		TRUE
A4261014	North Rhyne near Kappalunta	MDB-Mountlofty		A4261014				TRUE
A4261030	Marne @1KM D/S Jutland Rd Cross	MDB-Mountlofty		A4261030				TRUE
A4260605	Marne River at Marne Gorge	MDB-Mountlofty	A4261014-A4261030	A4260605				
A4260679	Mount Barker Creek upstream Bremer River Confluence	MDB-Mountlofty		A4260679				TRUE
A4260533	Bremer River near Hartley	MDB-Mountlofty	A4260679	A4260533				
A4261070	Bremer River at Bletchley Road	MDB-Mountlofty	A4260533	A4261070				
A4261072	Bremer River at Ballandown Road	MDB-Mountlofty	A4261070	A4261072				
A4260503	Angas River at Angas Weir	MDB-Mountlofty		A4260503				TRUE
A4261074	Angas River at Cheriton Road	MDB-Mountlofty	A4260503	A4261074				
A4260504	Finniss River 4km East of Yundi	MDB-Mountlofty		A4260504				
A4261075	Finniss River at Ford Road	MDB-Mountlofty	A4260504	A4261075				
A4260530	Currency Creek near Higgins	MDB-Mountlofty		A4260530				TRUE
A4261099	Currency Creek near Cemetery	MDB-Mountlofty	A4260530	A4261099				
409023	Edward D-S Stevens Weir	MDB-Murray	409003	409023-409020-409019			TRUE	
409202	Murray@Tocumwal	MDB-Murray	409002-403241-403247	409202	TRUE	TRUE	TRUE	
409207	Murray@Torrumbarry	MDB-Murray	405297-406263-406265-409215-405232	409207		TRUE	TRUE	
409075	BullataleCk U/S Edward	MDB-Murray		409075				TRUE
401013	Jingellic at Jingellc	MDB-Murray		401013				TRUE
401210	Snowy Ck at Granite Flat	MDB-Murray		401210				TRUE
401218	Tallangatta Creek at Bullioh	MDB-Murray		401218				TRUE
402204	Yackandandah Ck at Osbornes Flat	MDB-Murray		402204				TRUE

Reach ID	Name of main outlet	Region	ID(s) of inflow node(s)	ID(s) of outflow node(s)	Has Reservoir?	Has floodplain?	Has irrigation diversion?	Headwater catchment?
401012	Murray@Biggara	MDB-Murray		401012				TRUE
401014	Tooma at Pinegrove	MDB-Murray		401014				TRUE
401015	Bowna at Yambla	MDB-Murray		401015				
401202	Mitta Mitta River at Mitta Mitta	MDB-Murray	401211	401202				
401203	Mitta Mitta@Hinnomunjie	MDB-Murray		401203				TRUE
401230	Corryong Ck at Towong	MDB-Murray		401230				TRUE
402203	Kiewa@Mongans Br	MDB-Murray		402203				TRUE
402205	Kiewa@Bandiana	MDB-Murray	402222-402220-402204	402205				
403247	Black Dog Ck Ups@	MDB-Murray		403247				TRUE
403248	Indigo ck at Creamery brdg	MDB-Murray		403248				TRUE
405297	Warrigal Creek at Stewarts Bridge	MDB-Murray		405297				TRUE
406263	Mullers Creek at Murray Valley Highway	MDB-Murray		406263				TRUE
407252	Barr Creek at Capels Flume	MDB-Murray	407299	407252				
409013	Wakool @ Stoney Crossing	MDB-Murray	409061-409036	409013				
409015	Gulpa at Mathoura	MDB-Murray	409030	409015				
409017	Murray@Doctors Point	MDB-Murray	409016-402205	409017				
425007	Darling@Burtundy	MDB-Murray	425006	425007				
425012	Darling@Menindee Weir 32	MDB-Murray	425001-425044	425012				
409036	MerranCk U/S Wakool Junction	MDB-Murray		409036		TRUE		TRUE
425005	Darling at Pooncarie	MDB-Murray	425012-425018	425005-425019002		TRUE		
409008	Murray @ Gulpa	MDB-Murray	409202	409008-409030-409006		TRUE		
409005	Murray @ Barham	MDB-Murray	409207	409005-407299		TRUE		
409014	Edward@Moulamein	MDB-Murray	410053-409014002	409014		TRUE		
414201	Murray@Boundary Bend	MDB-Murray	414200-410130	414201		TRUE		
A4260507	Lindsay River at U-S of Lake Walla Walla	MDB-Murray	A4260505	A4260507		TRUE		
425013	Great Darling Anabranch@Wycot	MDB-Murray	425019	425013		TRUE		
A4260505	Murray at Lock 9	MDB-Murray	425011-425010	A4260505-426502		TRUE		
414218	Murray at Lock 7	MDB-Murray	A4260507	414218-A4260508		TRUE		
A4260511	Murray at Lock 6	MDB-Murray	A4260508-426502-414218	A4260511		TRUE		
A4260515	Murray at Lock 4	MDB-Murray	A4260511	A4260515		TRUE		
A4260516	Murray at Lock 3	MDB-Murray	A4260515	A4260516		TRUE		
A4260518	Murray at Lock 2	MDB-Murray	A4260516	A4260518		TRUE		
A4260902	Murray at Lock 1	MDB-Murray	A4260518	A4260902		TRUE		
A4261162	Murray at Murray bridge	MDB-Murray	A4260902-A4260605	A4261162		TRUE		
401201	Murray@Jingellic	MDB-Murray	401012-401230-401014	401201		TRUE		
401204	Mitta Mitta@Tallandoon	MDB-Murray	401202-401210	401204		TRUE		
402222	Kiewa@Kiewa (Main Stream)	MDB-Murray	402203	402222-402220		TRUE		
409002	Murray@Corowa	MDB-Murray	409017-403248	409002		TRUE		
409003	Edward at Deniliquin	MDB-Murray	409056-409047-409075	409003		TRUE		
409048	Dummy node - Edward@Moulamein	MDB-Murray	409023	409048-409014002		TRUE		

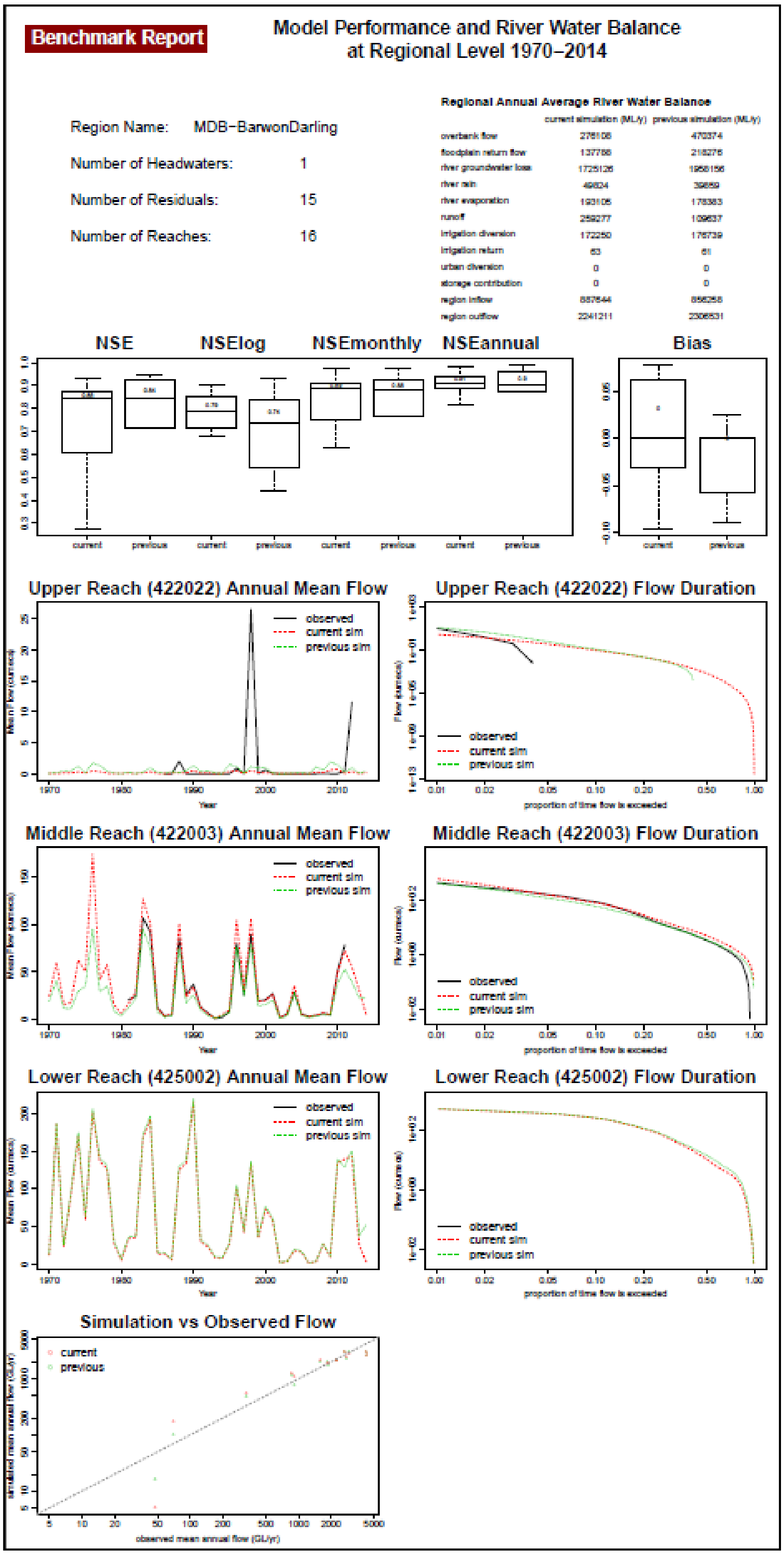
Reach ID	Name of main outlet	Region	ID(s) of inflow node(s)	ID(s) of outflow node(s)	Has Reservoir?	Has floodplain?	Has irrigation diversion?	Headwater catchment?
409034	Wakool at Kyalie	MDB-Murray	409035-409013	409034		TRUE		
409035	Edward @ liewah	MDB-Murray	409014	409035		TRUE		
409047	Edward@Toonalook	MDB-Murray	409015-409008	409047		TRUE		
409056	TuppalCk@Aratula Rd	MDB-Murray		409056		TRUE		TRUE
409061	Wakool @ Coonamit Br.	MDB-Murray	409019-409020-409048	409061		TRUE		
409204	Murray@Swan Hill	MDB-Murray	407252-407202-409005	409204		TRUE		
409215	Murray@Barmah	MDB-Murray	409006-404210	409215		TRUE		
409235	Murray at Piambie Pumps	MDB-Murray	409204	409235		TRUE		
414200	Murray@below Wakool Junction	MDB-Murray	409034-409235	414200		TRUE		
414203	Murray@Euston	MDB-Murray	414201	414203		TRUE		
414204	MURRAY RIVER @ RED CLIFFS	MDB-Murray	414207	414204		TRUE		
414207	Murray@Colignan	MDB-Murray	414203	414207		TRUE		
414210	MURRAY RIVER @ LOCK 11 MILDURA (HEAD GAUGE)	MDB-Murray	414204	414210		TRUE		
425006	Darling at Studley	MDB-Murray	425005	425006		TRUE		
425010	Murray@Lock No. 10 (Wentworth)	MDB-Murray	414210-425007	425010		TRUE		
425011	Great Darling Anabranch@Bulpunga	MDB-Murray	425013	425011		TRUE		
425019	Redbank Ck at D-S Packers Crossing	MDB-Murray	425014-425019002	425019		TRUE		
425014	Darling at Menindee Town	MDB-Murray	425002	425014-425001-425044	TRUE	TRUE		
401211	Mitta Mitta@Colemans	MDB-Murray	401203	401211	TRUE	TRUE		
409016	Murray@D/S Hume Weir (Heywoods)	MDB-Murray	401013-401204-401015-401218-401201	409016	TRUE	TRUE		
410001	Murrumbidgee@Wagga Wagga	MDB-Murrumbidgee	410004-410061-410043-410045-410047-410048	410001		TRUE	TRUE	
410002	Murrumbidgee at Hay	MDB-Murrumbidgee	410078	410002		TRUE	TRUE	
410003	Murrumbidgee at Balranald	MDB-Murrumbidgee	410041	410003		TRUE	TRUE	
410004	Murrumbidgee@Gundagai	MDB-Murrumbidgee	410038-410039-410044-410068-410025	410004			TRUE	
410017	Billabong Ck at Conargo	MDB-Murrumbidgee	410169-410168	410017		TRUE	TRUE	
410021	Murrumbidgee@Darlington Point	MDB-Murrumbidgee	410082	410021		TRUE	TRUE	
410023	Murrumbidgee at Berembed Weir	MDB-Murrumbidgee	410001-410103	410023		TRUE	TRUE	
410036	Murrumbidgee Yanco Weir	MDB-Murrumbidgee	410005	410036-410007			TRUE	
410040	Murrumbidgee @ Maude Weir	MDB-Murrumbidgee	410136	410040		TRUE	TRUE	
410041	Murrumbidgee D-S Redbank Weir	MDB-Murrumbidgee	410040	410041		TRUE	TRUE	
410078	Murrumbidgee at Carrathool	MDB-Murrumbidgee	410021	410078		TRUE	TRUE	
410082	Murrumbidgee D-S Gogelderie Weir	MDB-Murrumbidgee	410036	410082			TRUE	
410169	Yanco Ck at Yanco Br	MDB-Murrumbidgee	410015	410169		TRUE	TRUE	
410006	Tumut@Tumut	MDB-Murrumbidgee	410073-410057	410006				
410025	Jugiong Ck at Jugiong	MDB-Murrumbidgee		410025				TRUE
410038	Adjungbilly Dbalara	MDB-Murrumbidgee		410038				TRUE
410039	Tumut@Brungle Br	MDB-Murrumbidgee	410006-410059-410070-410071	410039				
410043	HillisCk Mount Adrah	MDB-Murrumbidgee		410043				TRUE
410045	BillabungCk at Sunnyside	MDB-Murrumbidgee		410045				TRUE

Reach ID	Name of main outlet	Region	ID(s) of inflow node(s)	ID(s) of outflow node(s)	Has Reservoir?	Has floodplain?	Has irrigation diversion?	Headwater catchment?
410047	Tarcutta @ Borambola	MDB-Murrumbidgee		410047				TRUE
410048	KyeambaCk at Ladysmith	MDB-Murrumbidgee		410048				TRUE
410059	Gilmore Ck at Gilmore	MDB-Murrumbidgee		410059				TRUE
410061	Adelong Ck Batlow Rd	MDB-Murrumbidgee		410061				TRUE
410062	Numeralla	MDB-Murrumbidgee		410062				TRUE
410067	Big Badja at Numeralla	MDB-Murrumbidgee		410067				TRUE
410068	Murrumbidgee at Glendale	MDB-Murrumbidgee	410008	410068				
410070	BombowleeCk at Bombowlee	MDB-Murrumbidgee		410070				TRUE
410071	Brungle Ck at Red Hill	MDB-Murrumbidgee		410071				TRUE
410076	Jerangle Road	MDB-Murrumbidgee		410076				TRUE
410077	Bredbo	MDB-Murrumbidgee		410077				TRUE
410101	Murrumbidgee at Pine Island	MDB-Murrumbidgee	410050-410077-410076-410141	410101				
410107	Mountain Ck at Mountain Ck	MDB-Murrumbidgee		410107				TRUE
410133	Coleambally Outfall Drain near Bundy	MDB-Murrumbidgee	410157	410133				
410141	Michelago	MDB-Murrumbidgee		410141				TRUE
410176	Yass @ U/S B/Juck	MDB-Murrumbidgee	410026	410176				
410014	Colombo creek @ Morunda	MDB-Murrumbidgee	410007	410014-410015				
410024	Goodradigbee@Wee Jasper (Kashmir)	MDB-Murrumbidgee		410024				TRUE
410026	Yass_(Yass_River)	MDB-Murrumbidgee		410026				TRUE
410033	Murrumbidgee@Mittagang Crossing	MDB-Murrumbidgee		410033				TRUE
410044	Muttama Ck @ Coolac	MDB-Murrumbidgee		410044				TRUE
410050	Murrumbidgee@Billilingra	MDB-Murrumbidgee	410033-410062-410067	410050				
410057	Gooba/GndraLacmalac	MDB-Murrumbidgee		410057				TRUE
410103	HoulaghansCk at Downside	MDB-Murrumbidgee		410103				TRUE
410130	Murrumbidgee@D/S Balranald Weir	MDB-Murrumbidgee	410003	410130				
410136	Murrumbidgee@D/S Hay Weir	MDB-Murrumbidgee	410002	410136				
410073	Tumut@Oddys Br	MDB-Murrumbidgee		410073	TRUE			TRUE
410093	Old Man Ck at Kywong	MDB-Murrumbidgee		410093		TRUE		TRUE
410157	Coleambally Outfall Drain at Booroorban	MDB-Murrumbidgee		410157		TRUE		TRUE
410012	Billabong CkCocketgedong	MDB-Murrumbidgee		410012		TRUE		TRUE
410016	Billabong Ck@Jerilderie	MDB-Murrumbidgee	410170	410016		TRUE		
410053	Billabong Ck at Bundy	MDB-Murrumbidgee	410017-410133-410148	410053		TRUE		
410005	Murrumbidgee at Narrendera	MDB-Murrumbidgee	410023-410093	410005		TRUE		
410168	Billabong Ck D-S Hartwood Weir	MDB-Murrumbidgee	410016	410168-410148		TRUE		
410170	BillabobgCk U-S Innes Br	MDB-Murrumbidgee	410014-410012	410170		TRUE		
410008	Murrumbidgee@Burrinjuck Dam	MDB-Murrumbidgee	410024-410176-410107-410101	410008	TRUE	TRUE		
419021	Namoi@Bugilbone (Riverview)	MDB-Namoi	419061-419068	419021		TRUE	TRUE	
419026	Namoi@Goangra	MDB-Namoi	419021-419072	419026		TRUE	TRUE	
419059	GunidgeraCk at D-S Reg	MDB-Namoi	419039	419059-419061-419061002			TRUE	
419068	Namoi@D/S Weeta Weir	MDB-Namoi	419059	419068			TRUE	

Reach ID	Name of main outlet	Region	ID(s) of inflow node(s)	ID(s) of outflow node(s)	Has Reservoir?	Has floodplain?	Has irrigation diversion?	Headwater catchment?
419089	Pian at DempseysBrdg	MDB-Namoi	419088	419089			TRUE	
419016	Cockburn_R_@Mulla_Crossing	MDB-Namoi		419016				TRUE
419088	PianCk @ Cubbaroo	MDB-Namoi	4.19E+08	419088				
419029	Ukolan	MDB-Namoi		419029				TRUE
419032	Coxs_Ck_@Boggabri	MDB-Namoi		419032				TRUE
419035	Timbumburi	MDB-Namoi		419035				TRUE
419051	Avoca_East	MDB-Namoi		419051				TRUE
419072	Kienbri_No.2	MDB-Namoi		419072				TRUE
419005	Namoi@NorthCuerindi	MDB-Namoi		419005				TRUE
419015	Peel@Piallamore	MDB-Namoi	419045	419015				
419020	Manilla@Brabri (Merriwee)	MDB-Namoi	419043	419020				
419022	Namoi@Manilla Railway Br	MDB-Namoi	419020-419005-419029	419022				
419024	Peel@Paradise Weir	MDB-Namoi	419015-419016	419024				
419049	Pian @ Waminda	MDB-Namoi	419089	419049				
419043	Manilla@D/S Split Rock Dam	MDB-Namoi		419043	TRUE			TRUE
419045	Peel@D/S Chaffey Dam	MDB-Namoi		419045	TRUE			TRUE
419001	Namoi@Gunnedah	MDB-Namoi	419007-419006-419027	419001		TRUE		
419003	Narrabri Ck@Narrabri	MDB-Namoi	419012-419051	419003		TRUE		
419006	Peel@Carrol Gap	MDB-Namoi	419024-419035	419006		TRUE		
419012	Namoi@Boggabri	MDB-Namoi	419001-419032	419012		TRUE		
419027	Mooki@Breeza	MDB-Namoi		419027		TRUE		
419039	Namoi @ Mollee	MDB-Namoi	419003	419039		TRUE		
419091	Namoi@Walgett	MDB-Namoi	419026-419049	419091		TRUE		
419007	Namoi@D/S Keepit Dam	MDB-Namoi	419022	419007	TRUE	TRUE		
403236	Barwidgeeck at Myrtleford	MDB-Ovens		403236				TRUE
403205	Ovens Rivers@Bright	MDB-Ovens		403205				TRUE
403209	Reedy ck at Wangaratta North	MDB-Ovens		403209				TRUE
403210	Ovens@Myrtleford	MDB-Ovens	403205-403233	403210				
403214	Happy Valley Ck at Rosewhite	MDB-Ovens		403214				TRUE
403220	Buffalo at Lake Buffalo	MDB-Ovens		403220				TRUE
403223	King at Docker Rd Br	MDB-Ovens	403240-403226	403223				
403224	Hurdle Ck at Bobinawarrah	MDB-Ovens		403224				TRUE
403226	Boggy Ck at Angleside	MDB-Ovens		403226				TRUE
403227	King at Cheshunt	MDB-Ovens	403228	403227				
403230	Ovens at Rocky Point	MDB-Ovens	403214-403236-403210-403220	403230				
403233	Buckland R at Harris Lane	MDB-Ovens		403233				TRUE
403240	King at Edi	MDB-Ovens	403227	403240				
403249	THREE MILE CREEK D-S YARRAWONGA RD at WANGARATTA	MDB-Ovens		403249				TRUE
403228	King at Lake William Hovell	MDB-Ovens		403228	TRUE			TRUE
403200	Ovens@Wangaratta (Combined Flow)	MDB-Ovens	403230-403223-403224	403200		TRUE		
403241	Ovens@Peechelba	MDB-Ovens	403200-403249-403209	403241		TRUE		
424202	Paroo River @ Yarronvale	MDB-Paroo		424202		TRUE		

Reach ID	Name of main outlet	Region	ID(s) of inflow node(s)	ID(s) of outflow node(s)	Has Reservoir?	Has floodplain?	Has irrigation diversion?	Headwater catchment?
424002	Paroo@Willara Crossing	MDB-Paroo	424201	424002		TRUE		
424001	Paroo@Wanaaring	MDB-Paroo	424002	424001		TRUE		
424201	Paroo@Caiwarro	MDB-Paroo	424202	424201		TRUE		
423002	Warrego@Fords Br (Main Channel	MDB-Warrego	423004	423002-423001		TRUE		
423201	Warrego R @ Charleville	MDB-Warrego	423204	423201		TRUE		
423203	Warrego@Wyandra	MDB-Warrego	423201-423205	423203		TRUE		
423204	Warrego@Augathella	MDB-Warrego		423204		TRUE		
423205	Binnowee_TM	MDB-Warrego		423205		TRUE		
423206	Warrego@Wallen	MDB-Warrego	423203	423206		TRUE		
423005	Warrego@Barringun	MDB-Warrego	423202	423005-423004		TRUE		
423202	Warrego@Cunnamulla	MDB-Warrego	423206	423202		TRUE		
415200	Wimmera@Horsham	MDB-Wimmera	415201-415223-415203	415200				
415201	Wimmera@Glenorchy Weir Tail Gauge	MDB-Wimmera	415206-415237	415201				
415202	Mackenzie at Wartook Reservoir	MDB-Wimmera		415202				TRUE
415203	Mt William Creek at Lake Lonsdale (Tail Gauge)	MDB-Wimmera	415214-415252	415203				
415206	Wimmera@Glynwylln	MDB-Wimmera	415238-415245-415207	415206				
415207	Wimmera at Eversley	MDB-Wimmera		415207				TRUE
415214	FyansCk at Lake Bellfield	MDB-Wimmera		415214				TRUE
415220	Avon River at Wimmera Highway	MDB-Wimmera		415220				TRUE
415226	Richardson River at Carrs Plains	MDB-Wimmera		415226				TRUE
415237	ConcongellaCk at Stawell	MDB-Wimmera		415237				TRUE
415238	Wattle Ck at Navarre	MDB-Wimmera		415238				TRUE
415245	Mount Cole Ck at Crowlands	MDB-Wimmera		415245				TRUE
415246	Wimmera@Lochiel Railway Br	MDB-Wimmera	415256	415246				
415247	Wimmera at Tarrenyurk	MDB-Wimmera	415246	415247				
415223	Mackenzie at Mckenzie Creek	MDB-Wimmera	415202	415223-415251				
415252	Mt William Ck at Mokepilly	MDB-Wimmera		415252				
415256	Wimmera at U-S of Dimboola	MDB-Wimmera	415251-415200	415256				
415257	Richardson River at Donald	MDB-Wimmera	415226-415220	415257				

Appendix 2: Benchmarking Report on AWRA-R v5.0 performance for different regions of MDB



Benchmark Report

Model Performance and River Water Balance at Regional Level 1970–2014

Region Name: MDB–BorderRivers

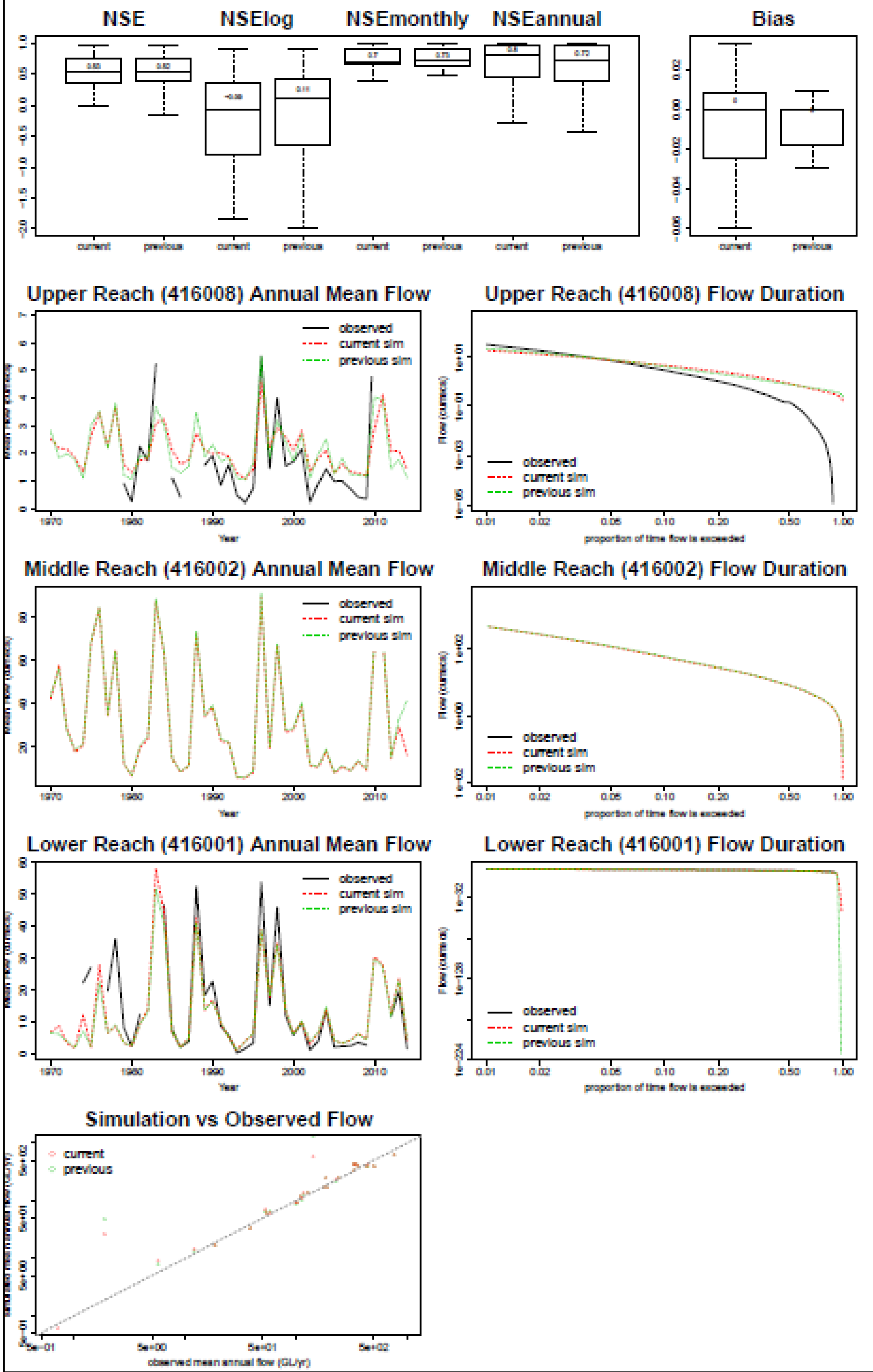
Number of Headwaters: 14

Number of Residuals: 18

Number of Reaches: 32

Regional Annual Average River Water Balance

	current simulation (ML/y)	previous simulation (ML/y)
overbank flow	58428	52196
floodplain return flow	41253	38555
river groundwater loss	667530	355935
river rain	41358	45925
river evaporation	81556	85416
runoff	1294544	1545458
irrigation diversion	133446	134634
irrigation return	10733	10895
urban diversion	0	0
storage contribution	31755	69300
region inflow	0	0
region outflow	415523	397266



Benchmark Report

Model Performance and River Water Balance at Regional Level 1970−2014

Region Name: MDB−Campaspe

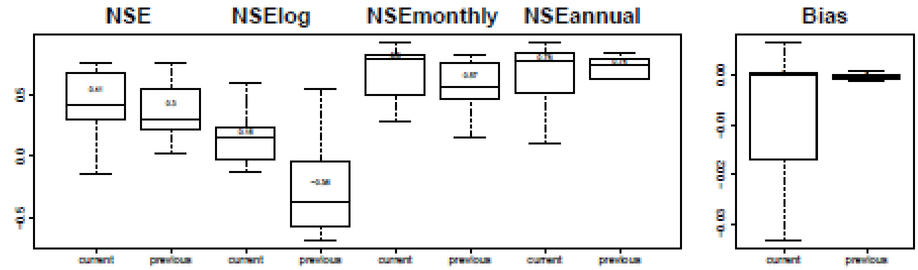
Number of Headwaters: 6

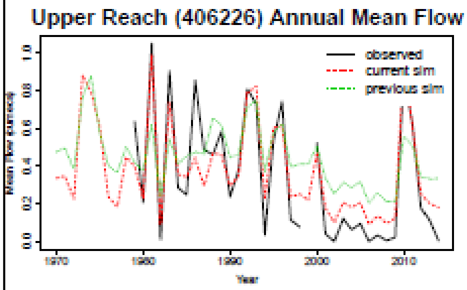
Number of Residuals: 5

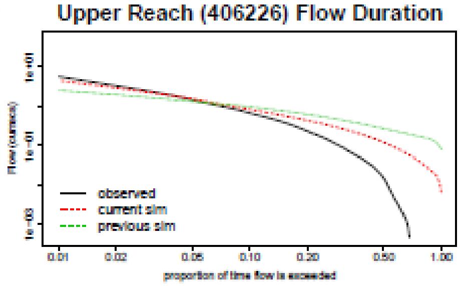
Number of Reaches: 11

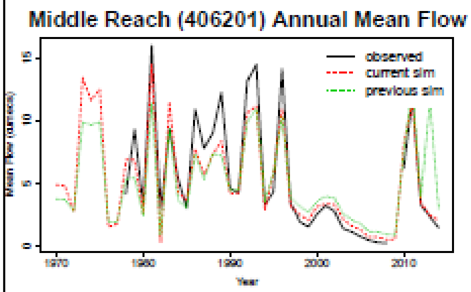
Regional Annual Average River Water Balance

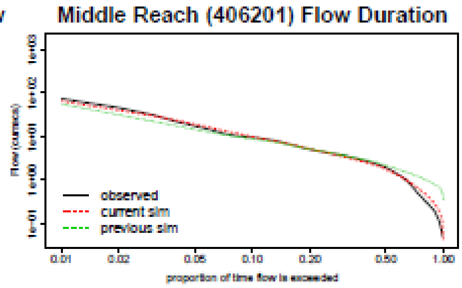
	current simulation (ML/y)	previous simulation (ML/y)
overbank flow	26962	26410
floodplain return flow	22570	17167
river groundwater loss	145187	165316
river rain	2389	2556
river evaporation	4759	5262
runoff	236711	263187
irrigation diversion	0	0
irrigation return	0	0
urban diversion	0	0
storage contribution	6794	59695
region inflow	0	0
region outflow	157584	159168

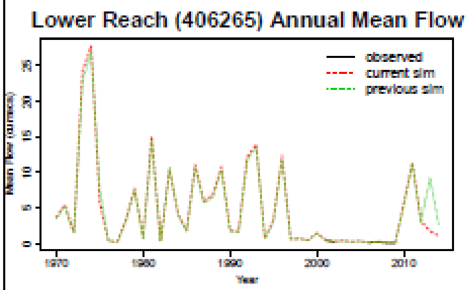


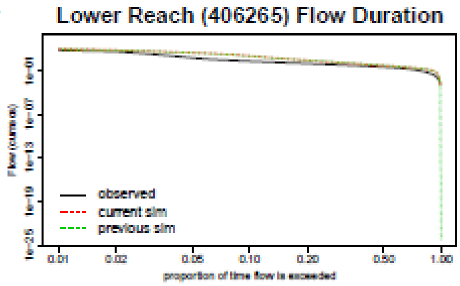


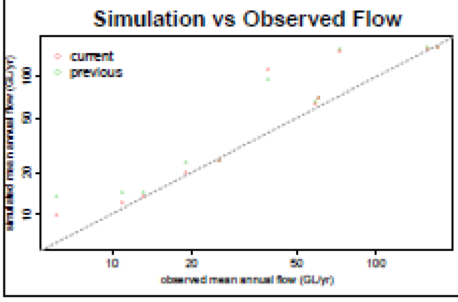


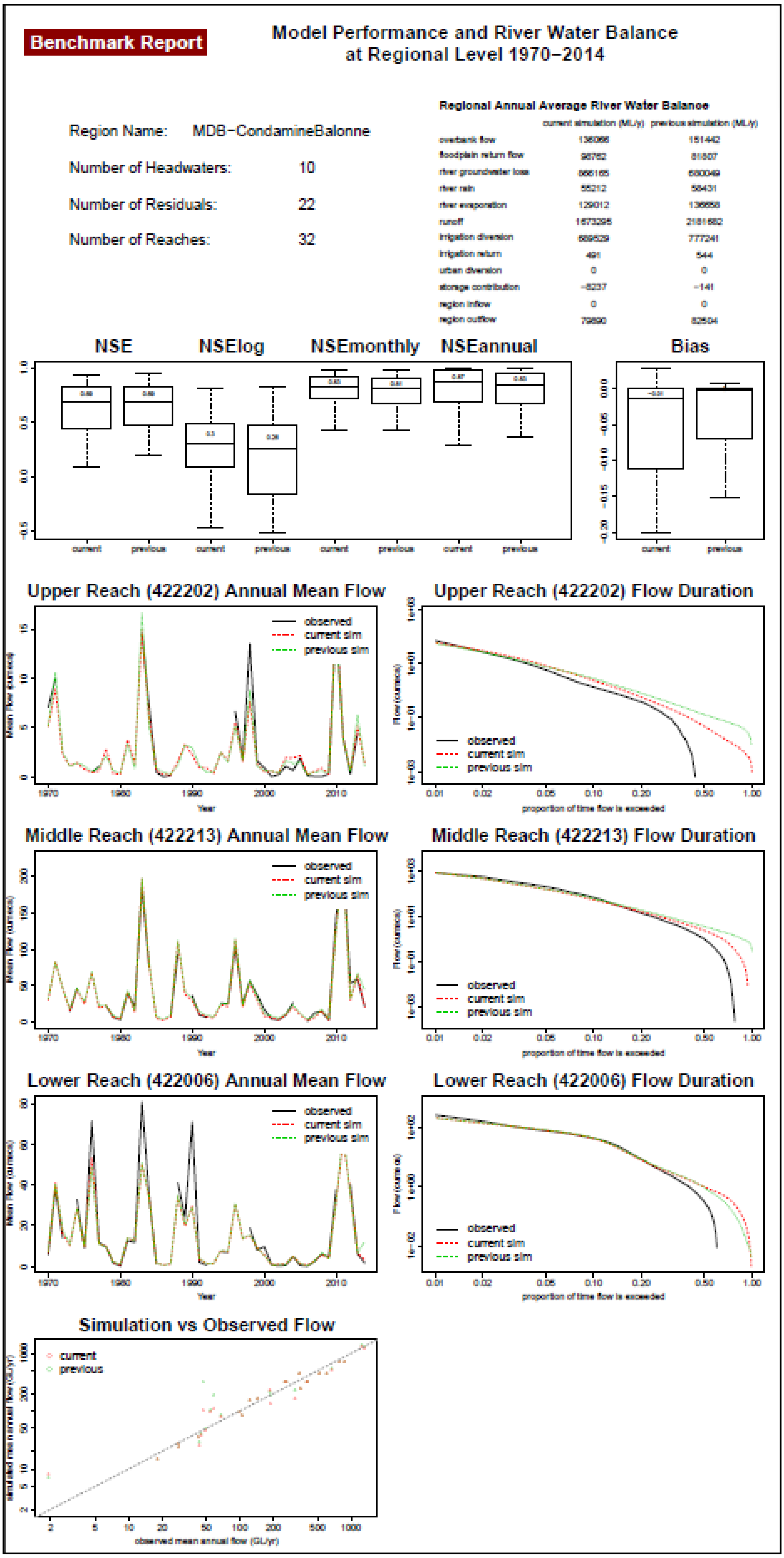


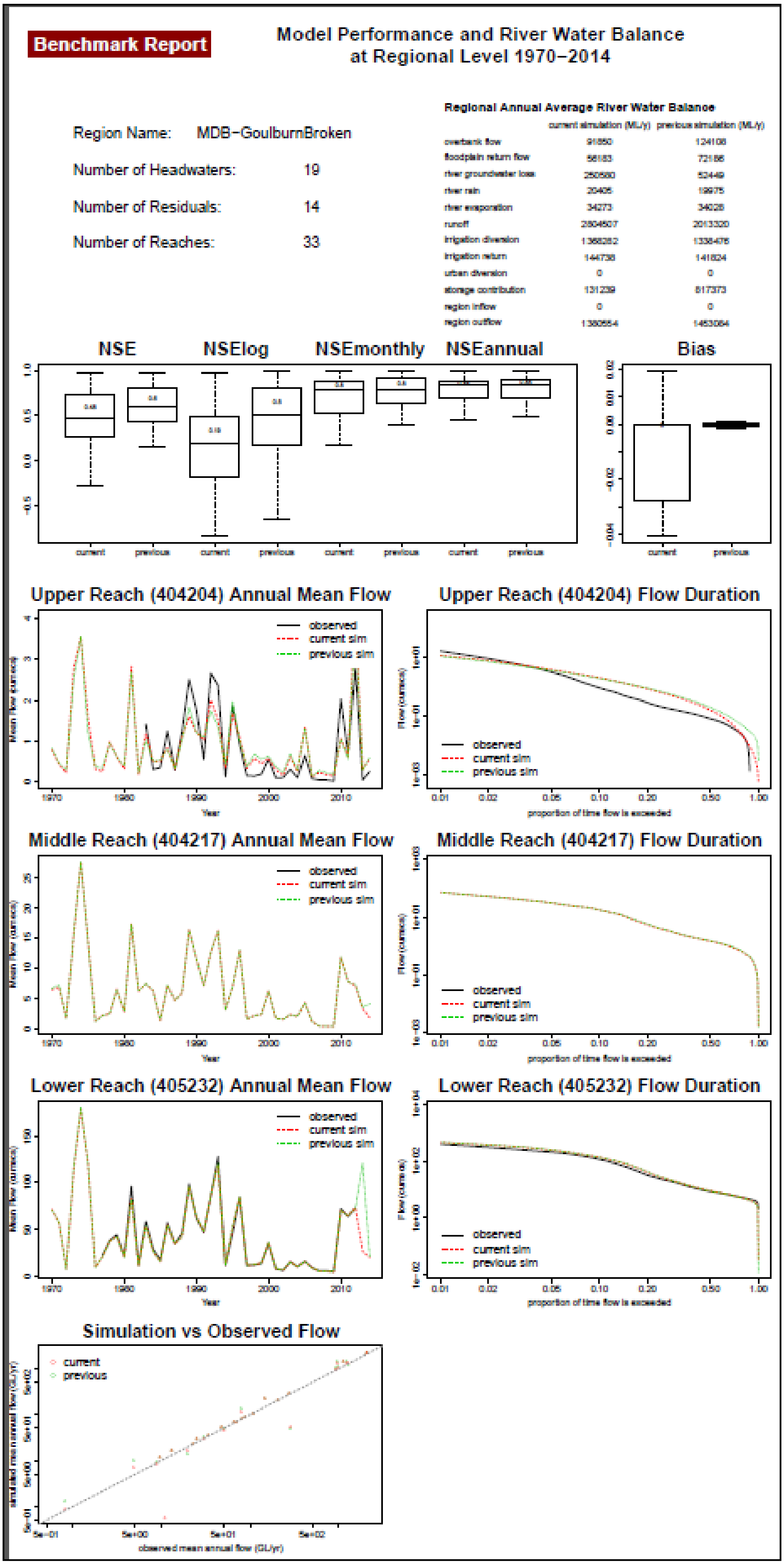









Benchmark Report
Model Performance and River Water Balance
at Regional Level 1970−2014
Region Name: MDB−CondamineBalonne
Number of Headwaters: 10
Number of Residuals: 22
Number of Reaches: 32
Regional Annual Average River Water Balance
current simulation (ML/y) previous simulation (ML/y)
overbank flow 136066 151442
floodplain return flow 98762 81807
river groundwater loss 866165 880049
river rain 55212 58431
river evaporation 129012 136658
runoff 1673295 2181682
irrigation diversion 689529 777241
irrigation return 491 544
urban diversion 0 0
storage contribution −8237 −141
region inflow 0 0
region outflow 79690 82504
NSE
NSElog
NSEmonthly
NSEannual
Bias
current
previous
Upper Reach (422202) Annual Mean Flow
Upper Reach (422202) Flow Duration
Middle Reach (422213) Annual Mean Flow
Middle Reach (422213) Flow Duration
Lower Reach (422006) Annual Mean Flow
Lower Reach (422006) Flow Duration
observed
current sim
previous sim
Year
proportion of time flow is exceeded
Simulation vs Observed Flow
observed mean annual flow (GL/yr)


Benchmark Report
Model Performance and River Water Balance
at Regional Level 1970–2014
Region Name: MDB–GoulburnBroken
Number of Headwaters: 19
Number of Residuals: 14
Number of Reaches: 33
Regional Annual Average River Water Balance
current simulation (ML/y) previous simulation (ML/y)
overbank flow 91850 124108
floodplain return flow 58183 72186
river groundwater loss 250580 52449
river rain 20405 19975
river evaporation 34273 34028
runoff 2804507 2013320
irrigation diversion 1368282 1338476
irrigation return 144738 141824
urban diversion 0 0
storage contribution 131239 817373
region inflow 0 0
region outflow 1380554 1453084
NSE
NSElog
NSEmonthly
NSEannual
Bias
current
previous
Upper Reach (404204) Annual Mean Flow
Upper Reach (404204) Flow Duration
Middle Reach (404217) Annual Mean Flow
Middle Reach (404217) Flow Duration
Lower Reach (405232) Annual Mean Flow
Lower Reach (405232) Flow Duration
observed
current sim
previous sim
Mean flow (cumecs)
Flow (cumecs)
Year
proportion of time flow is exceeded
Simulation vs Observed Flow
simulated mean annual flow (GL/yr)
observed mean annual flow (GL/yr)

Benchmark Report

Model Performance and River Water Balance at Regional Level 1970–2014

Region Name: MDB−Gwydir

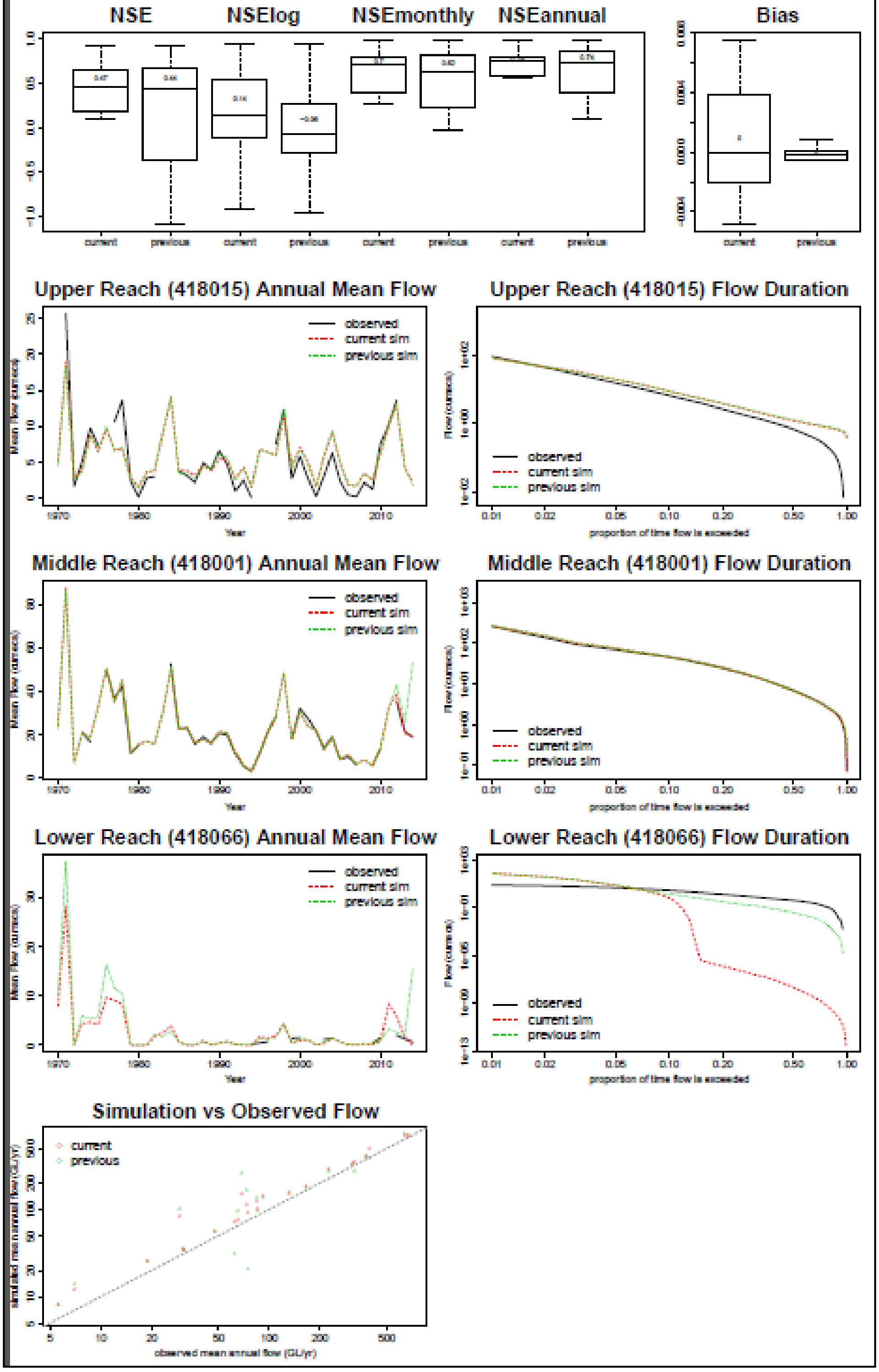
Number of Headwaters: 8

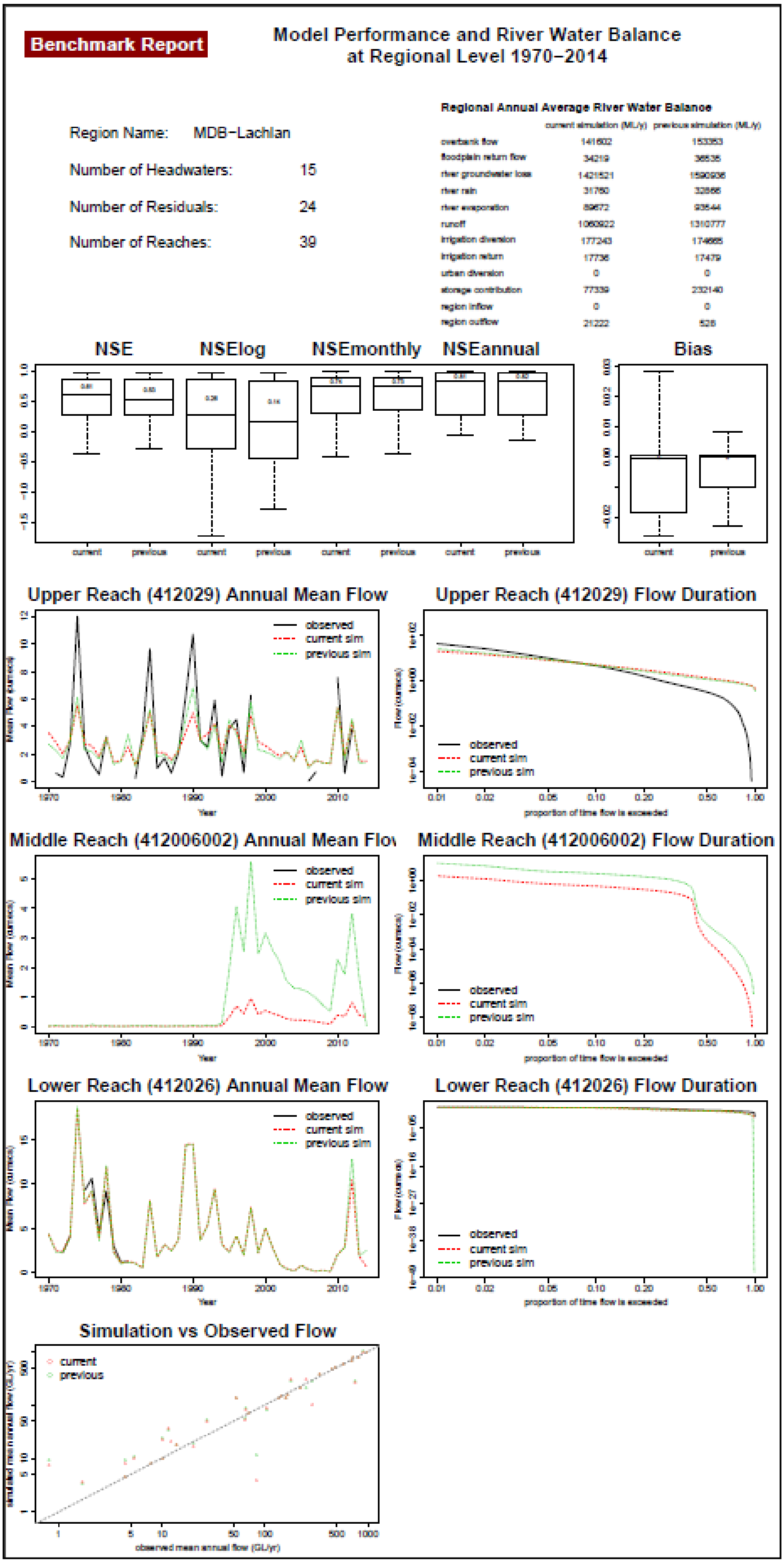
Number of Residuals: 16

Number of Reaches: 24

Regional Annual Average River Water Balance

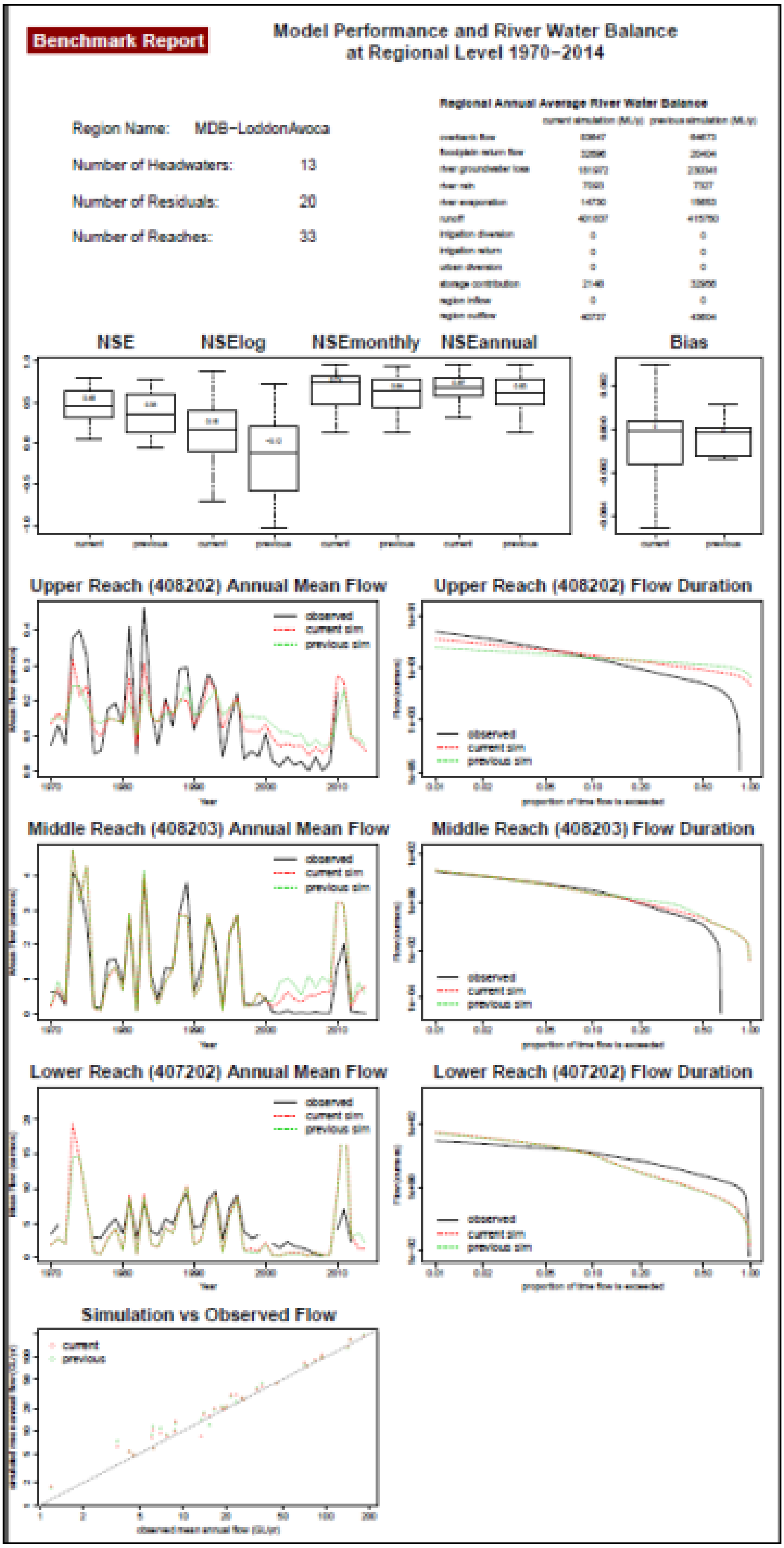
	current simulation (ML/y)	previous simulation (ML/y)
overbank flow	62135	44904
floodplain return flow	53966	37970
river groundwater loss	251576	261602
river rain	23468	24135
river evaporation	46269	37747
runoff	945548	1000493
irrigation diversion	353548	371351
irrigation return	37906	39655
urban diversion	0	0
storage contribution	12652	28263
region inflow	0	0
region outflow	150767	159968





Regional Annual Average River Water Balance

	current simulation (ML/y)	previous simulation (ML/y)
overbank flow	141602	153353
floodplain return flow	34219	38535
river groundwater loss	1421521	1590936
river rain	31760	32866
river evaporation	89672	93544
runoff	1060922	1310777
irrigation diversion	177243	174665
irrigation return	17736	17479
urban diversion	0	0
storage contribution	77339	232140
region inflow	0	0
region outflow	21222	528


Benchmark Report
Model Performance and River Water Balance
at Regional Level 1970−2014
Region Name: MDB−LoddonAvoca
Number of Headwaters: 13
Number of Residuals: 20
Number of Reaches: 33
Regional Annual Average River Water Balance
NSE
NSElog
NSEmonthly
NSEannual
Bias
Upper Reach (408202) Annual Mean Flow
Upper Reach (408202) Flow Duration
Middle Reach (408203) Annual Mean Flow
Middle Reach (408203) Flow Duration
Lower Reach (407202) Annual Mean Flow
Lower Reach (407202) Flow Duration
observed
current sim
previous sim
Simulation vs Observed Flow
current
previous

Benchmark Report

Model Performance and River Water Balance at Regional Level 1970–2014

Region Name: MDB–MacquarieCastlereagh

Number of Headwaters: 19

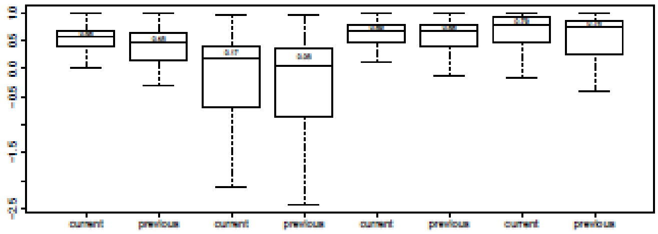
Number of Residuals: 32

Number of Reaches: 51

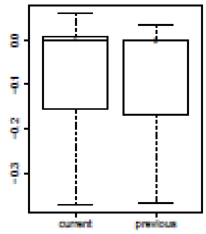
Regional Annual Average River Water Balance

	current simulation (ML/y)	previous simulation (ML/y)
overbank flow	115056	96305
floodplain return flow	53069	54229
river groundwater loss	1073190	975407
river rain	73517	68388
river evaporation	144886	161954
runoff	1749474	1581027
irrigation diversion	468897	475963
irrigation return	42948	43574
urban diversion	0	0
storage contribution	91503	273235
region inflow	0	0
region outflow	145734	149068

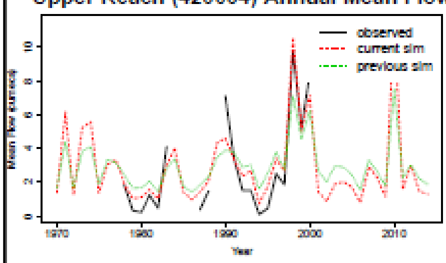
NSE NSElog NSEmonthly NSEannual



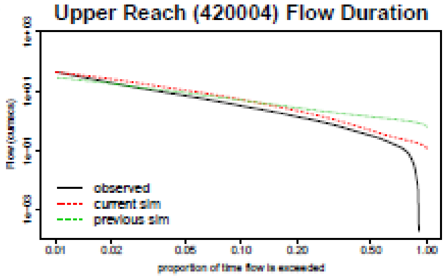
Bias



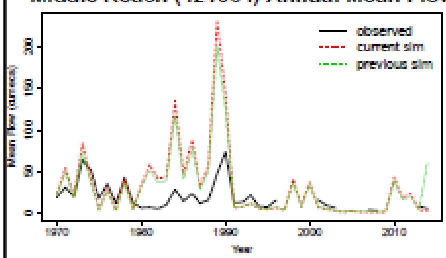
Upper Reach (420004) Annual Mean Flow



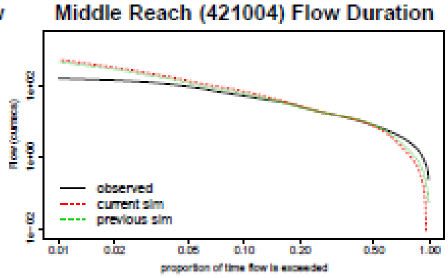
Upper Reach (420004) Flow Duration



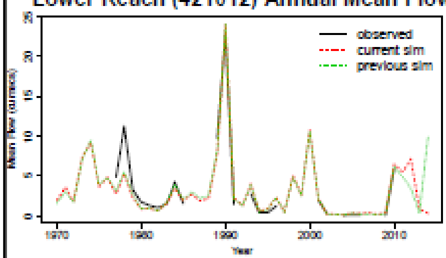
Middle Reach (421004) Annual Mean Flow



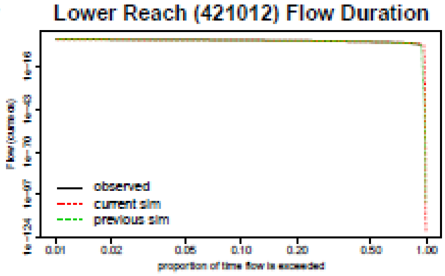
Middle Reach (421004) Flow Duration



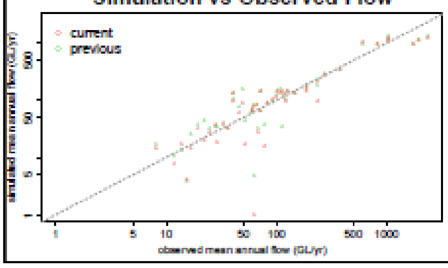
Lower Reach (421012) Annual Mean Flow

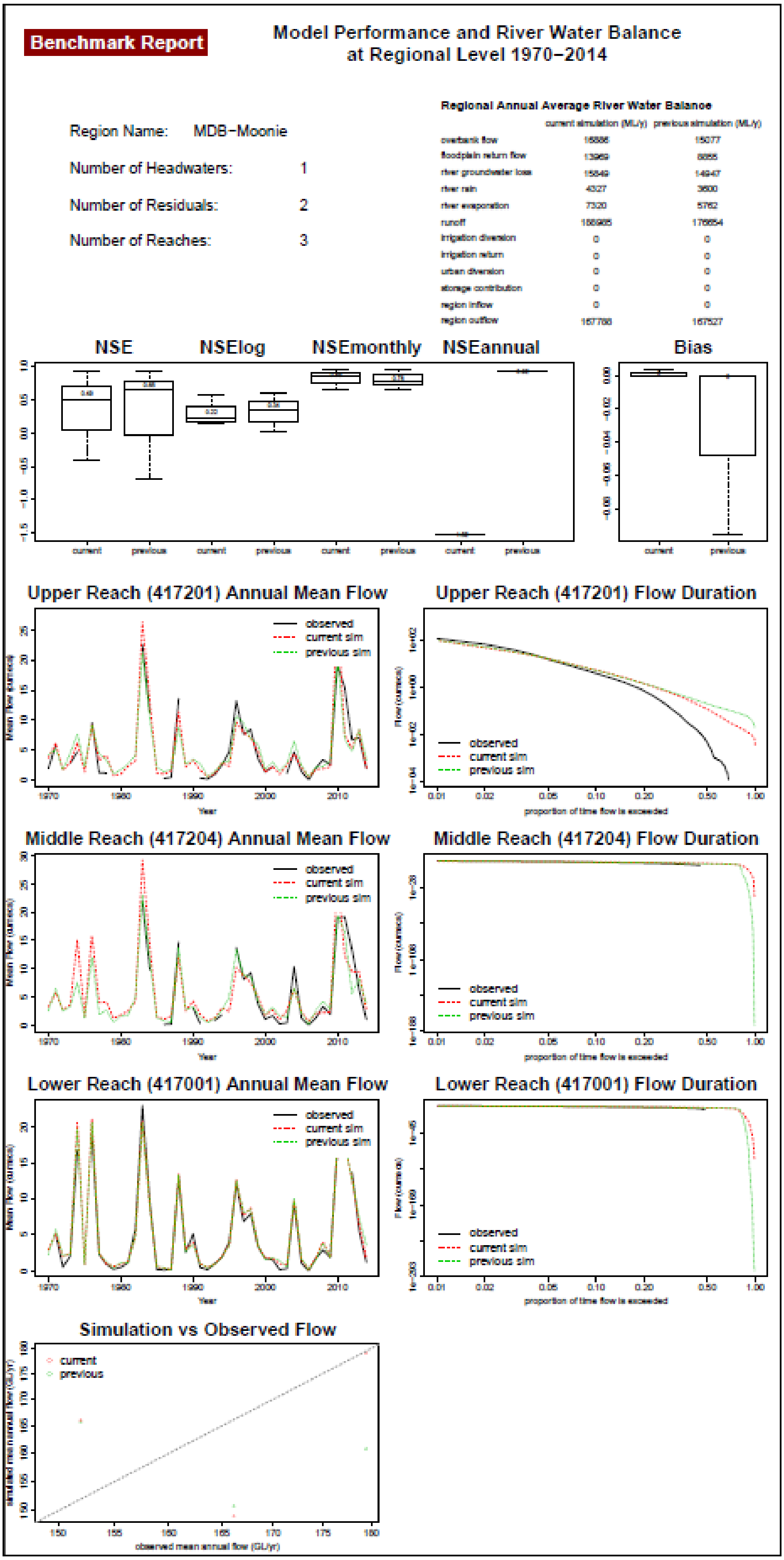


Lower Reach (421012) Flow Duration



Simulation vs Observed Flow




Benchmark Report
Model Performance and River Water Balance at Regional Level 1970–2014
Region Name: MDB–Moonie
Number of Headwaters: 1
Number of Residuals: 2
Number of Reaches: 3
Regional Annual Average River Water Balance
current simulation (ML/y) previous simulation (ML/y)
overbank flow 16886 15077
floodplain return flow 13969 8855
river groundwater loss 15849 14947
river rain 4327 3600
river evaporation 7320 5762
runoff 186965 176654
irrigation diversion 0 0
irrigation return 0 0
urban diversion 0 0
storage contribution 0 0
region inflow 0 0
region outflow 167768 167527
NSE
NSElog
NSEmonthly
NSEannual
Bias
current
previous
Upper Reach (417201) Annual Mean Flow
Upper Reach (417201) Flow Duration
Middle Reach (417204) Annual Mean Flow
Middle Reach (417204) Flow Duration
Lower Reach (417001) Annual Mean Flow
Lower Reach (417001) Flow Duration
observed
current sim
previous sim
Year
proportion of time flow is exceeded
Simulation vs Observed Flow
observed mean annual flow (GL/yr)

Benchmark Report

Model Performance and River Water Balance at Regional Level 1970–2014

Region Name: MDB–Mountlofty

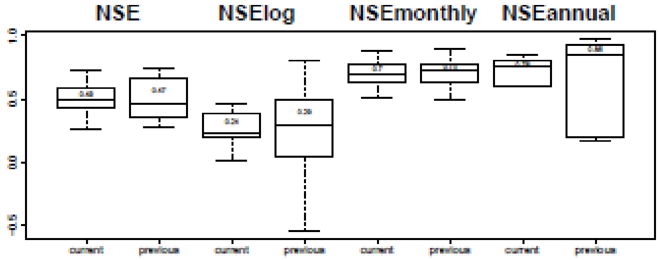
Number of Headwaters: 6

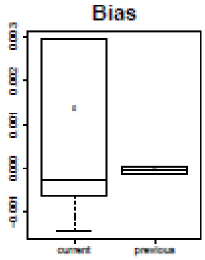
Number of Residuals: 7

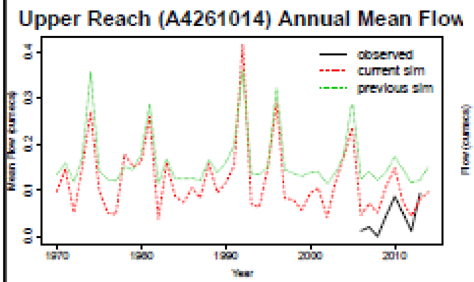
Number of Reaches: 13

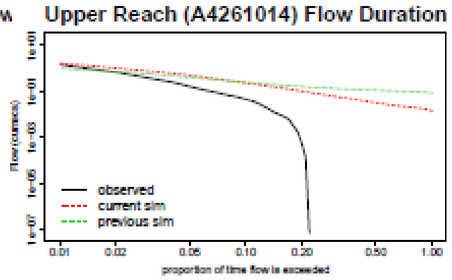
Regional Annual Average River Water Balance

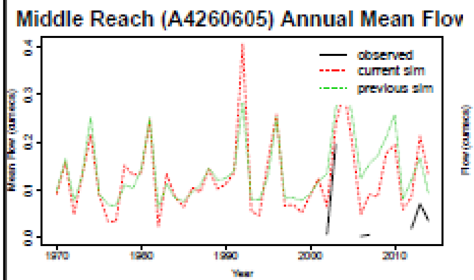
	current simulation (ML/y)	previous simulation (ML/y)
overbank flow	0	0
floodplain return flow	0	0
river groundwater loss	10248	10069
river rain	946	973
river evaporation	1633	2004
runoff	91587	92600
irrigation diversion	0	0
irrigation return	0	0
urban diversion	0	0
storage contribution	0	0
region inflow	0	0
region outflow	3991	4437

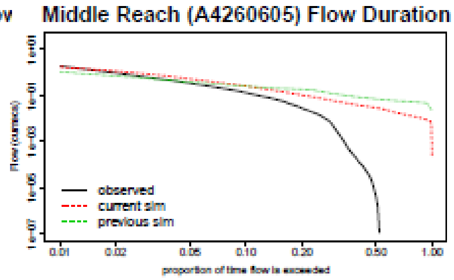


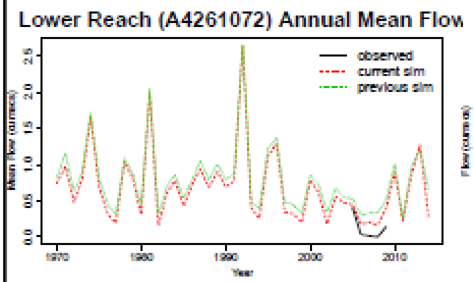


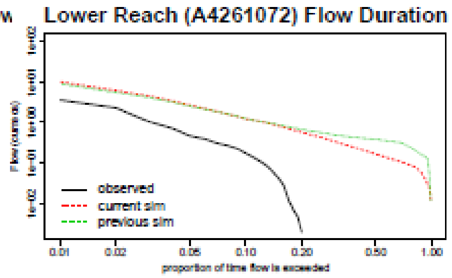


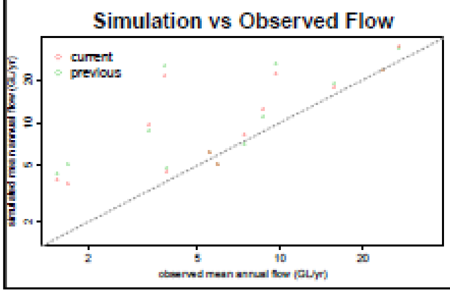












Benchmark Report

Model Performance and River Water Balance at Regional Level 1970–2014

Region Name: MDB–Murray

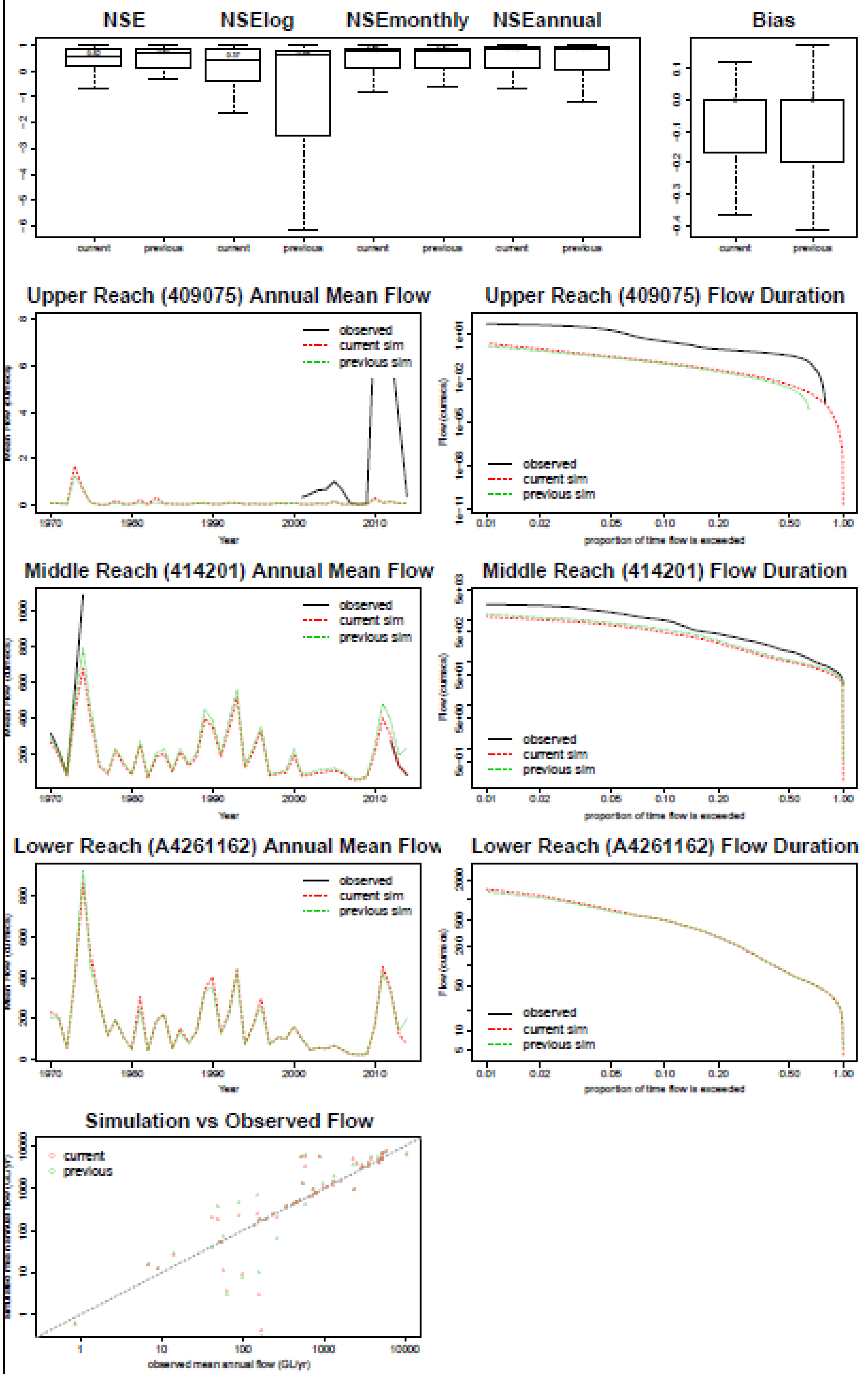
Number of Headwaters: 17

Number of Residuals: 51

Number of Reaches: 68

Regional Annual Average River Water Balance

	current simulation (ML/y)	previous simulation (ML/y)
overbank flow	1042360	903639
floodplain return flow	223296	224020
river groundwater loss	8478923	5051540
river rain	102215	106610
river evaporation	348883	370875
runoff	5703468	7182030
irrigation diversion	4626701	4611002
irrigation return	463717	462151
urban diversion	0	0
storage contribution	−104619	874873
region inflow	1743162	1738050
region outflow	5849360	5727233



Benchmark Report

Model Performance and River Water Balance at Regional Level 1970–2014

Region Name: MDB−Murrumbidgee

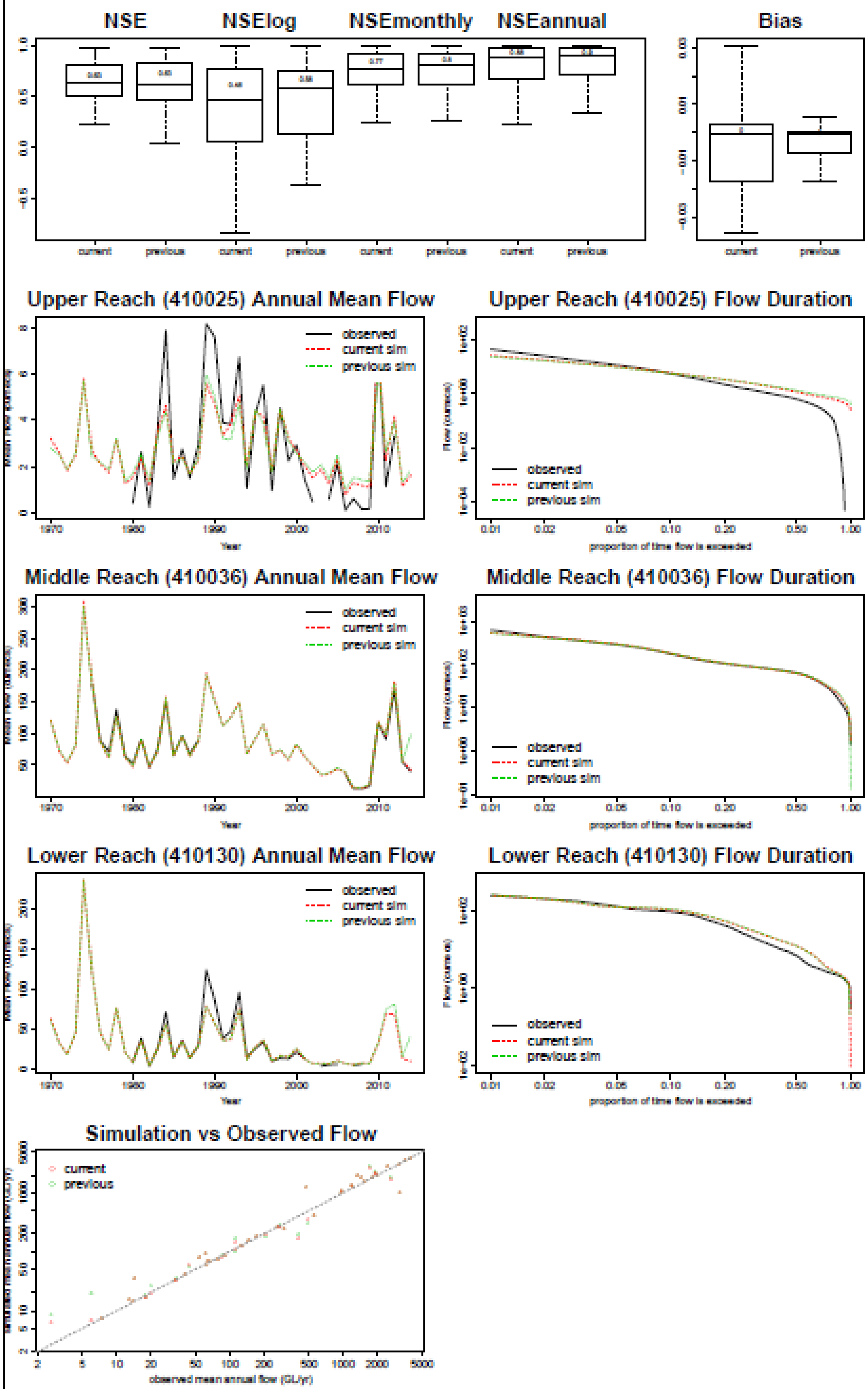
Number of Headwaters: 26

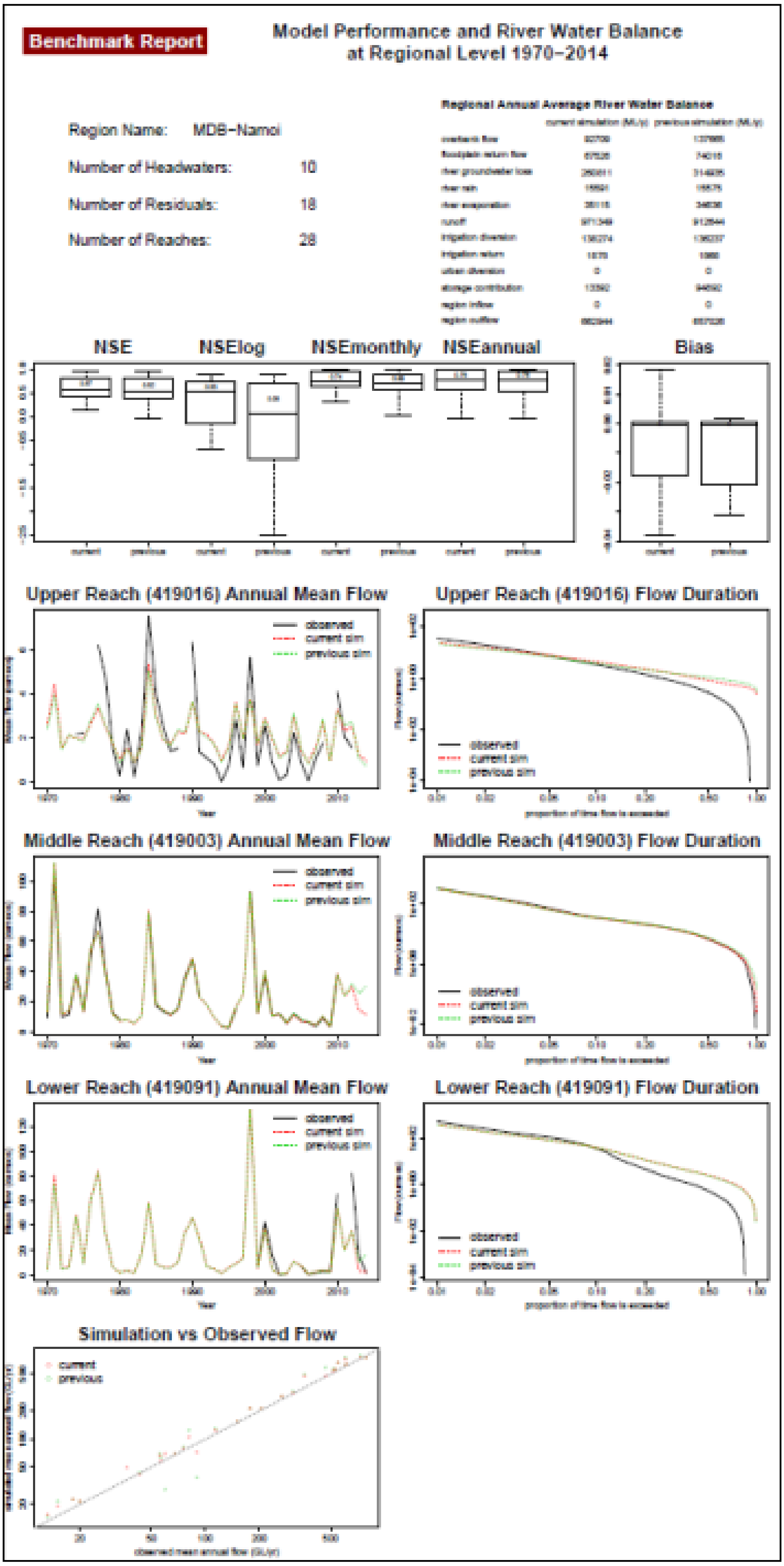
Number of Residuals: 29

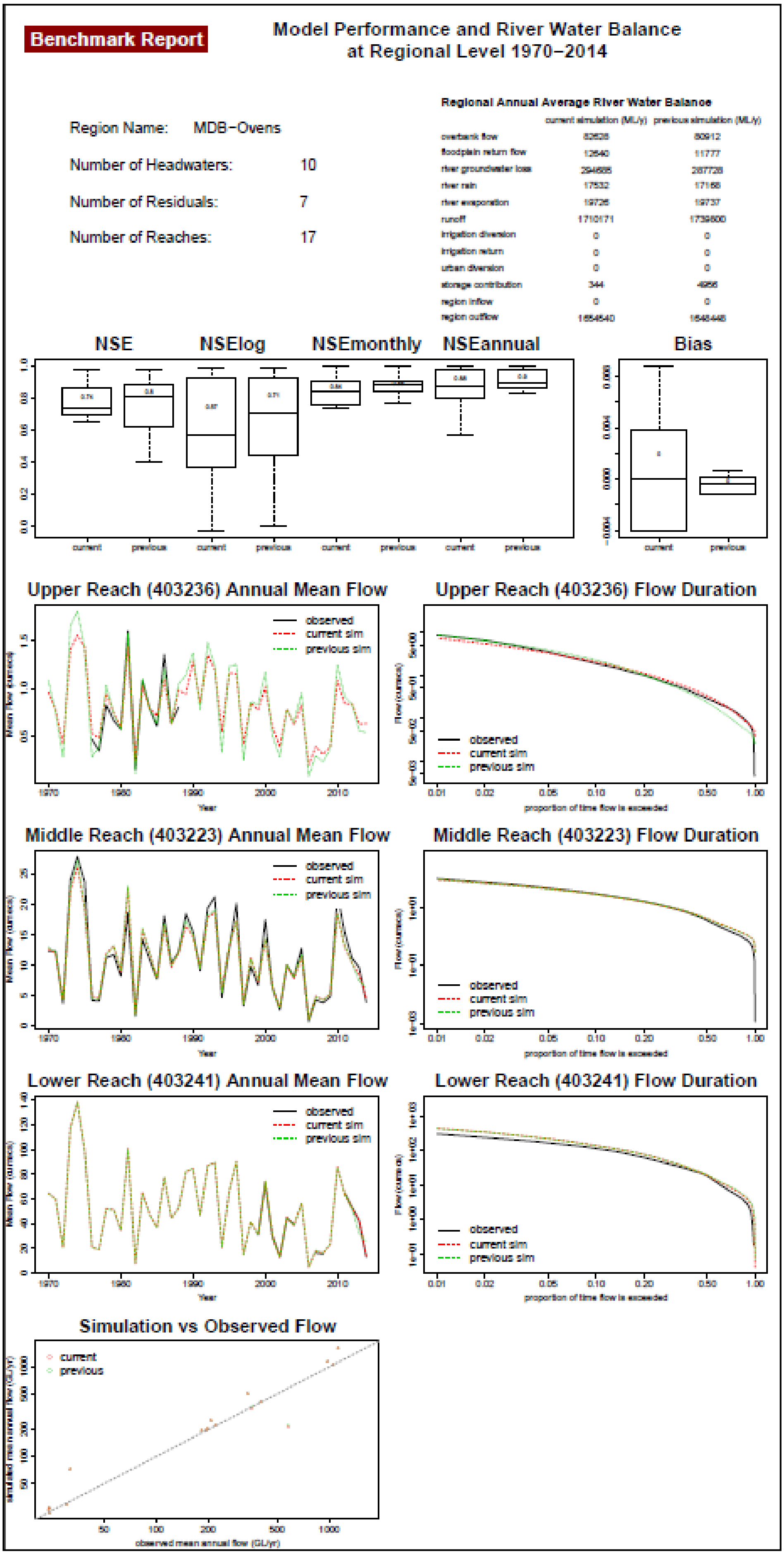
Number of Reaches: 55

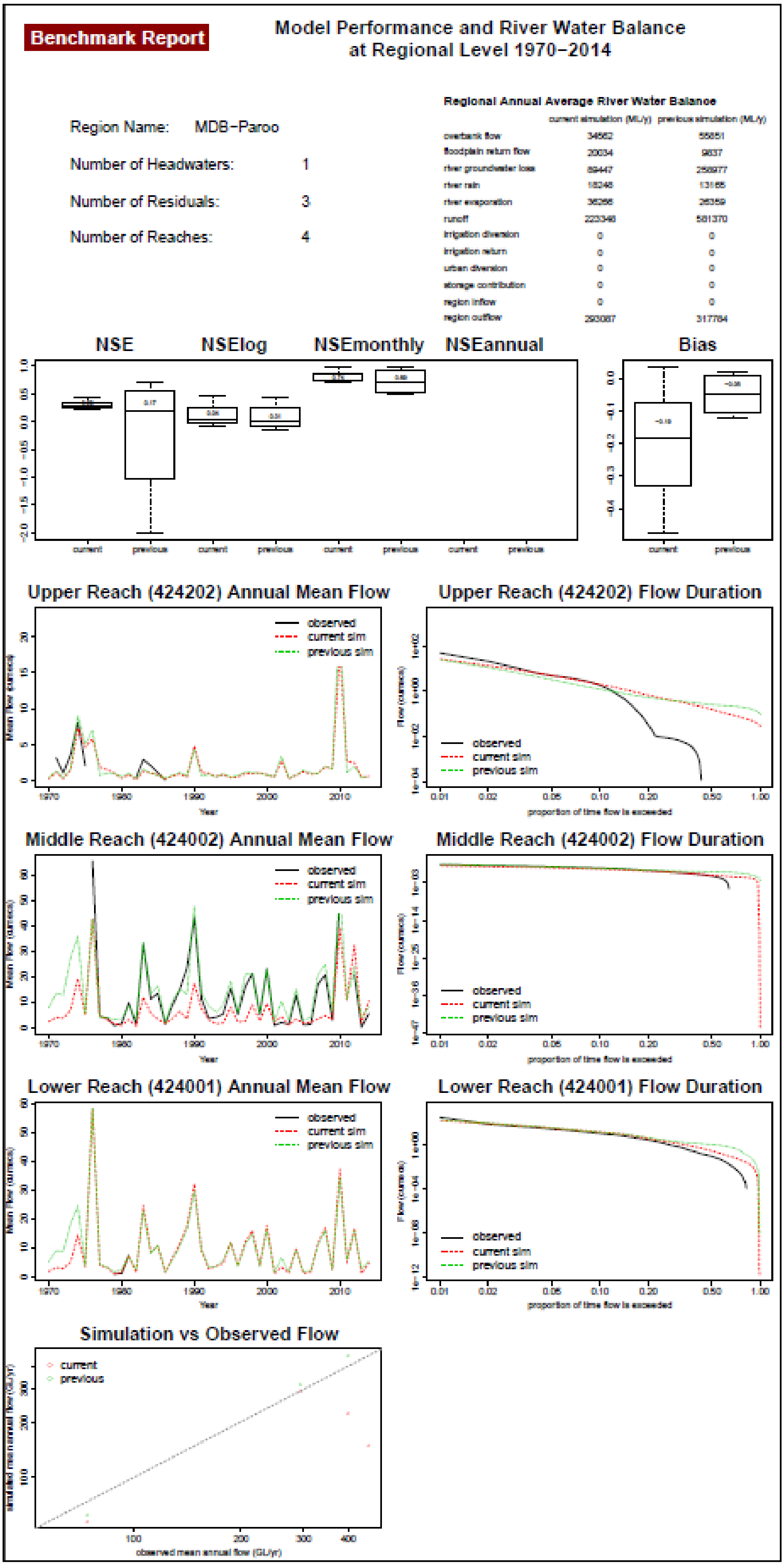
Regional Annual Average River Water Balance

	current simulation (ML/y)	previous simulation (ML/y)
overbank flow	288810	289758
floodplain return flow	109611	68491
river groundwater loss	1478118	1682403
river rain	38017	38108
river evaporation	77319	78352
runoff	4133590	4292532
irrigation diversion	1804403	1800606
irrigation return	181303	180926
urban diversion	0	0
storage contribution	105950	311387
region inflow	0	0
region outflow	348958	316230




Benchmark Report
Model Performance and River Water Balance
at Regional Level 1970–2014
Region Name: MDB–Namoi
Number of Headwaters: 10
Number of Residuals: 18
Number of Reaches: 28
Regional Annual Average River Water Balance
NSE
NSElog
NSEmonthly
NSEannual
Bias
Upper Reach (419016) Annual Mean Flow
Upper Reach (419016) Flow Duration
Middle Reach (419003) Annual Mean Flow
Middle Reach (419003) Flow Duration
Lower Reach (419091) Annual Mean Flow
Lower Reach (419091) Flow Duration
observed
current sim
previous sim
Simulation vs Observed Flow
current
previous


Benchmark Report
Model Performance and River Water Balance
at Regional Level 1970–2014
Region Name: MDB–Ovens
Number of Headwaters: 10
Number of Residuals: 7
Number of Reaches: 17
Regional Annual Average River Water Balance
current simulation (ML/y) previous simulation (ML/y)
overbank flow 82628 80912
floodplain return flow 12640 11777
river groundwater loss 294685 287728
river rain 17532 17168
river evaporation 19728 19737
runoff 1710171 1739800
irrigation diversion 0 0
irrigation return 0 0
urban diversion 0 0
storage contribution 344 -4956
region inflow 0 0
region outflow 1654640 1648448
NSE
NSElog
NSEmonthly
NSEannual
Bias
current
previous
Upper Reach (403236) Annual Mean Flow
Upper Reach (403236) Flow Duration
Middle Reach (403223) Annual Mean Flow
Middle Reach (403223) Flow Duration
Lower Reach (403241) Annual Mean Flow
Lower Reach (403241) Flow Duration
observed
current sim
previous sim
Year
proportion of time flow is exceeded
Simulation vs Observed Flow
current
previous
observed mean annual flow (GL/yr)



Benchmark Report
Model Performance and River Water Balance at Regional Level 1970−2014
Region Name: MDB−Paroo
Number of Headwaters: 1
Number of Residuals: 3
Number of Reaches: 4
Regional Annual Average River Water Balance
current simulation (ML/y) previous simulation (ML/y)
overbank flow 34562 55851
floodplain return flow 20034 9637
river groundwater loss 89447 256977
river rain 18248 13165
river evaporation 36266 26359
runoff 223348 581370
irrigation diversion 0 0
irrigation return 0 0
urban diversion 0 0
storage contribution 0 0
region inflow 0 0
region outflow 293087 317764
NSE
NSElog
NSEmonthly
NSEannual
Bias
current
previous
Upper Reach (424202) Annual Mean Flow
Upper Reach (424202) Flow Duration
Middle Reach (424002) Annual Mean Flow
Middle Reach (424002) Flow Duration
Lower Reach (424001) Annual Mean Flow
Lower Reach (424001) Flow Duration
observed
current sim
previous sim
Mean flow (cumecs)
Year
Flow (cumecs)
proportion of time flow is exceeded
Simulation vs Observed Flow
simulated mean annual flow (GL/yr)
observed mean annual flow (GL/yr)

Benchmark Report

Model Performance and River Water Balance at Regional Level 1970−2014

Region Name: MDB−Warrego

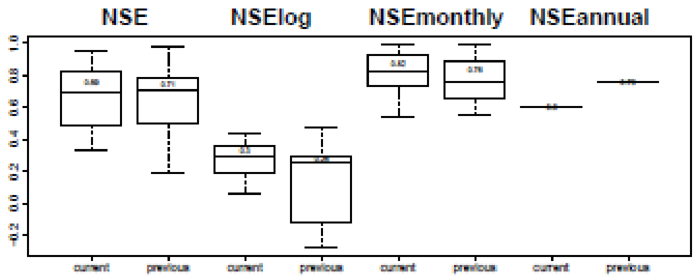
Number of Headwaters: 2

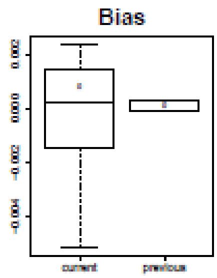
Number of Residuals: 6

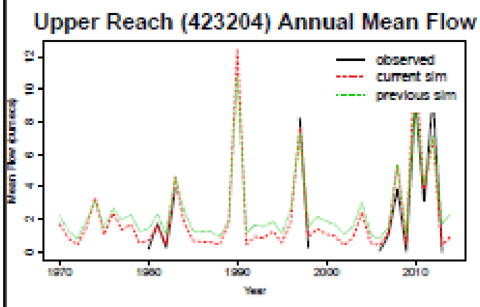
Number of Reaches: 8

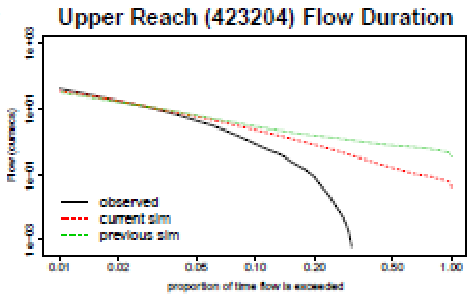
Regional Annual Average River Water Balance

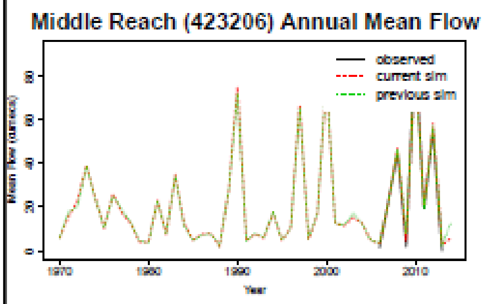
	current simulation (ML/y)	previous simulation (ML/y)
overbank flow	58663	64215
floodplain return flow	36750	16834
river groundwater loss	356762	386490
river rain	17010	17076
river evaporation	40544	42440
runoff	801825	803614
irrigation diversion	0	0
irrigation return	0	0
urban diversion	0	0
storage contribution	0	0
region inflow	0	0
region outflow	160481	125942

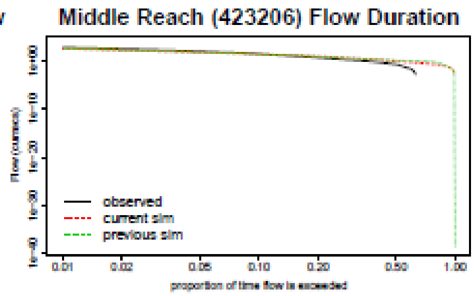


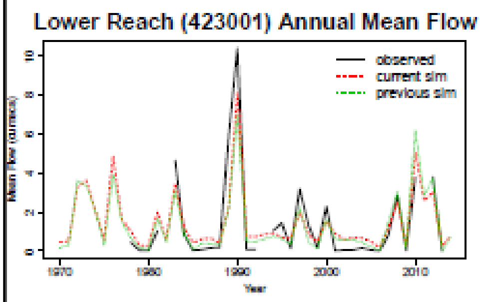


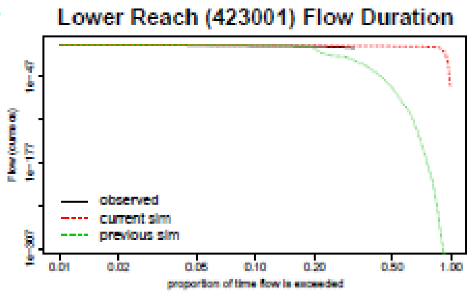


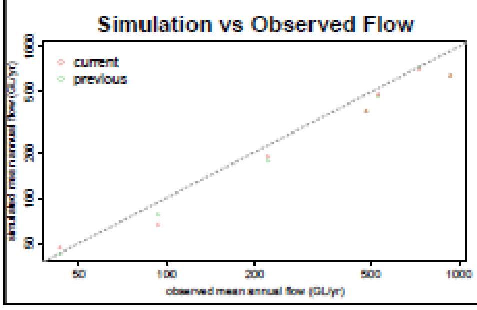












Benchmark Report

Model Performance and River Water Balance at Regional Level 1970−2014

Region Name: MDB−Wimmera

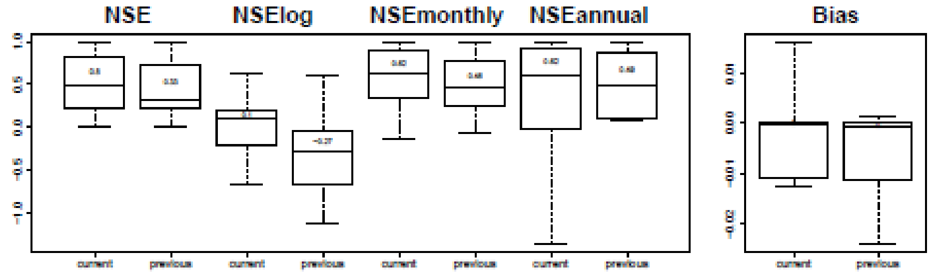
Number of Headwaters: 9

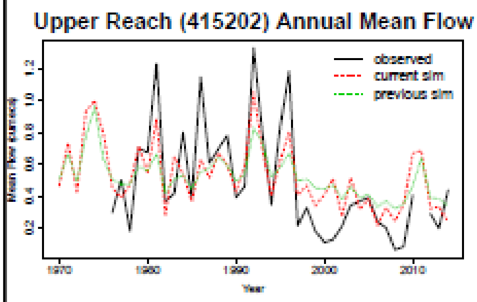
Number of Residuals: 9

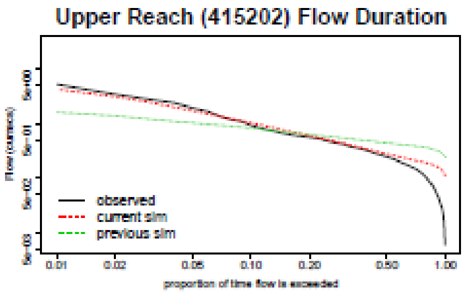
Number of Reaches: 18

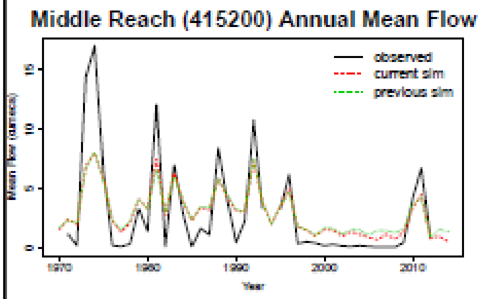
Regional Annual Average River Water Balance

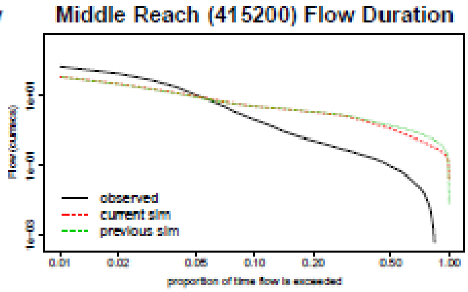
	current simulation (ML/y)	previous simulation (ML/y)
overbank flow	0	0
floodplain return flow	0	0
river groundwater loss	99874	90329
river rain	5713	5496
river evaporation	12726	14311
runoff	206881	209725
irrigation diversion	0	0
irrigation return	0	0
urban diversion	0	0
storage contribution	0	0
region inflow	0	0
region outflow	85959	85413

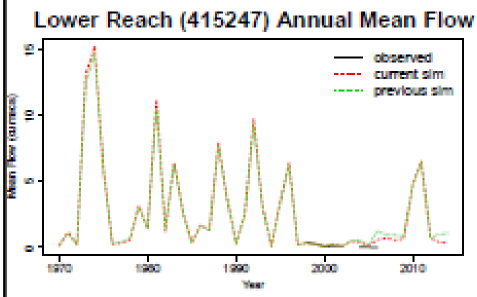


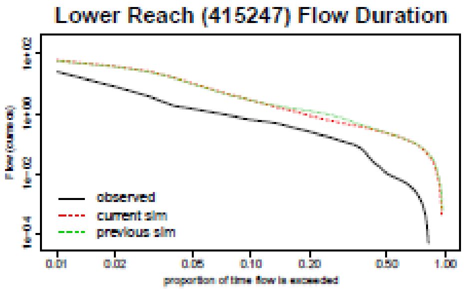


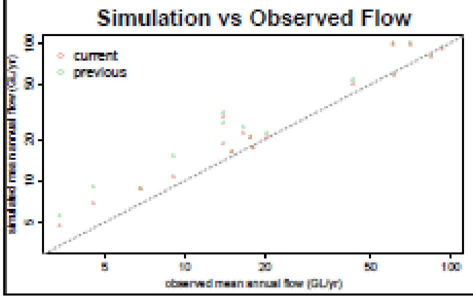












Appendix 3: List of inputs and outputs with the variable names used in the model

Time series variables of AWRA-R v5.0

Temporal variable (symbol)	Symbol used in combined file	Unit of input data	Reference equation
Rainfall at river (*P*)	rainfall.river	mm/day	Equation 32
Evaporation from river (*E*)	evap.river	mm/day	Equation 32
Rainfall at floodplain (P_{fp})	rainfall.floodplain	mm/day	Equation 36
Evaporation from floodplain (E_{fp})	evap.floodplain	mm/day	Equation 36
Irrigation diversion (Q_d)	irrigation.diversion	m^3/s	Equations 1, 30
Irrigation return flow (Q_{irr})	irrigation.returnflow	m^3/s	Equations 1, 31
Urban diversion (Q_u)	urban.diversion	m^3/s	Equation 1
AWRA-L runoff (Q_r)	awral.inflow	m^3/s	Equations 1, 4
Reservoir volume (*S*)	reservoir.volume	m^3	Equation 6
Reservoir area (*a*)	reservoir.area	m^2	Equation 6
Depth to groundwater (d_{gw})	depth.to.groundwater	m	Equations 22, 45, 50
River water depth(h_{rivw})	river.depth	m	Equations49, 51
River water width (X_{rivw})	river.width	m	Equation 49, 50, 51
Reservoir net diversion ($Q_{net\_transfer}$)	reservoir.net.diversion	m^3/s	Equation 5
Other river diversion(Q_{sd})	other.river.diversion	m^3/s	Equation 1
Inflow from each of the upstream nodes ($Q_{u/s}$)	inflow	m^3/s	Equations 1 & 2
Rainfall at reservoir (P_s)	rainfall.top	mm/day	Equation 6
Evaporation from reservoir (E_s)	evap.top	mm/day	Equation 6
Outflow at downstream nodes	outflow	m^3/s	For calibration

Parameters of AWRA-R v5.0 included the calibrated parameters

Parameter (symbol)	Symbols used in config file	Unit	Reference equation
River area alpha (α)	river.area.alpha	-	Equation 34
River area beta (β)	river.area.beta	-	Equation 34
Flood beta (C_{fp})	flood.beta	m^{-1}	Equation 39
Anabranch partition factor (C_a)	anabranch.top.a, anabranch.bottom.a	-	Equation 35
Anabranch exponent(B_a)	anabranch.top.b, anabranch.bottom.b	-	Equation 35
Total river length (*L*)	total.river.length	m	Equations 34, 43
River depth alpha (α_d)	river.depth.alpha	-	Equation 49 (to determine h_{rivw})
River depth beta (β_d)	river.depth.beta	-	Equation 49 (to determine h_{rivw})
Overbank flow threshold (*OT*) [calibrated]	overbankflow.threshold	m^3/sec	Equation 37

Parameter (symbol)	Symbols used in config file	Unit	Reference equation
Floodplain surface layer conductivity (K_c)	flood.ksat	m/sec	Equation 44
Aquifer specific yield (S_y)	aquifer.specific.yield	-	Equation 45
Aquifer hydraulic conductivity (K_{aq})	aquifer.ksat	m/sec	Equations 46, 51
Aquifer thickness (d_{aq})	aquifer.thickness	m	Equations 46, 51
Surface layer thickness (d_c)	surface.layer.thickness	m	Equations 44, 49
Riverbed conductivity (K_{rivc})	river.conductivity	m/sec	Equation 49
Area of residual catchment (A)	area.subcatchments	m^2	Equation 4
Length of reach inflow stream	Link.length	m	Equation 34
Flood return flow coefficient (FR) [calibrated]		-	Equation 41
Monod parameter (M_1) [calibrated]		m^3/sec	Equation 48
Monod parameter (M_2) [calibrated]		m^3/sec	Equation 48
Runoff correction factor (SF) [calibrated]		-	Equation 4
Lag [calibrated]		sec	Equation 3
K [calibrated]		sec	Equation 3
X [calibrated]		-	Equation 3

AWRA-R v5.0 outputs

Variables (symbol)	Symbols used in non-routing states file	Unit	Reference equation
Outflow ($\widehat{Q_{d/s}}$)	outflow	m^3/sec	Equation 1
Overbank flow (Q_{fp})	overbank.flow	m^3/sec	Equations 1, 37
Floodplain volume (V_{fp})	floodplain.volume	m^3	Equation 42
Flood plain area (A_{fp})	floodplain.area	m^2	Equations 39, 40
Flood plain return flow (Q_{fpr})	floodplain.returnflow	m^3/sec	Equations 1, 41
River rainfall flux (Q_p)	river.rainfall.flux	m^3/sec	Equations 1, 32
River evaporation flux (Q_e)	river.evap.flux	m^3/sec	Equations 1, 33
Floodplain rainfall flux	floodplain.rainfall.flux	m^3/sec	Equation 36
Floodplain evaporation flux	floodplain.evap.flux	m^3/sec	Equation 36
Floodplain groundwater loss (GWR_{fp})	floodplain.groundwater.loss	m^3/sec	Equations 36, 43
River groundwater loss (Q_{gw})	river.groundwater.loss	m^3/sec	Equations 1,
Anabranch loss (Q_a)	top.anabranch.loss, bottom.anabranch.loss	m^3/sec	Equations 1, 35
Reservoir rainfall flux	reservoir.rainfall.flux	m^3/sec	Equation 6
Reservoir evaporation flux	reservoir.evap.flux	m^3/sec	Equation 6
Reservoir contribution (Q_s)	reservoir.contribution	m^3/sec	Equations 1, 5
River water volume	river.volume	m^3	
Floodplain groundwater max change storage (ΔS)	floodplain.groundwater.max.change.storage	m^2/sec	Equation 43
Floodplain groundwater outflow (Q)	floodplain.groundwater.outflow	m^3/sec	Equation 43
Floodplain groundwater max potential infiltration (I)	floodplain.groundwater.max.infiltration	m^2/sec	Equation 44

Variables (symbol)	Symbols used in non-routing states file	Unit	Reference equation
River groundwater max change storage (ΔS_{riv})	river.groundwater.max.change.storage	m^2/sec	Equation 47, 50
River groundwater outflow (Q_{riv})	river.groundwater.outflow	m^3/sec	Equation 47, 51
river.groundwater.max.infiltration (I_{riv})	river.groundwater.max.infiltration	m^2/sec	Equation 49
River groundwater max monod loss (Q_{gwmond})	river.groundwater.max.monod.loss	m^3/sec	Equation 48

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